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

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EXECUTIVE SUMMARY

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A literature search was carried out for studies on the circulation and productivity of the Marlborough Sounds. Extensive information was available 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 proposed NZ King Salmon farm.

With the aim of identifying the species of finfish that might inhabit the water column at the proposed sites, summaries from two recreational fishing surveys and a study on finfish in the Sounds were tabulated. Managers of existing NZ King Salmon farms were asked to list 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 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.

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.
1. SCOPE

In this report, we synthesize existing background information on the pelagic habitat and the wild fish fauna of the Marlborough Sounds relevant to the NZ King Salmon proposal. We summarise 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 make predictions regarding the likely nature of interactions. Finally, the report provides suggestions as to how fish farm-fishery interactions can be managed to enhance any potentially positive and minimise any potentially negative interactions.

2. THE PELAGIC ENVIRONMENT AT PROPOSED SITES

2.1 The Existing Pelagic Habitat at the Proposed Sites

Because of the locations of the sites proposed for the NZ King Salmon project, four independent areas and their positions relative to Cook Strait are relevant here: outer Pelorus Sound contains the sites Kaitira (7.25 km from Cook Strait), Waitata (9.8 km from Cook Strait), Tapipi (9.7 km from Cook Strait), and Richmond (10.6 km from Cook Strait), which are all within Waitata Reach and in close proximity to one another; Port Gore contains Papatua (0.5 km from Cook Strait); mid-Queen Charlotte Sound contains Kaitapeha (23 km from Cook Strait) and Ruamoko (16 km from Cook Strait), close to the confluence of Tory Channel with Queen Charlotte Sound; and Tory Channel contains Ngamahau, within 5 km of Cook Strait. Because of their close proximity to Cook Strait, these sites will all be 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 studies of work have been done that can be used as a basis for such a characterisation. These studies can be categorised into the following three groups:

- descriptions of circulation within all the sounds by Heath (1974, 1976), Bradford et al (1987), Zeldis et al (2008) and others; and
- 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) by these descriptions include work by Gibbs et al (1992), Gibbs (1993, 2001), Gibbs & Vant (1997), Carter (1976).

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) and that drives the quality of the pelagic habitat in the outer sound.

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1 See Appendix A for definition.
Important features of the circulation in Pelorus Sound are:

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

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

Bradford et al. (1987) showed that, in a comparison of samples taken along Pelorus Sound in July 1981, the largest near-surface concentrations of chlorophyll a (>10 mg m⁻³) were located at a sampling station about 3.5 km west of the Tapipi and Richmond sites. Bradford et al. (1987) also showed that diatoms dominated the Pelorus Sound phytoplankton. Nitzschia pseudoseriata was the dominant species in the outer sound 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 document 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.

There is less information available for the other sounds, particularly (with reference to the present context) Queen Charlotte Sound, Tory Channel, and Port Gore. Bradford etal (1987), reporting on work carried out in July 1981, showed that chlorophyll $a$ concentrations were $>4$ mg m$^{-3}$ at their outermost sampling station in outer Queen Charlotte Sound (approx 18 km NE of Kaitapeha & Ruamoko), and that this concentration generally decreased in a southwesterly direction until, at their innermost station (approx 2.6 km NE of Kaitapeha & Ruamoko), the concentration was about 2 mg m$^{-3}$.

Some available information on tidal current is interesting in the present context. Heath (1974) showed that the tidal current in Tory Channel was "exceptionally high" at 3.4 ms$^{-1}$ (measured by the Hydrographic Department in 1956), compared with that in the outer Queen Charlotte Sound (0.5 ms$^{-1}$ measured by Heath 1974) at approximately 5 km NE of Kaitapeha & Ruamoko; 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 outer Queen Charlotte Sound and Tory Channel are 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.

Tidal maps by Bowman et al (1982) suggest that Port Gore is on a current boundary, which may explain the low flow at the Papatua site, despite its close proximity with Cook Strait. However, it is unclear whether conditions at this site would fluctuate under the ENSO-mediated circulation model of Zeldis et al (2008).

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 Morrisey 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.

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 (Kaitira, Waitata, Tapipi, and Richmond);
- Alligator Head (Port Gore);
- Inner and Outer Queen Charlotte (Kaitapeha and Ruamoko);
- and Tory Channel (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 into four, with the central division at the confluence the Sound with Tory Channel. By contrast, Davey et al (2008) divided Queen Charlotte Sound (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 (Kaitira, Waitata, Tapipi, and Richmond); Port Gore, zone 14 (Port Gore); Inner QCS δ zone 32, Mid 1 QCS δ zone 33, Mid 2 QCS δ zone 34, Long Island Marine Reserve δ zone 15 (Kaitapeha and Ruamokoko); and Tory Channel, zone 17 (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 δ Port Ligar; b δ Alligator Head; c δ Inner & Outer Queen Charlotte Sound; d δ Tory Channel; e δ elsewhere in Marlborough Sounds; (2) Bell (2001); a δ North Waitata Reach; b δ Port Gore; c δ Zones 32, 33, & 34 in Queen Charlotte Sound & zone 15 Long Island Marine Reserve; d δ 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).

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>Family</th>
<th>Morrisey</th>
<th>Bell</th>
<th>Davey</th>
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<th>Other Elasmobranchs</th>
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<td>Myliobatis tenuicaudatus</td>
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</table>

* Not included in lists by Davey et al (2008), but unlikely targets for fishers.
** Pilchard, herring, yellow-eyed mullet, and sprat sometimes misidentified for each other; herring was included in lists by Davey et al (2008).
† There may be some confusion in separating these two species.
‡ Only "wrasse" specified by Bell (2001); some could be the banded wrasse, Notolabrus fucicola.
  a δ Kaitira, Waitata, Tapipi, and Richmond; b δ Port Gore; c δ Kaitapeha and Ruamokoto; d δ Tory Channel; e δ elsewhere in Marlborough Sounds.
Morrissey is Morrissey et al (2006); Bell is Bell (2001); Davey is Davey et al (2008).

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 Waihinau. 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 which species were observed in the water 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 Waihinau; cryptic is not a measure of frequency and categorises those species that are known to be present but are seldom observed in the water column; “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

<table>
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<tr>
<th>Family</th>
<th>Species</th>
<th>Frequency</th>
<th>Farm 1</th>
<th>Farm 2</th>
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<td>Jack mackerel</td>
<td>High</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>Yellowtail kingfish</td>
<td>Med</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>Trevally</td>
<td>Low</td>
<td>✔</td>
<td></td>
<td></td>
<td>✔</td>
<td>b</td>
</tr>
<tr>
<td>Centrolophidae</td>
<td>Blue warehou</td>
<td>Low</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td>b</td>
</tr>
<tr>
<td>Cheilodactylida</td>
<td>Tarakihi</td>
<td>Cryptic</td>
<td>X</td>
<td>✔</td>
<td></td>
<td></td>
<td>X a</td>
</tr>
<tr>
<td>Clupeidae</td>
<td>Pilchard</td>
<td>High</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>c</td>
</tr>
<tr>
<td>Engraulidida</td>
<td>Anchovy</td>
<td>High</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>c</td>
</tr>
<tr>
<td>Gempylidae</td>
<td>Barracouta</td>
<td>Med</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>a</td>
</tr>
<tr>
<td>Hemiramphidae</td>
<td>Garfish (piper)</td>
<td>Med</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>b</td>
</tr>
<tr>
<td>Labridae</td>
<td>Spotty</td>
<td>Med</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>a</td>
</tr>
<tr>
<td>Monacanthida</td>
<td>Leatherjacket</td>
<td>Low</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>b</td>
</tr>
<tr>
<td>Muglidae</td>
<td>Yellow-eyed mullet</td>
<td>High</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>c</td>
</tr>
<tr>
<td>Pinguipedidae</td>
<td>Blue cod</td>
<td>Cryptic?</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>a</td>
</tr>
<tr>
<td>Scombridae</td>
<td>Blue mackerel</td>
<td>Low</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>c</td>
</tr>
<tr>
<td>Sparidae</td>
<td>Snapper</td>
<td>Cryptic</td>
<td>X</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>a</td>
</tr>
<tr>
<td>Squalidae</td>
<td>Spnay dogfish</td>
<td>High</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>a</td>
</tr>
<tr>
<td>Syngnathidae</td>
<td>Seahorse</td>
<td>Med</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>a</td>
</tr>
<tr>
<td>Triglidae</td>
<td>Gurnard</td>
<td>Low</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>b</td>
</tr>
<tr>
<td>Tripterygiidae</td>
<td>Triplefin spp</td>
<td>Med</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>c</td>
</tr>
<tr>
<td>Zeidae</td>
<td>John dory</td>
<td>Cryptic</td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
<td>b</td>
</tr>
</tbody>
</table>

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

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; Taylor & Paul 1998) may prey on more than one element of the chain as well as a variety of other organisms not included here.
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* grazes larger particle sizes than the pilchard/sardine species *Sardinops sagax*. Similarly for the Humboldt Current system, Espinoza et al (2009) have shown that the anchovy species *Engraulis ringens* prefers larger particle sizes than the pilchard species *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.

Another point that is relevant here relates to the community structure of a plankton population and how it varies under different environmental conditions. In their paper, van der Lingen et al (2006) reference the work of Michell-Innes & Pitcher (1992) 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.

This information represents the most up-to-date understanding of the trophic requirements of small, planktivorous pelagic fishes, which act as an energy conduit between phytoplankton/zooplankton and the higher finfish species that provide the basis of our commercial, recreational, and customary fisheries. For this reason, an understanding of the habitat at this level of detail is required if we aim to give a complete appraisal of the status of a pelagic habitat. Unfortunately, our knowledge of the Marlborough Sounds pelagic habitat in this regard is limited. While we do have some knowledge of the phytoplankton species present during particular years (Bradford et al 1987, Burns 1977), we have no time series data that can be summarised to provide information over several years and between El Niño/La Niña years. Zeldis et al (2008) have provided a model of varying productivity between summers of El Niño and La Niña conditions, but with few years of plankton data we cannot determine the degree to which the findings of Michell-Innes & Pitcher (1992) are relevant here.

Under these constraints we must lift our focus from this finest level and consider the status of the components that we know to be present in the system. The work of Morrisey et al (2006) indicates the presence of the key small pelagic finfish species, pilchard and anchovy, and this is largely supported by observations at the existing farms. The results of Gibbs (e.g., 1993, 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 of Fisheries (MFish) Stock Assessment Plenary document (Ministry of Fisheries 2010). 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. Instead, Table 3 was compiled to show 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 of Fisheries (2010).**

<table>
<thead>
<tr>
<th>Species</th>
<th>QMA</th>
<th>TACC (t)</th>
<th>Total TACC (t)</th>
<th>Species</th>
<th>QMA</th>
<th>TACC (t)</th>
<th>Total TACC (t)</th>
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</thead>
<tbody>
<tr>
<td>Anchovy</td>
<td>ANC 7</td>
<td>100</td>
<td>560</td>
<td>Leather jacket</td>
<td>LEA 2</td>
<td>*1 136</td>
<td>1 431</td>
</tr>
<tr>
<td>Barracouta</td>
<td>BAR 7</td>
<td>*11 173</td>
<td>32 672</td>
<td>Pilchard</td>
<td>PIL 7</td>
<td>150</td>
<td>2 485</td>
</tr>
<tr>
<td>Blue cod</td>
<td>BCO 7</td>
<td>70</td>
<td>2 680</td>
<td>Red cod</td>
<td>RCO 7</td>
<td>*3 126</td>
<td>8 278</td>
</tr>
<tr>
<td>Blue moki</td>
<td>MOK 1</td>
<td>*403</td>
<td>608</td>
<td>Rig</td>
<td>SPO 7</td>
<td>221</td>
<td>1 919</td>
</tr>
<tr>
<td>Butterfish</td>
<td>BUT 7</td>
<td>38</td>
<td>162</td>
<td>Sea perch</td>
<td>SPE 7</td>
<td>82</td>
<td>2 155</td>
</tr>
<tr>
<td>Flatfish</td>
<td>FLA 7</td>
<td>*2 066</td>
<td>5409</td>
<td>Snapper</td>
<td>SNA 7</td>
<td>200</td>
<td>6 357</td>
</tr>
<tr>
<td>Garfish</td>
<td>GAR 7</td>
<td>*8</td>
<td>50</td>
<td>Spiny dogfish</td>
<td>SPD 7</td>
<td>1 902</td>
<td>12 660</td>
</tr>
<tr>
<td>Gurnard</td>
<td>GUR 7</td>
<td>681</td>
<td>4 993</td>
<td>Stargazer</td>
<td>STA 7</td>
<td>997</td>
<td>5 412</td>
</tr>
<tr>
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<td>HPB 7</td>
<td>236</td>
<td>2 179</td>
<td>Tarakibi</td>
<td>TAR 7</td>
<td>1 088</td>
<td>6 438</td>
</tr>
<tr>
<td>Jack mackerel</td>
<td>JMA 7</td>
<td>*32 537</td>
<td>60 547</td>
<td>Trumpeter</td>
<td>TRU 7</td>
<td>6</td>
<td>144</td>
</tr>
<tr>
<td>John dory</td>
<td>JDO 7</td>
<td>114</td>
<td>1 129</td>
<td>Warehou</td>
<td>WAR 7</td>
<td>*1 120</td>
<td>4 513</td>
</tr>
<tr>
<td>Kahawai</td>
<td>KAH 3</td>
<td>410</td>
<td>2 728</td>
<td>Yellow-eyed mullet</td>
<td>YEM 7</td>
<td>5</td>
<td>68</td>
</tr>
<tr>
<td>Kingfish</td>
<td>KIN 7</td>
<td>7</td>
<td>200</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**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 fish which occur in close proximity to the cage structures (Boyra et al. 2004, Dempster et al. 2002, 2009), although aggregations of benthic fish are also important in some locations (Boyra et al. 2004, Dempster et al. 2009). 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.](image)

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), the 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.

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, Theunmeyer et al. 2003), the Canary Islands (Boya 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). 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), 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). These results imply that it is difficult to predict the wild fish aggregation sizes at any particular farm prior to its establishment.

However, 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. Around salmon farms in the Norwegian coastal ecosystem, the bentho-pelagic Gadus morhua were significantly more abundant on rocky bottoms than on plain sand or mud bottoms beneath salmon farms (Dempster et al. 2009). Similarly, G. morhua abundance was negatively correlated with water depth, indicating that farms in shallower areas aggregated more of this species. Several other species that were abundant around salmon farms (e.g. Pollachius virens and Melanogrammus aeglefinus) were unaffected by any of the farm attributes tested (benthic habitat type, depth, farm size; Dempster et al. 2009). Taken together, the results suggest that fish farms are most attractive to specific wild fish species when they are large in size, located in shallow waters, are close to the coast, and are placed over a rocky substrate.
From the existing evidence, we can infer that wild fish aggregations around the proposed new sites in the Marlborough Sounds will 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 et al. (2009) suggested that the influence of fish cages on the pelagic postlarval stage could affect the connectivity between recruits and adult stocks through a spatial modification of the available settlement habitat, alter mortality rates, and modify 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 the proposed new 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 (Jover et al. 2007, 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 a sparid (Boops boops) (Jover et al. 2007, Arechavala et al., 2010; 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, 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 loads of farm-associated wild fish are modified from control fish, but this effect is bi-directional. Some parasites increase in incidence and abundance on farm-associated wild fish, while others increase in incidence and abundance on farm-associated wild fish (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.

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 have 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) (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.

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 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 metals in salmon feeds

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 (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. Sediments below salmon cages hold elevated concentrations of some elements (e.g. 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 saithe 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.

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 (Uglem et al., 2009; Arachavalá et al. 2010). 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 studies on farm-associated Atlantic cod have shown that cod repeatedly move from fish farms (Uglem et al., 2008). Therefore, these species exhibit movement patterns that make them potential vectors for transmission of diseases and parasites both to farms and from farms into wild fish populations.

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 (Uglem et al., 2008).

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

Wild fish appear to play a significant role in assimilating nutrient wastes emitted by salmon farms. Within coastal salmon farming areas in Norway, the main species of aggregated fish, 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).

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, Krkošek et al. 2005; Ford & Myers 2008). Interbreeding 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).

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 (Jover et al. 2011). However, 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.

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 one species, we cannot reliably draw inference from this data.

4. ATTRACTION OF SHARKS TO MARINE FARMS AND 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 (*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.

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

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

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’s 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 reasons of 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, ʻwhalerʻ is the common name given sharks of the genus Carcharinus. In New Zealand the only species in this genus that commonly occurs around the North and northern South Island is the bronze whaler (C. brachyrus). By contrast, 20 species are reported in this genus from Australia and many of these require a detailed knowledge of shark taxonomy for positive identification because they lack distinctive markings.

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

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 et al., 2010). 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). Spatial protection from fishing will also reduce the possibility of harvesting any long lived benthic fish species in the vicinity of fish farms that may acquire elevated loads of mercury due to their association with farm-impacted sediments (e.g. deBruyn et al. 2006). Pelagic wild fish that aggregate at fish farms are likely to do so for shorter periods than more sedentary benthic species (Uglem et al. 2008, 2009). Thus, pelagic fish will not become ‘locked away’ from the regional fishery for extended periods. Spatial protection in the immediate surrounds of fish farms would provide only temporary protection while they were aggregated and more vulnerable at fish farms. Once they move away from farms, they will return to being subject to the standard fishing pressure of the region.

6. CONCLUSIONS FROM THE COMPILED INFORMATION

6.1 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 proposed NZ King Salmon sites, particularly those in Waitata Reach, although there is little information for Papatua.

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.
6.2 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 (Engraulididae), 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.

6.3 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.

2. Aggregations are temporally persistent, although specific species within the aggregated assemblage will likely vary with season, 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 specific wild fish species when the farm is large in size, located in shallow waters, is close to the coast, and is placed over a rocky substrate.

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.

6. 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.

7. Loads of specific parasites may be elevated in some farm-associated wild fish, while loads of some parasites may be reduced.

8. Fish 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.
9. 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.

10. 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.

11. 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. This process may lead to local changes in fish abundance. If farming is widespread within a region and traditional, recreational and commercial fishing pressure is intense, broader, regional-scale population implications are possible.

6.4 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. IMPLICATIONS FOR FISH FARMS IN THE MARLBOROUGH SOUNDS

7.1 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 proposed sites in Waitata Reach (Kaitira, Waitata, Tapipi, and Richmond), and there is also useful information for proposed sites in Queen Charlotte Sound (Kaitapeha, Ruomoko) and Tory Channel (Ngamahau). Far less can be inferred for Port Gore (Papatua) which was not included in the studies.

From this information, 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. SSW 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 Kaitira, Waitata, Tapipi, and Richmond, and also for Kaitapeha, Ruomoko, and Ngamahau, 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). In the case of Papatua no conclusion can be drawn δ while Port Gore is close to Cook Strait and therefore may be influenced by increased nutrient levels during upwelling events, there is no information to support or refute this suggestion.

7.2 Finfish Distributions and Existing NZ King Salmon Farms

Information from existing NZ King Salmon farms indicates very high observations of seasonally moderated numbers of the baitfish species, yellow-eyed mullet, pilchard, anchovy, and jack mackerel, as well as the ubiquitous spiny dogfish. The larger, predatory yellowtail kingfish was also described as a frequent visitor, though in much lower numbers. While distributions of the species observed in highest numbers cannot be inferred from recreational fishing survey data presented here, mainly because they would seldom be targeted by recreational fishers and therefore would not be recorded during the survey, the same seems unlikely for kingfish which have a distribution confined to the outer Queen Charlotte Sound in the survey data. It seems more likely that some other factor is 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.

It is difficult to be conclusive for species that show a restricted distribution in the recreational survey data. For example, there seems to be consistency with NZ King Salmon existing farm observations for jack mackerel (Port Ligar, Waihinau), but the reason for its absence from Otanerau is not immediately apparent δ such a mobile, widespread species is expected to be universal within the Sounds. One concludes that this is a species for which the recreational data may not be reliable in providing information on distribution. As has been discussed in the previous paragraph, it is not a popular target of recreational fishers and, as fishers know, it does not readily take bait.
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. In most cases there is consistency between datasets for these species from each of the two recreational surveys. While it seemed possible when the data were first summarised here, there is too much uncertainty for assignment of species with limited distributions to particular farms. Therefore, from the available data, no inference regarding differences in species compositions between proposed sites can be made.

Also discussed in the context of the existing farms was a group of fishes 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. Information from the recreational survey data indicated a universal distribution throughout the Sounds for the two most commonly occurring species, snapper and tarakihi. The third of these in the observational data from farms was John dory, which is only recorded from Port Ligar in the recreational survey data.

7.3 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 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 since fishing year 2004–05 and that almost all of this was taken by midwater trawl over deep water.

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 (Taylor & Julian 2008). It is most likely that the jack mackerel species occurring at NZ King Salmon farms is *Trachurus novaeezelandiae* (because of its more shallow water distribution compared with the other two jack mackerel species). 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. novaeezelandiae* is 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>
<thead>
<tr>
<th>Species</th>
<th>No of fish</th>
<th>Species</th>
<th>No of fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue cod</td>
<td>2642</td>
<td>Spotty</td>
<td>302</td>
</tr>
<tr>
<td>Snapper</td>
<td>731</td>
<td>Tarakihi</td>
<td>280</td>
</tr>
<tr>
<td>Sea perch</td>
<td>551</td>
<td>Hapuku</td>
<td>184</td>
</tr>
<tr>
<td>Flounder</td>
<td>539</td>
<td>Blue moki</td>
<td>155</td>
</tr>
<tr>
<td>Kahawai</td>
<td>441</td>
<td>Barracouta</td>
<td>140</td>
</tr>
</tbody>
</table>

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 benthio-pelagic species, so called because their normal
benthic habit is modified near the farms where they occasionally swim within the pelagic habitat. It is unknown however, the time frame over which a long term residency might persist.

7.4 Effects of Farms

From the information compiled here, it is clear that interactions will occur between wild pelagic finfish species and the new farms proposed by NZ King Salmon. 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 usually expected of 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, bentho-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 farming locations in the proposed plan change.

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.

7.5 Interactions of Fish Farms with Sharks

Information from existing NZ King Salmon farms indicates that a total of four shark species have been known to visit the farms. These include spiny dogfish, bronze whaler, blue shark, and seven-gill shark. According to information from DOC (Clinton Duffy, pers. comm., see Table 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.
8. 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. Thanks also to managers of existing farms for their information on observations of fish species at the farms.

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APPENDIX A: A Brief General Description of the Pelagic Habitat.

The marine pelagic ecosystem is the greatest in size among all ecosystems on the earth. It encompasses 99% of the total biosphere volume and is generally considered to have high resilience (Würtz 2010).

The term pelagic refers to those aquatic habitats within the water column that are off the bottom, and that range from just above the bottom, through midwater, to the surface. The pelagic habitat can be partitioned into several finer-scale habitats or zones, based largely on depth. For example, the epipelagic zone extends down from the surface to about 200 m. When the pelagic habitat is within the boundaries of the continental shelf it is referred to as neritic. The pelagic habitat can be characterised by particular features within the two broad categories of abiotic (non-living) and biotic (living).

The principal abiotic characteristics of a pelagic habitat include its physical characteristics such as temperature, light and turbidity, pressure (which is directly related to depth), current speeds, turbulence, and sound, and its water chemistry such as salinity, pH, dissolved oxygen concentration, and nutrient concentrations. The variables salinity and temperature define the density of a water body and its potential for stratification and stability (i.e., its resistance to vertical mixing) (Cloern 1991a, from Gibbs 1993). These features can strongly affect planktonic processes within the water body.

Members of the pelagic biota are classified as either planktonic (those organisms that are moved passively by the currents) or nektonic (those organisms that can swim strongly enough to propel themselves independently of the currents). Planktonic organisms may inhabit the plankton throughout their entire life cycle as holoplankton, or live only part of their life cycle in the plankton as meroplankton. Many invertebrate animals and fish have life histories that include planktonic eggs, larvae, and/or juveniles, followed by nektonic or benthic (bottom dwelling) stages as larger animals.

Compared with the full range of pelagic habitats, the neritic epipelagic habitat is relatively shallow and includes the water-air 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.