Habitats of Special Importance to Resident Killer Whales (Orcinus orca) off the West Coast of Canada

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John K B Ford
Fisheries and Oceans Canada, Pacific Biological Station

Amalis Riera
University of Victoria

Mayuko Otsuki
Hokkaido University

Robin Abernethy
Fisheries and Oceans Canada

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John K.B. Ford[1], James F. Pilkington[1], Amalis Reira[2], Mayuko Otsuki[1], Brian Gisborne[1], Robin M. Abernethy[1], Eva H. Stredulinsky[1], Jared R. Towers[1], and Graeme M. Ellis

[1]Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

[2]Earth and Ocean Sciences
University of Victoria
Victoria, BC V8W 2Y2

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Two populations of fish-eating Killer Whales, Northern Resident and Southern Resident, inhabit waters off Canada's west coast. The populations were listed under the Species at Risk Act (SARA) as Threatened and Endangered, respectively, in 2003. As required by the SARA, efforts have since been underway to identify critical habitat for these populations. Partial critical habitat was identified for each of the two populations in the 2011 Resident Killer Whale Recovery Strategy, which included a schedule of future studies to identify additional areas of critical habitat. In this report, we identify two new areas of special importance to Resident Killer Whales that potentially meet the criteria for designation as critical habitat under the SARA. One area includes waters on the continental shelf off southwestern Vancouver Island, including Swiftsure and La Perouse Banks. The other area includes waters of west Dixon Entrance, along the north coast of Graham Island from Langara Island to Rose Spit. Long-term vessel-based field studies and remote passive underwater acoustic monitoring show that both areas are important year-round habitat for Resident Killer Whales, especially for feeding on the whales' primary prey, Chinook Salmon. The biophysical functions, features and attributes of these habitats of special importance are described, and examples of activities likely to result in the destruction of these components of critical habitat are summarized.

Habitats d'importance particulière pour les épaulards (*Orcinus orca*) résidents de la côte ouest du Canada

RÉSUMÉ

Deux populations d'épaulards piscivores, les populations résidentes du Nord et du Sud du Pacifique, vivent dans les eaux qui bordent la côte ouest du Canada. Ces populations ont été inscrites à la *Loi sur les espèces en péril* (LEP) en tant qu'espèce menacée et en voie de disparition, respectivement, en 2003. Depuis, des efforts visant à déterminer l'habitat essentiel de ces populations sont en cours, conformément aux exigences de la LEP. Des habitats essentiels partiels ont été déterminés pour chacune des deux populations dans le cadre du programme de rétablissement de l'épaulard résident de 2011, lequel comptait un calendrier des études futures visant à cerner des zones d'habitat essentiel additionnelles. Dans ce rapport, nous nommons deux nouvelles zones d'importance particulière pour les épaulards résidents qui répondent potentiellement aux critères pour la désignation d'un habitat essentiel en vertu de la LEP. Une de ces zones comprend les eaux du plateau continental au sud-ouest de l'île de Vancouver, y compris les bancs Swiftsure et La Perouse. L'autre zone comprend les eaux à l'ouest de l'entrée Dixon, longeant la côte nord de l'île Graham, de l'île Langara à Rose Spit. Des études sur le terrain à long terme menées sur des navires et la surveillance acoustique passive sous-marine démontrent que ces deux zones constituent un habitat important pour l'épaulard résident à longueur d'année, notamment pour la consommation de la proie principale de l'épaulard, soit le saumon quinnat. Les fonctions, les caractéristiques et les attributs biophysiques de ces habitats d'importance particulière sont décrits, et des exemples d'activités susceptibles d'entraîner la destruction de ces composantes de l'habitat essentiel sont résumés.

1. INTRODUCTION

Two populations of fish-eating Killer Whales (*Orcinus orca*), known as Northern Residents and Southern Residents, inhabit waters off the Pacific coast of Canada (Bigg 1982; Bigg et al. 1990; Ford et al. 2000). These populations have been the subject of numerous field studies over the past 40 years which have been facilitated by visual or photographic identification of individual whales from distinctive natural markings. This effort has provided a complete registry of all members of the Resident populations, which has in turn yielded a detailed understanding of their social organization, life history and population dynamics (Bigg 1982; Bigg et al. 1987, 1990; Olesiuk et al. 1990; Ford et al. 2000; Olesiuk et al. 2005; Ford and Ellis 2014).

The two populations of Resident Killer Whales are small and do not mix despite having overlapping ranges. Each is acoustically, genetically and culturally distinct. Both Southern Resident (SRKW) and Northern Resident (NRKW) populations forage selectively for Chinook Salmon (*Oncorhynchus tshawytscha*) and Chum Salmon (*O. keta*), and their movement patterns appear to be influenced by the availability of these preferred prey species (Ford and Ellis 2006). The Northern Resident population, composed of 290 whales (2014 census; Towers et al. 2015), is found regularly in nearshore waters off northeastern Vancouver Island during summer and fall, though their overall range is considerably greater. The smaller Southern Resident population consisted of 81 whales in 2014 and is commonly found off southeastern Vancouver Island and adjacent inside waters of Washington state, from early summer to late fall.

In 2001, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed SRKWs as Endangered and NRKWs as Threatened due to their small population sizes, low reproductive rates, recent unexplained declines in numbers, and the existence of a variety of anthropogenic threats with the potential to prevent recovery or to cause further declines (COSEWIC 2001). Potentially important threats are reductions in the availability or quality of prey, environmental contamination, and both physical and acoustic disturbance caused by marine traffic and other industrial activities. These listings subsequently became law under Schedule 1 of the Canadian Species at Risk Act (SARA) in 2003. The Endangered and Threatened status of the SRKW and NRKW populations in Canada, respectively, was reaffirmed by COSEWIC in 2008. In the U.S., SRKWs were declared Depleted under the U.S. Marine Mammal Protection Act in 2003, Endangered by Washington State in 2004, and Endangered under the U.S. Endangered Species Act in 2006.

As mandated by the SARA, a team of specialists was assembled in 2004 in order to develop a recovery strategy to promote and facilitate the recovery and eventual de-listing of Northern and Southern Killer Whales in Canada. The goal of the draft recovery strategy that resulted from this process (Killer Whale Recovery Team 2006) is to ensure the long-term viability of Resident Killer Whale populations by achieving and maintaining demographic conditions that preserve their reproductive potential, genetic variation, and cultural continuity. The recovery planning process as dictated by SARA also requires the identification of critical habitat, defined in the Act as habitat that is necessary for the survival or recovery of a listed species, either in the recovery strategy document or in the subsequent action plan to implement the recovery strategy (Environment Canada 2004). Although published information on Resident Killer Whale distribution was available to the recovery team, this was deemed insufficient to identify critical habitat in the recovery strategy in sufficient detail to be biologically and legally defensible for designation under SARA.

To address this gap, Ford (2006) conducted an assessment of the distribution and habitat use patterns of Resident Killer Whales from published and unpublished data sources to identify areas that could be considered critical habitat for these populations. Two habitats of special importance were identified – one for each of the Resident populations – that appeared to meet the requirements for designation as critical habitat under SARA. Both of these areas corresponded to the well-known “core areas” for the two Resident populations (e.g., Bigg et al. 1990). The whales concentrate in these areas, particularly in summer and fall, to intercept migrating Chinook and Chum salmon. For the Northern population, waters of eastern Queen Charlotte Strait and Johnstone Strait off northeastern Vancouver Island were proposed and for the Southern population, Canadian portions of the Southern Strait of Georgia, Haro Strait and Juan de Fuca Strait, as well as certain connecting passes, were proposed. Two additional areas of special importance for NRKWs were identified in Ford (2006), Fitz Hugh Sound and Caamaño Sound, but existing evidence was considered insufficient to support inclusion of these areas in proposed critical habitat at the time

The two proposed critical habitat areas described in Ford (2006) were identified in the final Resident Killer Whale Recovery Strategy and were formally designated as such by a Protection Order under the SARA in 2009 (Fisheries and Oceans Canada 2011). Although these critical habitat areas are identified in the Recovery Strategy, it was recognized that additional areas critical to Resident Killer Whale recovery likely exist but had yet to be documented (Fisheries and Oceans Canada 2011). In particular, the distribution and habitat requirements of both Resident populations in winter and spring were very poorly known, as was the distribution of Northern Resident groups that do not frequent the identified critical habitat area of Johnstone Strait in summer and fall. The draft Action Plan that outlined approaches and activities needed to achieve the population and distribution objectives in the Recovery Strategy (Fisheries and Oceans Canada 2015a) gave a high priority to the identification of additional areas for critical habitat designation and protection.

In this report, we present new information on habitat use patterns of Resident Killer Whales in two areas – 1) off the southwestern coast of Vancouver Island and 2) western Dixon Entrance – that have been identified as having special importance to SRKWs and NRKWs, respectively. We propose that portions of these areas are required to meet the population and distribution recovery objectives of these populations yet are not included within currently designated critical habitats. Habitat use by Resident Killer Whales in these areas is described from long-term boat-based field studies, using photo-identification of individuals and prey fragment sampling to determine diet, as well as passive acoustic monitoring (PAM), by means of autonomous underwater recording instruments. As set out in DFO’s operational guidelines for the description of critical habitat (Fisheries and Oceans Canada 2015b), the functions, features and attributes of the proposed additions to Resident Killer Whale critical habitat are described, as are examples of anthropogenic activities likely to destroy critical habitat.

1.1. LIFE HISTORY, SOCIAL STRUCTURE AND ECOLOGY OF KILLER WHALES

The Killer Whale (*Orcinus orca*) is the largest member of the family Delphinidae and one of the most widely distributed mammals. It occurs in all the world’s oceans and most seas, but is most commonly found in productive coastal waters in high latitude regions. Forney and Wade (2006) estimated total abundance to be at least 50,000 whales, but this is likely far short of the true global abundance. The Killer Whale is the apex marine predator, capable of feeding on a great diversity of prey, from the largest whales to small schooling fish. It has no natural predators. Despite being a generalist predator as a species, different populations of Killer Whales often have highly specialized foraging strategies and diets (Riesch et al. 2012).

Three distinct lineages of Killer Whales have been described in coastal waters of the northeastern Pacific Ocean. These lineages named*, Resident, Transient (*or *Bigg’s)* and *Offshore*, differ in diet and foraging behaviour, acoustic behaviour, morphology, and genetic characteristics (Ford and Ellis 2014). Despite having overlapping ranges, these lineages do not mix and are thus socially and reproductively isolated from each other. Resident Killer Whales prey mainly on fish, particularly salmon, and some squid. Transient Killer Whales specialize on marine mammal prey, though they occasionally kill and eat seabirds and squid as well. There is no evidence from decades of field observations that they feed on fish. Offshore Killer Whales also feed on fish and may specialize on sharks (Ford et al. 1998, 2011; Ford and Ellis 2014). Neither Residents nor Offshores have been observed to prey on marine mammals. These foraging specializations appear to be fixed behavioural traits maintained by cultural transmission within populations.

Field studies undertaken in coastal waters of British Columbia and Washington State since 1973 have yielded much information on the abundance, movements, life history, social structure, behaviour, vocalizations, foraging ecology, and population dynamics of Resident Killer Whales (Bigg et al. 1976[1], 1990; Bain 1990; Olesiuk et al. 1990; Ford 1991; Osborne 1999; Deecke et al. 2000; Ford et al. 1998, 2000, 2005; Olesiuk et al. 2005; Ellis et al. 2011; Towers et al. 2015; Wright et al. 2016; see also reviews by Baird 2001; Wiles 2004; Killer Whale Recovery Team 2006; Reisch et al. 2012; Ford and Ellis 2014). These field studies have been conducted primarily in two core areas where Resident Killer Whales congregate during summer months: Johnstone Strait off northeastern Vancouver Island for NRKWs, and Haro Strait between Southern Vancouver Island and San Juan Island for SRKWs (Figures 2 and 17). Additional field efforts have also been made throughout coastal waters of British Columbia and Washington State, particularly in recent years.

The basic social unit of Resident Killer Whales is the *matriline*, which is composed of individuals that are closely related by matrilineal descent. Matrilines generally contain an old female, or matriarch, and 1-4 generations of her descendants of both sexes. Dispersal of individuals from the matriline is rare. Matrilines are composed of an average of 6 members (range 1-26, SE = 0.59, n = 50). Resident Killer Whales typically travel in *pods*, which consist of 1-12 related matrilines that spend the majority of their time together (Bigg et al. 1990; Ford et al. 2000). Different pods from the same population frequently travel together. Pods range in size from 3 to 45 individuals, although 10-20 is typical (Ford et al. 2000). Although some pods originally described in the 1970s and 1980s have maintained their stability, most have split in recent years (Ford et al. 2000; Stredulinsky 2016) and their member matrilines travel independently. Pods and matrilines have distinct vocal dialects that reflect their matrilineal genealogy (Ford 1991). Most pods and some matrilines can be readily identified by these distinctive dialects. *Clans* are groups of pods and matrilines that share a unique set of related dialects and have likely descended from a common matrilineal ancestor. Clans can be easily distinguished by ear because of their dissimilar dialects. Groups of pods with clans that have one or more stereotyped calls that are not shared by all clan members are referred to as *subclans*. The Northern Resident community consists of three clans, A, G, and R, with 16 pods and 34 matrilines. A and G clan have two subclans each, AA, AB, GG and GI. The Southern Resident community is made up of a single clan, J, which consists of 3 pods, J, K, and L, and 20 matrilines (Ford et al. 2000). Members of Northern Resident clans frequently associate with one another, but J clan maintains social isolation from other Residents.

Killer Whales are long lived animals that have a low reproductive potential. The life history parameters of Resident Killer Whales are presented in Olesiuk et al. (1990, 2005). Survival

[1] Bigg, M.A., MacAskie, I.B., and Ellis, G. 1976. Abundance and movements of killer whales off eastern and southern Vancouver Island with comments on management. Unpubl. Rep., Arctic Biological Station, Dept. of Fisheries and Environment, Ste Anne-de-Bellevue, QC.

patterns are typical of mammals, being U-shaped with highest mortality rates in very young (neonate) and very old age classes. Annual survival rates of juveniles and adults are high (0.97-0.99), particularly among mature females and during periods of population growth. During a period of growth in the NRKW population, females had a mean life expectancy of 46 years and a maximum longevity of about 80 years. Males had a mean life expectancy of 31 years, with maximum longevities of 60-70 years. Females give birth to their first viable calf at approximately 14 years, and produce an average of 4.7 calves over a 24-year reproductive lifespan. Gestation is 16-17 months and the minimum calving interval is about 3 years (mean = 4.9 years). Females give birth to their last calf at around 40 years, then become reproductively senescent for the remainder of their lives. Calving is diffusely seasonal, with a peak in fall and winter.

1.2. HABITAT CHARACTERISTICS AND USE BY RESIDENT KILLER WHALES

Resident Killer Whales are present in coastal waters of British Columbia in all months of the year (Bigg et al. 1976[1]; Ford et al. 2000, 2010). They range throughout the inside and outer coastal waters, but seldom occur beyond the continental shelf break (200 m isobath; Ford 2014). Although these whales may undertake extensive movements of up to 2000 km along the west coast of Canada and the US, many matrilines and pods inhabit relatively small core areas for periods of several weeks or months at a time (Bigg et al. 1990; Ford et al. 2000, unpubl. data). Concentrations of Resident whales in such habitats are strongly associated with the seasonal abundance of salmonids (*Oncorhynchus* spp.) returning to natal rivers to spawn from early summer through fall. Heimlich-Boran (1986) documented correlations between the occurrence of SRKWs and commercial and sport salmon fishery catches in US waters off southeastern Vancouver Island and in Puget Sound, though he did not differentiate between different salmonid species. Nichol and Shackleton (1996) showed positive correlations between the seasonal occurrence of various pods of NRKWs and abundance of Sockeye (*O. nerka*), Pink (*O. gorbuscha*) and Chum salmon in the Johnstone Strait area off northeastern Vancouver Island.

Subsequent studies of Resident Killer Whale diet in both of these regions have shown that although all species of salmonids are consumed, there is strong selectivity for Chinook Salmon during May to September, despite this species being far less abundant than Sockeye and Pink salmon which are not important prey species (Ford et al. 1998; Ford and Ellis 2005, 2006; Ford et al. 2010; Hanson et al. 2010a; M. Ford et al. 2016). Chinook Salmon are likely favoured as prey because of their large size, high lipid content, and their availability in nearshore waters throughout the year (Ford and Ellis 2006). Correlations between occurrence of Resident Killer Whales and abundance of Sockeye and Pink salmon are likely incidental, as the whales appear to be drawn to these core areas by Chinook Salmon which are also migrating through these waters at the same time as the smaller species. The locations of Resident Killer Whale concentrations during summer typically correspond to areas of high Chinook Salmon densities and coincide with commercial and recreational fisheries that target Chinook (Ford 2006; Ford et al. 2010).

In October and November, the diet of NRKWs shifts to predominantly Chum Salmon, which are abundant during their fall migration (Ford and Ellis 2006). SRKWs increase their use of Puget Sound during these months, likely to intercept migrating Chum Salmon as well as Chinook (Osborne 1999). By December, use of summer core areas decreases and most NRKWs and SRKWs appear to travel extensively in outer coastal waters through winter and spring, though their detailed movement patterns have not been determined (Nichol and Shackleton 1996; Osborne 1999; Ford et al. 2000; Wiles 2004; Hanson et al. 2013). Their diet during this period is also poorly known. It is likely that they maintain their focus on Chinook Salmon, which are available in outer coastal waters (Healey 1991; Quinn 2005), but it is possible that non-salmonid prey becomes a significant component of their diet at this time. However, the close relationship between patterns of mortality in Resident Killer Whales and coast-wide abundance of Chinook Salmon suggest strongly that this prey species may be an important limiting factor in their population dynamics (Ford et al. 2009; Ward et al. 2009; Veléz-Espino et al. 2014).

While occupying their nearshore core areas during summer and fall, Resident Killer Whales spend about 40-67% of their time foraging (Heimlich-Boran 1988; Ford 1989; Morton 1990, Felleman et al. 1991; Nichol and Shackleton 1996). Groups of whales disperse over several square kilometres, with individuals and subgroups foraging independently, but progressing at the same general speed (mean of 6 km/h) and in the same direction (Ford 1989). When foraging in open water areas, groups of whales often spread out more extensively, with individuals or subgroups more than 1 km apart, typically in a staggered broad front configuration. In such cases, a large aggregation of whales may extend laterally for 10 or more km, occupying areas of >100 km^2. Whales exchange calls frequently during foraging, presumably to maintain contact and coordinate movements while dispersed. Whales forage over both deep open water and in shallow nearshore waters, often in areas of strong tidal currents and mixing (Heimlich-Boran 1988; Ford et al. 1998). In areas of steep nearshore topography, whales frequently forage close to shore (Jacobsen 1990; Nichol and Shackleton 1996; Ford et al. 1998). Chinook Salmon tend to be found in such nearshore habitats more so than other salmonids (Stasko et al. 1976; Quinn et al. 1989, Candy and Quinn 1999), and the majority of Chinook kills observed in the Johnstone Strait core area were concentrated along steep shorelines (Ford and Ellis 2005). Studies of diving behaviour of SRKWs using suction-cup mounted time-depth recorders revealed that most diving activity is concentrated in the top 30 m of the water column, with occasional dives to depths of 100-200 m (Baird et al. 2005). Chinook Salmon swim at depths averaging 25-80 m, occasionally extending as deep as 300-400 m (Candy and Quinn 1999).

Resident Killer Whales appear to make extensive use of echolocation to locate and capture prey, though vision may also play a role at close ranges (Ford 1989; Barrett-Lennard et al. 1996). Studies of echolocation click structure and energy content in NRKWs suggest that they should be able to detect Chinook Salmon at ranges of about 100 m in average conditions, and less so as ambient noise increases (Au et al. 2004). SRKWs carrying time-depth recorders were found to have reduced dive rates and swimming speeds during night, suggesting that foraging activity may be reduced during hours of darkness (Baird et al. 2005).

Focal animal and focal group studies of foraging behaviour and prey handling of Resident whales indicate that the majority of salmon prey, regardless of species or size, are shared among close kin within matrilines (Ford and Ellis 2005, 2006; Wright et al. 2016). Adult males, which often forage alone, share only a minority of their prey.

In addition to foraging, Resident Killer Whales spend significant time resting, socializing and travelling in their summer-fall core areas. Following periods of foraging, pod or matriline members often slow and group closely side-by-side in a 'resting line', and undertake series of long, regular dives in unison. Forward progression of resting groups is slow, averaging 3 km/h, and vocal activity is reduced or absent (Ford 1989). Periods of resting last on average about 2 h, but can continue for up to 7 h. Overall, resting comprises 10-20% of the activity budget of Residents (Ford 1989; Morton 1990; Nichol and Shackleton 1996). Socializing activity occurs when whales engage in various physical interactions and surface-active displays, such as breaching, spyhopping, and tail slapping (Jacobsen 1986; Osborne 1986; Ford 1989). Such interactions are especially common among juvenile whales, and likely represent play. It is also probable that mating takes place during socializing periods, especially during the peak of the summer season when multiple pods congregate in core areas (Ford 1989; Ford et al. 2000). Although mating is rarely witnessed due to the constraints of surface-based observations, its occurrence during July and August, followed by a 16-17 month gestation period (Duffield et al. 1995), is consistent with a late fall – winter peak calving season (Olesiuk et al. 1990, 2005). Mating during times of summer aggregation would also provide opportunities for outbreeding, as genetic evidence indicates that Residents mate preferentially outside their pods or clans (Barrett-Lennard 2000). Socializing represents about 12-15% of the activity budget of Resident whales during summer (Heimlich-Boran 1988; Ford 1989; Morton 1990; Nichol and Shackleton 1996).

A group or groups of whales that are swimming in a constant direction, usually in a tight formation, without displaying any evidence of feeding, are considered to be travelling (Jacobsen 1986; Osborne 1986; Heimlich-Boran 1988; Ford 1989). Travelling often involves fast swimming at speeds of up to 20 km/h, but may also occur at slower speeds. Travelling comprises just 4-8% of the activity budget of NRKWs (Ford 1989; Morton 1990), but up to 25% for SRKWs (Heimlich-Boran 1988). An important pattern of habitat use by NRKWs is beach rubbing, which involves regular visits to particular beaches where the whales repeatedly rub their bodies on smooth pebbles in the shallows for periods averaging 0.2 h (Jacobsen 1986; Ford 1989; Briggs 1991[2]). Beach rubbing is an important activity in the Johnstone Strait core area, where it represents about 3-5% of the activity budget of whales during summer and fall (Ford 1989; Nichol and Shackleton 1996). Beach rubbing appears to be a traditional behaviour that has not been observed among SRKWs or other ecotypes (Heimlich-Boran 1988; Ford et al. 2000).

2. METHODS

2.1. PHOTO-IDENTIFICATION STUDIES

Data collected by the Cetacean Research Program (CRP, Pacific Biological Station (PBS), Nanaimo, British Columbia) and numerous collaborators during 1973-2014 were compiled into a database maintained at the PBS for the analyses of Resident Killer Whale distribution undertaken for this report. Each record in the database consists of a single *encounter*, which is the positive identification of members of one or more Resident Killer Whale matrilines or pods at a single location on a given day. A total of 8108 encounters with Resident Killer Whales were compiled in the PBS database, of which 6638 (82%) involved NRKWs, and 1470 (18%) involved SRKWs. The majority of encounters were documented by experienced observers while undertaking dedicated studies of Killer Whales. A variety of field methods were used to collect these data, depending on the research group or individuals involved, and the objectives and approach of their study. Observations were made from both boat-based and shore-based research platforms, and identification of whales present in an encounter was determined from photographs, by visual recognition of distinctive individuals, by acoustic monitoring or recording of vocalizations from shore-based or boat-deployed hydrophones, or by a combination of these methods. Data were also contributed by observers who collected identification photographs opportunistically during Killer Whale encounters made while undertaking other marine activities. There is no record of sighting effort by observers who contributed opportunistic data. Dedicated survey effort by researchers has been quantified by GPS vessel tracking since 2003. It should be noted that the position given for each encounter is the geographic coordinates where the whale(s) were first sighted, and do not reflect subsequent movements of the animals during the encounter or dispersion of individuals present.

[2] Briggs, D.A. 1991. Impact of human activities on killer whales at the rubbing beaches in the Robson Bight Ecological Reserve and adjacent waters during the summers of 1987 and 1989. Unpublished. Report, BC Parks, Government of BC.

Two supplemental data sources used to prepare range maps (Figures 1 and 2) include sightings from the BC Cetacean Sightings Network (BCCSN), managed jointly by the Vancouver Aquarium and the CRP; and the "Orca Master" database, maintained by the Whale Museum, Friday Harbor, WA. The BCCSN database is compiled primarily from opportunistic sightings from the public and whale watch operators. A total of 4180 Southern Resident and 1445 Northern Resident sightings were collected during 2000-2015. The Orca Master database is a compilation of largely opportunistic sightings of SRKWs made during 1990-2015 in waters of Juan de Fuca Strait, Georgia Strait, Puget Sound, and connecting channels and straits (Hauser 2006; Olsen et al. 2015). Sightings were obtained from a variety of sources including public reports, the commercial whale-watch industry pager network, the 'Soundwatch' on-the-water stewardship program, and independent researchers. Sightings are not independently geo-referenced, but are assigned to one of 441 quadrats in the study area, each 4.6 x 4.6 km in size. Sightings within each 21.2 km^2 quadrat are assigned the geographical coordinates at the centre of that quadrat. No effort was made to eliminate multiple sightings of the same whales on the same day from the database, which contained 73,581 sightings of SRKWs during 1990-2015. All maps were prepared using ArcGIS software (ESRI v 9.0).

2.2. PREDATION ANALYSES

To describe the potential relationship between Resident Killer Whale habitat use patterns and prey distribution, observations of predation involving confirmed prey species were compiled and analyzed. Prey species were identified from 1093 predation events during which prey fragments (fish scales and tissue scraps) were collected from the predation site. The field procedures for prey fragment collection are described in detail in Ford and Ellis (2006) and Ford et al. (2010). The great majority of prey were identified from scales (94%), but some (6%) were identified genetically from tissue samples by the Molecular Genetics Lab at PBS. Only predation events where the prey was killed, consumed, and positively identified to species, and where geographic position (latitude and longitude) was recorded, were used in spatial analyses.

Scales and/or tissue fragments from Chinook Salmon, which comprised the majority of Resident Killer Whale prey samples, were analysed genetically to identify stock and region of origin. Samples were combined across years for each of the two geographically separate locations, western Dixon Entrance and southwestern Vancouver Island. Variation at twelve to fifteen microsatellite loci were used to confirm species identification as well as to assign individual Chinook Salmon to region of origin using mixture analysis assigning unknown samples to a baseline. The baseline consisted of 268 populations ranging from southeastern Alaska to California grouped by 38 reporting regions using methodology in Beacham et al. (2003, 2006). Prey samples were assigned to stock and regional reporting groups using the Bayesian methods of Pella and Masuda (2001) as implemented in the program cBayes (Neaves et al. 2005).

2.3. ACOUSTIC DATA COLLECTION

The two areas considered in this report to potentially warrant identification as additional critical habitat for Resident Killer Whales are remote compared to the two currently designated critical habitat areas. They are also more exposed to open ocean conditions than the designated areas. As such, they are difficult to access and not conducive to conventional small-boat field studies, especially outside of summer. For this reason, passive acoustic monitoring (PAM) was used to assess year-round occurrence of Resident Killer Whales.

Two locations within the areas of potential critical habitat were selected for deployment of autonomous underwater acoustic recording systems:

2.3.1. Swiftsure Bank

Acoustic recordings were collected using AURAL-M2® (Multi-Électronique Ltd.) autonomous submersible recorders moored at a depth of ~75 m at Swiftsure Bank (48°31'N, 124°56'W), about 18 km off the southwestern coast of Vancouver Island and 25 km from the entrance to Juan de Fuca Strait (see Figure 11). A total of four consecutive AURAL-M2 deployments were made between 23 July 2009 and 31 July 2011 for a total of 680 days of monitoring effort (no recordings were made on 50 days (26 March to 15 May 2011) due to exhausted batteries).

Recordings were made at a sampling rate of 16,384 Hz, on an approximate 1/3 duty cycle (10 min continuous recording every 30 min until 1 May 2010; 9 min every 30 min until 26 March 2011; 4.5 min every 15 min until 31 July 2011). The duration of the acoustic samples was shortened by 1 minute to increase the total samples that could be stored on the AURAL's hard disk and the deployment duration without causing a noticeable difference in call detections. The duty cycle changed from 9 min every 30 min to 4.5 min every 15 min to reduce non-recording time between samples and increase the probability of detecting whales that produced few calls.

2.3.2. Langara Island

Long-term acoustic monitoring to determine seasonal occurrence of Resident Killer Whales in western Dixon Entrance was undertaken from instrumentation at Langara Island (see Figure 22). Recordings were made with a shore-based customized AURAL-M2 autonomous recorder connected by 300 m of armoured cable through the intertidal and subtidal zone to a Sparton 57B hydrophone anchored ~1 m off the seafloor at a depth of ~40 m. The location of the hydrophone was off Andrews Point, Langara Island (54°14.2'N, 132°57.6'W). Recordings analyzed here were made between 10 September 2009 and 12 June 2012. A sampling rate of 16,384 Hz was used and a 1/3 duty cycle (10 min of recording every 30 min).

2.4. ACOUSTIC ANALYSES

2.4.1. Killer Whale detection and identification

Acoustic data from Swiftsure Bank were analyzed for the presence of Killer Whale calls following the methodology described in Riera (2012) and Riera et al. (2013). The data were separated into two 12-month datasets: August 2009 to July 2010 (5760 acoustic files over 365 days) and August 2010 to July 2011 (4416 acoustic files over 315 days). Recordings collected during the first period were all inspected manually, which involved visually inspecting all recordings 30-sec at a time via spectrograms using the MATLAB® (Mathworks Inc) application TRITON® (Wiggins and Hildebrand 2007), and listening to portions of the recordings when needed for identification. To decrease analysis time, recordings collected during the second period were pre-screened using the SONS-DCL® application (Laboratori d'Aplicacions Bioacústiques, Barcelona) and only the portions of data that were found likely to contain whale calls were examined. The SONS-DCL application divided the recordings into segments of 16-sec duration then used a neural network algorithm to calculate a probability that each segment contained a short tonal signal (which could be a Killer Whale call). To calibrate the SONS-DCL detector, it was used on the first 12-month dataset that had already been analyzed manually and the results were compared with those from the manual analysis for detection probabilities of ≥40, ≥30 and ≥20%. A threshold probability of 20% resulted in a false negative rate of only 2%, so this was chosen to select data segments for further visual and acoustic inspection using a tool provided in the SONS-DCL application. When more resolution or sound reproduction was needed to positively identify the signal that triggered the detection, the AURAL file containing that segment was inspected with TRITON. For both datasets, a Killer Whale *detection* refers to an AURAL sample containing at least one verified Killer Whale call.

The procedures for analysis of acoustic data from the Langara recording instrument differed from the approach used for the Swiftsure Bank data. For the period of 10 September 2009 to 31 May 2011, recorded files were subsampled for manual analysis. Every second or third file was analysed manually by visual inspection of spectrograms (FFT size = 512 Hz) using Adobe Audition CS5.5 version 4.0., and by scrolling through the recording in 30-sec segments.

Any sounds found visually were inspected aurally to determine species. Once Killer Whale vocalizations were found, every unanalyzed recording file prior to and immediately following the detection recording was examined until two consecutive recording periods without a Killer Whale vocalization (i.e., 1 hr real-time) were encountered.

Recordings made between 5 June 2011 and 12 June 2012 were analysed using the Whistle and Moan detector in version 1.12.08 of PAMGuard® (Gillespie et al. 2013). This is a spectrogram-based tonal detector, which we configured with a minimum amplitude threshold of 6 dB for non-summer periods (Sept-May) and 8 dB for summer periods (June-August), as well as a high-pass filter set at 0.7 kHz. The filter was employed to minimize Humpback Whale detections during peak periods of song. The amplitude threshold was selected through trial and error in an attempt to find a balance between false-positive and false-negative detections. The 6 dB threshold was conservative, creating more false-positives in order to minimize false-negatives. We conducted a comparison between PAMGuard, SONS-DCL and the manual techniques described above on the same data set, which showed very little difference in the number of days Killer Whales were detected between methods (with PAMGuard exceeding manual and SON-DCL methods). During the summertime, the soundscape at the Langara hydrophone site is dominated by regular periods of intense noise from sport fishing activity. To adjust for the higher number of false-positives caused by this noise (which made analysis overwhelming), we opted for an 8 dB threshold, which reduced false-positives to a manageable level and provided comparable Killer Whale detections to previous years for these months. All detections made by the detector were examined and verified to species, effectively bringing the false-positive rate to zero. After detections were verified, the entire duration of every recording containing at least one confirmed Killer Whale detection was manually analysed using spectrograms in Adobe Audition CS5.5 in order to identify all call types present.

For both Swiftsure and Langara datasets, Killer Whale calls were identified to the highest resolution possible using a reference catalogue of spectrograms (Ford 1987) and a digitized visual and aural catalogue of call types (DFO CRP, unpubl. data). Identifications were first made to species, then to ecotype (Resident, Transient or Offshore Killer Whale). For some files with very faint calls or those with very low signal-to-noise ratios, it was only possible to determine species, and these were classified as ‘unknown Killer Whale’. When recording quality allowed, identifications of Resident Killer Whale calls were then made to the level of population (Northern or Southern), then to the clan, subclan or pod level.

2.4.2. Calculation of acoustic encounter durations

Calls attributed to the same pod(s) or clan(s) were often detected over multiple consecutive acoustic samples, indicating that whales were present within the area of detectability for prolonged periods. However, Resident Killer Whale groups seldom vocalize continuously over long periods, so multiple acoustic samples containing calls were often interspersed with samples that contained no calls. In such cases, the whales were likely within audible range but were temporarily silent or in a different activity state using quieter vocalization types that did not reach the hydrophone. In order to estimate how long particular pods or clans stayed within the monitored areas, series of acoustic samples containing the same call types (i.e., originating from the same group(s) of whales) were considered to represent a single “acoustic encounter” until a gap of 5 h without call detection occurred. The duration of this gap was somewhat arbitrary but was based on:

1. past experience with Resident Killer Whale vocal behaviour indicating that groups rarely maintain silence for periods longer than this; and
2. the size of the areas of detection relative to typical Killer Whale travel rates.

It was assumed that after a period of 5 hours, whales had left the area of detectability and subsequent detections were considered a new acoustic encounter.

2.4.3. Estimation of Killer Whale detection ranges

The areas over which Resident Killer Whales could potentially be detected acoustically were modelled for both Swiftsure and Langara monitoring locations for four representative months at each site. We began this process by modelling the transmission loss at both sites using the BELLHOP ray-tracing model (Porter 2011) available in the Effects of Sound on the Marine Environment 2012 Workbench framework software (ESME, D. Mountain, Curtin University, 2012). ESME used built-in environmental databases from the Oceanographic and Atmospheric Master Library (OAML) to acquire location-specific bathymetry (from Digital Bathymetry Database v5.4 at 0.5-min resolution), sound speed profiles (calculated at 15-min resolution from water temperature and salinity data in the Generalized Digital Environment Model v3.0.), bottom sediment composition (from Bottom Sediment Type v2.0 at 5-min resolution), and surface reflectivity (from Surface Marine Gridded Climatology v2.0 wind speed at 60-min resolution) for the months in question. To model the propagation of a Killer Whale call we used a call source level of 152 dB re 1 µPa @ 1m, which is the average source level for discrete calls produced by NRKWs reported by Miller (2006). We also specified a call frequency of 1200Hz, and a call duration of 1 second, both representative of the N05 call type (Ford 1987) produced commonly by NRKWs. Transmission loss was then modelled along 32 radials extending out from each site to a maximum extent of 45 km.

To determine the detection distance along each radial, we first assumed a calling depth of 10 m. The calling depth of Resident Killer Whales was estimated by averaging all dive depths from all DTAG data available from a previous study of Northern Resident foraging behaviour (Wright et al. 2017) resulting in an average dive depth of 7 m across all behaviour types. The closest transmission loss depth bin to this average was 10 m. Assuming that most calling behaviour will occur at the depth at which Killer Whales spend most of their time, we used 10 m as the representative calling depth for Resident Killer Whales. The detection distance along each radial was then determined as the distance at which the transmission loss at 10m depth fell below the maximum allowable transmission loss (MaxTL) represented by:

$$MaxTL = SL - NL - D$$

where *SL* is the call source level, *NL* is the ambient noise level, and *D* is the detectability of the signal. We chose to define detectability for a listening analyst for sound around 1200 Hz as 5 dB.

Ambient noise levels in the 1 Hz bands surrounding 1200 Hz were analysed for two years of data at each recording site: Swiftsure – September 2009-2010, January, June and July 2010-2011; Langara – April, June, October and January, 2010-2011. Calibrated power spectral densities (PSDs) were computed with 15-sec time averaging (Welch 1967) in 1 Hz bins (with a 1-sec window, 50% overlap) using the recorder and hydrophone manufacturer technical specifications and user defined gain settings. The PSDs were computed in R 3.0.0 using the software PAMGuide (Merchant et al. 2015). Prior to noise measurement, all periods in the PSD that overlapped with Killer Whale acoustic encounters (as defined earlier) were removed to try to exclude noise produced by Killer Whales in the measurements. For Langara, only nighttime data were used in order to exclude system noise introduced by the solar charging system on sunny days. The noise level (in units of dB re 1 μPa^2) for each month was then computed by integrating the spectral density over the 1199, 1200, and 1201 Hz bins.

Custom R scripts were used to calculate the position of maximum detection range along each radial in decimal degrees of latitude and longitude. These points were then connected to form a polygon representing the detection area around the hydrophone location. We calculated the area (in km^2) of the resulting detection polygon according to Bevis and Cambareri (1987). The polygon was then layered onto a bathymetric map of the region using R packages PBSmapping (Schnute et al. 2013) and marmap (Pante and Simon-Bouhet 2013). Bathymetry data for the figures were downloaded from Smith and Sandwell (1997).

2.5. SPATIAL ANALYSES

Spatial analyses involving effort tracks as well as encounter and prey sample locations were undertaken using ArcGIS (www.esri.ca). The coastline, bathymetric contours and encounters were projected into the appropriate UTM zone (WGS84 UTM8N/9N/10N). Depths for encounter and predation locations were extracted from a coastal digital elevation model raster developed by Geological Survey of Canada, gridded from 1:250000 Canadian Hydrographic Service (CHS) bathymetric contours.

3. RESULTS AND DISCUSSION

3.1. DESIGNATED CRITICAL HABITATS OF RESIDENT KILLER WHALES

In this section, the general patterns of seasonal occurrence and specific details of habitat use patterns in existing designated critical habitat areas are presented separately for the two Resident Killer Whale populations.

3.1.1. Southern Resident

Whales belonging to the Southern Resident Killer Whale population have been identified from Monterey Bay, California to Chatham Strait, southeastern Alaska, representing an overall range of approximately 2300 km along the coast (Figure 2). The great majority of encounters and sightings involving members of this population are located in the relatively protected inshore waters of the Salish Sea, which includes eastern Juan de Fuca Strait, Haro Strait, the Strait of Georgia, and various other connecting channels and passes. Most sightings have been recorded from late spring through early autumn, when survey effort is greatest and when most of the numerous studies of this population have been undertaken (e.g., Bigg et al. 1976[1], 1990; Balcomb et al. 1980[3]; Heimlich-Boran, 1986; Osborne 1986, 1999; Heimlich-Boran 1988; Felleman et al. 1991; Hoelzel 1993; Ford et al. 2000; Baird et al. 2005; Ford and Ellis 2005; Hauser et al. 2007; Hanson et al. 2010a). During this period, all three Southern Resident pods are regularly present within the Salish Sea, although the pattern of occurrence of each pod differs (Figure 3). J pod is usually found in inshore waters during all months of the year. K and L pods typically arrive to the Salish Sea in May or June and spend most of their time there until

[3] Balcomb, K.C. III, J. R. Boran, R.W. Osborne, and N.J. Haenel. 1980. Observations of killer whales (*Orcinus orca*) in greater Puget Sound, State of Washington. Report prepared for U.S. Marine Mammal Commission, MMC-78/13.

they depart in November or December. Both of these pods make regular trips during summer to areas off the western entrance of Juan de Fuca Strait and the west coast of Vancouver Island and Washington. Such excursions are typically of only a few days duration. J pod also makes these excursions, but less frequently.

During June to October, SRKWs concentrate their activity in eastern Haro Strait (off the west side of San Juan Island), Boundary Pass, southern Strait of Georgia, and eastern Juan de Fuca Strait. Relative use of these areas varies somewhat by pod (Hauser et al. 2007). As noted earlier, occurrence and movement patterns of whales in these areas is associated with the abundance of salmon of various species (Heimlich-Boran et al. 1986; Heimlich-Boran 1988; Felleman et al. 1991; McCluskey 2006; Hanson et al. 2010a), but identification of scales and tissue fragments from kill sites and analysis of DNA from scats has shown that Chinook Salmon form the majority of prey (Ford and Ellis 2006; Hanson et al. 2010a; M. Ford et al. 2016). These waters are important migratory corridors for Chinook Salmon bound for the Fraser River system, which, contains the largest spawning populations of Chinook on the west coast of North America. Notable foraging areas of high use by SRKWs are the nearshore waters of Haro Strait along the west and south coasts of San Juan Island, Boundary Pass, Juan de Fuca Strait close to the Vancouver Island shoreline, Swanson Channel, Active Pass, and waters off the mouth of the Fraser River (Hauser et al. 2007; Hanson et al. 2010a). Most of these waters are well mixed and turbulent due to strong tidal currents in Juan de Fuca Strait (Thomson 1981). In fall, the movements of Southern Resident whales in late October and November shift to include Puget Sound, and this is associated with the arrival of Chum Salmon migrating to rivers in that area (Osborne 1999). The winter distribution of SRKWs is relatively poorly known. K and L pods are mostly absent from inside waters during December to May, and recent sightings indicate that they range widely along the mainland US coast and off the west coast of Vancouver Island (Wiles 2004; Zamon et al. 2007). Their occurrence off the mouth of the Columbia River and in Monterey Bay, California, appears to be associated with local concentrations of Chinook Salmon (Wiles 2004; Zamon et al. 2007; Hanson et al. 2010b[4]).

Because all SRKWs spend such a large proportion of the year in the Salish Sea, which is a relatively small part of their overall range, and because their use of the area is dominated by foraging for seasonally-abundant migratory Chinook Salmon, the area of highest use by SRKWs in Canadian waters was proposed as potential critical habitat by Ford (2006). This area is approximately 3390 km^2 in size, and includes the Canadian side of Juan de Fuca and Haro straits and Boundary Pass, the waters surrounding the Southern Gulf Islands, and part of Southern Georgia Strait off the mouth of the Fraser River (Figure 4). These are all primary movement corridors and foraging locations for SRKWs in the area. The whales also utilize these waters for other important activities, including resting, socializing and mating. This proposed critical habitat area was identified in the final Resident Killer Whale Recovery Strategy and was formally designated as such by a Protection Order under the SARA in 2009 (Fisheries and Oceans Canada 2011). In 2006, the US government designated adjacent waters of the Salish Sea, including Puget Sound, as critical habitat under the U.S. Endangered Species Act (Federal Register 2006). This area comprises 6630 km^2 of marine habitat (Figure 4).

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[4] Hanson, M.P., Noren, D.P., Norris, T.F., Emmons, C.K., Holt, M.M., Phillips, E., Zamon, J.E., and Menkel, J. 2010b. Pacific Orca Distribution Survey (PODS) conducted aboard the NOAA ship McArthur II in March-April 2009. Unpubl. rep., NOAA/NMFS/Northwest Fisheries Science Center 2725 Montlake Blvd. E Seattle, WA 98112

3.1.2. Northern Resident

The range of NRKWs includes coastal waters from Glacier Bay, Alaska, to Gray's Harbor, Washington State, a linear distance of approximately 1500 km along the west coast. Sightings of NRKWs outside of Canadian waters are uncommon, however, and represent only 0.7% of the 6638 Northern Resident encounters in the PBS database. The locations of encounters with NRKWs, exclusive of the few in northern waters of Southeast Alaska, are shown in Figure 1. Although NRKWs have been encountered throughout coastal waters of BC, almost 90% of encounters were located off the northeastern coast of Vancouver Island, particularly in Johnstone Strait, Queen Charlotte Strait and connecting channels and passes. This area is the most readily accessible within the range of NRKWs, and is relatively protected and suitable for small boats. This area, particularly western Johnstone Strait, has been the focus of numerous field studies since the early 1970s (Spong et al. 1970, Bigg et al. 1976[1]) and commercial whale watching activity since 1980 (JSKWC 1991[5]). Areas to the north of Vancouver Island are more remote and generally accessible only by boat. Logistical difficulties have thus constrained field effort in much of these waters. Boat-based field effort has also been concentrated in summer months because of generally conducive weather and long hours of daylight. Field work from small boats is difficult during October–May in this region due to frequent periods of windy, inclement weather.

Despite the seasonal and geographic biases in survey effort over their range, the Johnstone Strait area has long been recognized as an area of great importance to NRKWs. Patterns of habitat use in the Johnstone Strait area were described in detail in Ford (2006), and are summarized here. NRKWs can be found in the Johnstone Strait area in all months of the year, but there is much seasonal variability. NRKWs used the area in all months, but encounter rates were highest during July-October with whales present on 82–84% of days with survey effort, and lowest during March-May at < 10% of effort days. Overall, NRKW encounters were documented on an average of 42% of effort days during 1990-2004. Typically, 15–40 whales representing several pods are present each day during July-September, with peak abundance in late July–mid August, when aggregations of up to about 100 NRKWs, or roughly a third of the population, are occasionally observed. Although all 16 NRKW pods have been documented in Johnstone Strait, different pods do not use the area equally. For example, during 1990–2004, all or part of A1 pod was present in 75% of encounters, compared to 0.7% of encounters for I18 pod, a group of similar size and a member of the same clan.

The primary feature drawing NRKW whales to the Johnstone Strait area is most probably the seasonal abundance of their preferred prey species, Chinook Salmon and, secondarily, Chum Salmon. Johnstone Strait, together with Juan de Fuca and Haro straits off Southern Vancouver Island, are the primary migratory corridors for salmonids returning to the Fraser River, which contains the largest populations of Chinook Salmon in North America (Northcote and Larkin 1989; DFO 2001). It is likely that Johnstone Strait, which is only 3.5–4.5 km wide for much of its 85 km length, acts as a geographical funnel to concentrate migrating salmon returning from outer coastal and offshore waters, and its steep sides provide physical barriers against which whales can chase and corral fish. Johnstone Strait may well provide conditions for Resident Killer Whales foraging for Chinook Salmon during summer, and Chum Salmon in fall, that are unparalleled in other areas in the population's range. Another important feature of the Johnstone Strait area is the availability of several small pebble beaches that are used regularly for rubbing by NRKWs. As noted previously, this appears to be an important traditional

[5] JSKWC (Johnstone Strait Killer Whale Committee). 1991. Background Report. BC Ministry of Lands and Parks, and Dept. of Fisheries and Oceans. 76 p. + appendices.

behaviour among whales in this area, and forms part of the cultural distinctiveness of the Northern Resident community.

The importance of the Johnstone Strait area to NRKWs was assessed during 1991–1992 by the Johnstone Strait Killer Whale Committee, a joint federal and provincial initiative tasked with developing management recommendations to mitigate potential human impacts on the whales and to ensure their continued use of the area. Among the recommendations made by the committee (JSKWC 1992[6]) was that a Special Management Zone be established for the core area used by NRKWs. This zone encompasses much of southeastern Queen Charlotte Strait and western Johnstone Strait, and includes the Robson Bight (Michael Bigg) Ecological Reserve, a 1248 ha area established by the BC Ministry of Environment in 1982 to protect Killer Whale rubbing beaches from human disturbance. The critical habitat for NRKWs proposed by Ford (2006) was based on this Special Management Zone plus an extension of ~50 km to the east in Johnstone Strait, which is also used frequently by whales. The total area involved is 905 km^2 (Figure 4). This proposed critical habitat area was identified in the final Resident Killer Whale Recovery Strategy and was formally designated by a Protection Order under the SARA in 2009 (Fisheries and Oceans Canada 2011).

3.2. NEW AREAS FOR CONSIDERATION AS CRITICAL HABITAT

This section describes seasonal occurrence and habitat use patterns of Resident Killer Whales in the two areas identified in this report as potential Critical Habitat: 1) southwestern Vancouver Island and 2) western Dixon Entrance.

3.2.1. Southwest Vancouver Island

Seasonal Occurrence and Distribution

Between 1974 and 2014, a total of 245 encounters with Resident Killer Whales were documented off the southwestern coast of Vancouver Island west of the entrance to Juan de Fuca Strait (Figure 5). All encounters prior to 2003, when dedicated surveys started in the area, and many since then, were made opportunistically by whale watch operators and other mariners and there is no record of sighting effort. Overall, 30% of encounters in this area were opportunistic and lack any related effort data. The remaining 70% were made during dedicated small-vessel marine mammal surveys by CRP and on Canadian Coast Guard (CCG) Science ships. Approximately 112,000 km of survey effort was made in the area, shown spatially in Figure 5 and by month in Figure 6. These show that effort was strongly biased seasonally towards summer (80% of effort during June–September) and spatially towards nearshore waters, and the same trends are likely the case for opportunistic encounters. As a result, patterns of seasonal occurrence and spatial distribution evident from these encounters must be interpreted cautiously.

Of the 245 Resident Killer Whale encounters off southwestern Vancouver Island, 196 (80%) were with SRKWs and 49 (20%) involved NRKWs. SRKWs and NRKWs were never encountered together, which is to be expected as the two populations are socially isolated and do not mix (Bigg 1982; Ford et al. 2000). Encounters with Resident Killer Whales took place in each month of the year, but varied widely by month. SRKWs were strongly seasonal, with 90% taking place during May to September and peaking in July (Figure 7). However, this peak in summer is highly correlated with the seasonal bias in survey effort ($r^2 = 0.85$, $p < 0.001$).

[6] JSKWC (Johnstone Strait Killer Whale Committee). 1992. Management Recommendations. BC Ministry of Lands and Parks, and Dept. of Fisheries and Oceans. 18 p. + appendices.

Encounters with NRKWs were more evenly distributed across the months (except for May with no encounters), with a peak in August. However, NRKW encounters were also significantly correlated with level of effort ($r^2 = 0.45$, $p = 0.016$). This suggests that the seasonal occurrence of Resident Killer Whales may not be accurately reflected by vessel-based encounters.

The majority of encounters with Resident Killer Whales took place within 20 km of shore and all were over the continental shelf, mostly well inside the 200 m depth isobath along the shelf break. The mean depth of locations where Resident Killer Whales were encountered in the area was 71.9 m (range 5–273 m, SE 2.9). Only 4% were at depths > 200 m.

All three SRKW pods and 15 of the 16 pods in the NRKW population were encountered off southwestern Vancouver Island. Of the SRKWs, the most common was L pod, one or more subgroups of which were present in 93% of SRKW encounters, followed by K pod (27%) and J pod (10%) (Figure 8). Of the NRKWs, the four pods belonging to G clan where clearly the most commonly encountered. They were present in 22–55% of NRKW encounters, depending on pod, more than double any other NRKW pods (Figure 9). Pods from A and R clans were present in 10% or fewer NRKW encounters. G clan was encountered in all months of the year except for May.

Passive acoustic monitoring at Swiftsure Bank provided insight into monthly occurrence of Resident Killer Whales off SW Vancouver Island that was less biased by heterogeneity in seasonal boat-based effort. The approximate area of potential detectability of Resident Killer Whale calls for selected months is shown in Figure 10. Seasonal variation in the extent of this area is fairly minor, varying from a low of 83 km^2 in January (maximum range = 7.2 km) to 135 km^2 in September (maximum range = 8.6 km). Resident Killer Whale calls were detected on a total of 244 days out of the 680 days (36%) of monitoring between 1 August 2009 and 31 July 2011. SRKW calls were detected on 163 days (24% of monitoring days) and NRKW calls on 95 days (14%). Most SRKW and NRKW detections occurred on separate days, but both populations were detected together on 14 days, typically several hours apart. The monthly occurrence of days with detections of calls is shown in Figure 10. SRKW detections occurred in all months of the year, but were most frequent in summer (May to September), reaching a peak of 60% of monitoring days in June. NRKW detections also occurred in all months, but were lower in mid summer and peaked in spring (42% of days in March) and late summer (33% of days in September).

All three SRKW pods were detected in all months of the year, with the exception of J pod in January and March and L pod in March (Figure 11). K and L pods were the most frequently detected, particularly during the summer months of June to September. J pod, on the other hand, was more frequently detected than K and L pods during February to May. For the Swiftsure part of the study, NRKW calls were only identified to the level of the clan, rather than to the pod as in SRKW (Figure 14). G clan was by far the predominant acoustic group of NRKW detected at Swiftsure, as was the case with vessel-based encounters off southwestern Vancouver Island. G clan groups were detected in all months of the year, with a peak of 41% of monitored days in March. Other months with substantial presence of G clan were September (33% of days) and April (30% of days).

Durations of acoustic encounters (periods of consecutive acoustic samples with detections of the same call repertoires and with gaps of < 5 h; see Methods) were similar for SRKW and NRKW. Acoustic encounters with SRKWs had a mean duration of 5.34 h (SE = 0.38, range 1–23) and NRKWs averaged 5.37 h (SE = 0.54, range 1–27 hr). Acoustic encounter durations by month are summarized for SRKW and NRKW in Figure 15. Durations with SRKWs were significantly longer in summer (mean = 5.97 h, April–September) than winter (mean = 3.42 h, October–March; Welch's t test, $t = 4.00$, $p < 0.001$). Average encounter duration was also longer in summer than winter for NRKW (6.19 h vs 4.60 h), but not significantly so (t = 1.47, p = 0.146).

Foraging Behaviour

A total of 201 predation events, 184 of which had confirmed prey species identification, were documented for Resident Killer Whales in western Juan de Fuca Strait and off southwestern Vancouver Island during 2003–2013. Of these, 180 (98%) were salmonids, with Chinook Salmon being the predominant species representing 88% of all prey items sampled. Other salmonid prey species included Coho (5%), Chum (3%), Steelhead (1%) and Sockeye (0.5%). Predation on Sablefish, the only non-salmonid prey identified, was observed on three occasions. Only NRKWs were observed to feed on Sablefish, and on two of the three occasions the whales spent several hours feeding on multiple individual fishes.

The spatial distribution of prey species taken in predation events is illustrated in Figure 16. The majority of predation events were documented within 15 km of the shore of Vancouver Island, where most of the survey effort and encounters were concentrated. Predation events took place in waters with depths averaging 89 m (SE = 3.6, range = 5–225 m, n = 221). The majority of predation took place in waters with bottom depths of 100 m or less, but 42% were over depths of >100 m. Only three predation events took place in waters > 200 m deep. On two occasions, in September of 2013 and 2014, NRKWs were observed feeding extensively on Sablefish very close at the edge of the shelf break in ~200 m depth. Predation on this deep-water species is rarely observed, but it is often the principal target of long-line fisheries depredation by Killer Whales in Alaska (Peterson et al. 2013), suggesting that it is a highly desirable prey species. It has been assumed that Sablefish are normally too deep to be profitable prey for Killer Whales, but in certain locations on the shelf break, upwelling conditions bring Sablefish to shallower depths (R. Kronlund, Pacific Biological Station, pers. comm.), making them accessible to Killer Whales.

Stock identification by DNA indicated that 80% of Chinook taken by the whales were from stocks in the Fraser River system, with South Thompson being the predominant stock (44%) (Figure 17A). Other important stocks were from rivers in Puget Sound (13%) and along the west coast of Vancouver Island (6%).

Significance of SW Vancouver Island as Resident Killer Whale habitat

Boat-based encounters and, especially, acoustic detections at Swiftsure Bank indicate that the waters off the southwestern coast of Vancouver Island, west of Juan de Fuca Strait, is important habitat for both SRKWs and NRKWs throughout most of the year. On average, Resident Killer Whales were detected on one out of every three days at Swiftsure Bank. During May to September, SRKWs were detected on 43% of monitored days. It is during these months that SRKWs typically spend the majority of time in inside waters to the south and east of southern Vancouver Island. These waters include Juan de Fuca Strait, Haro Strait, the southern Strait of Georgia, and channels and passes between the southern Gulf Islands and San Juan Islands, all of which are designated Critical Habitat for SRKW in Canada and the US (Bigg et al. 1976[1]; Balcomb et al. 1980[3]; Ford et al. 1994; Osborne 1999; Ford 2006). Hauser et al. (2007) noted that SRKW were present in this area on an average of 80% of days during May–September, 1996–2001, but absent from the area on the remaining 20% of days. Given the frequent summer occurrence of SRKW pods off southwestern Vancouver Island documented here, it is evident that this area is a primary habitat used by these whales when outside of existing Critical Habitat during May–September.

Although J pod is regularly documented in inside waters during all months of the year (Bigg et al. 1976[1]; Osborne 1999; Olson et al. 2015[7]), K and L pods generally leave the area for extended periods during November to May. The range of these pods during winter has long been poorly known but presumed to include waters off the outer coasts of Vancouver Island and Washington State (Bigg 1982; Osborne 1999; Ford et al. 2000). However, periodic sightings since the late 1990s of K and L pods off Oregon and central California indicate that their range is more extensive than once thought (Krahn et al. 2004; Wiles 2004; Balcomb 2006). More recently, passive acoustic monitoring using autonomous recorders deployed at seven locations from Cape Flattery, WA, to Point Reyes, CA, during January to June, 2006–2011, has provided more details on the occurrence of SRKW along the outer US mainland coast (Hanson et al. 2013). SRKWs were detected at all locations, most often off the mouth of the Columbia River and Westport, WA, during March. J pod was only detected off Cape Flattery, so more southerly detections only involved K and/or L pods. Overall, there were relatively few detections (average of < 4 per month) compared to those at Swiftsure Bank reported here, perhaps partly due to differences in instrumentation and duty cycles. The number of detections as well as recent sightings of SRKWs off the Columbia River during March and April led Hanson et al. (2013) to suggest that the whales may frequent this area in spring to intercept Chinook Salmon migrating to this river for spawning.

Although NRKWs were known to occur at least occasionally off the central west coast of Vancouver Island (Bigg 1982; Ford et al. 2000, Ford 2006; Figure 7, this report), the frequent occurrence of this population at Swiftsure Bank reported here was unexpected. NRKWs were detected in all months of the year, but especially in March and April, when there were detections on 41% and 30% of days respectively. In designated Critical Habitat for this population off northeastern Vancouver Island, NRKWs are typically found on < 10% of days during these months (see Figure 7 in Ford 2006). Pods belonging to G clan occur most often in the area, but all NRKW pods have been identified there. Southwestern Vancouver Island is thus important habitat for NRKWs as well as SRKWs.

The seasonal movement patterns of Resident Killer Whales appear to be influenced by the availability of Chinook Salmon, the whales' primary prey (Ford and Ellis 2006; Ford 2006; Ford et al. 2010; Hanson et al. 2010a). Prey identified from scales and tissue fragments recovered from kills off southwestern Vancouver Island were predominantly Chinook Salmon, consistent with findings in other parts of the range of both SRKW and NRKW (Ford and Ellis 2006; Hanson et al. 2010a; Ford et al. 2016). Waters off southwestern Vancouver Island, particularly over the various banks including Swiftsure Bank and La Perouse Bank, are known to be highly productive salmon habitats. These banks have long been targeted by both commercial and recreational salmon troll fisheries which target Chinook and Coho salmon (Milne 1964; Healey 1986; Healey et al. 1990). Southwestern Vancouver Island is the entry point to the 'funnel' of Juan de Fuca Strait, through which many Chinook Salmon migrate en route to the Fraser River. This river system was the source of 80% of Chinook eaten by Resident Killer Whales off southwestern Vancouver Island and Juan de Fuca Strait.

Observations of extensive Sablefish predation near the shelf break off southwestern Vancouver Island by NRKWs suggest that this may be an important foraging location for this prey species.

[7] Olson, J., Osborne, R.W., and Bennett, K. 2015. Final Program Report: SRKW Sighting Compilation 11th Edition. Unpubl. report from The Whale Museum, Friday Harbor, WA.

3.2.2. Western Dixon Entrance

Seasonal Occurrence

Research effort focused on cetaceans has been conducted annually in western Dixon Entrance since 1989. Each year during 1990–2014, typically two one-week periods of small-boat survey effort were undertaken by CRP researchers, one week in June or early July and another in early September. These surveys were based from Langara Island and were mostly focused within 15 km of its shoreline. Also since 1990, on an opportunistic basis, staff of Langara Fishing Lodge have periodically collected Killer Whale photographs for photo-identification purposes. Opportunistic sighting effort leading to such encounters was not recorded but it was focused in nearshore waters from mid May to early September. In addition to effort around Langara Island, cetacean surveys in Dixon Entrance aboard CCG Science ships and smaller vessels have been conducted in most years during 2003–2014, mostly during spring and fall. Overall, 13,577 km of survey effort was expended in western Dixon Entrance during 2003–2014, distributed seasonally as shown in Figure 19.

Between 1992 and 2014, a total of 102 encounters with Resident Killer Whales were documented in waters of western Dixon Entrance (Figure 18). Of these, 101 encounters involved NRKWs and only 1 involved SRKWs. Encounters were made in all months except December and January. However, they were strongly seasonal, with 82 (80%) of the total encounters taking place in May–July (Figure 20). This peak is likely strongly biased by seasonal effort. Although overall encounters are only weakly correlated with documented effort (Figure 19; $r^2 = 0.39$, $p = 0.03$), almost half of encounters resulted from opportunistic sightings by Langara Fishing Lodge personnel, for which there is no measure of effort.

Encounters were widely distributed in western Dixon Entrance, but showed a clear concentration around Langara Island. To some extent, this probably reflects spatially biased sighting effort. All but 6 of the 102 encounters occurred in waters shallower than the 200 m isobath north of Graham Island. This pattern was particularly evident off Langara Island, where there was substantial effort in water > 200 m deep but this resulted in only two encounters. The mean depth at locations where whales were encountered was 84.9 m (SE = 8.7, range = 7–429 m, n = 102).

All 16 pods belonging to the NRKW population were identified from encounters in western Dixon Entrance (Figure 21). Pods belonging to the G clan were the most commonly observed, with G01 pod, or matrilines belonging to the pod, being particularly frequent (present in 54% of all encounters). R01 pod (R clan) was present in 30% of encounters, while pods belonging to the A clan were each present in 20% or fewer of the encounters. SRKW whales were only encountered once in western Dixon Entrance. This involved K and L pods, which were photographed off the northeast side of Langara Island on 28 May 2003. SRKW whales are rarely sighted north of Vancouver Island.

Passive acoustic monitoring provides a more realistic reflection of the seasonality and composition of Resident Killer Whale occurrence in western Dixon Entrance that is less biased seasonally. The approximate area of potential detectability of Resident Killer Whale calls on the passive acoustic monitoring system at Langara Island for selected months is shown in Figure 22. Seasonal variation in the extent of this area ranged from 192 km^2 (maximum range = 12.3 km) to 339 km^2 (maximum range = 19.8 km). NRKW calls were detected on 380 days (38%) out of the total of 993 days of monitoring between September 2009 and June 2012. The monthly occurrence of days with detections of calls is shown in Figure 23. NRKW detections occurred in all months of the year, but were most frequent from February to June and somewhat less so in September to November. NRKW calls were detected on over half of all days in

March, April, and May. April was the peak month with detections on an average of 75% of monitoring days.

Unlike SRKWs, some NRKW pods cannot reliably be distinguished by group-specific calls. However, pods in A clan, with the exception of I01, I02, I18, C01, and D01, can be confidently distinguished in most circumstances. Vocalizations made by the I01, I02 and I18 pods are unique to those three groups and were identified as IA (for A clan I pods). Likewise vocalizations made by either C01 or D01 could be clumped into a common grouping called, CD, confidently. Thus, identifications presented here are to the level of the clan, subclan (for A and G clans), and pod (for A clan only). Overall, A clan was the most frequently detected although it was absent in June and July. G clan was the next most frequently detected, followed by R clan (Figure 24). Both subclans of A clan and G clan were detected in most months of the year, with the AB subclan being especially frequent in March to May (Figure 25). Of the pods in AA subclan, A01 was most frequently detected, though almost solely between January and May (Figure 26). A04 and A05 groups were only occasionally detected, and only between January and April. Of the pods in AB subclan, IA groups were most frequently detected, followed by the CD and H01 pods. Overall, of the pods detected from A clan, IA groups were detected in 40% of A clan detection days followed closely by the A01 pod in 33% of A clan detection days. Although detected less than IA and A01 pods, CD and H01 pods were detected far more than the B01, A04, and A05 groups. Seasonally, IA pods were detected primarily between March to May as well as after the summer during the August to November period. CD and H01 groups followed a similar seasonal pattern as the IA groups, and the A04 and A05 groups followed a similar seasonal pattern to the A01 groups.

Durations of acoustic encounters (periods of consecutive acoustic samples with detections of the same call repertoire(s) and with gaps of < 5 h; see Methods) are summarized by month in Figure 27. Acoustic encounters with NRKWs had an overall mean duration of 8.41 h (SE = 0.52, range 1–77 h). Durations were significantly longer in winter and spring (mean = 9.81 h, November–May) than summer and fall (mean = 4.73 h, June–October, Welch's t test, $t = 6.18$, $p < 0.001$).

Foraging Behaviour

A total of 96 predation events by NRKWs, 80 of which had confirmed prey species identification, were documented in western Dixon Entrance during 1997–2014. The locations of these kills by species is shown in Figure 28. Only two prey species were identified – 79 Chinook Salmon and 1 Pacific Halibut. Predation events were concentrated in waters extending about 20 km east of Langara Island, which is where most survey effort was focused. Mean water depth at locations of predation events was 96 m (SE = 9.0, range = 13–459 m). The majority of predation events took place in depths of <100 m, but 23% occurred in depths of >100 m. Ten percent of predation events were in depths of > 200 m, but these were within a few miles of the 200 m isobath.

Chinook Salmon eaten by Killer Whales in western Dixon Entrance were composed of a mixture of stocks from a wide range of river systems from northern British Columbia to California (Figure 17). Stock composition analysis using DNA microsatellites revealed at least 14 different stocks in the 74 Chinook samples analyzed. South Thompson, part of the Fraser River system, was the single most important stock, representing 31% of samples, while stocks from the Nass and Skeena River systems in northern BC accounted for 13% of the samples. Rivers on the outer coast of Washington, Oregon and California accounted for 45% of the Chinook samples. The most important of these outer coast systems were the Columbia River system (23%) and North & Central and South Oregon coastal stocks (15%).

Significance of western Dixon Entrance as Resident Killer Whale habitat

Western Dixon Entrance is clearly important habitat for NRKWs throughout the year but especially in late winter and spring. NRKWs were detected acoustically at Langara Island on an average of more than half of the days in each of March, April and May, 2009–2012. At this time of year, NRKWs are mostly absent from their summer core area and only designated Critical Habitat in Johnstone Strait off northeastern Vancouver Island (see Figure 7 in Ford 2006). There is no other known area within the range of the population that is frequented as often and regularly by NRKW groups as western Dixon Entrance.

Pods, and the clans with which they are affiliated, occurred in significantly different proportions in western Dixon Entrance compared to the Johnstone Strait Critical Habitat area. The presence of the three clans in photo-identification encounters shows highly significant differences between these two areas ($G = 158.5$, $p < 0.001$), with A clan pods being more commonly encountered in Johnstone Strait and G and R clan pods being more common in western Dixon Entrance (Figure 29). Although all 16 NRKW pods were identified in each area, many pods, particularly most of those belonging to the AB subclan, G clan and R clan, were present in a far greater proportion of encounters in western Dixon Entrance than in Johnstone Strait (Figure 30). These clans and subclans were also detected frequently on the Langara Island acoustic recorder. Certain pods that are rarely encountered in Johnstone Strait at any time of year were often encountered in western Dixon Entrance. For example, three pods in the A clan (AB subclan), I01, I02 and I18, are typically among the least frequently encountered groups in the NRKW population. On average, the three pods were present in only 1.4% of encounters in the Johnstone Strait critical habitat area, but they were present in 18.4% of encounters in western Dixon Entrance (Figure 30). Similarly, calls of these pods, or subgroups of these pods, were present acoustically on 31% of the total days with NRKW acoustic detections off Langara. From a critical habitat perspective, western Dixon Entrance would appear to be far more relevant to these and several other NRKW pods than is the Johnstone Strait area.

Western Dixon Entrance is an important foraging area for NRKWs, which target Chinook Salmon selectively. All but one of the 80 kills identified from NRKW predation in the area were of this species. Western Dixon Entrance has long been known as a productive commercial trolling ground for Chinook (Milne 1964) as well as an important area for recreational Chinook fishing (Winther and Beacham 2006; Gardner Pinfold 2010). It is important feeding area for Chinook, and is situated on migratory routes for a wide variety of Chinook stocks from numerous river systems along the west coast of North America (Healey 1991; Winther and Beacham 2006). The prolonged durations of acoustic encounters with NRKWs on the Langara Island recorder suggest that the animals regularly make use of the habitat, likely for foraging, rather than just transiting the area. Western Dixon Entrance is the only area within the range of NRKWs that is known to be occupied with such frequency and for such extended periods during late winter and spring, although southwestern Vancouver Island is also relatively important at that time of year.

3.3. HABITATS OF SPECIAL IMPORTANCE

Critical habitat is defined in the Species at Risk Act (S.C. 2002, c.29) (SARA) as “the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species’ critical habitat in the recovery strategy or in an action plan for the species”. The SARA defines habitat for aquatic species at risk as “spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced.” [s. 2(1)].

The goal of the Recovery Strategy for Resident Killer Whales (Fisheries and Oceans Canada 2011) is to “ensure the long-term viability of Resident Killer Whale populations by achieving and maintaining demographic conditions that preserve their reproductive potential, genetic variation, and cultural continuity”. Among the four principal objectives to achieve this goal, was to “Protect critical habitat for Resident Killer Whales and identify additional areas for critical habitat designation and protection”. The Recovery Strategy did not fully identify critical habitat because insufficient information was available at that time. Instead, two areas were identified as partial critical habitat, one for each Resident Killer Whale population (as shown in Figure 4). These existing critical habitat areas are used extensively during summer and fall but are mostly unoccupied during winter and spring. Also, for the NRKW critical habitat, a substantial portion of the population seldom or rarely uses the critical habitat area. A Schedule of Studies was developed in the Recovery Strategy, which called for “year-round comprehensive surveys to identify areas of occupancy” in order to “identify key feeding areas throughout the year to determine whether they should be proposed as additional critical habitat”. The subsequent draft Action Plan for Resident Killer Whales (Fisheries and Oceans Canada 2015a) includes several high priority actions related to the identification of additional critical habitat.

We propose that the two additional areas detailed above – southwestern Vancouver Island and western Dixon Entrance – are habitats of special importance that potentially meet the requirement for designation as critical habitat under the SARA for the SRKW and NRKW populations. Following recommended guidelines for the identification of critical habitat (Fisheries and Oceans 2015b), in this section we describe the biophysical functions, features and attributes of these potential critical habitat areas, then delineate them geographically.

3.3.1. Biophysical functions, features and attributes of critical habitat

As noted earlier, seasonal distribution and movement patterns of Resident Killer Whales are strongly associated with the availability of their preferred prey, Chinook Salmon, and secondarily, Chum Salmon (Ford 2006; Ford and Ellis 2006; Ford et al. 2010; Hanson et al. 2010a). Thus, habitats that are important for the survival and recovery of Resident Killer Whales are those that provide for profitable foraging on these key prey species. As described in Section 1.2, foraging occupies the greatest portion of the activity budget of Resident Killer Whales. Other activities, including resting and socializing, take place between foraging bouts and the locations of such activities are not determined by any particular feature of the whales' habitat. The only activity that is strictly associated with particular geographic locations is beach rubbing by NRKWs, which only takes place at specific traditional sites (Ford 2006).

Potential critical habitats off southwestern Vancouver Island and in western Dixon Entrance are both highly productive areas for Chinook and other salmonids, which is the most important feature that supports the function of feeding by Resident Killer Whales. Both areas are characterized by nutrient-rich waters resulting from strong tidal mixing and upwelling (Thomson 1981; Perry et al. 1983; McFarlane et al. 1997), which drives productivity of prey species favoured by Chinook Salmon – primarily Pacific herring, Pacific sand lance, and euphausiids (Healey et al. 1990; Healey 1991).

The functions, features and attributes of these potential critical habitat areas are summarized in Table 1.

To delineate critical habitat geographically within the southwestern coast of Vancouver Island and western Dixon Entrance areas, the “Bounding Box Approach” (BBA) was chosen as the most appropriate in both cases. This approach is used “to identify an area frequented by the species as the ‘bounding box’ within which the critical habitat features are found” (Fisheries and Oceans 2015b). For both areas, a bounding box was drawn to include locations of the majority of encounters with Resident Killer Whales as well as the majority of predation events. The seaward boundary in both cases was established by the general location of the 200 m isobath, beyond which encounters with Resident Killer Whales and predation events were rare. More specific details regarding critical habitat boundaries in each of the two candidate areas are described in the following sections.

Southwest Vancouver Island

The boundaries for the proposed critical habitat off southwestern Vancouver Island are illustrated in Figure 31A. This eastern boundary is contiguous with the western extent of existing critical habitat at the entrance to Juan de Fuca Strait. The southern boundary is formed by the Canadian Exclusive Economic Zone border and extends to the 200 m isobath. The northern boundary is a line perpendicular to the coastline starting at Quisitis Point (48°59.73'N, 125°40.12'W) that also extends seaward to the 200 m isobath (48°41.72'N 126°17.85'W). The western boundary is a straight line joining the offshore extent of the northern and southern boundary, roughly paralleling the 200 m isobath. The eastern boundary is the coast of Vancouver Island, except for a straight line between Amphitrite Point on the north side of Barkley Sound (48°55.23'N, 125°32.39'W) and Cape Beale on the south side (48°47.17'N, 125°13.04'W).

This 'bounding box' includes 90% of encounters documented with SRKWs off the west coast of Vancouver Island and the majority of NRKW encounters. There have been several encounters documented with SRKWs in waters to the north of the northern boundary, mostly in the Clayoquot Sound area. However, the number of encounters in this area are relatively low given the high observer effort associated with a large whale watching industry based out of the town of Tofino. Similarly, the number of sightings relative to effort is very low in Barkley Sound, and this area was also excluded from proposed critical habitat. The proposed critical habitat area includes the Canadian portions of Swiftsure Bank, where acoustic monitoring revealed considerable habitat use by both SRKW and NRKW over much of the year. It also includes several other relatively shallow banks including La Perouse Bank to the northwest which, like Swiftsure Bank, are among the most productive fishing areas for Chinook and other salmonids on the North American west coast (Healey et al. 1990; McFarlane et al. 1997). It is probable that the whales make greater use of these banks than the modest number of documented Resident Killer Whale encounters might suggest – this is likely a reflection of the relatively low observer effort in those areas. The westward boundary of the proposed critical habitat area coincides with the 200 m isobath, corresponding to the beginning of the continental slope. Resident Killer Whales range extensively over the continental shelf off southwestern Vancouver Island, but they seldom venture offshore of the shelf break (Ford et al. 2000; Ford 2014). It includes waters > 100 m deep, where almost half of predation events were documented. It also includes the locations near the shelf break where NRKWs have been observed to prey on Sablefish, a rarely observed but potentially important prey species. The area of this proposed critical habitat is 5025 km^2.

The range of SRKWs, primarily in winter and spring, continues to the south of this proposed critical habitat to include continental shelf waters off the west coast of Washington, Oregon and northern California, (Krahn et al. 2004; Hanson et al. 2013). This area has recently been the subject of a petition initiated by the Center of Biological Diversity (2014), which seeks to have the US National Ocean and Atmospheric Administration (NOAA) revise its existing critical habitat for SRKWs to include marine waters up to approximately 75 km off the outer mainland coast from Cape Flattery, Washington, to Point Reyes, California, which they consider to constitute essential foraging and wintering areas for this population. In response, NOAA has indicated that it intends to proceed with the petitioned action to revise critical habitat for SRKWs, but further research is needed "to inform any revision and meet the statutory requirements for designating or revising critical habitat" (Federal Register 2014). The proposed critical habitat extension in Canadian waters that is delineated here would be contiguous with this anticipated future extension of critical habitat off the US coast.

West Dixon Entrance

The boundaries for the proposed critical habitat in western Dixon Entrance are shown in Figure 31B. It includes most coastal waters off the north side of Graham Island out to the 200 m isobath, except for shallow areas of Naden Harbour, Massett Inlet, and McIntyre Bay. The western boundary is delineated by a line extending from Meares Point on Graham Island (54°11.06'N, 133° 01.56'W) to Iphigenia Point on the south side of Langara Island (54°11.42N, 133°00.76'W) and a line extending from Langara Point on Langara Island (54°15.37'N, 133°03.49'W) to a point 1.8 km (1 nm) to the north (54°15.99'N, 133°03.49'W). The northern boundary of the area extends approximately 90 km to the east from this point to a position 13 km north of Rose Point on Graham Island (54°16.03'N, 131°40.43'W). A straight line from this position to Rose Point forms the eastern boundary of the proposed area. Excluded from this area are shallow waters of Virago Sound (south of a line from Jorey Point (54°45.57'N, 132°34.30'W) to Cape Edensaw (54°05.86'N, 132°26.25'W)) and McIntyre Bay (south of a line from Striae Island(54°05.48'N, 132°15.39'W) to Rose Point). The total area of this proposed critical habitat is 1394 km^2.

This proposed critical habitat area includes the locations of 85% of encounters and 95% of predation events documented in western Dixon Entrance (Figures 18 and 27) as well as most of the estimated zone of detectability of Killer Whale calls from Langara Island. It also includes the main area of the highly productive Chinook troll fishery to the east of Langara Island that has continued for many decades and is the location of a major recreational fishery focused on Chinook (Milne 1964; Winther and Beacham 2006). This fishing ground extends roughly 20 km east of Langara Island, and the majority of NRKW predation has been observed there. Between this fishing ground and Rose Point at the eastern extent of the bounding box, predation on Chinook Salmon has been documented at a high rate relative to effort. Whales using this area typically arrive from the east having rounded Rose Point from Hecate Strait or eastern Dixon Entrance, and depart to the east when leaving the area. They have seldom been observed to travel or forage west of Langara Island, hence this area has not been included in proposed critical habitat. The Naden Harbour and Masset Inlet, as well as the shallow inshore portion of McIntyre Bay, have been excluded as the whales do not use these areas extensively.

3.4. ACTIVITIES LIKELY TO DESTROY CRITICAL HABITAT

Examples of activities that would likely destroy critical habitat for Resident Killer Whales are described in detail in the Recovery Strategy (Fisheries and Oceans Canada 2011). Most of these also apply to the new areas of critical habitat proposed here, except for activities that would affect beaches used for rubbing by NRKWs. No rubbing beaches have been identified in either of the proposed new critical habitat areas. Rather than repeat the detailed information provided in the Recovery Strategy, activities likely to result in the destruction of the biophysical functions, features and attributes of critical habitat are summarized in Table 2.

3.5. DATA GAPS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The addition of the two habitats of special importance described here to critical habitat areas already designated for Resident Killer Whales would result in a significantly greater proportion of the critical habitat of these populations being identified. However, there are likely additional areas that would qualify as critical habitat and should be assessed in the future. Three important areas described in Ford (2006) as potential critical habitat for NRKW have not been reconsidered here for various reasons. Additional information on NRKW use of the Chatham Sound and Fitz Hugh Sound areas have been collected by CRP researchers at the Pacific Biological Station, but there remains a need to collect data on habitat use during winter and spring. The third area – Caamaño Sound – has been the focus of an additional decade of year-round survey effort, much of it through acoustic monitoring, by the North Coast Cetacean Society. These data, combined with additional encounters by CRP researchers, may be sufficient to warrant a reassessment of this area as a candidate for addition to NRKW CH in the future.

As noted in the Recovery Strategy for Resident Killer Whales and Ford (2006), an important behavioural tradition of NRKWs is rubbing on certain pebble beaches within their range, and the whales are highly susceptible to disturbance while doing so. Although several rubbing beaches are within the designated critical habitat area of Johnstone Strait and Queen Charlotte Strait, additional rubbing beaches have been identified in areas to the north on Vancouver Island as well as on the central and north mainland BC coasts. Use of these rubbing sites – which may qualify as critical habitat – should be further investigated through the use of autonomous underwater acoustic recorders.

Another area of potential critical habitat for SRKWs is northern Strait of Georgia in winter and spring. Although K and L pods spend most of their time along the outer coast at this time of year, J pod tends to remain mostly within the Salish Sea area and makes frequent excursions to the northern Strait of Georgia area. The CRP is currently investigating the pod's use of this area with autonomous underwater recorders and/or remote camera systems.

Many aspects of the functions, features and attributes of both designated critical habitats and those proposed here are inadequately understood and require further study. For example, Resident Killer Whales likely require a minimum density of Chinook Salmon in critical habitat areas in order to forage profitably, which is why they concentrate in particular Chinook 'hot spots' at certain times of year. However, the minimum threshold of Chinook density below which the whales' catch per unit effort is insufficient is unknown. Studies to estimate such a threshold would be helpful in assessment of the extent of prey reduction that might constitute the destruction of the feeding and foraging function of Resident Killer Whale Critical Habitat. Similarly, further studies are needed to better understand the types and levels of underwater sound that cause short-term and long-term effects on Resident Killer Whales. There has been considerable recent research on the noise levels in Resident Killer Whale habitats and responses of the animals to such noise (e.g., Holt et al. 2009; Williams et al. 2014; Veirs et al. 2015), but thresholds that might result in critical habitat destruction are still unclear.

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6. TABLES

Table 1. Functions, features and attributes of potential critical habitat areas off southwestern Vancouver Island and in western Dixon Entrance.

Function	Feature	Attribute
Feeding and foraging	Sufficient quantity and quality of Chinook Salmon and other important prey species	Diversity of Chinook stocks with a variety of spatial and temporal migration patterns Other species that comprise part of the RKW diet
Feeding and foraging Reproduction, socializing, resting	Acoustic environment	Ambient noise levels that allow effective acoustic social signaling and echolocation to locate prey Noise levels that do not result in loss of habitat availability or function
Feeding and Foraging Reproduction, socializing, resting	Water column	Diversity of Chinook stocks with a variety of spatial and temporal migration patterns Other species that comprise part of the RKW diet Water and/or air quality of a sufficient level so as not to result in loss of function
Feeding and Foraging Reproduction, socializing, resting	Physical space	Unimpeded physical space surrounding individual whales (minimum 200 m for SW Vancouver Island)

Table 2. Activities that are likely to result in destruction of the biophysical functions, features and attributes of critical habitat.

Threat	Activity	Effect Pathway	Function Affected	Feature Affected	Attribute Affected
Reduced prey availability	Over fishing of prey species Other activities that are detrimental to habitat of prey	Loss of prey Loss of forage fish for prey species	Feeding and foraging	Sufficient prey density, quantity and quality	Diversity of Chinook Salmon stocks with a variety of spatial and temporal migration patterns Other species that comprise part of the RKW diet
Acoustic disturbance	Vessel traffic Seismic surveys, military and commercial sonars Pile driving, underwater explosions	Chronic noise resulting in masking of communication and echolocation Acoustic disturbance resulting in disruption of behaviour or displacement from habitat	Feeding and Foraging Reproduction, socializing, resting	Acoustic environment	Ambient noise levels that allow effective acoustic social signaling and echolocation to locate prey Noise levels that do not result in loss of habitat availability or function
Environmental contaminants	Deposit of deleterious substances into marine environment	Loss of prey or reduction in prey quality Loss of water and/or air quality	Feeding and foraging Reproduction, socializing and resting	Sufficient prey quantity and quality Water column Boundary air layer over ocean surface	Diversity of Chinook stocks with a variety of spatial and temporal migration patterns Other species that comprise part of the RKW diet Water and/or quality of a sufficient level so as not to result in loss of function
Physical disturbance	Vessel traffic in close proximity to whales	Reduction of physical space available to whales	Feeding and Foraging Reproduction, socializing, resting	Physical space	Unimpeded physical space surrounding individual whales (minimum 200 m for SW Vancouver Island)

7. FIGURES

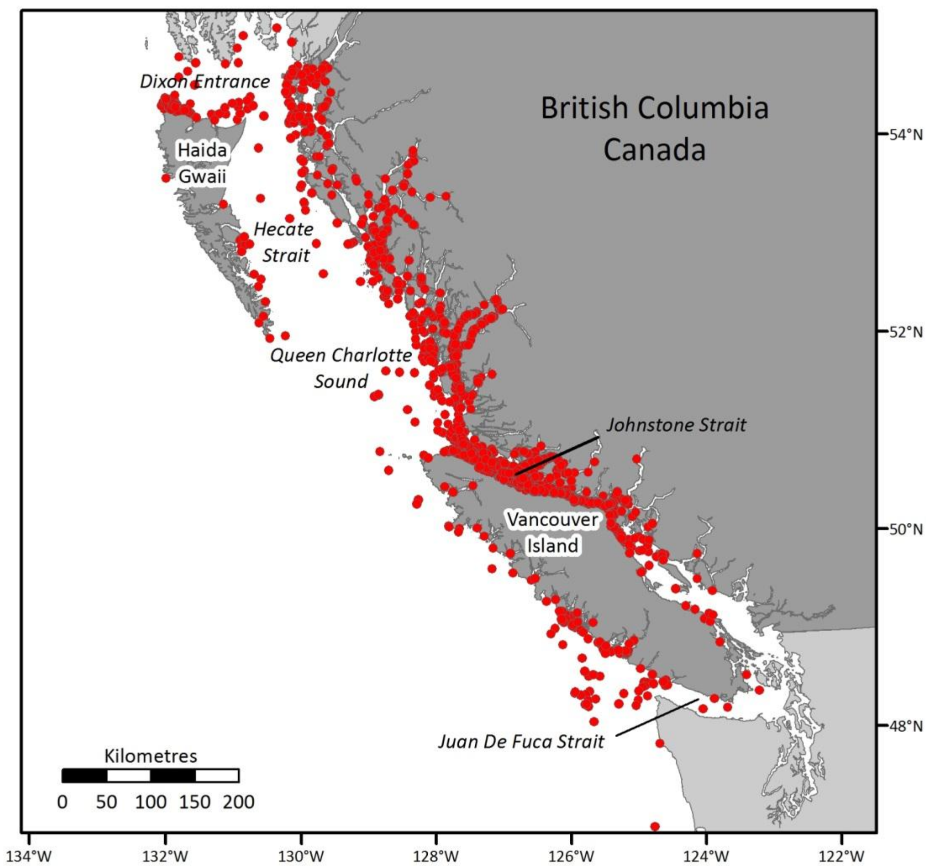


Figure 1. Locations of sightings and encounters with Northern Resident Killer Whales, 1973–2014. Encounters in central and northern southeastern Alaska are not shown. Data sources include the Cetacean Research Program, DFO (n = 6638 encounters, 1973-2014) and the BC Cetacean Sightings Network (n= 1445 sightings, 2000-2015).

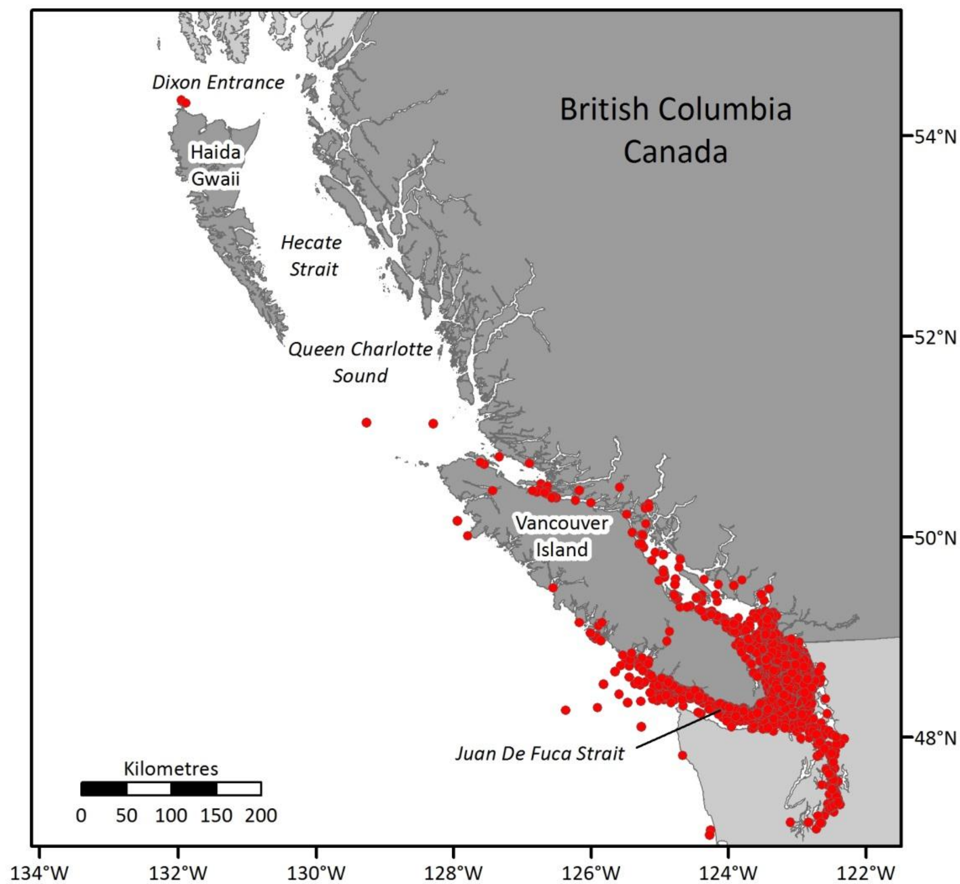


Figure 2. Distribution of sightings and encounters with Southern Resident Killer Whales. Map does not include one encounter documented in Chatham Strait, southeastern Alaska, or encounters south of Washington State. Data sources include the Cetacean Research Program, DFO (n = 1470 encounters, 1973-2014), BC Cetacean Sightings Network (n= 4180 sightings, 2000-2015), and The Whale Museum (n = 73,581 sightings, 1990-2015).

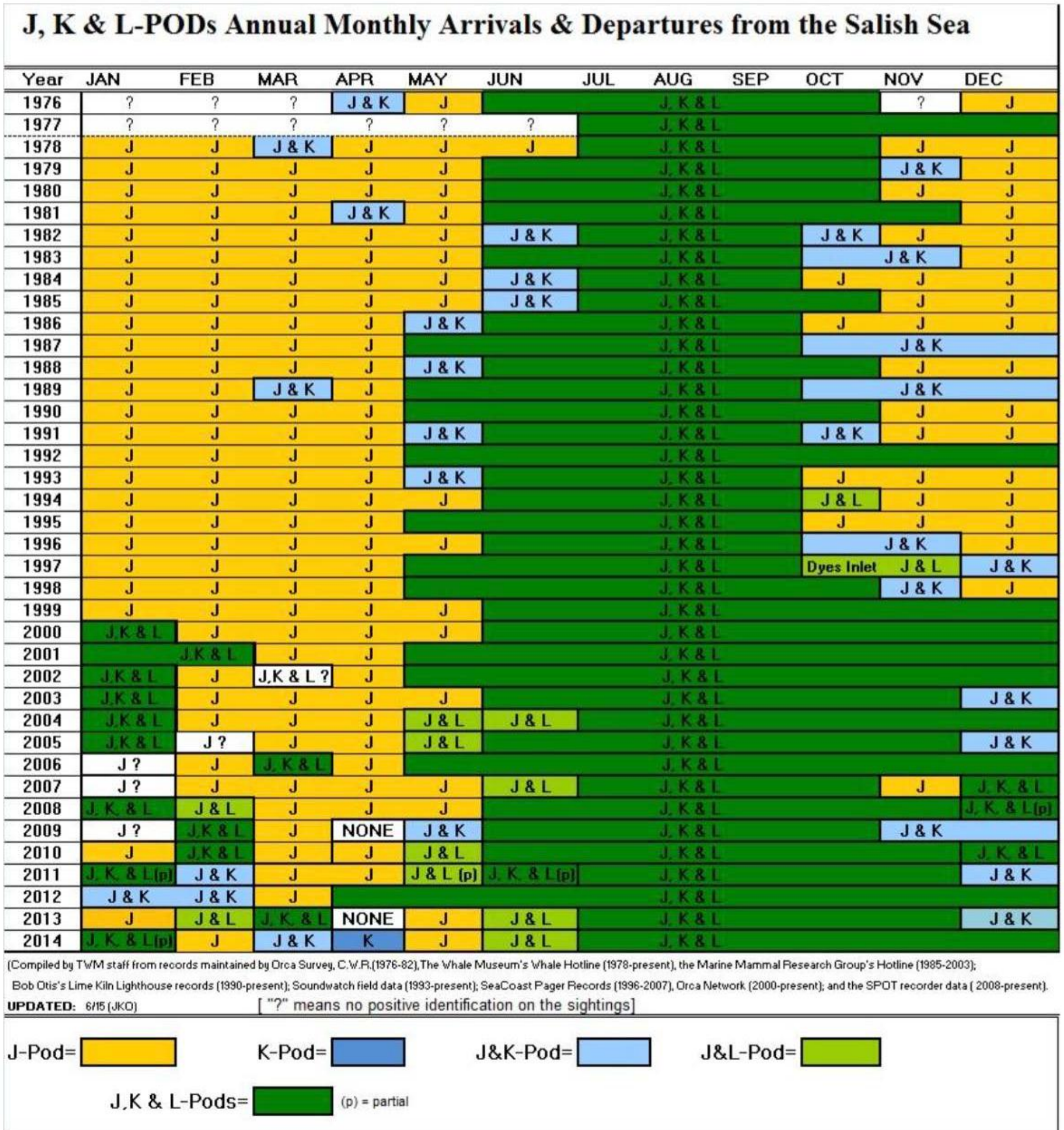


Figure 3. Monthly occurrence of the three southern resident pods J, K, and L, in the inland waters of the Salish Sea (primarily designated Critical Habitat in Canadian and US waters), 1976-2014. Figure from Olson et al. (2015[7]), reproduced courtesy of The Whale Museum, Friday Harbor, WA

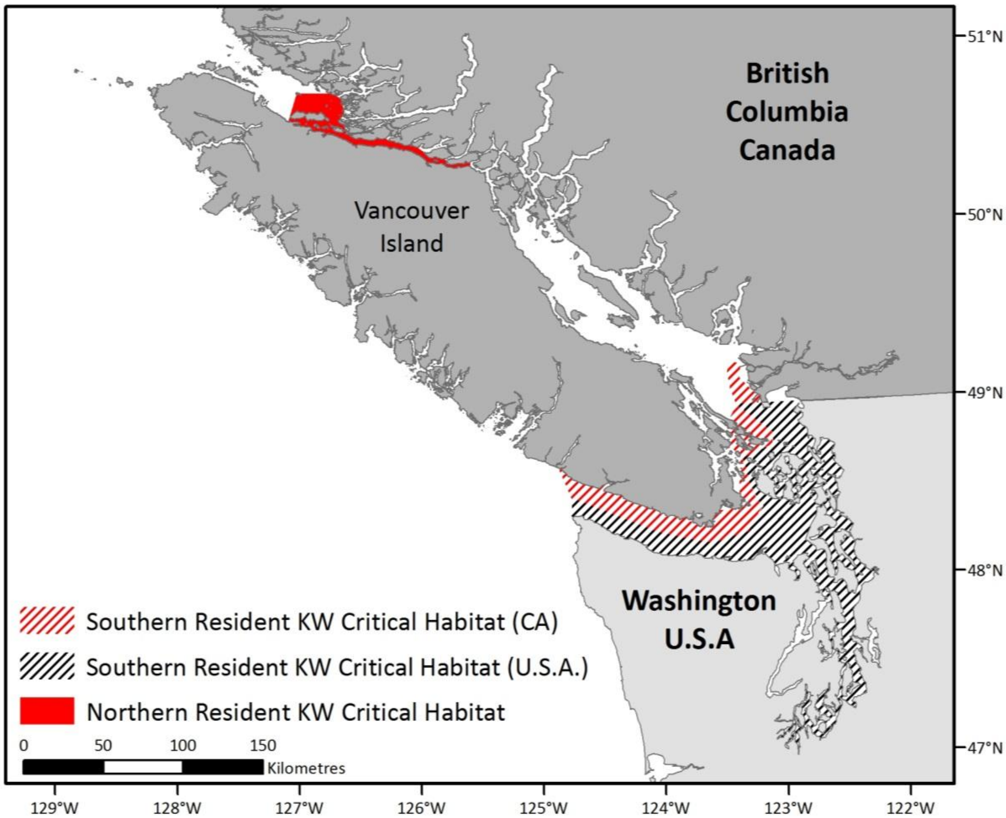


Figure 4. Critical Habitats for Southern and Northern Resident Killer Whales. Critical habitat in Canadian waters shown in red (designated in 2009), and in US waters in black (designated in 2006).

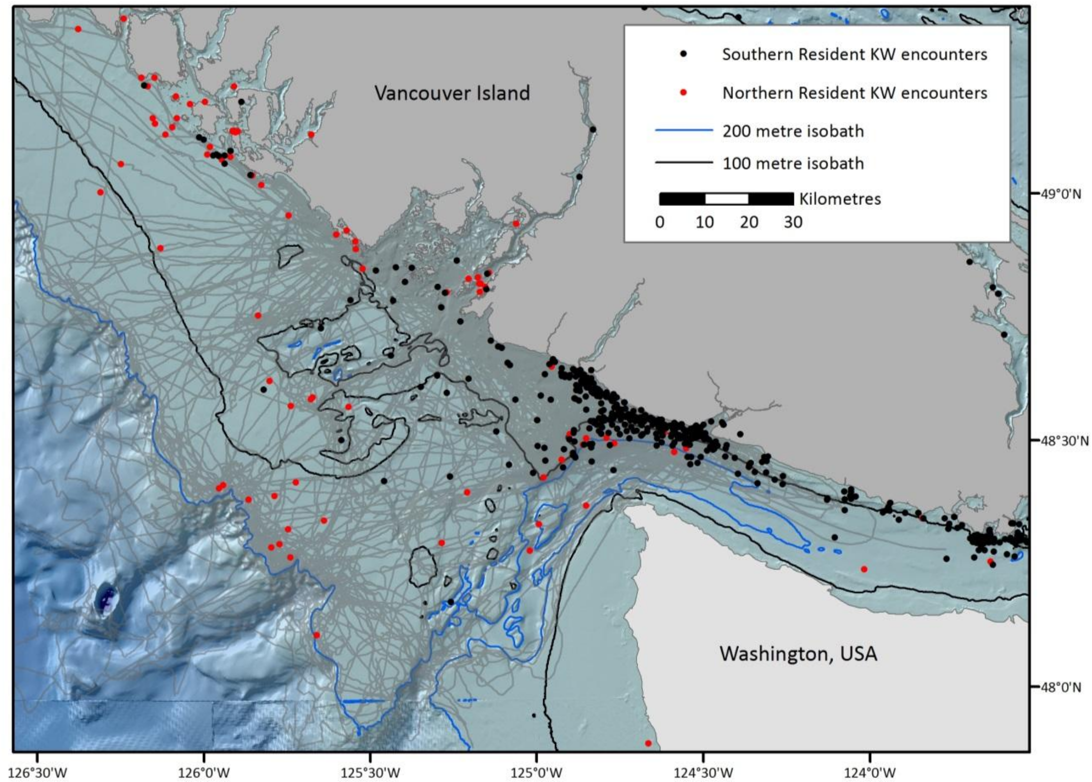


Figure 5. Locations of encounters with Southern Resident (black dots) and Northern Resident (red dots) Killer Whales in western Juan de Fuca Strait and off southwest Vancouver Island, 1974–2014. N = 196 SRKW encounters, 96 NRKW encounters. Survey effort tracklines are shown in light grey. Opportunistic sighting effort and dedicated survey effort pre-2003 not recorded.

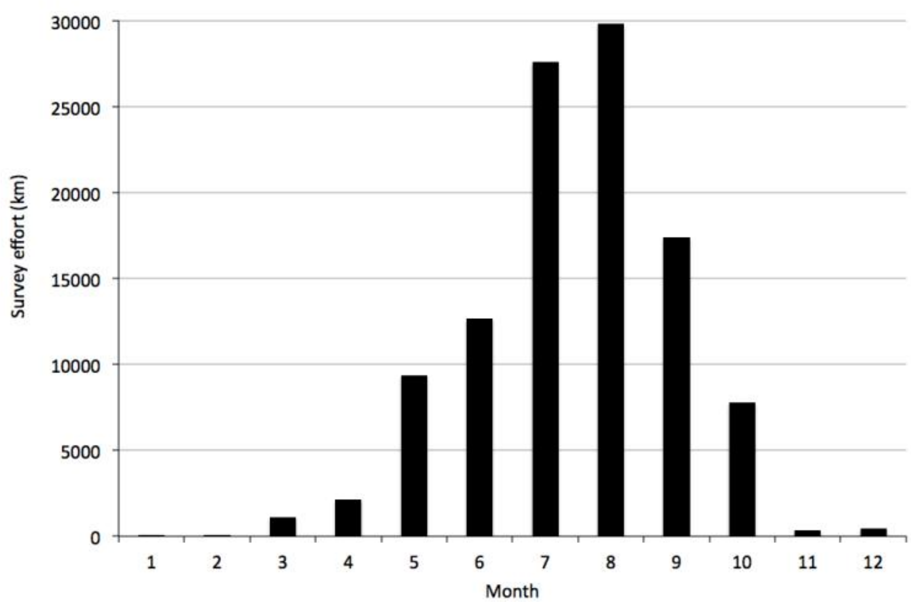


Figure 6. Monthly distribution of dedicated survey effort (km of survey trackline), southwest Vancouver Island. Area of survey effort shown in Figure 5. N = 108,729 km

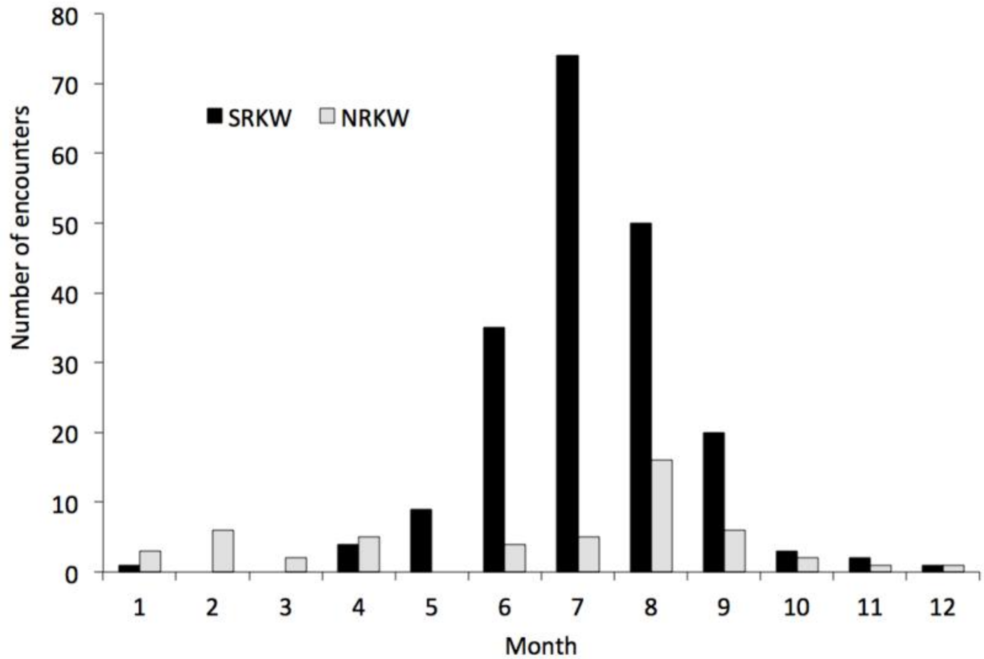


Figure 7. Total number of encounters by month with Southern Resident (SRKW) and Northern Resident (NRKW) Killer Whales off southwestern Vancouver Island (excluding Juan de Fuca Strait), 1974-2014. N = 245 encounters.

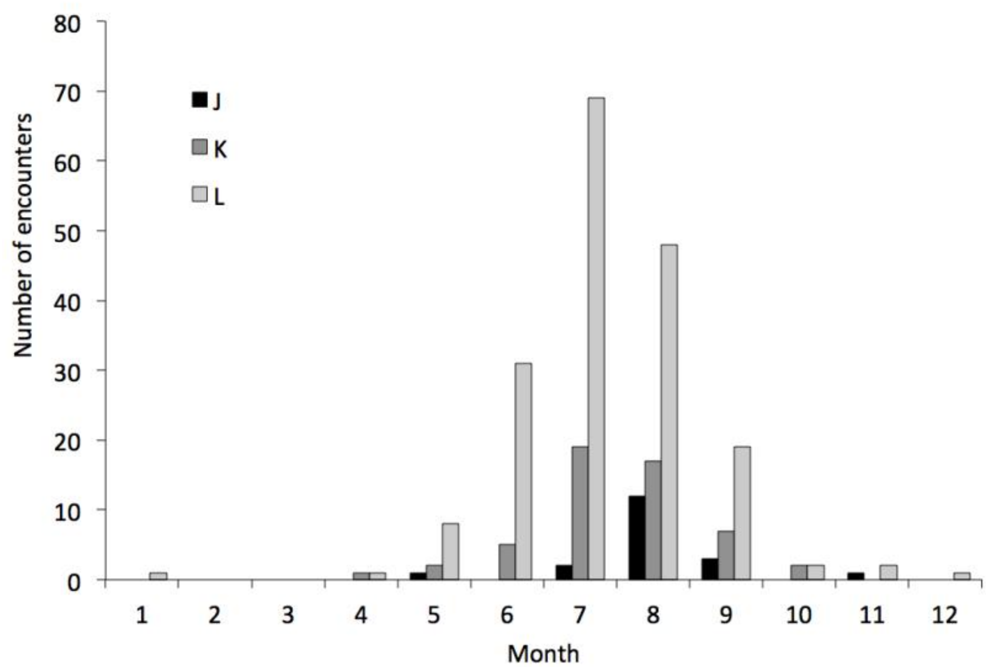


Figure 8. Occurrence of pods in SRKW encounters off southwestern Vancouver Island (excluding Juan de Fuca Strait) by month, 1974-2014. N = 196 SRKW encounters.

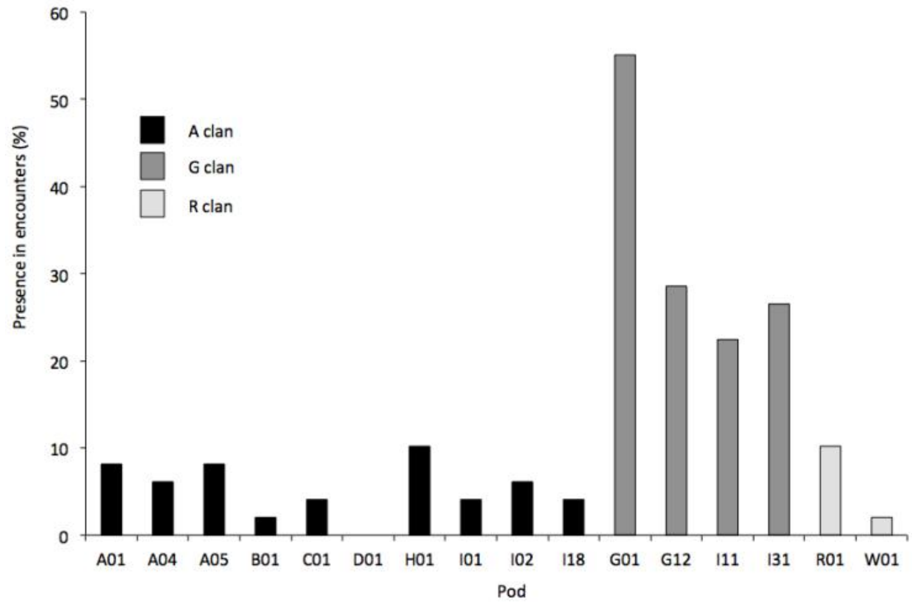


Figure 9. Presence of pods in NRKW encounters off southwestern Vancouver Island (excluding Juan de Fuca Strait), 1974-2014. N = 49 NRKW encounters. Clan affiliation of pods is shown by shading in legend.

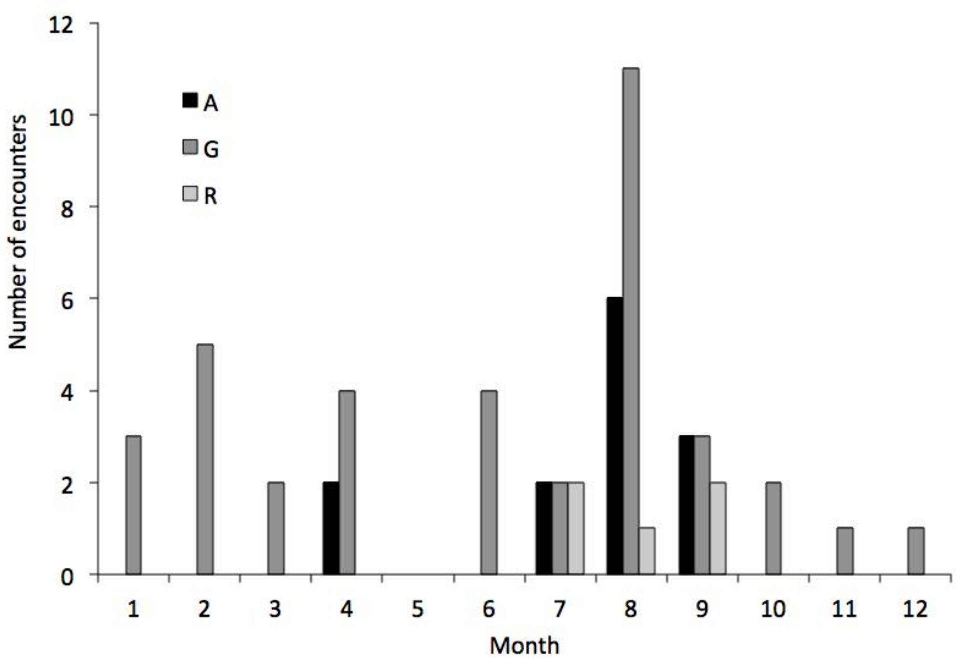


Figure 10. Occurrence of clans in NRKW encounters off southwestern Vancouver Island (excluding Juan de Fuca Strait) by month, 1974-2014. N = 49 NRKW encounters. Clan affiliation of pods is shown by shading in legend.

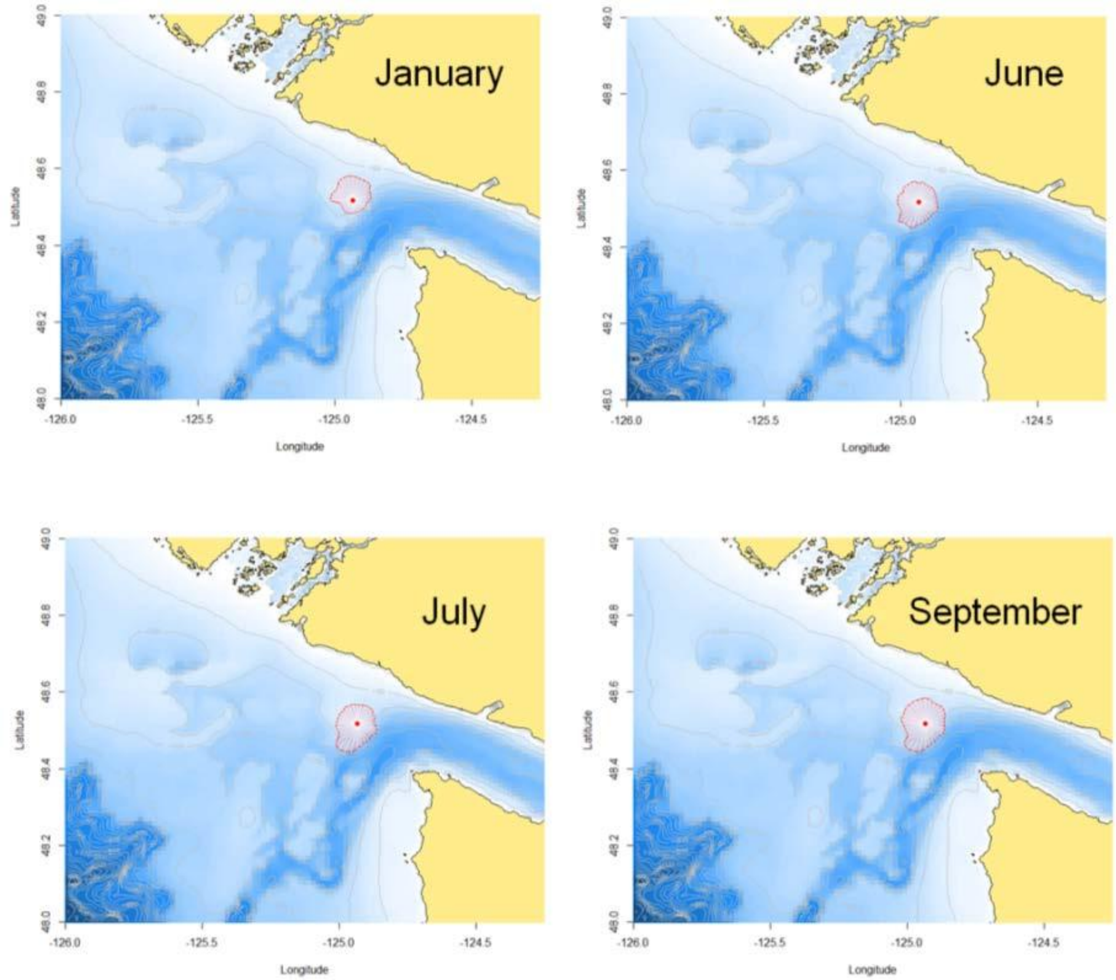


Figure 11. Estimated areas of potential detectability of Resident Killer Whale calls from acoustic recorder moored at Swiftsure Bank, for selected months, 2009-2011.

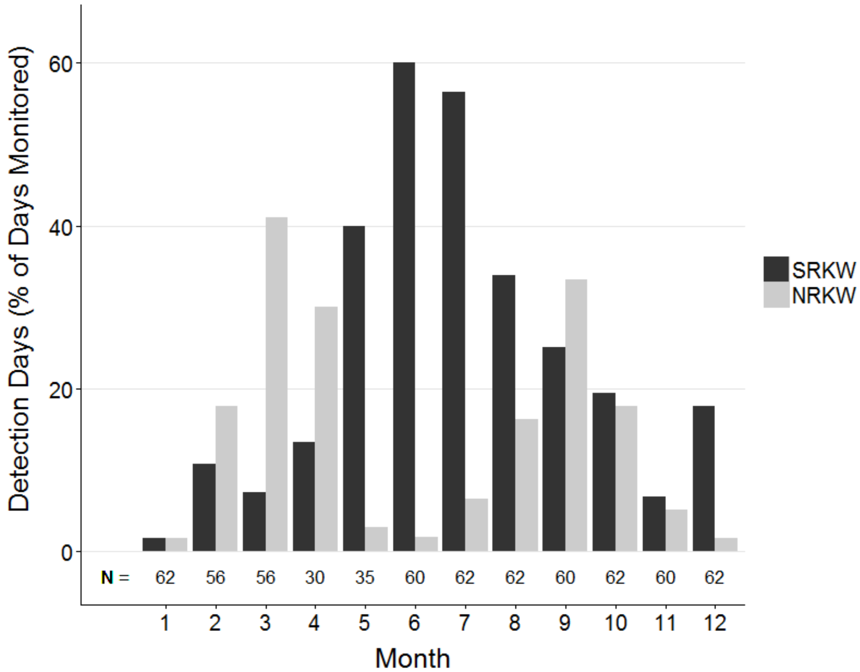


Figure 12. Monthly occurrence of acoustic detections of Southern and Northern Resident Killer Whales at Swiftsure Bank, 2009–2011. N = the cumulative total number of days monitored for each month.

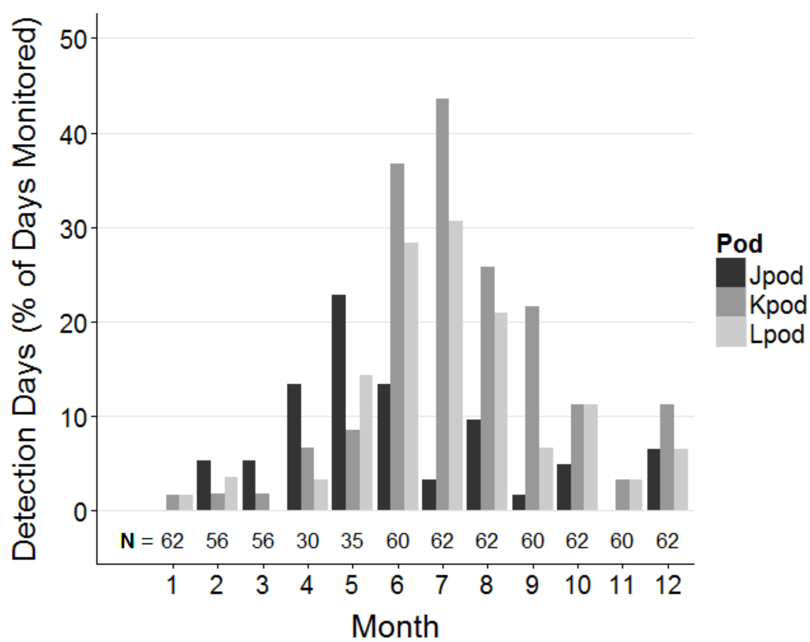


Figure 13. Monthly occurrence of acoustic detections of SRKW pods J, K and L at Swiftsure Bank, 2009–2011. N = the cumulative total number of days monitored for each month.

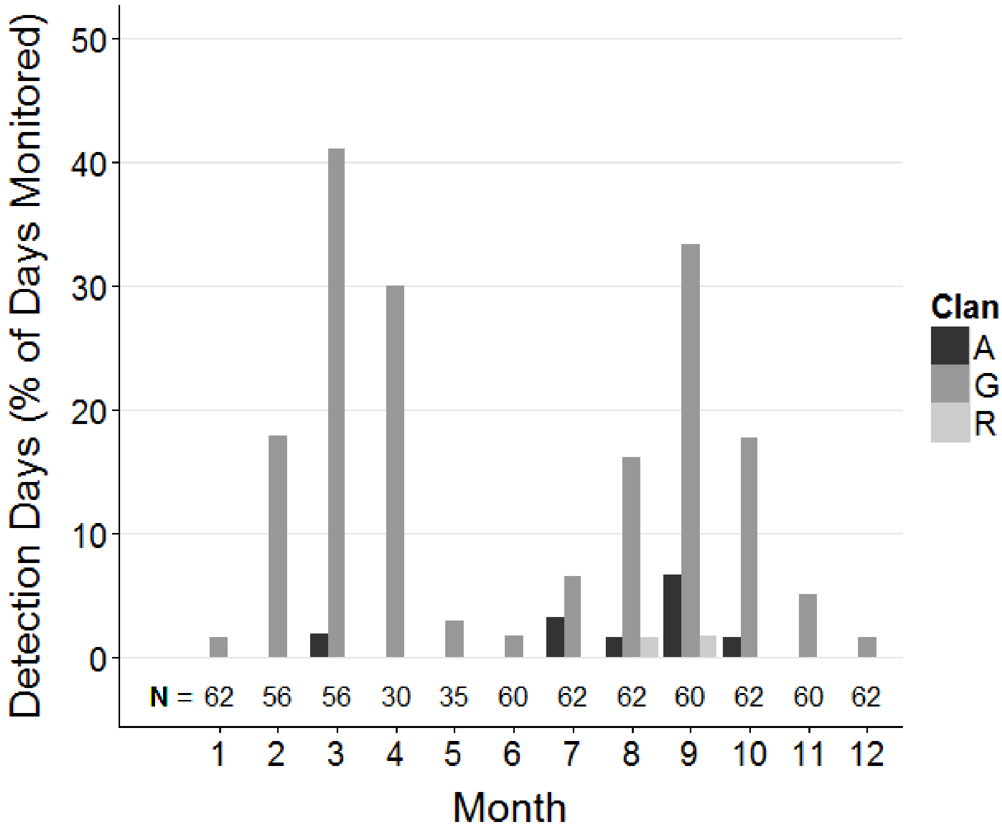
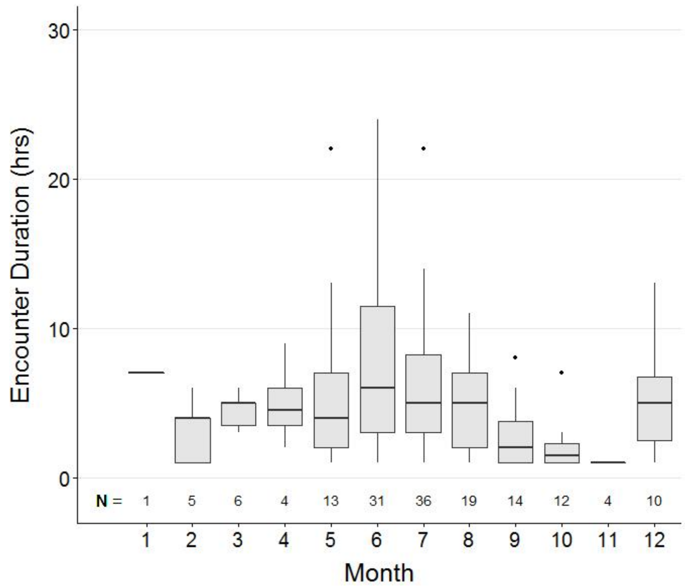


Figure 14. Monthly occurrence of acoustic detections of NRKW clans A, G and R at Swiftsure Bank, 2009–2011. N = the cumulative total number of days monitored for each month.

A.



B.

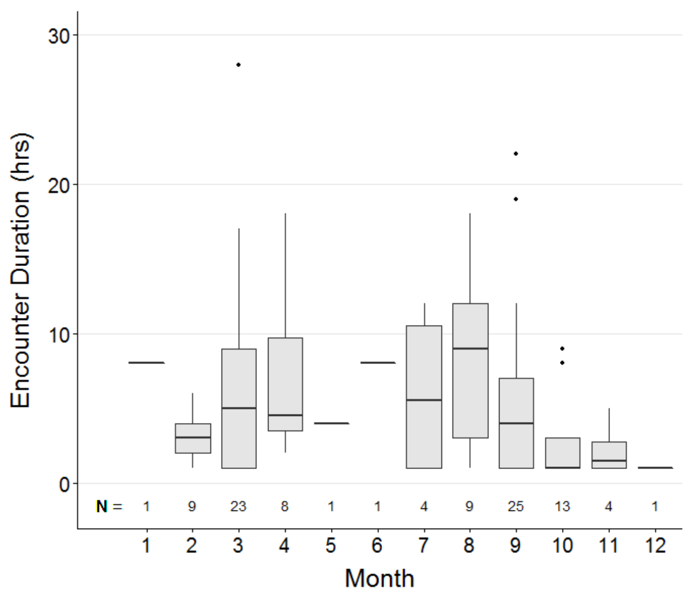


Figure 15. Acoustic encounter durations by month for SRKW (A, top panel) and NRKW (B, bottom panel) detections at Swiftsure Bank, 2009–2011. N = the number of acoustic encounters in each month. Boxes indicate the 25th –75th percentiles, black line in boxes indicates median, bars below and above box show the 10th and 90th percentiles, and black dots show outliers.

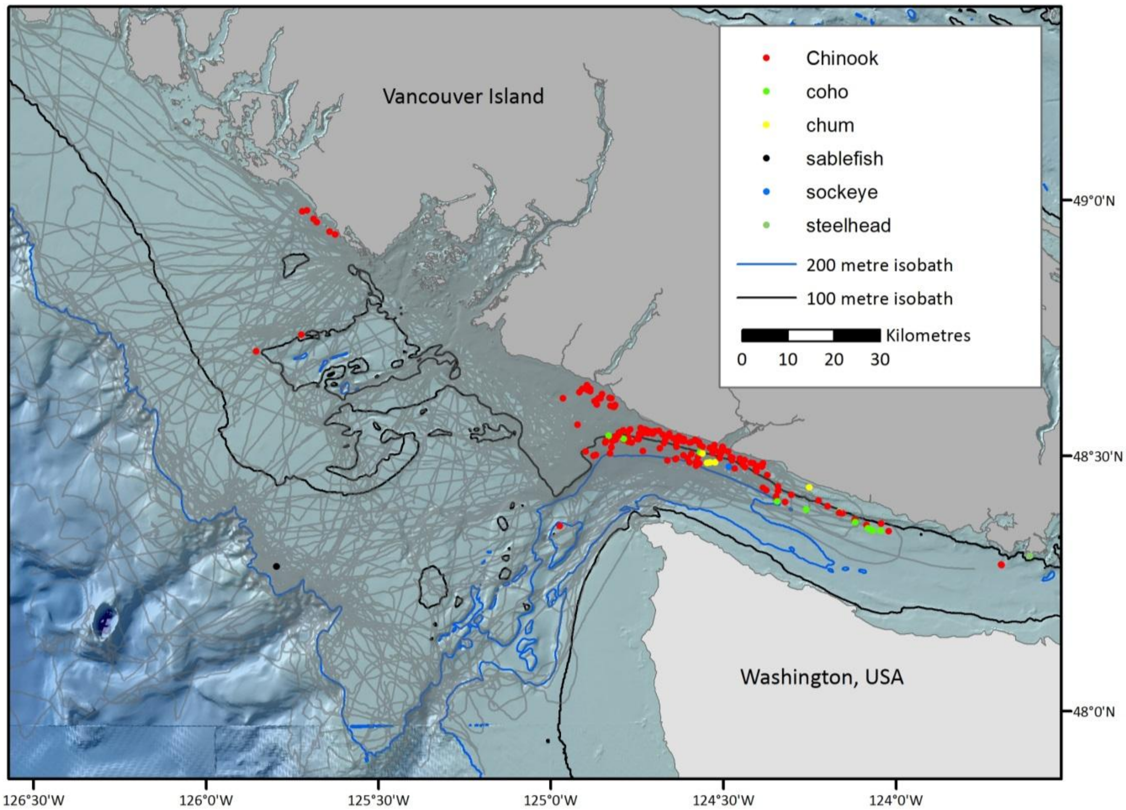
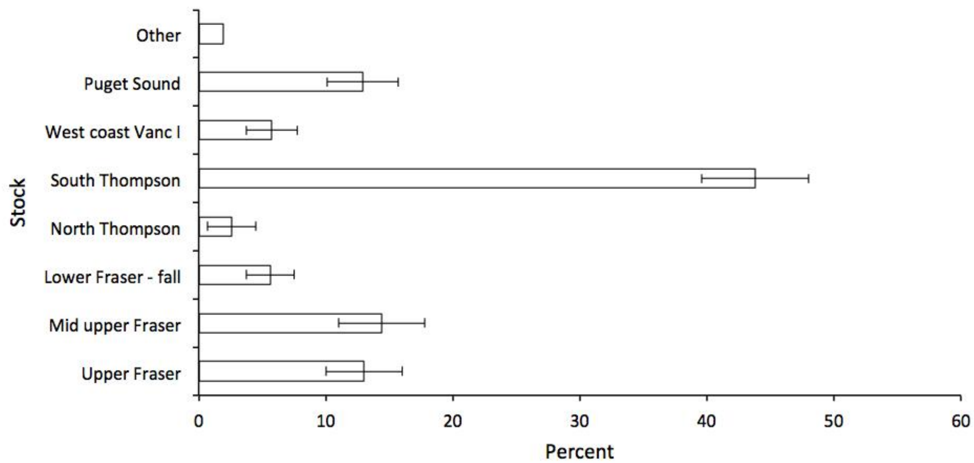


Figure 16. Locations of Resident Killer Whale predation events (n = 184) in western Juan de Fuca Strait and off southwest Vancouver Island. Identified prey species distinguished with coloured dots. Survey effort tracklines are shown in light grey.

A. SW Vancouver Island



B. W Dixon Entrance

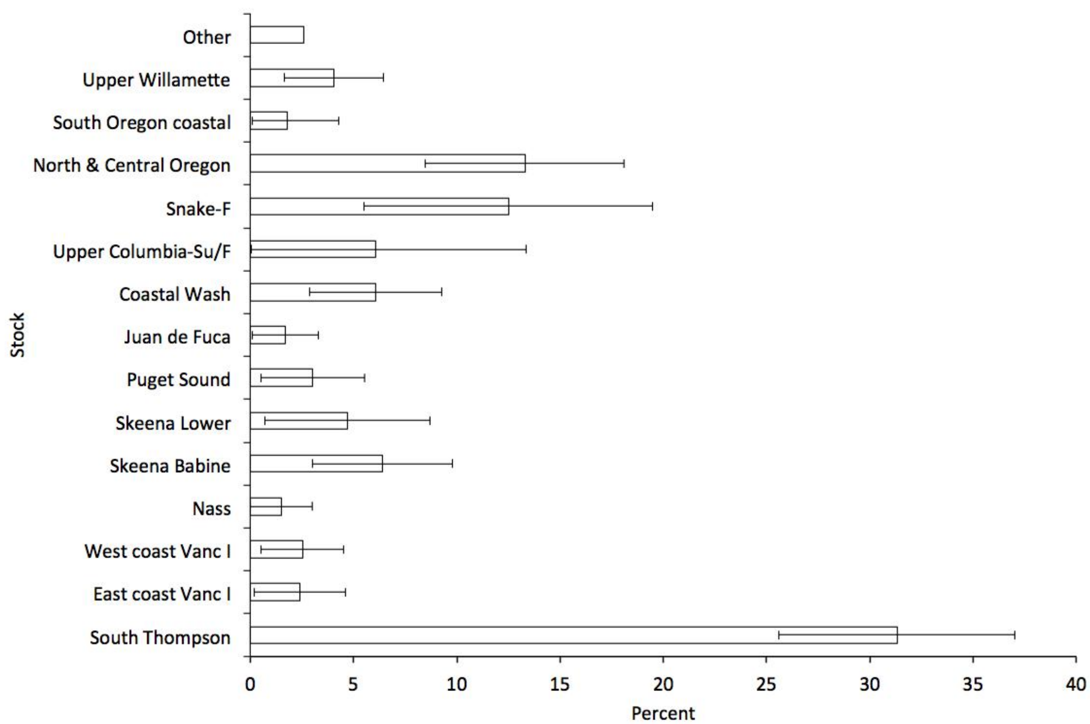


Figure 17. Stock proportions (±SE) of Chinook Salmon caught and consumed by Resident Killer Whales off southwest Vancouver Island (A, upper panel; n = 150), and in western Dixon Entrance (B, lower panel; n = 74). Note that scales on X axes differ between graphs.

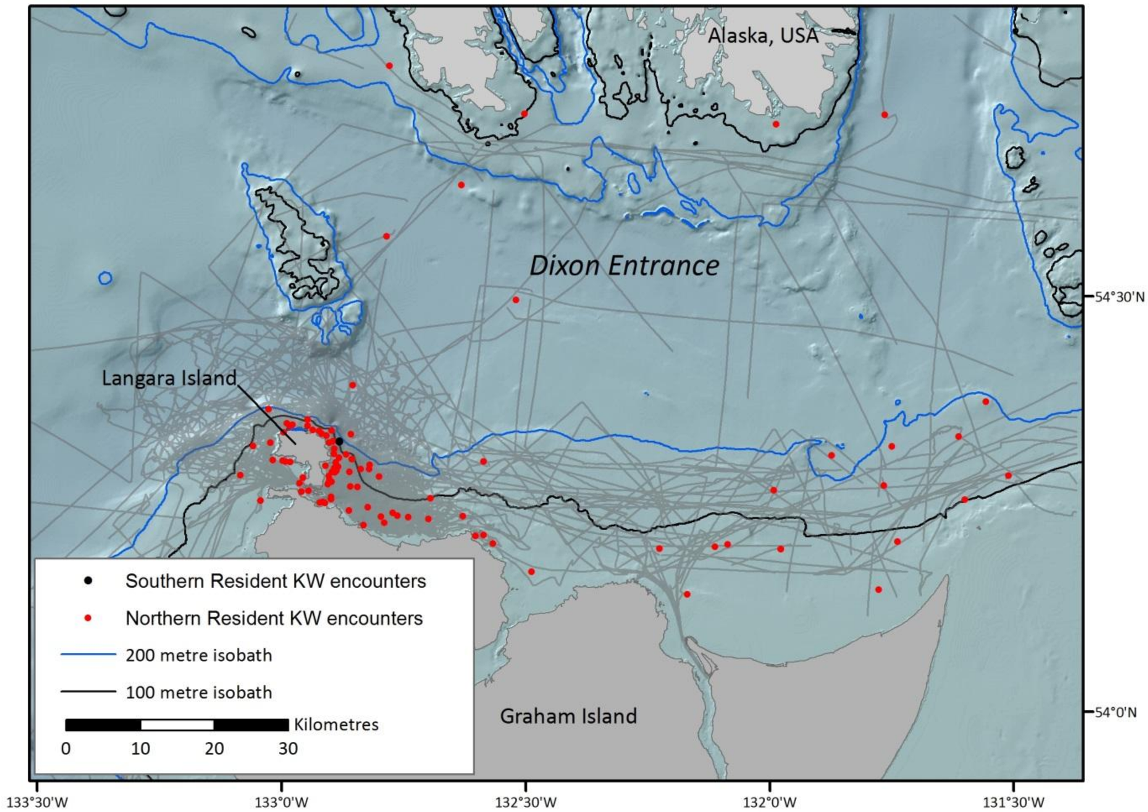


Figure 18. Locations of initial encounters with Northern Resident (red dots) and Southern Resident (black dot) Killer Whales in western Dixon Entrance, 1992–2014. N = 102 NRKW encounters, 1 SRKW encounter. Survey effort tracklines for 2003–2014 are shown in light grey. Opportunistic sighting effort and dedicated survey effort pre-2003 not recorded.

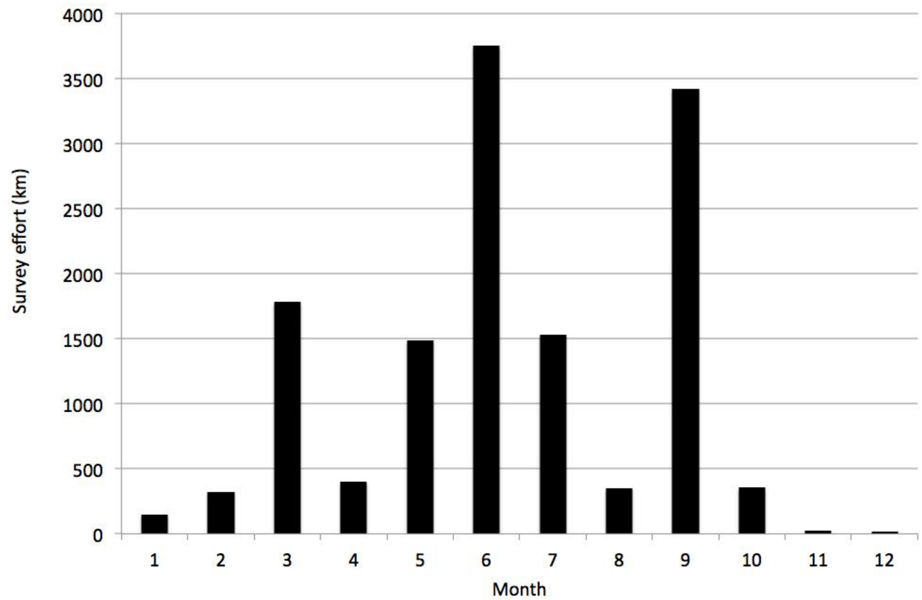


Figure 19. Monthly distribution of dedicated survey effort (km of survey trackline), west Dixon Entrance, 2003–2014. Area of survey effort (n = 13,577 km) shown in Figure 18.

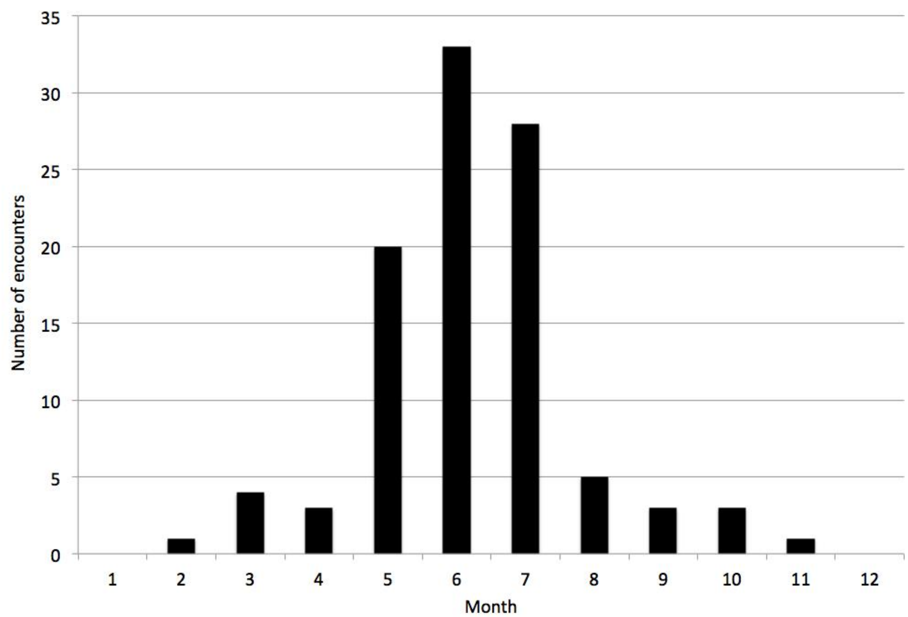


Figure 20. Total number of encounters by month with Northern Resident Killer Whales in west Dixon Entrance, 1993–2014. The single encounter with SRKW occurred in May and is not shown. N = 102 encounters.

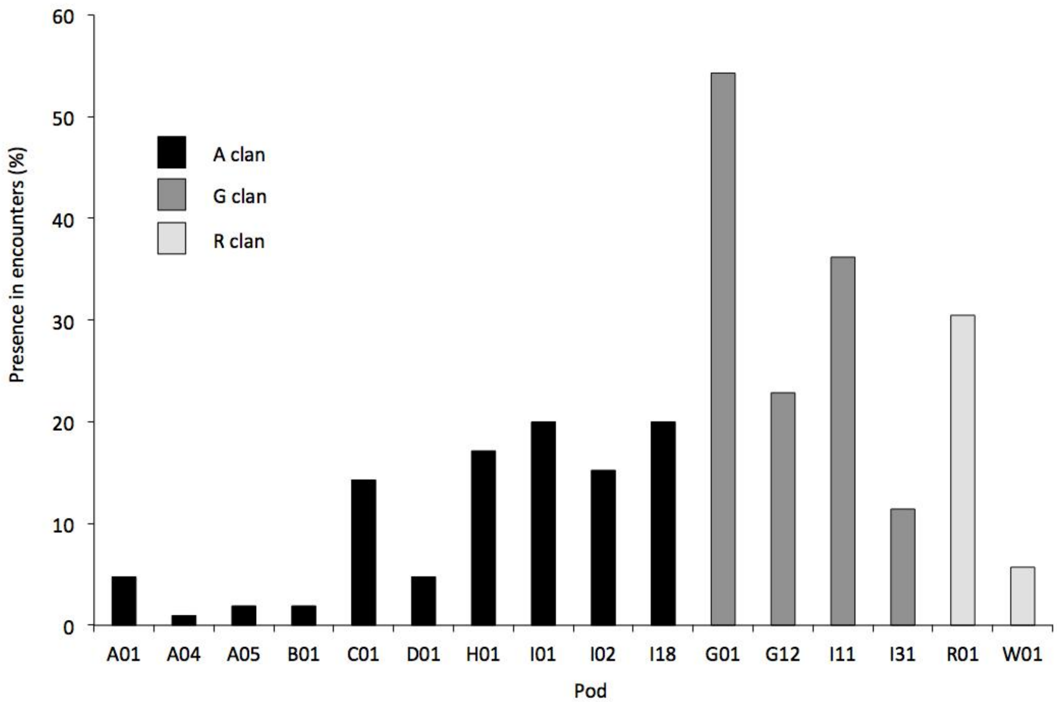


Figure 21. Presence of pods in Northern Resident encounters in west Dixon Entrance, 1993–2014. N = 102 encounters. Clan affiliation of pods is shown by shading in legend.

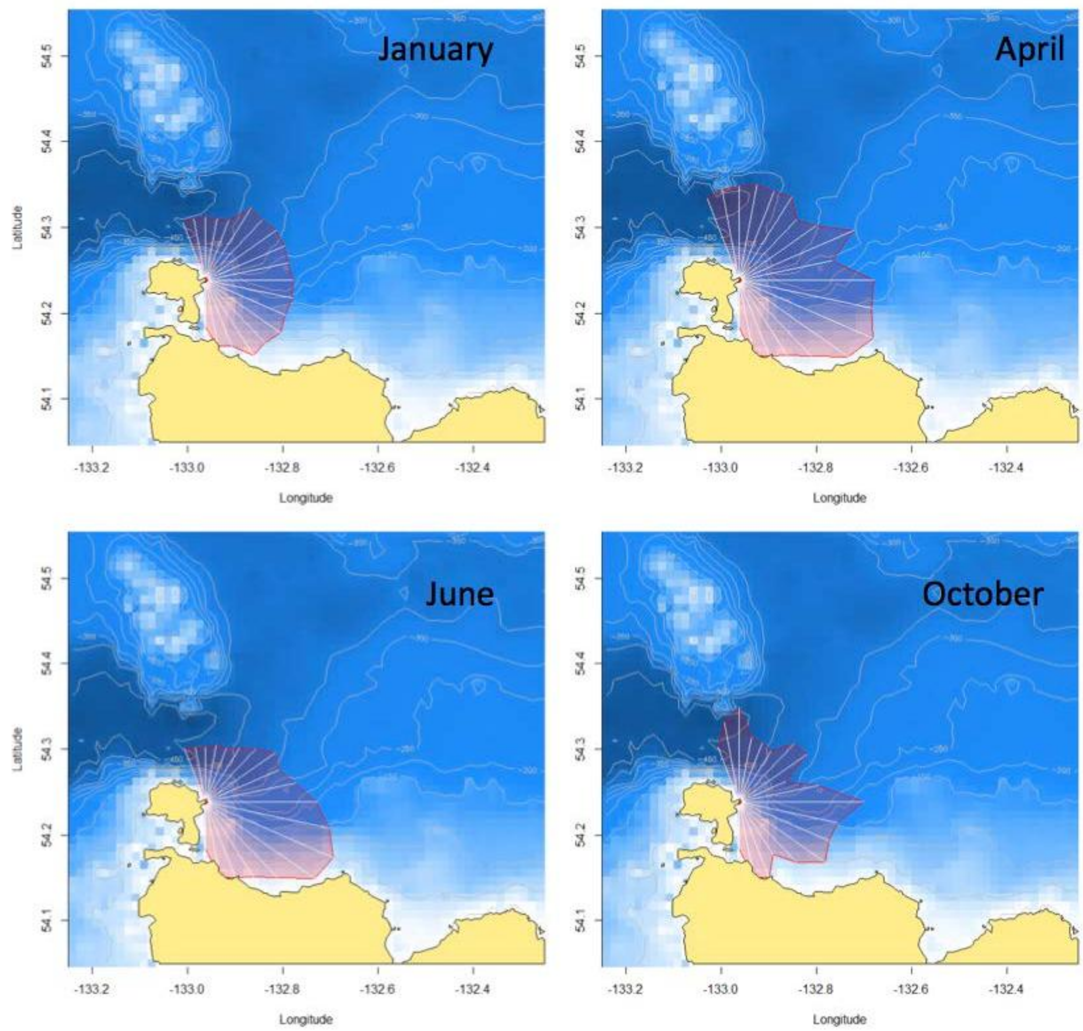


Figure 22. Estimated areas of potential detectability of Resident Killer Whale calls from the underwater recording system at Langara Island, for selected months 2010–2011.

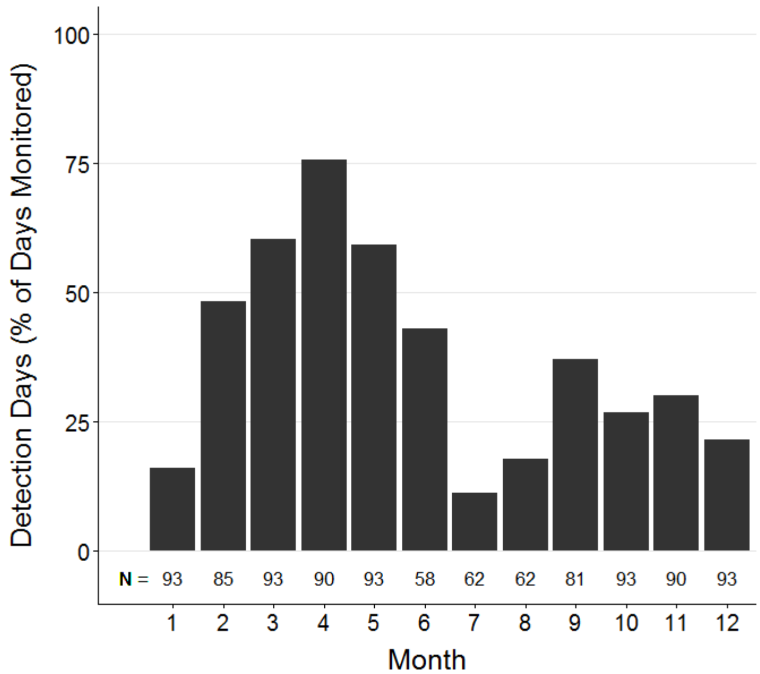


Figure 23. Proportion of days monitored acoustically that the Northern Resident Killer Whales were detected at Langara in each month, 2009–2012. N = cumulative total number of days monitored for each month.

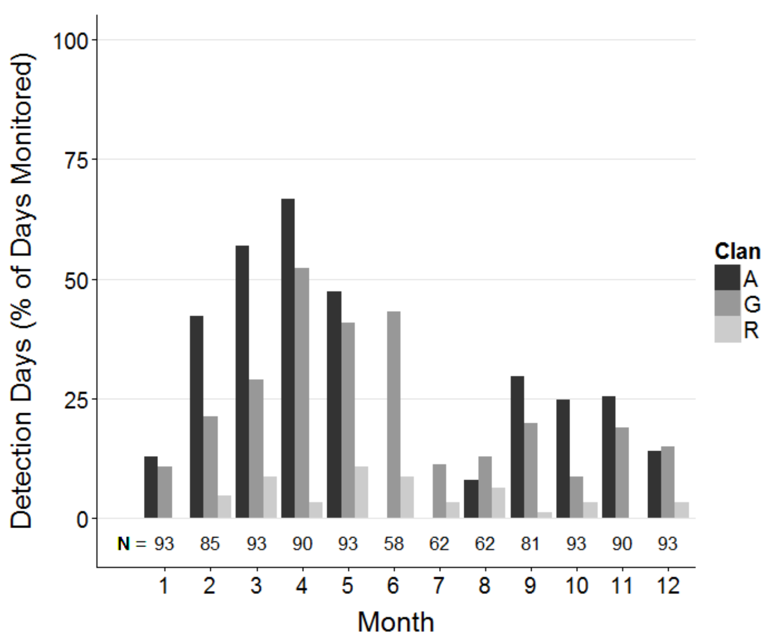


Figure 24. Proportion of days monitored with detections of the three Northern Resident clans A, G and R, for each month at Langara Island, 2009–2012. N = cumulative total number of days monitored for each month.

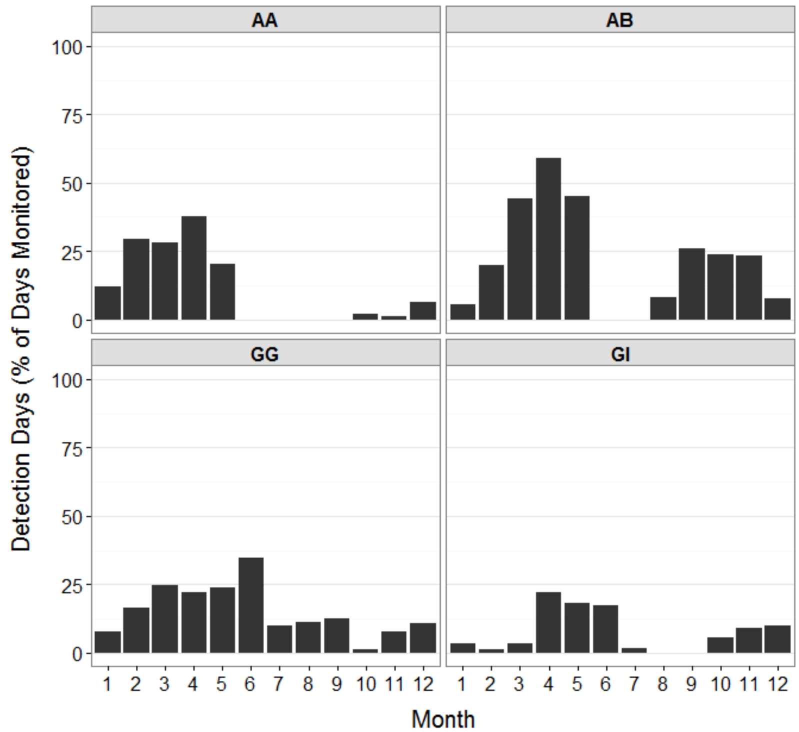


Figure 25. Proportion of days monitored that the subclans of Northern Resident clans A (AA and AB subclans) and G (GG and GI subclans), were detected at Langara Island in each month, 2009-2012.

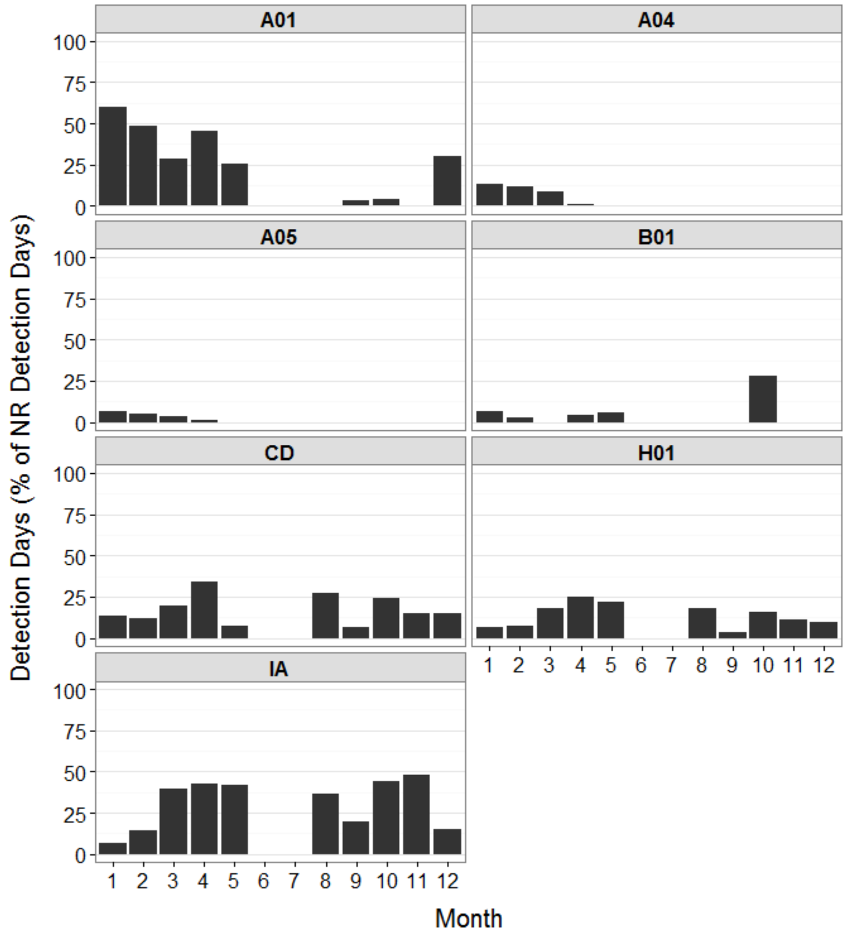


Figure 26. Percentage of total monthly NRKW detection days that each A clan pod grouping was present, 2009-2012.

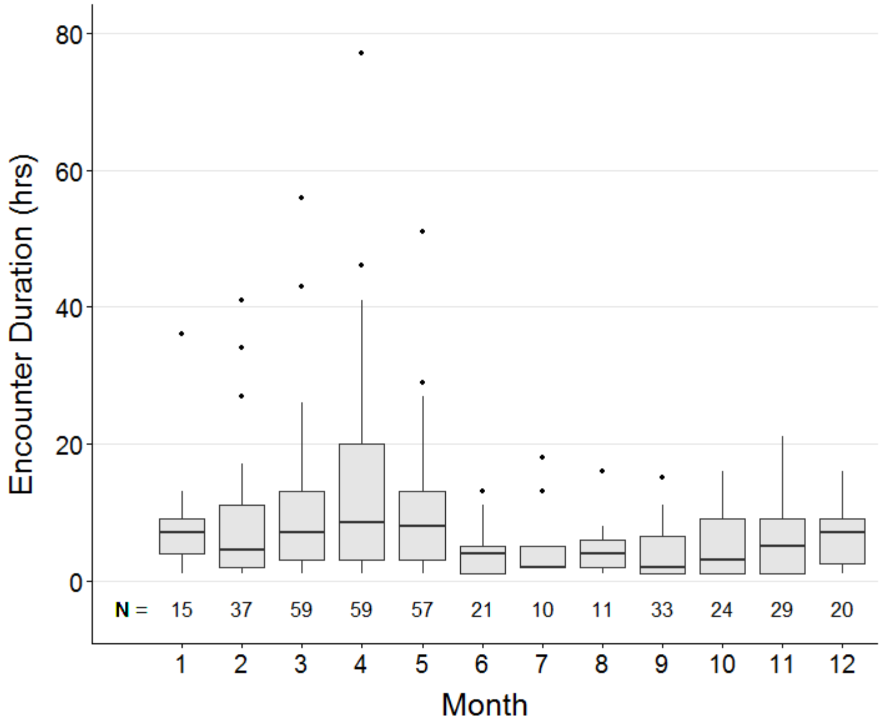


Figure 27. Durations of acoustic encounters in each month, 2009–2012. Boxes indicate the first and third quartiles and the band within the box indicates the median. Whiskers indicate range of minima and maxima, and dots show outliers. N = cumulative total number of days monitored for each month.

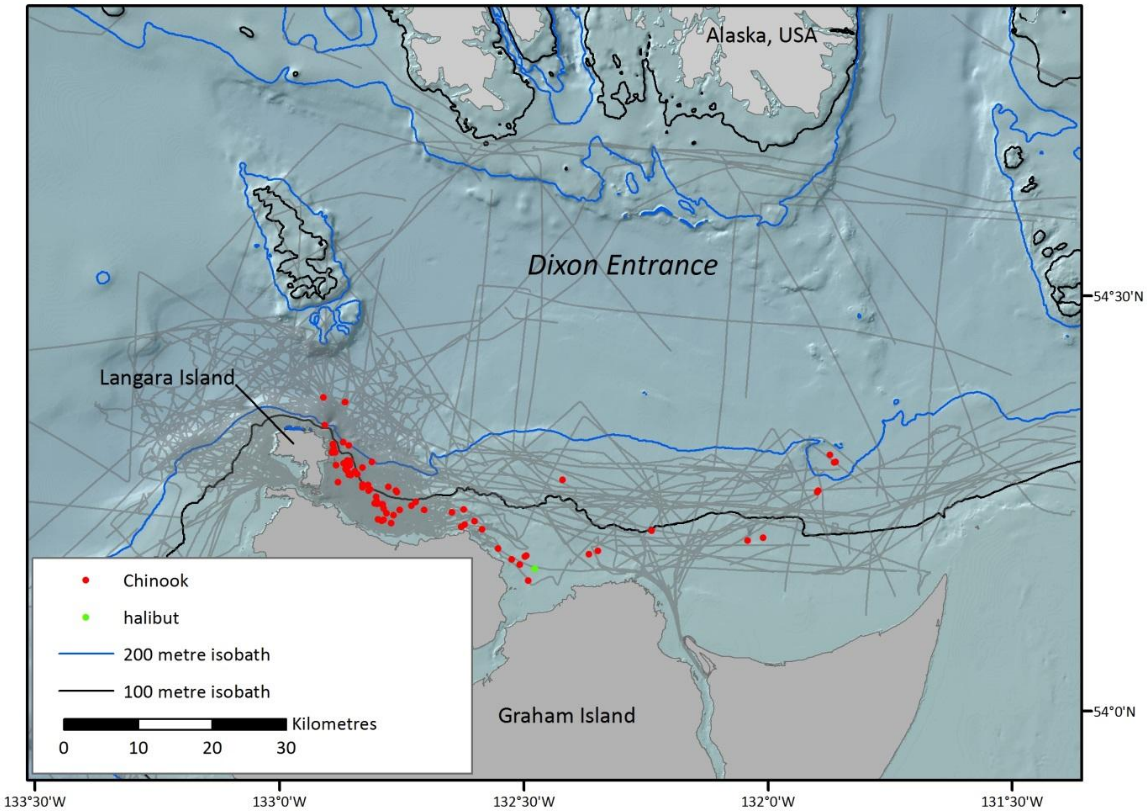


Figure 28. Locations of predation events by Northern Resident Killer Whales in western Dixon Entrance, 1997–2014. Species identification indicated by coloured dots. N = 80 kills. Survey effort tracklines for 2003–2014 are shown in light grey. Opportunistic sighting effort and dedicated survey effort pre-2003 not recorded.

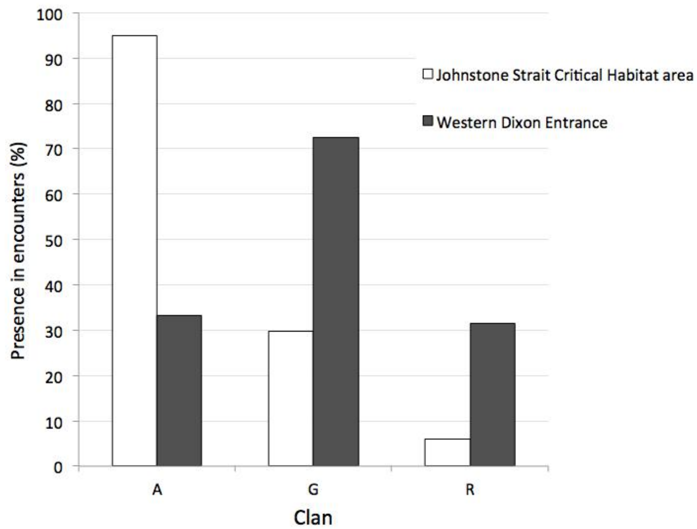


Figure 29. Presence of NRKW clans in encounters in the Johnstone Strait Critical Habitat area (open bars; N = 3704 encounters, 1990–2014) and western Dixon Entrance (closed bars; N = 102 encounters, 1993–2014).

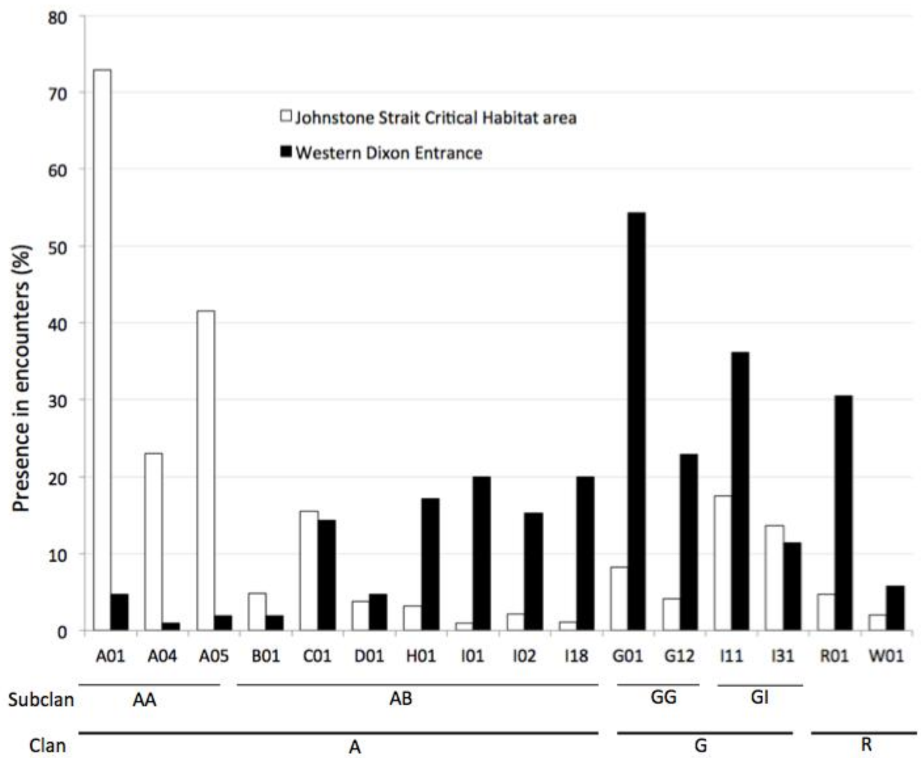
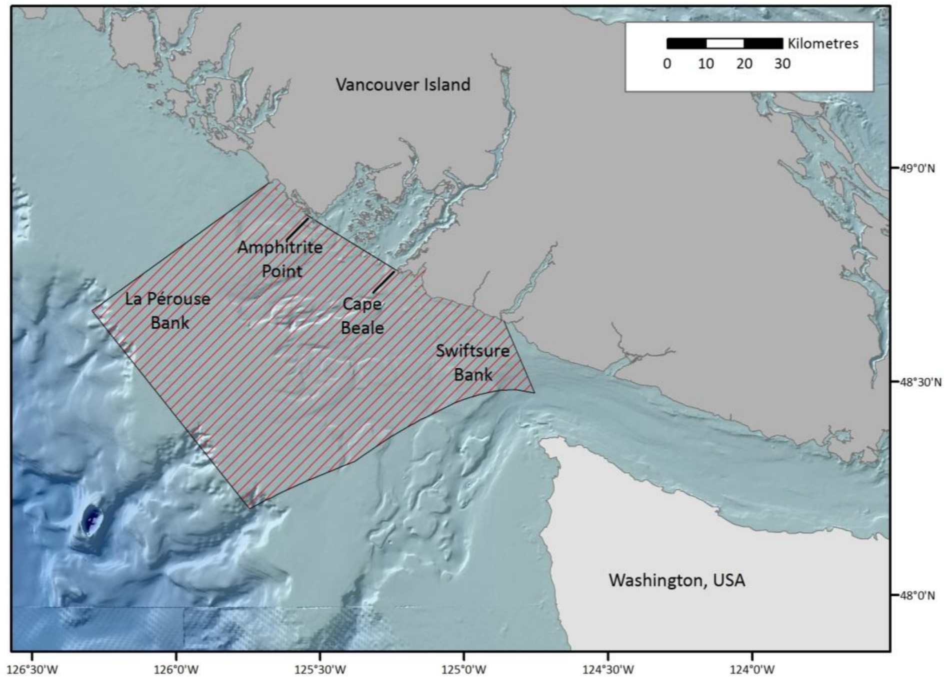


Figure 30. Presence of NRKW pods in encounters in the Johnstone Strait Critical Habitat area (open bars; N = 3704 encounters, 1990–2014) and western Dixon Entrance (closed bars; N = 102 encounters, 1993–2014).

A. Southwestern Vancouver Island



B. Western Dixon Entrance

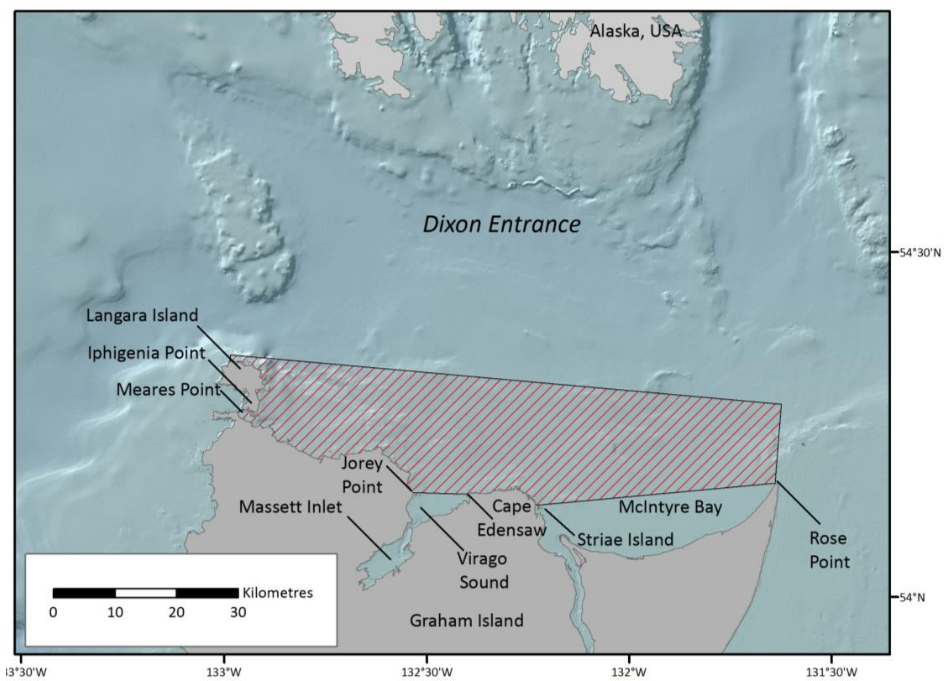


Figure 31. Habitats of special importance to Resident Killer Whales for southwestern Vancouver Island (A, top) and west Dixon Entrance (B, bottom).