

**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**

**Paul Taylor<sup>1</sup>  
Tim Dempster<sup>2</sup>**

**September 2016**

**<sup>1</sup>Statfishtics  
PO Box 12067  
Hamilton  
New Zealand 3248**

**<sup>2</sup>Tim Dempster  
Melbourne University  
Dept of Zoology  
Victoria 3010  
Australia**

## EXECUTIVE SUMMARY

**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. Taylor, P.R.; Dempster, T. 62 p.**

Extensive information was identified from a literature search on the circulation, stratification, and nutrient cycling in Pelorus Sound, mostly as studies related to the mussel farming in inner-Pelorus Sound, and including detailed descriptions of Waitata Reach. A number of studies described the circulation of Queen Charlotte Sound and Tory Channel. Results from these studies were used to develop a description of the pelagic habitat at the NZ King Salmon farms and relocation sites. With the aim of identifying the species of finfish that might inhabit the water column at existing and proposed relocation sites, summaries from two recreational fishing surveys and a study on finfish in the Sounds were tabulated. Managers of existing NZ King Salmon farms listed the species they had observed in and around the sea cages. Patterns and inconsistencies were identified and discussed.

Based on the characterisations of the pelagic habitat and data from the recreational fishing surveys, it is evident that the pelagic habitat of the outer Pelorus and Queen Charlotte Sounds, and Tory Channel is highly productive, supporting a wide range of marine organisms. In managing the NZ King Salmon sites it is necessary to ensure that adverse effects of the farming are avoided, remedied, or mitigated, so that pelagic habitat function is maintained and impacts on all finfish species are minimised, thus minimising impacts on species targeted in customary, recreational, and commercial fisheries.

An extensive overseas literature on the relationships between wild finfish species and salmon farms in the Mediterranean and Norway was summarised to develop an overview of the possible effects of salmon farms on the pelagic habitat and finfish species. This summary included information on various aspects of wild fish aggregations and the taxa (species and family) they comprise, and showed that in wild fish populations associated with salmon farms overseas, the main impact of the farms on these populations was through waste salmon feed that fell from the farm system.

Consumption of salmon feed by wild fish can affect them in several ways. In some cases they have exhibited increased body condition, which can either increase or reduce their reproductive fitness, depending on its quality relative to their natural diets. Other effects included increased organohalogenated contaminants and heavy metal loadings of the wild fish, although the levels were all well below public health limits set for safe consumption by humans. Elevated levels of heavy metals in wild fish are an unlikely result for Marlborough Sounds salmon farming under present conditions, but the long term effects (i.e. at the multi-decadal scale) through the function of bioaccumulation are seldom considered. To ensure that no such effects emerge, monitoring of key contaminants of public health interest should occur in long-lived, benthic-pelagic fish species, of recreational, commercial or traditional fishing interest, that reside in the near vicinity of salmon farms. Frequency of monitoring should be determined relative to the status of the benthic conditions beneath farms, as biological availability of certain heavy metals increases in anoxic sediments, and should also be compared to relevant control locations.

According to NZ King Salmon, feed-waste levels at existing farms is low (<0.1%), suggesting that effects on wild fish are likely to be low. However, such a conclusion cannot be reached without independent data on measurement of feed fallout. We therefore recommend independent monitoring of feed loss and variations in loss levels with location and time, at the proposed new farming locations.

The Department of Conservation expert on sharks was interviewed for information on sharks relevant to existing and proposed NZ King Salmon farms. Farm managers were also asked to comment on the species of shark they had observed. At least 14 species of shark are known to occur naturally in the Marlborough Sounds; 4 of these have been observed close to existing NZ King Salmon farms; all require a careful management approach to minimise interactions. It is recommended that NZ King Salmon adopt best practices as identified by industry members at the 2003 South Australian workshop.

The effects of farms at both the existing low-flow sites and the proposed relocation sites were evaluated in terms of Policy 11 of the New Zealand Coastal Policy Statement (NZCPS), which deals with indigenous biological diversity. This evaluation was carried out with reference to five questions concerning 1) indigenous fish that are listed as threatened or at risk, 2) habitats for fish species that are at the limit of their natural range, or are naturally rare, 3) nationally significant fish communities, 4) habitats that are important during the vulnerable life history stages of fish species and, 5) the relevance of areas and routes for migratory species and ecological corridors to the pelagic fish community.

The degree to which each of these areas of concern presented potential impact of the farms at existing and relocation sites varied, but ultimately it was concluded, based on the best available information, that any impact was likely to be low.

## Contents

EXECUTIVE SUMMARY .....	2
1. SCOPE.....	6
2. THE PELAGIC ENVIRONMENT AT PROPOSED SITES.....	6
2.1 The Existing Pelagic Habitat at the Proposed Sites .....	6
2.1.1 Background .....	6
2.1.2 Summary of existing information .....	7
2.2 A List of Finfish Species, Including Sharks, from the Marlborough Sounds .....	8
2.2.1 Previous Research Including Recreational Fishing Surveys .....	8
2.2.2 Information from Existing NZ King Salmon Farms .....	12
2.3 Ecosystem Productivity and Feeding in Pelagic Finfish Species .....	13
2.4 Commercial Fisheries in Areas Containing the Marlborough Sounds .....	15
3. EFFECTS OF CHANGES IN THE PELAGIC HABITAT ON PELAGIC FISH SPECIES .....	16
3.1 Size and Composition of Wild Fish Aggregations around Fish Farms.....	16
3.2 Spatial and Temporal Variability in Aggregations .....	18
3.3 Settlement of Juveniles Fish around Fish Farms .....	19
3.4 Consequences of association with Fish Farms for Wild Fish Diets, Body Condition and Parasite Loads .....	19
3.5 Physiological Consequences of Association with Fish Farms for Wild Fish.....	21
3.6 Organohalogenated Contaminants.....	22
3.6.1 Organohalogenated Contaminants in salmon feeds .....	22
3.6.2 Organohalogenated Contaminants in sediments and wild fish around salmon farms ....	22
3.7 Heavy Metals .....	23
3.7.1 Heavy metal accumulation at fish farms .....	23
3.7.2 Heavy metals in wild fish around salmon farms .....	24
3.8 Movements of Farm-Associated Fish .....	25
3.9 Wild Fish as Agents of Pelagic and Benthic Amelioration around Fish Farms .....	26
3.10 Interactions of Salmon Farms with Wild Salmonid Populations.....	26
3.11 Quality of Farm-Associated Wild Fish for Human Consumption.....	26
4. ATTRACTION OF SHARKS TO MARINE FARMS; CONSEQUENCES FOR HUMANS ....	27
4.1 Fish Farms and Predatory Fish.....	27
4.2 Shark Species in the Marlborough Sounds .....	27
4.3 Attraction of Shark Species to Fish Farms and Consequences for Humans .....	28
5. POSSIBLE EFFECTS OF MARINE FARMS ON THE PELAGIC FISH STOCK UTILISED BY COMMERCIAL, RECREATIONAL, AND CUSTOMARY FISHING .....	30
5.1 Ecosystem-Based Management of Fish Farming and Local Fisheries .....	30
6. CONSIDERING POLICY 11 OF THE NEW ZEALAND COASTAL POLICY STATEMENT	31
6.1 Indigenous fish species listed as threatened or at risk .....	31
6.1.1 Background .....	31
6.1.2 List of marine and diadromous species meeting the Policy 11 criteria for the Marlborough Sounds .....	32
6.1.4 Implications .....	34
6.1.5 Summary .....	36
6.2 Habitats for species at the limit of their range.....	37
6.3 Nationally significant fish communities .....	37
6.3.1 Rocky reef fish communities.....	37
6.3.2 The pelagic fish community .....	38
6.3.3 The demersal fish community .....	38
6.4 Habitats of importance during vulnerable life history stages .....	38
6.5 Relevance of the concepts of areas, routes and ecological corridors.....	39

6.5.1	Overview .....	39
6.5.2	Relevance .....	41
7.	CONCLUSIONS FROM THE COMPILED INFORMATION.....	42
7.1	The Pelagic Habitat in the Marlborough Sounds.....	42
7.2	Pelagic Finfish Species at Existing Farms in the Marlborough Sounds .....	42
7.3	Effects of Fish Farming on the Pelagic Habitat and Wild Fish .....	42
7.4	Interactions of Fish Farms with Sharks .....	44
7.5	The Effect of Fish Farms on the Indigenous Biological Diversity of Wild Fish.....	44
8.	IMPLICATIONS FOR FISH FARMS IN THE MARLBOROUGH SOUNDS .....	45
8.1	The Pelagic Habitat .....	45
8.2	Finfish Distributions and Existing NZ King Salmon Farms .....	46
8.3	Implications for customary, recreational, and commercial fisheries .....	46
8.4	Effects of Farms .....	47
8.5	Interactions of Fish Farms with Sharks .....	48
9.	ACKNOWLEDGEMENTS .....	50
10.	REFERENCES .....	50
	APPENDIX A: A Brief General Description of the Pelagic Habitat.....	65
	APPENDIX B: Policy 11 of The New Zealand Coastal Policy Statement (NZCPS) .....	66
	APPENDIX C: Predicted rocky reef species in 10 areas of the Marlborough Sounds .....	67

## 1. SCOPE

This report was originally written for the NZ King Salmon proposal for plan change and increased capacity in 2011. In it we synthesized existing background information on the pelagic habitat and the wild fish fauna of the Marlborough Sounds relevant to the NZ King Salmon proposal. We summarised the nature of the pelagic habitat at the proposed sites and the extensive international literature on farmed-wild fish population interactions, both in terms of the effects on wild fish populations and interactions that affect traditional, recreational and commercial harvests.

Based on the background knowledge of fish farms and wild fish interactions and knowledge of the pelagic habitat and the fish fauna present in the Marlborough Sounds, we made predictions regarding the likely nature of interactions. Finally, we provided suggestions as to how fish farm-fishery interactions can be managed to enhance any potentially positive, and minimise any potentially negative, interactions.

The present document is an updated version of the original report. Its function is to provide current information relevant to the NZ King Salmon proposal to relocate six of its existing low flow sites to areas of high flow. Consequently, reference is made only to existing farm sites and to the proposed relocation sites. Sites proposed but not granted from the original application have been omitted.

## 2. THE PELAGIC<sup>1</sup> ENVIRONMENT AT PROPOSED SITES

### 2.1 The Existing Pelagic Habitat at the Proposed Sites

#### 2.1.1 Background

Because of the locations of five existing sites and the nine relocation sites proposed by NZ King Salmon, two independent areas and their positions relative to Cook Strait are relevant here — outer Pelorus Sound contains the sites Waitata (9.8 km from Cook Strait) and Richmond (10.6 km from Cook Strait), and five of the relocation sites, which are all within relatively close proximity to one another; and Tory Channel contains Clay Point, Te Pangu, Ngamahau, and the remaining four relocation sites, all within about 12 km of Cook Strait. Because of their close proximity to Cook Strait, these sites are referred to here as being within the outer sounds.

There appears to be no study that has aimed specifically at characterising the pelagic habitat of the Marlborough Sounds. However, various “sets” of work have been done that can be used as a basis for such a characterisation. These studies can be categorised into the following four groups:

- descriptions of the large-scale circulation system Kahurangi-Tasman Bay-Cook Strait-Marlborough Sounds by Bowman et al (1982), Kibblewhite et al (1982), Vincent & Howard-Williams (1991), Heath & Gilmour (1987), Bradford et al (1986);
- descriptions of circulation within all the sounds by Heath (1974, 1976), Bradford et al (1987), Zeldis et al (2008, 2013) and others;
- descriptions of circulation, stratification, nutrient cycling etc in Pelorus Sound, mostly as studies related to the mussel farming in inner-Pelorus Sound (Beatrix & Crail Bay) — these descriptions include work by Gibbs et al (1992), Gibbs (1993, 2001), Gibbs & Vant (1997), Carter (1976); and
- summaries of water quality data including all existing historical data related to water quality monitoring in the Marlborough Sounds (Broekhuizen 2013) and recent data collected by Marlborough District Council (MDC) and the National Institute of Water and Atmospheric Research (NIWA) (Broekhuizen 2015).

---

<sup>1</sup> See Appendix A for definition.

### 2.1.2 Summary of existing information

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

Important features of the circulation in Pelorus Sound are:

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

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

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

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

Zeldis et al (2008) considered results from a number of the papers referenced above that documented previous work. Based on prior knowledge of river inputs and ENSO-related (El Niño-Southern Oscillation) meteorology, these researchers seasonally stratified by summer (Oct–Mar) and winter (Apr–Sep) their analysis of catchment and oceanic forcing of nutrient loading and biomass formation in Pelorus Sound. They analysed the two datasets separately and suggested a model for the two seasons that fluctuated between two extremes in each and accounted for years of high and low phytoplankton production in the sound, and hence productivity that was manifested in mussel yield.

Within this scheme, NNW wind stress intensified upwelling and advection of these cool waters into the sounds, resulting in increased productivity (it is generally considered that cool, upwelled waters are nutrient and oxygen rich); by contrast, SSE wind stress had the opposite effect. In summer, NNW wind stress was coupled with a negative southern oscillation index (SOI), indicating the presence of El Niño conditions; SSE stress was coupled with La Niña (positive SOI). The winter effects were not coupled with ENSO but had a similar result through rainfall and river flow that was increased by NNW wind stress, producing increased terrestrial nitrogen input and higher productivity. Once again, SSE wind stress resulted in decreased productivity, this time through decreased rainfall-induced terrestrial nitrogen input. This provides a good working model for the annual fluctuations we might expect at the proposed sites in outer Pelorus Sound.

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

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

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

## **2.2 A List of Finfish Species, Including Sharks, from the Marlborough Sounds**

### **2.2.1 Previous Research Including Recreational Fishing Surveys**

Table 1 contains lists of finfish species presented by Morrissey et al (2006) as potential colonisers of longline mussel farms in the Marlborough Sounds and Golden Bay, and of fish species documented in two characterisations of the recreational fishery in the Marlborough Sounds by Bell (2001) and Davey et al (2008). Lists also include species that are not truly pelagic i.e., reef species. Note that Bell (2001) and Davey et al (2008) did not list species with scientific names, so they have been added. There is the possibility of species being misidentified by recreational fishers.

Note that this section has been edited to switch the focus from the sites under discussion in the original NZ King Salmon project, to the sites of interest currently. Mostly this was easily achieved with deletions and substitutions. To avoid extensive changes to the coding and to the tables, reference to Port Gore remains. Note also that information relevant to Waitata and Richmond should also be considered relevant to the relocation sites 34, 106, 122, 124 and 125, and information relevant to the Tory Channel sites should also be considered relevant to the relocation sites 42, 47, 82, and 156.



Davey et al (2008) produced lists by several locations. After examination of these lists, species recorded at the following locations were listed in Table 1 as representing species that might be expected at the sites shown in parentheses:

Port Ligar (Waitata, and Richmond); Alligator Head (Port Gore); Inner and Outer Queen Charlotte (Ruakaka and Otanerau); and Tory Channel (Clay Point, Te Pangu, Ngamahau).

A similar treatment was made of the lists by Bell (2001), although area definitions were different than those of Davey et al (2008). For example, Bell (2001) divided Queen Charlotte Sound (QCS) into four, with the central division at the confluence of the Sound with Tory Channel. By contrast, Davey et al (2008) divided QCS in two. Bell's (2001) data from QCS was aggregated to reflect the zones of Davey et al (2008). The final aggregations were as follows:

Outer Waitata Reach, zone 22 (Waitata and Richmond); Port Gore, zone 14 (Port Gore); Inner QCS — zone 32, Mid 1 QCS — zone 33, Mid 2 QCS — zone 34, Long Island Marine Reserve — zone 15 (Ruakaka and Otanerau); and Tory Channel, zone 17 (Clay Point, Te Pangu, Ngamahau).

To simplify interpretation of Table 1, locations from the two studies were allocated to a generic coding as follows: (1) Davey et al (2008); a — Port Ligar; b — Alligator Head; c — Inner & Outer Queen Charlotte Sound; d — Tory Channel; e — elsewhere in Marlborough Sounds; (2) Bell (2001); a — North Waitata Reach; b — Port Gore; c — Zones 32, 33, & 34 in Queen Charlotte Sound & zone 15 Long Island Marine Reserve; d — Tory Channel. Note that these allocations are coarse in some cases.

Morrisey et al (2006) based their list on information from Kingsford & Choat (1985), Jones (1988), Kingsford 1993), Davidson (2001), Francis (2001), and on personal observations. Species were included either because they were locally common, or they or their taxonomic family had been recorded in association with drift algae or sessile invertebrates. Bell's (2001) list contained 11 finfish species, where Davey et al (2008) included 40 species including elasmobranchs. Both studies collected data over 12 months. Bell (2001) worked with 297 diarists; Davey et al (2008) collected data from 200 diarists.

**Table 1: Finfish and shark species listed by Bell (2001), Davey et al (2008), and Morrisey et al (2006), as occurring in the Marlborough Sounds, and locations relevant to the NZ King Salmon project where Bell (2001) and Davey et al (2008) recorded their occurrence; ticks indicate those species listed by Morrisey et al (2006).**

Species	Common name	Family	Morrisey	Bell	Davey
Pelagic finfish					
<i>Aldrichetta forsteri</i>	**Yellow-eyed mullet	Mugilidae	✓		c
<i>Arripis trutta</i>	Kahawai	Arripidae	✓	a,b,c,d	a,b,c,d
<i>Engraulis australis</i>	Anchovy	Engraulidae	✓		*
<i>Hyporhamphus ihi</i>	Garfish/Piper	Hemiramphidae	✓		e
<i>Pseudocaranx dentex</i>	Trevally	Carangidae			c
<i>Sardinops neopilchardus</i>	**Pilchard	Clupeidae	✓		*
<i>Seriola lalandi</i>	Yellowtail kingfish	Carangidae	✓		c
<i>Seriola lalandi</i>	Warehou	Centrolophidae			d
<i>Thyristes atun</i>	Barracouta	Gempylidae	✓	a,b,c,d	a,b,c,d
<i>Trachurus novaezelandiae</i>	Jack mackerel	Carangidae	✓		a
<i>Zeus faber</i>	John dory	Zeidae	✓		a
	**Herring				c
Reef/rocky bottom species					
<i>Aplodactylus arctidens</i>	Marblefish	Aplodactylidae			d
<i>Caesioperca lepidoptera</i>	Butterfly perch	Serranidae			c
<i>Cheilodactylus spectabilis</i>	Red moki	Cheilodactylidae			e
<i>Conger</i> spp.	Conger eel	Congridae			b

<b>Table 1: continued</b>					
Species	Common name	Family	Morrisey	Bell	Davey
<i>Forsterygion</i> spp.	Triplefin	Tripterygiidae	✓		
<i>Grahamina</i> spp.	Triplefin	Tripterygiidae	✓		
<i>Helicolenus percooides</i> <sup>†</sup>	Sea perch	Scorpaenidae		a,b,c,d	a,b,c,d
<i>Hippocampus abdominalis</i>	Seahorse	Syngnathidae	✓		
<i>Latridopsis ciliaris</i>	Blue moki	Latrididae		a,c,d	a,b,c,d
<i>Latris lineate</i>	Trumpeter	Latrididae			c,d
<i>Notolabrus celidotus</i>	Spotty	Labridae	✓		a,c,d
<i>Notolabrus fucicola</i>	Banded wrasse	Labridae			e
<i>Odax pullus</i>	Butterfish	Odacidae			a,b,c,d
<i>Parika scaber</i>	Leather jacket	Monacanthidae	✓		d
<i>Pseudolabrus miles</i>	Scarlet wrasse	Labridae		*a,b,c,d	a,c,d
<i>Lotella rhacinus</i>	Rock cod	Moridae			e
<i>Ruanoho</i> spp.	Triplefin	Tripterygiidae	✓		
<i>Scorpaena papillosus</i> <sup>†</sup>	Dwarf scorpionfish	Scorpaenidae			a
<i>Scorpi lineolatus</i>	Sweep	Kyphosidae			e
<i>Stigmatopora</i> spp.	Pipefishes	Syngnathidae	✓		
<i>Lissocampus</i> spp.	Pipefishes	Syngnathidae	✓		
Benthic/Demersal species					
<i>Chelidonichthys kumu</i>	(Red) Gurnard	Triglidae		a,b,c	b,c
<i>Nemadactylus macropterus</i>	Tarakihi	Cheilodactylidae		a,b,c,d	a,b,c,d
<i>Pagrus auratus</i>	Snapper	Sparidae	✓	a,c	a,b,c
<i>Parapercis colias</i>	Blue cod	Pinguipedidae		a,b,c,d	a,b,c,d
<i>Pelotretis/Peltorhamphus</i> spp.	Sole	Pleuronectidae			e
<i>Polyprius oxygeneios</i>	Hapuku	Percichthyidae			b,c,d
<i>Pseudophycis bachus</i>	Red cod	Moridae		a,c	a,c
<i>Rhombosolea</i> spp.	Flounder	Pleuronectidae			c
Unspecified	Stargazer	Leptoscyidae			b,c
Sharks					
<i>Alopias vulpinus</i>	Thresher shark	Aulopiidae			e
<i>Galeorhinus galeus</i>	Sand shark	Triakidae			
<i>Mustelus lenticulatus</i>	Rig	Triakidae			b,d
<i>Notorynchus cepedianus</i>	Seven-gill shark	Hexanchidae			e
<i>Squalus acanthias</i>	Spiny dogfish	Squalidae		a,c	a,b,c
Other Elasmobranchs					
Unspecified	Stingray	Dasyatidae			e
<i>Myliobatis tenuicaudatus</i>	Eagle ray	Myliobatidae			e
Unspecified	Skate	Rajidae			c

\* Not included in lists by Davey et al (2008), but unlikely targets for fishers.

\*\*Pilchard, herring, yellow-eyed mullet, and sprat sometimes misidentified for each other; herring was included in lists by Davey et al (2008).

<sup>†</sup>There may be some confusion in separating these two species.

<sup>\*</sup>Only “wrasse” specified by Bell (2001); some could be the banded wrasse, *Notolabrus fucicola*.

a — Waitata and Richmond; b — Port Gore; c — Ruakaka and Otanerau; d — Tory Channel; e — elsewhere in Marlborough Sounds.

Morrisey is Morrisey et al (2006); Bell is Bell (2001); Davey is Davey et al (2008).

Table 1 is a compilation of data from three sources. Morrisey et al. (2006) identified a group of species “that might associate with marine farms<sup>2</sup> in the geographical area”. They 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

<sup>2</sup> Mussel farms

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).

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

Table 1 is therefore a mixture of “projected” information (Morrisey et al 2006) and data collected from the recreational fishery. The projected information is included here to provide a range of species that might be expected at farm sites, based on the considerations of Morrisey et al. (2006). The recreational data is included to provide the only available recently published information on the range of finfish species present in the Sounds, which, because of the targeting strategies of recreational fishers, cannot provide an unbiased assessment of species presence and distribution. Note that sharks and other elasmobranchs are included in Table 1 for completeness, but are not discussed in the present context.

Data presented in Table 1 are included to provide some indication of which species might occur at the farm sites under discussion. They suggest that several species are widespread throughout the Marlborough Sounds, including kahawai and barracouta (pelagic species), sea perch, blue moki, scarlet wrasse, spotty and butterfish (reef/rock bottom species), and tarakihi, blue cod, gurnard and snapper (benthic/demersal species), while many other species exhibit more restricted distributions. Although these data were originally collected and used for scientifically valid investigations, they were not however, collected with the aim of providing definitive information on presence and distribution of finfish species in the Sounds and must therefore be used with caution.

For example, an examination of the pelagic finfish list shows two apparently widespread species, kahawai and barracouta, based on the number of probable farm sites where they might occur using the recreational fishing survey data of Bell (2001) and Davey et al. (2008). It is also clear that few of the other species in the pelagic list are preferred target species of recreational fishers: yellow-eyed mullet, anchovy, garfish, and pilchard are all small pelagic species, with only yellow-eyed mullet included as a very minor target (targeted on 7 of 27,843 trips); it is possible that fishers consider trevally and warehou lower value species, with trevally seldom targeted (targeted on 3 of 2784 trips) and warehou never recorded as a target species; barracouta is likely to be avoided and was never listed as a target species; and jack mackerel is targeted on only 3 of 2784 trips (see Davey et al. 2008, Table 20). Therefore, there is clearly sampling bias in using these data to determine distribution of species.

Yellowtail kingfish have a distribution restricted to the outer Queen Charlotte Sound in the survey data which is difficult to explain. It seems that some other factor was operating to prevent the data showing a more widespread distribution for this species. Perhaps fishers avoid them because they are known to be under-sized or, if they did catch them during the survey period, they were not recorded because they were undersized and therefore released.

Similar uncertainty can be argued for a number of species that show limited distributions in the recreational dataset. For example, hapuku is surely a species found in deep water. Its inclusion in the dataset is as an artefact firstly of the area boundaries defined in the recreational survey method, and secondly of the summarising that occurred here. For these reasons, use of the recreational data here is restricted to the universally distributed species only, unless there is some support from the

---

<sup>3</sup> More than one species could be targeted on a fishing trip, which inflates the trip count from the actual trip number of 2148 quoted elsewhere e.g, Table 5 (see Davey et al. 2008, Table 20).

observational dataset of Table 2. In most cases there is consistency between datasets for the universally distributed species from each of the two recreational surveys, but, because of the level of uncertainty in many cases, assignment of species with limited distributions to particular farms is only possible where the Table 2 caveat mentioned above is met.

## 2.2.2 Information from Existing NZ King Salmon Farms

Table 2 contains a list of finfish species observed at the existing farms: Otanerau, Ruakaka, Te Pangu, and Waihinu. In compiling this list, the aim was to focus a little more sharply the information from previous research summarised in Table 1. Note that the information in Table 2 is all anecdotal and based only on observations above the water. In an attempt to quantify these observations, they were assigned non-numeric frequencies, which are not based on count data but on the accumulated knowledge of the staff member providing the information. In three of the four cases this was the farm manager, who had spent long-standing, regular periods at the farm and had developed an understanding of the species observed and the relative frequency with which they were seen.

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

**Table 2: Finfish species observed at existing farms by farm staff; Farm 1 is Otanerau, Farm 2 is Ruakaka, Farm 3 is Te Pangu, Farm 4 is Waihinu; cryptic (X) is not a measure of frequency and categorises those species that are known to be present but are seldom observed in the water column; “Research” column indicates species appearing in previous research (Table 1) either wide spread within Sounds (a) or with limited distribution (b); c indicates no mention in Table 1, because an unlikely target species**

Family	Species	Frequency	Farm 1	Farm 2	Farm 3	Farm 4	Research
Arripidae	Kahawai	Med	✓	✓	✓	✓	a
Carangidae	Jack mackerel	High			✓	✓	b
	Yellowtail kingfish	Med	✓			✓	b
	Trevally	Low			✓		b
Centrolophidae	Blue warehou	Low			✓		b
Cheilodactylidae	Tarakihi	Cryptic	X	✓		X	a
Clupeidae	Pilchard	High	✓		✓	✓	c
Engraulidae	Anchovy	High				✓	c
Gempylidae	Barracouta	Med		✓		✓	a
Hemiramphidae	Garfish (piper)	Med	✓			✓	b
Labridae	Spotty	Med				✓	a
Monacanthidae	Leatherjacket	Low				✓	b
Mugilidae	Yellow-eyed mullet	High	✓	✓	✓	✓	c
Pinguipedidae	Blue cod	?Cryptic		✓			a
Scombridae	Blue mackerel	Low				✓	c
Sparidae	Snapper	Cryptic	X			X	a
Squalidae	Spiny dogfish	High	✓	✓		✓	a
Syngnathidae	Seahorse	Med				✓	c
Triglidae	Gurnard	Low		✓			b
Tripterygiidae	Triplefin spp	Med	✓			✓	c
Zeidae	John dory	Cryptic				X	b

NB: the presence of cryptic species (X) was usually known from angling events only, although they were observed in the water column at some sites (✓). Blue cod was listed at only one farm, but may be cryptic and therefore overlooked at others.

From discussions with the farm managers it was clear that yellow-eyed mullet (family Mugilidae) (Table 1) was the predominant species in cages at times when it was present, followed closely by pilchard (Clupeidae), anchovy (Engraulidae), and jack mackerel (Carangidae). It was also clear that the presence of these species was highly seasonal, and that they may appear as small juveniles because they are able to swim through the mesh into the cages. Cryptic species included snapper (Sparidae) and tarakihi (Cheilodactylidae). Results of previous research show that these two cryptic species have a wide distribution in the Sounds and can be expected at all proposed sites. Such a comparison cannot be made for the more common species however, because distributions from recreational fishing data are inconclusive, mainly because they are unlikely target species of recreational fishers (Tables 1 & 2).

## 2.3 Ecosystem Productivity and Feeding in Pelagic Finfish Species

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

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



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

The Benguela and Humbolt Currents are two of a number of boundary systems of the world that support major fisheries for small pelagic finfish species such as pilchard/sardine and/or anchovy. The structure of the biological communities of these large marine ecosystems is often characterised by large numbers of species at the lower (e.g., planktonic) and upper (i.e., apex and near apex) trophic levels, but with intermediate trophic levels dominated by one to only several species of small plankton-foraging finfish (see review by Bakun 1996). Modelling studies have been used to show that trophic dynamic variability in these ecosystems is usually the result of changes in the populations of the species inhabiting these intermediate trophic levels (Rice 1995). The structural shape of these

biological communities has resulted in the intermediate-level species being referred to as wasp-waist populations.

Within ecosystems, trophic control is referred to as either “bottom up” (i.e., increased production results in increased productivity for all trophic levels above) or “top down” (i.e., consumers depress the trophic level on which they feed, thereby indirectly increasing the next lower level). Within a wasp-waist system however, control is in both directions from the middle. As Bakun (1996) puts it, “The small clupeoid fishes that most often constitute the wasp-waist populations feature notable weak links in their life cycles, through which the variability in the physical ocean-atmosphere system is potentially able to exert direct control on their population dynamics, and thus on the trophic dynamics of the entire ecosystem”.

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

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

This information represents current understanding of the trophic dynamics of small, planktivorous pelagic fishes inhabiting wasp-waist populations in large marine ecosystems. The pilchard and anchovy analogues within the Marlborough Sounds probably also act as an energy conduit between phytoplankton/zooplankton and the higher finfish species that provide the basis of our commercial, recreational, and customary fisheries, but we know very little about their trophic dynamics or how valid it might be to describe their populations as wasp-waist. Some inference could be made from working through the discussion of van der Lingen (2009) and relating it to what is known about the local species. For example, a comparison of branchial basket sizes would provide insight into relative forage particle size and, knowing this, a time series characterisation of phytoplankton species from the databases described by Broekhuizen (2013, 2015) might provide some indication of which species dominated and when.

An understanding of the habitat at this level of detail is required for a complete appraisal of the status of a pelagic habitat. Obviously, our knowledge of the Marlborough Sounds pelagic habitat in this regard is limited. While we have had some knowledge of the phytoplankton species present during particular years (Bradford et al 1987, Burns 1977), the datasets described by Broekhuizen (2013, 2015) have only recently been identified and it is not certain that they can be summarised to provide information over several years and between El Niño/La Niña years. Zeldis et al (2008, 2013) have provided a model of varying productivity between summers of El Niño and La Niña conditions, but without a substantial time series of appropriate plankton data we cannot determine the degree to which the findings of van der Lingen et al. (2006a, 2006b, 2009) and others such as Mitchell-Innes & Pitcher (1992) are relevant here.

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

All of this suggests that the pelagic habitat in the Marlborough Sounds is likely to support productive populations of pelagic fish species, and recreational catches (Table 1) are testament to its continued functioning. However, there is one piece of information that suggests this system might be unsuccessful in always providing an ideal habitat for pelagic fish production. There may be periods when it fails to produce reliable levels of zooplankton production for the small omnivorous finfish to receive adequate nutrition according to the model suggested by van der Lingen (2006) and Espinoza et al (2009). Bradford et al (1987) observed high phytoplankton levels in May 1982 and suggested that this was the result of predation by the medusa *Aurelia aurita* on herbivorous zooplankton which, in turn, reduced grazing pressure on the phytoplankton species. Jellyfish blooms, specifically *Aurelia aurita*, seem to have been a frequent occurrence in the Marlborough Sounds during the 1980s when particular aspects of the work referenced above was under way (Max Gibbs, NIWA, pers. comm.), although it is unknown whether these blooms are a current feature of the ecosystem of the Marlborough Sounds or whether they regularly comprise species that feed on herbivorous zooplankton.

## **2.4 Commercial Fisheries in Areas Containing the Marlborough Sounds**

Species in Table 1 were examined with reference to the commercial fishing species documented in the Ministry for Primary Industries (MPI) Stock Assessment Plenary document (Ministry for Primary Industries 2015). Those that are commercially fished are listed in Table 3, along with the name of the quota management area (QMA) for that species that contains the Marlborough Sounds, and the total allowable commercial catch (TACC) for that QMA and for all QMAs combined. This list includes all commercial species from Table 1 and is not restricted to pelagic species. A best assessment of the relative importance of landings from the Marlborough Sounds for these species would require an analysis of relevant data from the MFish catch-effort database, but time constraints prevented this here. Instead, Table 3 was compiled to show the importance of each commercial fishery (i.e., for each species) in the QMA containing the Sounds by allowing a comparison of local TACC with total TACC (total for all QMAs) and highlighting those fisheries where the local QMA holds the largest TACC for the particular species. Fisheries in the QMA containing the Sounds for barracouta, blue moki, flatfish, jack mackerel, leather jacket, warehou, and red cod are important with TACC:total TACC ratios higher than 0.25. Most others are of moderate importance, with some (e.g., kingfish) minor fisheries. However, the importance of the contribution from the Sounds cannot be inferred using these data.

**Table 3: Commercial species from Table 1, quota management area containing Marlborough Sounds, TACC for that QMA, total all TACCs; (\*TACC/total TACC > 0.25). Source: Ministry for Primary Industries (2015).**

Species	QMA	TACC (t)	Total TACC (t)	Species	QMA	TACC	Total TACC (t)
Anchovy	ANC 7	100	560	Leather jacket	LEA 2	*1 136	1 431
Barracouta	BAR 7	*11 173	32 672	Pilchard	PIL 7	150	2 485
Blue cod	BCO 7	70	2331	Red cod	RCO 7	*3 126	9069
Blue moki	MOK 1	*403	608	Rig	SPO 7	221	1 941
Butterfish	BUT 7	38	162	Sea perch	SPE 7	82	2 190
Flatfish	FLA 7	*2 066	5419	Snapper	SNA 7	200	6 357
Garfish	GAR 7	*8	50	Spiny dogfish	SPD 7	1 902	12 660
Gurnard	GUR 7	785	5451	Stargazer	STA 7	1042	5456
Hapuku	HPB 7	236	2 181	Tarakihi	TAR 7	1 088	6 439
Jack mackerel	JMA 7	*32 537	60 547	Trumpeter	TRU 7	6	144
John dory	JDO 7	151	1 165	Warehou	WAR 7	*1 120	4 512
Kahawai	KAH 3	410	2 728	Yellow-eyed mullet	YEM 7	5	68
Kingfish	KIN 7	15	217				

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

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

As it is not possible to predict the specific make-up (i.e. abundance and composition) of wild fish aggregations that will occur at the proposed new farming sites, the information and inferences drawn in section 3 apply equally to all Plan Change Sites.

#### 3.1 Size and Composition of Wild Fish Aggregations around Fish Farms

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

Most aggregations around farms are dominated by pelagic or benthopelagic fish, which occur in close proximity to the cage structures (Arechavala-Lopez et al. 2015a, b, Bacher et al. 2012, Bagdonas et al. 2012, Boyra et al. 2004, Dempster et al. 2002, 2009, Goodbrand et al. 2012, Özgül and Angel 2013, Segvić Bubić et al. 2011), although aggregations of benthic fish are also important in some locations (Boyra et al. 2004, Dempster et al. 2009, Özgül and Angel 2013). Aggregations of wild fish that are typical target species of fisheries (e.g., carangids, mugilids and sparids; Figure 1) in a concentrated area may affect local fisheries in several ways.





**Figure 1. Wild sparids and carangids massed beneath a sea-cage fish farm in the Mediterranean Sea. The bottom of the cage structure can be seen as the dark area at the top of the frame.**

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

In the Mediterranean, large aggregations of up to 40 tons of wild fish composed of up to 33 fish taxa belonging to 17 families (Dempster et al., 2002, 2004, 2005; Fernandez-Jover et al., 2008) have been recorded around fish farms, with the average aggregated biomass across 9 farms sampled in the summer months estimated to be 12 tons. The most common families observed were Clupeidae, Sparidae, Mugilidae, and Carangidae (see Figure 1). Several pelagic planktivorous fish species (*Boops boops*, *Oblada melanura*, *Trachurus mediterraneus*, *Trachinotus ovatus*, *Sardinella aurita*) and several species belonging to the family Mugilidae were numerically dominant in assemblages, depending on both the farm and season (Fernandez-Jover et al., 2008). Larger predators (*Seriola dumerili* and *Pomatomus saltatrix*) are also present at many of the farms in large schools. Similarly large aggregations of wild fish have been noted around fish farms in Greece (Smith et al. 2003, Thetmeyer et al. 2003), the Canary Islands (Boyra et al. 2004, Tuya et al. 2005) and Australia (Dempster et al. 2004).

Table 2 indicates the species observed by farm managers around existing salmon farms in the Marlborough Sounds. This anecdotal information indicates that pelagic planktivorous fish, benthic species and higher trophic level predators are present. These functional groups of fish are similar to the groups of fish that occur around fish farms in other locations globally (Dempster et al. 2002, 2009). Furthermore, many of the families that are present around Marlborough Sounds farms (e.g. Carangidae, Mugilidae, Sparidae) are known to be highly attracted to fish farms in other areas. Thus,

many of the interactions between wild fish and fish farms in New Zealand are likely to be similar to those documented elsewhere.

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

### 3.2 Spatial and Temporal Variability in Aggregations

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

Previous studies of aggregated wild fish abundance and biomass around fish farms have determined several relationships with farm attributes that may be used to predict the size and nature of assemblages at new farming locations. In the Mediterranean, where pelagic species were dominant at farms and few benthic wild fish occurred, the abundance, biomass and number of wild fish species were negatively correlated with distance of farms from shore and positively correlated with size of farms (Dempster et al. 2002). In contrast, farm age and farm depth were not significantly related to any of these variables, although Bacher et al. 2015 found that substrate type significantly predicted fish aggregations under a Spanish sea-bream farm. Around salmon farms in the Norwegian coastal ecosystem, the benthic-pelagic *Gadus morhua* were significantly more abundant on rocky bottoms than on plain sand or mud bottoms beneath salmon farms (Dempster et al. 2009). Similarly, *G. morhua* abundance was negatively correlated with water depth, indicating that farms in shallower areas aggregated more of this species. Several other species that were abundant around salmon farms (e.g. *Pollachius virens* and *Melanogrammus aeglefinus*) were unaffected by any of the farm attributes tested (benthic habitat type, depth, farm size; Dempster et al. 2009). Taken together, the results suggest that fish farms are most attractive to wild fishes when they are large in size, located in shallow waters, are close to the coast, and are placed over a rocky substrate, although there are certain species that will likely be attracted regardless of these features.

Strong attraction to fish farms may interfere with spawning migrations or other behaviours. Otterå and Skilbrei (2014) tagged and tracked saithe in western Norway, and compared their findings to similar studies conducted prior to the expansion of salmon farming there. They found that distribution of saithe is strongly influenced by salmon farms, and that saithe are now less likely to undertake offshore spawning migration than before, especially smaller individuals. Whether this residence at salmon farms has a net negative effect on the population is unknown.

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

### 3.3 Settlement of Juveniles Fish around Fish Farms

Fish recruit to a wide variety of anthropogenically altered environments, including artificial structures such as docks, jetties (Rilov and Benayahu, 2000), oil platforms (Love et al., 1994), fish attraction devices, and artificial reefs (Beets, 1989). The majority of small juvenile fish that associate with artificial habitats only do so for a specific period of their life history and, as such, spawning periods are thought to regulate the appearance of these species around artificial structures (Dempster and Taquet, 2004). Information on the role of fish farms as settlement habitat is scarce. For Mediterranean fish farms, Fernandez-Jover et al. (2009) found that 20 juvenile fish species settle at farms throughout the year, mainly belonging to the families Sparidae, Mugilidae, and Atherinidae. The abundance of postlarvae and juveniles around a single cage of 12 m diameter may include tens of individuals of *Diplodus* spp. to thousands of individuals of *Atherina* spp. and *Mugil* spp. Fernandez-Jover and Sanchez-Jerez (2014) extended this work and reported juvenile carangids, clupeids, atherinids, sparids and mugilids present on sea cages at comparable densities to natural shallow rocky habitats. The influence of fish cages on the pelagic postlarval stage could affect the connectivity between recruits and fishing stocks, through a spatial modification of the available settlement habitat, alteration of mortality, and modification of trophic resources (e.g., increase of particulate organic matter or zooplankton abundance).

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

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

Diet, condition and parasite loads are all altered when wild fish closely associate with fish farms (Fernandez-Jover et al. 2007, Fernandez-Jover et al. 2010, Dempster et al. 2011). As wild fish in the vicinity of farms consume large amounts of waste feed that falls through the sea-cages, farm-associated fish usually have a significantly higher Fulton's condition index and/or hepatosomatic index and/or tissue fat content than control individuals, as has been described for saithe, Atlantic cod, horse mackerel (*Trachurus sp.*) and two sparids (*Boops boops* and *Sarpa salpa*) (Abaad et al. 2016; Fernandez-Jover et al. 2007, 2011, Arechavala-Lopez et al., 2010, 2015c; Dempster et al., 2011). Salmon farms in the Norwegian coastal ecosystem modified wild fish diets in both quality and quantity, thereby providing farm-associated wild fish with a strong trophic subsidy. This translated to greater body (saithe: 1.06–1.12 times; cod: 1.06–1.11 times) and liver condition indices (saithe: 1.4–1.8 times; cod: 2.0–2.8 times) than control fish caught distant from farms (Figure 2). While waste feed dominated diets of farm-associated saithe and cod, the composition of dietary items other than waste feed still differed, indicating that the availability of other types of prey differed between farm and non-farm locations. The sea floor beneath salmon farms have modified meio- and macro-fauna communities (Kutti et al. 2007) and modified fish assemblages (Dempster et al. 2009) compared to control locations, and wild fish associated with farms clearly also prey upon these fauna.

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



**Figure 2. 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.**

association with fish farms throughout summer and autumn could increase the fecundity of saithe and cod, which spawn in early spring, even if these fish migrate away from farms months prior to spawning.

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

Parasite and pathogen loads of farm-associated wild fish are modified from control fish, but this effect is bi-directional (Fernandez-Jover et al. 2010, Dempster et al. 2011). In the Norwegian coastal ecosystem, Dempster et al. (2011) found slightly elevated levels of the external parasites *Caligus* spp. and *Clavella* spp. on farm-associated wild fish, while the internal parasite *Anisakis simplex* was significantly less abundant in the livers of farm-associated saithe than wild saithe. Overall, these modified parasite loads appeared to have little detrimental effect upon wild fish condition. While abundances of parasites were altered, the strong effect of the trophic subsidy appeared to override any effects of altered loads upon wild fish condition.

Little is known about viral and bacterial transmission between farmed and wild fish. This issue is beyond the scope of the work documented here and is covered in the Disease Risk Assessment Report.

The rate of feed loss from sea-cage aquaculture is likely to vary considerably with location, environmental conditions (e.g. current strengths) and the feed-monitoring technologies in use. Current consensus is that few good, independent estimates of feed loss have been made for salmon aquaculture, but estimates of 1% to 5% feed loss within the Norwegian salmon farms have been made

(Otterå et al., 2009). An independent estimate based on the amount of waste feed found in the stomachs of wild fish living around 9 Norwegian salmon farms put feed loss at a minimum of 1.4% in the summer months (Dempster et al. 2009).

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

Within the Marlborough Sounds, no specific information exists on how the existing salmon farms might modify the condition and parasite loads of wild fish caught in the vicinity of salmon farms. However, as many of the same types of fish found (i.e. small planktivores, demersal fish and higher trophic level carnivores) around fish farms worldwide are found around the existing Marlborough Sounds farms (e.g. kahawai, jack mackerel, kingfish, pilchard, anchovy, mullet, tarakihi, spiny dogfish and snapper; Table 2), it is likely that the condition of the pelagic planktivores often observed around farms will be similarly increased.

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

### **3.5 Physiological Consequences of Association with Fish Farms for Wild Fish**

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

This enhanced biological condition is a typical marker of higher spawning success. However, the fat content and fatty acid composition of commercial aquafeeds may differ so greatly from typical natural fish diets that negative effects may occur. The fat concentration in food pellets used to feed sea bass and sea bream vary from 17% to 24% (Fernandez-Jover et al. 2007a). In addition, due to difficulties in obtaining fish oil and fish feed and their elevated prices, vegetable oils of terrestrial origin are used in the formulation. These vegetable oils include high concentrations of other ingredients such as oleic acid (18:1 $\omega$ 9), linoleic acid (18:2 $\omega$ 6), and  $\alpha$ -linolenic acid (18:3 $\omega$ 3). The introduction of this source of food to the marine environment modifies the fatty acid (FA) composition and fat content levels of tissues of wild fish that feed on the lost pellets may also be elevated (Fernandez-Jover et al. 2007). This has been demonstrated for saithe (*Pollachius virens*) (Arechavala-Lopez et al. 2015c; Skog et al., 2003; Fernandez-Jover et al., 2011) and *Gadus morhua* (Fernandez-Jover et al., 2011) living close to salmon farms along the Norwegian coastline. Farm-associated saithe and cod have significantly increased concentrations of terrestrial-derived FAs such as linoleic (18:2 $\omega$ 6) and oleic (18:1 $\omega$ 9) acids and decreased concentrations of long-chain omega-3 fatty acids (DHA) (22:6 $\omega$ 3) in the muscle and/or liver compared to wild control fish living in waters distant from farms. In addition, the  $\omega$ 3: $\omega$ 6 ratio clearly differed between farm-associated and control fish. Whether these modified fatty acid compositions alter egg composition and larval survival and thus alter reproductive success rates is presently unknown. Captive feeding trials suggest that a heavy reliance on farm feed may be deleterious for some species (e.g. Salze et al. 2005), but evidence for biosynthesis of essential fatty

acids in marine fish and invertebrates indicates that at least some farm-associated organisms are likely to be resilient to changes in dietary fatty acids (e.g. Laurel et al. 2010).

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

### **3.6 Organohalogenated Contaminants**

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

#### **3.6.1 Organohalogenated Contaminants in salmon feeds**

Organohalogenated Contaminants (OCs) include well-studied legacy compounds (i.e. polychlorinated biphenyls (PCBs) and OC-pesticides), and emerging pollutants such as polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD), in addition to perfluorooctane sulfonate (PFOS). The fish-based component of salmon feed (fish oil and fish meal which comprises approximately 25% of the Skretting salmon feed used by NZ King Salmon) is mostly produced from fish meal and oil from lipid-rich oceanic fishes, and contain traces of lipid-soluble OHCs such as organochlorines (OCs) and brominated flame retardants (BFRs) (Jacobs et al. 2002, Hellou et al. 2002, Kelly et al. 2008a, Berntssen et al. 2009).

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

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

#### **3.6.2 Organohalogenated Contaminants in sediments and wild fish around salmon farms**

OHCs may accumulate beneath salmon farms due to the sedimentation of waste feed and fish waste (e.g. Sather et al. 2006, Russell et al. 2011). In both cases where OHCs have been measured in sediments beneath salmon farms, concentrations were elevated only at a local scale (to 100 m). While

elevated relative to control sites, PCBs were found to be below the EAC (environmental assessment criteria) for most samples in Scotland (Russell et al. 2011) and those measured in Canada (Sather et al. 2006) were considered low relative to polluted marine sediments worldwide. No information is available concerning whether, or to what extent, these OHCs bioaccumulate in benthic invertebrates that may be prey items for wild fish below salmon farms.

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

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

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

Within the Marlborough Sounds, observations suggest that several long-lived demersal fish species (e.g. blue cod, snapper, spiny dogfish; Table 2) of commercial, recreational and traditional fishing interest reside in the vicinity of salmon farms. The existing evidence suggests that if organohalogenated contaminants occur in their tissues due to periods of extended residence and feeding on benthic invertebrates beneath salmon farms, levels are likely to remain below those that will affect the fish themselves and below those considered safe for human consumption. In addition, it may be possible that some lipid soluble OHCs (e.g. PFOS) may decrease in their tissues due to their association with farms as determined by Bustnes et al. (2010) for saithe.

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

### **3.7 Heavy Metals**

#### **3.7.1 Heavy metal accumulation at fish farms**

Fish feeds may contain trace concentrations of mercury (Hg) and other elements such as zinc (Zn), copper (Cu), cadmium (Cd), Iron (Fe), manganese (Mn), cobalt (Co), nickel (Ni) and lead (Pb) (Choi & Chec 1998; Lozentzen et al. 1998; 1999) in low levels.

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



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

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

While only trace concentrations are present in salmon feeds, the volume of feed introduced to the limited area of a salmon farm on a multi-year time scale may result in bio-accumulation of certain elements in sediments below farms. Where they are used, antifouling treatments such as Zn or Cu are also likely to contribute to metal accumulation in sediments (e.g. Nikolaou et al. 2014). Sediments below salmon cages hold elevated concentrations of some elements such as Zn, Cu Cd and Fe (e.g. Dean et al. 2007; Naylor et al. 1999). As benthic invertebrate abundance and biomass is typically also higher in farm-influenced locations (e.g. Kutti et al. 2007), and wild fish aggregated at salmon farms feed upon benthic invertebrates as well as salmon feed (e.g. Dempster et al. 2011), studies have sought to determine if heavy metals in wild fish around salmon farms are elevated.

### **3.7.2 Heavy metals in wild fish around salmon farms**

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

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



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

Within the Marlborough Sounds, anecdotal evidence suggests that several long-lived demersal fish species (e.g. blue cod, snapper, spiny dogfish; Table 2) reside in the vicinity of salmon farms. Blue cod and snapper, in particular, are targets for commercial, recreational and traditional fisheries. The existing evidence from studies elsewhere suggests that Hg levels in their tissues are likely to remain at levels below those considered safe for human consumption.

### **3.8 Movements of Farm-Associated Fish**

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

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

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

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

Wild fish appear to play a significant role in assimilating nutrient wastes emitted by salmon farms. Within coastal salmon farming areas in Norway, the main species of aggregated fish, *Pollachius virens*, rely on waste feed for over 70% of their diet when in the vicinity of farms, while several other species (*Gadus morhua*, *Melanogrammus aeglefinus* and *Scomber scombrus*) also consume lost pellets around farms (Dempster et al. 2011). Farm-associated *P. virens* caught during summer had an average of 14.2 g of waste pellets in their stomachs (Dempster et al. 2011). An aggregation size of 10 000 *P. virens*, which is within the range observed many farms (Dempster et al. 2009), would therefore equate to 142 kg of pellets consumed each day during summer, totalling 12.8 t of waste food consumed over a 3 mo period. For a farm with 1000 t of salmon that feeds at a rate of 1% of biomass (or 10 t) per day, 142 kg represents a minimum food loss of 1.4%. These estimates illustrate the capacity wild *P. virens* schools have in reducing particulate sedimentation around salmon farms, thus providing an ‘ecosystem service’ to fish farmers. Similar results have been found for wild fish aggregated around fish farms in the Mediterranean Sea (Vita et al. 2004), while a manipulative experiment under a sea-bream and sea-bass farm in the Spanish Mediterranean indicated that wild fish significantly lowered waste sedimentation rates (Sanz-Lázaro et al. 2011).

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

### 3.10 Interactions of Salmon Farms with Wild Salmonid Populations

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

### 3.11 Quality of Farm-Associated Wild Fish for Human Consumption

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

The assumed negative relationship between association with fish farms and inferior flesh quality is, however, only partially supported by scientific studies (Skog et al., 2003; Bjørn et al., 2007; Otterå et al., 2009). Differences in the fatty acid composition, fat content and other tissue attributes have been

detected between saithe caught near and distant from salmon farms (Fernandez-Jover et al. 2011), but in a controlled experiment, a sensory panel could not distinguish the taste of saithe fed an exclusively salmon feed diet for 8 months from saithe fed typical wild diets (Otterå et al., 2009). However, the wild saithe was different in tissue ‘dullness’ and chewing resistance. Both these attributes could have been due to saithe fed the exclusive salmon feed diet having a higher energetic status, with more muscle protein than saithe fed a typical wild diet. In the Mediterranean, farm-associated bogue (*Boops boops*) were ‘gentler’ in flavour and softer in texture than control samples, perhaps due to higher fat and lower water content (Bogdanović et al. 2012), indicating that any effects on the culinary quality of farm-associated fish are not necessarily negative.

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

## **4. ATTRACTION OF SHARKS TO MARINE FARMS; CONSEQUENCES FOR HUMANS**

### **4.1 Fish Farms and Predatory Fish**

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

The assemblages of small wild fish concentrated in large numbers around fish farms attract larger predatory fish species, such as *Coryphaena hippurus*, *Seriola dumerili*, *Pomatomus saltatrix*, *Dentex dentex*, and *Thunnus thynnus* (Dempster et al., 2002). The attraction of *P. saltatrix* (bluefish) to Mediterranean fish farms is of particular interest (Sanchez-Jerez et al., 2008) because it is an aggressive predator of economic importance. In some farms, bluefish intrude into cages, where they may kill or harm large numbers of farmed fish. This is a serious problem for farmers in terms of economic loss and added technical difficulties in the production process. Bluefish appear to use farms as a new and productive feeding habitat, which may be related to a reduction in trophic resources for these predators due to overfishing of their normal pelagic fish prey stocks. As bluefish are widely distributed, increased development of marine net pen farms in coastal and offshore areas will most likely also involve an increasing level of interaction between fish farms and bluefish populations.

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

### **4.2 Shark Species in the Marlborough Sounds**

At least 14 species of shark are known to occur naturally in the Marlborough Sounds (Clinton Duffy, DOC, pers. Comm.) (Table 4). These species may be encountered anywhere within the Sounds, with examples including instances of bronze whaler (*Carcharhinus brachyurus*) and smooth hammerhead (*Sphyrna zygaena*) sharks taken near the entrance to Mahau Sound, inner Pelorus Sound, and bronze whalers being seen by divers in Lochmara Bay, inner Queen Charlotte Sound. However, the occurrence of most sharks in the Marlborough Sounds, including the smaller bottom-inhabiting species, appears to be highly seasonal and is most likely related to several factors including the distribution of prey and behaviours related to reproductive cycles. Observations of most large pelagic sharks in the region usually occur only during late spring and summer, although great white sharks

**Table 4. Shark species known to occur in Marlborough Sounds, South Island, New Zealand. Source: Clinton Duffy, Dept of Conservation.**

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

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

(*Carcharodon carcharias*) are present year round in the Cook Strait area. Most historical observations of great white sharks from Marlborough Sounds have been recorded during autumn and winter (May to August) in association with commercial whaling operations, but recent satellite tracking data have shown that they are also present during summer.

Information from existing NZ King Salmon salmon farms includes observations of four shark species. The most common is the spiny dogfish (*Squalus acanthias*) which can appear in large numbers during March–May and again during spring (Rick Smale, Waihinu Farm Manager, pers. obs.). Sightings of bronze whalers (*Carcharhinus brachyurus*) have been common in summer months, though none were observed during the 2010–11 summer (Rick Smale, pers. obs.). There have also been occasional sightings of blue shark (*Prionace glauca*) and seven-gilled shark (*Notorynchus cepedianus*).

### 4.3 Attraction of Shark Species to Fish Farms and Consequences for Humans

The only study published in a primary journal examining this issue is by Papastamatiou et al. (2010). Their work suggested a marked difference between sandbar sharks (*Carcharhinus plumbeus*), which exhibited site fidelity to cages over a period of up to 2.5 yr, and tiger sharks (*Galeocerdo cuvier*), which were more transient and displayed short-term fidelity, although some sporadic reappearance did occur.

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

Interactions have been recorded between fish farms and a number of small bottom dwelling species and large pelagic species. Large pelagic species can economically impact fish farming operations through loss of stock (escapement and predation), damage to structures, and decreased production

from cultured fish under regular attack. The impact of bottom-dwelling shark species is usually focused on scavenging uneaten food beneath farms and dead fish accumulating in cages.

Shark mortalities relative to fish farms have resulted from entanglement, confinement in nets/pens, and culling. For safety some farm owners/managers have killed sharks before removing them from cages. In South Australia, methods of live release have been developed and in some cases reduction of shark numbers during periods of high abundance has been carried out by commercial fishers (Murray-Jones 2004). In New Zealand, culling in and around farms happens infrequently, if at all. According to anecdotal information, shark mortalities from entanglement or confinement are rare in New Zealand. Clinton Duffy (DOC) is not aware of any deaths of great white sharks in fish farms in New Zealand.

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

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

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

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

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

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

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

## 5. POSSIBLE EFFECTS OF MARINE FARMS ON THE PELAGIC FISH STOCK UTILISED BY COMMERCIAL, RECREATIONAL, AND CUSTOMARY FISHING

### 5.1 Ecosystem-Based Management of Fish Farming and Local Fisheries

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

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

Coastal fish farms have been suggested to have the potential to act either as ecological traps (Dwernychuk and Boag 1972) or population sources for wild fish populations, depending on how the interaction of fishing with fish farms is managed (Dempster et al. 2006, 2009, 2011). An ecological trap arises when artificial structures are added to natural habitats and induce mismatches between habitat preferences and fitness consequences. In the case of fish farms, if fishing is extensive on wild fish populations when they are aggregated and vulnerable, this may drive a local decline in fish populations through increasing mortality rates. As farms are attractive to wild fish, they will continue to draw fish into their vicinity where they can be fished, which could drive populations down. Alternately, if fishing is prohibited from the immediate surrounds of farms, this may allow the enhanced condition that wild fish generate due to their association with fish farms to translate to enhanced spawning success. With spatial protection from fishing, this may allow fish farms to act as population sources for certain fish stocks.

Spatial protection from fishing may not have to be extensive to be effective in protecting farm-associated wild fish, as wild fish are typically very tightly aggregated to the underwater farming structures (Dempster et al. 2002, 2010). In several Mediterranean countries, no fishing is allowed within the farm leasehold area (typically defined by corner marker buoys positioned 50 – 100 m from cages), and in Norway, no fishing is allowed within 100 m of fish farming structures. This relatively small spatial exclusion from fishing has the added advantage of reducing interactions of fishing gear with fish farming gear, and thus greatly reduces incidences of gear damage that may also lead to escapes of farmed fish. A further advantage of the no fishing restrictions in the immediate vicinity of fish farms is that wild fish are able to provide their ‘ecosystem service’ of consuming waste feed, and thus reducing the severity of any benthic impacts (e.g. Vita et al. 2004). In addition, recent evidence suggests a further useful ecosystem service in that the abundant large wild fish that aggregate around farms consume a significant proportion of the escapees and thus reduce their potential negative interactions with wild populations (Dempster et al. 2016). Spatial protection from fishing will also reduce the possibility of harvesting any long lived benthic fish species in the vicinity of fish farms that may acquire elevated loads of mercury due to their association with farm-impacted sediments (e.g.

deBruyn et al. 2006). Pelagic wild fish that aggregate at fish farms are likely to do so for shorter periods than more sedentary benthic species (Uglen et al. 2008, 2009). Thus, pelagic fish will not become 'locked away' from the regional fishery for extended periods. Spatial protection in the immediate surrounds of fish farms would provide only temporary protection while they were aggregated and more vulnerable at fish farms. Once they move away from farms, they will return to being subject to the standard fishing pressure of the region.

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

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

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

The work completed here has aimed to consider Policy 11 (Appendix B) of the NZCPS in terms of five questions. Policy 11 deals with indigenous biological diversity. The five questions refer to those areas of the Marlborough Sounds where the relocation sites are located. They are as follows:

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

### **6.1 Indigenous fish species listed as threatened or at risk<sup>4</sup>**

#### **6.1.1 Background**

A working list of relevant New Zealand fish species was compiled using selections from the NZTCS threatened and at risk lists and the IUCN red list. Included in this compilation were marine finfish species and diadromous<sup>5</sup> species from the freshwater lists.

At the time of writing this text (September 2016), the threatened and at risk lists for marine fish had not been updated since 2005. The 2008 NZTCS Manual documents a number of updates to classifications, which are consistent with Policy 11 as reproduced here in Appendix B. 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'.

---

<sup>4</sup> Common and scientific names used here are consistent with those used by IUCN and Roberts et al (2015).

<sup>5</sup> 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).

- ‘Chronically Threatened’, ‘Serious Decline’ and ‘Gradual Decline’ have been mostly replaced by a single new category, ‘Declining’.
- The ‘At Risk’ categories ‘Range Restricted’ and ‘Sparse’ have been replaced by a single category called ‘Naturally Uncommon’.

Thus, great white shark/white pointer (*Carcharodon carcharias*) and basking shark (*Cetorhinus maximus*) were re-categorised from ‘Gradual decline’ to ‘Declining’, but neither are endemic so are not included in the final list. A number of species were included in the 2005 list as ‘Sparse’ (i.e., Taxonomically determinate, 10 spp.) or ‘Range Restricted’ (i.e., Taxonomically determinate, 27 spp.; Taxonomically indeterminate, 6 spp.), which were re-categorised to ‘Naturally uncommon’. Of these, only two species from the original ‘Sparse’ list and one from ‘Range restricted’ fitted the criteria of endemic and distributed within the Marlborough Sounds: brotula (*Bidenichthys consobrinus*) and lancelet (*Epigonichthys hectori*) from ‘Sparse’; giant triplefin (*Blennodon dorsale*) from ‘Range restricted’.

Of a total of 24 possible candidates in the current NZTCS freshwater fish threatened and at risk lists, five species met the criteria of endemic, diadromous, and (probably) distributed within the Sounds. These were shortjaw kokopu (*Galaxias postvectis*) in the Threatened-Nationally vulnerable list, and longfin eel (*Anguilla dieffenbachii*), giant kokopu (*Galaxias argenteus*), bluegill bully (*Gobiomorphus hubbsi*), and redfin bully (*Gobiomorphus huttoni*) in the At risk-Declining 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 the Marlborough Sounds and other areas, such as around Cook and Foveaux straits, Fiordland and Stewart and Chatham islands, which may be the result of oceanographic conditions that are not favourable for the return to rivers of the marine-inhabiting juvenile phase.

A number of the species in the IUCN selection are distributed in or over deep water and are not discussed further here. These include black marlin (*Istiompax indica*), striped marlin (*Kajikia audax*), blue marlin (*Makaira nigricans*), ocean sunfish (*Mola mola*), shortbill spearfish (*Tetrapturus angustirostris*), albacore tuna (*Thunnus alalunga*), yellowfin tuna (*Thunnus albacares*), southern bluefin tuna (*Thunnus maccoyii*), bigeye tuna (*Thunnus obesus*), eightbar grouper (*Hyporthodus octofasciatus*/Epinephelus octofasciatus), and the Chilean jack mackerel (*Trachurus murphyi*). Several of the remaining species are unknown from the Sounds but are discussed below to clarify their distribution as absent.

The IUCN selection, for example, did not include species categorised as of ‘Least concern’. Information from other sources with regards dredging restrictions in spawning areas of elephant fish (*Callorhinchus milii*) and rough skate (*Raja nasuta*), which are considered ecologically significant marine sites in the Marlborough Sounds, strongly supports the inclusion of these two species within Section 1.4. They are both listed within the ‘Least concern’ category by the IUCN.

### **6.1.2 List of marine and diadromous species meeting the Policy 11 criteria for the Marlborough Sounds**

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

#### **Bluegilled bully (*Gobiomorphus hubbsi*)**

An endemic, diadromous (anadromous) species distributed throughout coastal regions of New Zealand including the South Island (McDowall 1978, Roberts et al 2015). It is expected that this includes the



Marlborough Sounds although there is no specific mention of the area in these publications. It is described as cryptic and secretive and rarely seen (Roberts et al 2015). Larvae spend several months at sea, their return coinciding with the whitebait runs.

### **Giant kokopu (*Galaxias argenteus*)**

An endemic, diadromous (anadromous) species distributed throughout lowland areas of the North and South Islands as well as several offshore islands (Roberts et al 2015). In the South Island, less common down the east coast to the Otago Peninsula. There is no specific reference to the Marlborough Sounds in the literature. A voucher specimen has been collected in Marlborough, but according to the map in Roberts et al (2015), appears to be from outside the area of the Sounds. Larvae return to freshwater as whitebait after a marine phase of about 18 weeks but, according to the McDowall (1978), this species in the whitebait catch late in the season. The “known distribution” map on the NIWA online site<sup>6</sup> includes several identification sites for this species in the Marlborough Sounds. This species spawns in autumn or early winter; “when the young hatch they must be washed out to sea” (McDowall 1978).

### **Longfinned eel (*Anguilla dieffenbachii*)**

An endemic, diadromous (catadromous) species widespread throughout New Zealand in freshwater, except above swift rapids and waterfalls. Not referenced specifically to the Marlborough Sounds area in the literature, and there is some uncertainty about what level of abundance the longfin might have in the Marlborough Sounds given its documented preference for fast flowing stony rivers and highland lakes, in contrast to the shortfin eel (*A. australis*) which prefers slow-flowing, soft-bottomed rivers and streams and lowland lakes (see review of freshwater eel biology in Ministry of Primary Industries 2015). Furthermore, Jellyman et al. (2002) showed higher densities for this species on the west coast. However, the “known distribution” map on the NIWA online site includes many<sup>7</sup> identification sites for this species in the Marlborough Sounds. Adults migrate to the sea during autumn, spawning in the sub-tropical Pacific. The leptocephalus larvae somehow returns to NZ waters, metamorphoses into the glass eel and, upon reaching freshwater in August to November, migrates up rivers and streams.

### **Redfinned bully (*Gobiomorphus huttoni*)**

As with the bluegill bully, this is an endemic, diadromous (anadromous) species distributed throughout coastal regions of New Zealand including the South Island (McDowall 1978, Roberts et al 2015). By contrast, more information is available with a distribution map in McDowall (1978) including sites in the Sounds area where identification has been made and, from the distribution map for this species in Roberts et al (2015), several museum voucher specimens appear to have been collected in this area.

Spawning in this species occurs “from about July onwards, probably until at least November” and “it is likely the female spawns twice each season” (McDowall 1978). “Development [of the egg] takes from two to four weeks” and after hatching the young migrate to the sea where the larval stage is spent, with a return to freshwater from about November onwards.

### **Shortjawed kokopu (*Galaxias postvectis*)**

An endemic, diadromous (anadromous) species distributed throughout the North and South Islands. There is no specific reference in the literature to the Marlborough Sounds. According to Roberts et al (2015) this species “is found in small streams and rivers with extensive marginal podocarp/broadleaf forest cover and complex structure (logs, large boulders, and overhangs) in the waterway”. The “known distribution” map on the NIWA online site<sup>8</sup> includes several identification sites for this species in the Marlborough Sounds.

---

<sup>6</sup> [https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/giant\\_kokopu](https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/giant_kokopu)

<sup>7</sup> [https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/longfin\\_eel](https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/longfin_eel)

<sup>8</sup> [https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/shortjaw\\_kokopu](https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/shortjaw_kokopu)

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 endemic to New Zealand and distributed within the Sounds area. All are diadromous. There is clear evidence that the redfin bully occurs in the Sounds, but none for the bluegill bully. Both species are described as widespread in New Zealand and, because of its cryptic, secretive habit, it is likely that the bluegill bully also inhabits the Sounds, particularly Pelorus Sound with its large freshwater component from the Pelorus River. Similarly for the remaining three species whose presence in the Sounds is not actually specified.

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

### 6.1.4 Implications

The diadromous habit of the species of interest means that the larval stage of all of them occurs within the marine environment. There is little information characterising this phase in any of these species, except the longfinned eel. It is therefore difficult to suggest the passage that may be utilised within the Sounds and whether the larvae of the bullies and galaxiidae travel beyond the Sounds. Given the size of the Pelorus River and the contrastingly low amount of freshwater catchment feeding into Queen Charlotte Sound, it seems likely that there will be a higher density of the larvae in the correct season within Pelorus Sound and side arms than in Queen Charlotte Sound.

One question to consider is whether the relocated sites would have a greater effect overall on these species than the existing sites. Although we know very little about the larval bullies and galaxiidae, we do know something about the hydrology of the Sounds, particular that of Pelorus Sound (see Section 2.1.2). An important feature is the “conveyor belt system” of Gibbs et al (1991) in which the incoming seawater moves along the bottom of the main channel and the outward-bound freshwater moves over the seawater. Given that larval fish are probably capable of adjusting their depth in the water column to take advantage of specific flow directions (see discussion in Section 6.5.1 below of the review by Bakun 1996), this provides a potential mechanism by which the larvae of interest may maintain a geographical position or optimum zone within the Sounds.

Migrations during the marine phases of these species comprise two components: the outward migration, from freshwater into the sea and beyond; and the returning migration, from Cook Strait, up the Sound, and into freshwater. Although it is unknown how far the migrations of larval bullies and galaxiidae take them, it is assumed that, unless they maintain a geographical position within the Sounds for a reason such as the availability of forage, they continue beyond the confines of the Sounds into habitat similar to that entered by individuals of these species undertaking similar migrations in

other areas of New Zealand. For the longfinned eel, it is well known that this species undertakes the entire journey, although no individual travels both legs of this journey consecutively.

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

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

As is discussed in Section 2.1.2, the depth of the photic zone increases with distance towards Cook Strait from Beatrix Bay, thus resulting in increasing productivity throughout the water column as surface phytoplankton become mixed into deeper layers and increasing light penetration with decreasing turbidity results in higher growth rates throughout a greater proportion of its volume. Consequently, as the larval bullies and galaxiidae move towards the outer Sounds, forage items become available deeper within the water column, so that, if they are maintaining their position within some geographical boundaries within the Sound, by riding the Gibbs conveyor they may be distributed at greater depth to maintain a positive energy balance as they swim.

This suggests that, under these conditions within Pelorus Sound, forage items for the larval species that are of interest here will be near the sea surface at points up the Sound away from the salmon farm sites, whereas closer to the farm sites they will be distributed throughout a much greater proportion of the depth range. If this is the case, one would expect a reduction in the numbers of larvae near the surface as pulses move down toward the farm sites. The timing of this mechanism seems to be about right, given that sampling for a number of the studies included in the discussion in Section 2.1.2 was carried out during winter, the time that outward migrations of the species of interest occur.

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

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

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

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

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

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

Information on the returning migration of the galaxiid juveniles is almost non-existent, apart from their size at this time, which is about 45–55mm. Schooling behaviour is a major characteristic of the five galaxiid species contributing to the whitebait fishery and, although there does not appear to be a description of the transition in the literature as there is for the glass eel, it seems reasonable to expect that something similar occurs in the returning galaxiid juveniles, which are a minor component of the New Zealand whitebait fishery (McDowall 1991). This assumption is supported to some degree by the fact that the whitebait fishery occurs within freshwater, not saltwater, as shoals of juvenile galaxiid fish are targeted when moving into New Zealand rivers and streams during the spring (McDowall 1991). Based on this assumption, it is suggested that the vulnerability to the relocated farms of returning juvenile giant kokopu and the shortjaw kokopu is low, for the same reason as that given for the returning glass eel.

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

**Consideration of the low flow sites** currently utilised suggests that the probability of these migrating species enter those farm sites will be related to “intended destination” of their migration. Generally, information on migrating adult eels suggests that they do not deviate from their course towards the spawning grounds (Jellyman & Tsukamoto 2002) except for vertical variations probably for predator avoidance and thermoregulation (Jellyman & Tsukamoto 2005). Their presence at the low flow sites is unlikely. By contrast, outgoing bully and galaxiid larvae inhabit the marine environment for a life history stage characterised by growth. While it is more likely that they would be found at high flow sites, their presence at low flow sites cannot be discounted, though the frequency would be low. Incoming migrating juvenile bullies and galaxiidae, and glass eels are more likely to inhabit zones where they can take advantage of the assistance provided by moving water, so it is more likely that they would come in contact with high flow sites than low flow sites. Given the probable low rate of contact, and the degree to which these species are widespread within New Zealand, the nett effect of any contact with low flow sites would likely be very low.

### 6.1.5 Summary

From the available information it seems that the early life history stages of the bully and galaxiid species of interest are mostly characterised by a dispersed distribution during their marine phase, which supports the conclusion that their vulnerability to relocated farms at the proposed high flow sites is likely to be low. This can be stated with more authority for Pelorus Sound than for Queen Charlotte Sound. It is also concluded that the vulnerability of both the outgoing adult eels and returning glass eels is low. The vulnerability of all these species to farms at the existing low flow sites is likely to be even lower than for the relocation sites.

## **6.2 Habitats for species at the limit of their range**

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

## **6.3 Nationally significant fish communities**

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

One aim of the present work has been to construct an inventory of fish species that might interact with the NZ King Salmon farms in the Sounds. However, there has been little information available on which to base this work. Essentially, the approach has been limited to the works of Morrissey et al (2006), a list of species that is largely inferred from several previous authors (see Section 2.2.1), two recreational fishing surveys by Bell (2001) and Davey et al (2008), and information that was collected from farm managers. While this information is useful here in a supplementary sense, it cannot be used as a basis for developing definitive descriptions of nationally significant fish communities.

### **6.3.1 Rocky reef fish communities**

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

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

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

#### **Method**

- Based on the locations of dive sites, the Sounds were divided into the following areas: Admiralty Bay, Waitata Reach to Tennyson Inlet, Pelorus Sound, Chetwode Islands to Alligator Head, Port Gore, Vicinity of Long Is, Outer Queen Charlotte Sound, Inner Queen Charlotte Sound, Tory Channel, and Port Underwood.
- The range of ordinal scale values were identified for each area from each species map and tabulated as a range e.g., 1.2–3.7.
- Species with zero values in all areas were removed from the list.

- Because of difficulties rationalising the ordinal ranges containing zero, the values were translated to provide a presence-absence summary.
- The data were sorted by taxonomic family and species and used to create Table C1<sup>9</sup>

## Results

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

## Conclusions

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

### 6.3.2 The pelagic fish community

Although there is no result of any community study specific to this group, it is worth noting that the population of pilchard inhabiting the area of the Sounds-Tasman Bay is extensive and, although not the subject of any ongoing study, was investigated in depth by Baker (1972), including the use of drift cards to characterise the movement of eggs and larvae from the spawning ground in Tasman Bay through French Pass into Admiralty Bay. Plankton samples from Baker's Admiralty Bay station indicated numbers of pilchard eggs and larvae from this area to be as high as the highest sample stations in Tasman Bay and higher than any throughout the remainder of the Sounds.

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

### 6.3.3 The demersal fish community

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

## 6.4 Habitats of importance during vulnerable life history stages

Two species inhabiting the Sounds have vulnerable life history stages because of their low fecundity and the long gestation period of the eggs after laying. The elephant fish (*Callorhinchus milii*) is oviparous, usually laying its egg cases on sand or muddy substrate; gestation is from 6 to 12 months (Roberts et al 2015). The rough skate (*Zearaja nasuta*) probably lays its fertilised eggs in leathery egg

---

<sup>9</sup> See Appendix C

cases in pairs (Francis 1997, Roberts et al 2015). In both species each egg case produces a single embryo.

Within the Sounds, rough skate spawn in Grove Arm between Ngakuta and Governor's Bays. Elephant fish spawn between Ngakuta and Blackwood Bays, with most spawning appearing to be in Kaipakirikiri Bay and the western arm of Kumutoto Bay at 4-12m depth.

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

### **6.5.1 Overview**

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

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

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

Puth & Wilson (2001) see boundaries and corridors as entities that are linked by their strong influence on ecological flows, not separate landscape components as they were usually considered. Instead they represent opposite ends of a continuum of flow regulation, with different effects on rates and direction of flow. Boundaries change flow direction through reflecting, stopping, or "shuttling"<sup>10</sup>; corridors provide unlimited movement across boundaries, and can even increase flow rates.

The human experience is largely with the terrestrial environment, so we tend to adopt known concepts from this experience when attempting to understand the aquatic environment, which is not necessarily the best approach. For example, Bakun (1996) observed that gravity is the most important dynamic constraint in the lives of terrestrial organisms, affecting all active movements and providing a particular system of ascendancy/refuge in predator/prey relationships i.e., prey can climb away from predators; some predators (e.g., birds of prey) can adopt a position of dominance above prey; and increasing body size requires increasing structural mass with associated weight increases, which can reduce speed and agility. However, this model does not effectively represent the aquatic environment, particularly marine habitats where Bakun (1996) suggests organisms are most often almost neutrally buoyant, so that the law of gravity is replaced by the laws of hydrodynamics in acting to constrain behaviour, and gravitational pull gives way to frictional drag as the main force opposing active movement.

---

<sup>10</sup> 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).

Therefore, strategies adopted by marine organisms to achieve a positive energy balance include those that reduce this frictional drag. For finfish species, Bakun (1996) points out that “many aspects of the biology and behaviour of fish give strong evidence for the importance of optimizing energy costs”, citing Lighthill (1977) and Wardle & Reid (1977) as researchers who have shown that there is a high degree of tuning in the swimming mechanics of fishes, effectively reducing the energy requirement for swimming. He also refers to the available information on fish migration routes, including work on the pink salmon (*Oncorhynchus gorbuscha*) by Royce et al (1968), skipjack tuna (*Katsuwonus pelamis*) by Seckel (1972), and plaice and cod by Hardin Jones (1977), to conclude that migrating fish tend to utilise ocean currents rather than oppose them, even when the fishes’ swimming speed is considerably higher than the current speed.

Bakun (1996) summarises the Hardin Jones (1977) study further, indicating that it documents the ability of these fish species to adjust their depth according to the tidal cycle, thereby accessing the oscillating tidal currents to achieve a positive energy balance during migratory swimming. The study highlights the structurally complex nature of the aquatic environment, where adjusting depth to gain advantage is a common strategy utilised by several different life history stages. In this adult cod and plaice case use depth adjustment to access the environmental corridors offered by tidal currents.

Bakun (1996) also discusses depth adjustment by larval fish to maintain their position within a boundary-delineated zone associated with a shelf-sea front. He cites the work of Iles and Sinclair (1982) who describe the presence of herring larvae within such a zone, suggesting that by maintaining their position either near the ocean surface or near the bottom, where water movement is on-shore (contrasted with midwater depths that are characterised by flow in the opposite direction), they avoid being carried offshore and could take advantage of the high concentration of preferred forage items such as crustacean nauplii in the pycnocline<sup>11</sup> region associated with the front. Bakun (1996) supports this suggestion by referencing the results of Buckley & Lough (1987), who describe more numerous, faster growing haddock larvae in such a region of the Georges Bank compared with other zones of that shelf complex.

Zones that exist at the surface and provide a system that inhibits oceanic flow are perhaps the most obvious areas where ecological boundaries operate. For example, Bakun (1996) refers to the Southern Californian Bight where a gyral geostrophic circulation pattern is dominant for most of the year and probably retains eggs and larvae. The sheltered nature of the area, from strong coastal winds, ensures a very low level of turbulent mixing and produces a layer of concentrated food particles (Lasker 1978), and the productivity is sustained at what appears to be a high level by strong local upwelling. The Bight is a major spawning ground for “the pelagic fishes that dominate the exploitable biomass of the California Current ecosystem” and Bakun (1996) references the work of Parrish et al (1981) who describe probable long-distance migrations of species such as the Pacific sardine (*Sardinops sagax*), hake (*Merluccius productus*), and blue mackerel (*Scomber japonicus*) to spawn in this area .

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

---

<sup>11</sup> A zone where water density increases with depth.



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

Afonso et al (2009) used passive telemetry to show that 'offshore' trevally can relinquish their seasonal attachment to the reef and replace it with periods of migratory behaviour, when, in short periods of only hours to just a few days, they can travel between areas and habitat types separated by tens of kilometres. These results show that the home ranges of trevally in this environment change substantially, and that this occurs not only between individuals comprising the two groups (coastal and offshore) within the population, but also for individuals during the course of a year.

Essentially, this question of fish movements and how they relate to the boundary-corridor continuum is complex, obscure, and varies both between and within species in a variety of ways, although there are certain aspects that are generally applicable over most species. However, the summary presented here is but a scratch upon the surface, not only of what actually exists in the wild, but also of what is known. The challenge in providing a useful overview is that while there is undoubtedly extensive knowledge that could be included, this knowledge has been documented from perspectives that are different to the one that interests us here, which adds a barrier to easy access and information flow.

## 6.5.2 Relevance

The relevance of this information to the Marlborough Sounds situation can be seen if we consider certain aspects of the pelagic habitat we have described in Section 2.1.2 and discuss them with reference to finfish species of interest here. The discussion of redfin and bluegill bullies, and giant and shortjaw kokopu in Section 6.1 provides a good example of how the corridor-barrier continuum might apply to the larvae of four fish species. The work of Baker (1972) indicates that at least one pelagic species (pilchard) utilises a corridor provided by a current system in the Marlborough Sounds to assist in moving eggs and larvae from a spawning ground to an area that is potentially highly productive offering optimum conditions for development through to recruitment to the adult population.

However, what we do not have is knowledge of what is actually happening with the fish. While we can speculate about their behaviour based on information from elsewhere, without appropriately designed experimental/investigative work we are without tests of any of the hypotheses that might be developed from this discussion. As was suggested above in Section 6.1, it seems unlikely that the nett effect of farms at the relocation sites on the finfish fauna through impacts on movement corridors and other components of the corridor-barrier continuum would be anything but low. Unlikely at least, to offset the flushing benefits and associated improvements to be gained from re-establishing farms in low flow areas to high flow sites.

Ultimately, however, it is in our best interests to begin investigating some of the ecological issues related to non-commercial finfish species. These species are almost always overlooked in the allocation of research funding, but like pilchard<sup>12</sup> and other small pelagic species, can occupy key positions in energy flow through inshore food webs.

---

<sup>12</sup> 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.

## **7. CONCLUSIONS FROM THE COMPILED INFORMATION**

### **7.1 The Pelagic Habitat in the Marlborough Sounds**

1. A body of work investigating a wide range of systems has provided useful information on which to base a characterisation of the pelagic habitat for the NZ King Salmon sites, particularly those in Waitata Reach.
2. Based on this information and two characterisations of recreational fishing, it is evident that the pelagic habitat of the outer Pelorus and Queen Charlotte Sounds, and Tory Channel is highly productive, supporting a wide range of marine organisms.
3. The relationship between ENSO-related events and the two hydrological features of Cook Strait upwelling and freshwater inflow from the Pelorus and Kaituna Rivers provide a mechanism that could be used to indicate gross changes in productivity in the Sounds.
4. The main aim in managing the new sites is to ensure that adverse effects of the farming are avoided, remedied, or mitigated, so that pelagic habitat function is maintained and impacts on all finfish species are minimised, thus minimising impacts on species targeted in customary, recreational, and commercial fisheries.

### **7.2 Pelagic Finfish Species at Existing Farms in the Marlborough Sounds**

1. A summary of observations at existing NZ King Salmon salmon farms in the Marlborough Sounds indicates that yellow-eyed mullet (family Mugilidae) was the predominant species in the cages during periods when it was present, followed closely by pilchard (Clupeidae), anchovy (Engraulidae), and jack mackerel (Carangidae).
2. It was clear that the presence of these species was highly seasonal, and that they may appear as small juveniles because they are able to swim through the mesh into the cages.
3. Cryptic species are defined as those that are known to be present often but which are seldom seen; the species in this category known to occur frequently include snapper (Sparidae) and tarakihi (Cheilodactylidae).
4. Larger predatory pelagic species such as yellowtail kingfish (Carangidae) also frequent existing farms.

### **7.3 Effects of Fish Farming on the Pelagic Habitat and Wild Fish**

1. Fish farms attract large, multi-species assemblages of wild fish which aggregate in their immediate vicinity. While no specific information exists for how wild fish interact with New Zealand's existing salmon farms, this effect appears universal as it has been detected in many places globally. Many of the functional and/or taxonomic fish groups that have been observed aggregating at fish farms elsewhere are also present in the Marlborough Sounds (e.g. carangids, sparids, mugilids), suggesting that we can expect similar behaviour here.
2. Aggregations are temporally persistent, although specific species within the aggregated assemblage will likely vary with season, reproductive stage and feeding regime, and

aggregations are typically made up of a high proportion of adult fish, making them particularly attractive locations for fishers.

3. Previous research suggests that while it is difficult to predict the types of fish and their numbers that will aggregate at any new farming site, fish farms are most attractive to the most wild fish species when the farm is large in size, located in shallow waters, and is close to the coast. The NZ King Salmon sites match some of these environmental criteria, with a relatively shallow, inshore location, indicating that the farms are likely to be attractive to a range of wild fish species.
4. Aggregation at fish farms leads to a shift away from a natural diet to a farm-modified diet for wild fish. Wild fish consume more food around fish farms than they do in natural habitats, and they feed extensively on feed that is lost from the farm cages.
5. Modified dietary intake leads to marked changes in the condition and physiological composition of wild fish that aggregate in the vicinity of fish farms. Condition and body fat content are typically elevated compared to fish that do not associate with farms. Traditionally, high condition indices suggest fish are in good health and good spawning condition.

Fatty acid compositions of wild fish tissues are altered compared to fish that do not associate with farms, with detectable increases in terrestrial-derived fatty acids, such as linoleic (18:2 $\omega$ 6) and oleic (18:1 $\omega$ 9) acids, and decreases in long-chain omega-3 fatty acids (DHA; 22:6 $\omega$ 3). The ecological effects of these changes on wild fish, if any, remain unknown, although the available evidence indicates that effects are likely to be dependent on the quantity of feed consumed relative to natural food sources.

6. Loads of specific parasites may be elevated in some farm-associated wild fish, while loads of some parasites may be reduced. Overall, the high food availability at farms appears to outweigh any increase in parasite loads for the wild fish assemblages studied to date. There is evidence of bi-directional pathogen transmission between farmed and wild fish, although the frequency and consequences for wild populations are not known. Very little research has been conducted in New Zealand on this subject, but the available information is covered in greater detail in the Disease Risk Assessment Report.
7. Elevated heavy metal concentrations are common in sediments beneath fish farms, and the presence of farms may elevate or reduce levels of some heavy metals in wild fish tissues, depending on the wild fish species. Elevated levels of mercury in the tissues of one long-lived, highly resident, demersal fish species and one mobile, pelagic fish species have been detected beneath salmon farms. While elevated, these levels were below public health limits set for safe consumption by humans.
8. Fish farms may elevate or reduce levels of some organohalogenated contaminants in wild fish tissues, depending on the wild fish species. Elevated levels of specific organohalogenated compounds have been detected for two pelagic fish species beneath salmon farms. While elevated, these levels fall below public health limits set for safe consumption by humans.
9. Traditional, recreational and commercial fishers have the potential to capture wild fish populations adjacent to fish farms, where wild fish are aggregated and more susceptible to fishing pressure. The nature and magnitude of the fishery-aquaculture interaction will depend on the types and abundances of wild fish that associate with the new farms and the extent to which traditional, recreational and commercial fisheries target aggregated wild fish at farming locations. Some of the fish species that we expect are most likely to aggregate at the farm sites are also heavily targeted by fishers in New Zealand (e.g. carangids, sparids).

10. Fishing at fish farms has the potential to increase fishing pressure on wild fish stocks as catch per unit effort will likely be high in the near vicinity of farms (unless a fishing exclusion zone around the farms is established). There are currently no restrictions on fishing near farms, and there is anecdotal evidence that fishers target areas around existing mussel farms in the Sounds. High catches may lead to local changes in fish abundance, and although not yet the case here, if farming becomes widespread within a region and traditional, recreational and commercial fishing pressure is intense, broader, regional-scale population implications are possible.

#### **7.4 Interactions of Fish Farms with Sharks**

1. There are 14 species of shark that occur naturally in Pelorus Sound.
2. While fish farms do not attract sharks into a particular region, they are likely to attract sharks inhabiting the area or passing through; this could result in temporary local concentrations of sharks around farms, depending on the species concerned.
3. The nature of shark-fish farm interactions will vary according to a number of variables, including the species of shark, the farm site, the season, the size of the farm, management practices, and the species being farmed.
4. There is too little knowledge of shark-farm interactions and shark populations in Marlborough Sounds to reach any definitive conclusions regarding the potential effects of salmon farming on local shark populations.
5. Nevertheless, mortality of large sharks due to entanglement or confinement in fish farms seems to occur infrequently.
6. It is unlikely that large pelagic sharks would remain in the vicinity of a farm for an extended period without receiving a reward of food.
7. It is unlikely that the methods developed for handling marine mammals will be transferable to large sharks; consideration should be given to the development of methods for the live release of shark species.
8. Although blue sharks and bronze whaler sharks are classified as potentially dangerous they do not behave aggressively toward humans under normal conditions.
9. While common sense and caution should always be exercised when interacting with sharks, the presence of shark species, particularly bronze whalers, does not represent an unacceptable risk to swimmers and divers.
10. Based on records to date, the actual risk of shark attack does not appear to be any greater around fish farms than in many other parts of New Zealand's marine environment (e.g. in close proximity to seal colonies or pods of dolphins, or in areas where schools of bait fish naturally aggregate).

#### **7.5 The Effect of Fish Farms on the Indigenous Biological Diversity of Wild Fish**

1. Five wild fish species were identified as meeting the NZTCS Policy 11 criteria for protection under clauses (a)(i) and (a)(ii) (see Appendix B). They are all endemic and diadromous, and, according to the best available information, are found within the Marlborough Sounds.

2. Little information is available for the marine phase of these species within the Marlborough Sounds.
3. Inference from studies elsewhere and what is known of the hydrology of Pelorus Sound in particular suggests that, at least within Pelorus Sound where it is expected that the highest density of these species will be distributed within the Sounds, vulnerability to the farms of the outgoing migratory adults and incoming glass eels of the longfinned eel, the outgoing larvae and returning juveniles of the two bully species, and the outgoing larvae of the two galaxiid species will be low.
4. There is no evidence for any finfish species at the limit of its range within the Marlborough Sounds.
5. No work has been published that specifies any fish communities of national significance within the Marlborough Sounds. This does not mean that none exists and available information on species from three broad assemblages (i.e., rocky reef, pelagic and demersal) either known from the Sounds or having a predicted presence there are summarised here. However, without information on the community function of each of the listed species, the effect of the farms cannot be evaluated beyond their effect on the species as individuals, which is summarised elsewhere in this section.
6. There are habitats that are important during vulnerable life history stages for two species in the Sounds. These are spawning grounds for rough skate in Grove Arm between Ngakuta and Governor's Bays and elephant fish between Ngakuta and Blackwood Bays, with most spawning appearing to be in Kaipakirikiri Bay and the western arm of Kumutoto Bay at 4-12m depth. These areas are distant from all the relocation sites as well as the current low flow sites and are therefore unlikely to be impacted by either the current or proposed site configurations.
7. Based on research carried out elsewhere it is clear that the concepts of areas and routes for migratory species and ecological corridors are relevant to the finfish community. Treating corridors and barriers as the two extremes of a continuum provides a useful model, which, when considered in terms of the hydrology within the Sounds, suggests how this model might be relevant in explaining why the impact on the species of interest by farms at both the low flow sites and the relocation sites is probably low.

## **8. IMPLICATIONS FOR FISH FARMS IN THE MARLBOROUGH SOUNDS**

### **8.1 The Pelagic Habitat**

A number of aspects of the pelagic habitat in the Marlborough Sounds have been well studied, particularly in Pelorus Sound. This is useful in developing an understanding of the sites in and near to Waitata Reach (Waitata and Richmond, the relocation sites 34, 106, 122, 124, 125, and possibly Waihinu and Forsyth. There is also useful information for sites in Queen Charlotte Sound (Ruakaka, Otanerau) and Tory Channel (Clay Point, Te Pangu, Ngamahau, and the relocation sites 42, 47, 82, and 156).

From the information summarised in Section 2, it is clear that a well-functioning pelagic habitat existed until about 1990, and there is no evidence to refute this being the case now. Recent independent analysis identified NNW weather as producing periods of high nutrient flow into Pelorus Sound, either from upwelling in Cook Strait in summer, or rain runoff via the Kaituna and Pelorus Rivers, in winter (Zeldis et al 2008, 2013). SSE weather was shown to result in lower nutrient levels. Although it was not included in the analysis it seems reasonable to conclude a similar result for the Queen Charlotte Sound-Tory Channel area when summer NNW weather generates nutrient inflow

from upwelling in Cook Strait. By contrast, a weaker response is concluded for this area in winter from increased rainfall because freshwater input is probably lower than for Pelorus Sound where rivers are considerably larger.

Thus, we can infer higher naturally mediated levels of nutrient influx to Waitata, Richmond and the relocation sites 34, 106, 122, 124, 125, and also for Ruakaka, Otanerau, Clay Point, Te Pangu, Ngamahau and the relocation sites 42, 47, 82, and 156, under NNW weather conditions in summer. Lower nutrient influx will occur at all these sites during NNW weather conditions in winter however, because of the relatively low freshwater input to Queen Charlotte Sound and because riverine inputs to outer Pelorus Sound are small compared with the large volume of water exchanged with Cook Strait through tidal wind driven and estuarine processes (see Water Column Report).

## **8.2 Finfish Distributions and Existing NZ King Salmon Farms**

A comparison of data in Tables 1 and 2 suggests obvious contradictions, which can be clarified to some degree in terms of targeting strategies by recreational fishers (see Section 2.2.1). By keeping these conditions in mind, the two datasets can be used together to suggest which species are most likely to occur at the sites of interest. Ultimately, it seems that the observational data from existing farms provide the better insight into species composition at existing and proposed relocation sites, but the data from Table 1 also provide some useful information.

There is a strong correlation<sup>13</sup> between the data of Morrissey et al. (2006) and the data from existing NZ King Salmon farms — 65–70% of the species listed by Morrissey et al. (2006) were identified in the data from existing farms (Table 2) (the upper value is dependent on the inclusion of a Syngnathidae species, which differ between the two datasets but for which misidentification is likely). Existing farm data indicate very high observations of seasonally moderated numbers of the baitfish species, yellow-eyed mullet, pilchard, anchovy, and jack mackerel, all of which were listed by Morrissey et al. (2006). The larger, predatory yellowtail kingfish was also described as a frequent visitor to existing farms (though in much lower numbers) and was listed by Morrissey et al. (2006).

The relationships between the recreational survey data and the existing farm data are more complex and less obvious, which may contribute to what appears to be a far lower correlation rate. However, the recreational data do support some interesting observations based on a certain level of correspondence between the two datasets. For example, john dory is recorded only from Port Ligar in the recreational data and is included only from Waihinau (close to Port Ligar) as a cryptic species in the existing farm data; and jack mackerel was only evident from Port Ligar in the recreational data, a restricted distribution that is partially in agreement with the existing farm data which include jack mackerel at only two of the four farms — Waihinau and Te Pangu (Tory Channel). Generally however, the highest correlation between the recreational and existing farm data is for larger, most often higher angler-valuable species, such as kahawai, tarakihi, snapper, and john dory, (the latter three being recorded most often as cryptic species from the existing farms), as well as barracouta. Species were categorised as cryptic because they were seldom observed despite often being taken in fishing events close to the farms. These species are mostly demersal, so their cryptic behaviour is expected.

## **8.3 Implications for customary, recreational, and commercial fisheries**

An examination of commercial fisheries targeting finfish species known from recreational surveys to be present in the Sounds showed that there are important fisheries for barracouta, blue moki, flatfish, jack mackerel, leather jacket, warehou, and red cod in the area containing the Sounds. Of these, only

---

<sup>13</sup> *Correlation* in this section relates only to simple eyeball and percentage estimation for comparisons of datasets. It does not include statistical testing.

jack mackerel has been identified as a frequent visitor of existing NZ King Salmon farms from anecdotal information. It would seem that the contribution of this species from the Sounds to the fishery is unlikely to be significant given that total landings have been between 28 000 and 36 500 t in JMA 7 (the area for jack mackerel fishing that includes the Marlborough Sounds) since fishing year 2004–05 and that almost all of this was taken by midwater trawl over deep water (Ministry for Primary Industries 2015).

Jack mackerel landings from the inshore trawl fishery in JMA 7 (see Table 3) are as bycatch of up to about 400 t per annum in the 2001–02 fishing year (Taylor & Julian 2008), although it is likely that in more recent years this figure has been lower, with an annual maximum of about 200 t (Rich Ford, MPI, pers. comm.). It is most likely that the jack mackerel species occurring at NZ King Salmon farms is *Trachurus novaezelandiae*, because of its more shallow water distribution compared with the other two jack mackerel species (Jones 1990). Because proportions of each of the jack mackerel species in inshore trawl landings are about equal (Taylor & Julian 2008), up to about 140 t of *T. novaezelandiae* is estimated as being taken per annum in this component of the overall JMA 7 fishery.

From the information summarised in Table 5, the most important recreational fishery is for blue cod. Species in the top ten finfish caught and kept during the survey by Davey et al (2008) that have been identified from existing-farm data are snapper, kahawai, tarakihi, and barracouta.

**Table 5. Numbers of the top ten finfish species caught and kept during 2148 fishing trips in the Marlborough Sounds. Source: Davey et al (2008).**

Species	No of fish	Species	No of fish
Blue cod	2642	Spotty	302
Snapper	731	Tarakihi	280
Sea perch	551	Hapuku	184
Flounder	539	Blue moki	155
Kahawai	441	Barracouta	140

From these results it can be seen that there are fisheries for a number of the wild fish species that come under the influence of existing farms. Consequently, any effects of the farms will potentially impact on these species, particularly if they are long term residents. It is unlikely that pelagic species will be long term residents, given their high mobility and the seasonality with which they visit existing farms. Likely candidates are the more sedentary benthic-pelagic species, so called because their normal benthic habit is modified near the farms where they occasionally swim within the pelagic habitat. However, the time frame over which a long term residency might persist is unknown.

## 8.4 Effects of Farms

From the information compiled here, it is clear that interactions occur between wild pelagic finfish species and NZ King Salmon farms including those proposed at relocation sites. Undoubtedly, such species are attracted to farms, often in such numbers that the result is higher densities than in areas where farms do not exist. There are several causes of attraction, including light, sound, at least two sources of food (i.e., other fish and feed pellets), and the action of the farm structure in providing protection from predators.

Discussion here of results from overseas research suggests that the potential for farms to act as ecological traps is of concern in avoiding adverse effects on wild finfish species. Fundamental to this action is the continued attraction of the farm for fish that incorrectly select the habitat surrounding a farm as one that will provide the resources they require to maximise their biological fitness. Under this scenario, increased body condition from consuming feed pellets actually reduces their reproductive

fitness when feed composition is of lower quality than their natural diet. At present, no direct evidence suggests that this is the case.

An alternative outcome occurs when artificial feed is of equal or higher quality than the natural diet and adds condition that increases the reproductive fitness of wild fish. Evidence from numerous overseas studies suggests that the condition of wild fish living around farms is significantly increased. However, an ecological trap may continue to operate if fish are harvested from around the farm at a rate that exceeds the maximum mortality in areas where there is no artificial aggregation. Because the farm continues to attract fish, such harvesting over a medium to long time frame could result in local depletions.

As is discussed above (Section 3), the alternative to the ecological trap is the population source, where any reproductive benefit gained by fish inhabiting the water column close to a farm increases their reproductive success. This is the result many expect from marine protected areas, where fish reproduction is allowed to occur without any anthropogenic interruption, which should increase reproductive success. The additional benefit that may be gained near a fish farm is any increased fitness from greater access to feed. If harvesting is prevented, increased wild fish biomass resulting from these reproductive gains adds to the overall biomass for the species that are present.

However, the discussion above indicates that increased condition is not the only possible outcome of consuming feed pellets. An important second effect concerns the various contaminants of wild fish with the implication of possible impacts on human health. This contamination introduces a number of potentially dangerous chemical species to the pelagic food web, but this danger is usually only realised when contamination reaches a level that is a health threat to humans. While some organohalogenated contaminants and mercury have been detected as slightly elevated in the tissues of wild fish that reside around salmon farms compared to other fish, these have never exceeded levels considered safe for human consumption. As was stated above, such levels are also an unlikely result for Marlborough Sounds salmon farming under present conditions, but the long term effects through the function of bioaccumulation are seldom considered. To ensure that no such effects emerge, monitoring of key contaminants of public health interest should occur in long-lived, benthic-pelagic fish species, of recreational, commercial or traditional fishing interest, that reside in the near vicinity of salmon farms. Such monitoring would first depend upon such species being identified to occur in the near vicinity of the salmon farms. Frequency of monitoring should be determined relative to the status of the benthic conditions beneath farms, as biological availability of certain heavy metals increases in anoxic sediments, and should also be compared to relevant control locations.

In the context of the overseas research discussed here, the volume and composition of feed pellets consumed by wild fish is probably the most important effect of fish farms on the wild fish population. The summaries from the international literature describe feed wastage from the cages in the order of 1 to 5%. It is the contention of NZ King Salmon however, that feed wastage levels at existing farms are low (<0.1%). Under these conditions, the effects on wild fish are likely to be lower than those described above, but such a conclusion cannot be reached without independent data on measurement of feed fallout from existing NZ King Salmon farms. We therefore recommend that independent monitoring of feed loss levels, and how these levels vary with location and time, occur at the proposed new farming locations.

## **8.5 Interactions of Fish Farms with Sharks**

Information from existing NZ King Salmon farms indicates that a total of four shark species have been known to visit the farms. These include spiny dogfish, bronze whaler, blue shark, and seven-gill shark. According to information from DOC (Clinton Duffy, pers. comm., see Table 4) the latter three of these are “potentially dangerous”, which is defined as any shark species known to engage in, or has been implicated in, unprovoked injurious attacks on humans or vessels. Spiny dogfish are “traumatogenic” which refers to species capable of inflicting serious injury if provoked or mistreated. Therefore, all



shark species known to occur at existing NZ King Salmon farms require a careful management approach.

During the South Australian workshop in 2003, agreement was reached that fresh dead fish caused most interactions with sharks and that most interactions were with bronze whalers after pupping in October–December. A useful strategy for NZ King Salmon to minimise interactions would be the adoption of the following set of best practices identified by industry members at that workshop:

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

## 9. ACKNOWLEDGEMENTS

We thank Clinton Duffy, Department of Conservation, for almost all of the information on sharks presented in Sections 4.2, 4.3, and 6.3. We also thank Max Gibbs, NIWA, for discussion on a number of aspects of the work carried out in Pelorus Sound during the 1980s, and managers of existing farms for their information on observations of fish species at the farms. Finally, thanks to Rich Ford (MPI) for comments on an earlier version of this updated report.

## 10. 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.
- 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. doi: 10.1111/j.1365-2109.2010.02683.x
- 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, et al (2015c) Assessing the influence of salmon farming through total lipids, fatty acids, and trace elements in the liver and muscle of wild saithe *Pollachius virens*. *Mar Coast Fish* 7:59–67. doi: 10.1080/19425120.2014.1001540
- August, S.M.; Hicks, B.J. 2008. Water temperature and upstream migration of glass eels in New Zealand: implications of climate change. *Environmental Biology of Fishes*, 81(2), pp.195-205.
- Autin, M. 1997. Commercial aquafeed manufacturer and production. *CIHEAM—Options Mediterraneennes* 22: 79–104.
- Bacher K, Gordo 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, Gordo 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. doi: 10.1111/are.12199

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., 1996. *Patterns in the ocean*. California Sea Grant, in cooperation with Centro de Investigaciones Biologicas del Noroeste, La Paz, Mexico.

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.

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.

Bakun, A. 1996. *Patterns in the ocean: ocean processes and marine population dynamics*. California Sea Grant College System, University of California Press, La Jolla, CA, 323pp.

Bearzi, G. 2002. Interactions between cetacean and fisheries in the Mediterranean Sea. In G. Notarbartolo di Sciara (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.

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).

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.

Beveridge, M.C.M. 1996. *Cage Aquaculture*. Fishing News Books, Blackwell, Oxford.

Bjorndal, 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.

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

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.

Bowman, M.J.; Jones, D.A.; Kibblewhite, A.C. 1982. Tidal studies. In Kibblewhite, A. C. ,Berquist, P. R. ,Foster, B. A. ,Gregory, M. R. andMiller, M. C. (eds). *Maui Development Environmental Study, report on phase two*. University of Auckland.

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.; Chang, F. H.; Baldwin, R.; Chapman, B.; Downes, M.; Woods, P. 1987. Hydrology, plankton, and nutrients in Pelorus Sound, New Zealand, July 1981 and May 1982. *New Zealand Journal of Marine and Freshwater Research* 21:223–233.

Bradford, J.M.; Lapennas, P.P.; Murtagh, R.A.; Chang, F.H.; Wilkinson, V. 1986. Factors controlling summer phytoplankton production in greater Cook Strait, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 20: 253–279.

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.

Broekhuizen, N. 2013. Review of historical water-quality data from Pelorus Sound and Queen Charlotte Sound: long-term NIWA time-series and Marlborough District Council time-series. NIWA Client Report No. HAM2013-070 prepared for New Zealand King Salmon.

Broekhuizen, N. 2015. Water Quality in the Marlborough Sounds — Annual Monitoring report July 2014–June 2015. NIWA Client Report No. HAM2013-094 prepared for Marlborough District Council.

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.

Burns, D.A. 1977. Distribution of planktonic diatoms in Pelorus Sound, South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 11: 275–295.

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* (in press) DOI: 10.1039/c1em10083a

Cardia, F., and A. Lovatelli. 2007. A review of cage aquaculture: Mediterranean Sea. In M. Halwart, D. Soto, and J.R. Arthur (Eds). *Cage Aquaculture—Regional Reviews and Global Overview*, pp. 156–187. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

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

Carter, L. 1976. Seston transport and deposition in Pelorus Sound, South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 10: 263–282.

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.

Chou C.L. 2007. A time series of mercury accumulation and improvement of dietary feed in net caged Atlantic salmon (*Salmo salar*). *Marine Pollution Bulletin* 54: 720-725.

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

Cloern, J.E. 1991b. Annual variations in river flow and primary production in the south San Francisco Bay estuary (USA). In: Elliott, M.; Ducrottoy, JP. Estuaries and coasts: spatial and temporal intercomparisons. Fredensborg, Denmark, Olsen and Olsen. Pp. 91–96.

Cole, R. 2002. Impacts of marine farming on wild fish populations. Final Research Report for Ministry of Fisheries Research Project ENV2000/08 Objective One. National Institute of Water and Atmospheric Research, Wellington. 49 pp.  
([http://www.aquaculture.govt.nz/files/pdfs/Impacts\\_of\\_marine\\_farming\\_on\\_wild\\_fish\\_stocks.pdf](http://www.aquaculture.govt.nz/files/pdfs/Impacts_of_marine_farming_on_wild_fish_stocks.pdf)).

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.

Colorni A, Diamant A, Eldar A, et al (2002) Streptococcus iniae infections in Red Sea cage-cultured and wild fishes. *Dis Aquat Organ* 49:165–170.

Davey, N.K.; Hartill, B.; Cairney, D.G.; Cole, R.G. 2008. Characterisation of the Marlborough Sounds recreational fishery and associated blue cod and snapper harvest estimates. *New Zealand Fisheries Assessment Report 2008/31*. 63 p.

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.

Davidson, R. J.; Baxter, A. S.; Duffy, C. A. J.; Gaze, P.; du Fresne, S.; Courtney, S.; Brosnan, B. 2015. Reassessment of selected significant marine sites (2014-2015) and evaluation of protection requirements for significant sites with benthic values. Prepared by Davidson Environmental Limited for Marlborough District Council and Department of Conservation. Survey and monitoring report no. 824.

Davidson R. J.; Duffy C.A.J.; Gaze P.; Baxter, A.; du Fresne S.; Courtney S.; Hamill P. 2011. Ecologically significant marine sites in Marlborough, New Zealand. Co-ordinated by Davidson Environmental Limited for Marlborough District Council and Department of Conservation. Published by Marlborough District Council.

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](http://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-Casaldueiro, and C. Valle. 2002. Attraction of wild fish to sea-cage 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* 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 (In Press) Recapturing escaped fish from marine aquaculture is largely unsuccessful: alternatives to reduce the number of escapees in the wild. *Reviews in Aquaculture* (in press)

Department of Conservation. 2010. <http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/coastal-management/nz-coastal-policy-statement-2010.pdf>

Diamant A (2001) Cross-infections between marine cage-cultured stocks and wild fish in the northern Red Sea: is the environment at risk? *Risk Anal Aquat Anim Heal Proc Off Int Epizooties–Off Int Epizooties*.

Diamant A, Banet A, Ucko M, et al (2000) Mycobacteriosis in wild rabbitfish *Siganus rivulatus* associated with cage farming in the Gulf of Eilat, Red Sea. *Dis Aquat Organ* 39:211–219.

Díaz López, B. 2005. Interactions between Mediterranean bottlenose dolphins (*Tursiops truncatus*) and gillnets off Sardinia, Italy. *ICES Journal of Marine Science* 63: 946–951.

Díaz-López, B. and J.A. Bernal-Shirai. 2007. Bottlenose dolphin (*Tursiops truncatus*) presence and incidental capture in a marine fish farm on the north-eastern coast of Sardinia (Italy). *Journal of the Marine Biological Association of U.K.* 87: 113–117.

Dill, L.M. 1983. Adaptive flexibility in the foraging behaviour of fishes. *Canadian Journal of Fisheries and Aquatic Sciences* 40: 398–408.

Dimitriou, E., G. Katselis, D.K. Moutopoulos, C. Akovitiotis and C. Koutsikopolous. 2007. Possible influence of reared gilthead sea bream (*Sparus aurata*, L.) on wild stocks in the area of the Messolonghi lagoon (Ionian Sea, Greece). *Aquaculture Research* 38: 398–408.

Dwernychuk, L.W.; Boag, D.A. 1972. Ducks nesting in association with gulls — an ecological trap? *Canadian Journal of Zoology* 50 (5): 559–563.

Easton M.D.L., D. Luszniak and E. Von der Geest. 2002. Preliminary examination of contaminant loadings in farmed salmon, wild salmon and commercial salmon feed. *Chemosphere* 46: 1053–1074.

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

FAO. 2007. The state of World Fisheries and Aquaculture; 2006. Rome. <http://www.fao.org/docrep/009/a0699e/a0699e00.htm>.

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. doi: 10.1093/icesjms/fsu153

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., J.A. Lopez Jimenez, P. Sanchez-Jerez, J. Bayle-Sempere, F. Gimenez Casalduero, F.J. Martinez Lopez, and T. Dempster. 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

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.

Fernandez-Jover D, Martinez-Rubio L, Sanchez-Jerez P, et al (2011) Waste feed from coastal fish farms: a trophic subsidy with compositional side-effects for wild gadoids. *Estuar Coast Shelf Sci* 91:559–568. doi: 10.1016/j.ecss.2010.12.009

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.

Forcada, A., C. Valle, P. Bonhomme, G. Criquet, G. Cadiou, P. Lenfant, and J.L. Sanchez-Lizaso. 2009. Effects of habitat on spillover from marine protected areas to artisanal fisheries. *Marine Ecology Progress Series* 379: 197–211.

- Ford, J.S. and R.A. Myers. 2008. A global assessment of salmon aquaculture impacts on wild salmonids. *PLoS Biology* 6: 411–417.
- Francis, M. 1996. Coastal Fishes of New Zealand: An identification guide. Reed Books, Auckland.
- 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, M. 2001. Coastal Fishes of New Zealand, third edition. Reed Books, Auckland. 103 pp.
- Freitas, D., J. Gomes, T. Sales-Luis, L. Madruga, C. Marques, G. Baptista, L.M. Rosalino, P. Antunes, R. Santos, and M. Santos-Reis. 2007. Otters and fish farms in the Sado estuary: Ecological and socioeconomic basis of a conflict. *Hydrobiologia* 587: 51–62.
- Gibbs, M. M. 1993: Morphometrically induced estuarine phytoplankton patchiness in Pelorus Sound, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 27: 191–199.
- Gibbs, M.M. 2001. Sedimentation, suspension, and resuspension in two contrasting coastal environments, Beatrix Bay and Tasman Bay, New Zealand, which thermally stratify in summer. *New Zealand Journal of Marine and Freshwater Research* 35:951–970.
- Gibbs, M.M.; James, M.R.; Pickmere, S.E.; Woods, P.H.; Shakespeare, B.S.; Hickman, R.W.; Illingworth, J. 1991. Hydrodynamic and water column properties at six stations associated with mussel farming in Pelorus Sound 1984–85. *New Zealand Journal of Marine and Freshwater Research* 25: 239–254.
- Gibbs, M.M.; Pickmere, S.E.; Woods, P.H.; Payne, G.W.; James, M.R.; Hickman, R.W.; Illingworth, J. 1992. Nutrient and chlorophyll *a* variability at six stations associated with mussel farming in Pelorus Sound, 1984–85. *New Zealand Journal of Marine and Freshwater Research* 26: 197–211.
- Gibbs, M.; Ross, A.; Downes, M. 2002. Nutrient cycling and fluxes in Beatrix Bay, Pelorus Sound, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 36: 675–697.
- Gibbs, M. M.; Vant, W. 1997: Seasonal changes in factors controlling phytoplankton in Beatrix Bay, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 31: 237–248.
- Glover KA, Sørvik AGE, Karlsbakk E, et al (2013) Molecular genetic analysis of stomach contents reveals wild Atlantic cod feeding on piscine reovirus (PRV) infected Atlantic salmon originating from a commercial fish farm. *PLoS One* 8:e60924.
- 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.
- 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.
- Grøttum, J.A. and M. Beveridge, 2007. A review of cage aquaculture: Northern Europe. In Halwart, M., Soto, D., Arthur, J.R. (Eds.). *Cage aquaculture—Regional reviews and global overview*. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 129–154 pp.
- Güçlüsoy, H. and Y. Savas. 2003. Interaction between monk seals *Monachus monachus* (Hermann, 1779) and marine fish farms in the Turkish Aegean and management of the problem. *Aquaculture Research* 34: 777–783.



Halwart, M., D. Soto, and J.R. Arthur. (Eds.). 2007. Cage aquaculture—Regional reviews and global overview. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 241 pp.

Hardin Jones, F.R. 1977. Performance and behaviour in migration. In: J.H. Steele (ed.) Fisheries mathematics, pp.131-144. Academic Press, London, New York, San Francisco. 198 pp.

Harris, T.F.W. 1990. Greater Cook Strait. Form and Flow. New Zealand Oceanographic Institute, Wellington, New Zealand.

Heath, R.A. 1974. Physical oceanographic observations in Marlborough Sounds. *New Zealand Journal of Marine and Freshwater Research* 8: 691–708.

Heath, R. A. 1976. Tidal variability of flow and water properties in Pelorus Sound, South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 10: 283–300.

Heath, R.A. 1982. Temporal variability of the waters of Pelorus Sound, South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 16: 95–110.

Heath, R.A. and Gilmour, A.E.1987. Flow and hydrological variability in the Kahurangi plume off north-west South Island, New Zealand, *New Zealand Journal of Marine and Freshwater Research*, 21: 125–139.

Hellou, J. Haya, K., Steller, S., Burrridge, 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.

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.

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.

ICES. 2006. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), April 24–28, 2006, Narragansett, Rhode Island, USA. ICES CM 2006/MCC:03. 195 pp.

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

Islam, M.S. 2005. Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: Review and analysis towards model development. *Marine Pollution Bulletin* 50: 48–61.

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

- 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.
- 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. 2002. First use of archival transmitters to track migrating freshwater eels *Anguilla dieffenbachii* at sea. *Marine Ecology Progress Series*, 233, pp.207-215.
- Jellyman, D.; Tsukamoto, K. 2005. Swimming depths of offshore migrating longfin eels *Anguilla dieffenbachii*. *Marine Ecology Progress Series*, 286, pp.261-267.
- 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.
- Jones, J.B. 1990. Jack mackerels (*Trachurus* spp.) in New Zealand waters. *New Zealand Fisheries Technical Report No. 23*: 28 p.
- 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.
- 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.
- Kibblewhite, A.C.; Berquist, P.R.; Foster, B.A.; Gregory, M.R.; Miller, M.C. *ed.*, 1982. Maui Development Study. Prepared at The University of Auckland for Shell BP and Todd Oil Services Limited. Woolmore Printing Ltd.
- 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. 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.
- Krkosek, M., J.S. Ford, and A. Morton. 2007. Declining wild salmon populations in relation to parasites from farm salmon. *Science* 318: 1772–1775.
- 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.
- 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.

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

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.

Machias, A., M. Giannoulaki, S. Somarakis, C.D. Maravelias, C. Neofitou, D. Koutsoubas, K.N. Papadopoulou, and I. Karakassis. 2006. Fish farming effects on local fisheries landings in oligotrophic seas. *Aquaculture*, 261(2): 809–816.

Magurran, A.E. 1990. The adaptive significance of schooling as an anti-predator defence in fish. *Ann. Zool. Fennici* 27: 51–66.

Marras, S.; Killen, S.S.; Lindström, J.; McKenzie, D.J.; Steffensen, J.F.; Domenici, P. 2015. Fish swimming in schools save energy regardless of their spatial position. *Behavioral ecology and sociobiology*, 69(2), pp.219-226.

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 PA (2007) You wouldn't spawn in a septic tank, would you? *Human Ecology* 35(5): 601–610.

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.

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.

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.

Morrissey, 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.

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.

Murray-Jones S (ed.) 2004. Workshop on shark interactions with aquaculture proceedings of the Shark Interactions with Aquaculture Workshop and Discussion Paper on Great White Sharks. FRDC 2002/040. Fisheries Research and Development Corporation and Department for Environment and Heritage, Adelaide. 78 pp.

Nash, C.E., R.N. Iwamoto, and C.V.W. Mahnken. 2000. Aquaculture risk management and marine mammal interactions in the Pacific Northwest. *Aquaculture* 183: 307–323.

Naylor, R.L., R.J. Goldburg, J.H. Primavera, N. Kautsky, M.C.M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, and M. Troell. 2000. Effect of aquaculture on world fish supplies. *Nature* 405: 1017–1024.

- 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.
- 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.
- 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): 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.
- Papastamatiou, Y.P.; Itano, D.G.; Dale, J.J.; Meyer, C.G.; Holland, K.N. 2010. Site fidelity and movements of sharks associated with ocean-farming cages in Hawaii. *Marine and Freshwater Research*, 61: 1366–1375.
- 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)*.
- 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.
- 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.
- 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.
- 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.

- 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* (in press) doi:10.1016/j.aquaculture.2011.06.030
- 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.
- Sepúlveda, F., S.L. Marín, and J. Carvajal. 2004. Metazoan parasites in wild fish and farmed salmon from aquaculture sites in southern Chile. *Aquaculture* 235(1–4): 89–100.
- Sepúlveda, M. and D. Oliva. 2005. Interactions between South American sea lions *Otaria flavescens* (Shaw) and salmon farms in southern Chile. *Aquaculture Research* 36: 1062–1068.
- 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.
- 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.

- 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., Julian, K.A. 2008. Species composition and seasonal variability in commercial catches of jack mackerel (*Trachurus declivis*, *T. murphyi*, *T. novaezelandiae*) in JMA 1, 3, and 7 during 2004–05. *New Zealand Fisheries Assessment Report 2008/25*. 24 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) (Mugiloidae: 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](http://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.
- Uglen, 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 farmed and local wild Atlantic cod (*Gadus morhua* L.) in a Norwegian fjord. *Aquaculture Research* 39: 158–170.
- Uglen, 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.
- Valle, C., J. Bayle, T. Dempster, P. Sanchez-Jerez, and F. Gimenez-Casaldueiro. 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., Chang, F.H., Cole, A., Downes, M.T., James, M.R., May, L., Moore, M., Woods, P.H. 1989a. Short-term changes in planktonic community structure and nitrogen transfers in a coastal upwelling system. *Estuarine Coastal and Shelf Science* 29: 131–150.

Vincent, W.F., Howard-Williams, C., Downes, M.T., Dryden, S.J. 1989b. Underwater light and photosynthesis at three sites in Pelorus Sound, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 23:79–81.

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.

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.

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.

Weir, L.K. and J.W.A. Grant. 2005. Effects of aquaculture on wild fish populations: A synthesis of data. *Environmental Reviews* 13: 145–168.

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

Zeldis, J.R., Hadfield, M.G., Booker, D.J. 2013. Influence of climate on Pelorus Sound mussel aquaculture yields: predictive models and underlying mechanisms. *Aquaculture Interactions*, 4: 1–15.

Zeldis J.R., Howard Williams C., Carter C.M., Schiel D.R. 2008. ENSO and riverine control of nutrient loading, phytoplankton biomass and mussel aquaculture yield in Pelorus Sound, New Zealand. *Marine Ecology Progress Series* 371: 131–142.



## **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: 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 C: Predicted rocky reef species in 10 areas of the Marlborough Sounds

**Table C1: Species predicted as present in the Marlborough Sounds using boosted regression tree modelling of dive survey data, sorted by Family; see text for further explanation. Source: Smith et al (2013)**

Family	Species	Common name	Admiralty Bay	Waitata to Tennyson	Pelorus Sound	Chetwodes to Alligator	Port Gore	Long Island	Outer QC*	Inner QC*	Tory Channel	Port Under-wood
Aplodactylidae	<i>Aplodactylus arctidens</i>	Marblefish				✓	✓	✓				✓
Carangidae	<i>Seriola lalandi</i>	Kingfish				✓		✓				
Cheilodactylidae	<i>Cheilodactylus spectabilis</i>	Red moki	✓			✓	✓	✓				✓
Cheilodactylidae	<i>Nemadactylus macropterus</i>	Tarakihi	✓			✓	✓	✓	✓	✓	✓	✓
Congridae	<i>Conger verreauxi</i>	Common conger eel	✓			✓	✓	✓	✓	✓	✓	✓
Kyphosidae	<i>Scorpius lineolatus</i>	Sweep						✓				
Labridae	<i>Notolabrus celidotus</i>	Spotty	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Labridae	<i>Notolabrus cinctus</i>	Girdled wrasse						✓				
Labridae	<i>Notolabrus fucicola</i>	Banded wrasse	✓	✓		✓	✓	✓	✓	✓	✓	✓
Labridae	<i>Pseudolabrus miles</i>	Scarlet wrasse	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Latridae	<i>Latridopsis ciliaris</i>	Blue moki				✓	✓	✓	✓	✓	✓	✓
Latridae	<i>Mendosoma lineatum</i>	Telescopefish						✓				
Monacanthidae	<i>Parika scaber</i>	Leatherjacket	✓	✓	✓	✓	✓		✓	✓	✓	✓
Moridae	<i>Lotella rhacina</i>	Rock cod	✓	✓	✓	✓	✓		✓	✓	✓	✓
Moridae	<i>Pseudophycis barbata</i>	Southern bastard cod	✓			✓	✓	✓				✓
Mugilidae	<i>Aldrichetta forsteri</i>	Yellow-eyed mullet	✓	✓	✓	✓	✓			✓	✓	✓
Mullidae	<i>Upeneichthys lineatus</i>	Goatfish	✓	✓	✓	✓		✓				
Odacidae	<i>Odax pullus</i>	Butterfish	✓	✓		✓	✓	✓	✓		✓	✓
Pinguipedidae	<i>Parapercis colias</i>	Blue cod	✓	✓	✓	✓	✓		✓	✓	✓	✓
Scorpaenidae	<i>Helicolenus percoides</i>	Sea perch			✓	✓	✓	✓	✓	✓	✓	
Scorpaenidae	<i>Scorpaena papillosus</i>	Dwarf scorpionfish	✓			✓	✓	✓			✓	✓
Serranidae	<i>Caesioperca lepidoptera</i>	Butterfly perch	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Serranidae	<i>Hypoplectrodes huntii</i>	Red-banded perch	✓			✓	✓	✓	✓	✓	✓	✓
Trachichthyidae	<i>Optivus elongatus</i>	Slender roughy	✓	✓		✓	✓	✓	✓		✓	

**Table B1: continued**

Trachichthyidae	<i>Paratrachichthys trailli</i>	Common roughy	✓				✓	✓	✓	✓		✓	✓
Tripterygiidae	<i>Forsterygion flavonigrum</i>	Yellow-black triplefin	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	<i>Forsterygion lapillum</i>	Common triplefin	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	<i>Forsterygion malcolmi</i>	Banded triplefin	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	<i>Forsterygion varium</i>	Variable triplefin	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	<i>Grahamina gymnota</i>	Robust triplefin		✓	✓						✓		
Tripterygiidae	<i>Karalepis stewarti</i>	Scaly-headed triplefin	✓				✓	✓	✓			✓	✓
Tripterygiidae	<i>Notoclinops caerulepunctus</i>	Blue dot triplefin	✓	✓			✓	✓	✓				
Tripterygiidae	<i>Notoclinops segmentatus</i>	Blue-eyed triplefin	✓	✓			✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	<i>Notoclinops yaldwyni</i>	Yaldwyn's triplefin	✓				✓	✓	✓	✓			
Tripterygiidae	<i>Obliquichthys maryannae</i>	Oblique-swimming triplefin	✓	✓			✓	✓	✓	✓		✓	✓
Tripterygiidae	<i>Ruanoho whero</i>	Spectacled triplefin	✓	✓			✓	✓	✓	✓	✓	✓	✓

\*QC: Queen Charlotte Sound.