Marine Mammals and Aquaculture, with Special Emphasis on Open Ocean Waters of New Zealand

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Abstract

The term 'aquaculture' encompasses seaweed, shrimp, shellfish, and finfish farming in fresh and marine water; but the present report concentrates on marine mammals and the marine environment. Aquaculture effects are largely 1) taking of space, including three-dimensional space but also acoustic-related space; 2) potential entanglement problems, especially for air-breathing vertebrates that become entangled and cannot ascend to the surface; and 3) degradation of the environment through waste, uneaten food and anti-biotic treatments. Marine mammal interactions with ocean aquaculture facilities have been described especially for the Mediterranean, some parts of northern Europe, Chile, Canada/United States on Atlantic and Pacific coasts, and New Zealand/Australia. However, data on interactions for offshore facilities are scarce, and present best comparisons for potential problems are with non-aquaculture set nets, lobster pots and attachments, and other fisheries that marine mammals need to avoid or can blunder into. In New Zealand, several species of fur seals, sea lions, dolphins, and baleen whales will come into contact with offshore aquaculture, but extent of negative effects including fatal entanglements are not known. Overall, while present data are scarce, needed are 1) informed siting of offshore facilities away from pinniped rookeries and dolphin/whale movement and migration patterns, 2) construction of holding devices without billowing nets and with rigid taught lines where lines are absolutely necessary, and 3) vigilant informed monitoring of potential and realised problems, with corrective actions to decrease negative aquaculture/marine mammal interactions as warranted.

Key words: Aquaculture, marine, finfish, shellfish, mussel, oyster, shrimp, seaweed, marine mammals, pinnipeds, odontocetes, mysticetes, habitat, disturbance, entanglement

I. Overall scope of this report

Fisheries New Zealand of Ministry for Primary Industries, Manatū Ahu Matua, has asked me to provide:

1) A review of the scientific literature for all available information on marine mammal aquaculture interactions with a focus on open ocean/pelagic aquaculture. Most of the international literature is on nearshore aquaculture facilities, so major research papers are highlighted, with potential application to open ocean comments as applicable.

2) An evaluation of the likelihood of interaction and/or capture (interpreted by me as entanglement) **for different combinations of marine mammals/aquaculture facilities (and the characteristics of the installations that affect this likelihood).**

3) A relative estimation of the likelihood that these interactions result in lethal/non-lethal outcomes for each species. Items 2) and 3) are handled in the prose Discussion section for several species of potential concern in New Zealand oceanic waters, and in a Risk Assessment Summary of aquaculture on marine mammals. However, I am incapable of providing an overall assessment on a species by species basis.

II. Introduction

The world is becoming ever-more reliant on fresh water and marine aquaculture, and millions of people purchase sustainably grown shrimp, Atlantic salmon (*Salmo salar*), and other invertebrates and fishes from farmed background (FAO 2019). Finfish that need to be fed by humans may require more calories than their final product from nature and other human controlled production to come to market, and not all cost-benefit avenues have been analyzed (Price et al. 2017). Seaweeds as food seem an especially useful aquaculture potential for humans, as they occur closer to primary productivity than are animals and may even be good for climate change amelioration (Duarte et al. 2017). There is no further detailed analysis of seaweed farming here, due to a paucity of information.

The term 'aquaculture' encompasses seaweed, shrimp, shellfish, and finfish farming. These have largely consisted of farms nears-shore, but there is increasing interest in offshore areas including much deeper water. Part of this shift in interest is trying to minimise a 'not in my backyard' human-response phenomenon, and part of it has to do with logistics of building farms in rather larger expanses of environment, and thereby minimising the at least perceived environmental footprint of said farming. While we know quite a bit about impacts of nearshore farming on marine megafauna (e.g. fishes, birds, turtles, and marine mammals; Kemper et al. 2003 and Clement 2013 provide valuable summaries, largely for marine mammals), we know relatively little about interactions with marine mammals and potential problems of farms in offshore—often but not always—deeper waters.

Aquaculture effects on the marine environment are largely 1) taking of space, including three dimensional space but also acoustic-related space; 2) potential entanglement problems, especially for air-breathing vertebrates that become entangled and cannot ascend to the surface; and 3) degradation of the environment through waste and, where relevant uneaten food and anti-biotic treatments. Overall, most marine mammals and aquaculture seem to occur together quite well, although our understanding of short-term interactions and potential long-term consequences are imperfect (Würsig and Gailey 2002, Kemper et al. 2003, Clement 2013). Gentry et al. (2017) provided a general overview of offshore aquaculture and its problems, but also opportunities relative to sustainability of the industry's development. The New Zealand Ministry for Primary Industries (2013) summarised important ecological effects of New Zealand aquaculture, and suggested management options for mitigating potential negative effects. For aquaculture to thrive while meeting environmental and other concerns, a wholistic approach is needed with multiple stakeholders fully involved (Piwetz 2011 provides the outline of such a framework).

While types of aquaculture differ in terms of their potential impacts on marine mammals, similarities of all seem to be the taking of space, and the fact that especially loose lines and aspects of netting can endanger entanglement of animals who then cannot return to the surface and may suffocate or drown. These entanglements are not unlike those associated with set nets, shark exclusion nets, or lobster pot lines and buoys. Large baleen whales can often power through such entanglements (and may destroy them in the process), only to be harmed and even succumb to them later as they carry the gear with them (Price et al. 2017, IWC 2020); smaller toothed whales (including dolphins) and furred mammals generally extricate themselves but at times cannot do so and suffocate. New Zealand fur seals (*Arctocephalus forsteri*), Hector's dolphins (*Cephalorhynchus hectori hectori*), bottlenose dolphins (*Tursiops truncatus*) and dusky dolphins (*Lagenorhynchus obscurus*) have been reported entangled in salmon farm gear in the Marlborough Sounds (Clement 2013).

Open ocean aquaculture may have broader ecosystem impacts through changes to marine habitats, food webs and productivity, with flow-on effects for marine mammals. These are important considerations but are beyond the scope of this marine mammal-focused evaluation.

III. Types of aquaculture gear and marine mammal considerations, general

Aquaculture requires containment (e.g. nets, cages or bins) or lines for attachment of the target species, and associated lines and wires for anchoring. Structures and anchoring systems are made of generally corrosion-resistant materials, and various plastic-derived materials such as polyesters, nylons, and rubbers are especially favored for modern use. While stainless steel has been the most important metal for structural integrity, recent use of copper alloys seems especially beneficial due to copper's antimicrobial and therefore anti-biofouling as well as resistance to marine corrosion properties (Braithwaite and McEvoy 2005). Specifics of gear for shellfish and finfish aquaculture are described in Kemper et al. (2003), Price et al. (2017), Clement (2019, 2020), Clement and Elvines (2019), and others. Overall, the best possible tautness of structures and lines seems especially important in allaying marine mammal entanglements, as it is also for fisheries nets, crab and lobster pots, and other non-aquaculture structures (Gales et al. 2003, Berkenbusch et al. 2013).

Aquaculture industries have difficult concerns to solve, as they need to provide a safe environment for their target species of growth; at the same time as they minimise the risk of entanglement of birds, sea turtles, and marine mammals. Entanglement is not the only problem, of course, because food and antibiotics provided for finfish also cause environmental concerns that can cascade to other species, noise of farm operations and support ships can be an ongoing source of disturbance, and the overall taking of environmental space can be detrimental to some species (Markowitz et al. 2004). The location of aquaculture facilities as far away as possible from species that may depredate on the facilities and may be harmed as a result (Kemper et al. 2003) seems to be particularly important. Often it may be best to locate aquaculture facilities away from the nearshore and into open-water environments where there is much more space for marine vertebrates that move through to be accommodated. We need to assess especially migratory movements of marine mammals in this context, and for scientific advice on siting of proposed facilities relative to potential problems. For example, Clement (2019, 2020) and Clement and Elvines (2019) go a long way towards making insightful recommendations for several proposed projects in disparate regions for finfish aquaculture in New Zealand. Those recent reports are addressed in more detail later in this evaluation.

IV. Types of marine mammals, general

While there have been useful retrospectives of marine mammals involved with aquaculture facilities (Kemper et al. 2003, Price et al. 2017), it is not always clear to what extent certain types and traits of species relate to more or fewer chances for endangerment. Marine mammals of concern in New Zealand are:

1) Pinnipeds, including phocids or 'true seals' that propel themselves largely with hind flipper movements; and otariids, sea lions and fur seals, that propel themselves with large front flippers that can arguably cause them to be more easily entangled in fishing and aquaculture gear than are phocids. Especially otariids are attracted to finfish aquaculture to predate on the fish being farmed or to fishes that aggregate around fish farms due to the farmed fish needing to be artificially fed. Either way, there are concomitant problems of occasional entanglements as well as ripping of nets due to sharp incisors of insistent animals trying to get at the fish inside enclosures.

(2) Cetaceans (baleen whales and toothed whales, including dolphins, and porpoises). Baleen whales (mysticetes) tend to be large, at 5m length and much more, and quite often interact with fishing nets, cray pots and the like. Myers and Moore (2020) present a recent example for lobster trap gear and North Atlantic right whales (*Eubalaena glacialis*) entanglement. Especially younger whales often play with lines and buoys, and can inadvertently become entangled, a major problem with especially right whales (*Eubalaena* sp.), gray whales (*Eschrichtius robustus*), and humpback whales (*Megaptera novaeangliae*). Southern right whales (*E. australis*) and humpback whales migrate along all shores of New Zealand,

and are particularly susceptible to lines and nets, although very few entanglements relative to aquaculture facilities have been documented (Clement 2019, 2020).

There has been much written about baleen whales not echolocating (as toothed whales do), and thereby potentially "blundering into" nets and other obstructions. But, baleen whales are finely attuned to the environment around them, with sensory hairs on the jaw and an extremely sensitive skin (Drake et al. 2015, as one example) and they may become entangled now and then probably quite often because they cannot resist interacting with novel-appearing items in the water (see Payne 1995 for southern right whales). On the other hand, toothed whales (odontocetes) have highly-acute directional echolocation abilities for detecting items in the environment at much greater distances than allowed by sight even in clear waters in daytime. However, as they move about in oceanic waters, their echolocation is not all that often "turned on", and they may be (although all potential data are not in) just as likely to become entangled in some types of netting and other structures as are mysticetes. Even with sight and echolocation capabilities, monofilament nets are not easily seen underwater. Smaller odontocetes tend to be more tightly maneuverable than their larger-bodied cousins, but also less strong, so a billowing net or set of non-taut weaving lines can also cause immediate fatal entanglement (Price et al. 2017). However, large baleen whales that power through the fisheries devices very often carry lines and pots, etc., with them, and can die weeks to months, perhaps at times even years, later due to the initial entanglement (Van Der Hoop et al. 2017).

Further complications in attempting to describe chances for entanglements per potential number of interactants are:

1) We do not know how many animals are passing through unhindered, unaffected, by objects in the water; and

2) Besides the general patterns of morphology (e.g. otariids, right whales and especially humpback whales have large front flippers), behavior (otariids interact with anything that might be an easy meal), and maneuverability, there is individuality in behaviors of each of the broad categories mentioned above. Not only are there likely to be age and sex specific differences (young curious "investigating" males versus, perhaps, cautious and wary adult females with calves); but there are, similar to human societies, those who engage in risky behaviors, and those who do not, the phenomenon of animal personalities (Gowans 2019, Würsig 2019, Díaz-López 2020). Also, some species (e.g. humpback whales) have a propensity to roll when entangled, which is one of the reasons for tight multipole wrapping of lines around bodies, tail stocks etc.

Dolphins caught in salmon cage nets in the Marlborough Sounds tend to be caught with their rostrums/teeth. Cetaceans also cannot swim backwards, and thus have difficulty in extracting themselves by trying to push forwards. It is these differences by animal type, species, and individuality in behaviors and therefore potential interactional problems that will be best to incorporate into modern overall risk assessments as scientists, industry personnel, and managers proceed.

V. Examples of interactional situations, worldwide

Oceanic aquaculture facilities occur in disparate locales and biomes, with fewer in very high latitudes of both hemispheres. We know most about aquaculture relative to marine mammals in **V.a,b,c.** the Mediterranean Sea and some NE Atlantic and adjacent waters (mainly UK/Scotland, Iceland, and Norway), **V.d.** off Chile, **V.e.** in some US and Canadian waters, especially the NW Atlantic, and **V.f.** off Australia/New Zealand. There is intensive generally close-to-shore marine aquaculture throughout much of Asia/Indonesia, but there has not been much research on marine mammal relevance in these areas. There are many more countries and locales with aquaculture, with summaries of realized and potential effects in Würsig and Gailey (2002), Kemper et al. (2003), Clement (2013), Price et al. (2017), and others. I do not attempt to represent all citations but highlight several that may be of special importance relative to considerations of offshore aquaculture in New Zealand.

V.a. Intensive aquaculture in the Mediterranean Sea relies largely on the fin fishes seabass (*Dicentrarchus* sp.), seabream (*Sparus* sp. and *Diplodus* sp.), bluefin tuna (*Thunnus* sp.), and others (Conides and Kevrekidus 2005; Piroddi et al. 2011). However, there is also some Mediterranean mussel (*Mytilus galloprovincialis)* farming, generally very close to shore (Gangnery et al. 2004 and Andrisoa et al. 2019 provide good examples).

Some cage designs are open on top, others are closed, but all attract dolphins -- almost exclusively bottlenose dolphins in the Mediterranean due to food pellets that attract wild fishes to the immediate vicinity of the farms (Bonizzoni et al. 2014), and presence of farmed fish (Díaz López, 2006, 2009). Fish farms in several Greek areas have changed common bottlenose dolphin (from here on the term 'bottlenose dolphin' refers to the common one, *T. truncatus*) movement patterns and habitat use characteristics, apparently to better find food near fish farms than in a generally depauperate sea due to human overexploitation (Bearzi et al. 2019, Bonizzoni et al. 2019).

Studies carried out in NW Sardinia revealed a significant upward trend in abundance of bottlenose dolphins and a reduction of social interactions associated with a temporal switch to food sources provided by a seabass/seabream farm (Díaz López 2019). Díaz López (2017) found that at least some dolphins were especially interested in catching wounded discarded farmed fish during harvesting operations, and he hypothesized that some dolphins have become reliant on such discards. Earlier on, during a 15-month long study, Díaz López and Shirai (2007) had counted approximately one dolphin per month incidentally entangled and suffocated in that fish farm, due to the (temporary) use of antipredator nets around the floating cages. Bonizzoni et al. (in review) did not find attraction by bottlenose dolphins towards mussel farms off Veneto, Italy (but see below for a different area).

In the Turkish Aegean Sea, Mediterranean monk seals (*Monachus monachus*) took fish out of sea bass and sea bream farms by damaging the nets of holding pens, largely at night and in wintertime. In that case, intense lights and noises did not deter the seals, but anti-predator nets around the farms alleviated the problem. It is unknown whether endangered monk seals died in those nets (Güçlüsoy and Savas 2003).

V.b. In NE Atlantic waters, Díaz López and Methion (2017) found an attraction of bottlenose dolphins to Mediterranean mussel farm rafts in Galician (NW Spain) waters, due to wild fish attracted to the floating raft systems. Bottlenose dolphins more often foraged near shellfish farms than away from them (Methion & Díaz López, 2019). This reliable and readily-located food source near shellfish farm areas has also been linked to dolphins' social structure, with bottlenose dolphins preferring to affiliate with other individuals that foraged within/near shellfish farms at similar frequencies (Methion & Díaz López, 2020).

V.c. In northern European waters, especially shellfish production occurs, with little assessment of species interactions beyond some seals and harbor porpoises (*Phocoena phocoena*). Harbor seal (*Phoca vitulina*) numbers (and measures of other species diversity) in inshore Irish waters were broadly similar at and away from nearshore (to 20 m deep) blue mussel (*M. edulis*) farms with floating long lines 15 m deep (Roycraft et al. 2004). While there were no apparent negative interactions related to farms and harbor seals, the authors worried that parasites carried by seals could be spread to biota in and near farms, but with no direct evidence. A rather thorough account is by MacCormack et al. (2009), as an overview of intensive shellfish and finfish farming, with impacts on ecosystems in the north-east Atlantic under the Convention for the Protection of the Environment of the North-East Atlantic (OSPAR, named for initial meetings in **Os**lo and **Par**is). This account does not feature marine mammals, however. There is considerable seal predation on fin fish farms in Scotland (and elsewhere), discussed by Northridge et al. (2013).

Young (2015) provides a worthwhile international review of important marine mammal interactions with mussel aquaculture gear; with special reference to Iceland, where the mussel industry is still small. She reports the entanglement of a young humpback whale in a single dropper spat collector in an experimental mussel farm in Miðfjörður, Northwest Iceland. The collector was about 5 m long, with a weight at one end attached to a 50 m headrope. The ropes were entangled around the tail, and the whale appears to have suffocated. Young (2015) mentions that in her opinion it is the thinner lines/ropes that may be more dangerous for entanglements, and that—overall—the greater tension of mussel lines than that of most lines holding crab pots and other stationary fisheries catching devices tends to reduce entanglement risk (see also Lindell and Bailey 2015).

V.d. The inshore waters of southern Chile have become important for nearshore mussel (*Mytilus* sp.) and salmon farming, largely of Atlantic salmon (*Salmo salar*), coho salmon (*Oncorhynchus kisutch),* and rainbow trout (*O. mykiss*) (Kemper et al. 2003, Vilata et al. 2010). These same waters harbor South American sea lions (*Otaria flavescens),* Chilean dolphins (*Cephaloryhnchus eutropia*), Peale's dolphins (*Lagenorhynchus australis*), and Burmeister's porpoises (*Phocoena spinipinnis*). All four species move near farms and at times interact with them, with sea lions being major predators of farmed finfish and other fish attracted to the farms. South American fur seals (*Arctocephalus australis*) occur in the most southern of these waters, but feed almost exclusively in deeper offshore habitats, and do not seem to interact with aquaculture to a meaningful degree (Vilata et al. 2010). Bottlenose dolphins do not tend to co-occur with aquaculture farms in Chile, but killer whales (*Orcinus orca*), have been sighted occasionally very close to fish farms, apparently in part to take sea lions that aggregate around farms (Sonja Heinrich, pers. comm. July 2020).

Chilean dolphins tend to prefer less than 30m depth and turbid waters closer to shore, as do co-generic Hector's dolphins (*C. hectori*) (Dawson 2018, Heinrich et al. 2019). Chilean dolphin habitat overlaps extensively with mussel farm sites in the Chiloe Archipelago. Although Chilean dolphins readily swim between mussel lines (Sonja Heinrich, pers. comm. June 2020), they seem to not use areas where lines are densely packed (Ribeiro et al., 2005), possibly because their preferred schooling prey might not be available in these parts.

Peale's dolphins are a southern hemisphere *Lagenorhynchus*, and like dusky dolphins of New Zealand prefer slightly more open waters, but not at all in as deep waters as off Kaikōura (for example, Würsig et al. 2007, Heinrich et al. 2019). Nevertheless, Peale’s dolphin habitats seem quite similar to dusky dolphins traveling within the Marlborough Sounds, New Zealand. Unlike the reports for dusky dolphins (Markowitz et al. 2004, Pearson et al. 2012), mussel farms seem not to interfere with Peale’s dolphin feeding behavior, but the dolphins have to traverse extensive farm sites to move between patches of preferred coastal habitat, so this also may imply partial habitat exclusion (Heinrich et al. 2019).

Despite the high intensity of salmon farming in southern Chile, there have been only six verified reports of deaths (2007–2017) due to entanglements in farm support lines for Chilean dolphins, none for Peale's dolphins, one for a juvenile humpback whale, one very recent death of a sei whale (*Balaenoptera borealis*), and entanglement and release of an apparent adult humpback whale (Espinosa-Miranda et al. 2020). However, Sonja Heinrich (pers. comm., 28 June 2020) cautions that, in her words:

" There is substantial overlap between Chilean dolphins and mussel farms. While mussel farms do not seem to cause direct mortality, they may affect carrying capacity due to reduced habitat quality. Salmon farms may also affect habitat quality, but more importantly can also cause entanglement in anti-predator netting. For Chilean dolphins, unlike other cetaceans, such entanglements seem to be deadly. This might be the most immediate threat to them in the southern fjords where salmon farms are now extremely widespread, and where farms are sited in or close to Chilean dolphin habitat. Unfortunately, current reporting is inadequate, and official records are incomplete and sketchy.

Why are only Chilean dolphins reported in fish farm nets but not Peale's dolphins or Burmeister's porpoises? All three species have been observed near fish farms by researchers and farm workers alike. Burmeister's porpoises have also been bycaught in midwater gillnets in Chiloe (Pers. Comm. Sonja Heinrich, July 2020), so as to be expected, nets in their habitat can cause entanglements. Why then are there no reports of porpoises or Peale's dolphins being recovered in fish farm nets? Particularly Peale's dolphins are easily recognizable and visible (because they are attracted to boats), are widespread, and most likely the most numerous small cetacean species in the southern fjords."

This personal report by a long-term researcher of marine mammals in Chilean waters represents a general caution that data on interactions with aquaculture facilities are difficult to obtain and contextualise. While direct mortality clearly has the most immediate impact on populations, a measure of mortality alone is not likely to properly, nor fully, evaluate potential effects of near-shore or oceanic aquaculture facilities towards marine mammal health and well-being.

V.e. United States and Canadian waters of Atlantic and Pacific coasts harbor mainly shellfish and finfish aquaculture, but generally not in as high intensity as parts of the Mediterranean Sea (for finfish), NE Atlantic (for shellfish), and southern Chile (for both). In the Bay of Fundy, Canada, finfish aquaculture is prevalent, and harbor porpoises often occur in association. However, while there is some fish taking near and occasionally inside farms, there is little evidence for nets being damaged. Haarr et al. (2009) provide an overview of porpoise presence from echolocation data. Pinnipeds, largely sea lions and seals, have been a problem as predators near and in finfish (largely salmonid) farms on both coasts, and culling (=killing) of pinnipeds was widespread in the early years of aquafarming (Jamieson and Olesiuk 2001). Culling is rarely allowed these days, and there are in place better aquacultural practices of more rigid containing structures and tighter support lines, etc., than 20 years ago (Price et al. 2017 for USA; DFO 2020 for Canada).

While there are no detailed published accounts of cetacean mortalities related to aquaculture in USA waters (Price et al. 2017), Lloyd (2003) relates a potential eyewitness account of a gray whale entangled in aquaculture netting or lines, off California over 20 years ago. Johnson et al. (2005) list a North Atlantic right whale as dying in an aquaculture facility, but details are not published. Price et al. (2017) mention two humpback whales dying in salmon farm lines in Canada. Price et al. (2017) also summarise the rather large number of entanglements of especially North Atlantic right whales and humpback whales in especially buoy and ground lines holding traps and gillnets, and stress that any lines—thus similar lines fixed to aquaculture facilities—may be detrimental to these protected species. Fin (*Balaenoptera physalus*), sei, and minke whales (*B. acutorostrata*) have also become entangled and died in commercially-set (but not aquaculture) lines in North America (Waring et al. 2015). An excellent summary of gillnet and other entangling fisheries, with applicability towards aquaculture as applies to connecting lines and gear, is provided by Reeves et al. (2013).

Overall, the still rather small finfish marine aquaculture industry in the United States and Canada has become more efficient and less reliant on harmful antibiotics in the past 15 years or so, and Rust et al. (2014) claim an overall positive environmental effect, including most likely (my addition) towards marine mammals.

There are no concerted studies of algae aquaculture related to marine mammals. Hughes et al. (2014) modelled potential problems caused by harbor seals and California sea lions to the OMEGA integrated aquatic system to produce biofuels, treat and recycle wastewater, capture CO_2, and expand algae aquaculture production in Monterey Bay, California. They found no obvious adverse reactions to the experimental facility nor to marine mammals, although more detailed studies in actual oceanic conditions are needed.

V.f. Australia/New Zealand. The three major species of New Zealand aquaculture are New Zealand green-lipped mussel (*Perna canaliculus*), Pacific oyster (*Magallana gigas,* also known as *Crassostrea gigas*), and king (also termed Chinook) salmon (*Oncorhynchus tshawytscha*).

Lloyd (2003) described the mussel farming industry in New Zealand, analysed data up to 2003 relative to marine mammals, and cautioned that while few adverse effects had been determined, spatial exclusion (especially near shore) may be particularly detrimental in some bays and sounds. He expressed that entanglement could become a problem in deeper oceanic waters as the industry moves offshore. Clement (2013) summarised the status of overall aquaculture and marine mammal interactions, one decade after Lloyd (2003). The Ministry for Primary Industries (2013) provided assessments of data needs and potential mitigations (but no specifics about marine mammal entanglements, leaving this to the companion report by Clement 2013); details are not repeated here.

In New Zealand, direct fatal interactions with aquaculture farms have been few. Lloyd (2003) and Clement (2013) briefly mention that two Bryde's whales (*Balaenoptera edeni*)—possibly only one)—died in lines associated with mussel spat or other farm activities. In Australia, at least one humpback whale died in mussel crop lines (Clement 2013), probably one other in an abalone farm and two to three in a pearl-oyster farm facility (Groom and Coughran 2012). A humpback whale calf became entangled in mussel spat collecting lines in Western Australia and was disentangled and safely released (Groom and Coughran 2012).

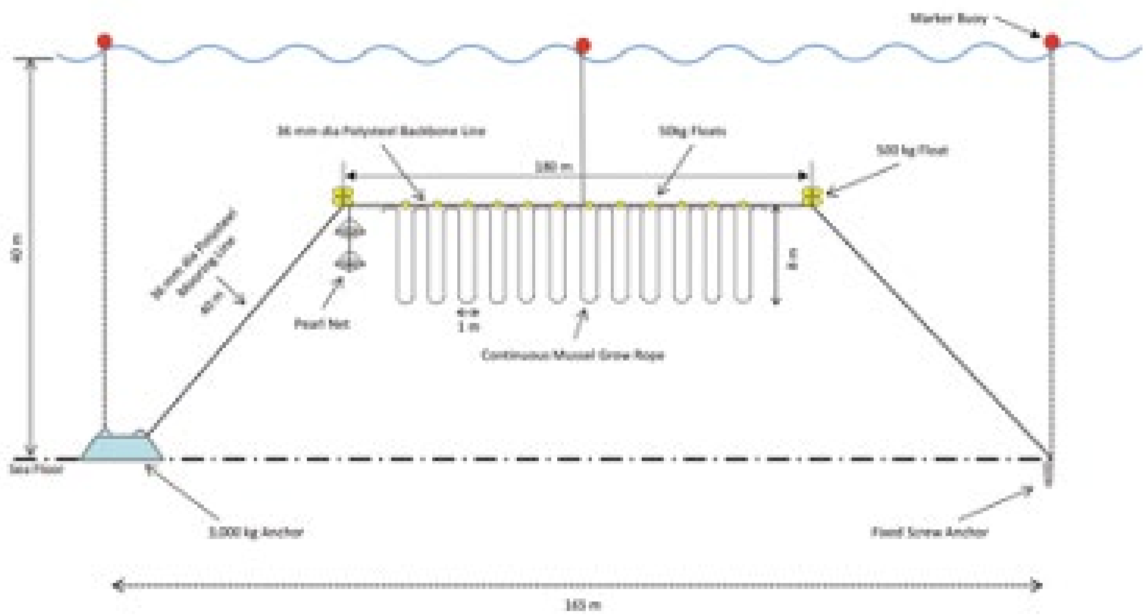
Markowitz et al. (2004), Pearson (2009), and Pearson et al. (2012) presented evidence that mussel farms along shore in Admiralty Bay, Marlborough Sounds, New Zealand, by taking up space near shore inhibited movements of dusky dolphins, and especially their habit of encircling schooling finfish prey for bait ball feeding. They found no direct negative spatial interactions for common dolphins (*Delphinus delphis*) and bottlenose dolphins in Admiralty Bay, which moved though mussel farms apparently unhindered.

Watson-Capps and Mann (2005) found that Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Shark Bay, Australia decreased their use in a bay with pearl farm structures, similar to mussel farms and once again due to space taken up by the farm structures. Once the farms were removed, dolphins re-used the area in similar fashion as before oyster farm placement (Janet Mann, Personal Communication, April 15, 2020). Such observations relative to shellfish farms were made in shallow water and may not be as important in the more extensive habitat available in open waters, but, if longline operations depend on nearshore spat collection farms for seed stock, the issue may still be relevant (Price et al. 2017).

Dugongs are incidentally captured in small-scale fisheries, and it is possible that their entanglement in aquaculture facilities is under-reported. One adult male dugong was reported entangled in lines associated with a seaweed farm in Palawan, Philippines, and there exist other anecdotal but unpublished reports of similar deaths (Poonian and Lopez 2016). While dugongs are present along northern shores of Australia, they do not occur (nor do any other sirenians) in New Zealand waters.

VI. Offshore aquaculture in New Zealand, as related to marine mammals

VI.a. Mussel (and any other bivalve) farming devices in offshore (generally 'deeper') waters are likely to be similar to those presently used in shallow waters, with probable differences in attachments to the bottom, and with the possibility of no or very few extraneous lines from the basic hanging rope system (Lloyd 2003). Submerged farms may be utilised offshore if wave conditions are too rough to maintain traditional-style floats at the surface.



A representative schematic of sub-merged offshore longline systems used for suspension culture of mussels, with a single looped grow rope configuration (adapted from Vincent Prien, Isles of Shoals Mariculture,LLC, Rye, NH, pers.comm., and taken from Price et al. 2017. For construction details, see Price et al. 2017), but see also slight differences in such configuration by Lloyd 2003 and Clement 2013).

VI.b. Various types of enclosing devices, or pens, are considered especially for finfish farming in deep waters. These include:

Flexible ring pens (described at https://www.gaelforceaquaculture.com/pen-systems/aquaflex-250-pen/) for finfish farming. One possibility is a version of the "Aquaflex 250 pen" that is about 35-80 m in circumference with about 250 mm diameter flotation pipes arranged in modular design. However, this design seems particularly efficient for inshore (more protected) waters and needs some adaptation for oceanic use. The Polarcirkel (described in https://www.akvagroup.com/pen-based-aquaculture/pens-nets/plastic-pens) allows for cages with circumferences from 60 to 240m, and may be particularly applicable to offshore farms in New Zealand.

Rigid pen structures are composed of rigid plastic, stainless steel, or copper beams with netting between struts. There are various shapes for such structures, but one rather recent one is essentially a 3-dimensional polygon, allowing for great stability, large volume, and semi or full submersion. The basic structure is described in https://patentimages.storage.googleapis.com/dd/e5/18/f28469aadfa299/US8424491.pdf
See figure from Price et al. (2017). These types of devices can be at or near the surface (semi-submerged) or fully-submerged. A description for a semi-submerged pen is here:
https://patents.google.com/patent/WO2017153417A1/en

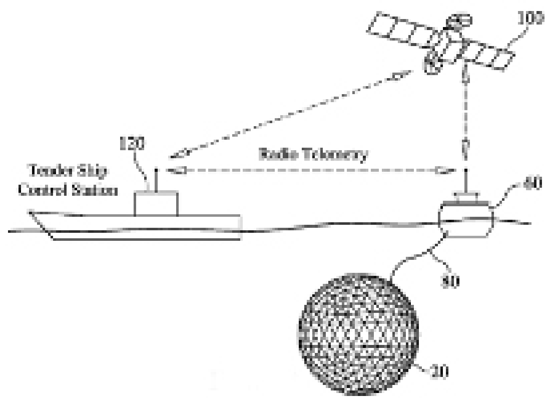
Mobile rigid structures, including submerged towed devices are gaining credence for use in offshore operations. They generally consist of a large top-side buoy or tender ship (or both) for storing and delivering feed and for telemetry positioning signals, whether by point to point sources on ship or land, satellite, or both. The structure is navigated and maintained in a geostationary position within the ocean by position-correction technology and is propelled by thrusters attached to the cage enclosure or the topside buoy or tender vessel.

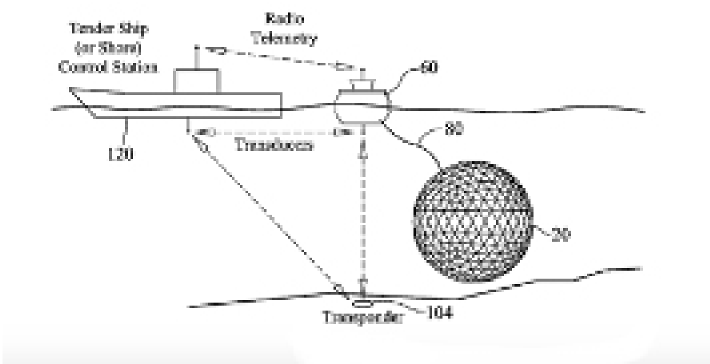
A detailed description of several mobile designs is given at: https://patentimages.storage.googleapis.com/2b/e5/16/ddc1537af91cc8/US9655347.pdf.
The description below is taken verbatim from the above web site,

"The self-positioning, self-powered fish-farming structure enables unmanned, extended marine deployment in deeper ocean waters without the need for tethering or anchoring to the ocean floor. Multiple structures can be maintained in a spaced apart configuration to comprise a flotilla of fish farming structures attended by a tender ship that is autonomous, easily serviced and conveniently relocated".

A schematic taken from that web site is given on the next page.

Mobile rigid structures can also be in the form of near-surface large-scale steel tubes that support suspended nets and are self-propelled to avoid storms, minimise potentially harmful environmental effects in one stationary area, and could even ‘steer clear of’ a particularly-well-used migratory route of right or humpback whales (for example) during migration seasons.





VI.c. Marine mammals most likely to come into contact with offshore aquaculture in New Zealand. Marine mammals of concern in New Zealand waters are pinnipeds (phocids and ortariids) and cetaceans (baleen and toothed whales). These range from the top carnivorous killer whale or orca that feeds on large fishes, rays, and other marine mammals, to southern right whales that feed on clouds of tiny calanoid copepods. There is great morphologic, behavioural, and ecologic diversity among these groups, summarised here.

Pinnipeds of main concern relative to interactions with offshore aquaculture are New Zealand fur seals and the endangered New Zealand sea lion (*Phocarctos hookeri*), the former quite ubiquitous on both shores of the main islands as well as islands to the south; the latter found only in the southern parts of the South Island and to its south. While both spend much of their time nearshore, they traverse and feed in deeper offshore waters and are thus likely to come into contact with any offshore aquaculture facilities (see for example Lloyd 2003, also see Baker et al. 2019).

Odontocete cetaceans (toothed whales including dolphins) are ubiquitous in almost all New Zealand marine waters. Off the North Island, these are mainly killer whales (orca) and common and bottlenose dolphins, with some dusky dolphins especially in southern waters. Off the west coast of the North Island, the highly endangered Māui dolphin (*Cephalorhynchus hectori maui*) occurs nearshore, but probably also into deeper oceanic waters at least at times.

Off the South Island, dusky and common dolphins occur quite usually, with common dolphins having moved further south in the past several decades (Baker et al. 2019). Bottlenose dolphins occur in discrete areas as different populations, with especially worrisome declines in the Bay of Islands (North Island) and Doubtful Sound (west South Island). There is a discrete bottlenose dolphin population centered on Foveaux

Strait, extending northwards to Otago Peninsula and west to the southern Fiords (Brough et al. 2015); this southern population overlaps with proposed offshore aquaculture off Stewart Island. Orca occur on both shores of the South Island, as well as in southern and Sub-Antarctic islands, with some probably at times coming up from the Antarctic. Sperm whales (*Physeter macrocephalus*) occur especially in deeper waters such as near the Kaikōura Canyon, South Island, but can traverse in any offshore waters of both islands.

Mysticete cetaceans (baleen whales) occur off the coasts of both major islands, as well as islands to the south. Minke (*Balaenoptera sp.*) and Bryde's (*B. edeni*) whales occur mainly off the North Island, but it is largely humpback and southern right whales that migrate past both North and South Island, as well as islands to the south. They can occur during any seasons, but their migration routes (see Fig. 1) are mainly during Spring and Autumn. Southern right whales also linger especially in the southern parts of the South Island, and—while numbers are still small—mate and calve there. They are likely to come into contact with offshore aquaculture facilities in that area. Off the west coast of the North Island, in and near the Taranaki Bight, a blue whale (*Balaenoptera musculus*) foraging ground has been discovered (Torres 2013), and this is of concern relative to any development of mining or other human activities, including aquaculture, in that area.

VI.d. Recently-proposed finfish aquaculture in offshore settings. There are (at least) three recently-proposed finfish aquaculture facilities in New Zealand, one off the north coast of the South Island and two near Stewart Island.

One finfish aquaculture facility is of a proposed salmon farm (by New Zealand King Salmon Co. Ltd) offshore the Marlborough Sounds, with a marine mammal assessment by Clement and Elvines (2019). Numbers of pens and types are not yet known. The general Cook Strait, and nearby South Taranaki Bight harbor mainly New Zealand fur seals, common, dusky and bottlenose dolphins, killer whales, and southern right and humpback whales migrating through. Nearby Marlborough Sounds also have nationally threatened Hector's dolphins, killer whales, and bottlenose dolphins. While the proposed farm area does not appear to be primary habitat for these species, it is nevertheless possible that individuals or groups of each species could come in contact with the farms.

Clement and Elvines (2019) opine that main effects of this proposal are potential habitat displacement by marine mammal species, and especially potential entanglement in lines and other aspects of structure of the farms. I agree, especially if endangered animals are displaced or entangled. Other potential impacts such as underwater noise, lighting, and trophic flow-on effects (see also Price et al. 2017) are possible. Overall, I concur with Clement and Elvines (2019) that effects are likely to be low, but the worry about entanglement is always present. My advice is to a) build structures with rigid ribs and non-billowing nets and keep support lines to an absolute minimum—and as taut as absolutely possible—with construction devices to enhance tautness considering vagaries of winds, currents, and tides.

Predator (seal exclusion) nets pose the greatest potential risk. They are on the outside and any tears or other holes could be places where marine mammals trying to get through could become entangled. Holes in the net could also allow animals to get between the predator net and the fish pen. Gaps created during maintenance (e.g. if net panels are being replaced or cleaned) could also allow animals past the predator net. Entrapment may occur between the predator net and the fish pen (depending of separation distances) or if the predator net is allowed to billow, creating pockets in which an animal could become entrapped and unable to surface.

Ngāi Tahu Seafood Resources Ltd. has applied to establish a large salmon farm off the north coast of Stewart Island, with a marine mammal assessment by Clement (2019). This proposal is for of up to 118 circular pens in an area of 2500 ha, about 2–6 km from the northern coast of Stewart Island, Southland, in waters 20–40 m deep. The general Foveaux Strait and Stewart Island area has at least 6 resident marine mammals or seasonal visitors most likely to come into contact with the farm area: New Zealand fur seals, New Zealand sea lions, killer whales, bottlenose dolphins; and largely migratory southern right and humpback whales. The area is also a potential breeding area for southern right whales.

Potential effects by the farms are similar to those stated for the Marlborough Sounds, with the very low potential involvement of Hector's dolphins and the added involvement of New Zealand sea lions. Since both of these New Zealand species are threatened or nationally vulnerable, any major disturbance or even single fatalities are of special importance. Both species can become entangled in nets and drown.

Sanford Ltd has proposed to establish 5 offshore salmon farms in Foveaux Strait, east of Ruapuke Island. Each farm would be about 157 ha, with circle pens. The ecological area is somewhat similar to that of the Ngāi Tahu proposed farm (above), and therefore species involved are similar. However, since Sanford Ltd. is in much deeper water than the Ngāi Tahu proposed farm, and is further offshore, this area is more likely to be in the migratory path of humpback whales and perhaps less used by bottlenose dolphions than closer inshore. These details do not seem to be available for marine mammals, however, and are my conjecture only. The marine mammal assessment (Clement 2020) recommends that for this farm (and the two others above), a detailed Marine Mammal Management Plan needs to be made before beginning operations. This would include detailed descriptions of farm construction and moorings; management best practices related to feed, attending barges, noises and lights, etc.; and a monitoring plan relative to marine mammal presence and potential interactions. My recommendation regarding minimising lines and maximising their tautness stands also for this latter farm proposal.

There is also interest in various places along the east coast of the South Island, including off the north Otago coast and off Canterbury. New Zealand King Salmon have a consented monitoring site off Otago, and another company is investigating a site off Otago (Andrew Baxter, pers. comm., July 2020). This large area along the South Island eastern coast warrants attention as well, as migrating large whales, Hector's dolphins, dusky dolphins, fur seals, and sea lions occur there. I have no further information on this point, however, but mention it as one avenue for further data, discussion, and research.

Figure 1. Areas of special significance for marine mammals in New Zealand. From poster provided by Rob Suisted and Nadine Gibbs, and drawn by Chris Edkins, Department of Conservation, Wellington. Reprinted from Lloyd 2003.

VII. Discussion

There is general agreement in the literature that major marine mammal issues of large structures in the water relate to 1) competition for space by habitat modification or exclusion, 2) underwater noise or light disturbance, 3) flow-on effects due to alterations in trophic pathways, and—probably most importantly (especially for threatened species)—4) the possibility of entanglement. These are given by Würsig and Gailey (2002), Lloyd (2003), Kemper et al. (2003), Clement (2013), and others. Items 1–3 above are potentially important, but—besides data we have for exclusion of several odontocete species from near-shore shellfish facilities in Australia, Chile, and New Zealand (summarised in Section IIIc) —we have no further evidence of meaningful exclusion of habitat, especially in offshore oceanic waters where there is much space for marine mammals to exist, and for migratory animals to pass by. We also know from other studies that noise and lights can change marine mammal patterns of behaviour, as attractants and deterrents (see Richardson and Würsig 1997 as one example); and we assume that flow-on effects of environmental alterations may be important, especially as relate to contaminated substances taken in by higher trophic level seals and dolphins, again without detailed information but discussed by many (Bearzi et al. 2016).

Overall, scale relative to potential or realised harm is important, as a 1000 ha farm that may (or may not) exclude or displace 100 animals is of greater impact significance than one that is 1–10 ha in size and may exclude far fewer (of the same species) over the same time. Several displaced animals are probably better off than one or a few dead ones (but this assertion is open to argument, as displacement can result in presently unmeasurable negative impacts in future). There is also the recognition that some species/populations are simply not doing as well as others, so one Hector's or Māui dolphin dead due to entanglement is likely of greater conservation importance than one or a few more dead dusky dolphins, simply due to their relative population sizes (however, I recognise that this is an incomplete argument based on a past or present (human) system of validity; the one of 100 Hector's dolphin dead is not "more precious" than the 1 in 10 000 dusky dolphin dead; Bearzi 2020).

Otariid sea lions and fur seals tend to interact more with nets and lines than do phocid seals, increasing the risks for finfish aquaculture and the seals (entanglement and other negative interactions). Dolphins tend to not purposefully interact with shellfish or finfish aquaculture, except for bottlenose dolphins that may become used to taking wild fish that aggregate around finfish enclosures due to human-supplied feed. Killer whales may be attracted to finfish aquaculture sites due to the presence of aggregated otariids. Overall, if the enclosures are solidly built in modern fashion and well maintained, there should be no or minimal incursion by pinniped and odontocete predators, no harm to the facility and no harm to the marine mammals. The caveat to this is as always—looseness of nets and lines can cause entanglement of any marine mammal.

Site-specific features of farm infrastructure pose potential risk for entanglement and injury, with considerations of how nets and high-tension anchor lines, horizontal back-bones, vertically hanging, mussel-embedded longlines, or surface buoy marker lines are deployed. Overall, for shellfish farms, it is the slacker grow out lines, spat collecting lines, and surface marker buoy lines that cause the most concern (Lloyd 2003, Clement 2013). These are likely to pose similar problems with supporting lines for any type of aquaculture, including finfish enclosures and seaweed farms.

Acoustic Deterrent Devices and Acoustic Harassment Devices (ADDs and AHDs) have long been used to attempt to keep animals away from human activities, on land and in the sea. These and other attempts at mitigating negative effects by marine mammals on aquaculture are reviewed by Würsig and Gailey (2002) and are not deemed appropriate modern methods. Acoustic devices have been developed in the marine environment particularly to attempt to keep marine mammals away from fishing operations, aquaculture sites, and more recently away from industrial operations that might be harmful to the animals themselves. Predator models and sound devices (imitating killer whales for example) are not effective, as animals quickly recognise what is a real predator signal and what is not (Coram et al. 2014). At any rate, there is significant human-made noise in the ocean already, and ADDs, AHDs, and similar devices do not help to ameliorate this effect (see also Díaz-López and Mariño 2011).

Johnson et al. (2005) summarised evidence that humpback whales tended to be entangled in lines and other fisheries gear by the tail, whereas North Atlantic right whales were entangled around the mouth. This makes sense, as the giant tail of humpback whales is a major propulsive mechanism, and the huge curved mouth of right (and bowhead) whales is most likely to be entangled while they sieve for clouds of calanoid copepods. The entanglement point is perhaps immaterial, if the whale suffocates as a result, or dies later on (Van Der Hoop 2017).

Price et al. (2017) provide perhaps the best summary of our present knowledge about potential fatal interactions with aquaculture facilities. An edited version of this is supplied here:

"... studies suggest interactions and entanglements with ... aquaculture gear worldwide are rare and close approaches by protected species are seldom documented. Entanglement risk for cetaceans depends on several species-specific factors. Inquisitive or playful individuals will be more at risk. Species or individuals that roll when encountering entangling gear may be more likely to become severely wrapped. Additionally, entanglements occurring below the surface will be difficult to detect. Species that do not echolocate may not perceive three-dimensional farm structures as well as species that do. In general, larger, less agile species with flippers and fins that extend relatively far from the body and gaping mouths may be more likely to have negative physical interactions. It is largely unknown how marine animals perceive man-made structures in the ocean, and therefore using visual, other sensory cues to elicit an aversion behavior often involves tentative investigation.... Though there is concern about potential indirect ecosystem effects that may affect marine mammals, there is currently little or no research in that area.

Entanglement of marine mammals in lines may result in death by drowning (Comment by BW: Cetaceans close their blowhole(s)when underwater, even when in distress, and asphyxiate rather than drown), *but can also cause impaired locomotion, decreased ability to forage, tissue infection and necrosis, all which may lead to traumatic injuries, prolonged suffering and starvation leading to death. Thus, interactions with aquaculture gear must consider the potential for both immediate mortality as well as secondary impacts".*

Moore (2019), after spending over 20 years of his and his colleagues' lives on the problem of marine mammal entanglements (personal communication, 6 July 2020), avows that the absolutely best manner to avoid direct and 'down the line' fatalities of especially large whales is to minimise lines in the water. Efforts by others have been made, and are laudable (DeCew et al. 2012), but it is incumbent on humans who use the marine environment to minimise and—as absolutely possible—eliminate lines in the water. While taut lines are better than those that may billow due to vagaries of wind and currents, the elimination of as many lines as possible in the water column is the obvious best strategy for minimizing potential entanglements by marine mammals. It is very difficult to keep lines taut.

VIII. Summary of potential interactional problems and potential solutions

New Zealand has many cetaceans and pinnipeds, but the most likely to interact with offshore aquaculture are New Zealand fur seals, New Zealand sea lions; bottlenose, Hector's, Māui, common, dusky, and bottlenose dolphins; killer whales; and southern right and humpback whales migrating through. The southern areas also represent potential breeding sites for southern right whales. Off the North Island, minke and Bryde's whales occur commonly, and blue whales have lately been described in many New Zealand waters (Baker et al. 2019). The above is not a complete list, and interested readers are urged to consult Baker et al. (2019).

Aquaculture effects on the marine environment include 1) taking of space, including three-dimensional space but also acoustic-related space; 2) potential entanglement problems, especially for air-breathing vertebrates that become entangled and cannot ascend to the surface; and 3) degradation of the environment through waste and, where relevant uneaten food and anti-biotic treatments.

1) The taking of space may not be as important a consideration in deeper waters offshore as for areas and species of inshore/nearshore more shallow habitats. Nevertheless, the size of an aquaculture facility is likely important, especially if it is in the direct migratory (or otherwise) movement pattern of pinnipeds in or traveling to/from foraging sites, and especially relative to movements of large cetaceans. Potential solutions are to site aquaculture facilities as far as possible from onshore pinniped rookeries (see also Kemper et al. 2003), and to carefully map cetacean movements in and near potential aquaculture facilities, and to re-

locate them to avoid important marine mammal travel routes. One possibility is to have sites be mobile, to avoid major migration routes of humpback and right whales (for example) during migratory seasons.

2) I agree with Price et al. (2017) that there are quite a few similarities with especially stationary fisheries devices (such as set nets, lobster traps, etc.), especially as concern anchoring and buoy lines, and the possibilities of becoming entangled in lines and net gear. Mesh size and line gauge or thickness are important here. I am not an expert on these, and different mesh sizes will entangle different marine mammals differently. For example, the 10x10cm drift net mesh size to capture the target species totoaba, a drum fish (*Totoaba macdonaldi*) is unfortunately 'perfect' for capturing the presently most-endangered cetacean on Earth, the vaquita (*Phocoena sinus*) in the Gulf of California, Mexico. Vaquita are about the same size as Hector's and Māui dolphins. Mesh size should be as small as possible and line size as robust (and taut) as possible to minimise marine mammal entanglements (Price et al. 2017). Knowlton et al. (2015) recommend that ropes and lines should have a breaking strength of less than 1700lbs (771kg) to reduce (by their modelling) large whale entanglements by about 72%, or three quarters of entanglement endangerment. For smaller animals, especially billowing nets that create 'pinch points' that can keep entangled marine mammals from surfacing need to be avoided. Here, constant diligent monitoring and maintenance of nets and lines are paramount.

Clement and Elvines (2019) opine that main effects of a proposal are potential habitat displacement by marine mammal species, and especially potential entanglement in lines and other aspects of structure of the farms. I agree, especially if endangered animals are displaced or entangled. Other potential impacts such as underwater noise, lighting, and trophic flow-on effects (see also Price et al. 2017) are possible. Overall, I concur with Clement and Elvines (2019) that effects are likely to be low, but the worry about entanglement is always present. My advice is to a) build structures with rigid ribs and non-billowing nets and keep support lines to an absolute minimum—and as taut as absolutely possible—with construction devices to enhance tautness considering vagaries of winds, currents, and tides.

3) Environmental degradation due to aquaculture facilities is an ever-present concern, including degradation of the substrate under shellfish and (especially) finfish farms. We have very little data relative to marine mammals to go on, but I suggest that this is an avenue for expanded research. If the habitat near aquaculture facilities is compromised, does or does not this immediate compromise affect the marine mammals of concern? We can imagine that it might, if (for example) there is an increased risk of disease vectors as a result of the environmental degradation, but—again—this area of investigation needs further research results and potential considerations.

4) Above all, especially due to our present incomplete knowledge of potential effects of marine farms in deeper offshore waters, I strongly encourage research and vigilant informed monitoring of potential and realised problems, with corrective actions to decrease negative aquaculture/marine mammal interactions. This translates to knowing a) where pinnipeds and cetaceans occur in proposed aquaculture sites, with seasonal timings as appropriate, b) how interactions of pinnipeds and cetaceans with offshore facilities may decrease their use of the areas or increase their vulnerability of being affected by exclusion of entanglement, and c) any other effects to marine mammal occurrence and well-being due to the human-constructed facility in their home.

IX. Risk assessment summary of offshore aquaculture on marine mammals

1) Habitat exclusion is likely to be **minor** in deep waters and can be (partially) addressed by siting and manoeuverability of facilities, as expressed above. However, the size of an aquaculture facility is important here, as one that takes hundreds of hectares of space is likely to be more disruptive to habitat use/migrations than one that takes only several hectares.

2) Entanglement issues, while only occasional and sporadic, are likely to be **serious** for marine mammals, including at different scales of small dolphins and pinnipeds to large whales. These can be partially mitigated by keeping lines as taut as possible, as thick and easily detectable as possible, and minimising anchor and buoy lines throughout. Mesh sizes, attention to possibilities of billowing and pinch-points, and other potential hazards to marine mammals need to be assessed and vigilantly controlled against during operations. Constant marine farm maintenance and vigilance are important and need to be (in my opinion) incorporated into any marine farm permits, and then rigorously adopted/enforced. If all mitigation measures are in place, the issues may be changed from **serious** to **minor**.

3) The effects (towards marine mammals) of environmental degradation due to bottom effects and other aspects of potential pollution are presently unknown. Noise pollution is a part of this, as prevalence and timing of support vessels and other activities (such as noise from generators) need to be considered (and minimised whenever possible). Light pollution, while a major concern for marine birds, is probably minor for marine mammals. I urge further study in these realms, while I presently believe that such effects are likely to be **minor** in the open ocean.

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