Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2006/072

Document de recherche 2006/072

An Assessment of Critical Habitats of Resident Killer Whales in Waters off the Pacific Coast of Canada

Évaluation des habitats essentiels des populations résidentes d'orques dans les eaux de la côte du Pacifique du Canada

John K.B. Ford

Fisheries & Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road,
Nanaimo, BC, Canada V9T 6N7

ISSN 1499-3848 (Printed / Imprimé)

ABSTRACT

Two populations of fish-eating killer whales, *northern residents* and *southern residents*, inhabit waters off Canada's west coast. These populations are listed as threatened and endangered, respectively, under the Species-at-Risk Act (SARA) because of their small sizes, recent declining population trends, and the vulnerability of their habitat and food supply to anthropogenic impacts. As required by SARA, a Killer Whale Recovery Team was assembled to develop a recovery strategy for resident killer whales, which was recently completed in draft form. Although the Team was able to define a number of recovery objectives and approaches, it was unable to identify in sufficient detail areas of critical habitat, as required in the SARA recovery process. This report describes analyses of published information and unpublished data undertaken in order to better define patterns of movements and habitat use by resident killer whales, and proposes two areas – one for each of the two resident killer whale populations – that appear to meet the requirements for designation as critical habitat under SARA. Two additional areas are described that are clearly of seasonal importance to northern residents and are identified as potential critical habitat. These areas are all situated on important migratory corridors for chinook salmon, the preferred prey species of resident killer whales. Seasonal occurrence of whales in these habitats is strongly associated with salmon abundance and foraging is the primary activity undertaken there. Other important life processes, including resting, socializing, mating, and, for northern residents, beach rubbing, are also undertaken in these areas. Additional critical habitats likely exist for resident killer whales, but further studies, particularly in remote areas and in winter to early spring, will be needed for their identification.

RÉSUMÉ

Deux populations d'orques piscivores, les populations *résidentes du Nord* et du *Sud* du Pacifique, vivent dans les eaux qui bordent la côte ouest du Canada. Ces populations figurent sur la liste de la *Loi sur les espèces en péril* (LEP), la population du Nord étant déclarée « menacée » et celle du Sud, « en voie de disparition ». Elles y ont été inscrites en raison de leur petite taille, des tendances à la baisse récentes, ainsi que de la vulnérabilité de leur habitat et de leur approvisionnement alimentaire face aux conséquences des activités anthropiques. Comme le requiert la LEP, une équipe d'experts a été réunie en vue d'élaborer une stratégie de rétablissement des populations résidentes d'orques. L'équipe a récemment terminé son ébauche. Bien qu'elle ait pu établir un certain nombre d'objectifs et de méthodes de rétablissement, elle n'a pu délimiter avec suffisamment de précision les habitats essentiels, comme l'exige le processus de rétablissement de la LEP. Le présent rapport décrit les analyses de données publiées et non publiées, entreprises en vue de mieux cerner les habitudes de déplacement des populations résidentes d'orques et leur utilisation de l'habitat. Les auteurs y proposent deux zones – l'une pour chacune des populations résidentes – qui semblent répondre aux critères de désignation d'habitat essentiel en vertu de la LEP. Deux autres zones, qui ont clairement une importance saisonnière pour la population résidente du Nord, ont été décrites et pourraient constituer des habitats essentiels. Ces zones se trouvent toutes deux le long d'importants couloirs de migration du saumon quinnat, proie privilégiée des populations résidentes d'orques. La présence saisonnière des orques dans ces habitats est étroitement liée à l'abondance du saumon; la recherche de nourriture y est la principale activité des orques. Des processus biologiques importants, comme le repos, la socialisation, l'accouplement et, pour la population résidente du Nord, l'échouage sur la plage, s'y déroulent également. Il existe d'autres habitats essentiels des populations résidentes d'orques, mais il faudra, pour bien les délimiter, entreprendre d'autres études, surtout dans des zones éloignées et pendant l'hiver, jusqu'au début du printemps.

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, also referred to as *resident communities*, have been the subject of numerous field studies over the past 30 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).

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 resident 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 2005). The northern resident community, comprised of 219 whales (2004 census), 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 community contained 87 whales in 2004 and is commonly found off southeastern Vancouver Island and in Puget Sound, Washington, from early summer to late fall.

In 2001, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed southern residents as Endangered and northern residents 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. 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 2002. In the U.S., southern residents 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 SARA, a team of specialists was assembled in 2004 in order to develop a 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.

The purpose of this report is to evaluate both published and unpublished literature and data in order to define and identify habitat that can be considered to be both necessary and sufficient to support the population and distribution objectives and, ultimately, the conservation goal identified in the draft recovery strategy for resident killer whales in Canada. These are the first steps in the process leading to the eventual legal designation of critical habitat for resident killer whales and its protection under SARA[1].

Methods

Overview of study area and populations

Field studies undertaken in coastal waters of British Columbia and Washington State since 1973 have yielded considerable information on the abundance, movements, life history, social structure, behaviour, vocalizations, foraging ecology, and population dynamics of resident killer whales (Bain 1990; Bigg et al. 1976, 1990; Olesiuk et al. 1990; Ford 1991; Osborne 1999; Deecke et al. 2000; Ford et al. 1998, 2000, 2005; Olesiuk et al. 2005; see also reviews by Baird 2001; Wiles 2004; Killer Whale Recovery Team 2006). 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 northern residents, and Haro Strait between southern Vancouver Island and San Juan Is. for southern residents (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 comprised of individuals that are closely related by matrilineal descent. Matrilines generally contain an old female, or matriarch, and 1-3 generations of her descendents of both sexes. Dispersal of individuals from the matriline is extremely rare (Ford et al. 2000). Matrilines are comprised 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 community 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, others have split in recent years (Ford et al. 2000; Ford and Ellis 2002) 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 comprised 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. The northern resident community consists of 3 clans, A, G, and R, with 16 pods and 34 matrilines, and the southern resident community is made up of a single clan, J, which is comprised of 3 pods 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.

[1] The interpretation and criteria for the identification of critical habitat herein are based on draft policy of the Government of Canada (Environment Canada 2004) available at the time of review and publication, and may be subject to change.

Datasets and Analyses

Data collected by numerous observers during 1973-2005 were compiled into a database maintained at the Pacific Biological Station (PBS) for the analyses of resident killer whale distribution undertaken here. 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, pods or clans at a single location on a given day. A total of 5884 encounters with resident killer whales were compiled in the PBS database, of which 4765 (81%) involved northern residents, and 1119 (19%) involved southern residents. The principal sources of these data and field methods employed are summarized in Table 1. 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, 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.

As a result of the diversity in data sources and collection methods, the level of detail available for killer whale encounters varies considerably. Encounters made during dedicated studies using photo-identification are the most complete, and can be considered to have reliably documented all matrilines present in the majority of cases (for description of photo-identification methodology, see Bigg et al. (1990) or Ford et al. (2000)). Encounters based on opportunistically-collected photo-identifications are often incomplete, as only a portion of the individuals present were photographed in many cases. Encounters based solely on acoustical identification using vocal dialects are often limited in resolution to the clan or pod level. In only a minority of cases could matrilines be reliably identified from acoustics alone. Encounters based on acoustics alone may also under-represent the number of whales present, as some matrilines or pods in mixed groupings may be silent (Nichol and Shackleton 1996). Geographical coordinates for the location of killer whale encounters also vary in precision and accuracy. In the early years of the field studies, the location of killer whale encounters were generally noted as a particular body of water, often with reference to distance and direction to nearby landmarks. Coordinates were later estimated from these descriptive locations and entered in the database. In cases where no references to landmarks were specified, a nominal position was chosen to represent encounters in a given body of water. It is unlikely that these nominal positions differ from the actual locations of such encounters by more than about 10 km. An exception are encounters collected by Orcalab in Johnstone Strait off northeastern Vancouver Island (Fig. 2), which may have been located up to 10 km east or west of the nominal position in the 3-4 km wide strait. Encounters documented from shore-based platforms were also assigned nominal positions offshore of the observer's location. Since the availability of GPS systems in the early 1990s, the positions of boat-based encounters have been recorded with much higher levels of accuracy. A single set of geographical coordinates for the location where an encounter began was utilized in this analysis.

An additional source utilized in the following analyses include a long-term database maintained by the Whale Museum, Friday Harbor, WA. This database is a compilation of largely opportunistic sightings of southern resident killer whales made during 1990-2003 in waters of Juan de Fuca Strait, Georgia Strait, Puget Sound, and connecting channels and straits (see Hauser 2006). 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. Multiple sightings of the same whales on the same day were eliminated from the dataset to avoid duplication, which yielded 11,836 unique sightings in the database. All maps were prepared using ArcGIS software (ESRI v 9.0).

Results and Discussion

Habitat characteristics and use by resident killer whales

As a species, the killer whale has a cosmopolitan distribution that is the largest of any cetacean. The species occurs in all the world's oceans, including both shallow nearshore and oceanic habitats in tropical to polar environments. However, they tend to be most abundant in coastal waters and at mid to high latitudes, particularly in areas of high ocean productivity (Dahlheim and Heyning 1999; Forney and Wade 2006). As the oceans' apex predator, killer whales feed on a great diversity of prey, and more than 120 species of fishes, invertebrates, sea turtles, sea birds and marine mammals have been recorded in the species' diet (Ford and Ellis 2006). Despite being a generalist as a species, killer whale populations can have highly divergent foraging specializations. The seasonal range and movement patterns of many of these populations appear to be linked to the distribution and abundance of their preferred prey species. No population of killer whale has been observed to undertake annual north-south migrations such as those of larger cetaceans, which are associated with seasonal calving (Baird 2000; Ford 2002).

Resident killer whales are present in coastal waters of British Columbia in all months of the year (Bigg et al. 1976; Ford et al. 2000). 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 a few weeks or months (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 southern residents 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 northern residents 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 strong selectivity for chinook salmon during May to September, despite this species being far less abundant than sockeye and pink salmon, which appear not to be significant prey species (Ford et al. 1998; Ford and Ellis 2005, 2006). 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 resident killer whales and abundance of sockeye and pink salmon are thus incidental, and 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 these smaller salmonids. In October and November, the diet of resident killer whales shifts to predominantly chum salmon, which are abundant during their fall migration (Ford and Ellis 2006). By December, use of these core areas decreases, and most northern and southern residents appear to travel extensively in outer coastal waters through winter and spring, though their actual movement patterns have not been determined (Nichol and Shackleton 1996; Osborne 1999; Ford et al. 2000; Wiles 2004). Their diet during this period is unknown; it is likely that they maintain their preference for 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 chinook is the preferred prey of these animals year-round, and that this prey species may be an important limiting factor in their population dynamics (Ford et al. 2005).

While occupying their nearshore core areas during summer and fall, resident killer whales spend about 40-67% of their time foraging (Heimlich-Boran 1988f; Ford 1989; Morton 1990, Fellemen et al. 1991; Nichol and Shackleton 1996). Groups of whales generally 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). 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 (Figure 9; Ford and Ellis 2005). Studies of diving behaviour of southern residents 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 northern residents 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). Southern residents 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). Recent focal animal and focal group studies of foraging behaviour and prey handling by resident whales indicate that the majority of salmon prey, regardless of species or size, are shared among members of cooperatively-foraging matrilines (Ford and Ellis 2005). 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 a 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 10-21% 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, mating 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).

Group 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 a slower speeds. Travelling comprises just 4-8% of the activity budget of northern residents (Ford 1989; Morton 1990), but up to 25% for southern residents (Heimlich-Boran 1988). An important pattern of habitat use by northern resident killer whales is beach rubbing, which involves regular visits to particular small 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). 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 exclusive to northern residents, as it has not been observed among southern resident killer whales (Heimlich-Boran 1988; Ford et al. 2000).

Critical Habitats of Resident Killer whales

In the following sections, the available data on the seasonal occurrence of northern and southern resident killer whales are examined to identify in detail patterns of use of waters that can be considered to represent critical habitat as defined in SARA. Two critical habitat areas are proposed, one each for northern residents and southern residents. Other areas of potential critical habitat that require further study are also identified.

Northern Residents

The range of northern resident killer whales includes coastal waters from Glacier Bay, Alaska, to Gray's Harbor, Washington State, a linear distance of approximately 1500 km along the west coast (Fig. 1). Sightings of northern residents outside of Canadian waters are uncommon, however, and represent only 0.4% of the 4765 northern resident encounters in the PBS database. The locations of encounters with northern residents, exclusive of these few in US waters, are shown in Figure 2. Although northern residents have been encountered throughout coastal waters of BC, almost 90% of encounters are located off the northeastern coast of Vancouver Island, particularly in Johnstone Strait, Queen Charlotte Strait and connecting channels and passes. The frequency of encounters with northern residents by month is shown in Figure 3. The animals are present in all months, but encounters are strongly seasonal, with over 70% being recorded in the 4 mos of July-October, and less than 10% in the 4 mos of January-April.

Both the geographical and seasonal distribution of encounters with northern resident killer whales are biased by non-uniform observer effort. The inshore waters off northeastern Vancouver Island are the most readily accessible within the range of northern residents, and are 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) and commercial whale watching activity since 1980 (Johnstone Strait Killer Whale Committee (JSKWC) 1991). 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 calm conditions, warm 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 these biases, the overall patterns of occurrence indicate that these whales frequent certain areas more than others along the coast, and that there is a strong seasonal component to these movements. The Johnstone Strait area is clearly very important for these animals, a fact that has been recognized frequently in the literature over the past three decades, and it is an obvious candidate for critical habitat designation. However, there are additional locations along the coast that are also important to northern resident whales at certain times of the year, and may warrant consideration as critical habitat in the future. Two such areas, Fitz Hugh Sound and Caamano Sound, are described in the following sections.

<u>Johnstone Strait</u>

The Johnstone Strait area was first recognized as prime habitat for killer whales by Spong et al. (1970), who noted that the regular summer occurrence of killer whales in the strait began with the onset of salmon migration. Annual field studies by M. Bigg and co-workers in Johnstone Strait from 1972 onwards documented the population structure of the resident killer whales by means of individual photo-identification, and further established this area as a core habitat for the northern resident community (Bigg et al. 1976; Bigg 1982). This work was followed by a variety of studies on the behaviour, vocalizations, social organization, feeding habits, life history, and population dynamics of northern residents in the Johnstone Strait area (e.g., Ford and Fisher 1982, Jacobsen 1986, 1990; Bigg et al. 1990; Ford 1989, 1991; Olesiuk et al. 1990; Felleman et al. 1991; Bain 1990;

Rose 1992). Nichol (1990) and Nichol and Shackleton (1996) investigated the association between the occurrence of northern residents and salmon abundance in Johnstone Strait during 1985-89, using both acoustic monitoring and sighting effort to assess year-round whale occurrence. They noted that residents were uncommon in the strait from January to June, and then the frequency of sightings rose sharply in July, peaked in August, and declined steadily from September to December. Correlations between the occurrence of certain northern resident groups and the abundance of pink and sockeye salmon were documented, but, as described above, these were likely incidental as the whales in the strait forage selectively for the less abundant chinook salmon, which migrate through the area concurrently (Ford and Ellis 2005, 2006).

The importance of the Johnstone Strait area to northern resident killer whales 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) was that a Special Management Zone (SMZ) be established for the core area used by northern residents. This zone, shown in Figure 4, 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. Although the SMZ included the core area of western Johnstone Strait, more recent sighting data contained in the PBS database indicate that the whales also make regular use of eastern portions of Johnstone Strait, beyond the eastern boundary of the Zone. For this reason, the area proposed here to comprise the Johnstone Strait Critical Habitat includes the same boundaries as the SMZ with the exception that the eastern boundary in Johnstone Strait is extended approximately 50 km to the southeast (Figure 5). The total area involved is 905 km^2.

To investigate recent patterns of whale use of the proposed Johnstone Strait Critical Habitat area, encounters recorded by various research programs during 1990-2004 were analysed. Data for July-August each year were collected primarily by observers based on a 50m cliff on West Cracroft Island across from the Robson Bight / Michael Bigg Ecological Reserve, working on behalf of BC Parks and in collaboration with local whale watch operators and boat-based researchers (Figure 4). Data for September to June were compiled by researchers with Orcalab, a research facility on nearby Hanson Island, using acoustic and visual methods to detect and identify whales (see Methods for more details). Observer effort was essentially continuous during July-October in each year, and on > 95% of days during November-June. These analyses show that killer whale use of the area has been quite consistent over the 1990-2004 period, with encounters being recorded on an average of 41.6% of effort days in each year (SE = 1.47, range = 36.4-55.9%; Figure 6). As expected, distribution of encounters in the area by month was highly seasonal. Northern residents used the area in all months, but encounter rates were highest during July-October with whales present on 82-84% of effort days, and lowest during March-May at < 10% of effort days (Figure 7).

It is difficult to quantify seasonal changes in abundance of killer whales using Johnstone Strait because of seasonal differences in identification methodology (mostly acoustics in winter, visual observation and photo-ID in summer). However, it is clear that the number of whales per encounter is lower in winter (mean = 1.3 matrilines/encounter January-April, N = 248) than in summer (mean = 4.1 matrilines/encounter, July-September, N = 1248). Typically, 15-40 whales are present per day during July-September, with peak abundance in late July-mid August, when aggregations of up to about 100 northern residents, or roughly 50% of the community, are occasionally observed (Ford 1984; Nichol 1990; JSKWC 1991). These seasonal aggregations may be important in maintaining social cohesion of the resident community and, as mentioned previously, may provide mating opportunities across pods and clans that are critical for outbreeding. Although all northern resident pods have been documented in Johnstone Strait, different pods do not use the area equally (Ford 1984; Nichol 1990). 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 (Figure 8). This area appears to be critical habitat for a substantial component, but not all, of the northern resident community.

The primary factor drawing northern resident whales to the Johnstone Strait area is most probably the seasonal abundance of their preferred prey species, chinook and chum salmon. Johnstone Strait, together with Juan de Fuca Strait 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). Of 149 chinook salmon taken by killer whales in the Johnstone Strait area and sampled for genetic stock identity, 99 (66%) were from populations in the Fraser River system (Ford and Ellis, unpubl. data). The remaining chinook kills were from stocks as far north as the Skeena River in northern BC, and the Columbia River in Oregon, USA. 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 (Figure 9; Ford and Ellis 2005). Johnstone Strait may well provide conditions for chinook salmon foraging during summer, and chum salmon foraging in fall, that are unparalleled in other areas in the community's range. This is the primary reason the area is proposed here to constitute critical habitat as defined by SARA.

Another important feature of the proposed Johnstone Strait Critical Habitat is the availability of a number of small pebble beaches that are used regularly for rubbing by northern residents. As mentioned previously, this appears to be an important traditional behaviour among whales in this area, and forms part of the cultural distinctiveness of the northern resident community. In addition to the 2 well-documented rubbing beaches within the Robson Bight (Michael Bigg) Ecological Reserve (Jacobsen 1986; Ford 1989; Briggs 1991; Trites and Hochachka 1994), there are 5 other rubbing beaches within the proposed critical habitat that are regularly visited by the whales.

Fitz Hugh Sound

The Fitz Hugh Sound area is one of two potential critical habitats for northern resident killer whales on the mainland coast north of Vancouver Island (Figure 2). It comprises most of Fitz Hugh Sound and the adjoining Fisher, Dean, Labouchere, and Burke Channels, which encircle King Island. The total area involved is 1005 km^2 (Figure 10). This relatively remote area has received far less study effort than the Johnstone Strait area, but there is evidence suggesting that it may warrant designation as a seasonal critical habitat in the future. Nichol (1990) and Nichol and Shackleton (1996) undertook field studies there from late-April to mid-June, 1989, and encountered northern resident whales on 25 of 36 observation days (70%). They noted that many of the pods found in this area were commonly seen later in the summer in Johnstone Strait, and suggested that this area may be an important foraging habitat prior to the arrival of migrating salmon in Johnstone Strait in July. Subsequent field studies in this area during 1990-2004 documented northern residents on 56 of 150 effort days during May-July (37%), an encounter rate that is similar to the year-round average for Johnstone Strait. Little boat-based field effort has been made in the Fitz Hugh Sound in other months of the year, but a hydrophone system monitored during 2001-2004 at Addenbroke Island Lightstation, at the southern boundary of the area, has detected northern residents only sporadically during August-April. All 16 northern resident pods have been documented using the Fitz Hugh Sound area, although the frequency of occurrence of different pods varies somewhat from that seen in Johnstone Strait (Figure 11).

It is probable that northern resident killer whales use the Fitz Hugh Sound area primarily to intercept chinook salmon migrating to the Dean and Bella Coola rivers, which enter the ocean near the eastern end of Burke and Dean channels (Figure 10). The Bella Coola River system supports by far the largest spawning population of chinook on the central mainland coast. A major chinook hatchery was established in the early 1980s on the Atnarko River, a tributary of the Bella Coola River, which has substantially increased local abundance of chinook (Riddell 2004). These are relatively early chinook runs, with fish arriving in Fitz Hugh Sound and Burke and Dean channels in early April and reaching peak numbers in mid-June (Nichol 1990; Healey 1991). Killer whales spend most of their time during this period foraging along the steep shorelines of King Island, where chinook tend to concentrate. All 30 kills observed and sampled from northern residents during 1991-1996 in this area were chinook salmon and, although no genetic stock identifications are available, the majority were likely bound for these rivers (Ford and Ellis 2005, unpubl. data). During the April-June period, northern residents in this area can be found almost daily in some years, yet they are relatively scarce in Johnstone Strait at this time (Figure 7). As Nichol and Shackleton (1996) suggest, the Fitz Hugh Sound area is likely an important feeding area for several northern resident pods prior to their arrival in the Johnstone Strait area in early July. This area also contains at least one rubbing beach, located in Burke Channel (J. Ford, unpubl. data).

Caamano Sound

The second potential critical habitat on the central-north mainland coast is the Caamano Sound area (Figure 12). This encompasses 1187 km^2 of waters at the entrance to Douglas Channel, a deep, narrow coastal fjord that extends 80 km into the interior of B.C. It includes most of Caamano Sound and Whale and Squally channels, which surround Gil Island. Like the Fitz Hugh Sound area, Caamano Sound is a remote location that until recently has received relatively little research effort. Field surveys undertaken during the 1990s by the Cetacean Research Program, PBS/DFO, however, suggested that northern resident killer whales are found frequently in this area during May-June. In 2003, the North Coast Cetacean Society established a permanent shore-based research station on Gil Island, overlooking Whale Channel, and developed a network of radio-linked hydrophones to monitor for killer whales. This has provided year-round effort that shows that northern resident killer whales are found in the area most months of the year, but most frequently during April to June (Figure 13). Their presence during these months coincides with the arrival of chinook salmon migrating from outer coast waters to spawning rivers in the Douglas Channel area, and in particular the Kitimat River, which has enhanced chinook production as a result of a hatchery facility operating since the late 1970s (Riddell 2004). No sampling of killer whale predation events has taken place in this area.

All northern resident pods have been encountered in the Caamano Sound area. The frequency distribution of resident pods using this area is similar to that seen in Johnstone

Strait (Figure 14). It appears probable that the Caamano Sound area serves a similar function as Fitz Hugh Sound, that being as an important chinook foraging area for northern residents prior to the summer arrival of migrating salmon in Johnstone Strait, about 300 km to the south.

Chatham Sound

Another important area for northern residents on the north coast is Chatham Sound and adjoining waters, which is near the city of Prince Rupert and the BC/Alaska border (Figure 2). These waters appear to be used mostly during May to mid-July, a timing that coincides with the migration of chinook salmon to the Skeena and Nass river systems, which are the major sources of chinook in northern BC (Riddell 2004). Early-run chum salmon are also present during this period, which is much earlier than chum populations along the southern BC coast, which peak in September and October (Ryall et al. 1999; Riddell 2004). Of 26 predation events sampled from resident whales in the Chatham Sound area during June-July 2004-05, 14 were chinook salmon and 12 were chum (Ford and Ellis 2006, unpubl. data).

The Chatham Sound area appears to be important habitat for northern residents during the early summer, but the whales are scarce after late July. Although they can be found almost daily during late-June to early-July, none was encountered in 25 days of field effort in the area during 28 Jul – 23 August, 1978 (Cetacean Research Program, PBS/DFO, unpubl. data). Local whale watch operators focusing mostly on humpback whales also report very few resident killer whales after mid-July.

Patterns of whale occurrence and habitat utilization in the Chatham Sound are not yet known in sufficient detail to warrant this area being proposed as potential critical habitat. Future studies may provide such information and the area's status should be re-examined at that time.

Southern Residents

Whales belonging to the southern resident killer whale community have been identified from Monterey Bay, California to Langara Island, British Columbia, representing an overall range of approximately 2000 km along the coast (Figure 1). The great majority of encounters and sightings involving members of this community are located in the relatively protected inshore waters of the Georgia Basin, which includes eastern Juan de Fuca Strait, Haro Strait, Georgia Strait, and various other connecting channels and passes (Figure 15). As with northern residents, most sightings are recorded from late spring through early autumn, when survey effort is greatest and when most of the numerous studies of this community have been undertaken (Bigg et al. 1976, 1990; Balcomb et al. 1980; Heimlich-Boran, 1986; Osborne 1986, 1999; Heimlich-Boran 1988; Felleman et al. 1991; Ford et al. 2000; Hoelzel 2003; Baird et al. 2005; Ford and Ellis 2005; see also reviews by Krahn et al. 2004 and Wiles 2004). During this period, all three southern resident pods are regularly present within the Georgia Basin, although the pattern of occurrence of each pod differs (Figure 16). J pod is usually present in inshore waters during all months of the year. K and L pods typically arrive to the Georgia Basin in May or June and spend most of their time there until they depart in October or November. Both these pods make regular trips, typically of only a few days duration, to areas off the western entrance of Juan de Fuca Strait and the west coast of Vancouver Island and Washington. J pod also makes these excursions, but less frequently.

During June to October, southern residents concentrate their activity in eastern Haro Strait (off the west side of San Juan Island), Boundary Pass, southern Georgia Strait, and eastern Juan de Fuca Strait. Relative use of these areas varies somewhat by pod (Hauser 2006; Hauser et al. 2006). As discussed 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), but identification of scales and tissue fragments from kill sites has shown that chinook salmon form the majority of prey (Ford and Ellis 2005, 2006; Hanson et al. 2006). These waters are important migratory corridors for chinook salmon bound for the Fraser River system, which, as mentioned earlier, contains the largest spawning populations of chinook on the west coast. Of 30 chinook sampled from southern resident kills from outer Juan de Fuca Strait to Haro Strait and identified genetically by stock, 23 (76%) were from populations in the Fraser River system, with the remainder from various rivers on the east coast of Vancouver Island, Puget Sound, and the Columbia River (Ford and Ellis, unpubl. data). Notable foraging areas of high use by southern residents 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. 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 more to include Puget Sound, and this is associated with the arrival of chum salmon migrating to rivers in that area (Osborne 1999). Limited sampling of kills made in Puget Sound confirm that chum salmon, as well as chinook, are taken (J. Durban, unpubl. data; Hanson et al. 2006). As with northern residents, the winter distribution of southern residents is poorly known. K and L pods are generally absent from inside waters during December to May, and recent sightings indicate that they range widely along the mainland coast and off the west coast of Vancouver Island (Wiles 2004; Balcomb 2006). Their occurrence off the mouth of the Columbia River and in Monterey Bay, California, appears to be associated with local concentrations of chinook (Wiles 2004; Balcomb 2006).

Because all southern residents spend such a large proportion of the year in the inside waters of Georgia Basin and Puget Sound, 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, it is clear that this region is very important to these animals and should be considered as critical habitat. More specifically, the area proposed here for designation as critical habitat in Canadian waters, and that recently proposed for similar designation under the U.S. Endangered Species Act (NMFS, 2006), is shown in Figures 17 and 18. The area proposed for critical habitat in Canadian waters 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. These are all primary movement corridors and foraging locations for southern residents in the area. The whales also utilize these waters for other important activities, including resting, socializing and mating.

Conclusions

Defining and identifying critical habitat for cetaceans can be very difficult. Many of the features used to define critical habitats of terrestrial species, such as nesting or denning locations, are not relevant to these highly mobile animals. Cetacean movements are largely dictated by the distribution of their prey, and other life processes, such as resting, socializing, mating, and calving, are undertaken wherever the animals happen to be in order to feed. Notable exceptions to this are many of the baleen whales, which undertake long seasonal migrations between high-latitude feeding areas and low-latitude areas specifically for breeding. Critical foraging habitats for cetaceans can be highly variable from season-to-season and year-to-year, depending on the location of upwelling events and other ephemeral oceanographic processes that can affect the spatial and temporal distribution of marine productivity (Bjørge 2002; Hoyt 2005).

The distribution of resident killer whales appears to be driven primarily by the availability of their preferred prey, chinook and chum salmon. The spatial and temporal distribution of these prey species is, at least during the migratory phase of their life cycle as they return to their natal rivers to spawn, determined by innate timing processes and the geographical location of their destination. The two critical habitats and two potential critical habitats of resident killer whales described here have a number of features in common:

1. they are situated on the migratory pathways of chinook salmon returning to the most important spawning rivers in the local area, but are generally not located in close proximity to those rivers;

2. they are located in areas where migratory salmon returning from the open ocean or outer coastal waters first encounter geographic obstacles that increase their density while on migration. In other words, they act as funnels to concentrate prey, which likely increases the whales' foraging success;

3. they are characterized by well-mixed water with strong tidal currents, and steep bathymetry and shorelines that may further concentrate salmon prey;

4. their utilization by resident whales is strongly associated temporally with the presence of chinook and chum salmon.

The critical habitats proposed here exist only as a result of the availability of sufficient concentrations of prey species – primarily chinook and chum salmon – that make them profitable foraging habitats for resident killer whales. Without adequate prey availability, the whales would likely abandon these areas and could suffer reduced survival as a result. Recent analyses suggest that the abundance of chinook salmon may ultimately limit resident populations, and reduced availability of this prey species may result in increased mortality rates (Ford et al. 2005).

The process leading to designation of critical habitat under SARA requires that they not only be described spatially and temporally, but also that potential or existing threats to these habitats be identified (Environment Canada 2004). A full description of such threats is beyond the scope of this report, but detailed reviews can be found in the draft Resident Killer Whale Recovery Strategy (Killer Whale Recovery Team 2006), and in Wiles (2004) and Krahn et al. (2004). Because resident killer whale critical habitats are determined primarily by the availability of chinook and chum salmon for predation, any anthropogenic activities that might reduce the abundance of these prey species to levels below those needed to sustain these populations, or interfere with the whales' ability to successfully forage for them, could be considered to threaten quality of these habitats. Threats to salmon abundance include over-fishing, either within or outside critical habitats, and degradation of spawning habitats. It is noteworthy that the majority of chinook salmon available to resident whales in at least some of these critical habitats are hatchery-produced fish, and future utilization of these habitats may be dependent on continued hatchery production, as many wild stocks of chinook in the region are depleted (DFO 2001; Riddell 2004). Threats to the whales' ability to successfully forage for these prey species might include increased backgrounds of vessel noise, which could mask echolocation signals needed to locate and capture salmon, or disturbance to complex behaviours associated with feeding, such as cooperative foraging and food sharing (Erbe 2002; Au et al. 2004; Ford and Ellis 2005).

Although foraging opportunities may be the main determinant of critical habitats of resident killer whales, other life processes undertaken in these habitats, such as resting, socializing, and beach rubbing, are also of importance. Any activities that potentially disturb these processes might ultimately lead to displacement of whales from critical habitat. Several studies conducted within the critical habitats proposed here have documented short-term behavioural reactions by whales to approaching vessels, but the long-term significance of these reactions are not yet clear (Williams et al. 2002a, b; Trites and Hochachka 1994; Trites et al. 2002; Bain et al. 2006).

Finally, it is important to recognize that the year-round life cycle of resident killer whales is inadequately understood at present. There are ample data available on the whales' use of two highly important areas – Johnstone Strait for northern residents and Haro Strait-Georgia Basin for southern residents – that their suitability for designation as critical habitat under SARA should be clearly evident. The two potential critical habitats identified here – Fitz Hugh Sound and Caamano Sound – are less studied and additional information is required in order to determine whether they warrant designation as critical habitat. There may well be additional critical habitats for resident killer whales that are not yet known, and further field studies are needed, particularly in remote parts of their range and during winter, to identify and document these in detail so that they too might receive the protection necessary to ensure the recovery of these populations.

Acknowledgements

I thank the following for their assistance with this project: G. Ellis (PBS, DFO) for his long-term efforts to identify and understand the habits and habitats of resident killer whales, and for insightful suggestions and advice; H. Symonds and P. Spong (Orcalab) for compiling and making available their data on northern residents in the Johnstone Strait area; H. Meuter and J. Wray (North Coast Cetacean Society) for providing data on northern residents in the Caamano Sound area; R. Osborne (The Whale Museum), L. Barre (NMFS) and D. Hauser (U of Washington) for data and other unpublished information on southern residents; R. Abernethy, K. Davies, B. Lofgren and M. Webb (PBS, DFO) for assistance with data compilation and entry; A. Phillips (PBS, DFO) for data analysis and interpretation; D. Johannessen and P. Ross (IOS, DFO) for their perspectives on the definition of critical habitat for resident killer whales; and D. Sandilands (BC Cetacean Sightings Network) for producing maps of killer whale sightings and proposed critical habitats.

Literature Cited

Au, W. W. L., J. K. B. Ford, J. Horne, and K. A. Newman Allman. 2004. Echolocation signals of free-ranging killer whales (*Orcinus orca*) and modeling of foraging for chinook salmon (*Oncorhynchus tshawytscha*). Journal of the Acoustical Society of America 221:559-564.

Bain, D.E. 1990. Testing the validity of inferences drawn from photo-identification data, with special reference to the studies of the killer whales (*Orcinus orca*) in British Columbia. Report of the International Whaling Commission Special Issue 12: 93-100.

Bain, D.E., R. Williams, J.C. Smith, E. Ashe, and D. Lusseau. 2006. Land-based studies of the effects of vessel traffic on the behavior of northern and southern resident killer whales (*Orcinus* spp.). In: Proceedings of the 2006 Symposium on Southern Resident Killer Whales, 3-5 April, 2006. NOAA Western Regional Center Auditorium, Seattle, WA.

Baird, R.W. 2000. The killer whales, foraging specializations and group hunting. Pages 127-153 *in* J. Mann, R.C. Connor, P.L. Tyack, and H. Whitehead (editors). Cetacean societies: field studies of dolphins and whales. University of Chicago Press, Chicago, Illinois.

Baird, R.W. 2001. Status of killer whales, *Orcinus orca*, in Canada. Canadian Field Naturalist 115:676-701.

Baird R.W., M.B. Hanson, and L. M. Dill 2005. Factors influencing the diving behaviour of fish-eating killer whales: sex differences and diel and interannual variation in diving rates. Canadian Journal of Zoology 83:257-267

Balcomb, K.C. III. 2006. Winter distribution of southern resident killer whales, 2003-2006. In: Proceedings of the 2006 Symposium on Southern Resident Killer Whales, 3-5 April, 2006. NOAA Western Regional Center Auditorium, Seattle, WA.

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.

Barrett-Lennard, L.G. 2000. Population structure and mating patterns of killer whales as revealed by DNA analysis. Ph.D. Thesis, University of British Columbia, Vancouver, British Columbia.

Barrett-Lennard, L.G., J.K.B. Ford and K. Heise. 1996. The mixed blessing of echolocation: Differences in sonar use by fish-eating and mammal-eating killer whales. Animal Behaviour 51: 553-565.

Bigg, M. 1982. An assessment of killer whale (*Orcinus orca*) stocks off Vancouver Island, British Columbia. Report of the International Whaling Commission 32: 655- 666.

Bigg, M.A., I.B. MacAskie and G. Ellis. 1976. Abundance and movements of killer whales off eastern and southern Vancouver Island with comments on management. Unpubl. report Arctic Biological Station, Ste. Anne de Bellevue, Quebec.

Bigg, M.A., G.M. Ellis, J.K.B. Ford, and K.C. Balcomb. 1987. Killer whales: a study of their identification, genealogy, and natural history in British Columbia and Washington State. Phantom Press, Nanaimo, British Columbia.

Bigg, M.A., P.F. Olesiuk, G.M. Ellis, J.K.B. Ford, and K.C. Balcomb. 1990. Social organization and genealogy of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission Special Issue 12:383-405.

Bjørge, A. 2002. How persistent are marine mammal habitats in an ocean of variability? Habitat use, home range and site fidelity in marine mammals. In: Evans and Raga, eds. Marine Mammals: Biology and Conservation. Academic/Plenum Publishers.

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.

Candy, J. R., and T. P. Quinn. 1999. Behaviour of adult chinook salmon (*Oncorhynchus tshawytscha*) in British Columbia coastal waters determined from ultrasonic telemetry. Canadian Journal of Zoology 77:1161-1169.

Dahlheim, M.E. and J.E. Heyning. 1999. Killer whale *Orcinus orca* (Linnaeus, 1758). Pages 281-322 *in* S. Ridgway and R. Harrison (editors). Handbook of marine mammals, Volume 6. Academic Press, San Diego, California.

Deecke, V.B., J.K.B. Ford, and P. Spong. 2000. Dialect change in resident killer whales: implications for vocal learning and cultural transmission. Animal Behaviour 60: 629-638.

DFO 2001. Fish stocks of the Pacific coast. Fisheries and Oceans Canada. 152 pp.

Duffield, D.A., D.K. Odell, J.F. McBain, and B. Andrews. 1995. Killer whale (*Orcinus orca*) reproduction at Sea World. Zoo Biology 14:417-430.

Environment Canada. 2004. Federal policy discussion paper: critical habitat. Species at Risk Recovery Program, February 2004.

Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. Marine Mammal Science 18:394-418.

Felleman, F.L., J.R. Heimlich-Boran, and R.W. Osborne. 1991. The feeding ecology of killer whales (*Orcinus orca*) in the Pacific Northwest. Pages 113-147 *in* K. Pryor and K.S. Norris (editors). Dolphin societies: discoveries and puzzles. University of California Press, Berkeley, California.

Ford, J.K.B. 1984. Call traditions and dialects of killer whales (*Orcinus orca*) in British Columbia. Ph.D. dissertation, University of British Columbia. 435 p.

Ford, J.K.B. 1989. Acoustic behaviour of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia, Canada. Canadian Journal of Zoology 69: 1454-1483.

Ford, J.K.B. 1991. Vocal traditions among resident killer whales (*Orcinus orca*) in coastal waters of British Columbia, Canada. Canadian Journal of Zoology 69: 1454-1483.

Ford, J.K.B. 2002. Killer Whale *Orcinus orca*. In: Perrin, W.F., Wursig, B., and H.G.M. Thewissen (eds.), The Encyclopedia of Marine Mammals. Academic Press, New York. pp. 669-676.

Ford, J.K.B., and G.M. Ellis. 2005. Prey selection and food sharing by fish-eating 'resident' killer whales (*Orcinus orca*) in British Columbia. DFO Can. Sci. Adv. Sec. Res. Doc. 2005/041.

Ford, J.K.B., and G.M. Ellis. 2006. Selective foraging by fish-eating killer whales *Orcinus orca* in British Columbia. Marine Ecology Progress Series 316:185-199.

Ford, J.K.B., G.M. Ellis, P.F. Olesiuk. 2005. Linking prey and populations dynamics: did food limitation cause recent declines of 'resident' killer whales (*Orcinus orca)* in British Columbia. DFO Can. Sci. Adv. Sec. Res. Doc. 2005/042.

Ford, J.K.B., G.M. Ellis, and K.C. Balcomb. 2000. Killer whales: the natural history and genealogy of *Orcinus orca* in British Columbia and Washington. Second edition. UBC Press, Vancouver, British Columbia. 104 pp.

Ford, J.K.B., G.M. Ellis, L.G. Barrett-Lennard, A.B. Morton, R.S. Palm, and K.C. Balcomb. 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters. Canadian Journal of Zoology 76:1456-1471.

Ford, J.K.B., and H.D. Fisher 1982. Killer whale (*Orcinus orca*) dialects as an indicator of stocks in British Columbia. Report of the International Whaling Commission, 32:671-679.

Forney, K. A. and P. Wade. 2006. Worldwide distribution and abundance of killer whales. *In* J. A. Estes, R. L. Brownell, Jr., D. P. DeMaster, D. F. Doak, and T. M. Williams (editors). Whales, whaling and ocean ecosystems. University of California Press, Berkeley, California.

Hanson, M.B., R.W. Baird, and G.S. Schorr. 2006. Diet studies of "southern resident" killer whales in their summer and fall range: prey sampling and behavioral cues of predation. In: Proceedings of the 2006 Symposium on Southern Resident Killer Whales, 3-5 April, 2006. NOAA Western Regional Center Auditorium, Seattle, WA.

Hauser, D.D.W. 2006. Summer space use of southern resident killer whales (*Orcinus orca*) within Washington and British Columbia inshore waters. MSc thesis, University of Washington, Seattle.

Hauser, D.D.W., M. G. Logsdon, E.E. Holmes, G.R. VanBlaricom, and R.W. Osborne. 2006. Effects of environmental factors and temporal scale on pod-specific SRKW summer distribution patterns: implications for designating critical habitat.

Proceedings of the 2006 Symposium on Southern Resident Killer Whales, 3-5 April, 2006. NOAA Western Regional Center Auditorium, Seattle, WA.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 313-393 *in* C. Groot and L. Margolis (editors). Pacific salmon life histories. UBC Press, Vancouver, British Columbia.

Heimlich-Boran, J.R. 1986. Fishery correlations with the occurrence of killer whales in Greater Puget Sound. Pages 113-131 *in* B.C. Kirkevold and J.S. Lockard (editors). Behavioural biology of killer whales. Alan R. Liss, New York, New York.

Heimlich-Boran, J.R. 1988. Behavioural ecology of killer whales (O*rcinus orca*) in the Pacific Northwest. Canadian Journal of Zoology 66:565-578.

Hoelzel, A.R. 1993. Foraging behaviour and social group dynamics in Puget Sound killer whales. Animal Behaviour 45:581-591.

Hoyt, E. 2005. Marine protected areas for whales, dolphins and porpoises. Earthscan, London.

Jacobsen, J.K. 1986. The behavior of *Orcinus orca* in the Johnstone Strait, British Columbia. *In* B. C. Kirkevold and J. S. Lockard (editors). Behavioral Biology of Killer Whales. Alan R. Liss, Inc., New York.

Jacobsen, J.K. 1990. Associations and social behaviors among killer whales (*Orcinus orca*) in the Johnstone Strait, British Columbia, 1979-1986. MSc thesis, Humboldt State University, California.

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

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

Killer Whale Recovery Team. 2006. Recovery strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada [Draft]. Species at Risk Act Recovery Strategy Series. Fisheries & Oceans Canada. Ottawa

Krahn, M.M., M.J. Ford, W.F. Perrin, P.R. Wade, R.P. Angliss, M.B. Hanson, B.L. Taylor, G.M. Ylitalo, M.E. Dahlheim, J.E. Stein, and R.S. Waples. 2004. 2004 Status review of southern resident killer whales *(Orcinus orca)* under the Endangered Species Act. U.S. Dept. Commer, NOAA Tech. Memo. NMFSNWFSC- 62, 73 p. Available from http://www.nwr.noaa.gov

Morton, A.B. 1990. A quantitative comparison of the behavior of resident and transient forms of the killer whale off the central British Columbia coast. Report of the International Whaling Commission., Special Issue 12:245-248.

NMFS 2006. Designation of critical habitat for southern resident killer whales: biological report. National Marine Fisheries Service, Northwest Region.

Nichol, L.M. 1990. Seasonal movements and foraging behaviour of resident killer whales (*Orcinus orca)* in relation to the inshore distribution of salmon (*Oncorhynchus sp.).* M.Sc. Thesis, University of British Columbia, Vancouver.

Nichol, L.M. and D.M. Shackleton. 1996. Seasonal movements and foraging behaviour of northern resident killer whales (*Orcinus orca*) in relation to the inshore distribution of salmon (*Oncorhynchus* spp.) in British Columbia. Canadian Journal of Zoology 74:983-991.

Northcote, T.G. & P.A. Larkin. 1989. The Fraser River: A major salmonine production system. P.172-204 IN: Dodge, D.P. (ed.). Proceedings of the International Large River Symposium. Canadian Special Publication in Fisheries and Aquatic Science 106.

Olesiuk, P.F., M.A. Bigg, and G.M. Ellis. 1990. Life history and population dynamics of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission Special Issue 12:209-243.

Olesiuk, P. F., G. M. Ellis, and J. K. B. Ford. 2005. Life history and population dynamics of northern resident killer whales (*Orcinus orca*) in British Columbia. DFO Can. Sci. Adv. Sec. Res. Doc. 2005/045.

Osborne, R. W. 1986. A behavioral budget of Puget Sound killer whales. *In* B. C. Kirkevold & J. S. Lockard (editors) Behavioral biology of killer whales. Alan R. Liss, New York. pp. 211-249.

Osborne, R.W. 1999. A historical ecology of Salish Sea "resident" killer whales (O*rcinus orca*), with implications for management. Ph.D. Thesis, University of Victoria, Victoria, British Columbia.

Quinn, T.P. 2005. The behavior and ecology of Pacific salmon and trout. UBC Press, Vancouver, B.C.

Quinn, T.P., B.A. terHart, and C. Groot. 1989. Migratory orientation and vertical movements of homing adult sockeye salmon, *Oncorhynchus nerka*, in coastal waters. Animal Behaviour 37:587-599.

Riddell, B. 2004. Pacific salmon resources in central and north coast British Columbia. Prepared for the Pacific Fisheries Resource Conservation Council, Vancouver, BC. 23 pp. Available from www.fish.bc.ca

Rose, N.A. 1992. The social dynamics of male killer whales, *Orcinus orca*, in Johnstone Strait, British Columbia. PhD thesis, University of California, Santa Cruz, CA.

Spong, P., J. Bradford, and D. White. 1970. Field studies of the behaviour of the killer whales (*Orcinus orca*). Proceedings of the 7th Annual Conference on Biological Sonar and Diving Mammals, Stanford University, Palo Alto, CA. pp. 169-174.

Stasko, A.B., R.M. Horral, and A.D. Hasler. 1976. Coastal movements of adults Fraer River sockeye salmon (*Oncorhynchus nerka*) observed by ultrasonic tracking. Transactions of the American Fisheries Society 105:674-71.

Thomson, R.E. 1981. Oceanography of the British Columbia coast. Canadian Special Publication of Fisheries and Aquatic Sciences 56.

Trites, A.W., D.E. Bain, R.M. Williams, and J.K.B. Ford. 2002. A review of short- and long-term effects of whale watching on killer whales in British Columbia. Pages 165-167 *in* the Fourth International Orca Symposium and Workshop, September 23-28, 2002. CEBC-CNRS, France.

Trites, A.W. and W. Hochachka. 1994. Killer whales and vessel activity in Robson Bight from 1991 to 1993. Unpublished report for BC Parks by the Marine Mammal Research Unit, University of British Columbia. 46 pp.

Wiles, G.J. 2004. Washington state status report for the killer whale. Washington Department of Fish and Wildlife, Olympia. 106 p.

Williams, R., A.W. Trites, and D.E. Bain. 2002a. Behavioural responses of killer whales (O*rcinus orca*) to whale-watching boats; opportunistic observations and experimental approaches. Journal of the Zoological Society of London 256:255-270.

Williams, R., D.E. Bain, J.K.B. Ford, and A.W. Trites. 2002b. Behavioural responses of male killer whales to a ‘leapfrogging’ vessel. Journal of Cetacean Research and Management 4(3): 305-310.

TABLES

Table 1. Sources of resident killer whale encounter data in database maintained at the Pacific Biological Station, Nanaimo, B.C., and used in the current analyses.

Source	No. of Encounters	Years	Platform type	ID Method
Cetacean Research Program, DFO	2984	1973-2005	Boat	Photo-ID, visual, acoustic
BC Parks	875	1992-2004	Shore, from 50m high cliff	Visual using binoculars & spotting scopes
Orcalab	1408	1985-2005	Shore	Acoustic, using radio-linked hydrophone network; visual, from two shore stations
BC Cetacean Sightings Network	533	2001-2005	Boat, shore	Various: visual, photo-ID
North Coast Cetacean Society	84	2003-2005	Shore, boat	Acoustic, visual, photo-ID

FIGURES

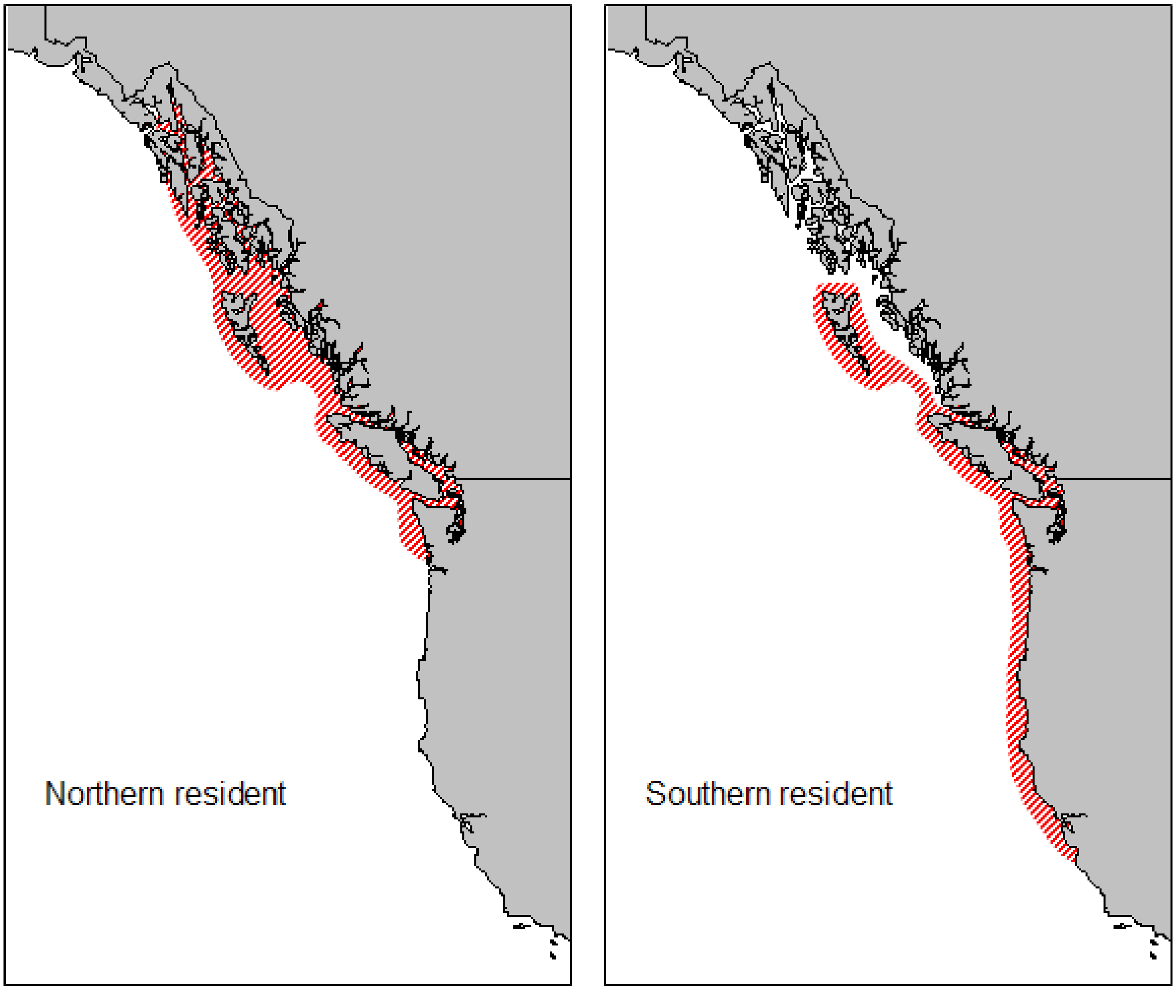

Figure 1. Known geographical ranges of northern (left) and southern (right) resident killer whales. Extent of movement offshore is unknown.

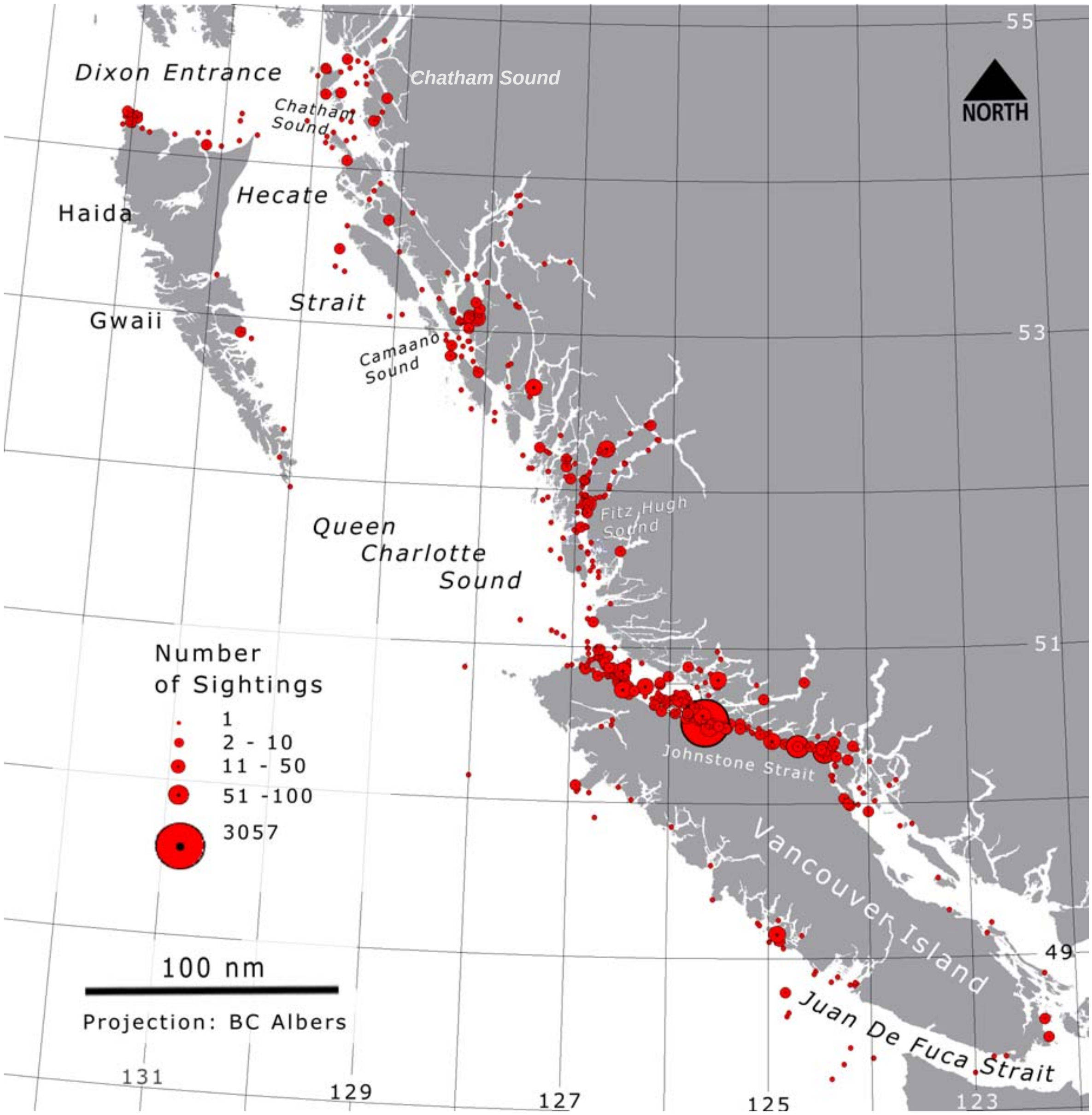

Figure 2. Locations of encounters with northern resident killer whales, 1973-2005. N = 4765 encounters.

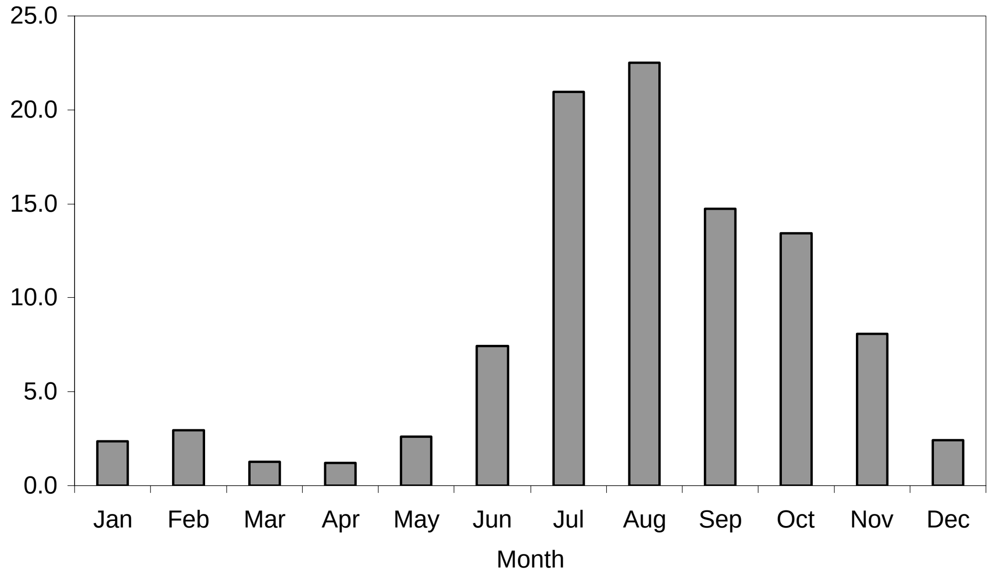

Figure 3. Frequency distribution of northern resident killer whale encounters by month, 1973-2005, all regions. N = 4765 encounters.

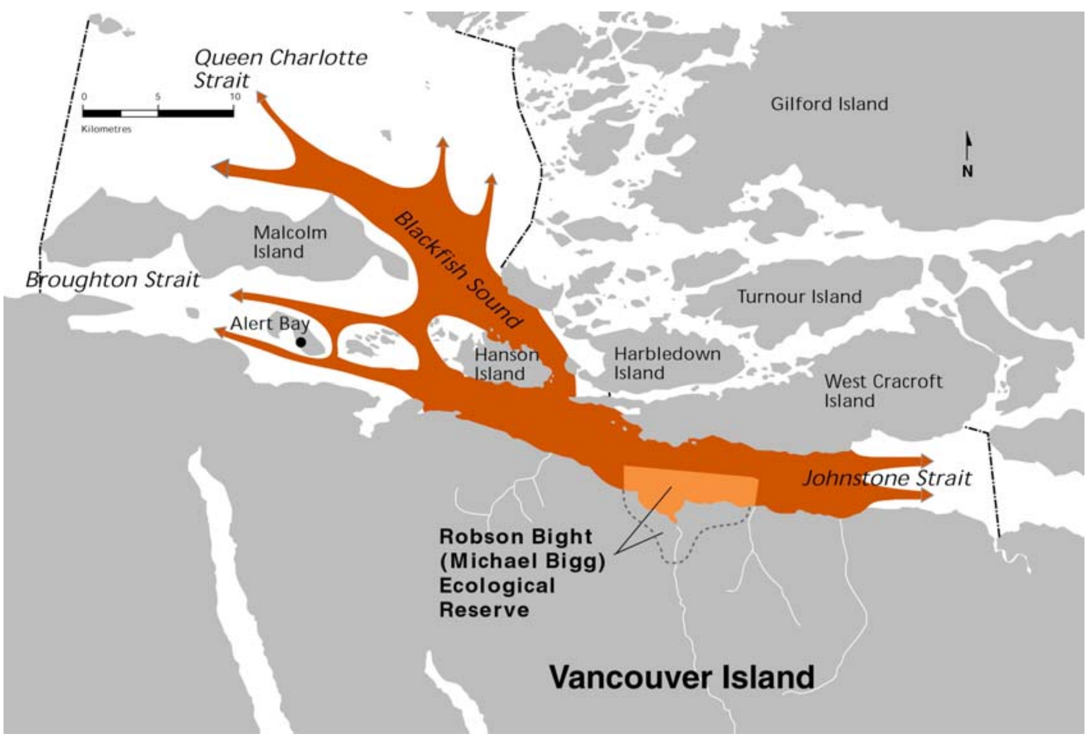

Figure 4. Typical travel and foraging routes of northern resident killer whales in the western Johnstone Strait area, and the location of the Robson Bight (Michael Bigg) Ecological Reserve. Dashed lines indicate boundaries of Special Management Zone proposed by the Johnstone Strait Killer Whale Committee (1992). Map modified from Ford et al. (2000).

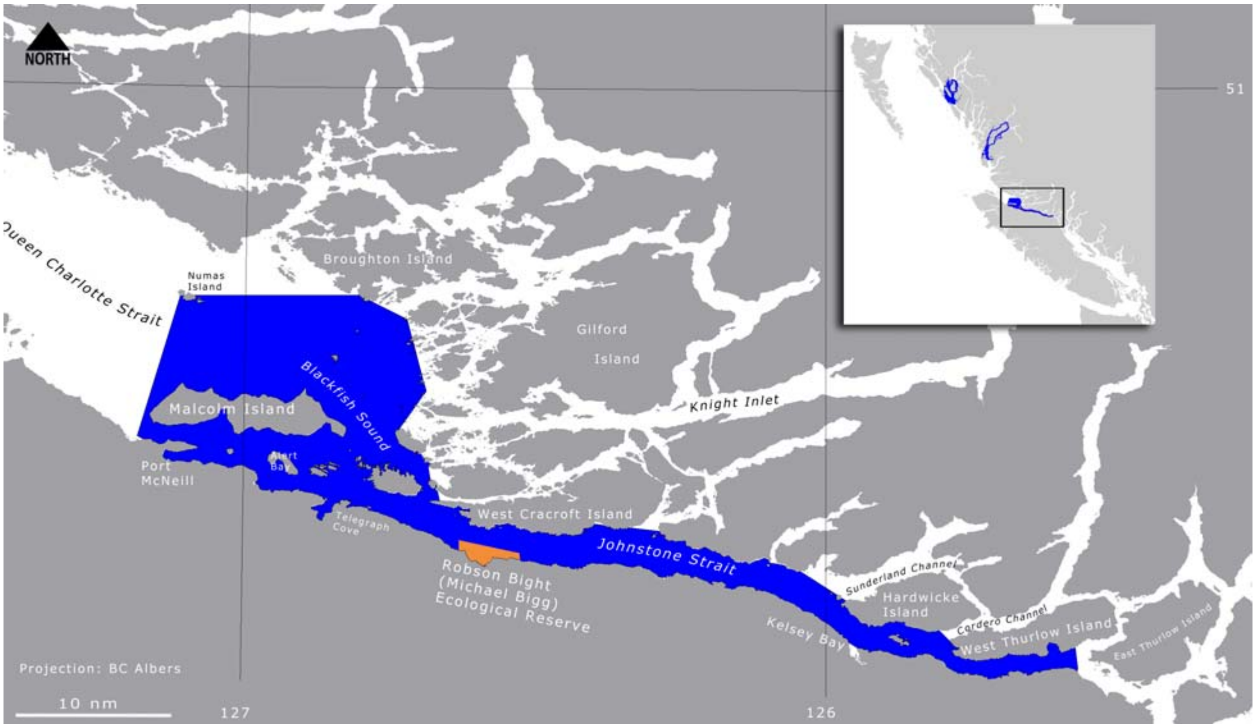

Figure 5. Proposed critical habitat for northern resident killer whales in the Johnstone Strait area, northeastern Vancouver Island.

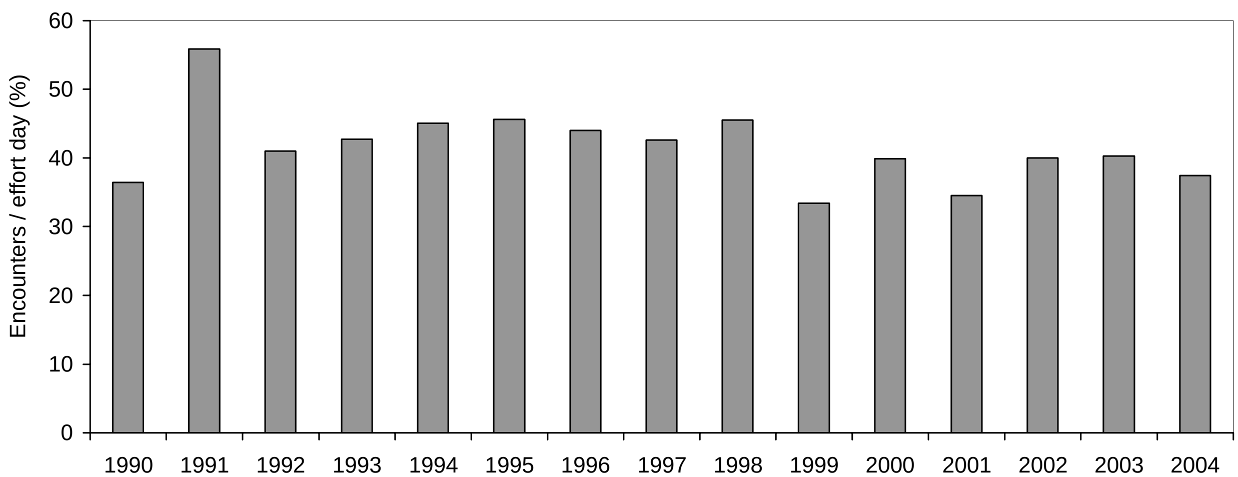

Figure 6. Percentage of days with observer effort that northern resident killer whales were encountered within the Johnstone Strait critical habitat area for each year during 1990-2004. N = 2274 encounters.

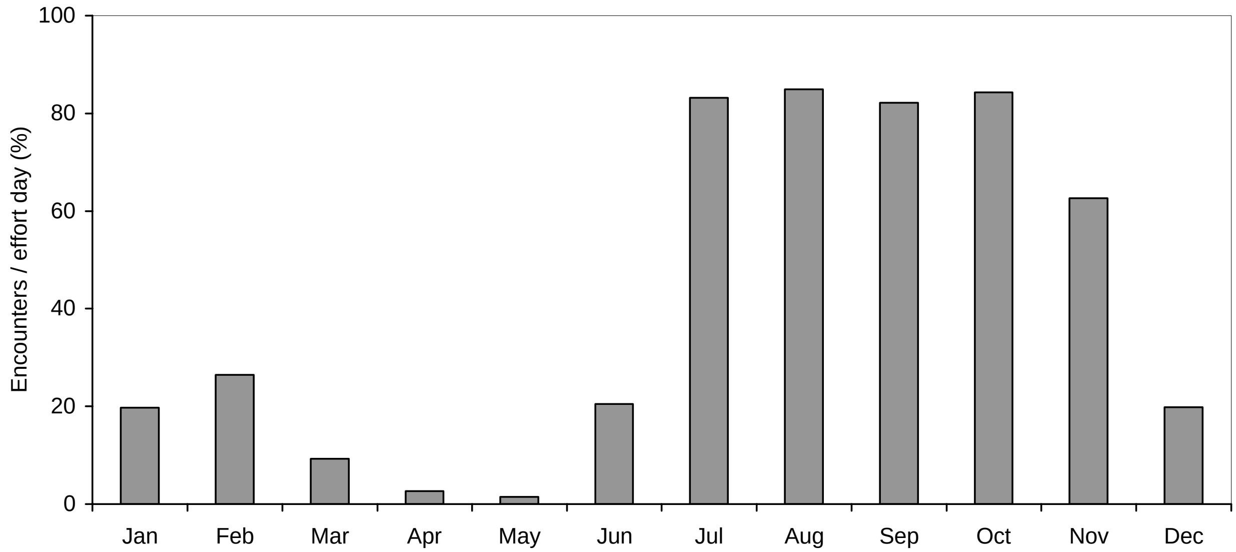

Figure 7. Percentage of days with observer effort that northern resident killer whales were encountered within the Johnstone Strait critical habitat area, by month during 1990-2004 combined. N = 2274 encounters.

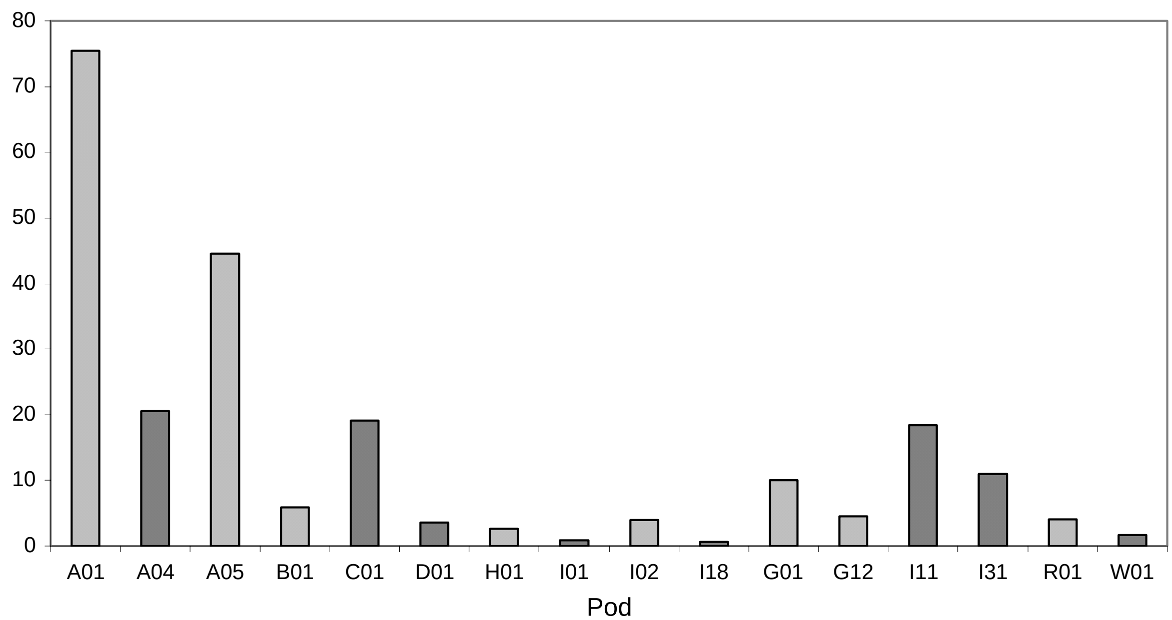

Figure 8. Frequency of occurrence of the 16 northern resident pods in encounters within Johnstone Strait critical habitat area, 1990-2004. N = 2384 encounters.

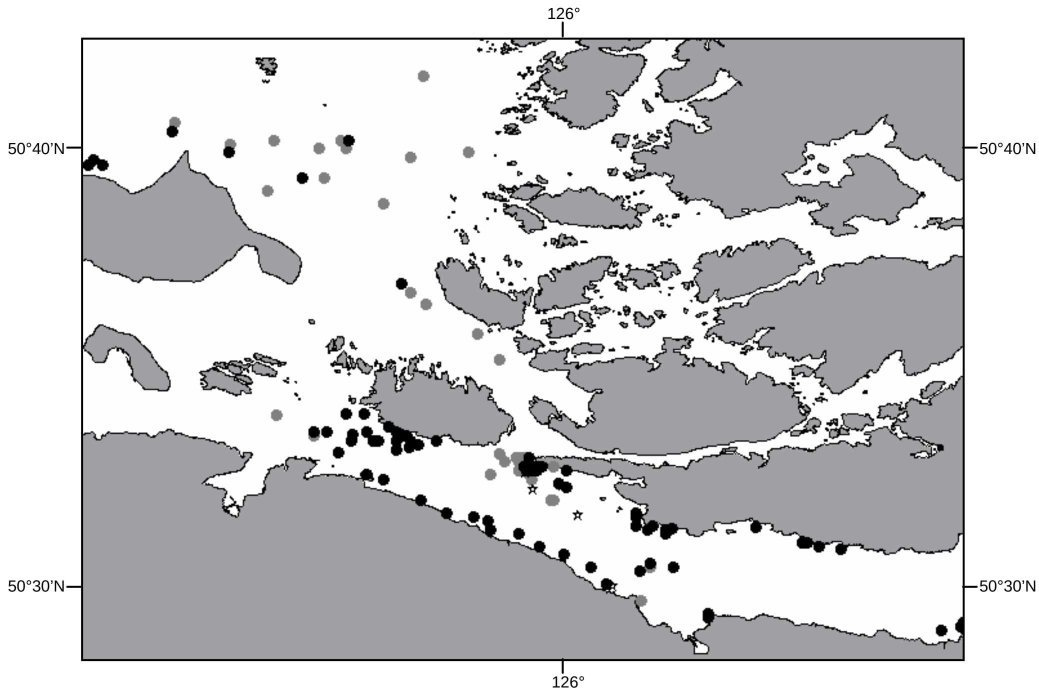

Figure 9. Locations of feeding events by killer whales in western Johnstone Strait, B.C., July-October 2004. Shown are kills of chinook (black circles), chum (grey circles) and coho salmon (stars). (From Ford and Ellis 2005).

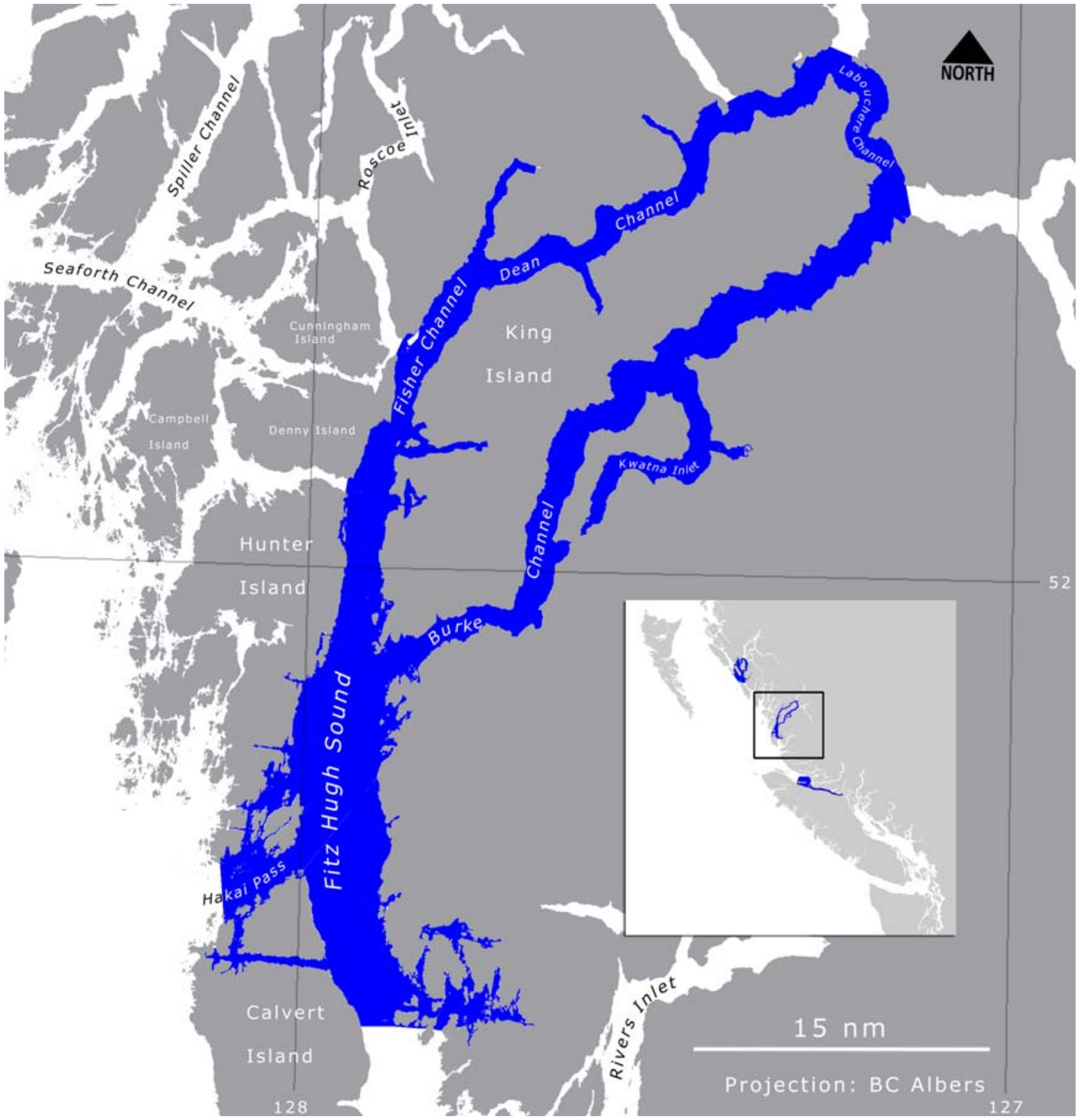

Figure 10. Potential critical habitat for northern resident killer whales in the Fitz Hugh Sound area.

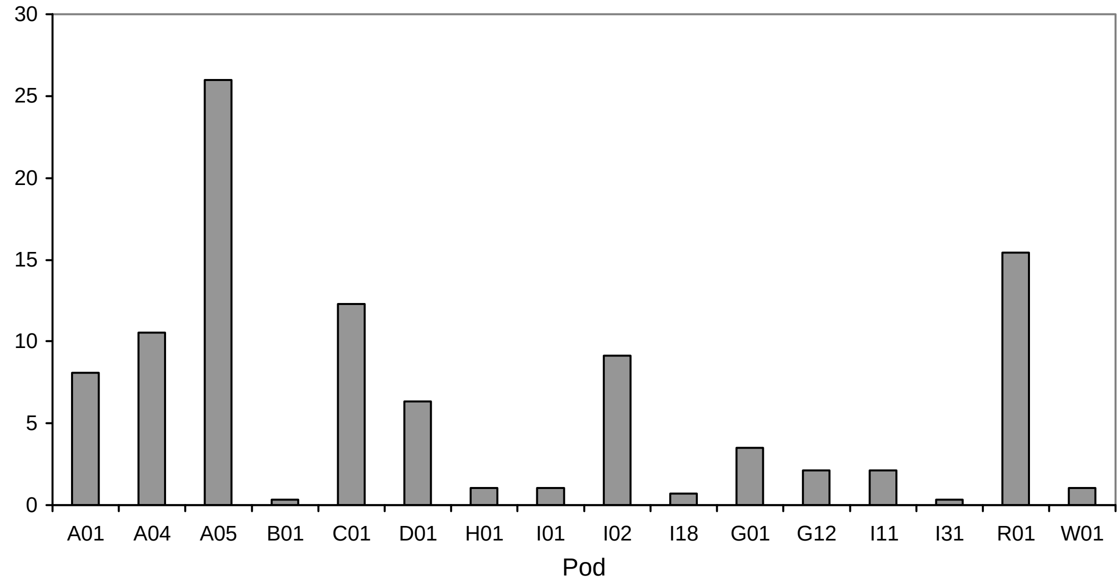

Figure 11. Frequency of occurrence of the 16 northern resident pods in encounters within the potential Fitz Hugh Sound critical habitat area, 1975-2004. N = 124 encounters.

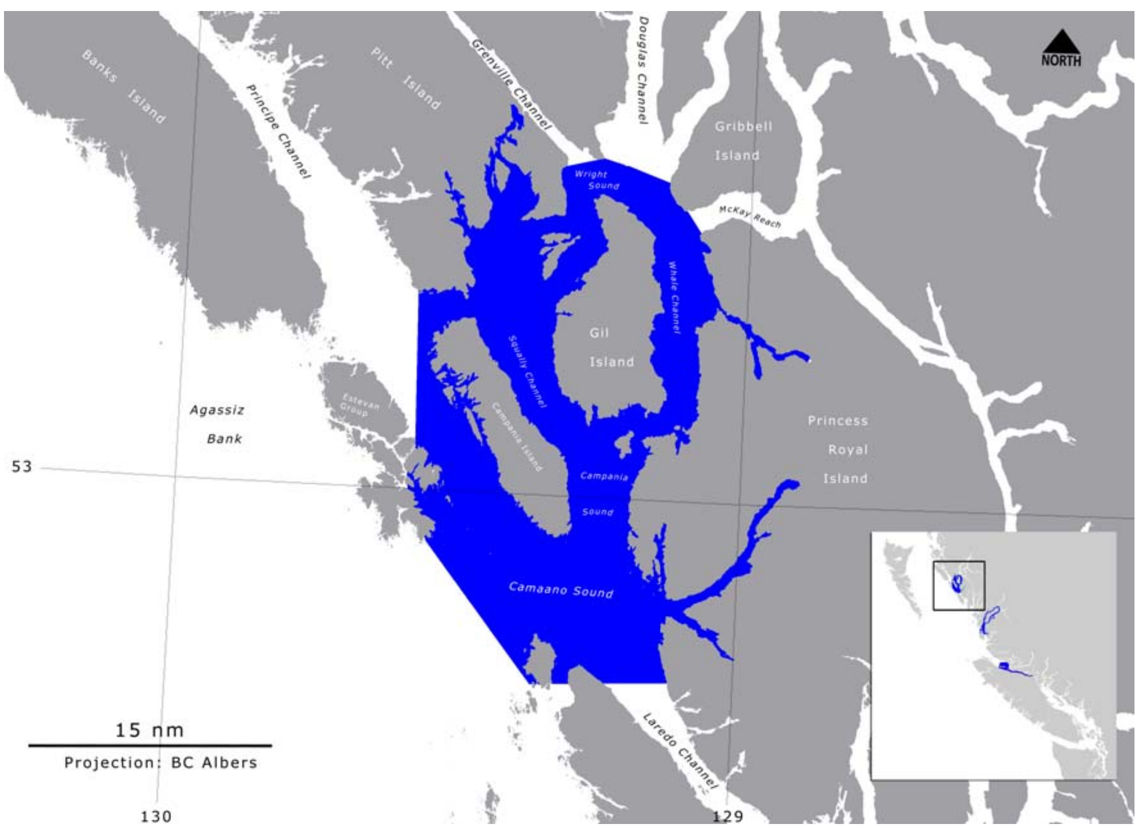

Figure 12. Potential critical habitat for northern resident killer whales in the Caamano Sound area.

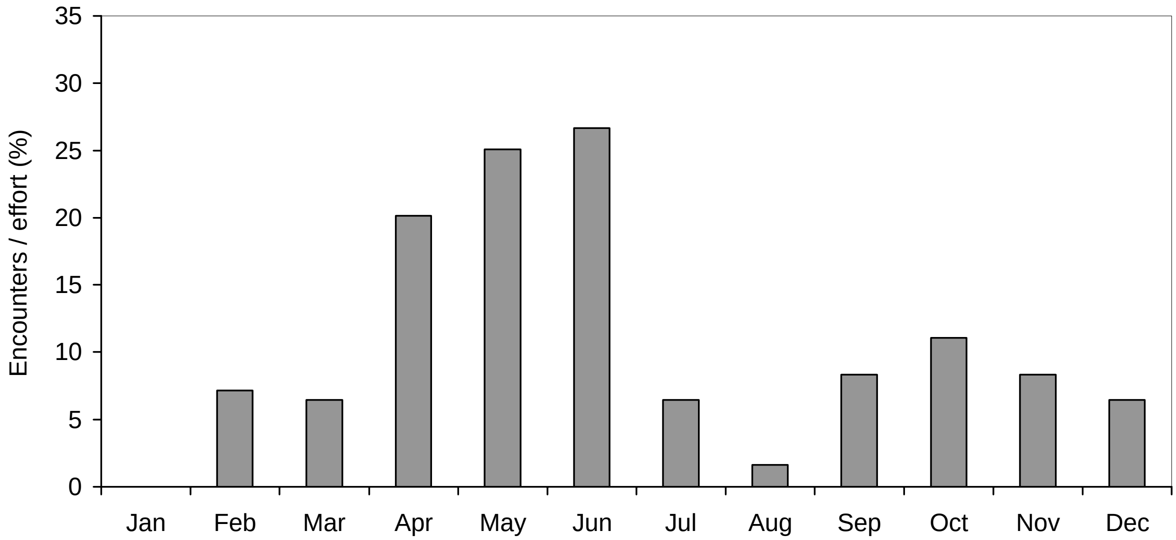

Figure 13.   Percentage of days with observer effort that northern resident killer whales were encountered within the potential Caamano Sound critical habitat area, by month during 2004-05. N = 72 encounters.

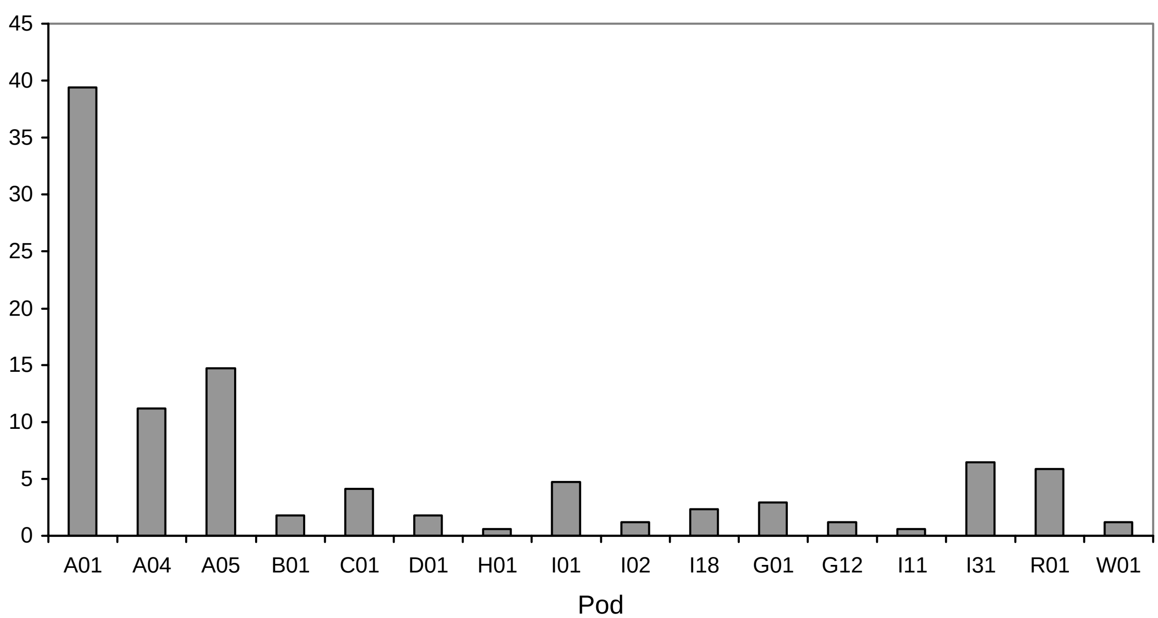

Figure 14. Frequency of occurrence of the 16 northern resident pods in encounters within the potential Caamano Sound critical habitat area, 1977-2005. N = 121 encounters.

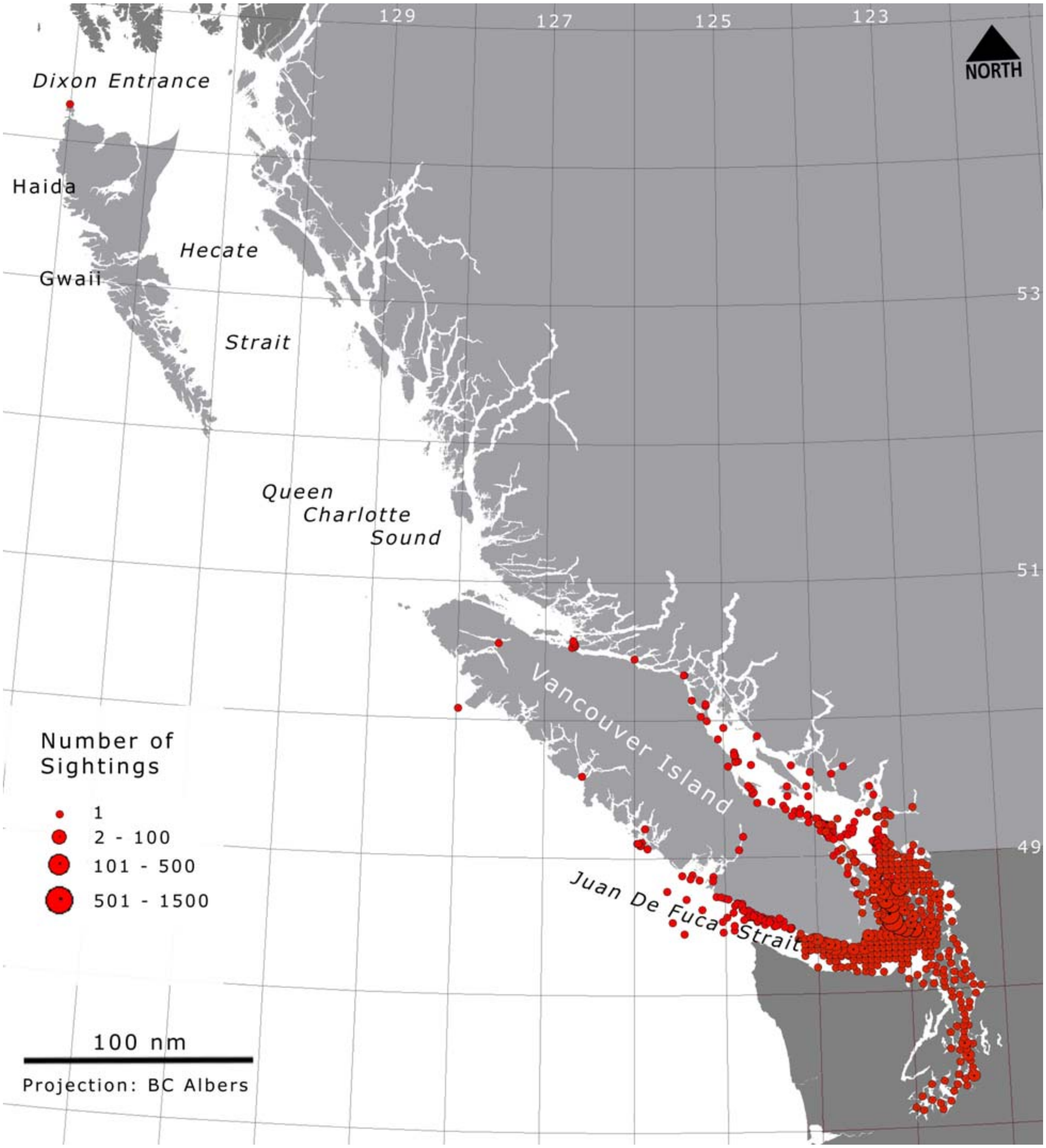

Figure 15. Distribution of sightings and encounters with southern resident killer whales off British Columbia and the inside waters of Washington State. Data sources include the Cetacean Research Program, DFO (n = 586 encounters, 1973-2005), BC Cetacean Sightings Network (n= 534 sightings, 2000-2005), and The Whale Museum (n = 11,836 sightings, 1990-2003).

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1976	?	?	?	J & K	J			J, K & L			?	J
1977	?	?	?	?	?	?		J, K & L				
1978	J	J	J & K	J	J	J		J, K & L			J	J
1979	J	J	J	J	J			J, K & L			J & K	J
1980	J	J	J	J	J			J, K & L			J	J
1981	J	J	J	J & K	J			J, K & L				J
1982	J	J	J	J	J	J & K		J, K & L		J & K	J	J
1983	J	J	J	J	J			J, K & L			J & K	J
1984	J	J	J	J	J	J & K		J, K & L		J	J	J
1985	J	J	J	J	J	J & K		J, K & L			J	J
1986	J	J	J	J	J & K			J, K & L		J	J	J
1987	J	J	J	J	J			J, K & L			J & K	
1988	J	J	J	J	J & K			J, K & L			J	J
1989	J	J	J & K	J				J, K & L			J & K	
1990	J	J	J	J				J, K & L			J	J
1991	J	J	J	J	J & K			J, K & L		J & K	J	J
1992	J	J	J	J				J, K & L				
1993	J	J	J	J	J & K			J, K & L		J	J	J
1994	J	J	J	J	J			J, K & L		J & L	J	J
1995	J	J	J	J				J, K & L		J	J	J
1996	J	J	J	J	J			J, K & L			J & K	J
1997	J	J	J	J	J			J, K & L		Dyes Inlet	J & L	J
1998	J	J	J	J				J, K & L			J & K	J
1999	J	J	J	J	J			J, K & L				
2000	J,K & L	J	J	J	J			J, K & L				
2001		J,K & L	J	J				J, K & L				
2002		J,K & L	J	J				J, K & L				
2003		J,K & L	J	J	J			J, K & L				J & K
2004	J,K & L											

J-Pod= J&K-Pod= J&L-Pod= J,K & L-Pods=

Figure 16. Monthly occurrence of the three southern resident pods J, K, and L, in the inland waters of Washington and BC, 1976-2004. Figure courtesy of R. Osborne, The Whale Museum, Friday Harbor, WA.

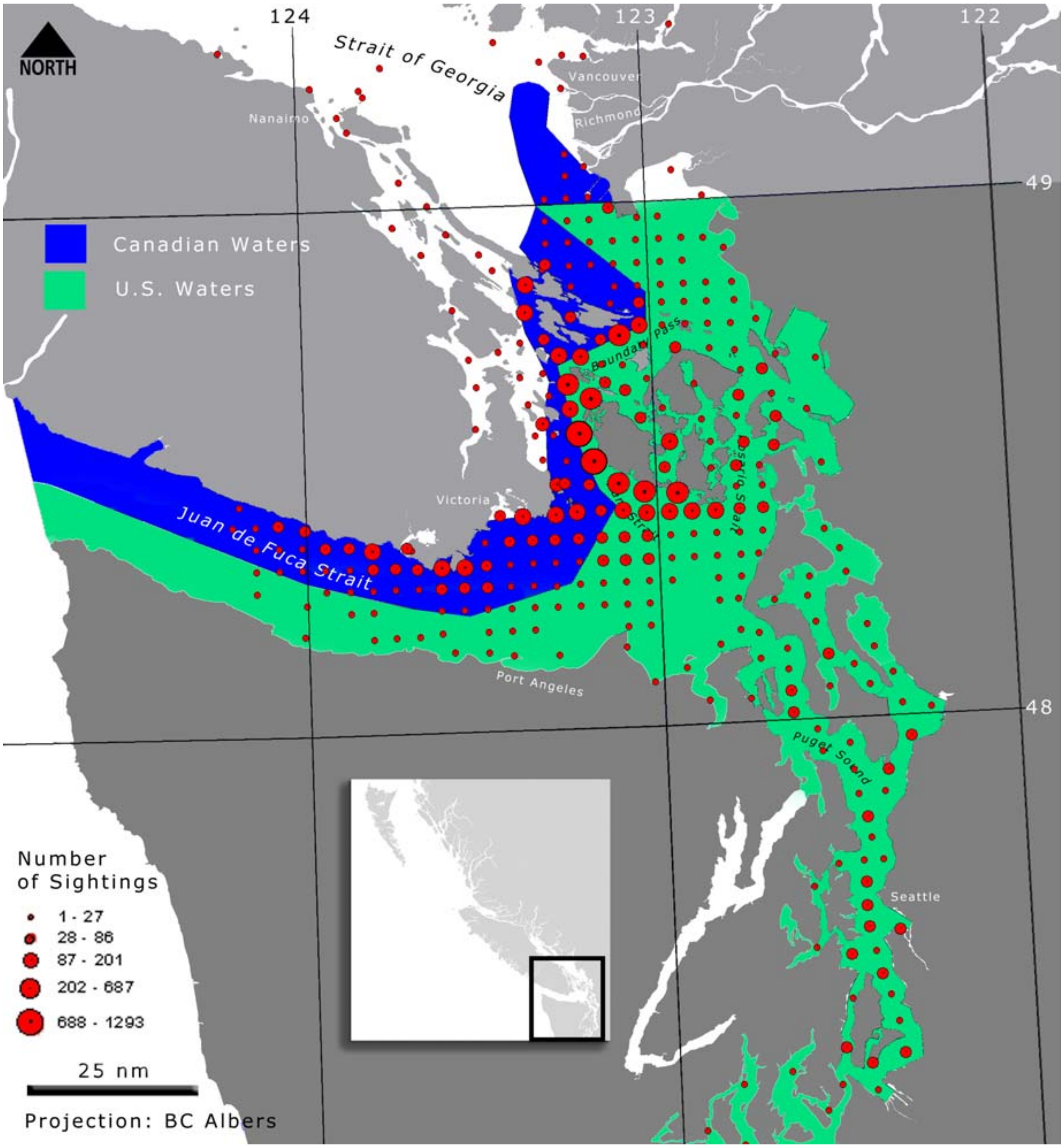

Figure 17. Distribution of southern resident killer whale sightings from the Whale Museum's (Friday Harbor, WA) 'Orca Master' database for 1990-2003 (see Methods for details). Sightings are arranged into a grid of quadrats, the number of which are indicated by red circles of varying sizes positioned in the centre of each quadrat. Also shown in green is the proposed critical habitat areas under consideration in US waters (NMFS 2006) and, in blue, critical habitat areas proposed here for Canadian waters. Sightings data courtesy of R. Osborne (Whale Museum) and Lynne Barre (National Marine Fisheries Service).

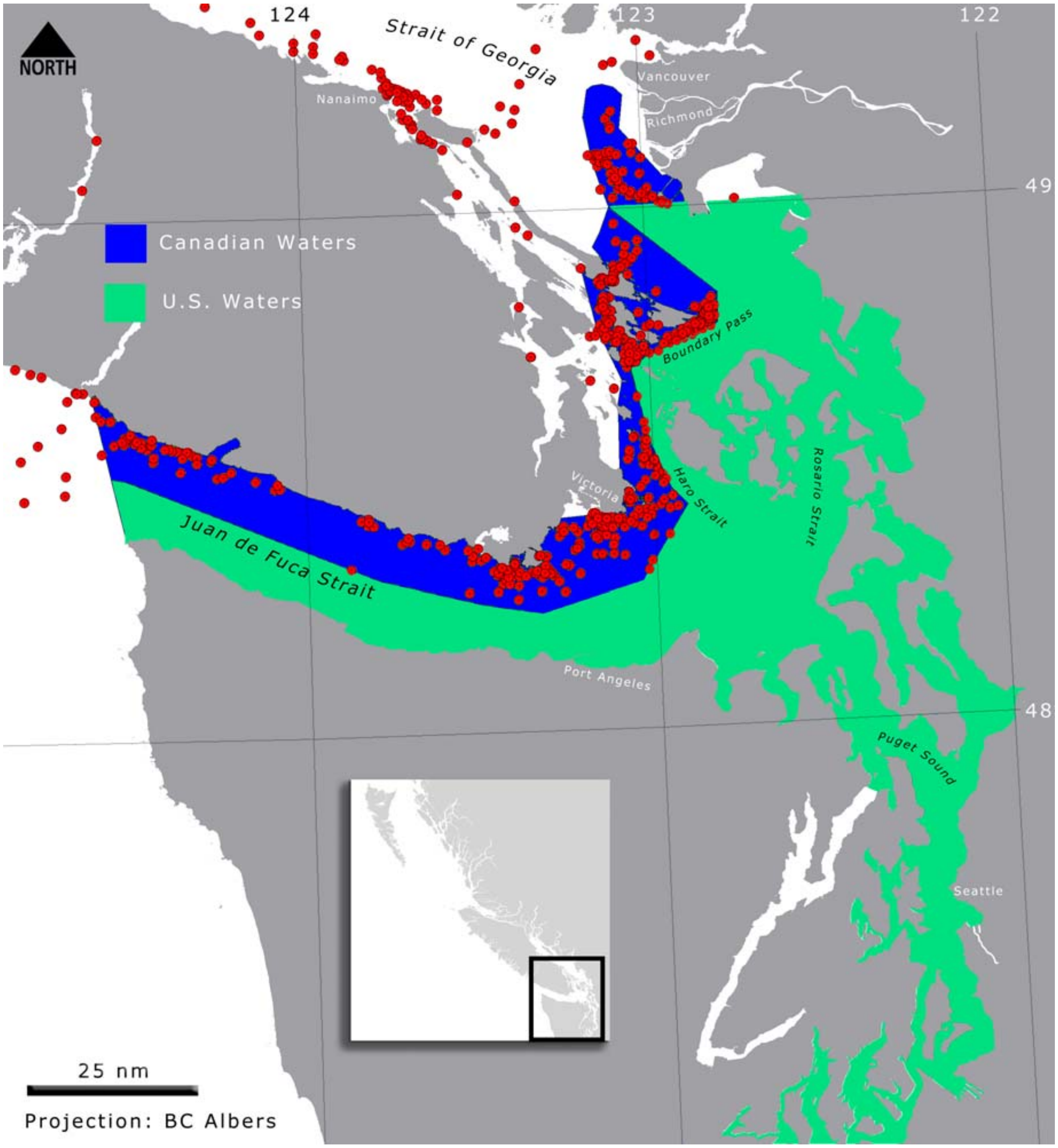

Figure 18. Distribution of southern resident killer whale sightings in Canadian waters, from databases maintained by the Cetacean Research Program, DFO, and the BC Cetacean Sightings Network, 1973-2005. Each red circle indicates a single sighting. Also shown in green is the proposed critical habitat areas under consideration in US waters (NMFS 2006) and, in blue, critical habitat areas proposed here for Canadian waters.