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# Information in Support of the Identification of Critical Habitat for Transient Killer Whales (*Orcinus orca*) off the West Coast of Canada

# Renseignements à l'appui de la désignation de l'habitat essentiel des épaulards migrateurs (*Orcinus orca*) au large de la côte Ouest canadienne

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## ABSTRACT

Mammal-eating transient killer whales off Canada's Pacific coast are listed as Threatened under the *Species-at-Risk Act*. A Recovery Strategy for transient killer whales was prepared by DFO in 2007, but insufficient information was available to identify critical habitat in that document. Here we present an assessment of the habitat use and requirements of West Coast Transient (WCT) killer whales in order to provide the basis for the identification of critical habitat for this population. For this assessment, we used an archive of photo-identifications of individual WCT whales collected during 3582 encounters between 1958 and 2011. Based on frequency of occurrence and distribution, we defined two putative subpopulations, a well-known inner coast subpopulation and an outer coast subpopulation that remains poorly known. The inner coast population was composed of 304 individuals identified during 2988 encounters between 1990 and 2011, and this dataset was used to analyse movement and habitat use patterns. The outer coast subpopulation comprised 217 individuals that were rarely encountered. These whales were found in deeper water, further from land, and closer to the continental shelf break than inner coast whales. WCT killer whales are highly mobile and range over the entire BC coast throughout the year. They forage for marine mammal prey in all marine habitats, primarily in close proximity to coastlines. We describe the biophysical functions, features, and attributes of this habitat, most of which involve feeding and adequate abundance and distribution of prey. Based on existing information, we suggest that a habitat area that includes Pacific coast marine waters up to 3 nautical miles (5.56 km) from shore is of sufficient extent to provide for the population and distribution objectives described in this population's Recovery Strategy, at least for the inner coast subpopulation. This area encompasses the locations of over 90% of all individual identifications and predation events documented with the inner coast WCT subpopulation since 1990. It also includes 64% of identifications of the outer coast subpopulation. This area comprises 40,358 square km, or about 8.9% of Canadian waters off the west coast. Examples of activities likely to destroy critical habitat are described.

## RÉSUMÉ

Les épaulards migrateurs qui se nourrissent de mammifères au large de la côte canadienne du Pacifique figurent sur la liste des espèces menacées en vertu de la *Loi sur les espèces en péril*. Un programme de rétablissement pour les épaulards migrateurs a été préparé par Pêches et Océans Canada en 2007, mais le Ministère ne disposait pas de renseignements suffisants pour désigner l'habitat essentiel dans ce document. Nous présentons ici une évaluation de l'utilisation et des exigences liées à l'habitat des épaulards migrateurs de la côte Ouest afin de poser les jalons de la désignation de l'habitat essentiel pour cette population. Pour cette évaluation, nous avons utilisé des archives de photo-identifications d'épaulards migrateurs individuels recueillies au cours de 3 582 rencontres entre 1958 et 2011. D'après la fréquence de l'occurrence et la répartition, nous avons défini deux sous-populations putatives, une sous-population bien connue de la côte intérieure et une sous-population de la côte extérieure pour laquelle on dispose de peu de renseignements. La population de la côte intérieure était composée de 304 individus identifiés lors de 2 988 rencontres entre 1990 et 2011, et on a utilisé cet ensemble de données pour analyser les modèles de déplacement et d'utilisation de l'habitat. La sous-population de la côte extérieure comprenait 217 individus qu'on a rarement rencontrés. Ces épaulards étaient présents dans des eaux plus profondes, plus loin des terres, et plus près du rebord du plateau continental que ceux de la côte intérieure. Les épaulards migrateurs sont extrêmement mobiles et leur aire de répartition comprend toute la côte de la Colombie-Britannique, tout au long de l'année. Leurs proies sont des mammifères marins dans tous les habitats marins, essentiellement ceux qui se trouvent à proximité des côtes. Nous décrivons les fonctions, caractéristiques et attributs biophysiques de cet habitat, dont la majeure partie comprend l'alimentation ainsi que l'abondance et la répartition adéquates des proies. Sur la base de l'information existante, nous suggérons qu'une zone d'habitat qui comprend les eaux marines de la côte du Pacifique jusqu'à trois milles nautiques (5,56 kilomètres) du rivage a une portée suffisante pour atteindre les objectifs en matière de population et de répartition décrits dans le programme de rétablissement de cette population, du moins pour la sous-population de la côte intérieure. Cette zone englobe les emplacements de plus de 90 % de l'ensemble des identifications et des événements de prédation consignés pour la sous-population d'épaulards migrateurs de la côte intérieure depuis 1990. Elle comprend également 64 % des identifications de la sous-population de la côte extérieure. Cette zone a une superficie de 40 358 kilomètres carrés, soit environ 8,9 % des eaux canadiennes au large de la côte Ouest. Le document comprend des descriptions d'exemples d'activités susceptibles de détruire l'habitat essentiel.

# INTRODUCTION

In April 1999, the transient killer whale population off Canada's west coast was designated Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The status of this population was reassessed in 2001 based on an existing status report (Baird 1999) and an addendum containing updated information (Trites and Barrett-Lennard 2001), and uplisted to Threatened in November 2001. This population became legally listed on Schedule 1 with the proclamation of the Species-at-Risk Act (SARA) in 2003. The Threatened status of this population was reaffirmed by COSEWIC in 2008.

A recovery strategy for transient killer whales in Canada was prepared by DFO (Fisheries and Oceans Canada 2007). The stated goal of the Recovery Strategy is to: *to attain long-term viability of the West Coast transient killer whale population by providing the conditions necessary to preserve the population's reproductive potential, genetic variation, and cultural continuity*. Although the Recovery Strategy did not specify what constituted "viability" of this population, it outlined population and distribution objectives that were considered to be interim measures of recovery success over a five-year period following the strategy's completion. Key among these are that the population size, averaged over the next five years, will remain at or above the current (2007) level, that the transient killer whale population will continue to use its known range, and that prey will be available within that range to allow for recovery, and that studies will be undertaken to determine how the range is utilized at a population and subpopulation level

As dictated in the SARA, Recovery Strategies are legally required to identify critical habitat, which is defined as *the habitat that is necessary for the survival or recovery of a listed wildlife species that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species* (SARA s.2 (1)). In cases where information is insufficient to identify Critical Habitat, the recovery strategy must include a schedule of studies to obtain such information. At the time the Transient Killer Whale Recovery Strategy was prepared, it was judged by the technical team involved in its drafting that existing information was inadequate to identify critical habitat and a schedule of studies was included in the document.

In this report, we present updated analyses intended to describe the extent of habitat required to meet the population and distribution recovery objectives for transient killer whales in British Columbia. This information will assist in the identification and designation of critical habitat for West Coast transient killer whales.

## BACKGROUND: LIFE HISTORY, SOCIAL STRUCTURE AND ECOLOGY OF KILLER WHALES

The following provides broad background information on the life history and ecology of killer whales globally as well as in Canadian west coast waters, followed by more detailed description of the West Coast Transient (WCT) population that is the focus of this study. 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. There is an estimated total abundance of at least 50,000 (Forney and Wade 2006), 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.

Three distinct assemblages, or lineages, of killer whales have been described in coastal waters of the northeastern Pacific Ocean. These lineages, named *transient, resident* and *offshore*, differ in diet and foraging behaviour, acoustic behaviour, morphology, and genetic characteristics. Despite having overlapping ranges, these lineages do not mix and are thus socially and reproductively isolated from each other. Recent studies have indicated that transient killer whales are the most genetically divergent of these lineages and warrant distinct species status (Morin et al. 2010). Transient killer whales (also known as Bigg's killer whales) specialize on marine mammal prey, though they occasionally kill and eat seabirds as well. There is no evidence from decades of field observations that they feed on fish. Resident killer whales prey mainly on fish, particularly salmon, and some squid. Offshore killer whales also feed on fish and may specialize on sharks (Ford et al. 2011). 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.

Three putative populations of transient killer whales have been described from studies in nearshore waters of the northeastern Pacific. These are the so-called *West Coast transients*, distributed along the west coast of the mainland US and Canada, the *AT1 transients*, centered in Prince William Sound and Kenai Fjords, Alaska, and the *Gulf of Alaska transients,* most reliably seen between the central Gulf of Alaska and the central Aleutian Islands (Ford and Ellis 1999; Allen and Angliss 2011; Matkin et al. 2012). The AT1 population has declined sharply in recent years to only 7 animals and faces eventual extinction (Matkin et al. 2012).

The West Coast Transient (WCT) population is the only one known to frequent Canadian waters, and is the focus of this report. This population is distributed throughout coastal waters of British Columbia. In 1999, it was estimated from long-term photo identification studies to contain 219 whales, though long gaps between sightings of some individuals added considerable uncertainty to this estimate (Ford and Ellis 1999). An additional 100 or so transient killer whales identified off central California (Black et al. 1997) were in the past considered to be an extension of this population because of acoustical similarities and occasional mixing with WCT individuals in BC waters (Ford and Ellis 1999). However, a recent reassessment by the technical team involved with developing the transient killer whale recovery strategy indicated that the available evidence was insufficient to warrant inclusion of these whales in the WCT population (Fisheries and Oceans Canada 2007). This was also the case for Gulf of Alaska transients, which are seen occasionally within the range of WCT whales but had only been observed to travel in association with WCT whales on one occasion. A population abundance estimate for WCT whales based on a Bayesian "capture–recapture" approach was prepared for a recovery potential assessment of this population (Ford et al. 2007). This indicated that the population has been increasing since the 1970s, and was composed of about 262 whales in 2006.

Killer whales are long lived animals that have a low reproductive potential. Best known are resident killer whales, and their life history parameters as presented in Olesiuk et al. (2005) may be generally representative of transients as well. Survival patterns are typical of mammals, being U-shaped with highest mortality rates in very young (neonate) and very old age classes. 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 northern resident killer whale 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.

Killer whales tend to live in long-term matrilineal groups (Bigg et al. 1990; Ford et al. 2000). In resident killer whales, social structure is extremely stable, as there is no dispersal from the natal group by either sex. Thus, the basic social unit, known as a *matriline*, can be comprised of up to 4 generations of whales, generally a post-reproductive female matriarch and her living descendants. Transient killer whale society is also matrilineally based, but is considerably more dynamic than that of residents. A key difference is the regular dispersal of individuals from the natal matriline in transients (Baird and Dill 1996; Ford and Ellis 1999). Once dispersed, whales will travel with other transient groups for variable periods, and may only associate with their natal matriline occasionally. As a result of dispersal, transient matrilines tend to be smaller than those of residents, and long-term associations of closely-related matrilines equivalent to resident pods do not exist. Typical group sizes of transients are 3-6 individuals, though temporary associations of over 30 whales have been observed. Transients are acoustically quiet compared to residents, probably because their hunting strategy relies on stealthy approaches to unwary marine mammals. When vocal, WCTs share a common set of distinct stereotyped calls that do not have dialect variations as seen in residents.

WCT killer whales feed on a variety of marine mammal species. Along the coast of British Columbia and southeastern Alaska, their primary prey is the harbour seal (*Phoca vitulina*), which represented roughly one-half of observed kills and harassments (unsuccessful attacks) documented by Ford et al. (1998, 2007). Other important prey species included Steller sea lions (*Eumetopias jubatus*), Dall's porpoise (*Phocoenoides dalli*), and harbour porpoise (*Phocoena phocoena*).

## METHODS

### PHOTO-IDENTIFICATION STUDIES

WCT killer whales have been studied by means of photographic identification of individuals from natural markings for almost four decades. Field studies using this technique have been undertaken each year since the early 1970s (Bigg et al. 1987, 1990; Ford and Ellis 1999; Ford et al. 2007; Towers et al. 2012). This long-term effort has resulted in an archive of identification photographs collected from 3582 encounters with WCT whales by over 100 collaborators between 1958 and 2011 in waters from British Columbia, Southeast Alaska, and Washington State. This archive, maintained by the Cetacean Research Program (CRP) at the Pacific Biological Station (Fisheries and Oceans Canada, Nanaimo, B.C.), has resulted in a database containing more than 15,000 positive individual whale identifications. Over five hundred unique identification numbers have been assigned. Approximately 70 per cent of encounters were made by field researchers with the CRP and other organizations and institutions, with the remainder based on identification photographs contributed by natural history tour and whale watching operators and the general public.

Due to the unpredictable movements of WCT killer whales, encounters were generally made opportunistically while researchers were undertaking field studies focused on resident killer whales and other cetacean species. Similarly, natural history tour and whale watch operators typically encountered and photographed transients during unrelated activities or while searching for other whale populations or species. Many encounters within a 20 km radius of the Pacific Biological Station (Nanaimo, BC) were made by CRP researchers responding to sightings reported by the public via a telephone hotline. Thus, very few WCT encounters resulted from dedicated survey effort focused on this population.

## PREDATION ANALYSES

To describe the potential relationship between WCT killer whale habitat use patterns and prey distribution, observations of predation involving confirmed prey species were compiled and analyzed. Prey species were identified from 421 predation events mostly by direct observation in the field (97%) but some (3%) were identified from tissue recovered at the predation site and later identified by genetic analysis. 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.

## SPATIAL ANALYSES

Spatial analyses were undertaken using ArcGIS (http://www.esri.ca/). The coastline, bathymetric contours and encounters were projected into the appropriate UTM zone (WGS84 UTM8N/9N/10N) in preparation for distance analysis. To measure the distance between encounter locations and the nearest shore or specific bathymetric contours, the encounters were spatially joined to the target (shoreline or contour), generating a distance attribute for each encounter (in metres). Depths 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. Descriptive statistics of depth and distance for each individual animal were calculated from this data. As the distribution for all depth and distance data were usually found to be non-normal, in most cases non-parametric Kolmogorov-Smirnov tests were used to determine significance of differences. ANOVA was used in one case where variances were homogeneous. To examine the distribution of WCT whales in different areas of the BC coast, we divided the region into a grid of 5x5 km cells, and examined the total number of encounters, the 'effective' number of individuals identified, and a diversity index in each of these cells. The 'effective' number is a count of animals for each cell that takes into account both the number of unique individuals encountered and the evenness of the distribution of encounters among individuals, according to the following formula (derived from Simpson, 1949):

$$\text{Effective count} = N^2/\sum n_i^2$$

where N is total identifications and $n_i$ is the number of identifications of whale i. For example, if 4 encounters occur in a grid cell, three with whale *a* and one with whale *b*, conventional counting would conclude that the unique individual count would equal two. However, as the distribution of encounters between the two whales was uneven, the effective count measure would compensate for this and supply a value of 1.6 unique individuals. The diversity index provides a measure of high (1.0) to low (0.0) diversity of encountered individuals by normalizing the effective count by the total number of identifications in each grid cell.

## MOVEMENT/RESIGHT ANALYSES

A major issue in dealing with photo-identification data for WCT killer whales, and one that plagues the majority of cetacean analyses, is unevenly and non-randomly distributed spatial and temporal effort. The non-systematic collection of data tends to skew spatial and associative data sets and, if not taken into account when using traditional mark-recapture techniques, misrepresents the true movement dynamics of a population (Whitehead 2001). By using number of identifications as the measure of effort – as we did here – issues of uneven and unquantified effort are partially mitigated, thereby allowing all types of encounter data (opportunistic, incidental, and survey) to be used together, to form a robust model of animal use within particular study regions. In order to analyze general WCT spatial use of the northeastern Pacific coast, the area was divided into seven different regions (see Figure 13). As effort within regions tended to be unevenly distributed temporally, with most effort occurring in the summer, the dataset was restricted to June–September. Analyses were performed using SOCPROG software (compiled version 2.4; Whitehead 2009a). In order to examine the use of each region, lagged identification rates (LIR) were calculated for each region. The LIR is based on the probability that an individual identified in a given study region at any time would be identified from any identification made in the same study area after a given time lag; this is estimated from proportion of pairs of identifications of an individual at various time units apart (Whitehead 2001). By plotting LIR against time lag, one can estimate the use of the region by the population (e.g., number of animals in the study region, mean time spent in/out of the region) by fitting models by maximum likelihood and binomial loss (see Figure 14). In order to examine longer term site fidelity, SOCPROG was used again to generate annual transition probabilities (ATP) – the probability that an individual identified in a given year would be resighted in the same region the year after. In order to do this, the program finds a set of parameters that maximizes the likelihood of the identification data using the Poisson approximation (Whitehead 2009b).

# RESULTS AND DISCUSSION

## DATASET USED FOR HABITAT ASSESSMENT

A total of 15,904 positive individual identifications were made from photographs taken during 3582 encounters with WCT killer whales during 1958 to 2011. The number of encounters by year over this time series is shown in Figure 1 (dedicated field studies using photo-identification began in 1973 – the five earlier encounters were from historical photographs). As discussed below, the increase in annual number of encounters reflects both increasing survey effort and a growing population. A total of 521 unique WCT individuals were identified during this time series. Prior to undertaking detailed spatial analyses of habitat use, we chose to restrict the dataset to the period 1990 to 2011, because 1) the period from the 1970s through the 1980s was characterized by immigration of individuals into inner coast waters, likely in response to growing prey populations (Ford et al. 2007), and 2) movements of individuals during this dynamic period may not reflect recent habitat use patterns. This eliminated 11.6% of the encounters (415 of 3582), but only 8.9% of the total individual identifications (1413 of 15,904). We also removed encounters that did not contain precise geographical locations (n = 30) or where individuals were identified visually rather than by photographs (n = 21). The remaining dataset used for spatial analyses contained 3090 encounters involving 14,284 individual identifications of a total of 521 unique WCT whales.

There is evidence that the WCT population along the coasts of British Columbia and southeastern Alaska may comprise two fairly discrete clusters that are spatially and socially heterogeneous. Although most animals in the population were encountered repeatedly in nearshore waters, a substantial proportion were identified only rarely (most seen in fewer than 10 encounters) and typically in outer coast waters. Many of these individuals appear to be members of adjacent populations found in waters to the south or north. Forty-six whales have been identified off central California (Black et al. 1997) and 14 are known from the southern Alaska coast (west of southeastern Alaska) (Matkin et al. 1999). These whales also differ in vocal dialect from those commonly found in nearshore BC waters (Ford 1984, unpubl. data; Deecke et al. 2005) and those from Alaska differ in mitochondrial DNA haplotype (Barrett-Lennard and Ellis 2001). These rare individuals – referred to here as “outer coast” WCT whales – appear to differ in habitat use, being found mostly in deep waters over the continental shelf and along the exposed west coast, and rarely if at all are seen in inner coast waters where there is considerable survey effort. Most have not been seen in association with the more commonly observed transients that frequent protected inshore waters –we refer to these here as “inner coast" WCT whales. The rarity of encounters with outer coast WCT individuals is likely a result of the comparatively little survey effort conducted in exposed coastal waters more than 10 km from shore.

To evaluate the spatial heterogeneity between outer coast and inner coast WCT killer whales, we split the overall population into two groups based on frequency of encounters – those identified fewer than 15 times includes all individuals considered to be outer coast WCT whales and those identified 15 or more times includes all well known inner coast WCT whales. The numbers of encounters, individual identifications and unique individuals in these two sets of whales are provided in Table 1, and the locations of encounters with each are depicted in Figure 2. Outer coast WCT whales represented only 4.9% of the total individual identifications but comprised 217 of the 521 unique WCT individuals (41.7%) identified in the overall population. The mean number of identifications of outer coast WCT whales was 3.3 (SE = 0.2), while inner coast WCT whales were each identified on an average of 44.7 occasions (SE = 2.5).

To assess whether inner and outer coast WCT killer whales differed significantly in their tendency to be found in deeper, exposed coast versus shallower, protected inshore waters, we compared their encounter locations in British Columbia with respect to depth, distance from the continental shelf slope, and distance from shore. Inner coast WCT whales were identified in water depths averaging 98.0 m (SE = 1.1, range = 1–1195 m, n = 10,298 identifications) while outer coast WCT whales were found over mean depths of 247.6 m (SE = 2.3, range = 6–2887 m, n = 546 identifications). Outer coast WCT whales were thus found at depths averaging 2.5 times that of inner coast transients ($Z = 6.44$, $p < 0.001$). Distances of encounters to the nearest shore are shown in Figure 3. Inner and outer coast WCT whales differed significantly in their distance from shore ($Z = 9.56$; $p < 0.001$) – the mean distance from shore for inner coast WCT individuals was 2.1 km (SE = 0.04) while outer coast WCT individuals averaged 8.5 km (SE = 0.5). Over 70% of encounters with inner coast WCT whales took place within 2 km of shore, compared to only 46% for outer coast WCT whales. Distances of the two groups to the continental shelf slope (as indicated by the outer 200 m isobath) also differed significantly. Inner coast WCT whales were encountered at mean distances of 66.4 km to the outer 200 m isobath (SE = 0.3, range = 0.1–184 km), more than double the mean distance of 28.8 km that outer coast WCT individuals were encountered from this isobath (SE = 1.3, range = 0.1–166 km; $Z = 12.11$, $p < 0.001$).

Based on the analyses above and other lines of evidence described previously, these outer coast WCT killer whales may represent a discrete subpopulation that differs in habitat use patterns from the more commonly encountered inner coast WCT whales. Because this putative subpopulation was so rarely encountered, its habitat requirements are poorly understood. Thus, detailed spatial analyses and descriptions of habitat use in this report pertain primarily to the well-known inner coast WCT killer whales, which comprised 304 individuals identified during 2988 encounters between 1990 and 2011.

## ABUNDANCE AND DISTRIBUTION

Previous abundance estimates using photo-identification data for WCT killer whales indicated that the population has increased significantly since field studies began in the early 1970s. Ford et al. (2007) used Bayesian "capture–recapture" models to show that the population increased rapidly between 1975 and about 1990, driven largely by immigration of animals into the study area. Immigration slowed during the late 1980s, with continued growth being driven primarily by recruitment of new calves. The abundance in 2006 was estimated to be 262 whales. Although there were indications that growth was slowing in the last few years of the time series, updated analyses through 2010 have found that growth is continuing at about 3% per annum (Durban et al., in prep.). The rates of discovery of all identified inner coast WCT individuals and non-calves during 1974 to 2011 are depicted in Figure 4. This shows that there has been essentially no new discovery of non-calf individuals and thus no immigration into the inner coast WCT population since 1990, and that growth since then has been through recruitment of calves into the population. Growth in the population is also reflected in increasing group sizes over the time series. Median group sizes increased from 3.5 in the 1970s to 4.0 in the 2000s, and maximum group sizes increased as well (Figures 5 and 6). Groups of more than 10 individuals were rare during the 1970s and 1980s, but were routinely observed during the past decade, with some temporary aggregations exceeding 30 animals.

WCT killer whales are widely distributed in coastal waters of the eastern North Pacific. They occur along the exposed outer coast as well as in protected inshore channels, straits, passages and inlets. They are most commonly observed within 10 km of the coast but, as discussed previously, this may reflect a bias in sighting effort favouring nearshore waters. The subpopulation primarily under consideration here – inner coast WCT individuals – are found from the northernmost inlets of southeastern Alaska (approximately 59°N) to northern California (approximately 41°N), a linear distance of over 2000 km along the west coast. In Alaska, none of these individuals have been observed to the west of southeastern Alaska, where other transient killer whale populations have been described (Matkin et al. 2012). There are only 17 encounters with the inner coast WCT subpopulation south of Cape Flattery, Washington, on the outer coast of the US mainland. Members of the putative outer coast WCT subpopulation have been identified further to the south – as far as central California – and to the northwest in the Gulf of Alaska.

Within this overall range, encounters have been concentrated in certain regions, notably off eastern and southwestern Vancouver Island, off southeast Moresby Island (Haida Gwaii), in channels along the central and northern BC mainland coast, and in the northern half of the southeastern Alaska panhandle (Figure 2). It is important to recognize that these areas of apparent high density are also areas of high observer effort, and that portions of coast with few or no encounters are, in most cases, areas with minimal observer effort. Since observer effort was often not documented, it is difficult to correct for this bias quantitatively. However, to obtain some perspective on potentially important areas, the density of encounters, the effective count of individuals and a diversity index were plotted on a grid of 5x5 km cells over the BC coast. The effective count of unique individuals takes into account both the number of unique individuals encountered and the evenness of the distribution of encounters among individuals (Simpson, 1949). For example, if 4 encounters occur in a grid cell, three with whale a and one with whale b, conventional counting would conclude that the unique individual count would equal two. However, as the distribution of encounters between the two whales was uneven, the effective count measure would compensate for this and give a value of 1.6 unique individuals. The diversity index indicates a measure of high (1.0) to low (0.0) diversity of encountered individuals by normalizing the effective count by the total number of identifications in each grid cell.

The density of encounters in British Columbia waters arranged into a 5 by 5 km grid is shown in Figure 7, and the effective count of unique individuals in the same grid is shown in Figure 8. These both show a similar pattern – encounters and total individuals are clearly greatest in four hotspots: in the Clayoquot Sound area on the west coast of Vancouver Island, in eastern Juan de Fuca Strait and Haro Strait near Victoria at the south end of Vancouver Island, in central Strait of Georgia near Nanaimo off eastern Vancouver Island, and in the Johnstone Strait area off northeastern Vancouver Island. However, when the index of WCT diversity is plotted on the same map grid (Figure 9), a more even distribution is revealed, suggesting that the relatively high densities of WCT whales in these hotspots is driven more by effort than an actual heterogeneity in habitat use. Each of these four areas has had many years with high levels of observer effort, considerably more than any other region in the study area. There is thus little evidence for the existence of particular locations in BC nearshore waters that are strongly favoured by WCT killer whales over others.

## LARGE-SCALE MOVEMENTS AND SITE FIDELITY

WCT killer whales are highly mobile and travel widely within their range. Most whales in the inner coast subpopulation have been encountered in locations spread over hundreds of kilometres of coastline, and often make extensive transits of their range over relatively short periods of time. A typical example of the coast-wide movements of these whales is depicted in Figure 10. This plot shows the locations of encounters with a group of nine transients known as the T100/101s, over the course of one year. Although the whales were encountered most frequently around Vancouver Island, they made two separate excursions to the northern portion of southeastern Alaska during the year. These long-range transits involved minimum mean rates of 43–138 km of latitude per day – the actual distance covered by the animals on these excursions was likely much greater.

As might be expected, the extent of the latitudinal range of encounter locations with individual WCT whales is strongly correlated with the cumulative number of encounters with those individuals (Kendall's tau-b, $\tau_b = 0.36$, $p < 0.001$). However, the relationship between latitudinal extent and number of encounters, plotted in Figure 11, is not a simple linear one. Two clusters are apparent in this relationship – one is concentrated around 6 degrees of latitude and the other around 10 degrees. To some extent, this split likely reflects spatial heterogeneity of sampling effort along the coast. Six degrees of latitude corresponds to the distance between southern Vancouver Island – a sampling hotspot – and northern British Columbia, and 10 degrees between southern Vancouver Island and Glacier Bay, southeast Alaska, another sampling hotspot. An area of relatively low sampling effort exists in the southern portion of the southeastern Alaska panhandle (Fig. 2), which corresponds to a distance of 7–9 degrees of latitude from southern Vancouver Island. Although this area of low effort may partly account for the gap in this latitude range in the plot in Figure 11, it is unlikely to explain why many common individuals that have been encountered on numerous occasions (> 50) are limited in the latitudinal extent of their range. It seems most likely that these animals have higher levels of site fidelity and simply do not use the entire range of the population.

To further examine the extent of range-wide movements and site fidelity of individual WCT whales, we plotted the distribution of encounter locations by latitude for 91 of the most commonly identified individuals (those animals encountered on 50 or more occasions; Figure 12). This indicates that some whales show strong site fidelity to particular portions of the coast, especially in southeastern Alaska (north of 56°N) and off Vancouver Island (48°–51°N), while others appear to have weaker site fidelity and use broader sections of the coast. Despite there being variable degrees of site fidelity, most individuals have been encountered over the majority of the latitudinal extent of the population's range.

To assess in greater detail the use by individual WCT whales of their overall range, we divided the coastal study area into seven regions, shown together with the location of encounters within each region, in Figure 13. We then examined the number of WCT individuals that were identified within each region and the number that were identified in more than one region over the time series (Table 2). More than half of the population was identified in 5 of the 7 regions, with the greatest proportion (81%) being identified in the northeastern Vancouver Island region. The region with the lowest proportion of the population was northwestern Vancouver Island (24%), an area that has received the least survey effort. Pairwise comparisons showed substantial movement (i.e., re-identification) of individuals among regions, with rates varying according to the sample size for the regions being compared. We next fit a maximum-likelihood movement model to this dataset to calculate the probabilities of individuals moving between regions on an annual basis (the annual transition probability (ATP); see Methods). This model also calculates the probability of an animal being re-identified within each region annually, and outside of any identified region (i.e., outside of the study area). The resulting probabilities, shown in Table 3, indicate that there is substantial annual movement of individuals among the majority of regions as well as outside these regions (i.e., outside the study area). Southeastern Alaska showed a particularly high probability of re-identification of individuals across years, indicating relatively high site fidelity. Other areas showed a lower probability of re-identification within the same region.

Another measure of site fidelity and movement among regions is the lagged identification rate (LIR) of individuals (see Methods). LIR plots for two regions, northeastern Vancouver Island and southeastern Vancouver Island, for which there are sufficient sample sizes of photo-identifications, are depicted in Figure 14. These both show the LIRs to drop precipitously between 0 and 10 days, which indicates that the majority of animals leave the region during this period. The LIRs then settle to a fairly constant low level over longer lags, which reflects animals returning to the region after having previously left.

Detailed assessment of potential seasonal movement patterns of WCT whales is confounded by temporal heterogeneity in sampling effort. In most survey areas, effort is concentrated during June through September, when weather is favourable for field work and days are long. Survey effort outside of this period has been, in most areas, minimal or non-existent. However, one region where effort has been reasonably consistent throughout the year is off southeastern Vancouver Island. A sighting network in the area of Nanaimo has facilitated encounters in all months of the year in the central Strait of Georgia area, and effort by data contributors based in Victoria has been year-round for the past decade. Thus, the monthly frequency of occurrence off southeastern Vancouver Island, shown in Figure 15, is unlikely to be seriously biased other than by an expected decline in sightability of whales during winter due to short day lengths and frequent periods of inclement weather. This shows fairly consistent occurrence of transients in most months, with a slight increase in April and May and a more pronounced peak in August and September. Use of the area in June and July is lower than what might be expected given long days and favourable weather. It may be that this decline as well as the peaks in August and September are related to the availability of harbour seal pups – this is discussed in greater detail in the following section.

In summary, these analyses of large-scale movement patterns all indicate that individual WCT killer whales are highly mobile and utilize much of the overall population range. Despite these broad movements, many individuals show a relatively high degree of site fidelity, returning repeatedly to particular coastal regions. Site fidelity may result from the benefits individuals would gain from familiarity with particular habitats and the location of prey resources within them, thereby improving their foraging success. WCT whales are present in their overall range throughout the year.

## DISTRIBUTION AND LARGE-SCALE MOVEMENTS RELATED TO PREDATION

WCT killer whales are marine-mammal hunting specialists. Like most mammalian predators, their distribution and movement patterns are likely linked to the seasonal abundance and distribution of their prey. WCT whales hunt most species of marine mammals commonly found within their coastal range, with the exception of adults of the largest whales in the region – grey whale, humpback whale, and fin whale. The frequency distribution of marine mammal species killed and consumed by transient killer whales in the study area is shown in Figure 16. The most common prey species was harbour seal, representing 52% of all predation events, followed by harbour porpoise (17%) and Steller sea lion (13%). The remaining prey species were each represented in less than 10% of predation events – Dall's porpoise, Pacific white-sided dolphin, California sea lion, minke whale, northern elephant seal and sea otter, in order of decreasing importance. There is no evidence that individual WCT whales specialize on particular prey species or types (e.g., porpoises versus seals). The diet breadth of individuals (number of prey species) is significantly correlated with the cumulative number of times those individuals are observed in predation events (Ford et al. 1998; Straley et al. 2007). Most whales that were observed in at least 10 predation events had preyed upon all four of the top prey species – harbour seal, harbour porpoise, Steller sea lion and Dall's porpoise – which together comprised more than 90% of documented kills.

The important prey species consumed by WCT whales are widely distributed in the study area, although each differs somewhat in habitat preferences. The locations of predation events for the top four prey species are shown in Figure 17. All four species were taken in all regions of the coast. The wide distribution of harbour seal kills reflects their near ubiquitous occurrence in nearshore coastal waters (Olesiuk 2010). Harbour porpoises are also distributed widely along the BC coast, although their preference for waters of less than 100 m depth limits the extent of their offshore occurrence (Figure 18). Dall's porpoises are common in both inshore and offshore waters (Figure 19), although kills of this species were almost entirely within 3 km of shore (see section Small-scale Patterns of Habitat Use, below). This likely reflects the paucity of encounters of WCT whales in offshore waters, due at least in part to low survey effort in such areas. Steller sea lions are found in both inshore and offshore waters, although their distribution varies seasonally (COSEWIC 2003). There did not appear to be any strong regional variation in the relative importance of the principal prey species with the exception of harbour seals, which comprised 67% of total kills off southeastern Vancouver Island but only 46% outside of this region. This likely reflects the considerable abundance of harbour seals in the Strait of Georgia area, which has about five times the density of other areas of the BC coast (13.1 versus 2.6 seals per km of shoreline; Olesiuk 2010).

It is difficult to assess quantitatively whether large-scale movements of WCT whales vary in relation to any temporal or spatial variation in the availability of important prey species. The majority of WCT sightings were opportunistic and no reliable data are available on survey effort with which to correct for seasonal or geographic bias. No seasonal shift was apparent in the occurrence of important prey species in the diet of WCT whales. The four principal prey species were documented being consumed in most or, in the case of harbour seals, all months of the year (Figure 20). The frequency of recorded predation events for all species was greatest during the summer months, corresponding to the marked increase in effort and encounters during this season (Figure 15). Harbour porpoises and Dall's porpoises are common year-round in BC waters, but insufficient effort-corrected sightings data are available to determine whether there are seasonal changes in distribution or abundance. Steller sea lions move between seasonal haulouts and rookeries, but no information is available on their densities, and hence availability to WCT whales, in open waters. For harbour seals, however, there is some indication that the timing of pupping may have some influence on the occurrence of WCT whales in at least two regions – southeastern Alaska and southeastern Vancouver Island. Given the importance of harbour seals in WCT diet, the post pupping season is likely a time of prime foraging for these predators. Although smaller than adults, harbour seal pups are still a significant prey item – they are born at a mean mass of 11 kg, which doubles by the time they are weaned 4–5 weeks later (Cottrell et al. 2002). They are abundant and likely naïve and highly vulnerable, especially around the time of weaning. The timing of pupping season varies with latitude – in southeastern Alaska to northern BC, the mean date of pupping is mid June (Temte et al. 1991; Mathews and Pendleton 2006), while off southeastern Vancouver Island it is more than six weeks later, peaking in early August (Temte et al. 1991). The frequency of occurrence of WCT whales in these two regions over the months of June to September – a period of consistent effort in both regions – is depicted in Figure 21. This shows a clear peak in whale occurrence in southeastern Alaska from mid June to mid July, and a later peak from mid August to late September off southeastern Vancouver Island. These peaks occur in the weeks immediately following the peak of pupping in both regions.

## SMALL-SCALE PATTERNS OF HABITAT USE

Small-scale movement patterns of WCT killer whales in their habitat can be characterized as constant, unpredictable, and at times erratic. The animals tend to travel in small groups (mean group sizes shown in Fig. 5), swimming constantly at speeds of 3–9 km/hr. They typically make 4–8 deep dives per hour, each separated by a series of 5–12 short, shallow dives and surfacings at which time the individuals breathe (Ford and Ellis 1999, in press; Miller et al. 2010). WCT whales are usually found close to land – over half of all encounters took place within 1 km of the nearest shore (Fig. 3). They often swim in very shallow water within tens of metres of shorelines and around rocky reefs and islets, and tend to enter inlets and bays rather than crossing their entrances. Although they frequently change their headings while swimming, they rarely reverse their course and retrace their path unless they are exiting a narrow, dead-end inlet. They typically cover 75–150 km of coastline per day. An example of movement patterns in a small portion of their range can be seen in Figure 22, which depicts the travel routes of WCT killer whales in Clayoquot Sound, on the west coast of Vancouver Island, during more than 1200 encounters between 1991 and 2011. This shows that the animals utilized a wide variety of travel routes as they explored inlets, bays and coves throughout the Sound.

The patterns of local movements of WCT whales are most likely a reflection of the method by which they hunt their marine mammal prey. Foraging occupies the majority of their daylight activity budget – typically over 90% of their time is spent either foraging or travelling, which are difficult activity states to distinguish from each other (Morton 1990; Baird and Dill 1995; Ford and Ellis 1999). As described previously, WCT whales hunt most species of marine mammals that occur in inshore waters of BC, with the exception of large species of whales. Their hunting strategy appears to depend on stealth and surprise attack on marine mammals that they detect visually or perhaps through passive listening to hydrodynamic sounds or vocalizations produced by the prey. WCT whales rarely produce communication signals or use echolocation clicks to navigate or detect prey, presumably because these sounds would alert potential prey to the whales' approach, making them more difficult to capture (Barrett-Lennard et al. 1996; Deecke et al. 2005). WCT whales routinely undertake long dives of 5–7 min duration while foraging, double the typical dive times of resident killer whales foraging for salmon (Morton 1990). Despite these prolonged dives, the whales seldom dive deeper than 50 m (Miller et al. 2010), suggesting that prey are mostly detected in the shallow, photic zone. Infrequent surfacing periods likely reduces the probability that whales will be detected visually above the surface by vigilant pinnipeds.

WCT killer whales detect and attack prey opportunistically in open water, rather than targeting specific species (as suggested by the lack of specialization on particular prey species or types). Although whales may closely approach pinniped haulouts, they do not linger at such sites nor does their foraging success appear to be related to proximity to haulouts. The distances to the nearest shore and water depths at the locations of predation events are depicted in Figure 23. The mean distance was 2.1 km (SE = 0.21), with 95% taking place less than 10 km from shore. The mean depth of waters where kills were made was 93 m (SE = 5.88), with 89% taking place in waters with depths of less than 200 m. Distance from shore for kills of different prey species are summarized in Figure 24. Distances for the top four prey species did not differ significantly (Table 4; Kruskal-Wallis test, $H = 2.78$, $p = 0.43$). The distribution by water depth of predation events involving different prey species is depicted in Figure 25. Comparisons of depths of kills of the top four important prey species revealed significant differences (Table 4; ANOVA (log transformed data), F = 15.64, $p < 0.001$), with Dall's porpoises being killed at greater depths (mean = 240 m) than harbour seals (mean = 67 m), harbour porpoises (mean = 92 m), and sea lions (Steller and California sea lions combined; mean = 88 m) (Tukey-Kramer test, $p < 0.001$). Depths for kills of harbour seals, harbour porpoises, and sea lions did not differ significantly.

To determine if predation rates involving harbour seals were related to proximity to haulouts, we examined the distance of harbour seal kills to the nearest haulout in the Strait of Georgia area. Locations and sizes of haulout sites were based on 2008 survey data presented in Olesiuk (2010). These showed that the mean distance of harbour seal kills from the nearest haulout was 2.98 km, and the mean distance to the nearest haulout with a sizeable number of animals (> 50 seals) was 4.51 km (Table 5). This suggests that WCT killer whales do not hunt harbour seals in close proximity to haulouts, but rather take this species in open water, where the seals are presumably dispersed and foraging.

Resource depression – a decrease in the rate of prey capture owing to the activities of the predator – likely plays an important role in determining local movement patterns of WCT killer whales in their habitat. Two forms of resource depression – behavioural depression and microhabitat depression (Charnov et al. 1976) – both come into play once prey are aware of the presence of WCT whales. Harbour seals have been documented to alter their behaviour in response to playback of WCT vocalizations, surfacing less frequently or moving from the area (Deecke et al. 2002). There are numerous anecdotal observations of harbour seals retreating into the shallows or kelp beds when WCT whales are nearby, although they do not seem to haulout as an anti-predator response. Both Dall's porpoise and Pacific white-sided dolphin flee at high speed once they've been alerted to the presence of WCT whales (G. Ellis, J. Ford, unpubl. observations). Similarly, minke whales flee from pursuing WCT whales by sprinting at high speed for periods of up to an hour, and continue to do so after the predators have abandoned the chase (Ford et al. 2005; Ford and Reeves 2008). Marine mammals may respond to the presence of WCT whales even when acoustic monitoring has failed to detect any obvious vocalizations from the whales, and the whales themselves have not shown any signs of having detected the potential prey (J. Ford, G. Ellis, unpubl. observations). WCT whales often vocalize during or immediately following predation events (Deecke et al. 2005), which would alert all marine mammals in the vicinity to the predators' presence. Given that WCT killer whales hunt by stealth and sneak attack, once the element of surprise is gone it is likely more profitable for a group to move out of the area in search of new prey that would be unaware of their presence. This would explain why WCT whales are constantly on the move, spending very little time in any given area even if that area contains high densities of marine mammal prey. The effects of resource depression may be an issue for more than just the whales that have caused it – other WCT groups coming into an area would likely experience reduced hunting success caused by the transit of an earlier group until such effects have diminished. This likely promotes separation of WCT groups in space and time in their habitat.

## CRITICAL HABITAT: BIOPHYSICAL FUNCTIONS, FEATURES AND THEIR ATTRIBUTES

According to DFO's guidelines for the identification of critical habitat (Fisheries and Oceans Canada 2011), its biophysical function describes how the critical habitat is used by the species to support specific life processes. In the case of WCT killer whales, the species is non-migratory and a substantial proportion of the putative inner coast subpopulation spends the majority of its life cycle within coastal waters of British Columbia. Critical habitat in Canada must therefore support all life processes necessary for the survival and recovery of WCT killer whales. Clearly of prominent importance is feeding, but other vital life processes include reproduction (courtship, mating, calving, nursing, etc), socializing, and resting. Foraging or travelling between foraging locations dominates the activity budget of WCT killer whales, and many other life processes are no doubt undertaken concurrently with this activity. No specific locations or habitat types are known to be utilized for processes other than feeding.

The biophysical features of critical habitat are how that habitat provides for the functions described (Fisheries and Oceans Canada 2011). Since a primary function of critical habitat for WCT killer whales is feeding, food availability is certainly of paramount importance. Based on the foraging ecology of WCT whales, food availability would require adequate year-round supplies of a variety of marine mammal prey species, especially harbour seals, harbour porpoises, Steller sea lions, and Dall's porpoises, species that in aggregate comprise over 90% of observed predation. Adequate food availability also requires that the critical habitat be of sufficient geographical scope to allow potential exploitation of locally abundant prey resources that may vary seasonally, for example harbour seal pups. Another important feature of critical habitat may be the underwater acoustic environment, which must be of sufficient quality (i.e., low levels of anthropogenic ambient noise) that it enables the animals to utilize passive listening to detect prey and to communicate vocally.

The biophysical attributes of critical habitat can be defined as the components of the features that together allow those features to support the function of the habitat (Fisheries and Oceans Canada 2011). For there to be sufficient food availability, important prey species must not only be abundant enough to support the WCT population, they must be distributed widely in the whales' habitat so that efficient foraging is possible. Although it is possible to estimate the energetic (i.e., caloric) requirements of WCT killer whales, it is difficult to translate this into the biomass and number of individuals of various prey species needed to support the existing population or to sustain continued growth. More information is needed on the age and size classes (and thus, mass) of individuals preyed upon by WCT whales, the relative profitability of each prey species, and the factors that lead the whales to choose one prey species over another. Reliable abundance estimates for prey within the range of WCT whales are available for only two species – the harbour seal and Steller sea lion. It is reasonable to conclude that current prey abundance is sufficient to sustain the existing population of WCT killer whales, which has been growing for several decades.

In terms of the extent of critical habitat needed for sufficient food availability, however, the overall abundance of prey species in that habitat is not the only important attribute. Others include a wide distribution of this prey over a geographical scale that is sufficient to allow the whales to maintain adequate capture rates by mitigating the effects of local resource depression through continual movement. There is, however, insufficient information with which to quantitatively estimate the geographic densities of different prey species that support the food availability feature of critical habitat. Attributes that are important in the acoustic environment of critical habitat are similarly difficult to assess. There is considerable uncertainty about the effects of both chronic and acute anthropogenic noise on cetaceans generally (Nowacek et al. 2007), and WCT killer whales specifically (Fisheries and Oceans Canada 2007; Ford et al. 2007). Furthermore, the extent to which WCT whales rely on underwater acoustics to detect prey and undertake other important life processes is poorly known. It is currently not possible to define quantitatively the specific attributes that contribute to the features of the acoustic environment that facilitate critical habitat functions.

## IDENTIFICATION OF HABITAT NECESSARY TO MEET RECOVERY OBJECTIVES

Following recommendations provided in DFO's operational guidelines for the identification of critical habitat, we have used the *bounding box* approach to identify habitat necessary to meet population and distribution recovery objectives for WCT killer whales (Fisheries and Oceans Canada 2007, 2011). This approach is proposed when the exact location of critical habitat features and their attributes are not well known, even though the features that are essential to the survival or recovery of the species are understood. We have also chosen this approach because the quality and quantity of those attributes are poorly known (e.g., the overall abundance and densities of prey species needed for sufficient food availability). For wide ranging marine species such as WCT killer whales, the bounding box containing critical habitat may be the overall area of occupancy of the species. For WCT whales, the area of occupancy is extensive and likely includes some waters that have not yet been identified. For this reason, we propose a bounding box that would include the great majority of known important habitat of WCT whales. By including all nearshore marine waters within 3 nautical miles (5.56 km) of land, the area of critical habitat encompasses the locations of 92% of all individual identifications of inner coast WCT whales and 64% of identifications of outer coast WCT whales made in BC waters between 1990 and 2011. Furthermore, this area also includes the locations of 90% of all predation events observed during the same period. A map showing the boundaries of this proposed habitat area is provided in Figure 26. It should be noted that this habitat area should be considered that necessary to meet population and distribution recovery objectives for inner coast WCT killer whales only – further studies of distribution, movements and foraging ecology of outer coast WCT whales are needed in order to identify areas of potential critical habitat for that subpopulation.

## ACTIVITIES LIKELY TO RESULT IN THE DESTRUCTION OF CRITICAL HABITAT

When critical habitat is identified, SARA requires that “examples of activities that are likely to result in its destruction will be provided”. Most known threats to WCT killer whales and their habitat are described in detail in the recovery strategy (Fisheries and Oceans Canada 2007) or recovery potential assessment (Ford et al. 2007) for this population. Threats that we believe meet the criteria for consideration as “activities likely to result in the destruction of critical habitat”, as outlined in Fisheries and Oceans Canada (2011), are included below.

### Reduction in Prey Abundance or Availability

Any activity that would result in reduced abundance or availability could be considered destruction of WCT critical habitat. Large scale culls and harvests of pinnipeds in the late 1800s to mid 1900s depleted populations of harbour seals and Steller sea lions (COSEWIC 2003; Olesiuk 2010). This likely had a major effect on the abundance and distribution of WCT whales in BC waters. Occurrence of WCT whales in the Strait of Georgia has shown a strong increase over the past four decades, associated with the return of harbour seal abundance to historical levels in this area (Ford et al. 2007). No renewed harvesting or large-scale culling of pinnipeds is currently anticipated in the region.

### Oil Spills

Although catastrophic oil spills in the marine environment are rare events, they are known to result in significant mortality to marine mammals. The 1989 Exxon Valdez oil spill in Prince William Sound, Alaska, was linked to unprecedented mortality rates of both fish-eating resident killer whales and mammal-eating transient killer whales (Matkin et al. 2008, 2012). The spill also resulted in considerable direct mortality to harbour seals during and immediately following the spill and continued declines over the next decade (Frost et al. 1999). By 1997, the abundance of harbour seals in Prince William Sound had declined by 63% (Frost et al. 1999). Given that significant volumes of oil are transported through inside passages along the BC coast each year and that there are new proposals currently in review for a substantial expansion of this activity, catastrophic oil spills should be considered as a potential cause of destruction of critical habitat through direct mortality and subsequent reduced availability of prey of WCT killer whales. Although such an event (i.e., catastrophic oil spill) is unlikely, destruction of critical habitat would likely result were it to take place – in such cases, the activity leading to the event (e.g., marine transportation of oil) should be identified as such a threat (Fisheries and Oceans Canada 2011). The amount of habitat destruction caused by an oil spill would depend on the location, volume of oil spilled, and the extent of area impacted.

**Industrial Developments in Confined Passages**

Developments that involve the introduction of novel objects and/or noise, especially in confined passages, could result in displacement or barriers to movements in critical habitat. New technologies being developed to exploit sources of green energy in the marine environment include the installation of underwater hydroelectric turbines in areas of high tidal flows. Although there are many configurations of such devices, most involve arrays of turbines anchored to the seabed, each with multiple blades that are either open or shielded within a duct or tube to direct water flow. Turbine rotation speed depends on current velocity, but speeds of up to 20–30 RPM are typical with blade tip velocities of up to 12 m/s (23 knots) (Wilson et al. 2007). Although potential blade strikes are an issue of concern for marine mammals, of greater relevance to impacts on critical habitat is the physical presence of such devices and the underwater noise they produce during operation. Turbines generate sufficient broadband noise to be detectable by killer whales at ranges of at least several hundred metres and potentially up to several kilometres (Wilson et al. 2007; Admiralty Inlet Pilot Tidal Project 2012). Although sound levels are no greater than a moderate sized motorized vessel, the frequency spectrum of turbine noise is unlike that of vessels and thus would be unfamiliar to whales. This, coupled with the physical presence of a novel rotating underwater object, may cause whales to avoid these devices. Similar responses from the whales' marine mammal prey may also occur.

Several project proposals in BC involve placement of tidal energy turbines in narrow passages between 100 and 800 m across, where tidal currents are concentrated. Many of these passages, including Dodd Narrows, Blackney Pass, Porlier Pass, and Seymour Narrows, are important thoroughfares for WCT killer whales as they move through proposed critical habitat. Should these devices present an obstacle to passage by WCT whales, it may prevent them from efficiently utilizing important feeding areas or otherwise restrict free movements through their habitat. Because there have been very few deployments of underwater turbines within WCT range to date, there is no information on the probability of avoidance of these devices. However, there is a precedent for a novel, man-made structure having apparently impeded the passage of WCT whales in the past. On two occasions, in 2003 and 2005, two different groups of WCT whales spent 59 and 172 days respectively within Hood Canal, Washington, a narrow, 100 km long fjord (London 2006). Considering the normal large-scale movement patterns of WCT whales (described in previous sections of this report), such long-term residency in one area is strikingly atypical of these animals. Hood Canal is unlike any other inlet on the coast in that its entrance is crossed by a 2 km long floating bridge that supports up to 20,000 vehicle transits per day. A likely scenario is that the whales entered during a period when the bridge was opened to allow ship passage, then were subsequently reluctant to pass under it once closed. The potential for the installation of tidal energy turbines in key passageways to detrimentally alter WCT whales' use of proposed critical habitat requires further study.

**Environmental Contaminants**

Killer whales in coastal waters of the northeastern Pacific carry significant concentrations of Persistent Bioaccumulating Toxins (PBTs) in their tissue. Of greatest concern are polychlorinated biphenyls (PCBs), which are found at extremely high concentrations in WCT killer whales due to their consumption of marine mammals that are already contaminated with PCBs (Ross et al. 2000). These compounds are not typically acutely toxic, but can potentially have chronic, slow-acting effects as ‘hormone mimics’ or ‘endocrine disruptors’. Although health effects have not been demonstrated in killer whales, high levels of PCBs in harbour seals have been associated with immunosuppression and endocrine disruption (Mos et al. 2006). Although PCB levels are declining in the environment, recent models suggest that it will take decades before PCB levels in killer whales fall below the thresholds for adverse effects seen in other species (Hickie et al. 2007). Also of concern are rapidly increasing levels of polybrominated diphenyl ethers (PBDEs), which have recently become widely used as flame retardants in a variety of products. As with PCBs, the potential direct effect of PBDEs on transient killer whale health is not clear, there is growing evidence of endocrine disruption and immunotoxicity in other species (Fisheries and Oceans Canada 2007). Should high levels of PBTs be introduced into WCT killer whale critical habitat, concentrations of these toxins in WCT whales might be expected to increase due to bioaccumulation through their marine mammal prey. Depending on the degree of contamination, this could be considered destruction of critical habitat.

**Acoustic Disturbance from Human Activities**

There has been increasing concern in recent years about the potential effects of underwater noise on cetaceans. Acoustic disturbance can be of two types: chronic and acute. Chronic noise is primarily associated with motorized vessel traffic of all types, from commercial shipping to whale watching. Chronic noise can result in masking of communication signals used for social contact or behavioural coordination, or interfere with echolocation signals used for navigation and discrimination. WCT killer whales often forage in silence and may rely on passive listening to locate their prey (Barrett- Lennard et al. 1996). Masking effects of increasing background noise could thus reduce their foraging efficiency and the function of critical habitat.

Sources of acute noise include military and commercial sonars, airguns used in seismic surveys, and underwater explosions usually associated with construction. These sounds can be extremely intense and may travel large distances underwater. Loud acute noises have the potential to cause a variety of effects in cetaceans, including hearing threshold shifts, production of stress hormones, and tissue damage, as well as a variety of behavioural responses. Intense sounds generated by acoustic deterrent devices (ADDs) used to deter pinnipeds from aquaculture facilities off northeastern Vancouver Island in the late 1980s to early 1990s appeared to displace WCT whales from important feeding habitats (Morton and Symonds 2002). Sounds from these devices were also shown to cause harbour porpoises, an important prey species for WCT whales, to leave the ensonified area (Olesiuk et al. 2002).

**Physical Disturbance**

Vessels moving in close proximity have the potential to affect WCT killer whales by disrupting behaviours. Although no studies have focused on WCT whales specifically, resident killer whales have been shown to alter their swimming behaviour when approached by boats (Williams et al. 2002, 2006). With the increased intensity of whale watching activity in the vicinity of WCT killer whales in some areas, there is a potential for vessels to disrupt hunting behaviour, thereby reducing overall foraging success. WCT killer whale attacks on marine mammals are often protracted and involve energetic, high-speed swimming, and vessels in close proximity can cause the whales to abandon their attack, or provide the prey item with a refuge to escape from the attacking whales. Reduction in prey capture rates due to disturbance could be considered a loss of function of critical habitat.

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# TABLES

*Table 1. Numbers of encounters, individual identifications, and unique individuals for "inner coast" and "outer coast" WCT killer whales, 1990–2011.*

| 1990-2011 dataset | Inner coast (≥ 15 encounters) | Outer coast (< 15 encounters) | Total |
|---|---|---|---|
| No. of encounters | 2988 | 230 | 3090 |
| No. of individual identifications | 13,577 | 707 | 14,284 |
| No. of unique individuals | 304 | 217 | 521 |

*Table 2. Identifications of WCT individuals in different study regions, 1990-2011. Descending diagonal (shaded) indicates total number of unique individuals identified within each region (% of known population in parentheses). Values in other cells indicate the number of individuals identified in two different regions. Full region names for abbreviations are provided in Figure 13.*

| | SEAK | HG | NC | SWVI | SEVI | NWVI | NEVI |
|---|---|---|---|---|---|---|---|
| SEAK | 197 (65%) | 103 | 77 | 148 | 156 | 33 | 155 |
| HG | | 169 (56%) | 95 | 134 | 132 | 59 | 144 |
| NC | | | 148 (49%) | 129 | 105 | 52 | 131 |
| SWVI | | | | 229 (75%) | 179 | 72 | 193 |
| SEVI | | | | | 224 (74%) | 66 | 200 |
| NWVI | | | | | | 73 (24%) | 65 |
| NEVI | | | | | | | 246 (81%) |

*Table 3. Annual transition probabilities between coastal regions (shown in Figure 13) based on a movement model. Cell values are the probabilities of a whale identified in one region (the "from" region) being identified in another region (the "to" region) on an annual basis. Values on the descending diagonal (shaded) are the probabilities of individuals being re-identified in the same region across years. 'Outside' is an area not included in the seven identified regions and for which no data have been collected. The dataset used in the model was restricted to the months of June–September for consistency of seasonal effort among regions.*

| | | *To region* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SEAK | HG | NC | SWVI | SEVI | NWVI | NEVI | Outside |
| *From region* | SEAK | 94% | 1% | 0% | 1% | 2% | 0% | 2% | 0% |
| | HG | 2% | 19% | 22% | 16% | 9% | 16% | 7% | 9% |
| | NC | 2% | 13% | 43% | 6% | 4% | 8% | 13% | 12% |
| | SWVI | 3% | 18% | 14% | 16% | 15% | 8% | 13% | 14% |
| | SEVI | 13% | 11% | 11% | 7% | 13% | 18% | 14% | 12% |
| | NWVI | 11% | 9% | 20% | 11% | 2% | 26% | 9% | 12% |
| | NEVI | 9% | 11% | 15% | 13% | 14% | 11% | 18% | 10% |
| | Outside | 0% | 13% | 14% | 10% | 22% | 17% | 8% | 16% |

*Table 4. Distance from nearest shore (km) and depth at location (m) of predation events by WCT whales. 'Sea lion' is Steller and California sea lion combined.*

| Species | N | Distance from shore (km) | | Depth at location (m) | |
|---|---|---|---|---|---|
| | | Mean | SE | Mean | SE |
| Harbour seal | 177 | 1.1 | 0.17 | 67 | 6.04 |
| Harbour porpoise | 53 | 3.4 | 0.81 | 92 | 12.2 |
| Sea lion | 53 | 3.1 | 0.68 | 88 | 10.5 |
| Dall's porpoise | 26 | 2.0 | 0.89 | 240 | 38.8 |

*Table 5. Distances from nearest harbour seal haulouts for kills of that species, Strait of Georgia. Distances from haulouts of all sizes as well as large haulouts are tabulated. Haulout data based on 2008 survey in Olesiuk (2010).*

| Distance from nearest haulout (km) | All haulouts (mean = 73 seals per haulout) | Haulouts with > 50 seals (mean = 148 seals per haulout) |
|---|---|---|
| Mean | 2.98 | 4.51 |
| Median | 2.36 | 3.97 |
| Minimum | 0.1 | 0.5 |
| Maximum | 9.6 | 14.3 |

## FIGURES

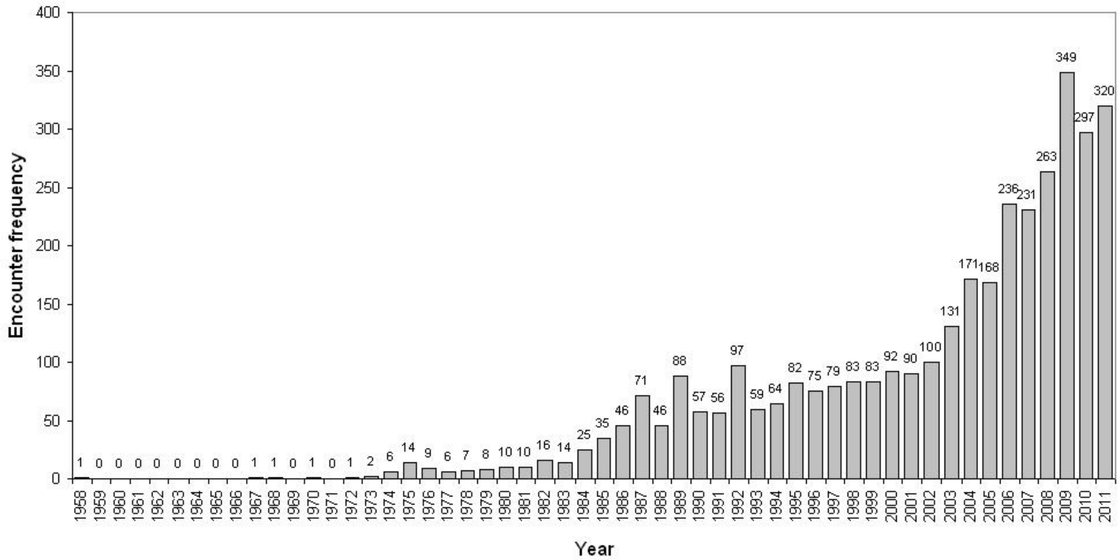


*Figure 1. Frequency of encounters by year with WCT killer whales, 1958–2011. N = 3582 encounters.*

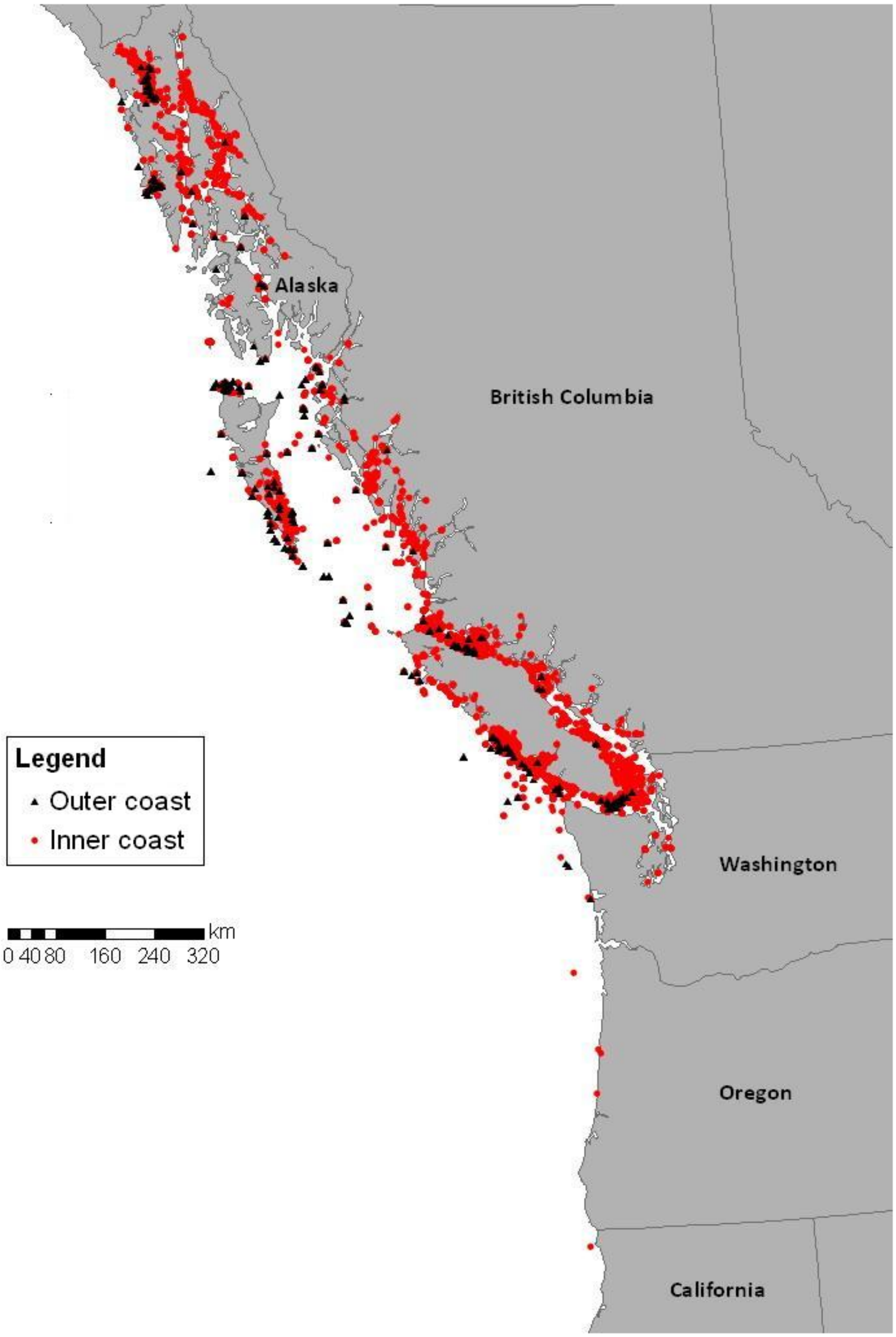


*Figure 2. Locations of encounters with West Coast Transient killer whales. Individuals belonging to the inner coast WCT subpopulation are shown with red circles (n = 3445 encounters), and outer coast WCT individuals are shown with black triangles (n = 232 encounters).*

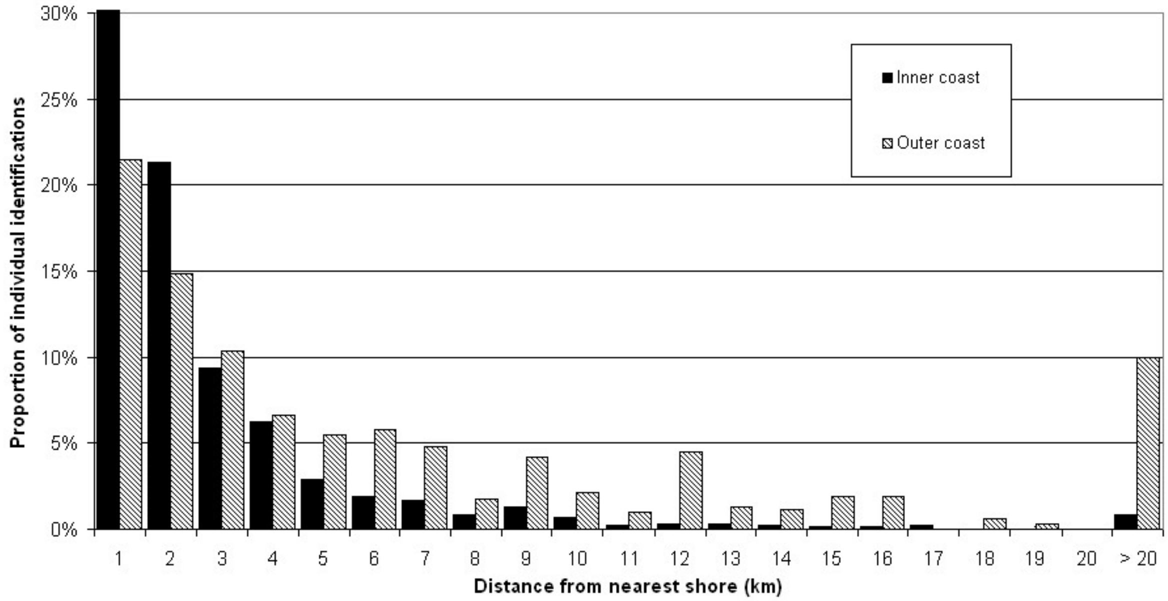


*Figure 3. Distance to closest shore for encounters with inner coast WCT whales (black bars; n = 13,165 identifications) and outer coast WCT whales (hatched bars, n = 693 identifications).*

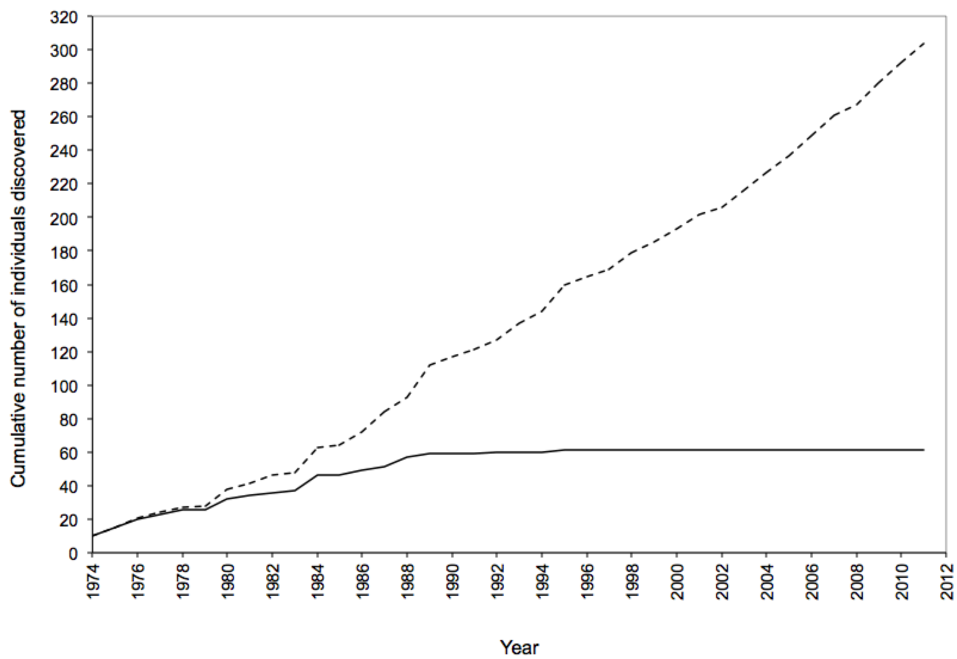


*Figure 4. Discovery of distinct individuals in the inner coast WCT subpopulation over the 1974-2011 time series. Curves are shown for all whales in the subpopulation (dashed line) and members of this subpopulation that were not known calves that recruited during the study period (solid line).*

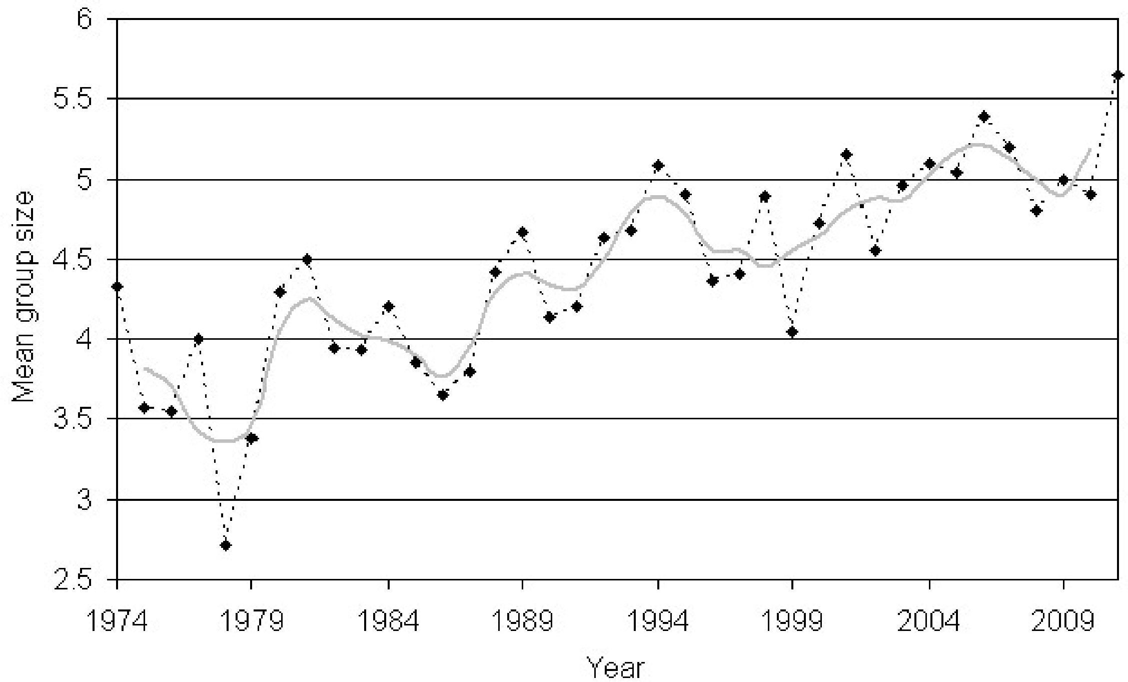


*Figure 5. Mean group size in encounters with inner coast WCT killer whales, 1974-2011. Annual mean is depicted with points and dashed lines, three year running mean shown with grey line.*

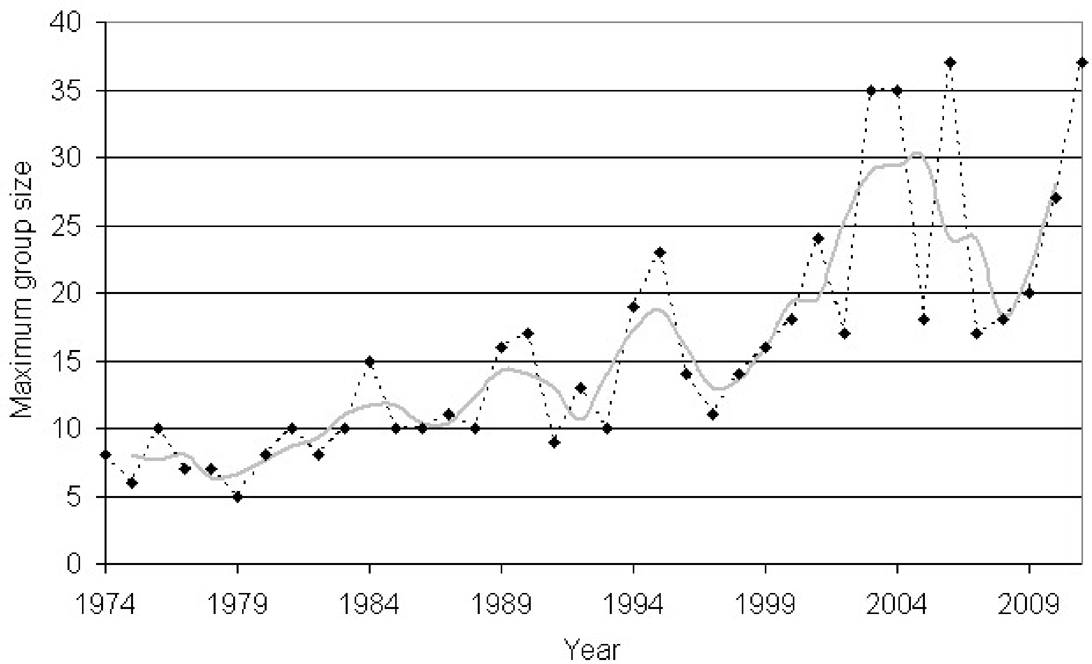


*Figure 6. Maximum group size of encounters with inner coast WCT killer whales, 1974-2011. Annual maximum is depicted with points and dashed line, three year running mean shown with grey line.*

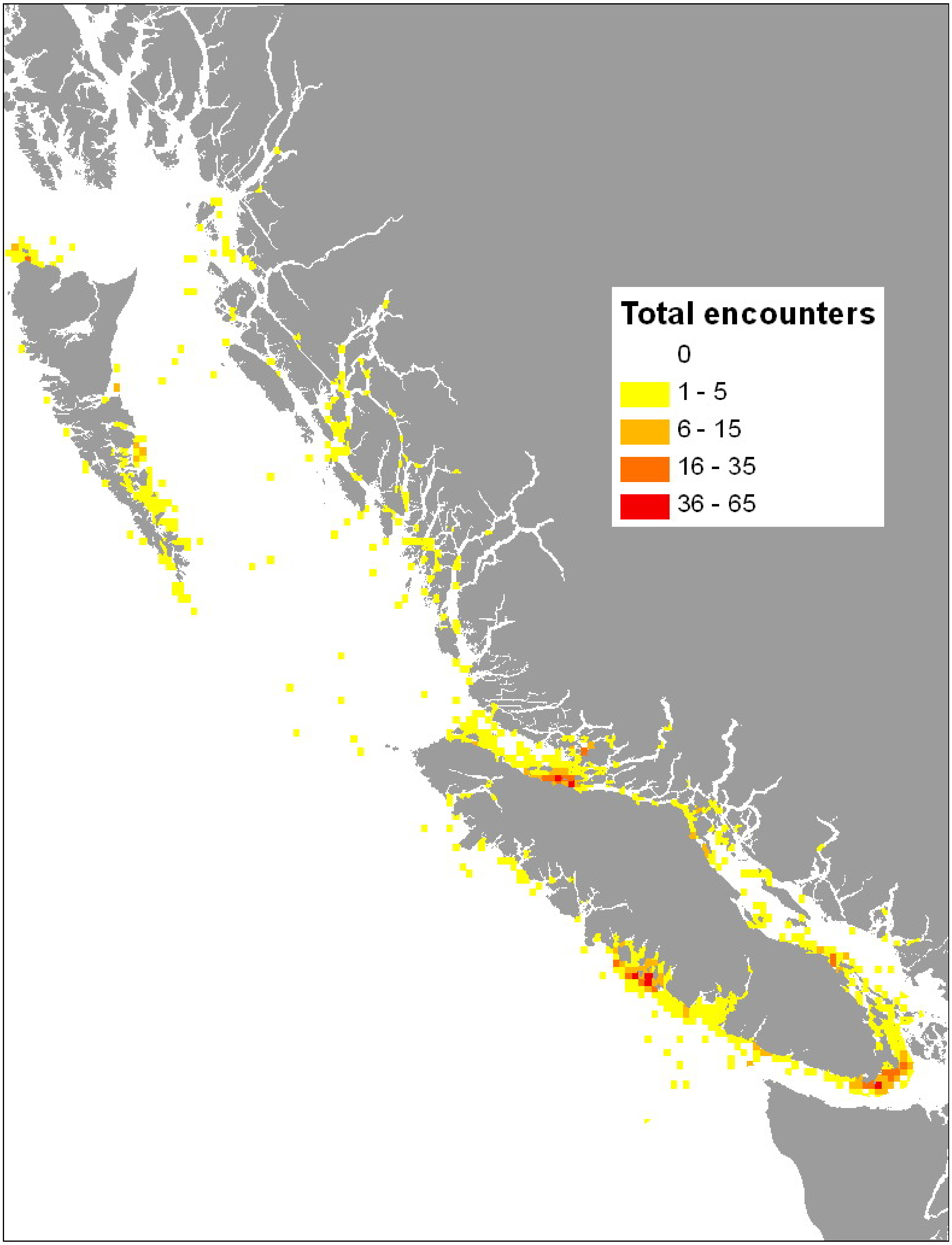


*Figure 7. Map showing cumulative number of encounters with inner coast WCT killer whales, by 5x5 km grid. N = 2988 encounters during 1990-2011.*

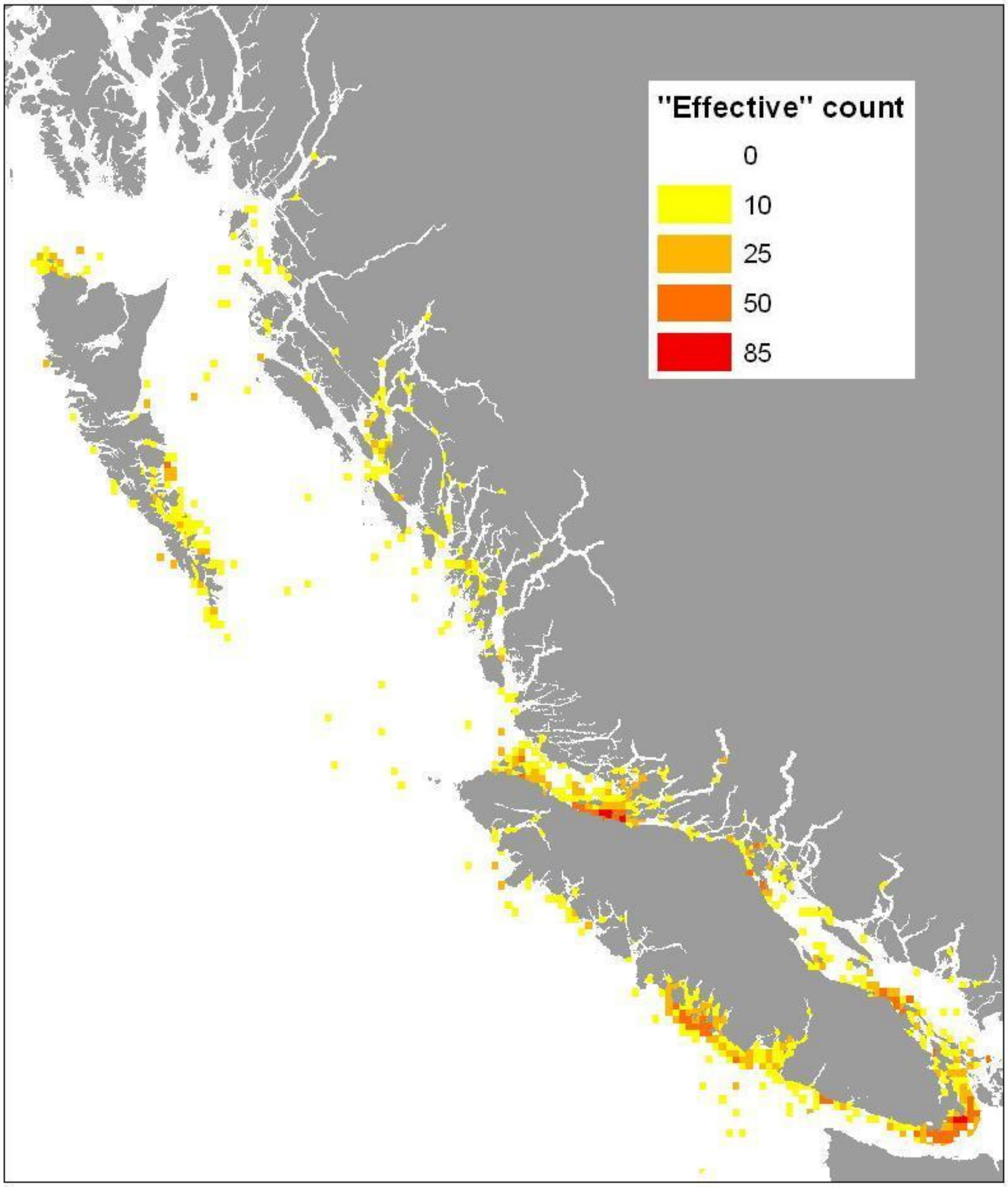


*Figure 8. Map showing the 'effective' count of unique individual identifications of inner coast WCT killer whales, by 5x5 km grid cells. N = 13,577 identifications during 1990-2011.*

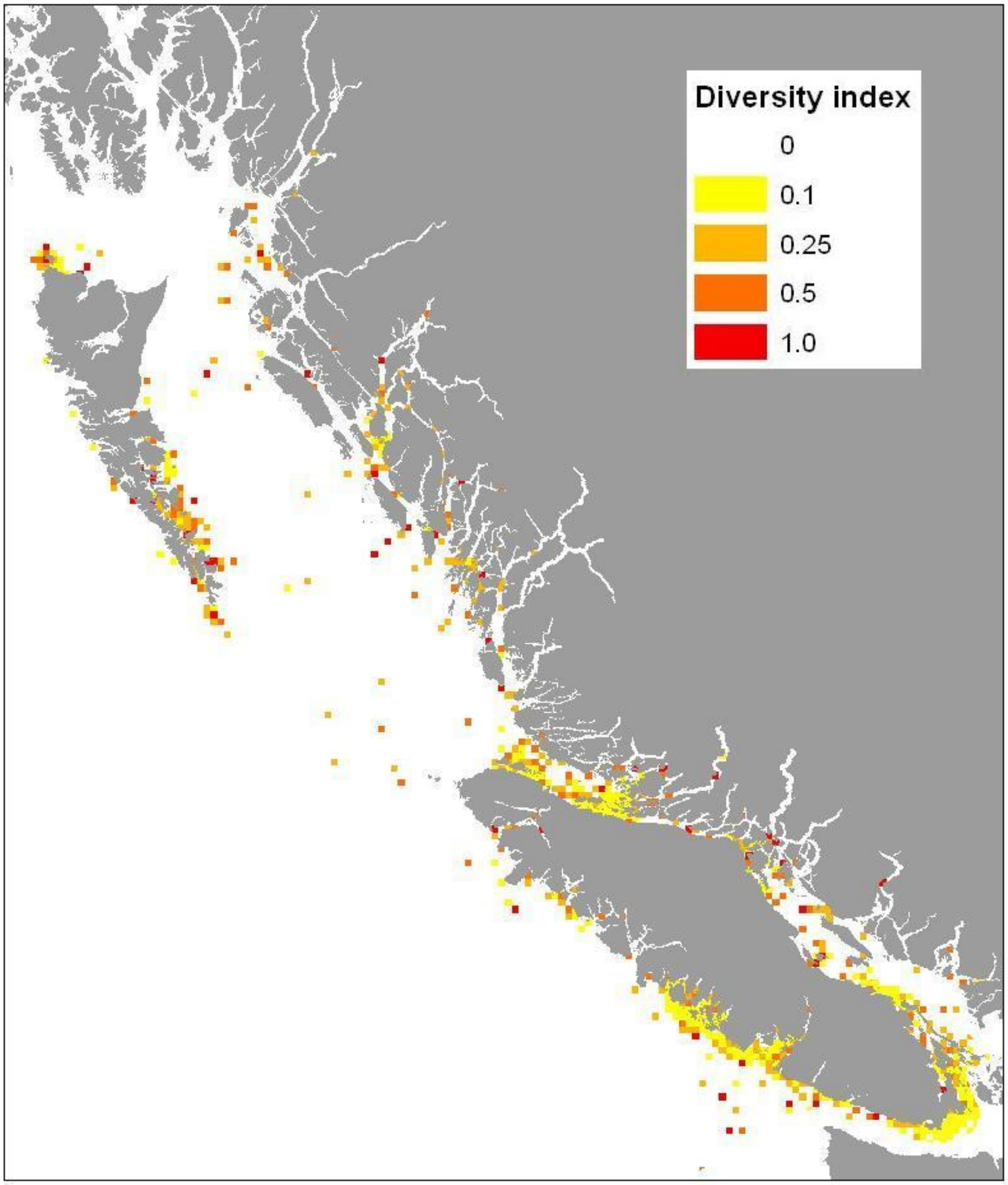


*Figure 9. Map showing the relative diversity of inner coast WCT killer whales in BC waters, by 5x5 km grid cells. Colours indicate relative diversity according to an index calculated from the effective count of unique identifications (shown in Fig. 8) normalized by the total number of encounters for each cell (shown in Fig. 7).*

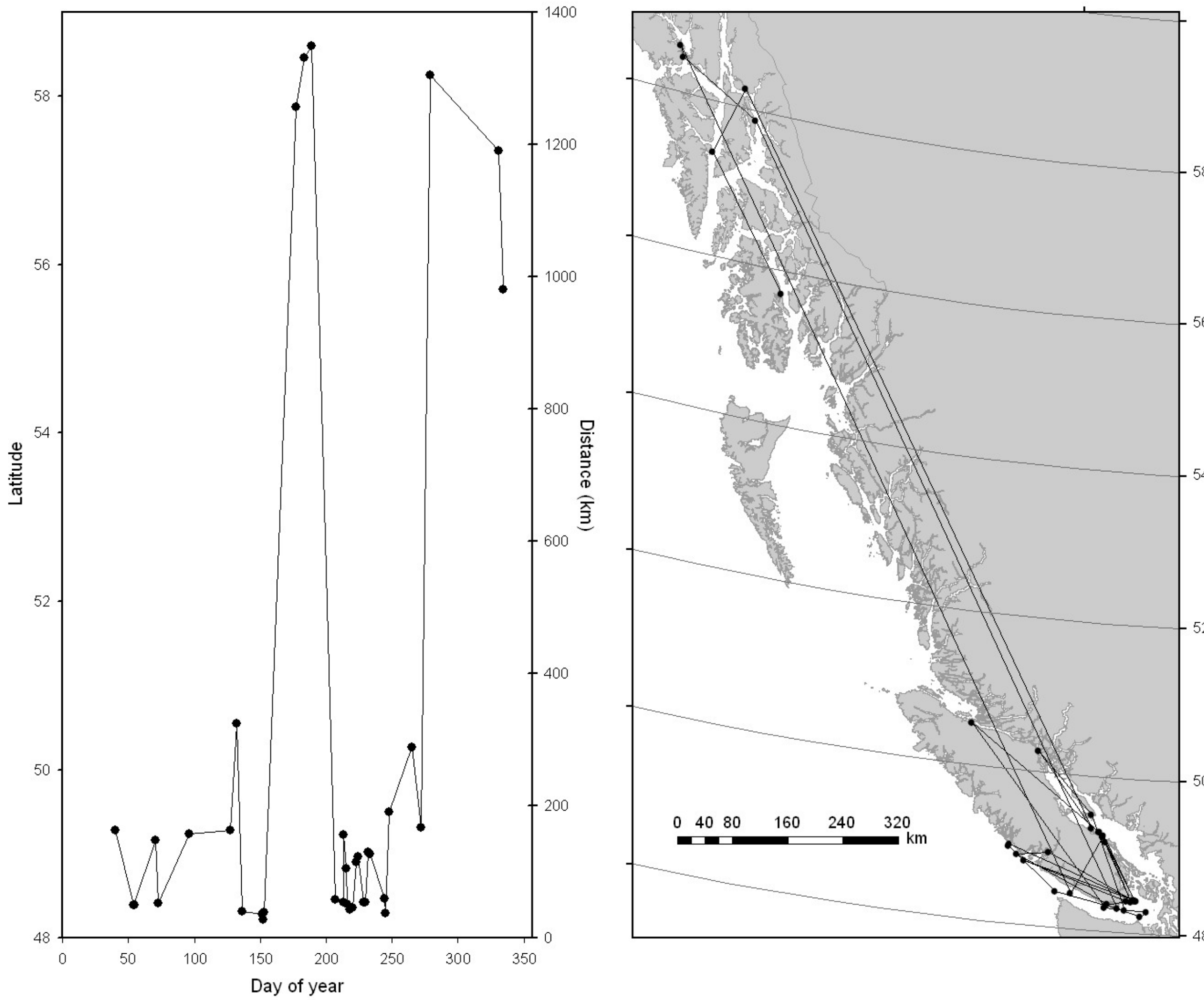


*Figure 10. Examples of encounter locations with a representative inner coast WCT killer whale group, the T100/T101s, over the course of one year. The left panel plots the 36 encounter locations according to their latitude and day of year (2009), and the right panel shows these locations according to their geographical position.*

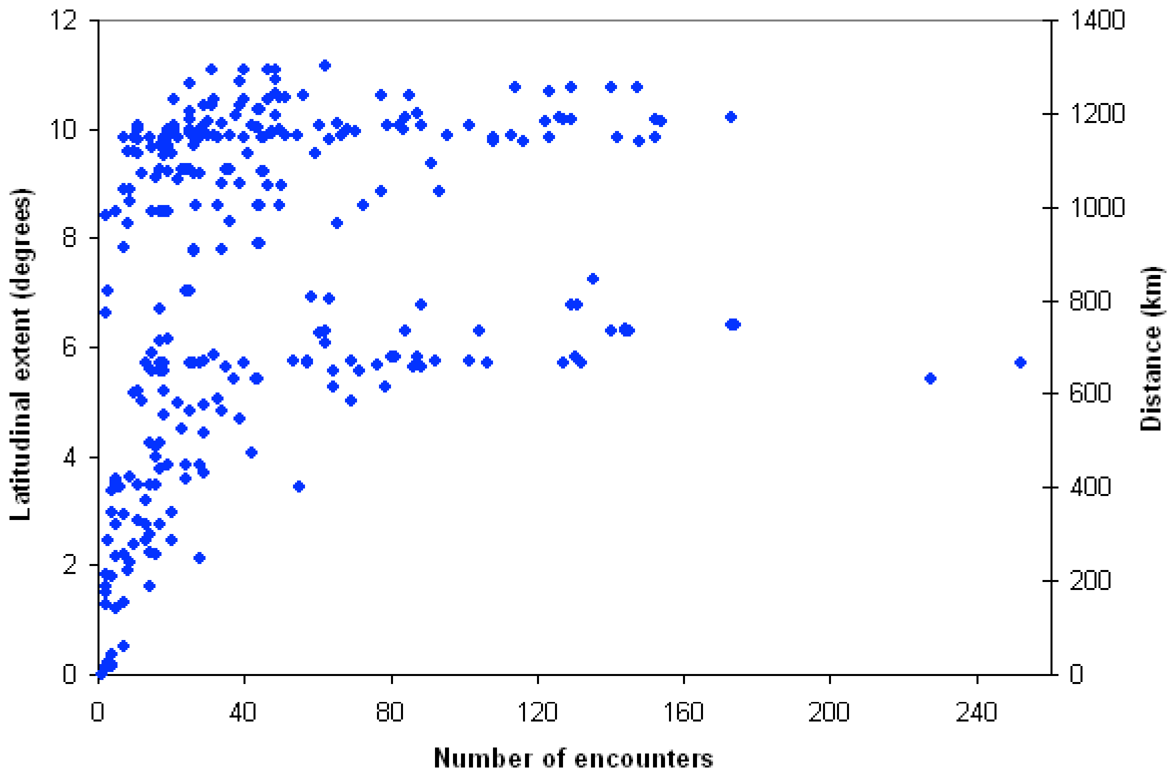


*Figure 11. The extent of latitudinal range (in degrees) of encounter locations for each individual WCT killer whale relative to the total number of encounters with that individual. Equivalent linear north-south distance along the coast is shown in the right hand axis.*

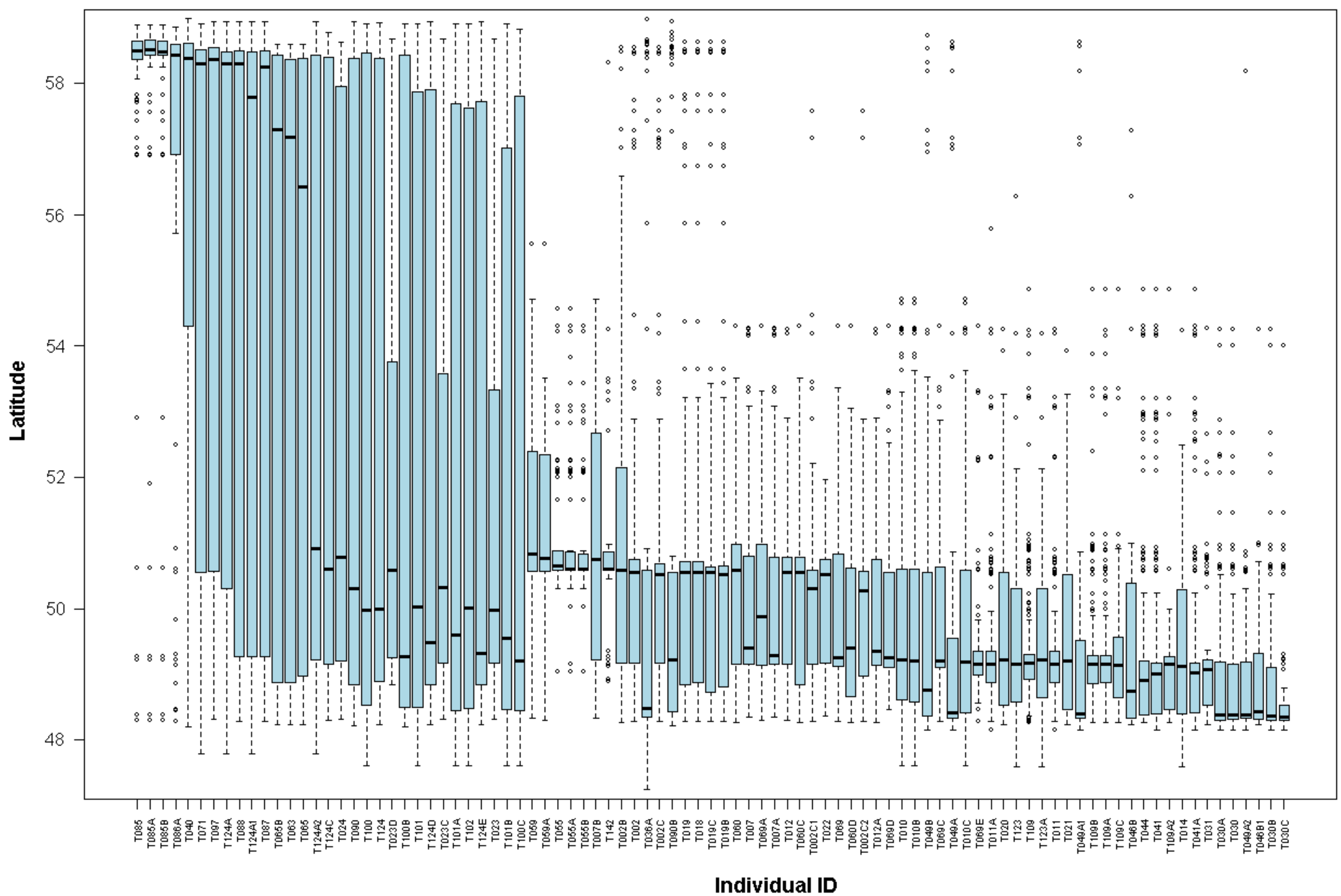


*Figure 12. Box plot showing distribution of encounters involving 91 of the most commonly identified WCT killer whales (> 50 encounters each, 1990-2011) with respect to degrees of latitude. Whale IDs are arranged in order of decreasing mean latitude. Boxes indicate the 25$^{th}$ –75$^{th}$ percentiles, black line in boxes indicates median, bars below and above box show the 10$^{th}$ and 90$^{th}$ percentiles, and open circles show outliers.*

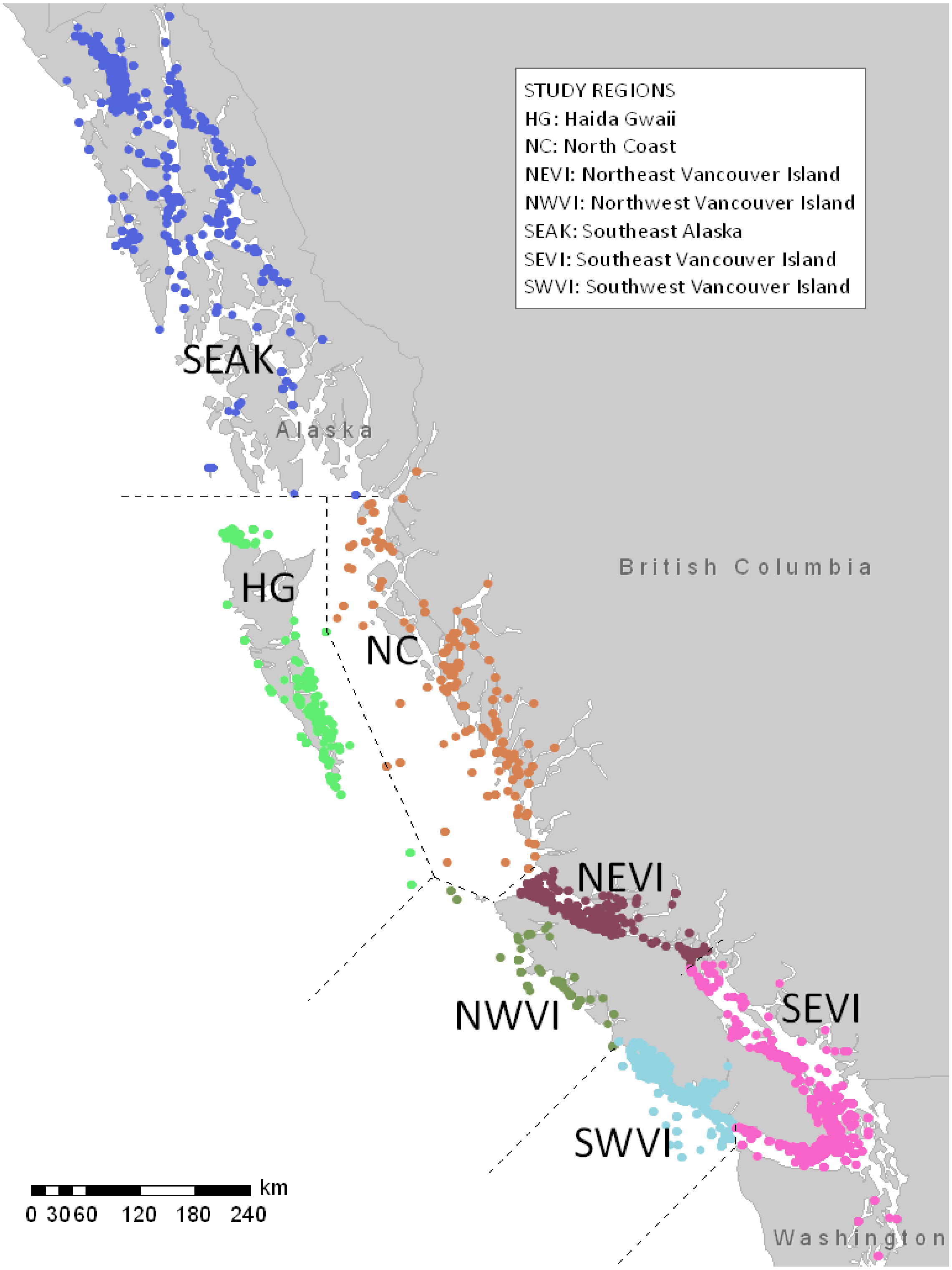


*Figure 13. Regions of the overall range of inner coast WCT killer whales used for spatial analyses with locations of WCT killer whale encounters according to regional division. N = 2988 encounters during 1990–2011.*

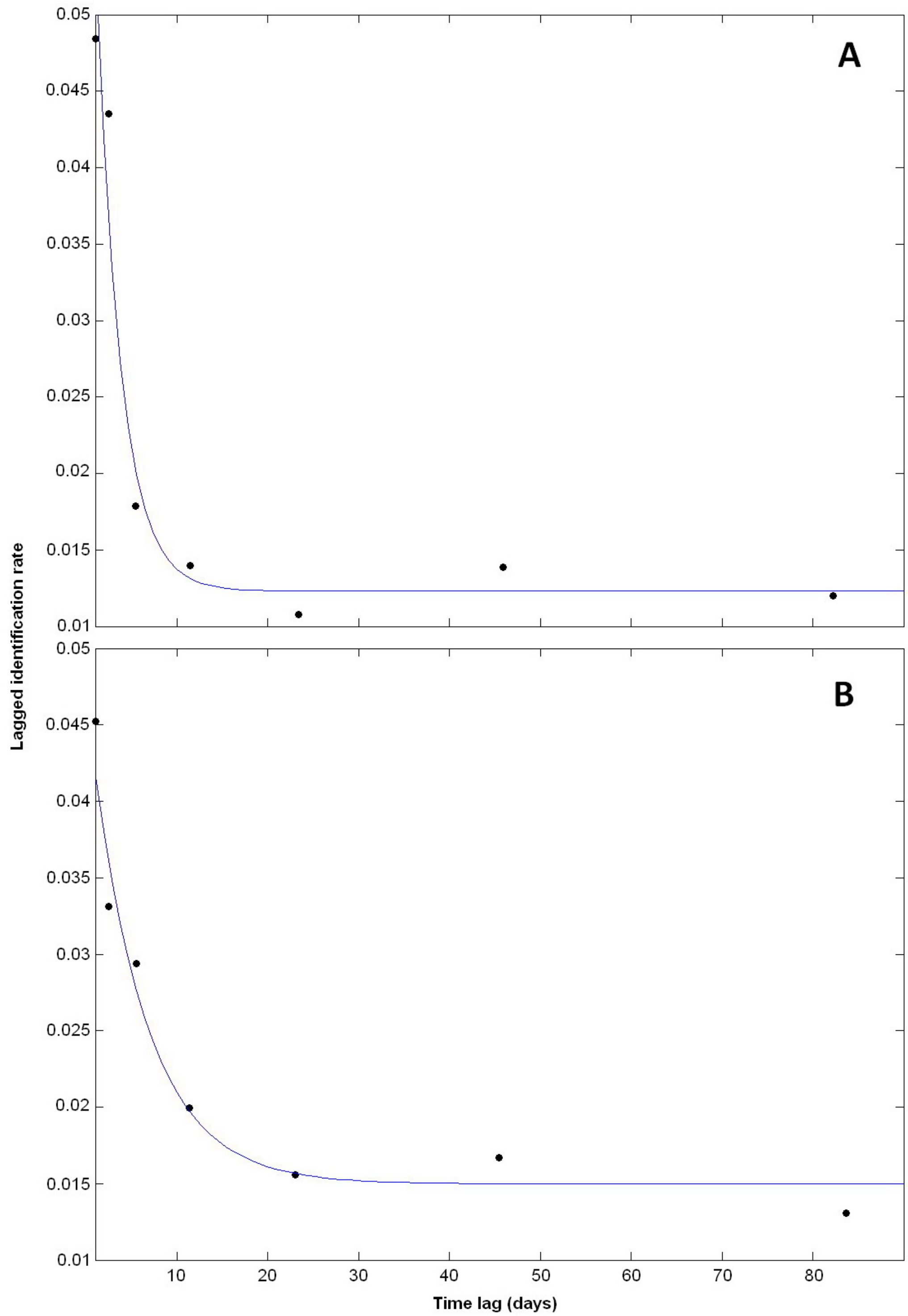


*Figure 14. Lagged identification rates for WCT killer whales photo-identified in A) the northeastern Vancouver Island region (n = 1463 IDs) and B) southeastern Vancouver Island region (n = 1711 IDs), June–September, 1999–2011. The sharp drop in the slope indicates that most whales likely leave the region within a period of 10 days of identification.*

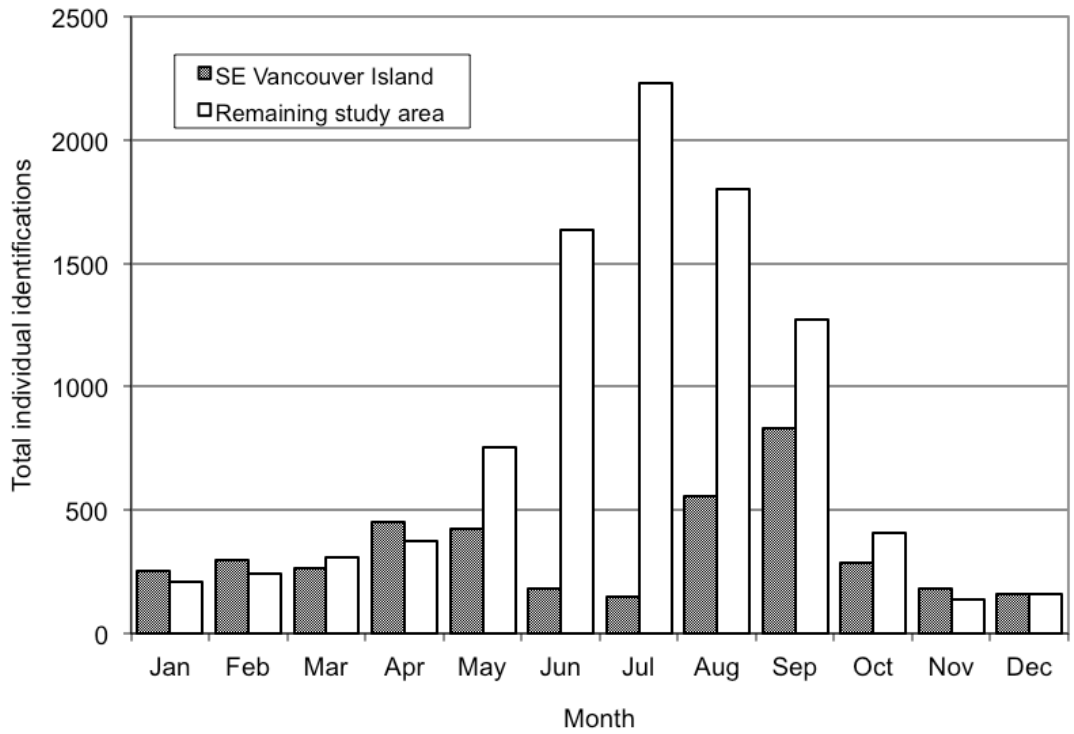


*Figure 15. Frequency distribution by month of identifications of individual WCT killer whales in the waters off southeast Vancouver Island (shaded bars; n = 4039 IDs) and the remainder of the study area (open bars, n = 9525 IDs), 1990-2011.*

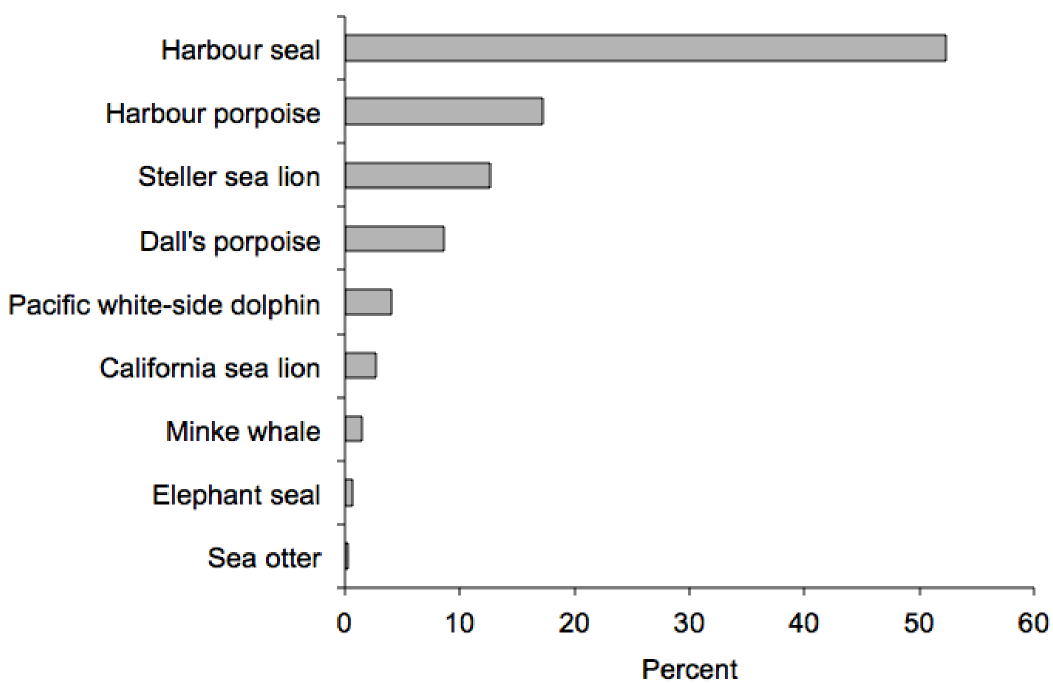


*Figure 16. Frequency distribution of marine mammal species killed during 416 predation events by WCT killer whales. The top four species accounted for > 90% of kills.*

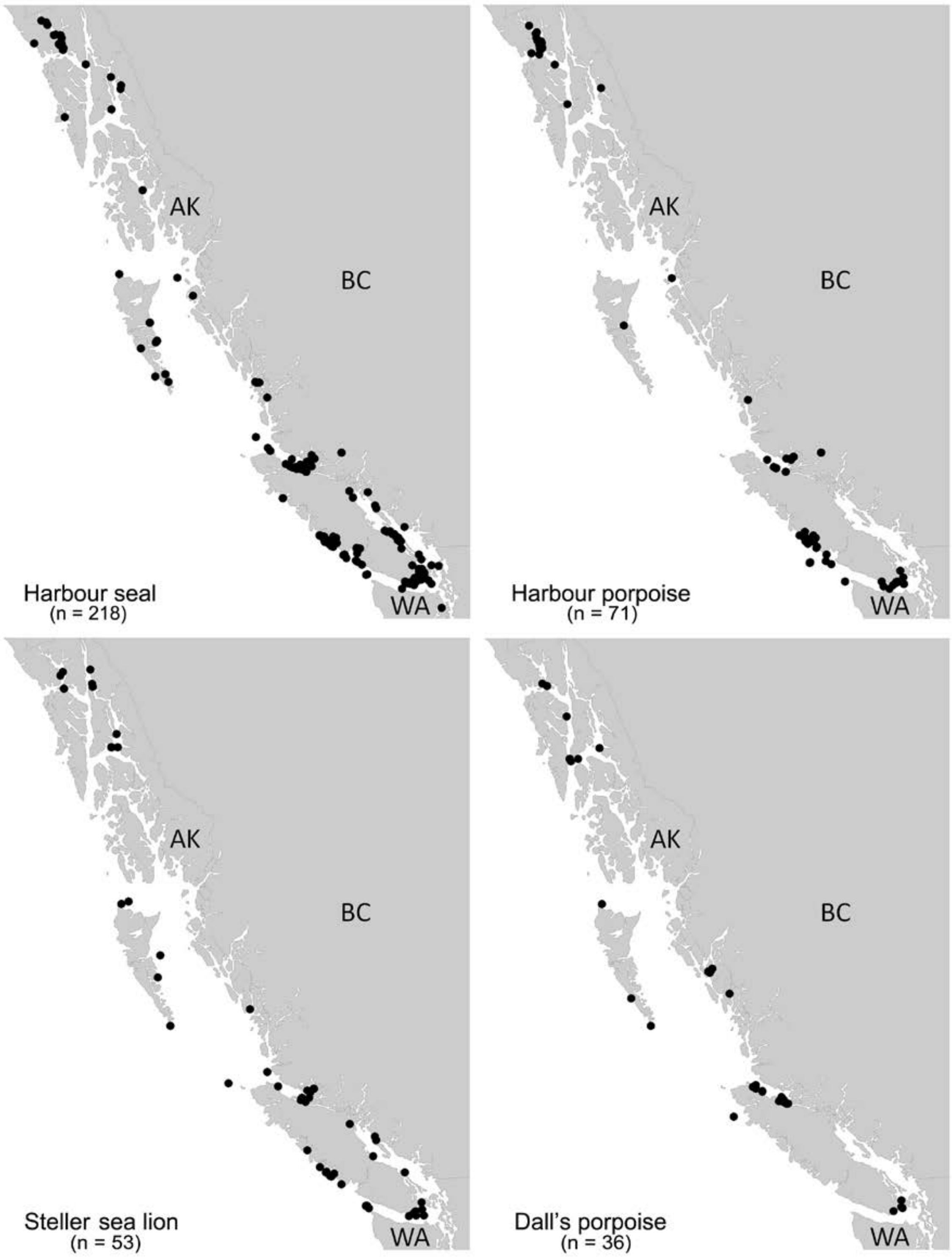


*Figure 17. Locations of predation events by WCT killer whales involving their four most important prey species, harbour seal, harbour porpoise, Steller sea lion, and Dall's porpoise. These four species comprise over 90% of the 419 documented marine mammal kills by transients.*

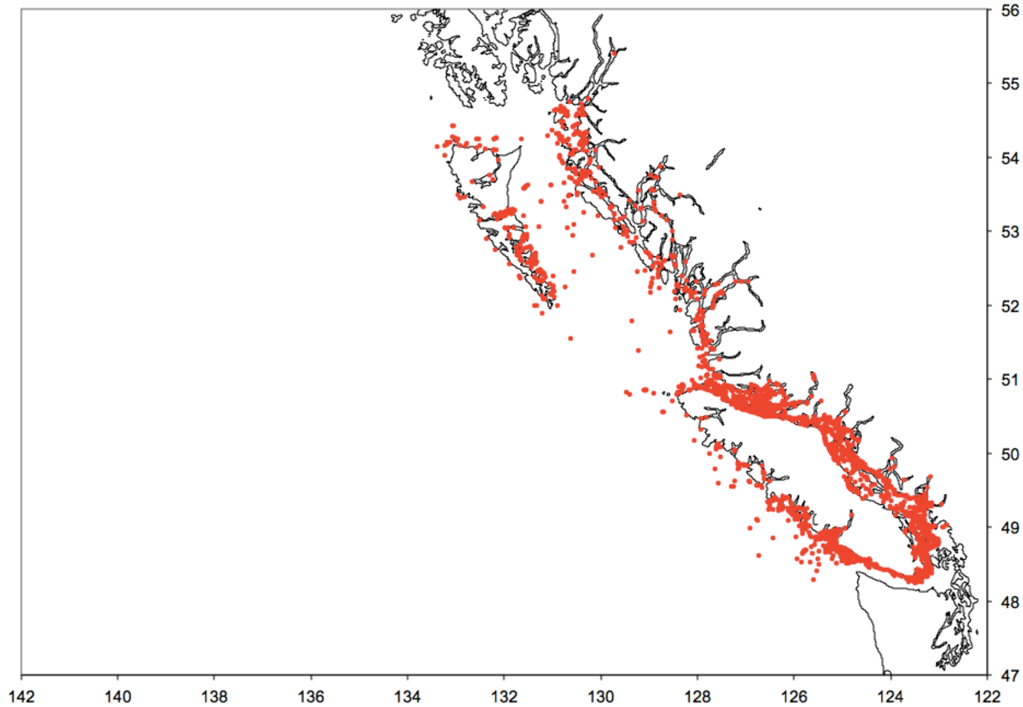


*Figure 18. Map of sightings of harbour porpoises in British Columbia. Sighting data from Ford et al. (2010) and BC Cetacean Sightings Network.*

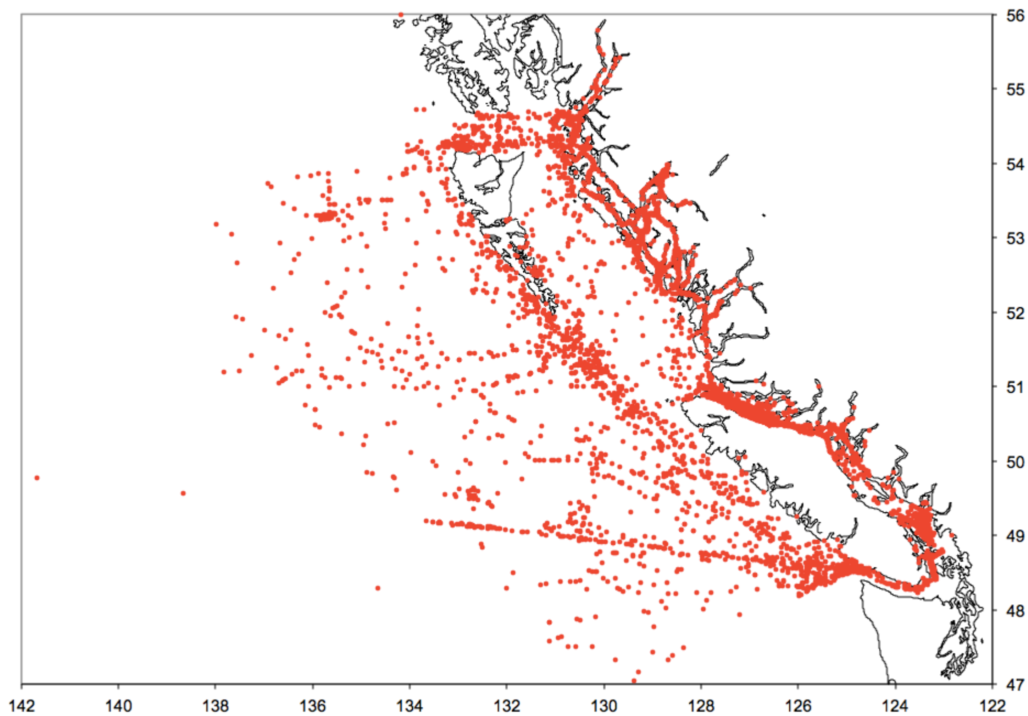


*Figure 19. Map of sightings of Dall's porpoises in British Columbia. Sighting data from Ford et al. (2010) and BC Cetacean Sightings Network.*

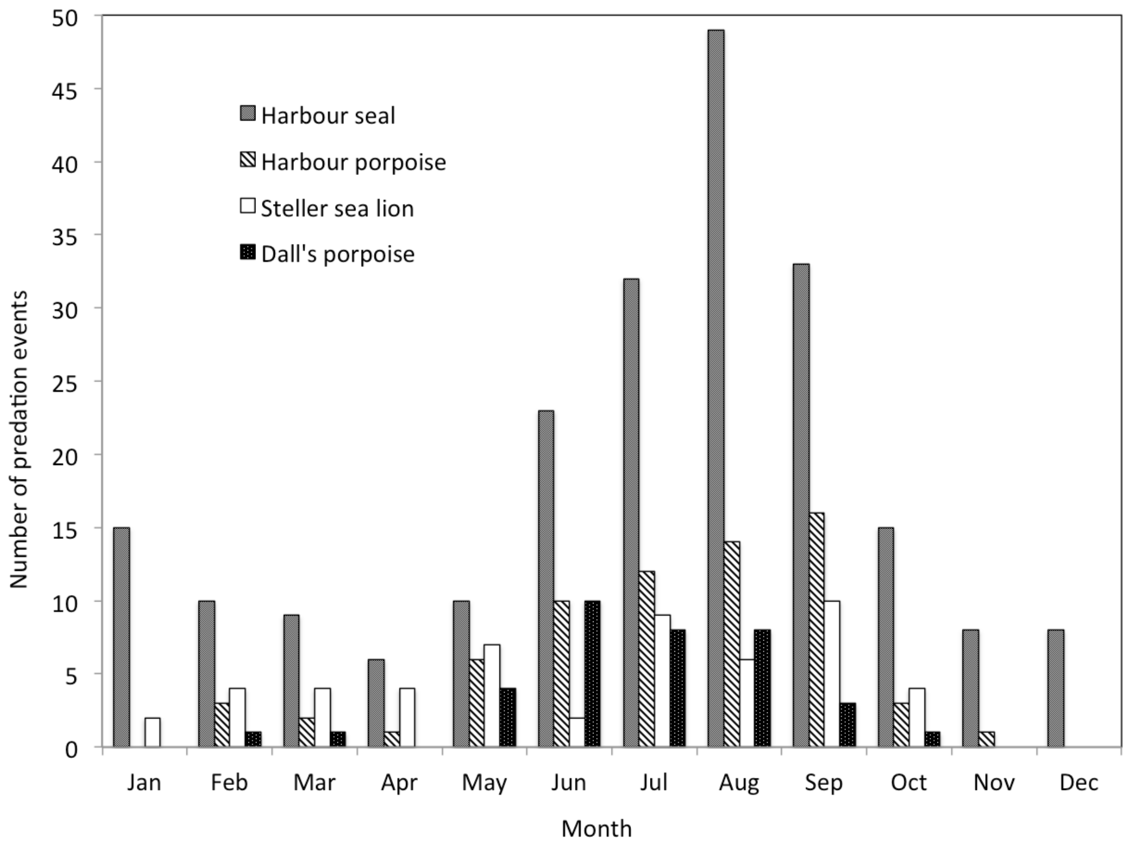


*Figure 20. Monthly distribution of predation events by WCT killer whales involving their four most important prey species, harbour seal, harbour porpoise, Steller sea lion, and Dall's porpoise. Samples sizes as in Figure 17.*

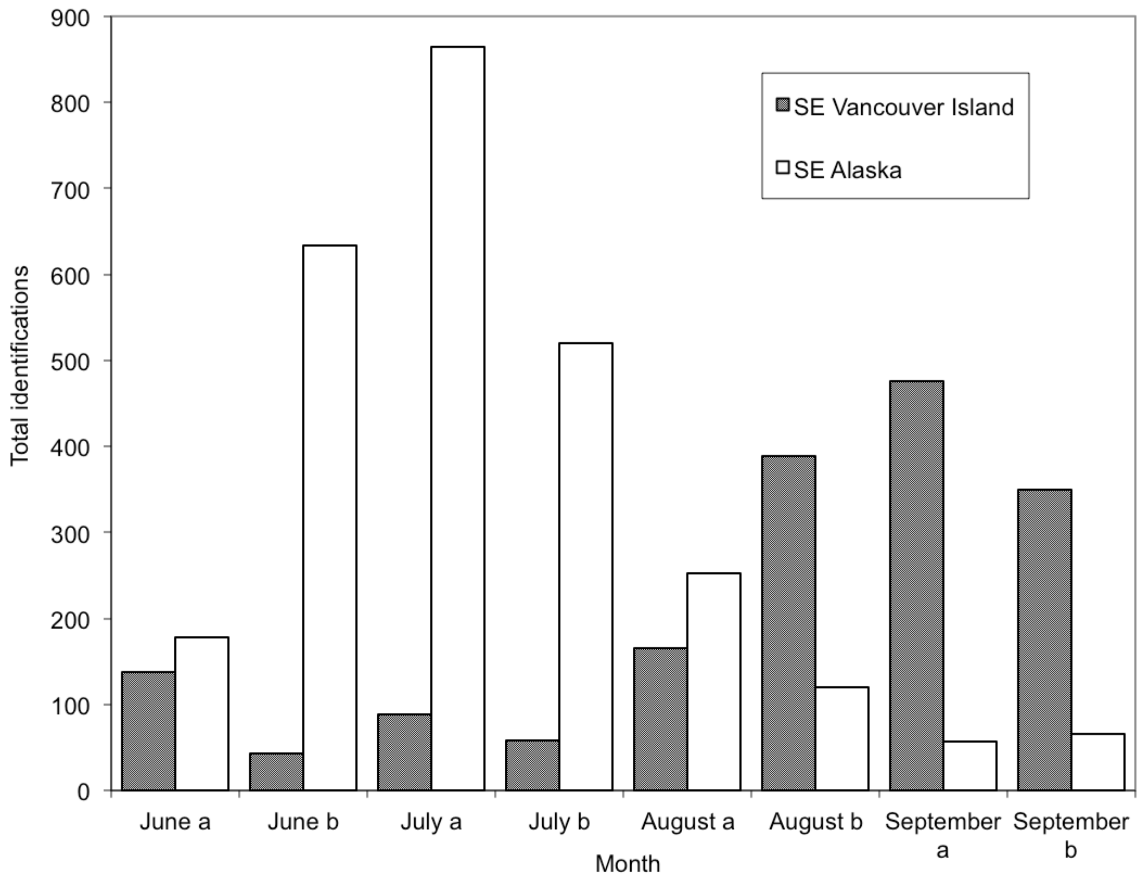


*Figure 21. Biweekly frequency of occurrence of WCT killer whales during June–September, 1990–2011, in southeastern Alaska (open bars; n = 2691 IDs) and off southeastern Vancouver Island (shaded bars; n = 1707 IDs). Bi-weekly intervals in each month are identified by the letters a and b.*

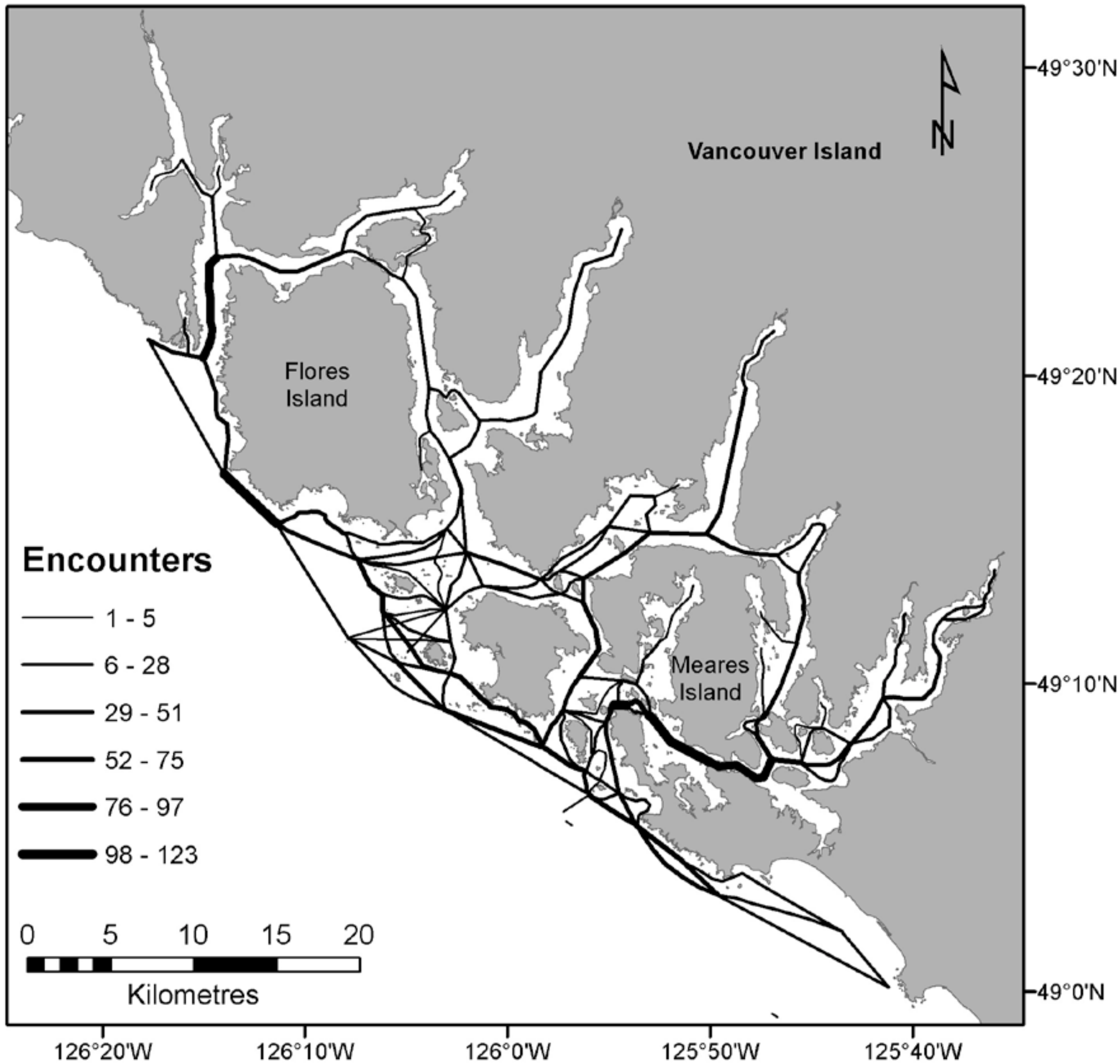


*Figure 22. Travel routes of WCT killer whales in inshore waters of Clayoquot Sound, west coast of Vancouver Island. Width of lines reflect frequency of use. N = 1204 encounters (SIMRS database), 1991–2011, with whales tracked over a total of 14,448 km. Modified from original map provided courtesy of R. Palm, Strawberry Isle Marine Research Society (SIMRS), Tofino, BC.*

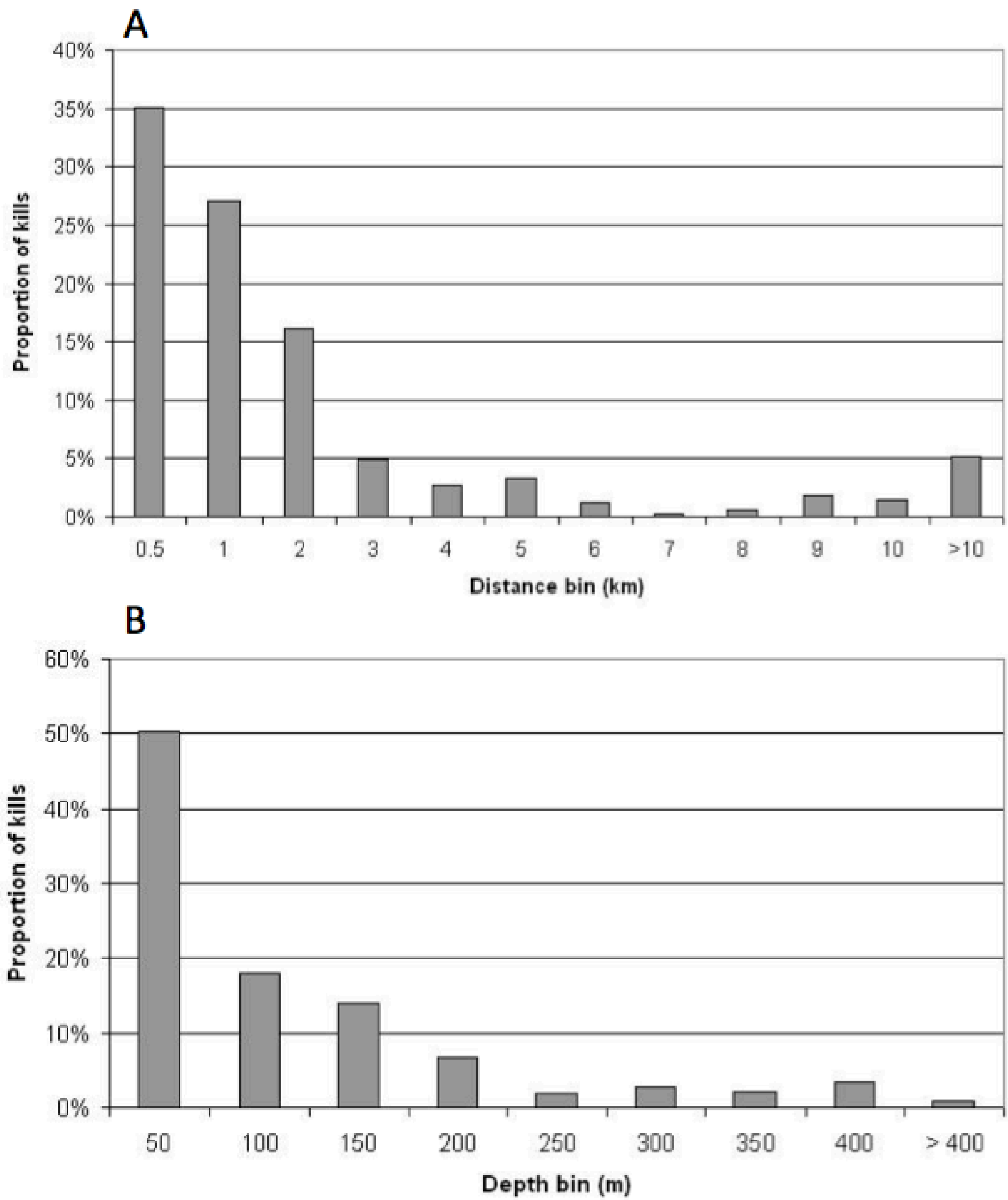


*Figure 23. Distances to nearest shore (A) and water depths (B) for locations of predation events by WCT killer whales. N = 328 kills.*

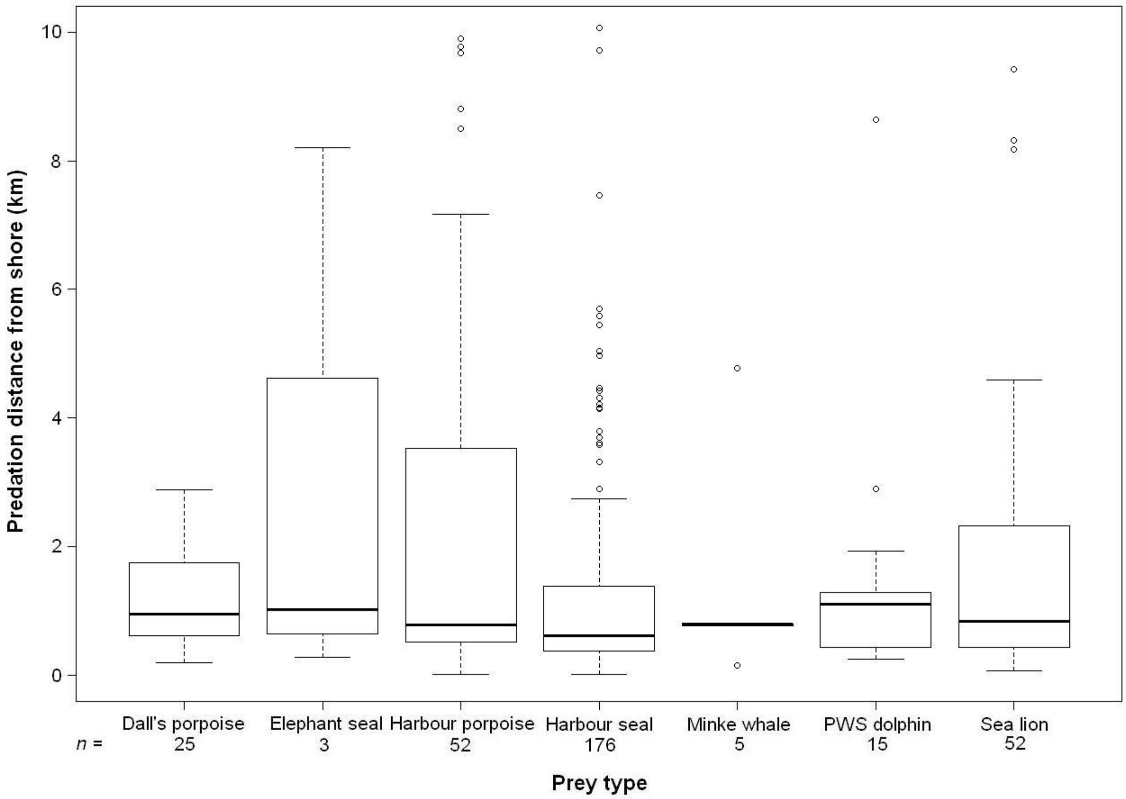


*Figure 24. Box plot showing distance from nearest shore for WCT killer whale predation events involving different prey species. 'Sea lion' includes both Steller sea lion and California sea lion. N = 328 kills.*

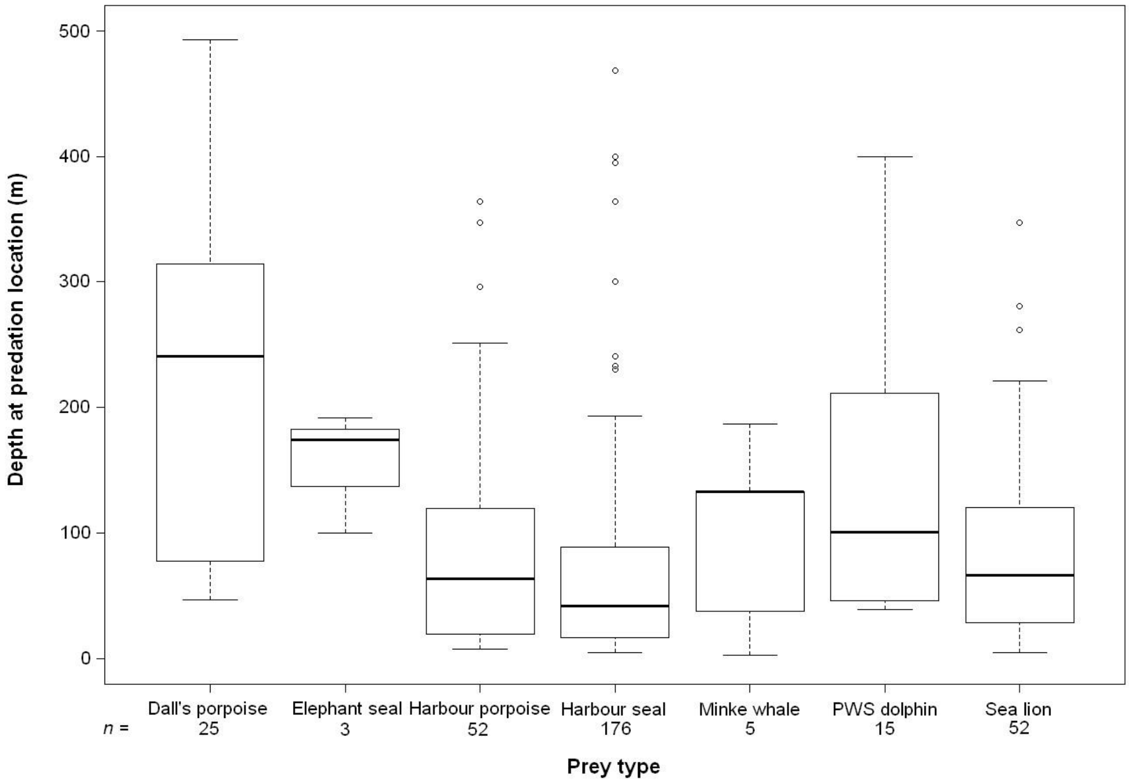


*Figure 25. Box plot showing depth at the locations of WCT killer whale predation events involving different prey species. 'Sea lion' includes both Steller sea lion and California sea lion. N = 328 kills.*

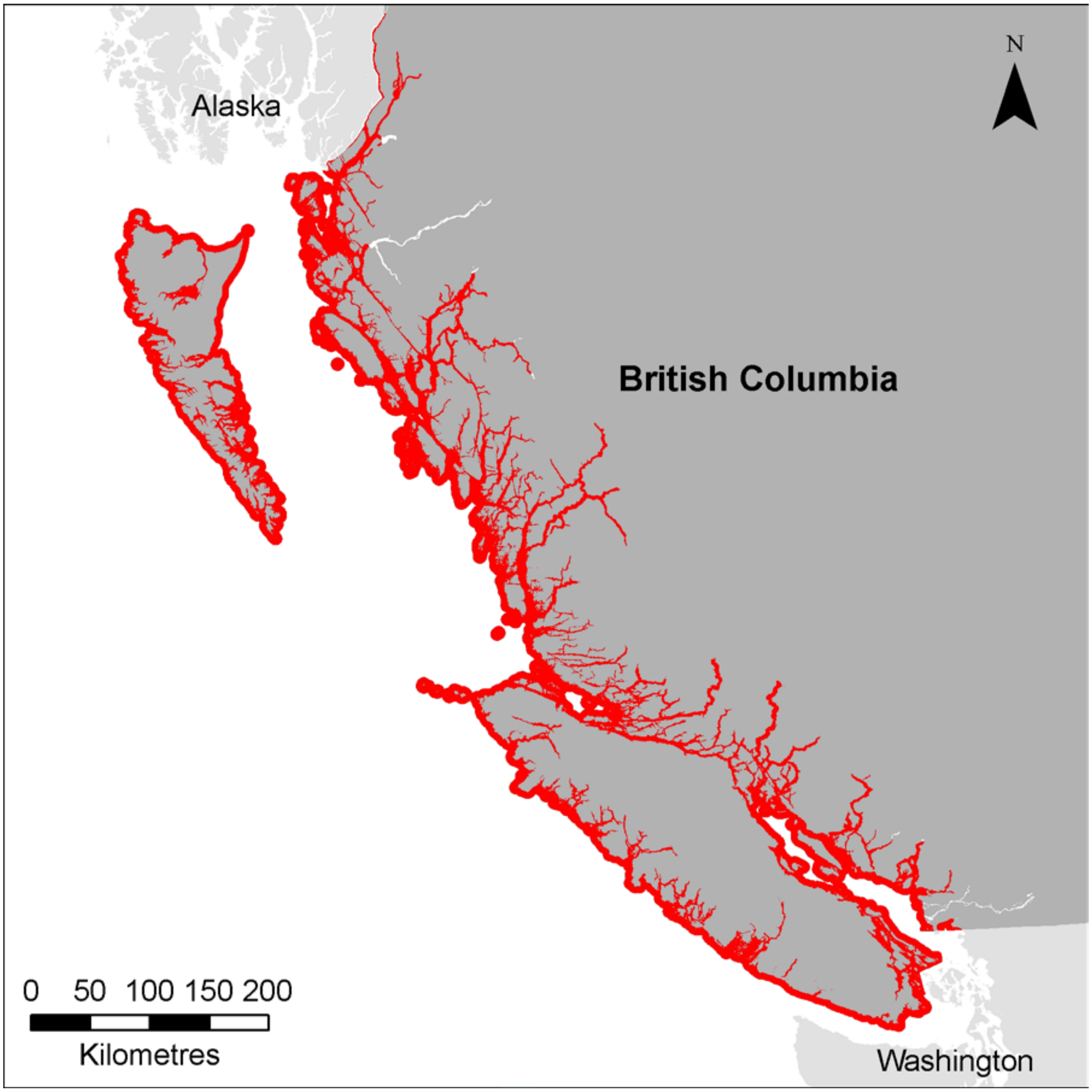


*Figure 26. Map showing the habitat considered necessary for meeting recovery objectives for inner coast WCT killer whales. Area includes marine waters bounded by a distance of 3 nautical miles (5.56 km) from the nearest shore. This area includes the locations of over 90% of all individual identifications and predation events documented in BC waters during 1990-2011.*