NIWA
Taihoro Nukurangi

Review of potential NZ sea lion interactions with aquaculture at Port Pegasus/Pikihatiti

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Executive summary

- Port Pegasus supports a small but growing breeding population of New Zealand (NZ) sea lions (*Phocarctos hookeri*), designated as 'Nationally Critical' by the NZ Classification System and 'Endangered' by the International Union of Conservation of Nature. The Stewart Island population was deemed by the 2017 Threat Management Plan to be of special conservation importance due to: its future growth potential; its proximity to pre-human breeding habitat on the mainland; and because it is close to achieving breeding colony status (41 pups counted in 2017, compared with the requirement for 35 pups born annually in 5 consecutive years).

- The Southland Regional Development Strategy has identified Port Pegasus as a potential area for salmon (*Salmonidae*) aquaculture. DOC and MPI requested a review of existing observations of NZ sea lions at Stewart Island and global experiences with aquaculture-otariid (fur seal and sea lion) interactions to inform an assessment of the potential impacts of the proposed fish farm at Port Pegasus on NZ sea lions.

- Annual surveys of pup numbers and distribution confirm that Port Pegasus is the main breeding location of the Stewart Island population. An analysis of tracking data found that reproductive females forage almost entirely within 50 km of Port Pegasus and that the North Arm of Port Pegasus was well-used. A female haul-out site was identified within 1 km of proposed salmon grow-out pens. A non-linear increase in interactions has been observed for fish farms located within 20 km of existing haul-out sites of other otariid species. As such, the potential for interactions between NZ sea lions and the proposed salmon farms at Port Pegasus is extremely high.

- The global review identified potential direct interactions that were consistent across otariids, including: entanglement mortality in nets and intentional harm to 'problem' individuals. Also, some potential indirect effects, including: habitat loss or degradation, visual or noise disturbance and the spread of parasites and disease.

- Some consistently effective measures were identified for minimising direct interactions, including: the use of steel cages, or well-tensioned and maintained predator nets. However, the nature of interactions varied by otariid species and prior experience of NZ sea lion interactions with fish farms is extremely limited. Following best-practise, fish farm operators would need to demonstrate that management systems can be developed to effectively manage all potential direct and indirect interactions with NZ sea lions. Potential interactions with resident females and pups at Port Pegasus that disturb breeding sites or disrupt breeding behaviour are of particular concern.

- The Stewart Island NZ sea lion population is thought to be growing and have ample resources for this growth to continue. Otariids are capable of rapid population growth (10-fold increase over 20 years assuming an Rmax of 0.12—used as a default for otariids) and rapid growth has already been observed in other NZ sea lion populations. An eventual switch to colonial breeding is expected, though the locations of future breeding colonies are difficult to predict. Aquaculture planning at Port Pegasus should consider the implications of a major increase in NZ sea lion numbers and associated changes to demographic composition and behaviour that could dramatically alter the frequency and nature of interactions in future years.

1 Introduction

1.1 New Zealand sea lions

New Zealand sea lions (*Phocarctos hookeri*) (Figure 1-1) are endemic to New Zealand (NZ) and once bred widely around the mainland, the Chatham Islands and the NZ Sub-Antarctic Islands (Collins *et al.* 2014a; Rawlence *et al.* 2016) (Figure 1-2). Mainland populations were extirpated shortly after the first human settlers arrived in the 13th Century (Collins *et al.* 2014b), then remaining Sub-Antarctic populations were decimated by commercial sealing in the 19th Century. Following the cessation of commercial sealing there has been a partial recovery in their numbers and breeding range (Childerhouse & Gales 1998), but the number of breeding locations is still very low (Auckland Islands, Campbell Island, Stewart Island and the Otago Coast) and 98% of the species' pup production occurs at the Auckland Islands and Campbell Island in the NZ Sub-Antarctic (Figure 1-2) (DOC/MPI 2017).

Figure 1-1: New Zealand sea lion at Stewart Island. Photograph by Olly Gooday.

Pup production at the main breeding population at the Auckland Islands has declined by ~50 % since the late-1990s, leading to the species' designation as Nationally Critical within NZ (Baker *et al.*, 2016). Since the early 1990s, we have observed the rapid growth of the Campbell Island population (Maloney *et al.* 2012; Roberts 2014), which now contributes ~30% of the species' reproductive output. Also, since the early 1990s, NZ sea lions have begun to recolonise their historical range on Stewart Island and the NZ mainland. Contemporary accounts indicate that NZ sea lions were abundant at Stewart Island in the early 19th Century and were reported to be breeding (Begg & Begg 1979) and "numerous" around Port Pegasus by Shephard in 1826 (Howard 1940), but disappeared from Stewart Island sometime before 1874 (McConnell 2001; Thomson 1874). The process of recovering their historical breeding range has been slowed by this species' strong tendency for natal philopatry, where individuals choose to breed where they were themselves born (Chilvers & Wilkinson 2008). The Stewart Island population now contributes ~40 pups per annum, or ~1.5% of the total species' reproductive output (Figure 1-3).

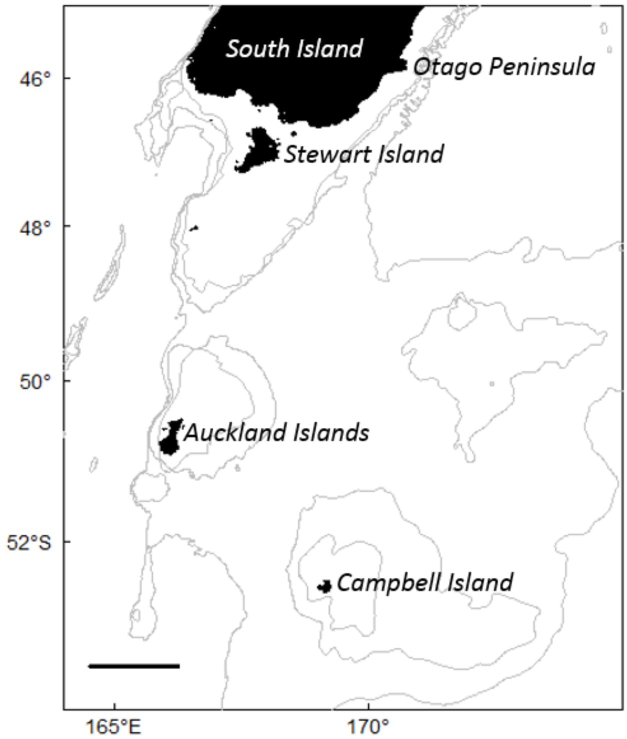

Figure 1-2: New Zealand sea lion breeding locations. Grey lines represent the 200 m, 500 m and 1000 m bathymetric contours; scale bar = 100km.

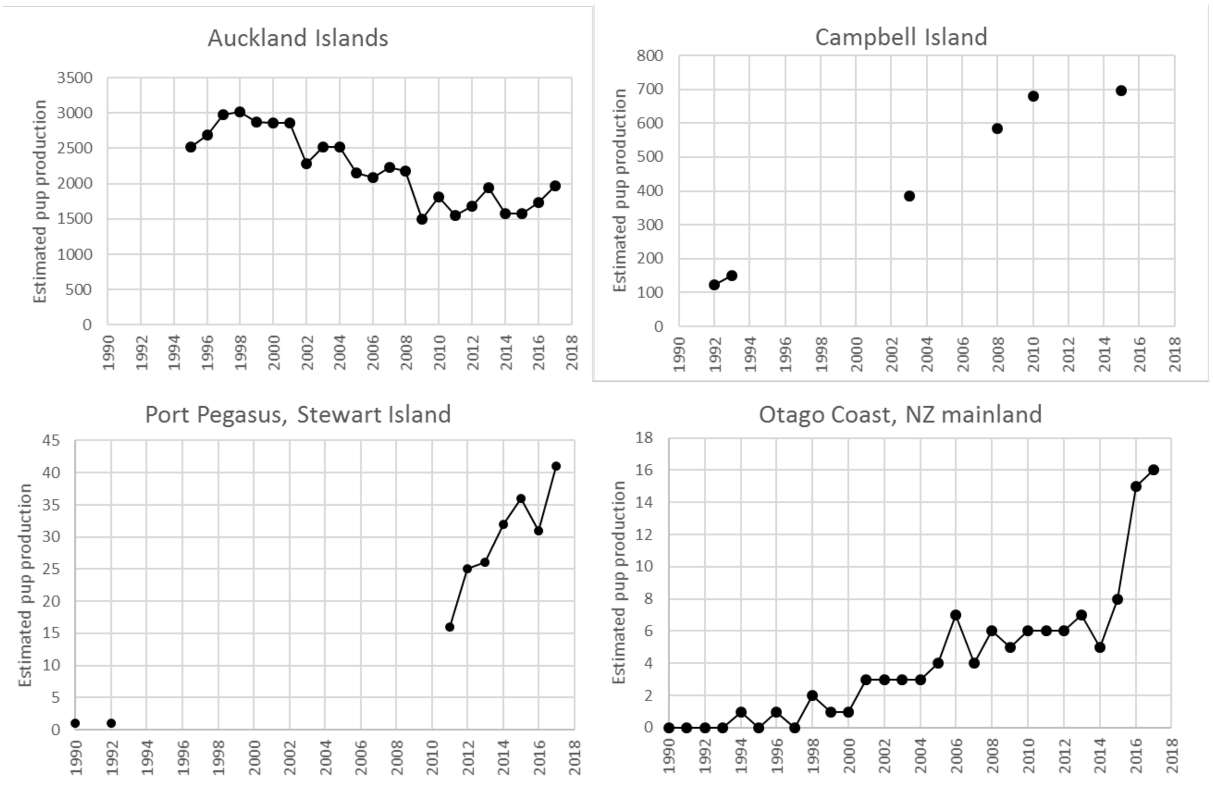

Figure 1-3: Estimates of NZ sea lion pup production by breeding location since 1990.

1.2 Salmon aquaculture at Port Pegasus

The Southland Regional Development Strategy (SoRDS) has identified Port Pegasus as a potential area for salmon (*Salmonidae*) aquaculture. A benthic habitat assessment prioritised locations for salmon farm operations within the North Arm region of Port Pegasus (Fletcher *et al*. 2017) (Figure A-1, Appendix A). This assessment used buffers to avoid areas of hard or coarse-grained substrate that would potentially be ideal habitat for sensitive marine biota. Water current and depth measurements were also used to guide suitable locations for pen sites, which, when combined with the marine biota buffer areas, identified the mid-channel region of Big Ship Passage (west of Pearl Island) to have the greatest potential for farming. Four sites were selected for grow-out pens within Big Ship Passage and a single smolt pen site on the northern coastline of the North Arm (Figure A-1, Appendix A). The site selection process and feed regimes scenarios are described in more detail in Appendix B. A maximum of 16 pens (polar circles with 160 m circumference and 20 m spacing between pens) was considered at each of the four grow-out sites in Big Ship Passage; and a maximum of 8 pens (100 m circumference and 20 m between pens) was considered for the smolt site (Figure A-1, Appendix A) (Fletcher *et al*. 2017). An example of a polar circle salmon pen is shown below (Figure 1-4).

Figure 1-4: Polar circle salmon pens at Macquarie Harbour, Tasmania. Perimeter jump fence and anti-predator netting visible above the surface.

In addition to the benthic habitat assessment by Fletcher *et al*. (2017) referred to above, an assessment of natural character, landscape and visual amenity effects (Bentley 2017), an assessment of benthic effects, a hydrodynamic study (Knight et al. 2017) and an economic assessment (NZIER 2017) are underway or approaching completion. In addition, DOC and MPI have requested an assessment of the potential impacts of aquaculture development on NZ sea lions at Port Pegasus, Stewart Island, including:

- **A review of global fish farm impacts on sea lions and fur seals**

- A review of NZ and international literature and expertise on the potential impacts of finfish farming operations on otariids; and
- A review of potential management (including mitigation measures) with relevance to the case of salmon farms and NZ sea lions at Port Pegasus.

- **A review of the spatial distribution, behaviour and ecology of NZ sea lions at Port Pegasus.**
  - Analyse available data and anecdotal information on their distribution, foraging and behaviour at and around Port Pegasus
  - Summarise relevant information with respect to the ecology of NZ sea lions around Port Pegasus, including dietary studies and information with respect to prey availability
- **Advice and recommendations with respect to:**
  - The potential impacts of fish farming on NZ sea lions at Port Pegasus and *vice versa*;
  - Mitigation measures to address potential interactions; and
  - Further science, technical advice and actions to address key gaps in our understanding with respect to the above.

2 Sources of information

2.1 NZ sea lions at Stewart Island

The main sources of information for reviewing the population size, spatial distribution and ecology of NZ sea lions at Stewart Islands were:

- Reports of annual surveys of the spatial extent and magnitude of pupping at Stewart Island (e.g., Chilvers 2016).
- Raw foraging location data obtained from a tracking study of breeding-age females at Stewart Island in 2012 and 2013 (Chilvers 2014).
- Information from dietary studies of NZ sea lions at Stewart Island and Snares Islands (Lalas *et al.* 2014; Lalas & Webster 2014; McConnell 2001).
- A recent survey of the spatial distribution and abundance of NZ sea lion prey species at the Auckland Islands and Stewart–Snares shelf (Roberts *et al.* 2017).

In addition, context with respect to NZ sea lion population dynamics and their threats was obtained from a review of the literature on NZ sea lions and other otariids (e.g., Roberts & Doonan 2016). Of the four known breeding locations (Auckland Island, Campbell Island, Stewart Island and Otago Coast), there is probably least information from Stewart Island, though species' traits with respect to breeding behaviour, the demographic rates that typically drive population change, may also apply to the Stewart Island population.

2.2 Review of interactions between fish farms and otariids

The primary sources of information for reviewing otariid-fish farm interactions include:

- Consultation with experts in fish farm-otariid interactions
  - Martin Cawthorn (marine mammal scientist, Cawthorn & Associates), 8th July 2017
  - Mark Gillard (environmental compliance manager, New Zealand King Salmon Co. Ltd), 10th July 2017
  - Mary-Anne Lea (marine mammal scientist, University of Tasmania), 28th July 2017
  - Tommy Foggo (Southland manager, Sanford Ltd.), 14th August 2017
- Consultation with attendees of a Southland Aquaculture Reference Group (SARG) meeting, 11th July 2017
- Published literature with respect to fish farm-otariid interactions:
  - Technical reports
  - Management plans
  - Peer-reviewed journal articles
- Statement of evidence to the Board of Inquiry considering NZ King Salmon Co. Ltd's requests to change the Marlborough Sounds Resource Management Plan.
  - Andrew Baxter (Marine Technical Advisor, Department of Conservation)
- Habitat assessments of Port Pegasus
  - Benthic habitat assessment of North Arm, Port Pegasus (Fletcher *et al.* 2017)

3 NZ sea lions at Stewart Island

3.1 Conservation context

NZ sea lions are currently classified as “Nationally Critical” within NZ (Baker *et al.* 2016) and “Endangered” by International Union for Conservation of Nature (IUCN) (Chilvers 2015). These classifications were based on low overall numbers of mature females, few breeding colonies (breeding colonies are defined as populations with >35 pups per year for each of 5 consecutive years, i.e., not a reference to colonial or non-colonial breeding strategy) (DOC/MPI 2017) and the rapid decline of the main breeding population at the Auckland Islands since the late-1990s (Figure 1-3).

A Threat Management Plan (TMP) was recently developed for NZ sea lions. This was informed by extensive expert and stakeholder consultation and a quantitative risk assessment of threats to NZ sea lion populations (DOC/MPI 2017; Roberts & Doonan 2016). The vision of the 2017 NZ sea lion TMP was to:

> “*promote the recovery and ensure the long-term viability of New Zealand sea lions, with the ultimate goal of achieving ‘Not Threatened’ status*” (DOC/MPI 2017).

The 2017 NZ sea lion TMP stated the following *species-level* objectives, to:

1. Halt the decline of the New Zealand sea lion population within 5 years; and

2. Ensure the New Zealand sea lion population is stable or increasing within 20 years, with the ultimate goal of achieving 'Not Threatened' status (DOC/MPI 2017).

With respect to achieving a 'Non-Threatened' status, the following requirements would need to be met:

- A stable population trend across the species;
- More than 20,000 mature individuals; and
- More than the current two breeding populations/colonies (currently at Auckland Islands and Campbell Island) (DOC/MPI 2017).

The Stewart Island population is close to achieving breeding colony status—41 pups were counted here in 2017 (Figure 1-3) compared with the annual threshold of 35 pups. As such the continued recovery of the Stewart Island population would be required to meet the vision and species-level goals of the NZ sea lion TMP. As such, human threats to the Stewart Island breeding population that could jeopardise the progression to non-threatened status should be avoided. Adult female and pup survival were highlighted by the TMP risk assessment as key demographic rates affecting population change by the TMP risk assessment (Roberts & Doonan 2016).

The Stewart Island population is currently too small to make a major contribution to meeting the first of the TMP species goals (listed above) within 5 years, though it was deemed by the 2017 TMP to be of special conservation importance due to: its intrinsic growth potential over longer time scales (i.e. to meet the second species-based goal) (also see Appendix C) and; its potential to safeguard/speed the recovery of the pre-human mainland breeding range due to its proximity to the mainland. In the context of the evident instability of population numbers at the main Sub-Antarctic Islands breeding colonies (Figure 1-3), the Stewart Island and NZ mainland sea lion populations are arguably of disproportionate importance to the future recovery of this species.

In addition, the TMP stated the following *population-level* objectives specifically for the Stewart Island population, which aim to facilitate population growth to achieve breeding colony status:

1. Annual pup counts remain at a number higher than 35 for 5 years in a row, qualifying Stewart Island/Rakiura as a new breeding colony;

2. Continued increase in number of pups born to enable colonial breeding behaviour;

3. No deliberate human-caused mortality (e.g., shootings); and

4. Increased public interest and involvement in the conservation of sea lions (DOC/MPI 2017).

With respect to the second population objective, NZ sea lions and other sea lion/fur seal species favour non-colonial breeding at low population size. Breeders then coalesce into colonies once a threshold population size is exceeded. This shift in breeding strategy is thought to protect vulnerable pups from harassment by males and predators whilst mothers are foraging at sea (Campagna *et al.* 1992; Cassini 1999). The growing NZ sea lion population at Campbell Island switched to colonial breeding once the breeding population was sufficient to produce 150-400 pups (Roberts 2014), compared with the current annual production of ~40 pups at Stewart Island.

The main perceived threats impacting on recolonising populations on the NZ mainland (e.g. commercial set-net fishery related mortality; deliberate human mortality; pollution-related entanglement; and male aggression) have different characteristics to those affecting the larger Sub-Antarctic populations (bacterial disease, food availability, commercial trawl mortality), caused by their increased overlap with human activity. However, the Stewart Island population is still the least well-understood in terms of the demographic drivers of population changes (e.g., the relative importance of pup survival versus adult survival or breeding rate) or of key external threats likely to be impacting on this population (Roberts & Doonan 2016).

3.2 Spatial distribution & ecology

3.2.1 Population size & demographic composition

Since the confirmation of a small breeding site at Port Pegasus in 2011, field studies on NZ sea lions at Stewart Island have focussed on breeding females and their pups (Chilvers 2011). The initial increase in pup counts from 16 in 2011 to 26 in 2013 (Figure 1-3) was thought to relate to an increase in search effort of areas used by mothers and pups rather than an increase in numbers (Chilvers 2013). The 2013 count was considered a good estimate of total pup production at Stewart Island in that year (Chilvers 2013), and the increase in pup production estimates since then up to 41 pups in 2017 (DOC unpublished data) suggests the Stewart Island breeding population is currently growing.

Applying a pup multiplier of 4.5 (calculated for a growing NZ sea lion population; Roberts 2014) to an annual production of 40 pups, gives an estimated population size of ~180 individuals excluding pups, of which approximately half would be females. The population of males, which will also include individuals born on Sub-Antarctic islands, is probably much greater than this (Chilvers 2016).

3.2.2 Spatial distribution

All pups counted by annual surveys since 2011 were located around Port Pegasus. These surveys have focused search effort in and around Port Pegasus (i.e. not all of Stewart Island) though in some years effort was extended to include adjacent coastal areas, informed by anecdotal reports from the public. The author is not aware of any direct observations of NZ sea lion pup births at Stewart Island, but given the concentration of pup observations around Port Pegasus in autumn (~3 months after their probable pupping date), it is likely that these pups were born in the Port Pegasus area. However, a pup survey conducted in January 2016 (approximately a month after probable pupping) found only two pups around Port Pegasus and concluded that they could be born outside of Port Pegasus before being moved in by mothers around February (Laura Boren unpublished data).

The pup survey was extended beyond Port Pegasus to Lords River and Port Adventure in 2013, but no mothers or pups were found (Chilvers 2013). Martin Cawthorn (pers. comm.) has regularly seen NZ sea lions at Lords River, which was reported to be a breeding site in the early 19th Century (Stark 1986). There have been a few reports of pups sighted away from Port Pegasus in recent years, e.g., one at Codfish Island and another in Paterson's Inlet, though Chilvers (2013) deemed that "the majority of the Stewart Island habitat is not suitable as an area that mothers and their pups would haul out" on the basis that they would be difficult for pups to access. It is likely that breeding age females at Stewart Island primarily use Port Pegasus as a place for pupping, pup-rearing and as a base for foraging at sea.

Raw tracking data were obtained for 12 breeding age females fitted with GPS or SPLASH data archiving tags (that transmit to the Argos system) in the Port Pegasus region at Stewart Island in 2012 and 2013 (Chilvers 2014). All except one was confirmed to be with a pup in that year (Table 3-1). Foraging location observations were entirely from autumn months only (March to June), corresponding with the midway point in the typical lactation period, which extends ~10 months after pupping in December/early January. This small sample from a limited period indicates that lactating females almost entirely forage within 50 km of Port Pegasus (Figure 3-1). Probable foraging hotpots include the waters within Port Pegasus, open water to the south of Port Pegasus and the Titi/Muttonbird Islands to the south-west of Stewart Island. Within the Port Pegasus region, foraging is most concentrated around Pearl Island, Noble Island, Pigeon House and Disappointment Cove, with haul-outs at these and various other locations around both the North and South Arms of Port Pegasus (see Figure 3-1 and Figure 3-2).

The spatial foraging data were replotted excluding females fitted with GPS-tagged females. GPS tags report locational data with greater precision that SPLASH tags, though with greater frequency and, so, the combined spatial foraging distribution would be overly represented by the GPS-tagged females. However, Port Pegasus remained the centre of foraging for lactating female NZ sea lions at Stewart Island, when the GPS-tagged females were removed from the sample (see Figure C-1, Appendix C).

Foraging depth data were collected for some individuals. These data were not analysed for this study, but a previous analysis found they have an average dive depth of ~60 m depth, which is between that of females at Otago Peninsula females (~20 m depth) and comparatively deep-diving females at the Auckland Islands (~130 m depth) (Chilvers 2014). This indicates that a considerable portion of their foraging occurs outside Port Pegasus and this is consistent with the spatial foraging data (Figure 3-1).

Table 3-1: Details of female NZ sea lions from which tracking data were obtained in 2012 and 2013. All except one was confirmed to be with a pup in that season.

						Reported locations by month			
Year	**Flipper tag ID**	**With pup**	**Standard length (cm)**	**Tracking type**	**Tracking ID**	**Mar**	**Apr**	**May**	**Jun**
2012	6064	Y	181	GPS	11645			1 045	
2012	E789	Y	193	GPS	11646			912	
2012	E793	UNK	187	SPLASH	102658			102	
2012	E794	Y	188	SPLASH	102655			690	471
2013	H822	Y	191	SPLASH	76965	22			
2013	H823	Y	172	SPLASH	76963	144	321		
2013	H824	Y	188	SPLASH	89572	59		70	
2013	E788	Y	181	SPLASH	89574	80			
2013	6064	Y	182	SPLASH	98812	117			
2013	H825	Y	188	SPLASH	98810	142	124		
2013	H828	Y	179	SPLASH	102653	111	127	2	
2013	H826	Y	169	SPLASH	102658	138	256		

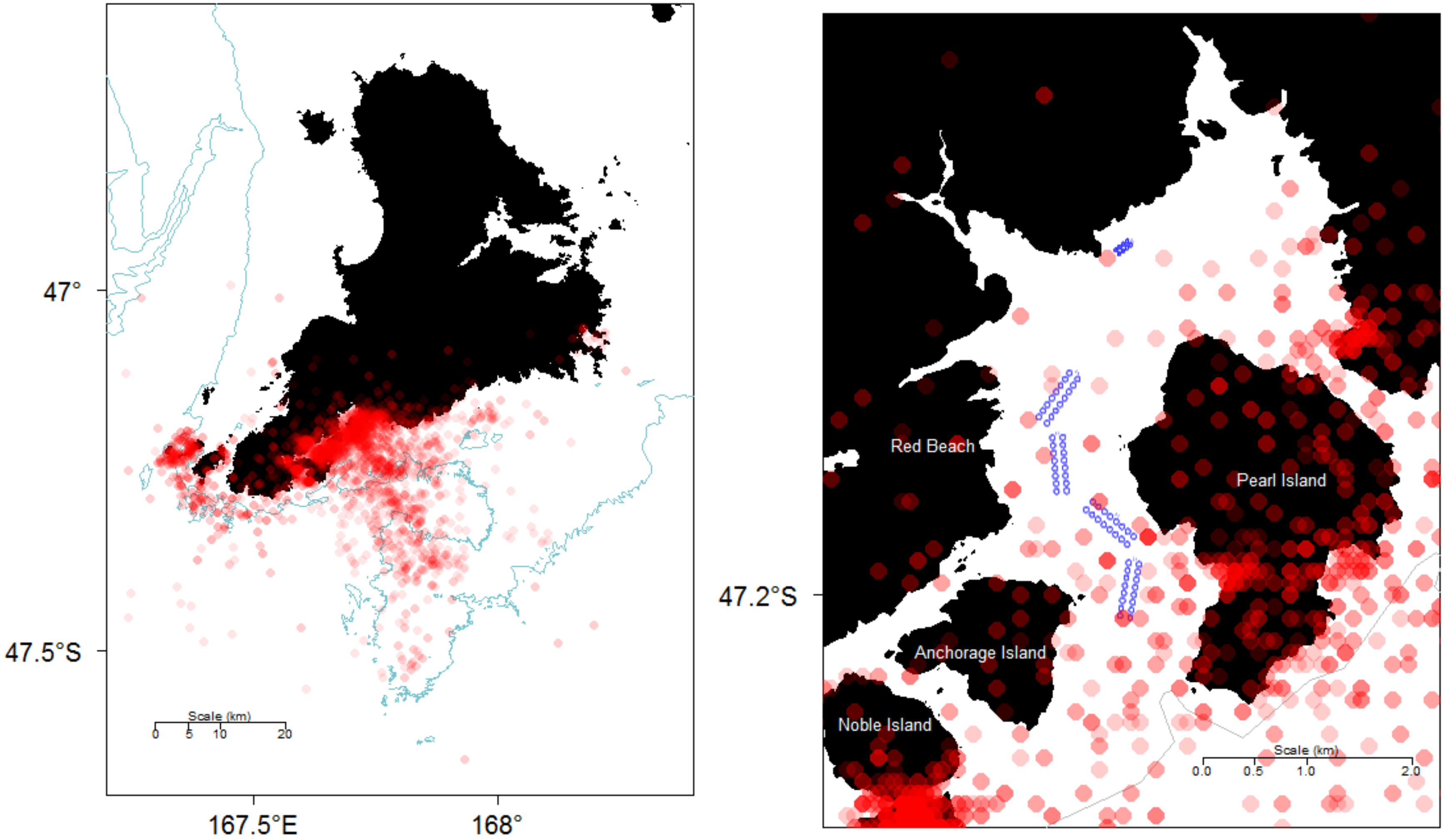

Figure 3-1: Spatial distribution of 12 female NZ sea lions fitted with tracking devices at Port Pegasus in the autumns of 2012 and 2013, including 11 confirmed with pups, at two alternative spatial scales: all of Stewart Island (left); and North Arm of Port Pegasus (right). Smolt and grow-out pens under Scenario 1 (See Figure A-1) are marked on the plot in blue, comprising four clusters of growth pens in the south and a single cluster of smolt pens in the north.

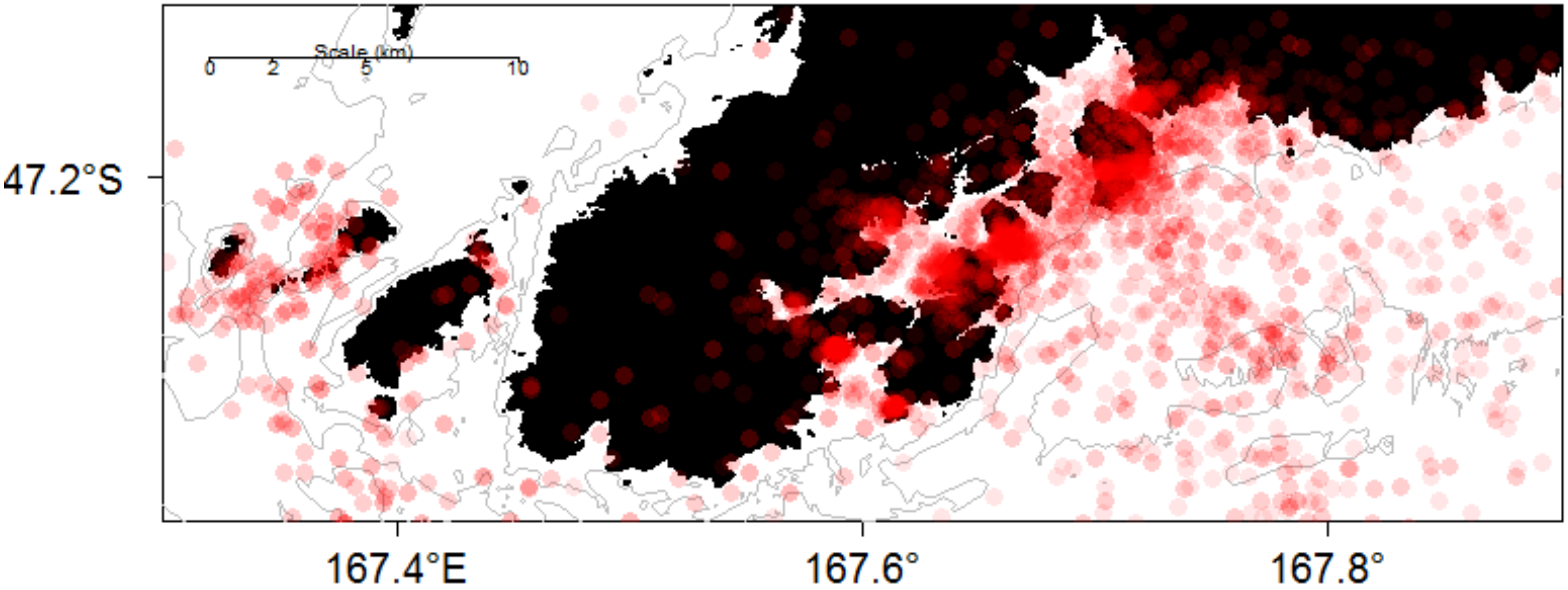

Figure 3-2: Spatial distribution of 12 female NZ sea lions fitted with tracking devices at Port Pegasus in the autumns of 2012 and 2013, including 11 confirmed with pups, at Port Pegasus and Titi/Muttonbird Islands.

3.2.3 Diet and prey resources

Dietary information for the Stewart Island population is limited to two studies of hard part remains from scats collected around Port Pegasus: one from 114 scats collected in October 1999 (McConnell 2001) and another from 179 scats in Jan/Feb 2013 (Lalas *et al*. 2014). The 1999 study was deemed to represent the diet of males only and the main prey species in terms of reconstituted mass were sea perch (*Helicolenus percoides*) (19% *M*), blue cod (*Parapercis colias*) (18% *M*), skate (*Raja sp.*) (18% *M*) and red cod (*Pseudophychis bachus*) (17% *M*) (McConnell 2001). The 2013 study found considerable variability in key prey species depending on sampling site (Lalas et al. 2014). Whereas, redbait (*Emmelichthys nitidus*), blue cod and rough skate (*Raja nasuta*) dominated samples collected on the south coast outside of Port Pegasus (see Figure 3-3) (Lalas et al. 2014). This diet composition was similar to that of NZ sea lions at nearby Snares Islands, for which blue cod, rough skate and redbait each comprised more than 5% of the reconstituted diet mass (Lalas & Webster 2014).

Key prey species vary by NZ sea lion population and this is thought to reflect regional variation in the prey mix available to NZ sea lions (Roberts & Lalas 2015). There is also likely to be strong seasonal variation in the spatial and bathymetric distribution of foraging (as observed in NZ sea lions at the Auckland Islands; Chilvers *et al.* 2013) and of diet composition (e.g. the Otago Peninsula population; Lalas 1997), such that the winter/spring foraging and diet of the Stewart Island population may be quite different from that observed in summer/autumn.

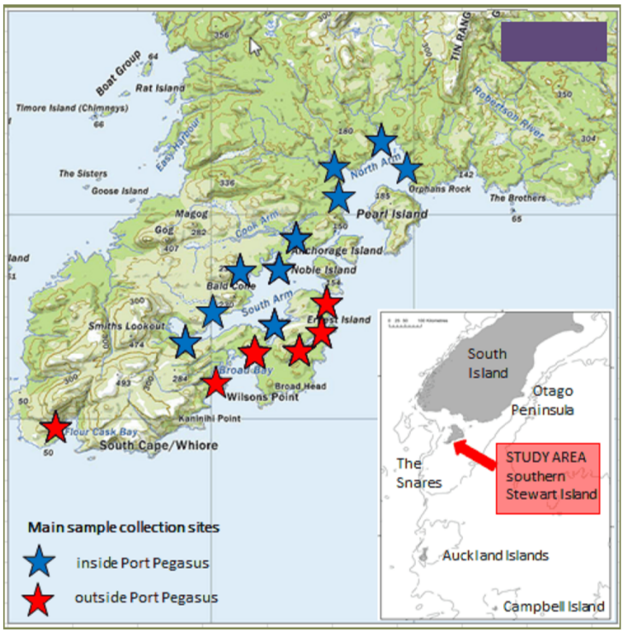

Figure 3-3: Distribution of NZ sea lion scat and regurgitate samples analysed for a dietary analysis by Lalas *et al.* 2014 This figure was taken from Lalas *et al.* 2014.

A survey of the spatial distribution of known NZ sea lion prey species was undertaken around the Auckland Islands and Stewart-Snares shelf area in autumn of 2016, using a bottom trawl and towed camera transects (Roberts *et al.* 2017). At the Auckland Islands, few key prey species were found shallower than 150 m depth and this is the probable reason for the extreme deep-diving of this population (the deepest diving of all otariid populations). This contrasted with the Stewart-Snares shelf, where known NZ sea lion prey including blue cod, barracouta (*Thyrsites atun*) and jack mackerel sp. (*Trachurus* sp.)—all of which were prey species from the 1999 diet study at Port Pegasus (McConnell 2001)—are all abundant shallower than 150 m, where they should be highly available to foraging NZ sea lions (Figure 3-4). In addition, hoki (*Macruronus novaezelandiae*) and southern arrow squid (*Nototodarus sloanii*), both known prey of the Auckland Islands population, were also abundant over deeper slopes, but still accessible to Stewart Island NZ sea lions (Roberts *et al.* 2017). As such, there appears to be ample food resources for continued growth of the Stewart Island population if other potential threats such as disease, deliberate human mortality or fishery interactions do not prevent it from fulfilling its growth potential.

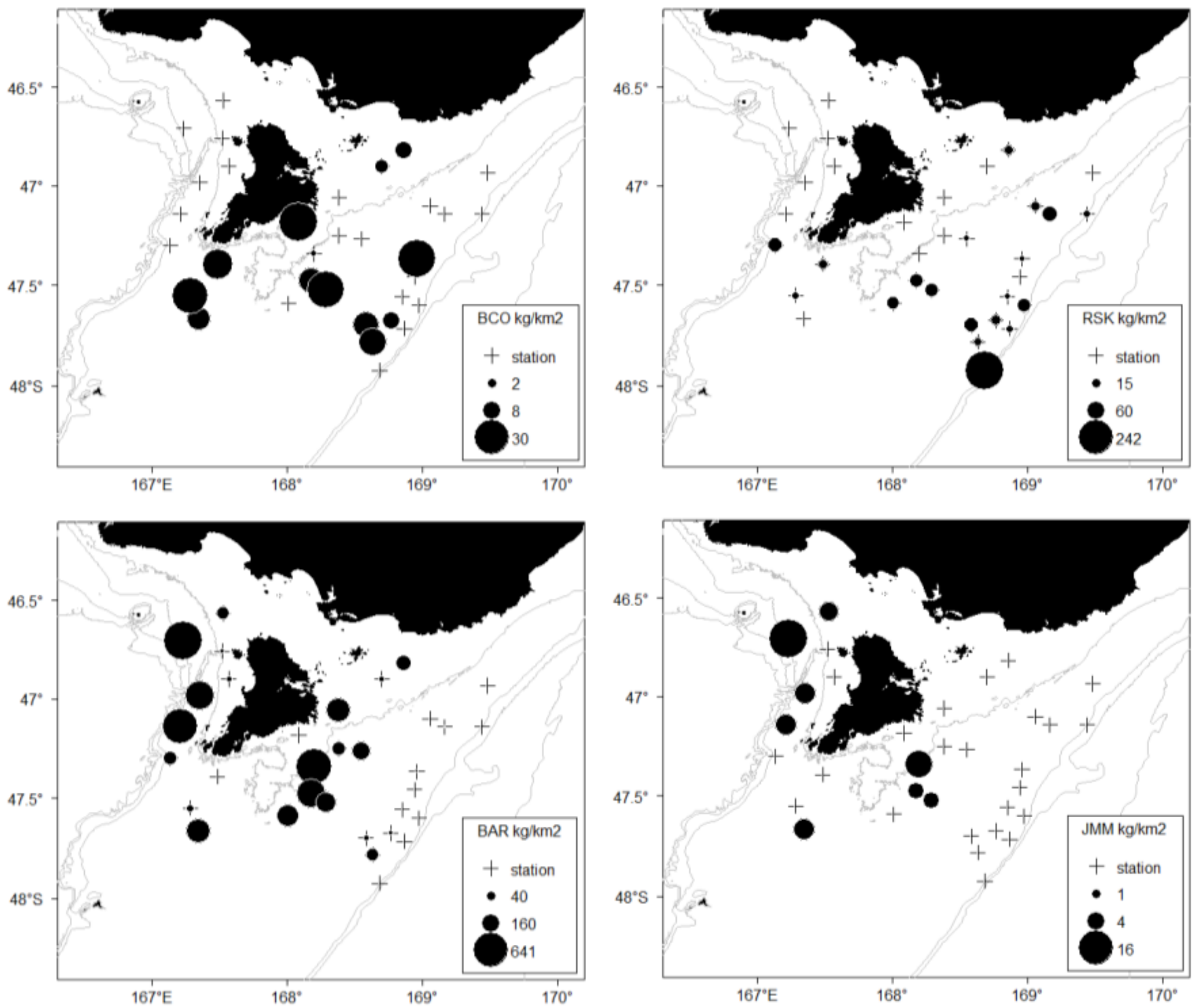

Figure 3-4: Species catch density by bottom trawl station of selected species in the Stewart-Snares NZ sea lion prey survey area. Isobaths represented by grey lines are for 100 m, 200 m, 500 m and 750 m depth. Crosses show the location of tows with zero catch for a species. Species codes are: BCO, blue cod (*Parapercis colias*); RSK, rough skate (*Raja nasuta*); BAR, barracouta (*Thyrsites atun*); and JMM, Chilean jack mackerel (*Trachurus murphyi*). Figure taken from an unpublished MPI report, summarised by Roberts *et al.* 2017.

4 Otariid-aquaculture interactions

Generally, the information with respect to interactions has focused on detrimental impacts to aquaculture rather than on otariids. Furthermore, there is very little information on the long-term and overall effects of aquaculture interactions on otariids (Kemper et al., 2003).

Most of the reviewed reference material related to experiences of interactions between otariids and finfish farms, though interactions between grey seals (*Halichoerus grypus*) (a phocid seal) and salmon farms are also well-documented and are referred to below where relevant. The main case studies were:

- NZ fur seal/kekeno (*Arctocephalus forsteri*) and chinook salmon (*Oncorhynchus tsawytsha*) farms around NZ (Stewart Island, Marlborough and Banks Peninsula);
- NZ fur seal, Australian fur seal (*Arctocephalus pusillus doriferus*) and Australian sea lion (*Neophoca cinerea*) around South Australia and Tasmania;
- Steller sea lions (*Eumetopias jubatus*), California sea lion (*Zalophus californianus*) on the Pacific Coast of Canada and the US; and
- South American sea lion (*Otaria flavescens*) and South American fur seal (*Arctocephalus australis*) along the coast of Chile.

NZ sea lions are occasionally observed from fish farms in Big Glory Bay, Stewart Island, where they were described as "disinterested" in salmon farms using steel cages (pers. comm. Tommy Foggo), though their interactions with aquaculture operations are generally poorly characterised. There is still no direct experience of interactions with breeding female and pup NZ sea lions and the precise nature and aggressiveness of interactions is known to vary by demographic grouping (Kemper *et al.* 2003). The characteristics of interactions are also known to vary by species (Kemper *et al*. 2003). Gregarious California sea lions are increasing in numbers on the coast of British Columbia, Canada, where interactions with fish farms have been much more aggressive than of native Steller sea lions, damaging farm facilities and threatening employees and divers (Cermaq 2012). Nonetheless, some generalisations with respect to the nature of interactions and of the effectiveness of mitigation measures could be drawn and may apply to otariids in general.

4.1 Characterisation of interactions

Salmonid farms are known to be particularly attractive to otariids and interactions occur at most if not all operations that overlap with the distribution of fur seal or sea lion species (Kemper *et al.* 2003). Otariids may use a variety of methods to gain access to stock, including: breaking holes in nets (often targeting poorly maintained areas in netting); charging at predator nets to push them into the stock net; use of positive buoyancy to lift the bottom net up to the stock net; sitting on pontoons; using currents at ebb and flow tides to facilitate access to fish; and scrambling over perimeter fences (DAFF 2007; Kemper *et al.* 2003; Vilata *et al*. 2009).

Aspects of these interactions that could be **detrimental to otariids**, include direct effects:

- **Entanglement or entrapment within anti-predator nets or between nets** leading to injury or suffocation and death. Mortalities of Australian fur seals occurred due to entanglement in predator nets or as seals became trapped between the predator net and the stock net (Kemper *et al.* 2003).
- **Vessel strike by boats operating on or near the fish farm.**
- **Intentional harm including illegal killing** of 'problem' individuals prompted by real or perceived competition for space or fishery resource (DAFF, 2007).

The potential indirect effects are less will understood and include:

- **Habitat loss/degradation** through increased sedimentation and local eutrophication. Waste feed and faeces will tend to collect on the seabed under and immediately surrounding fish pens. Associated increases in organic matter will then impact benthic habitat (FRS 2004; Würsig & Gailey, 2002).
- **Changes in trophic interactions & energy budgets** (Clement, 2013; Würsig & Gailey, 2002).
- **Displacement from foraging habitat** (Clement, 2013; NOAA, 2013)
- **Modified behavior of otariids** and increased dependence on fish farm interactions for sustenance. New haul-out sites will often appear close to aquaculture facilities of otariids attracted by scent trails and visual cues including birds that flock to salmon pens to eat the fish feed (pers. comm. Mary-Anne Lea, Martin Cawthorn). There may be an associated loss of familiarity with natural foraging grounds.
- **Attraction to artificial lighting** (Clements, 2013).
- **Discharge of medicines and antifoulants.** A variety of medicines are used to maintain fish health with unknown effects on resident otariids. The application of antibiotics (which may still be used occasionally in New Zealand on a case-by-case basis) to treat bacterial infections has declined in recent years due to effective vaccination programs (FRS 2004, NOAA 2013). Likewise, antifoulant chemicals are largely being replaced with onshore de-fouling and mechanical methods (NOAA 2013).
- **Transfer of parasites and disease between stock, wild fish & otariids.** Several studies have found evidence for transfer of disease between wild and farmed fish (reviewed by Peeler & Murray 2004). Chemical therapeutants are used to control sea lice and other external parasites (not used in New Zealand). These are administered by immersion or via medicated feed and have toxic effects on all crustaceans (including zooplankton) near fish farms, some of which could perform key ecosystem functions or be prey of otariids (NOAA 2013; Tett 2008). Disease transfer to NZ sea lions is a particular concern, given that a protracted outbreak of *Klebsiella pneaumoniae* is likely to be the main cause of mortality in NZ sea lions pups at the Auckland Islands (DOC/MPI 2017). The transfer of disease between stock, wild fish and otariids (in either direction) is poorly understood and will be the subject of a Ph.D. study based at the University of Tasmania (pers. comm. Mary-Anne Lea).
- **Noise, visual and physical disturbance to otariids.** NZ sea lions have a preference for haul-out sites that are distantly located from human activity. The effects of noise pollution are typically considered for cetaceans and are more likely to be ignored for otariids. Stewart Island breeding mothers with pups are likely to be most sensitive to disturbance given their cryptic tendencies on land.

There may also be some positive effects for otariids. Fish farm activity and the loss of feed to surrounding waters will attract wild fish and megafauna, which may then be predated by otariids. For example, salmon farms around Marlborough, NZ attract barracouta (pers. comm. Mark Gillard), a known prey species of NZ sea lions (Augé *et al.* 2011).

Aspects of these otariid-aquaculture interactions that are **detrimental to aquaculture** include:

- **Economic loss associated with loss of or stress-effects to stock.** Otariids can cause loss of fish through direct predation, injury and escape through bite holes in the grow-out pen nets. Fish that become stressed through the presence of otariids often exhibit slower growth rates and increased disease susceptibility (Cermaq, 2012; NOAA, 2013). Sepúlveda (1998) estimated a total loss of 3.4 thousand tonnes of farmed salmon across the 10th Region of Chile in 1997 due to attacks by South American sea lions. This was equivalent to US$8.5 million at that time.
- **Economic loss associated with damage to nets** caused by seals attempting to gain access to fish pens or from biting fish through netting. The costs of maintaining nets may be even higher than of loss to stock—Brunetti *et al.* (1998) estimated an annual cost including loss of stock and net/gear maintenance of about US$21 million.
- **Bites/stress for workers** maintaining stock, pens, anti-predator gear/devices or removing otariids from nets (Goldsworthy *et al.* 2009). Bites from otariids typically have high infection rates and can require hospital treatment.

4.2 Mitigation measures

Measures shown to be effective for minimising or mitigating negative interactions include:

- **Siting fish farms away from pre-existing haul-out sites and foraging grounds**. Studies have reported a non-linear increase in interactions with increasing proximity to existing sea lion and fur seal haul-out sites (Pemberton & Shaughnessy 1993). Farms within 20 km of known haul-outs were predicted to suffer 10 times as many attacks from Australian fur seals as those 40 km away (Pemberton & Shaughnessy 1993) (Figure 4-1). Buffer zones are used in South Australia to minimise interactions with Australian sea lions, set to 5 km for small breeding populations (<70 pups) and 15 km for large breeding populations (70+ pups) (Marine Mammal–Marine Protected Area Aquaculture Working Group 2004), though Australian sea lions are capable of foraging greater distances than this (Goldsworthy *et al.* 2009) (as are NZ sea lions at Stewart Island; Figure 3-1). Goldsworthy *et al.* (2009) recommended siting fish farms away from critical foraging habitat and movement corridors identified from tracking studies, focussing on the most important demographic groups.
- **Prompt removal of dead fish (‘morts’) from pens.** This minimises the spread of disease and reduces interactions of otariids attempting to bite dead fish through the bottom of the pen (DAFF 2007).
- **Predator nets.** A good review of best practice with respect to predator net configuration and maintenance for minimizing otariid interactions is given by Baxter (2012) and McConnell & Pannell (2014). Well-tensioned and maintained (anti-)predator nets are widely regarded among the best methods for reducing otariid interactions with finfish farms. A 2 m buffer area between predator nets and grow nets was recommended by Stewardson *et al*. (2008). Poorly maintained, baggy predator nets can cause entanglement mortality of otariids (Kemper *et al.* 2003). Appropriate mesh sizes are species and farm specific. The use of small mesh size (200 mm) has been recommended to reduce entanglement mortality of juvenile NZ fur seals pushing their heads through nets (Baxter 2012), though reducing the mesh sizes will restrict flow rates through fish pens (pers. comm. Mark Gillard). Predator net mesh sizes used

for South American sea lions range from 250-500 mm (Sepúlveda & Olivia 2005). Thicker net twine may also reduce the incidence of entanglement in predator nets (Baxter 2012).

- **Jump fences**. These are commonly used and are located along the perimeter at the join of the predator net (Goldsworthy *et al.* 2009) (see Figure 1-4). Jump fences used in the Marlborough Sounds prevent salmon from leaving and NZ fur seals from entering stock pens (pers. comm. Martin Cawthorn). Marlborough operators use a fence height of 2 m for NZ fur seals (pers. comm. Mark Gillard); fences of 1-3 m are used for South American sea lions (Kemper *et al*. 2003).
- **Steel cages** are effective for preventing otariid access to stock, but are expensive and require low stocking densities (pers. comm. Mary-Anne Lea). These have been used at Big Glory Bay, Stewart Island where they were described as highly effective at reducing both NZ fur seal and NZ sea lion interactions (pers. comm. Tommy Foggo).
- **Electric fencing on farm structures.** This was found to be an effective method in NZ farms, resulting in a 75% reduction in NZ fur seals jumping onto structures to gain access to pens (pers. comm. Martin Cawthorn), but was deemed to be ineffective in the long-run for Australian fur seals in Australia (Kemper *et al.* 2003) and was deemed unreliable in exposed conditions by Goldsworthy *et al*. (2009).
- **Bird/aerial netting** restrict access to otariids able to bypass jump fences (DAFF, 2007) (see Figure 1-4).
- **False bottoms** on grow-out pen nets to restrict access to stock from underneath pens (DAFF, 2007).

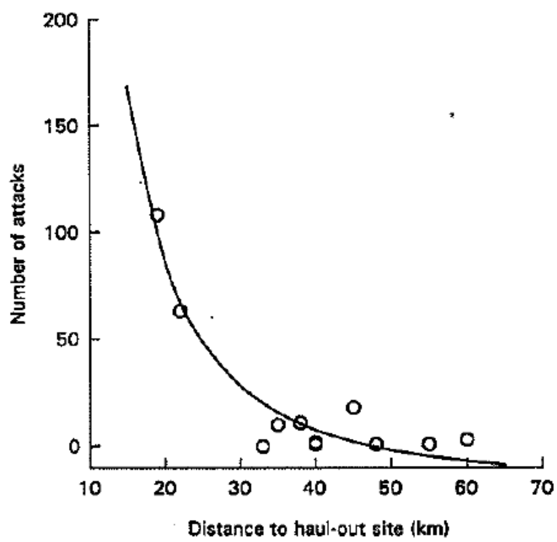

Figure 4-1: Interaction rate between Australian fur seals and salmonid farm nets in Tasmanian fish farms. Figure taken from Pemberton & Shaughnessy (1993).

Mitigation measures generally found to be ineffective for minimising or mitigating negative interactions include:

- **Relocation of otariids**. Relocation trials of male Australian fur seals in Tasmanian farms found that approximately half of subsequent recaptures were of seals released some distance from fish farms and that some 'trap-happy' individuals may be recaptured on numerous occasions (Hume *et al.* 2002).
- **Acoustic harassment devices (AHDs) and tuna bombs.** These were mostly found to be ineffective for South American sea lions (Sepúlveda & Olivia 2005) and typically only have short term deterrent effects on New Zealand fur seals, which rapidly learn to tolerate them (Baxter 2012). Acoustic methods can also include playback of predator vocalisations (e.g. killer whales, Quick *et al*. 2004).
- **Visual deterrents.** A fibreglass model of an orca was not found to be effective for South American sea lions (Sepúlveda & Olivia 2005).
- **Emetics** (Würsig and Gailey 2002).
- **Boat pursuit** (DAFF, 2007).
- **Deliberate shooting of nuisance seals** (Cermaq 2012), rubber bullets, bean bag loads and cattle prods (pers. comm. Helen McConnell).

Operational measures to minimise modifications to benthic habitat include automated feed management systems such as the camera-based systems currently used on NZ fish farms that detect fall-through of feed (pers. comm. Martin Cawthorn, Mark Gillard).

The dynamics of disease transfer between stock, wild fish and otariids are poorly understood and should be a key consideration for NZ sea lions. In addition, there should be consideration of potential spread of diseases from farm workers and this should include planning for suitable human waste management as well as fish farm waste. Measures to prevent the introduction or attraction of pest species will be another means for minimising the potential introduction of diseases to the NZ sea lion population. To minimise physical disturbance, workers should seek to avoid areas commonly used by NZ sea lions, particularly by breeding females and their pups.

4.3 Management plans

Aquaculture planning that follows best-practise will develop and implement management plans describing protocols for minimise the potential for interactions with otariids and other protected species. Previous examples of this include: Predator Management Plans (Cermaq 2012), Marine Mammal Entanglement Protocol or Wildlife Interaction Avoidance Strategies (DAFF 2007) and a Predator Avoidance Plan (Clement 2013). In addition, Clement (2013) recommends the development of best practise guides for noise and artificial lighting. Goldsworthy et al (2009) recommended that any management plans should form part of an accredited Environmental Management Strategy (EMS) that is subject to regular formal assessments. Goldsworthy et al (2009) also recommended:

- Standard measures for recording and evaluating otariid interactions and monitoring of nearby otariid populations to assess any potential fish farm impacts before and after farm establishment; and
- Quantitative trials of any new mitigation techniques and/or management modifications on an adaptive basis.

To achieve the above it will be necessary to develop locally-based expertise in mitigating and managing interactions.

5 Discussion & recommendations

5.1 Probable NZ sea lion interactions and mitigation

Clement (2013) concluded that the most important factor in limiting adverse effects of finfish aquaculture on marine mammals in New Zealand is to avoid overlapping with critical habitats. To date, spatial overlap between finfish farms and critical marine habitat has been quite limited around New Zealand and, as such, impacts on marine mammals have generally been minor so that interactions would only be expected to affect individuals as opposed to whole populations (Clement 2013). This lack of experience is a disadvantage for assessing the potential impacts of proposed fish farm operations on NZ sea lions at Port Pegasus.

Experiences from otariid species indicate a non-linear increase in interactions for aquaculture facilities located within 20 km of existing haul-out sites (Pemberton & Shaughnessy 1993). Given that a breeding female haul-out site was identified on the western side of Pearl Island, within 1 km of the preferred salmon grow-out pen in the North Arm of Port Pegasus (Figure 3-2), interactions with NZ sea lions are likely to be frequent. Note that this does not account for changes in foraging and the likely appearance of new haul-out sites in this area if a salmon fish farm was located in Port Pegasus. Pemberton noted that the significance of distance to existing rookeries is diminished by individuals relocating to haul-outs near to fish farms (Marine Mammal–Marine Protected Area Aquaculture Working Group 2004). The main management restriction to limit interactions between finfish aquaculture and Australian sea lions in South Australia are finfish aquaculture buffer zones, set to 5 km for small rookeries (<70 pups) and 15 km for large rookeries (70+ pups) (Marine Mammal–Marine Protected Area Aquaculture Working Group 2004), though both Australian sea lions and NZ sea lions are known to regularly forage further than this. However, the author understands there are few if any other suitable locations for salmon grow-out pens within Port Pegasus that would allow appropriately-sized buffer zones for minimising interactions.

Small, isolated populations such as the NZ sea lion population at Port Pegasus may be more vulnerable to detrimental interactions with fish farms (Clement 2013). While small populations are capable of rapid growth, they are also more vulnerable to low levels of anthropogenic mortality (Goldsworthy et al. 2009), the effects of demographic stochasticity (Gabriel & Bürger 1992) and elevated threats relating to non-colonial breeding, such as increased male harassment mortality of pups (Campagna *et al*. 1992). Potential fish farm interactions with resident females and pups at Port Pegasus and that disturb breeding sites or disrupt breeding behaviour are of particular concern. The NZ sea lions' strong tendency for natal philopatry (Chilvers & Wilkinson 2008) means that the recolonisation of this breeding site may take a long time in the event of its extirpation.

Deliberate human mortality was identified as one of the main threats to the recovery of the Otago Peninsula population of NZ sea lions (Roberts & Doonan, 2016). Illegal killing typically by shooting is commonly documented in the literature regarding otariid-fish farm interactions (e.g. DAFF, 2007) and illegal shootings of NZ sea lions have occurred at Stewart Island in the past (McConnell, 2001). The capacity to monitor and police these and other illicit events around Stewart Island is likely to be diminished by its remote location. Third-party monitoring of fish farm operations and NZ sea lion interactions would be an option for developing an independent assessment of whether this could be an issue at Port Pegasus.

Experiences of NZ sea lion interactions with existing fish farms are limited to anecdotal observations of NZ sea lions at Big Glory Bay, Stewart Island (pers. comm. Tommy Foggo). Furthermore, the nature of otariid-aquaculture interactions varies by demographic grouping and species. However, the brief review (above) provides a guide to probable interactions and effective mitigation measures. Some potential negative effects on NZ sea lions (including entanglement mortality in nets and modifications to NZ sea lion behaviour) and potentially effective mitigation measures were identified (e.g., well-maintained predator nets, jump fences and steel cages) (pers. comm. Mark Gillard, Tommy Foggo). Jump fences may also be effective for NZ sea lions, given that they are not so agile as NZ fur seals (pers. comm. Martin Cawthorn).

Any aquaculture development at Port Pegasus or mitigation measures to minimise interactions, however well-designed, may still need to be modified through adaptive management. Given that NZ sea lions are designated as 'Nationally Critical' within NZ (Baker *et al.* 2016) and Endangered by the IUCN, and the TMP objectives aim to promote the continued recovery of this population (DOC/MPI 2017), fish farm developers would need to be confident of avoiding all mortality to NZ sea lions and any potential detriment effects, particularly where they could affect the small resident population of females. They would also need to demonstrate to decision makers that management systems are in place that would effectively manage all potential direct and indirect interactions with NZ sea lions. Goldsworthy et al (2009) stressed the importance of baseline ecological knowledge of otariid populations before aquaculture development, though the required demographic observations were not available to conduct a quantitative risk assessment for this population for the most recent NZ sea lion TMP (Roberts & Doonan, 2016). Advancing key uncertainties with respect to the baseline ecological knowledge of the Stewart Island population of NZ sea lions will be fundamental to underpin a robust management plan for managing fish farm interactions at Port Pegasus.

5.2 Planning for population growth

Recent census results indicate the Stewart Island population is growing and a review of their prey indicated they have ample resources for this growth to continue. If this population was able to grow at the maximum used as a default for otariids (Rmax of 0.12; Wade 1998), then a 10-fold increase in females would be possible within 20 years (Figure D-1, Appendix D). Rapid population growth has already been observed of NZ sea lions at both Campbell Island and the Otago mainland (see Figure 1-3). In the event of continued population growth an eventual switch to colonial breeding is expected, though the locations of future breeding colonies are difficult to predict. The associated changes in NZ sea lion numbers, demographic composition and behaviour should all be major considerations for fish farm planning at Port Pegasus.

5.3 Research and data needs

The Stewart Island population is probably the least well-understood in terms of demographic causes of population changes and key population threats (Roberts & Doonan 2016), though deliberate human mortality is known to be a problem (DOC/MPI 2017). It is recommended that sufficient resighting information of marked individuals is collected to inform the development of a demographic model for assessing the population consequences of anthropogenic sources of mortality. This would also allow the assessment of mortality thresholds beyond which it would not be possible to achieve the TMP population goals.

In addition, only a small sample of tracking data has been collected to date and all from the autumn period. Their foraging is likely to be seasonally variable based on observations from other populations (Chilvers *et al.* 2013). For example, interaction of South American sea lions and of male Australian fur seals in salmonid farms was seasonal, with most seals trapped during winter (Hume *et al.* 2002; Vilata *et al.* 2010). It is recommended that foraging studies are conducted at other times of the year to assess the likelihood of interactions outside of autumn months. In addition, tracking studies of other demographic groups including males and juvenile/non-breeding females would allow a more complete assessment of potential overlap with proposed fish farms.

Given the precarious conservation status of this species, it is recommended that a more in-depth study is undertaken building on this review, to inform the formulation of best-practices that could be followed to ensure that any negative impacts on NZ sea lions would be kept to an absolute minimum.

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7 Glossary of abbreviations and terms

AHD	Acoustic Harassment Device
IUCN	International Union of Conservation of Nature
NZ	New Zealand
SARG	Southland Aquaculture Reference Group
SoRDS	Southland Regional Development Strategy
TMP	Threat Management Plan

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Appendix A Location of proposed fish farm operations

Figure A-1: Location of salmon farm grow-out and smolt pens proposed under Scenario 1. Figure reproduced from Boffa & Miskell (2017).

Appendix B Explanation of farm site selection and production scenarios

Selection of potential farm areas

Results of the benthic habitat assessment were used to prioritise potential locations for finfish farming operations within the Port Pegasus North Arm area. Circular exclusion 'buffers' were placed around areas of hard substrate or coarse-grained sediments (100 m radius) and areas containing potentially sensitive taxa (250 m radius), identified through sonar imagery and drop-camera transects. Larger exclusion zones were used for potentially sensitive taxa as their exact densities and distributions are unknown.

To provide additional guidance on suitable locations for potential farm sites, an Index of Suitable Location (ISL) for finfish farming was calculated for the entire North Arm area, based on depth and water current data. Results of the ISL analysis indicated that mid-channel areas in Big Ship Passage have the greatest potential for farming, when taking into account exclusion buffers and water depth.

Four potential farming (grow out) areas (c. 10 h each) were subsequently selected within Big Ship Passage (f1, f2, f3 & f4), along with a smaller smolt growing area (c. 1.3 h) at the northern coastline. The smolt farm location was selected as it provided some separation from grow-out areas, a feature that was requested during discussions with industry. A maximum of 16 x 160 m circumference pens (two rows of eight pens, c. 20 m spacing between pens) was considered at each of the four potential farming areas. A maximum of 8 x 100 m circumference pens (two rows of four pens, c. 15 m spacing between pens) was considered for the smolt growing area.

Depositional modelling and feed inputs

As an indicator of likely finfish production capacity within the North Arm area, varying feed input and cage configuration scenarios (a, b, c & d) were modelled across the four farming areas using DEPOMOD v 2.2. Two sets of scenarios were modelled (1 & 2), based on the farming areas operating in a similar way to either low-flow or more dispersive (high-flow[1]) sites within the Marlborough Sounds. This modelling was undertaken to test two very different biophysical response regimes to varying feed inputs.

Maximum feed inputs per pen for each farm area were based on preliminary DEPOMOD assessments for a range of feed inputs for a single pen at each farm area (131 - 400 t). Feed inputs that resulted in maximum depositional rates of ~6 kg m^{-2} yr^{-1} at the net pen edge were used for DEPOMOD assessments for the low-flow farm scenarios. Feed inputs that resulted in maximum depositional rates of ~13 kg m^{-2} yr^{-1} at the net pen edge were used for DEPOMOD assessments for the high-flow farm scenarios. These levels of deposition are predicted to result in c. ES 5 conditions if the effects of

[1] This does not suggest that farm sites are 'high-flow', rather that some of the sites may be 'low-flow sites with episodic wave action' which may have a mitigating effect on benthic enrichment. The magnitude of that potential beneficial effect is currently unknown. The use of the high-flow assumption is for comparison purposes only, and does not suggest that the potential effect from waves would be of similar magnitude as high-flow tidal currents in the Marlborough Sounds. The 'high-flow' based scenarios and their associated potential production figures should therefore be interpreted with caution.

the farm are similar to low-flow or high-flow farm sites in the Marlborough Sounds region, respectively.

A maximum of 64 grow-out pens (16 pens per area) across the four farm areas were assessed in the modelling, so maximum production was associated with all pens operating at all farms (Table B-1). Scenarios with lower levels of production were achieved by reducing the number of pens at each of the farm areas. Across the two sets of scenarios (low-flow/high-flow), feed input per pen over a 1-year period varied depending on whether the effects of the farms were modelled as behaving like low-flow or high-flow sites.

As the total number of pens varied across scenarios, the total feed input at each farm area also varied. The feed inputs resulted in scenarios with a range of production levels at each site (~2,800 - 8,000 t production, per annum; Table B-1). The likely production from each scenario was estimated using a feed conversion efficiency (FCE) ratio of 1.7:1.

For the smolt farm, a feed level of 5% of the total feed input across the four grow-out farms was used across the two sets of scenarios (238 - 680 t per annum; Table B-1). Smolt feed was spread evenly across 4, 6 or 8 smolt pens in each scenario, which resulted in feed inputs of 60 - 102 t per pen (per annum).

Table B-1. Farm scenarios and parameters, including feed input per pen (tonnes per annum), number of pens (160 m circumference for grow-out and 100 m circumference for smolt), total feed input and estimated production (tonnes per annum) for the four grow-out areas (f1-f4) and the smolt growing area.

Scenario	Input parameters	Farming area				Grow-out totals	Smolt totals
		f1	f2	f3	f4		
1a	Feed per pen (tonne)	131	131	150	225		64
	Number pens	16	16	16	16	64	8
	Total feed (tonne)	2 100	2 100	2 400	3 600	10 200	510
	Total production (FCE 1.7)	1 235	1 235	1 412	2 118	6 000	
2a	Feed per pen (tonne)	131	131	150	225		63
	Number pens	8	10	14	14	46	6
	Total feed (tonne)	1 050	1 312.5	2 100	3 150	7 613	381
	Total production (FCE 1.7)	618	772	1 235	1 853	4 478	
3a	Feed per pen (tonne)	131	131	150	225		79
	Number pens	6	8	12	12	38	4
	Total feed (tonne)	787.5	1 050	1 800	2 700	6 338	317
	Total production (FCE 1.7)	463	618	1 059	1 588	3 728	
4a	Feed per pen (tonne)	131	131	150	225		60
	Number pens	4	6	8	10	28	4
	Total feed (tonne)	525	787.5	1 200	2 250	4 763	238
	Total production (FCE 1.7)	309	463	706	1 324	2 801	
1b	Feed per pen (tonne)	175	175	200	300		85
	Number pens	16	16	16	16	64	8
	Total feed (tonne)	2 800	2 800	3 200	4 800	13 600	680
	Total production (FCE 1.7)	1 647	1 647	1 882	2 824	8 000	
2b	Feed per pen (tonne)	175	175	200	300		85
	Number pens	8	10	14	14	46	6
	Total feed (tonne)	1 400	1 750	2 800	4 200	10 150	508
	Total production (FCE 1.7)	824	1 029	1 647	2 471	5 971	
3b	Feed per pen (tonne)	175	175	200	300		102
	Number pens	6	8	12	12	42	4
	Total feed (tonne)	1 050	1 400	2 400	3 600	8 450	407
	Total production (FCE 1.7)	618	824	1 412	2 118	4 971	
4b	Feed per pen (tonne)	175	175	200	300		79
	Number pens	4	6	8	10	32	4
	Total feed (tonne)	700	1 050	1 600	3 000	6 350	317
	Total production (FCE 1.7)	412	618	941	1 765	3 735	

Appendix C Additional analysis of spatial foraging distribution

The spatial foraging data shown in Figure 3-1 and Figure 3-2 were replotted excluding two females fitted with GPS tags, which report position more frequently than SPLASH tags, and so may have biased the spatial representation. The change in the overall spatial distribution of foraging was minimal (compare Figure 3-1 and Figure 3-2 with Figure C-1), though Noble Island and the Titi/Muttonbird Islands no longer show up as foraging hotspots. Regardless, Port Pegasus was the centre of foraging for lactating female NZ sea lions at Stewart Island, once GPS-tagged females were removed from the sample.

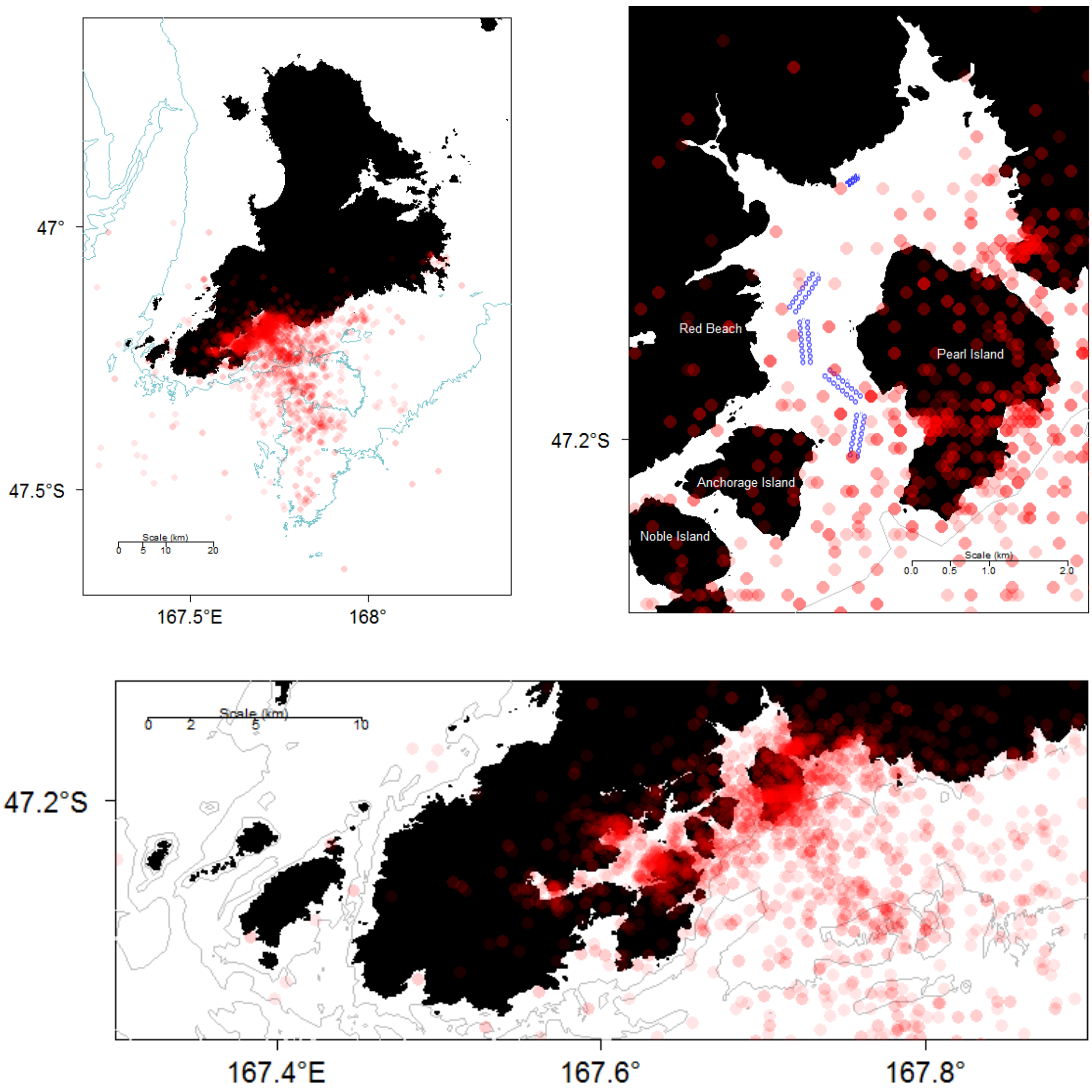

Figure C-1: Spatial distribution of 10 female NZ sea lions fitted with SPLASH tags at Port Pegasus in the autumn months of 2012 and 2013 (excluding two individuals with GPS tags). Both SPLASH and GPS-tagged females are shown in Figure 3-1 and Figure 3-2 for comparison. Candidate locations of smolt and grow-out pens are marked on the top-right hand plot in blue—these are plotted for Scenario 1, which has four clusters of grow-out pens in the south and a single cluster of smolt pens in the north.

Appendix D NZ sea lion population growth scenarios at Port Pegasus, Stewart Island

Under optimal conditions otariid (fur seal and sea lion) populations are by default assumed capable of growing at an Rmax of 0.12 (Wade 1998), equivalent to a lambda of 1.127 (an increase of 12.7 % per annum). Applying this growth rate to an annual pup production of 40 in 2017 (approximating to recent pup counts at Port Pegasus) would result in a pup production of ~440 pups in 2037 (over 20 years). Using the 95% credible interval of the population growth estimated for the Otago Peninsula population (1.053–1.087) (Roberts & Doonan 2016) gave 110-210 pups in 2037 (Figure D-1). Note that Roberts & Doonan (2016) only used pup counts up to 2015 and the minimum count of pups along the Otago Coast including the Otago Peninsula increased markedly in 2016 and 2017 (see Figure 1-3). This indicates that the population growth rate of mature females on the Otago Peninsula was higher than estimated by Roberts & Doonan (2016).

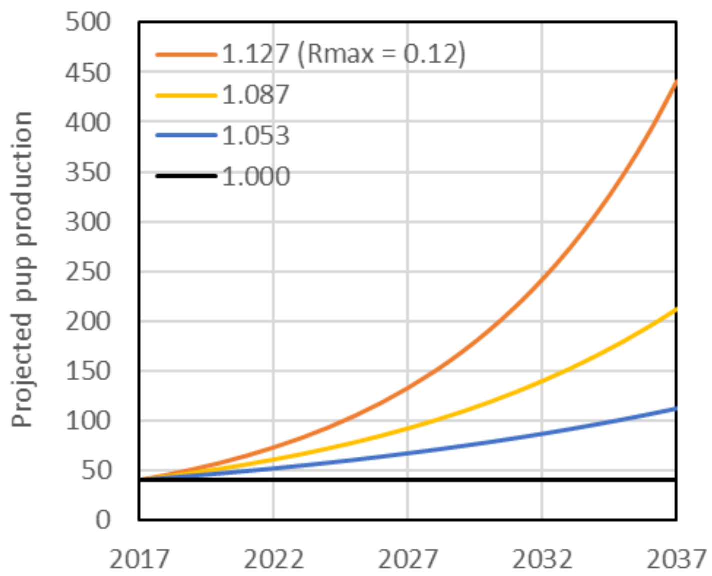

Figure D-1: Projected pup production at Port Pegasus, Stewart Island under alternative population growth scenarios: lambda = 1.127 (consistent with Rmax = 0.12, the default value used for risk assessments of otariids and other pinniped species (Wade 1998)); lambda = 1.053 and 1.087 (95 credible intervals of population growth at the Otago Peninsula (Roberts & Doonan 2016)); lambda = 1.000 (stable population size).

References

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Wade, P.R. (1998). Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science, 14: 1-37.