Draft

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Recovery Strategy Series

Amended Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada

Killer Whale

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For copies of the recovery strategy, or for additional information on species at risk, including Committee on the Status of Endangered Wildlife in Canada (COSEWIC) Status Reports, residence descriptions, action plans, and other related recovery documents, please visit the SAR Public Registry.

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Preface

The federal, provincial, and territorial government signatories under the Accord for the Protection of Species at Risk (1996) agreed to establish complementary legislation and programs that provide for effective protection of species at risk throughout Canada. Under the Species at Risk Act (S.C. 2002, c.29) (SARA), the federal competent ministers are responsible for the preparation of a recovery strategy for species listed as extirpated, endangered, or threatened and are required to report on progress five years after the publication of the final document on the Species at Risk Public Registry.

The Minister of Fisheries and Oceans and the Minister responsible for the Parks Canada Agency are the competent ministers under SARA for the Northern and Southern Resident Killer Whale and have prepared this strategy, as per section 37 of SARA. In preparing this recovery strategy, the competent ministers have considered, as per section 38 of SARA, the commitment of the Government of Canada to conserving biological diversity and to the principle that, if there are threats of serious or irreversible damage to the listed species, cost-effective measures to prevent the reduction or loss of the species should not be postponed for a lack of full scientific certainty. To the extent possible, the recovery strategy has been prepared in cooperation with Environment and Climate Change Canada and the Province of British Columbia, as per section 39(1) of SARA. In addition, both populations are considered trans-boundary in United States waters. The U.S. National Oceanic and Atmospheric Administration also participated in its preparation.

As stated in the preamble to SARA, success in the recovery of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy and will not be achieved by Fisheries and Oceans Canada, the Parks Canada Agency, or any other jurisdiction alone. The cost of conserving species at risk is shared amongst different constituencies. All Canadians are invited to join in supporting and implementing this strategy for the benefit of the Northern and Southern Resident Killer Whale and Canadian society as a whole.

In addition to this recovery strategy, an action plan for the Northern and Southern Resident Killer Whales has been developed that provides information on recovery measures underway and to be taken by Fisheries and Oceans Canada, the Parks Canada Agency and other jurisdictions and organizations involved in the conservation of the species. Implementation of this strategy is subject to appropriations, priorities, and budgetary constraints of the participating jurisdictions and organizations. Multi-species action plans have also been developed by the Parks Canada Agency that include recovery measures for Northern and Southern Resident Killer Whales.

Acknowledgements

Fisheries and Oceans Canada wishes to thank the Resident Killer Whale Recovery Team (Appendix B) for its efforts in developing the 2008 recovery strategy for the Northern and Southern Resident Killer Whales in Canada. The Team members were generous in contributing their own time to the development of the proposed recovery strategy. The recovery strategy is based on an extensive literature review and on technical input from individual team members and from group discussions and was mostly written by Kathy Heise. The Recovery Team is grateful for the expert reviews provided by Dr. Volker Deecke of the University of British Columbia and Dr. Christophe Guinet, Centre d'Etudes Biologiques de Chize, France. The cover photo was provided by Graeme Ellis. Doug Sandilands (Vancouver Aquarium Marine Science Centre) provided Figure 1. The amendments in the 2011 recovery strategy were prepared by Fisheries and Oceans Canada. The 2018 amendment to the recovery strategy was prepared with input from Dr. John Ford, Dr. Sheila Thornton, Dr. Thomas Doniol-Valcroze, Dr. Lisa Jones, and Dr. Lance Barrett-Lennard. Robin Abernethy prepared Figures 4 and 5.

Strategic environmental assessment statement

A strategic environmental assessment (SEA) is conducted on all SARA recovery planning documents, in accordance with the Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals. The purpose of a SEA is to incorporate environmental considerations into the development of public policies, plans, and program proposals to support environmentally-sound decision making.

Recovery planning is intended to benefit species at risk and biodiversity in general. However, it is recognized that strategies may also inadvertently lead to environmental effects beyond the intended benefits. The planning process based on national guidelines directly incorporates consideration of all environmental effects, with a particular focus on possible impacts on non-target species or habitats. The results of the SEA are incorporated directly in the strategy itself, but are also summarized below.

While this recovery strategy will clearly benefit the environment by promoting the recovery of the Northern and Southern Resident Killer Whales, several potentially adverse effects also were considered. Through the development of this strategy numerous anthropogenic factors that jeopardize or have potential to jeopardize the recovery of these populations were evaluated and are presented. Principal among the anthropogenic factors or threats are environmental contamination, reductions in the availability or quality of prey, and both physical and acoustic disturbance. In some cases these factors threaten the populations; in other cases they may affect critical habitat. It was concluded that some threats can be mitigated through the use of existing legislation, policies, and programs and, in fact, there are numerous examples of mitigation measures that are currently employed outlined herein. However, in other cases the threat and/or the potential mitigation measure(s) require further research or evaluation before recommendations on specific actions or activities can be formulated. The general type of research, evaluation, and approaches for mitigation are presented in this strategy. However, through the course of action planning, specific activities for recovery and mitigation have been evaluated and detailed in the action plan for these populations along with an evaluation of effects and costs of these activities and measures. Therefore, taking into account the general nature of the recommendations for mitigation to recover these populations and that many of the recommendations to protect critical habitat fall under existing legislation and policies, this strategy will not entail any new significant adverse effects.

Executive summary

Two distinct populations of Resident Killer Whales (*Orcinus orca*), known as the Northern and Southern Residents, occupy the waters off the west coast of Canada. In 2001, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated Southern Resident Killer Whales as Endangered and Northern Resident Killer Whales as Threatened. Both populations are listed in Schedule 1 of the Species at Risk Act (SARA). These two populations are acoustically, genetically, and culturally distinct.

The "Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada" was finalized and published on the Species at Risk Public Registry in 2008. Minor amendments to the recovery strategy were made in 2011 to provide additional clarification regarding critical habitat for Northern and Southern Resident Killer Whales. This recovery strategy is herewith amended once again to include identification of additional critical habitat for these populations and to provide minor updates to background and species information. Additionally, sections of the recovery strategy have been reordered to align with current templates. This recovery strategy is considered one in a series of documents for this species that are linked and should be taken into consideration together; including the COSEWIC status report (COSEWIC 2008) and the Action Plan for the Northern and Southern Resident Killer Whale (*Orcinus orca*) in Canada (DFO 2017a). Recovery has been determined to be biologically and technically feasible.

Resident Killer Whale populations in Canadian Pacific waters are presently considered to be at risk because of their small population size, low reproductive rate, and the existence of a variety of anthropogenic threats that have the potential to prevent recovery or to cause further declines. Principal among these anthropogenic threats are environmental contamination, reductions in the availability or quality of prey, and both physical and acoustic disturbance. Even under the most optimistic scenario (human activities do not increase mortality or decrease reproduction), the species' low intrinsic growth rate means that the time frame for recovery will be more than one generation (25 years).

The Southern Resident Killer Whale population has fluctuated between 70 and 99 individuals since 1976, and consisted of 76 members in 2017 (Center for Whale Research unpublished data). During the summer and fall, Southern Residents are primarily found in the trans-boundary waters of Haro Strait, Boundary Pass, the eastern portion of Juan de Fuca Strait, and southern portions of the Strait of Georgia. Some members of the population typically remain in the same general area in winter and spring, but others range over much greater distances, and have been reported as far south as central California, and as far north as southeastern Alaska. During the summer and fall, the principal prey of Southern Residents is Chinook and Chum Salmon (*Oncorhynchus tshawytscha* and *O. keta*); less is known of their diet in the winter and spring.

The Northern Resident Killer Whale population experienced a decline of 7% between 1997 and 2002, but since that time has been increasing at a mean rate of 2.9% per year, reaching approximately 309 individuals in 2017 (Towers et al. 2015; Fisheries and Oceans Canada Cetacean Research Program (DFO-CRP) unpublished data). The population appears to spend the majority of its time from Campbell River and Alberni Inlet northwest to Dixon Entrance, but has been sighted as far south as Grays Harbor, Washington, and as far north as Glacier Bay, Alaska (Ford et al. 2000; 2017). Northern Residents also feed primarily on Chinook and Chum Salmon during the summer and fall. However, like Southern Residents, less is known of their

winter distribution and diet, and this knowledge gap must be addressed to fully understand the principal threats affecting the population.

The goal of the Resident Killer Whale recovery strategy 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[1]".

In order to achieve this goal, four principal objectives have been identified. They are:

Objective 1: ensure that Resident Killer Whales have an adequate and accessible food supply to allow recovery

Objective 2: ensure that chemical and biological pollutants do not prevent the recovery of Resident Killer Whale populations

Objective 3: ensure that disturbance from human activities does not prevent the recovery of Resident Killer Whales

Objective 4: protect critical habitat for Resident Killer Whales and identify additional areas for critical habitat designation and protection

A description of the broad strategies to be taken to address threats to the species' survival and recovery, as well as research and management approaches needed to meet the recovery goal and objectives are included in section 6. These strategies helped to inform the development of specific recovery measures in the action plan for Northern and Southern Resident Killer Whales. However, significant gaps in knowledge about Killer Whales remain and numerous actions have been identified to address these knowledge gaps and to identify further directions for recovery.

For Northern and Southern Resident Killer Whales, critical habitat is identified to the extent possible using the best available information, and provides the functions, features, and attributes necessary to support the species' life-cycle processes and contribute to achieving the species' recovery goal and objectives. This recovery strategy identifies critical habitat for Resident Killer Whales as four geographical areas: 1) the waters of Johnstone Strait and southeastern Queen Charlotte Strait (Northern Resident Killer Whale critical habitat); 2) transboundary waters in southern British Columbia, including southern Georgia Strait, Haro Strait, and Juan de Fuca Strait (Southern Resident Killer Whale critical habitat); 3) waters on the continental shelf off southwestern Vancouver Island, including Swiftsure and La Pérouse Banks (Northern and Southern Resident Killer Whale critical habitat); and 4) waters of west Dixon Entrance, along the north coast of Graham Island from Langara to Rose Spit (Northern Resident Killer Whale critical habitat) (section 7).

The Action Plan for the Northern and Southern Resident Killer Whale (*Orcinus orca*) in Canada was finalized and posted on the Species at Risk Public Registry in 2017. Additionally, multi-species action plans developed by the Parks Canada Agency include recovery measures for Northern and Southern Resident Killer Whales.

[1] Culture refers to a body of information and behavioural traits that are transmitted within and between generations by social learning

Recovery feasibility summary

Resident Killer Whale populations are not expected to achieve high abundances that might result in a de-listing due to their ecological position as upper trophic-level predators coupled with their apparent propensity to live in relatively small populations. Despite this, and despite gaps in our knowledge, the Recovery Team views the recovery of both populations to a more robust and sustainable status as technically and biologically feasible. Both populations have males, reproductive and pre-reproductive females, and the capacity to grow. During past periods of population growth, annual increases of approximately 3% have been recorded (see 3.3.2 in Population size and trends). Growth is unlikely to exceed these levels due to the low reproductive rate of the species, and therefore the recovery of Northern and Southern Resident Killer Whales can be expected to take more than one generation. Due to its small size, the Southern Resident Killer Whale population will be particularly vulnerable to catastrophic events and continue to have a high risk of extinction during this period.

Technologies and methodologies currently exist to reduce many of the threats facing Killer Whales, their prey and their habitat. As well, identification of critical habitat and the protection of all critical habitat areas from further degradation will ensure that Resident Killer Whales have sufficient habitat for recovery. The action plan for Northern and Southern Resident Killer Whales describes 98 recovery measures to address threats to the species and monitor its recovery, many of which are underway. As Killer Whales travel regularly across international borders, it is timely that both the Washington State and the United States federal governments are also engaged in conservation actions to promote the recovery of both populations.

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1. Introduction

Two distinct populations of Resident Killer Whales (*Orcinus orca*), known as the Northern and Southern Residents, occupy Canadian Pacific waters. Northern Resident Killer Whales are listed as Threatened and Southern Resident Killer Whales are listed as Endangered under the Species at Risk Act (SARA).

The Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada was finalized and published on the Species at Risk Public Registry in 2008. Minor amendments to the recovery strategy were made in 2011 to provide additional clarification regarding critical habitat for Northern and Southern Resident Killer Whales. In 2018, the recovery strategy was amended again to include identification of additional critical habitat for these populations (section 7) and to provide minor updates to background and species information. Further, minor changes were made to the formatting of this recovery strategy to adhere to current national templates where possible. This recovery strategy is considered one in a series of documents for this species that are linked and should be taken into consideration together; including the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report (COSEWIC 2008) and an action plan (DFO 2017a).

2. COSEWIC species assessment information

Date of Assessment: November 2008

Common name: Killer Whale - Northern Resident population

Scientific name: Orcinus orca

Status: Threatened

Reason for designation: The population is small, and is limited by the availability of its principal prey, Chinook Salmon. It is also at risk from physical and acoustical disturbance, oil spills and contaminants. However, this population has been increasing slowly since monitoring began in 1975.

Occurrence: Pacific Ocean

Status history: The “North Pacific Resident populations” were given a single designation of Threatened in April 1999. Split into three populations in November 2001. The Northern Resident population was designated Threatened in November 2001. Status re-examined and confirmed in November 2008. Last assessment based on an update status report.

Date of Assessment: November 2008

Common name: Killer Whale - Southern Resident population

Scientific name: Orcinus orca

Status: Endangered

Reason for designation: The population is small and declining, and the decline is expected to continue. Southern Residents are limited by the availability of their principal prey, Chinook Salmon. There are forecasts of continued low abundance of Chinook Salmon. Southern Residents are also threatened by increasing physical and acoustical disturbance, oil spills and contaminants.

Occurrence: Pacific Ocean

Status history: The "North Pacific Resident populations" were given a single designation of Threatened in April 1999. Split into three populations in November 2001. The Southern Resident population was designated Endangered in November 2001. Status re-examined and confirmed in November 2008. Last assessment based on an update status report.

3. Species information

3.1 Description

The Killer Whale is the largest member of the dolphin family, Delphinidae. Its size, striking black and white colouring and tall dorsal fin are the main identifying characteristics. Killer Whales are mainly black above and white below, with a white oval eye patch, and a grey saddle patch below the dorsal fin. Each Killer Whale has a uniquely shaped dorsal fin and saddle patch, and most animals have naturally acquired nicks and scars. Individual Killer Whales are identified using photographs of the dorsal fin, saddle patch, and sometimes eye patches (Ford et al. 2000). They are sexually dimorphic. Maximum recorded lengths and weights for male Killer Whales are 9.0 m and 5,568 kg respectively, whereas females are smaller at 7.7 m and 4,000 kg (Dahlheim and Heyning 1999). The tall triangular dorsal fin of adult males is often as high as 1.8 m, while in juveniles and adult females it reaches 0.9 m or less. In adult males, the paddle-shaped pectoral fins and tail flukes are longer and broader and the fluke tips curl downward (Bigg et al. 1987).

Currently, most authorities consider Killer Whales to be one species, *Orcinus orca*, having regional variations in diet, size, colouration, and vocal patterns (Heyning and Dahlheim 1988; Ford et al. 2000; Barrett-Lennard and Ellis 2001). Two and possibly three distinct species have recently been proposed for Antarctic populations (Mikhalev et al. 1981; Berzin and Vladimorov 1983; Pitman and Ensor 2003), but they are not currently widely accepted (Reeves et al. 2004). In addition, recent genetic studies report little global variation in mitochondrial DNA suggesting that the population segregation indicated by the morphological differences described above is relatively recent (Barrett-Lennard 2000; Hoelzel et al. 2002).

Three distinct forms, or ecotypes, of Killer Whale inhabit Canadian Pacific waters: Transient, Offshore, and Resident. These forms are sympatric but socially isolated and differ in their dietary preferences, genetics, morphology and behaviour (Ford et al. 1998; 2000; Barrett-Lennard and Ellis 2001). Transient Killer Whales feed on marine mammals; particularly Harbour Seals (*Phoca vitulina*), porpoises, and sea lions (Ford et al. 1998). They travel in small, acoustically quiet groups that rely on stealth to find their prey (Ford and Ellis 1999). To the experienced eye, the dorsal fins of Transient Killer Whales tend to be pointed and their saddle patches are large and uniformly grey (Ford et al. 2000). Offshore Killer Whales are not as well understood as Residents and Transients. They feed primarily on elasmobranchs, but have also been documented to prey on teleost fishes, including Chinook Salmon (Heise et al. 2003; Ford et al. 2014). They often travel in large acoustically active groups of 30 or more whales, using frequent echolocation and social calls (Ford et al. 2000). The dorsal fins of Offshore Killer Whales are more rounded than those of Transients, and their saddle patches may either be uniformly grey or may contain a black region.

Resident Killer Whales are the best understood of the three ecotypes. They feed exclusively on fish and cephalopods and usually travel in acoustically active groups of 10 to 25 or more whales (Ford et al. 2000). The tips of their dorsal fins tend to be rounded at the leading edge and have a fairly abrupt angle at the trailing edge. Their saddle patches may be uniformly grey or contain a black region. The social organization of Resident Killer Whales is highly structured. Their fundamental unit is the matriline, comprising all surviving members of a female lineage. A typical matriline comprises an adult female, her offspring, and the offspring of her daughters. Both sexes remain within their natal matriline for life (Bigg et al. 1990). Social systems in which both sexes remain with their mother for life have only been described in one other mammalian species, the Long-Finned Pilot Whale (*Globicephala melas*) (Amos et al. 1993). Bigg et al. (1990) defined pods as groups of closely related matrilines that travel, forage, socialize, and rest with each other at least 50% of the time, and predicted that pods, like matrilines, would be stable over many generations. However, Ford and Ellis (2002) showed that inter-matriline association patterns in the Northern Residents have evolved over the past decade such that some of the pods identified by Bigg et al. (1990) now fail to meet the 50% criterion. Their analysis suggests that pods are best defined as transitional groupings that reflect the relatedness of recently diverged matrilines.

Each Resident pod has a unique dialect made up of approximately a dozen discrete calls (Ford 1989; 1991). These dialects can be distinguished, providing each pod with a unique acoustic signature. Dialects are probably learned from mothers and other associated kin and are highly stable over time (Ford et al. 2000). Their function is not entirely understood, although it appears that they play an important role in mate selection (Barrett-Lennard 2000, discussed below in section 3.4.1. Culture). Despite having distinct dialects, some pods share certain calls and call variants. Pods that share one or more calls belong to a common clan.

Resident Killer Whales that share a common range and that associate at least occasionally are considered to be members of the same community or population. There are two communities of Resident Killer Whales in British Columbia, the Northern Residents and the Southern Residents. Despite having overlapping ranges, these two communities are acoustically, genetically, and culturally distinct. The Northern Resident community consists of three clans, and the Southern Resident community consists of one.

The existence of two distinct populations of Resident Killer Whales using the waters of Washington and British Columbia has been recognized by both the Canadian and U.S. governments. In 2001 COSEWIC assessed Northern Residents as Threatened and Southern Residents as Endangered. In the United States, marine mammals are afforded federal protection under both the Marine Mammal Protection Act (MMPA) and, when listed, under the

Endangered Species Act (ESA). The Southern Residents were listed as 'depleted' under the MMPA in 2003. In February 2006, Southern Resident Killer Whales were listed as Endangered under the ESA. In June 2004, the Washington State Department of Fish and Wildlife added Southern Resident Killer Whales to their Endangered Species List.

3.2 Distribution

3.2.1. Global range

Killer Whales are found in all oceans, and are most common in areas associated with high ocean productivity in mid to high latitudes (Forney and Wade 2006). They are able to tolerate temperatures ranging from those found in polar waters to the tropics, and have been recorded in water ranging from shallow (several metres) to open ocean depths (Baird 2001).

3.2.2. Canadian Pacific range

Killer Whales are found in all three of Canada's oceans, as well as occasionally in Hudson Bay and in the Gulf of St. Lawrence. They are rarely documented in the northwestern Atlantic, but their occurrence in the eastern Arctic has been increasing in recent years (COSEWIC 2008; Ferguson et al. 2010). In British Columbia (BC), Killer Whales have been recorded throughout almost all salt-water areas, including many long inlets, narrow channels, and deep embayments (Baird 2001). The three ecotypes of BC Killer Whales (Offshore, Transient, and Resident) do not appear to interact socially despite their overlapping ranges (Ford et al. 2000). Offshore Killer Whales are most often sighted on the continental shelf off the outer coast, but they are occasionally found in protected inside waters (Ford et al. 2000). Transient Killer Whales range throughout the area, as do Resident Killer Whales (Ford and Ellis 1999; Ford et al. 2000). Residents and Transients have occasionally been seen in close proximity to each other, but rarely interact (Ford and Ellis 1999). Figure 1 shows many place names mentioned in the text, as well as the general ranges of Northern and Southern Residents.

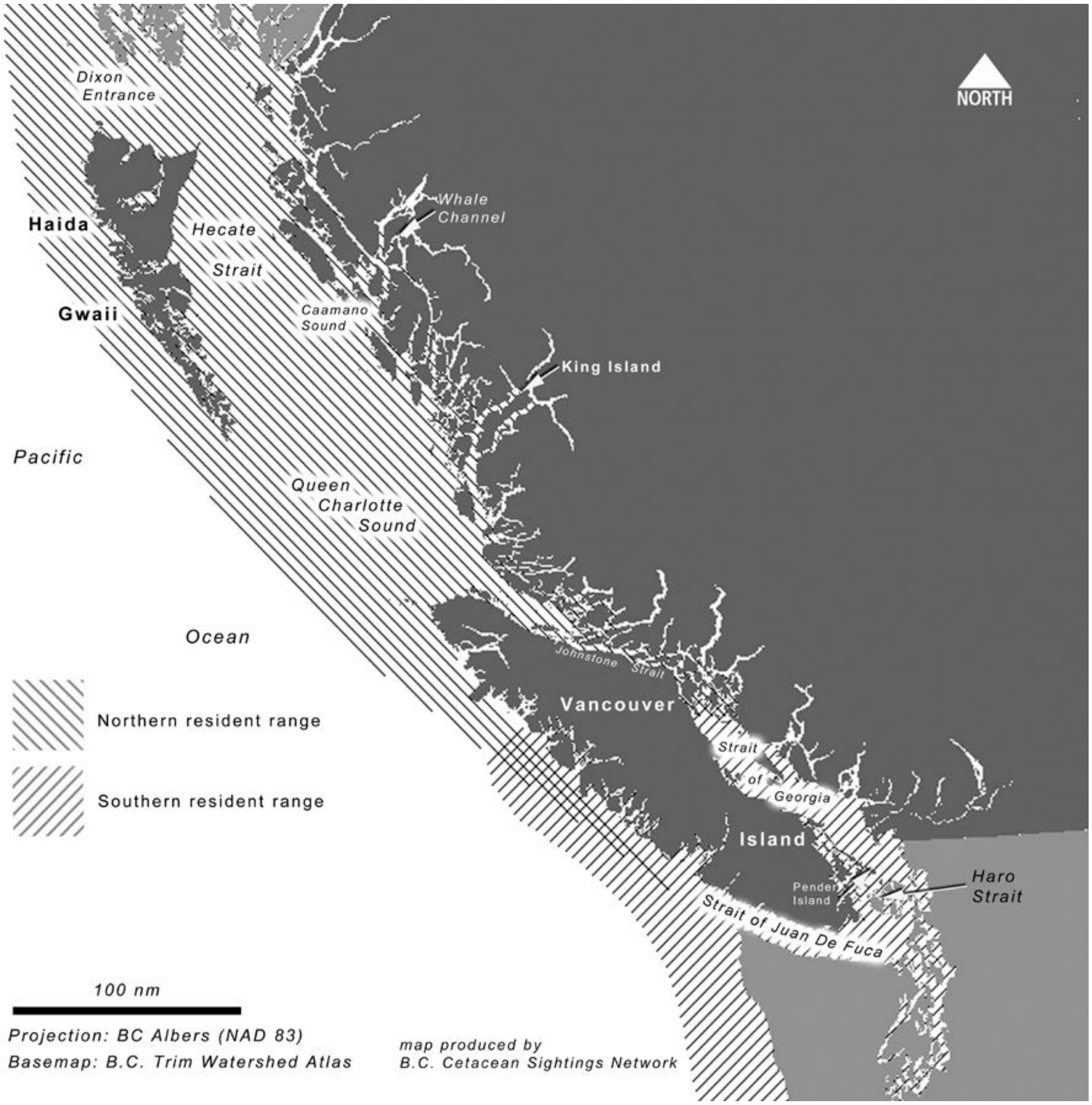

Figure 1. The coast of British Columbia and northwest Washington State showing the general ranges of Northern and Southern Resident Killer Whales

Southern Residents

The community of Southern Residents comprises a single acoustic clan, J clan, which is composed of three pods (referred to as J, K, and L) containing a total of 20 matrilines (Ford et al. 2000). The known range of this community is from southeastern Alaska to central California (Ford et al. 2017). During summer, its members are usually found in waters off southern Vancouver Island and Northern Washington State, where they congregate to intercept migratory salmon. The main area of concentration for Southern Residents is Haro Strait and vicinity off southeastern Vancouver Island (Figure 1), but they are commonly seen in Juan de Fuca Strait, and the southern Strait of Georgia (Ford et al. 2000). Of the three Southern Resident pods, J pod is most commonly seen in inside waters throughout the year, and appears to seldom leave the Strait of Georgia-Puget Sound-Juan de Fuca Strait region in most years (Ford et al. 2000). K and L pods are more often found in western Juan de Fuca Strait and off the outer coasts of

Washington State and Vancouver Island. Unlike J pod, K and L pods typically leave inshore waters in winter and return in May or June. Their range during this period is poorly known, but they have been sighted as far south as Monterey Bay, California and as far north as Chatham Strait, southeastern Alaska (Ford et al. 2017).

Northern Residents

The Northern Resident Killer Whale community comprises three acoustic clans (A, G, and R) containing 34 matrilines, which range from Glacier Bay, Alaska to Grays Harbor, Washington (Ford et al. 2000; Ford et al. 2017). From June to October, some Northern Resident Killer Whales are frequently documented in Johnstone Strait and Queen Charlotte Strait (Figure 1), off northeastern Vancouver Island (Ford et al. 2000). Their range at other times of the year is not as well understood. Small groups of Northern Residents are sometimes seen in Johnstone Strait and other inshore waters along the BC coast in winter (Ford et al. 2000) but such sightings are rare even when seasonal changes in observer effort are taken into account.

There is no evidence that clans are restricted to specific regions within the range of their community, but some show an apparent preference for particular areas (Ford et al. 2000). For example, the most commonly sighted whales off northeastern Vancouver Island belong to A clan, whereas most of the whales sighted off the west coast of Vancouver Island belong to G clan, and R clan seems to prefer the northern part of the community's range. The range of Northern Residents overlaps with Southern Residents and with a community referred to as the southern Alaskan Residents. Northern Residents have never been seen associating with members of the Southern Resident community, and while they were observed travelling in proximity to a southern Alaskan Resident pod on one occasion (Dahlheim et al. 1997), it is not clear that social mixing took place. Genetic studies have not ruled out the possibility of occasional breeding between the Northern Resident and southern Alaskan Resident communities (Barrett-Lennard and Ellis 2001).

3.3 Population size and trends

3.3.1 Global

Little is known of the historic abundance of Killer Whales, except that they were "not numerous" (Scammon 1874). Since the early 1970s, photo-identification studies have provided reasonable population estimates for Killer Whales in the near-shore waters of the northeastern Pacific (Washington, BC, Alaska, and California), and similar work is now underway in several other coastal regions (e.g. the Gulf of California, the Russian Far East, New Zealand, Patagonia, Iceland, and Norway). In other areas line transect surveys have been used to provide population estimates. These include the Antarctic (25,000 whales, Branch and Butterworth 2001) and the Eastern Tropical Pacific (8,500 whales, Wade and Gerrodette 1993). As such, the worldwide abundance of Killer Whales is probably between 40,000 and 60,000 whales (Forney and Wade 2006). Trend data for Killer Whales are generally not available, with the exception of Killer Whales in BC (discussed below) and southern Alaskan Residents (population thought to be generally increasing, Matkin et al. 2008) and for a small population of Transients in Prince William Sound (AT1s, currently in decline, not likely to recover, Saulitis et al. 2002).

3.3.2 British Columbia

There are no population estimates for Killer Whales in BC prior to 1960. Population censuses for Killer Whales are now conducted annually using photo-identification of individuals. Population trends vary by community and clan. For the purposes of the recovery strategy, data held by the Center for Whale Research (CWR), Friday Harbor, Washington, were used to describe the population status and trends of Southern Resident Killer Whales. Data held by the Fisheries and Oceans Canada Cetacean Research Program (DFO-CRP) were used to describe the Northern Resident Killer Whale population. Whales are censused slightly differently by each research group.[2]

The Southern Resident count includes all whales that are seen during a calendar year, and mortalities are included in the count depending on when they take place. For example, a whale that is not seen from March onwards is assumed to be dead. There is less certainty that a whale that is not seen in November or December is dead, and it may be included in the count. In recent years, observer effort has been high and most members of the Southern Resident community are photographed annually, so the count is reasonably precise.

The Northern Resident count also includes all whales that are documented during a calendar year. However, not all members of the Northern Resident community are seen each year, so the count data are generally less precise than for the Southern Residents.

In 2017, there were a total of approximately 385 Northern and Southern Resident Killer Whales (CWR unpublished data; DFO-CRP unpublished data). By comparison there were approximately 521 Transient (Ford et al. 2013) and 300 Offshore Killer Whales (Ford et al. 2014), although these numbers are less precise than the Resident counts, because not all individuals are encountered each year (Ford et al. 2000).

Southern Residents

The size of the Southern Resident community has been known since the first complete photo-identification census in 1976 (CWR unpublished data). Figure 2 shows the size of each pod as well as the fluctuation in the total population of the Southern Resident community from 1976-

[2] Note that there are small discrepancies in the Southern Resident counts in the literature due to different methods of recording when whales are considered to enter or leave the population.

2017.

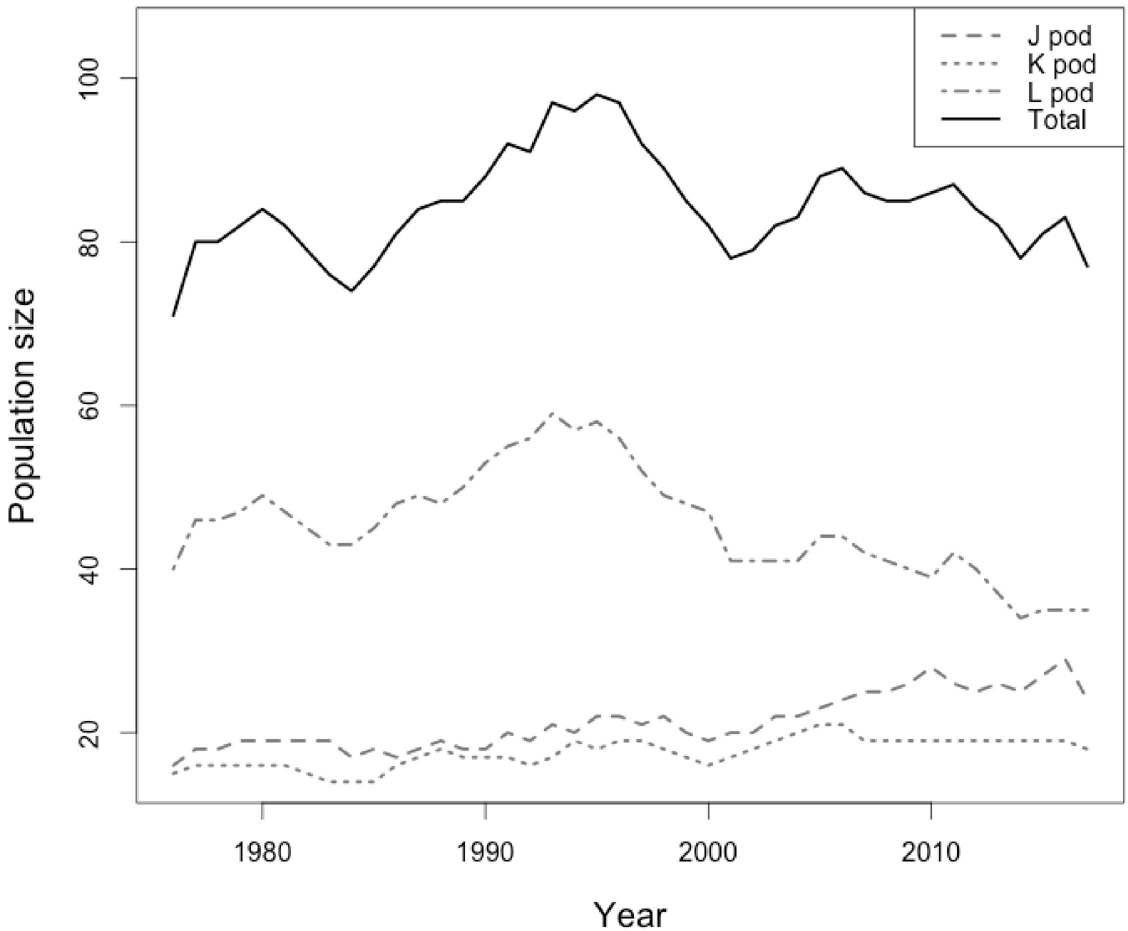

Figure 2. Population size and trends for Southern Resident Killer Whales from 1976-2017. Data source: Center for Whale Research (unpublished).

Although the Southern Resident community was likely increasing in size in the early 1960s, the number of whales in the community dropped dramatically in the late 1960s and early 1970s due to live capture for aquariums (Bigg and Wolman 1975). A total of 47 individuals that are known or likely to have been Southern Residents were captured and removed from the population (Bigg et al. 1990). The population increased 19% (3.1% per year) from a low of 70 individuals after the live-captures ended in 1973, to 83 whales in 1980, although the growth rate varied by pod (Figure 2). From 1981-1984 the population declined 11% (-2.7% per year) to 74 whales as a result of lower birth rates, higher mortality for adult females and juveniles (Taylor and Plater 2001), and lower numbers of mature animals, especially males, which was caused by selective cropping in previous years (Olesiuk et al. 1990). From 1985 to 1995, the number of Southern Residents increased by 34% (2.9% per year) to 99 animals. A surge in the number of mature individuals, an increase in births, and a decrease in deaths contributed to the population growth. Another decline began in 1996, with an extended period of poor survival (Taylor and Plater 2001; Krahn et al. 2002) and low fecundity (Krahn et al. 2004) resulting in a decline of 17% (-2.9% per year) to 81 whales in 2001. Since 2001, the population has fluctuated between 76 and 89 individuals, and consisted of 76 members in 2017 (CWR unpublished data).

Population viability analyses (PVA) have been used to estimate the extinction risk of Southern Resident Killer Whales (Taylor and Plater 2001; Krahn et al. 2002; 2004). As would be expected, extinction risk increases when the frequency and magnitude of catastrophes such as oil spills and disease epidemics are elevated. These models predict that if the mortality and reproductive rates of the 1990s persist, there is a 6-100% probability that the population will be extinct within 100 years, and a 68-100% risk that the population will be extinct within 300 years. Extinction of the Southern Resident population can be regarded as inevitable in these scenarios under the assumptions of the analyses, and catastrophic events simply hasten its demise. When the mortality and reproductive rates of the entire 1974-2000 period are used, the risk of the population going extinct declines to 0-55% over 100 years and 2-100% over 300 years. A more recent PVA predicted survival and recovery rates of Southern Resident Killer Whales based on sex-structured models and high-quality demographic data that encompassed one Killer Whale generation (25 years; 1987-2011). These models predicted an annual decline of 0.91% for this population, with an extinction risk of 49% over a 100-year period (Velez-Espino et al. 2014). A PVA that explored the relative importance of the primary anthropogenic threats (Chinook prey availability, noise and disturbance, and contaminants) to Southern Resident Killer Whale population trajectories was constructed by Lacy et al. (2017). These models predicted that prey limitation had the greatest potential to impact population growth, but that either higher levels of noise and disturbance or higher levels of PCB contamination would also be sufficient to shift population trajectories from slow positive growth into decline.

Northern Residents

The Northern Resident community was likely increasing in size during the early 1960s, but was cropped by the live capture fishery of 1964-1973, during which at least 14 individuals were removed. Twelve of those are known to have been from one pod (A5, Bigg et al. 1990). When first censused in 1974, the Northern Resident community was estimated to contain approximately 120 whales. Although abundance estimates for Northern Residents are less precise than those for Southern Residents because not all matrilines are seen each year, it appears that the Northern Resident community grew steadily during the period 1974 to 1991 (approximately 3.4% per year, Figure 3). The population increased to 220 animals in 1997 (growth of 3.0% per year, Towers et al. 2015). Several reasons have been postulated for the Northern Residents' success relative to Southern Residents during this period: the population's larger size may have buffered changes in birth and death rates, fewer animals were captured during the live-capture fishery (Olesiuk et al. 1990), and in general they are exposed to less disturbance and environmental contamination. Between 1997 and 2003, the Northern Resident community declined 7% to 205 whales in 2003 (Towers et al. 2015, Figure 3). The increased mortality rates that drove the declines during this period for both Northern and Southern Residents coincided with a period of reduced range-wide Chinook Salmon abundance (Ford et al. 2010). The Northern Resident Killer Whale population has been increasing at an annual average rate of 2.9% since that time, reaching approximately 309 individuals in 2017 (Towers et al. 2015; DFO-CRP unpublished data). Population viability analyses based on sex-structured models and high-quality demographic data predicted a 1.58% annual increase and an extinction risk of 0% for Northern Resident Killer Whales over a 100-year period (Velez-Espino et al. 2014).

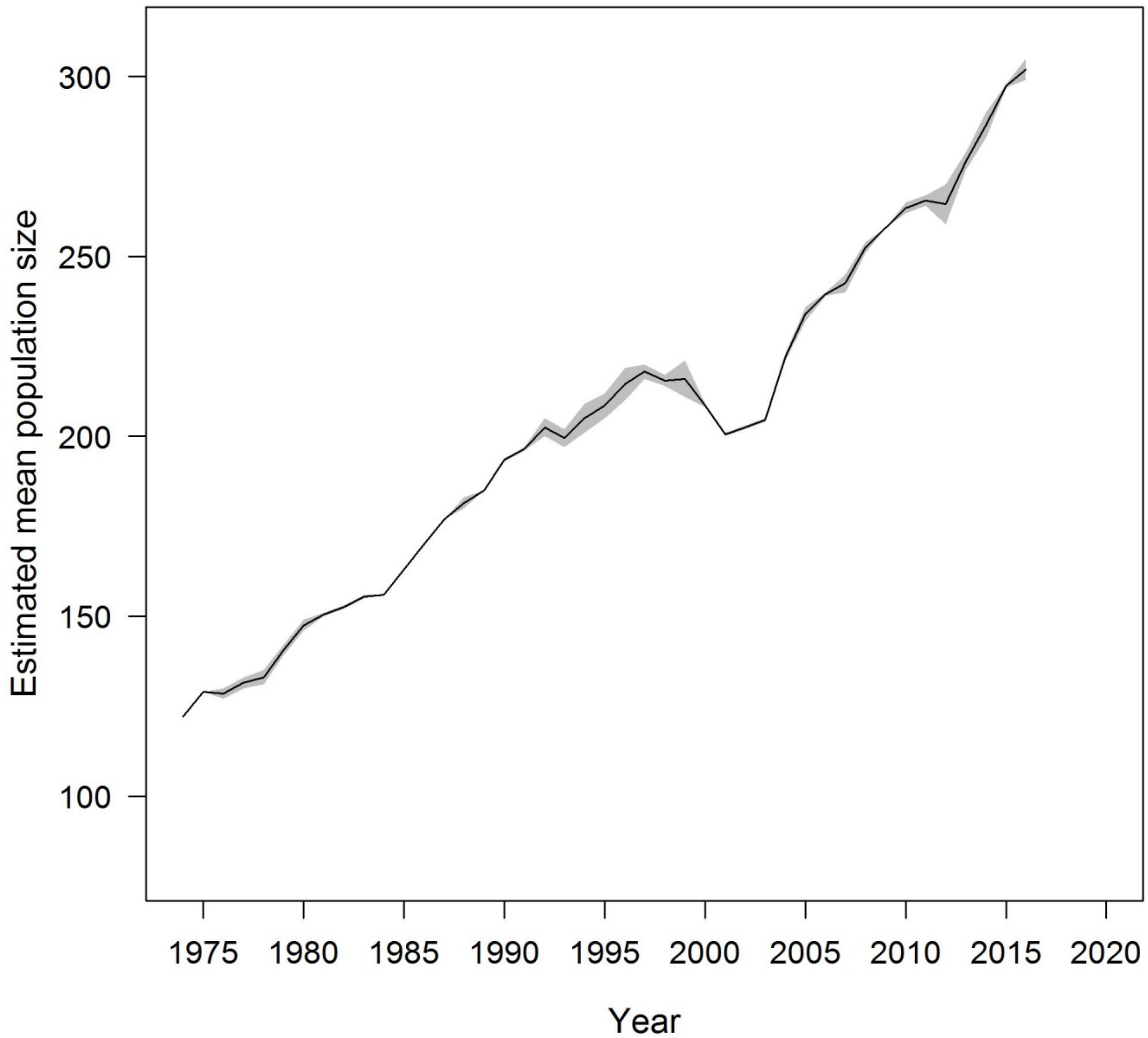

Figure 3. Population size and trends for Northern Resident Killer Whales from 1974 to 2016. In years with uncertainty, the minimum and maximum population sizes are represented with grey shading. Data sources: Towers et al. (2015); DFO-CRP (unpublished).

3.4 Natural factors affecting population viability and recovery

It is important to note that Northern and Southern Resident Killer Whales have been studied primarily in protected waters during the months of May to October (Ford et al. 1998; 2000). Their behaviour and ecology in other areas and seasons is less well-known.

3.4.1. Biological limiting factors

The following description of the biology of Killer Whales is based on data from both the Northern and Southern Resident populations. Essentially, Resident Killer Whales feed on fish and do not switch to marine mammals when their principal prey species are not abundant. They are long-lived animals with no natural predators. On average, females produce a single calf every five to six years during a 25-year reproductive period, and as a result the population has an inherently slow rate of growth. Resident Killer Whales have strong cultural traditions that influence their association and mating behaviours, which also limits the capacity for the population to grow. More detailed information on the factors that may limit the ability of Resident Killer Whale populations to grow is provided below.

Diet

Although Killer Whales feed on a wide range of prey species globally, Northern and Southern Resident Killer Whales are dietary specialists, feeding primarily on fish (Ford et al. 1998). Unlike Transient Killer Whales, Resident Killer Whales do not feed on marine mammals and the breadth of their diet appears to be quite limited. Extensive surface observations and collection of prey fragments from sites of kills by Resident Killer Whales have shown that these whales forage selectively for certain salmonids regardless of their abundance (Ford and Ellis 2005; Ford et al. 2010; Hanson et al. 2010). Chinook Salmon is the predominant prey species taken by both Northern and Southern Resident communities during May-August, but Chum Salmon is more prevalent in September-October. Coho Salmon (*Oncorhynchus kisutch*) are taken in low numbers in June-October, but Sockeye (*O. nerka*) and Pink (*O. gorbuscha*) Salmon are not significant prey species despite their high seasonal abundance. Non-salmonid fishes do not appear to represent an important component of Resident Killer Whale diet during May-October. Stomach content analysis from stranded Killer Whales and fecal sampling from live whales also support the importance of Chinook and Chum Salmon in Resident Killer Whale diet (Ford et al. 1998; Hanson et al. 2010).

Resident Killer Whales likely forage selectively for Chinook Salmon over other available salmonids because of the large size, high fat content, and year-round availability of this species in coastal waters (Ford et al. 1998; Ford and Ellis 2005). Killer Whales feeding at Langara Island in Haida Gwaii (Queen Charlotte Islands) are known to feed on Chinook from stocks returning to rivers as far north as northern BC and as far south as California (Ford et al. 2017).
The movement patterns of Resident Killer Whales are influenced by the availability of their preferred prey. During the summer months, Resident Killer Whale distribution is associated spatially and temporally with the migratory routes of Chinook Salmon as this important prey species returns to natal streams to spawn (Ford and Ellis 2005). In fall, the presence of Chum Salmon appears to influence the movements of Resident Killer Whales. In Johnstone Strait, Chum Salmon is the primary prey species taken by Northern Residents from late September through October (Ford and Ellis 2005). Fall movements of Southern Resident pods into Puget Sound were roughly correlated with runs of Chum Salmon, as well as Chinook (Osborne 1999). Recent winter sightings of Southern Resident Killer Whales in central California were coincident with high local densities of Chinook Salmon (N. Black, Monterey Bay Whale Watch, unpublished data).

Social organization

The social structure of Killer Whales in BC appears to be complex and differs among the three ecotypes (Ford and Ellis 1999; Ford et al. 2000). The social structure of Resident Killer Whales is the best understood, and one of its unique features is that there is no permanent dispersal of either sex from the natal group. The basic social unit of Resident Killer Whales is the matriline, composed of an older female (or matriarch), her male and female offspring, and the offspring of her daughters (Ford et al. 2000). Because matriarchs have long life spans, some matrilines may contain four or more generations. In over three decades of study, immigration and emigration have rarely been observed (Bigg et al. 1990; Ford et al. 2000). Two recent cases of juvenile

Resident Killer Whales leaving their matrilines and traveling alone are considered to be exceptional, isolated incidents. One, a female calf referred to as A73, or Springer, was separated from her pod shortly after her mother died and was observed alone after a brief period of association with a pod from another clan. She was subsequently reunited with her pod and joined another matriline. The second incident involved a male calf L98, or Luna, who became isolated from his pod and all other Killer Whales for unknown reasons in 2001.

Although individuals do not disperse from their natal group, matriline splitting does occasionally occur. For example, sisters often begin to spend more and more time apart after their mother dies, and their own matrilines may eventually become socially independent (Bigg et al. 1990; Ford et al. 2000; Ford and Ellis 2002). Stredulinsky (2016) conducted an analysis of matriline fission and found that group splitting is driven primarily by population growth and by the demographic composition of groups.

Reproductive parameters

Females reach sexual maturity, defined as the age of first successful pregnancy, at 15 years on average (range 12-18 years) (Olesiuk et al. 1990). Males reach sexual maturity, defined as when the dorsal fin shape changes sufficiently to distinguish males from females, at 15 years on average (range 10-17 years). Males reach physical maturity (when the dorsal fin reaches its full height) at about 20 years. Genetic paternity testing indicates that males rarely reproduce before 25 years of age (Barrett-Lennard 2000). The gestation period of Killer Whales is typically 16 to 17 months, one of the longest of all whales (Walker et al. 1988; Duffield et al. 1995). Only single calves are normally born. Only one possible case of twins has been reported (Olesiuk et al. 1990).

Approximately equal numbers of males and females are born (Dahlheim and Heyning 1999) and newborn calves are between 218 and 257 cm long (Olesiuk et al. 1990). Haenel (1986) estimated that calves are weaned at one to two years of age. The interval between calving is usually about five years for Northern Residents and six years for Southern Residents (DFO-CRP unpublished data). However the interval is highly variable, ranges from two to 12 years, and increases with age until menopause (Olesiuk et al. 1990). Overall, females have an average of five viable calves in a 25 year reproductive lifespan (Olesiuk et al. 1990). Calving occurs year-round, but appears to peak between fall and spring.

Mating behaviour

Mating behaviour between male and female Killer Whales has rarely been observed in the wild. However, genetic evidence has revealed that Resident Killer Whales have a propensity to mate outside their matriline (and clan, in the case of Northern Residents) but inside their community (Barrett-Lennard 2000; Barrett-Lennard and Ellis 2001). This minimizes the possibility of inbreeding very effectively, but restricts the options for mating if the population becomes very small. For example, in the Southern Resident community there may be an extreme shortage of sexually mature males, particularly for L pod females, assuming females select mates outside their pod.

Survival and longevity

Survival of Resident Killer Whales varies with age. Neonate mortality (from birth to six months of age) is high, reported at approximately 43% for all Residents (Olesiuk et al. 1990), and 42% for Northern Residents (Bain 1990). Accordingly, average life expectancy is reported for an animal that survives the first six months, and is estimated to be 50 years for females and 29 years for males (Olesiuk et al. 1990). Maximum longevity for females is an estimated 80-90 years and for males is 50-60 years (Olesiuk et al. 1990). Although a typical trait in most mammals, the shorter lifespan of males could be related to sexual selection (Baird 2000) or to higher levels of persistent chemicals, such as PCBs (Ross et al. 2000). The bioaccumulation of toxins is discussed in greater detail in section 4.2.1. Atypical, however, is the prolonged post reproductive period of females, discussed in the following section. Recent evidence suggests that declines in both the Northern and Southern Resident populations (all age and sex classes) can be attributed to an increase in mortality rates (Ford et al. 2005) as well as a decrease in fecundity for Southern Residents (Krahn et al. 2004). The potential causes of the population declines are discussed in section 4.

Reproductive senescence

The average life span of female Resident Killer Whales is approximately 50 years, but on average they produce their last calf at 39, and a significant number live to 70 years or more (Olesiuk et al. 1990). The ‘grandmother hypothesis’ suggests that the presence of older females in a group can increase the survival of offspring, and this may indeed be true for Killer Whales (see discussion under Culture below). In any case, when evaluating the status of Killer Whale populations, it is important to consider the age structure of the population and to note that post-reproductive adult females are no longer able to contribute directly to population growth. In an endangered population of Transient Killer Whales in southern Alaska (AT1s), no calves have been born since 1984. Since the remaining females are near or beyond their reproductive years, the population is on the verge of extinction (Saulitis et al. 2002), with virtually no prospect for recovery, even though it may persist for many more years.

Culture

Culture refers to a body of information and behavioural traits that are transmitted within and between generations by social learning. Until recently, culture was generally considered a distinguishing feature of human societies. Of late, the concept of culture has been broadened to include non-human mammals and birds (reviewed in Rendell and Whitehead 2001) and there is strong evidence for it in both Northern and Southern Resident Killer Whales, and southern Alaskan Resident Killer Whales (Ford 1991; Ford et al. 1998; Barrett-Lennard et al. 2001; Yurk et al. 2002). There is also evidence for culture in other cetaceans, such as Sperm Whales (Whitehead and Rendell 2004), although not to the same extent as for Resident Killer Whales (Rendell and Whitehead 2001).

Dialects are the best studied form of culture in Killer Whales. A calf learns its dialect from its mother and other closely related adults, retains it for life, and passes it on to the next generation with few modifications (Ford 1991; Deecke et al. 2000; Miller and Bain 2000). These culturally-transmitted dialects may play an important role in inbreeding avoidance, since females apparently prefer males from dialect groups other than their own (Barrett-Lennard 2000; Yurk et al. 2002).

Culture also appears to play an important role in feeding, with dietary preferences and probably foraging techniques and areas passed on culturally (Ford et al. 1998). Culture may also select for longevity in Killer Whales, as it provides a mechanism for older individuals to increase the fitness of their offspring and relatives by transferring knowledge to them (Barrett-Lennard et al. 2001). Foster et al. (2012) found that both reproductive and post-reproductive female Resident Killer Whales increase their own offspring’s survival. This is particularly evident for older male offspring: the death of post-reproductive female Resident Killer Whales increases mortality risk by almost 14-fold in their >30 year old sons. Prey sharing among Resident Killer Whales is likely one way that older individuals increase the fitness of their offspring. Cooperative prey sharing has been documented by all age and sex classes of Resident Killer Whales, but adult females share most frequently (Wright et al. 2016). Adult female Northern Resident Killer Whales share over 90% of the fish that they catch, most often with their offspring (Ford and Ellis 2006; Wright et al. 2016), and thus play a significant role in provisioning these members of their matrilines.

Culture may help animals adapt to changing environments by allowing them to learn from each other in addition to learning from experience. For example, based on differences in foraging success by sympatric clans of Sperm Whales under different climatic regimes, Whitehead et al. (2004) suggest that cultural diversity may be even more significant than genetic diversity in helping Sperm Whales to deal with a changing ocean climate. While we do not know if this is true for Resident Killer Whales, we do know that they respond culturally to anthropogenic changes in their environment. In Alaska, Resident Killer Whales responded to longline fishing in areas of Alaska by learning to raid the gear and take fish, and this behaviour spread rapidly throughout the population (Matkin and Saulitis 1994). Depredation of Pacific Halibut longline fisheries and salmon troll fisheries is also known to occur in BC waters (Ford 2014).

Depensation

Resident Killer Whale populations are at risk simply by virtue of their small population size. In general, small populations have an increased likelihood of inbreeding and lower reproductive rates, which can lead to low genetic variability, reduced resilience against disease and pollution, reduced population fitness, and elevated extinction risks due to catastrophic events. Pacific Resident Killer Whale populations are considered small, at 76 Southern Residents and approximately 309 Northern Residents in 2017 (CWR unpublished data; DFO-CRP unpublished data). If either Resident population is reduced further, they may be faced with a shortage of suitable mates. Among the Southern Residents, L pod females may be particularly vulnerable to this scenario because of the small number of reproductive males in J and K pod. Even under ideal conditions, the population will recover slowly because Killer Whales calve relatively infrequently.

Northern Resident Killer Whales have been shown to minimize inbreeding and its inherent risks by consistently selecting unrelated mates (Barrett-Lennard and Ellis 2001), suggesting that this population is more genetically viable than would be expected from population size alone. In contrast, recent evidence of incestuous mating among Southern Resident Killer Whales presented by Ford et al. (2018) suggests that they may be substantially more vulnerable to negative effects of inbreeding, particularly if the population remains at or below its present size for multiple generations.

Natural mortality

Killer Whales have no recorded predators, other than humans. There are several potential sources of natural mortality that may impact Killer Whales: entrapment in coastal lagoons or constricted bays, accidental beaching, disease, parasitism, biotoxins, and starvation (Baird 2001). However, it cannot be ruled out that anthropogenic factors may make Killer Whales more vulnerable to natural sources of mortality. For example, disturbance from intense noise may cause animals to strand (Perrin and Geraci 2002). In this case, the proximate cause of death, stranding, is a natural source of mortality, but the death would be ultimately human-caused.

3.4.2. Other natural limiting factors

Entrapment and/or accidental beaching

Accidental beaching and entrapment are sometimes a source of mortality for Killer Whales. At least four mass strandings involving more than 36 individuals occurred in BC in the 1940s (Cameron 1941; Carl 1946; Pike and MacAskie 1969; Mitchell and Reeves 1988). Although the causes of mass strandings in toothed whales are uncertain, disease, parasitism, and disturbance from intense underwater noise have been suggested as possible causes (Perrin and Geraci 2002). Two possible cases of temporary entrapment have been reported for Southern Resident Killer Whales (Shore 1995; 1998). In 1991, J pod spent 11 days in Sechelt Inlet, apparently reluctant to exit through a constricted entrance with tidal rapids. In 1997, 19 Killer Whales spent 30 days in Dyes Inlet, Puget Sound, possibly because they were reluctant to pass under a noisy bridge (Shore 1998).

Disease and parasitism

Diseases in captive Killer Whales have been well studied, but little is known of diseases in wild Killer Whales (Gaydos et al. 2004). Causes of mortality for captive Killer Whales include pneumonia, systemic mycosis, other bacterial infections, and mediastinal abscesses (Greenwood and Taylor 1985). Of 16 pathogens identified in Killer Whales, three have been detected in wild individuals: marine *Brucella*, *Edwardsiella tarda*, and cetacean poxvirus (Gaydos et al. 2004). A severe infection of *E. tarda* resulted in the death of a Southern Resident male in 2000 (Ford et al. 2000). Marine *Brucella* may cause abortions and reduced fecundity in Killer Whales (Gaydos et al. 2004). Cetacean poxvirus can cause mortality in calves and causes skin lesions (Van Bressem et al. 1999). Twenty-seven additional pathogens have been identified in sympatric odontocetes that may be transmittable to Killer Whales (Gaydos et al. 2004).

External parasites of Killer Whales have been reported in Mexico (Black et al. 1997), but none have been observed on Resident Killer Whales in BC (Baird 2001). Internal parasites of Killer Whales include various trematodes, cestodes, and nematodes (Heyning and Dahlheim 1988; Raverty et al. 2014). These endoparasites are usually acquired through infected food, but the amount of infection and their contribution to Killer Whale mortality are not known at this time.

Algal blooms

Harmful algal blooms (HABs) are blooms of algae that produce biotoxins such as paralytic shellfish poison, domoic acid, saxitoxin, and brevitoxin. Such toxins can accumulate in the tissues of species that ingest them and are magnified up the food chain. Mortality of Humpback Whales (*Megaptera novaeangliae*) off Massachusetts in 1987 and California Sea Lions (*Zalophus californianus*) in California in 1998 have been linked to biotoxin exposure (Geraci et al. 1989; Scholin et al. 2000). Several species of marine mammals have been shown to have a potential susceptibility to the neurotoxic effects of biotoxins (Trainer and Baden 1999). Given the apparent increase in HAB event frequency, and the potential for toxic effects in Killer Whales, there may be some risk to Resident Killer Whales exposed to biotoxins through HABs, although the risk is thought to be low (Krahn et al. 2002).

Regime shifts

In the North Pacific, there are widespread changes that occur in the circulation and physical properties of the ocean. These changes take place on decadal time scales and are referred to as ‘regime shifts’ (see reviews in Francis et al. 1998; Benson and Trites 2002). Such shifts may happen quite quickly, and result in dramatic changes in the distribution and/ or abundance of many species, ranging from zooplankton to fish and possibly marine mammals and seabirds. If the distribution or abundance of Resident Killer Whale prey changed significantly following a regime shift, it is possible that Killer Whales could be affected.

4. Threats

4.1. Historic threats

Pliny the Roman scholar first described a Killer Whale as an “enormous mass of flesh armed with savage teeth” during the first century AD. Since then written records have often depicted Killer Whales as savage, destructive, ferocious, and a danger to humans. However, they were rarely hunted, with the exception of Japanese, Norwegian and Russian whalers. Contemporary fishermen have viewed the Killer Whale as a competitor for their fish and a threat to their livelihood (Olesiuk et al. 1990; Ford et al. 2000). The live capture of Killer Whales for aquariums in the 1960s and early 1970s reduced local populations, some drastically.

Harvest and live captures

Killer Whales were hunted commercially, but whaling operations generally targeted other species of whales. In Canada, there are only a few harvest records of Killer Whales, most of which took place on the east coast and in the Arctic (e.g. Mitchell and Reeves 1988; Reeves and Mitchell 1988). However, large numbers of whales were taken in other areas of the world. The Japanese killed 60 Killer Whales per year between 1948 and 1957 (Nishiwaki and Handa 1958). Norwegian whalers culled 2,345 Killer Whales between 1938 and 1981 (Øien 1988). The former USSR captured approximately 25 Killer Whales per year in the Antarctic and harvested 906 whales in one season (Berzin and Vladimirov 1983). In 1982, the International Whaling Commission recommended a halt to the harvest of Killer Whales until the impact on populations was better understood. No Killer Whales have been reported taken since then, though small numbers may continue to be caught but remain unreported. For example, genetic testing has revealed the presence of Killer Whale in meat sold in Japanese and Korean markets (Baker et al. 2000).

In the late 1960s and early 1970s, Killer Whales were sought extensively for display in public aquaria. While they were captured from various areas throughout the world, the majority came from the waters of the northeastern Pacific Ocean. Between 1962 and 1974, 68 Killer Whales were taken from this area, 47 of which are known or assumed to be Southern Residents (Olesiuk et al. 1990). This cropping clearly had a major impact on the Southern Resident community, which numbered only 70 animals in 1974, and has likely affected productivity of the community for many years after the live captures ended in 1975.

Intentional shootings

Historically, negative attitudes towards Killer Whales in BC led to efforts by both government and individuals to cull local populations through shooting. In 1960, the federal Fisheries Department mounted a land-based machine gun near sports fishing lodges near Campbell River to reduce the number of Killer Whales (Ford et al. 2000). Fortunately it was never fired. In the 1960s and 1970s, approximately one quarter of whales live captured for aquaria had gunshot wounds (Ford et al. 2000). Societal attitudes towards Killer Whales have changed since 1974, and fresh bullet wounds are now rarely, if ever, seen on whales in BC and Washington (Ford et al. 2000), although even occasional shootings could limit population growth.

Acoustic harassment devices

Aquaculture farms in Washington and BC have used acoustic harassment devices (AHDs) that emit loud signals underwater to reduce depredation by Harbour Seals and sea lions. Some signals may be heard from up to 50 km away (Morton and Symonds 2002). Their use at a farm near Northern Vancouver Island was associated with significant declines in the use of nearby waters by both Resident and Transient Killer Whales (Morton and Symonds 2002). Harbour Porpoise abundance was also found to drop dramatically when AHDs were in active use (Olesiuk et al. 2002). The use of AHDs is no longer permitted in BC or in Washington. They are still used at Ballard Locks in Seattle to deter sea lions, but the configuration of the canal limits the amount of noise escaping to the open ocean (Bain 1996).

4.2. Current threats

A variety of threats may directly impact Northern and Southern Resident Killer Whale populations in BC, particularly because of their small population sizes. Threats include environmental contaminants (including oil spills), reduced prey availability, disturbance and noise pollution, each of which is discussed in more detail below. An additional emerging threat, vessel strikes, was identified during a science-based review of recovery actions for Southern Resident Killer Whales (DFO 2017c). Other threats such as mortality in fishing gear have posed a threat to cetacean populations in other areas, and could potentially impact Resident Killer Whales. Climate change is affecting entire ecosystems, and it is likely that in order to survive, Killer Whales will have to adapt to the consequences of local changes in their prey base. How current threats may act synergistically to impact Killer Whales is unknown, but in other species multiple stressors have been shown to have strong negative and often lethal effects, particularly when animals carry elevated levels of environmental contaminants (Sih et al. 2004).

The extent to which Northern and Southern Resident Killer Whales are affected by anthropogenic threats varies, depending on the threat. For example, Northern Resident Killer Whales may be more vulnerable to seismic surveys on the north coast, particularly if the moratorium on oil and gas exploration is lifted, whereas Southern Residents, by virtue of the waters they spend significant time in, may be more vulnerable to environmental contaminants.

4.2.1. Environmental contaminants

There are numerous chemical and biological pollutants that may directly or indirectly impact Resident Killer Whales, ranging from persistent organic pollutants (POPs) to antibiotic resistant bacteria and exotic species. Below we describe the major types of contaminants, their sources and their potential effects on Killer Whales (where known). For a list of the acronyms mentioned below, see Appendix C. There have been only a handful of studies that have measured contaminant levels in Killer Whales, and for obvious reasons no controlled experiments have been done to assess how these contaminants may affect them directly. However, the effects of contaminants on other species such as pinnipeds are better understood, and in many cases can be generalized to Killer Whales, particularly because the physiological processes of mammals are similar across different species. This 'weight of evidence' approach is outlined elsewhere for marine mammals (Ross 2000).

Although it is important to assess the direct effects of contaminants, Fleeger et al. (2003) make an important case for considering their 'indirect' effects on community structure, as well as on individual organisms and their behaviour. In a review of 150 studies, contamination resulted in changes in species abundance and community structure. Sixty percent of the communities that were experimentally manipulated showed a reduction in upper trophic level predators, which masked, enhanced or confused the interpretation of any direct effects of contaminants on individual organisms or species.

Persistent organic pollutants (POPs)

There are likely thousands of chemicals to be found in the Killer Whales of BC, but a few key classes are of particular concern today. Studies of environmental contaminants in Resident and Transient Killer Whales in BC and Washington have revealed that they are among the most contaminated mammals in the world (Ross et al. 2000; 2002; Krahn et al. 2009). Killer Whales are vulnerable to accumulating high concentrations of POPs because they are long-lived animals that feed high in the food web (Ross et al. 2000; 2002; Rayne et al. 2004; Ross 2006). POPs are persistent, they bioaccumulate in fatty tissues, and are toxic, features that have led to increased regulatory scrutiny of these chemicals by authorities around the world. POPs include 'legacy' contaminants such as the polychlorinated biphenyls (PCBs) and the organochlorine pesticide DDT which are no longer widely used in industrialized countries, but remain persistent in the environment. The so-called 'dirty dozen' POPs are encompassed under the terms of the Stockholm Convention which aims to phase out use of chemicals of global ecotoxicological concern. They also include the polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs or furans), by-products of incomplete combustion, of pesticide manufacture, and of the (now regulated) use of elemental chlorine and pentachlorophenol (PCP) in pulp and paper bleaching and wood treatment processes, respectively. In recent years, regulations have resulted in a reduction in the release of such contaminants into the marine environment (Hagen et al. 1997).

Contaminants of 'current concern' in the industrial world include the new generation of polybrominated trienylethers (PBTs), flame retardants such as polybrominated diphenylethers (PBDEs), as well as currently used pesticides. Table 1 lists the POPs that are a concern for Resident Killer Whales, and the reader is referred to Grant and Ross (2002) for a more thorough synthesis of what is known about the risks that contaminants pose to Southern Resident Killer Whales.

Polychlorinated biphenyls (PCBs)

Surprisingly high concentrations of PCBs are found in both Southern and Northern Resident Killer Whales relative to marine mammals from other parts of the world (Ross et al. 2000). The PCB levels found in Transients and Southern Residents exceed those found in St. Lawrence Beluga Whales (*Delphinapterus leucas*) by a factor of two to four times, and are considerably higher than thresholds for PCB-associated reproductive impairment, skeletal abnormalities, immunotoxicity and endocrine disruption in pinnipeds (reviewed in Ross 2000). Ross et al. (2000) found that PCB concentrations increase with age in male Killer Whales, but decline in reproductively active females. Consistent with observations in other mammals, including humans, reproductive females pass PCBs to their offspring, particularly the first born, during gestation and lactation (Tanabe and Tatsukawa 1992; Borrell et al. 1995; Ylitalo et al. 2001).

Dioxins and furans

Levels of dioxins and furans were found to be low in the blubber of Resident and Transient Killer Whale populations in BC (Ross et al. 2000). This may be partly explained by low levels of dioxins and furans in their diet, but Killer Whales may also metabolize and excrete dioxin-like compounds more effectively than PCBs (Ross 2000).

Table 1. Persistent organic pollutants that may pose a risk to Resident Killer Whales.

Pollutant	Use/Source	Persistent	Bio-accumulate	Risk
DDT (Dichlorodi-phenyl trichloroethane	pesticide used in some countries, banned in North America, persists in terrestrial runoff >30 years post ban, enters atmosphere from areas where still in use	yes	yes	reproductive impairment, immunosuppression, adrenal and thyroid effects
PCBs (Polychlorinated Biphenyls)	electrical transformer and capacitor fluid, limited use in North America but enters environment from runoff, spills, and incineration	yes	yes	reproductive impairment, skeletal abnormalities, immunotoxicity, and endocrine disruption
Dioxins and Furans	by-product of chlorine bleaching, wood product processing and incomplete combustion. Mills less of a source now. Current sources include burning of salt-laden wood, municipal incinerators, and residential wood and wood waste combustion; in runoff from sewage sludge, wood treatment	yes	yes	thymus and liver damage, birth defects, reproductive impairment, endocrine disruption, immunotoxicity, and cancer
PAHs (Persistent Polycyclic aromatic hydrocarbons)	by-product of fuel combustion, aluminium smelting, wood treatment, oil spills, metallurgical and coking plants, pulp and paper mills	yes	no	carcinogenic
flame retardants, esp. PBBs and PBDEs (Polybrominated diphenyl ethers)	flame retardants; in electrical components and backings of televisions and computers, in textiles and vehicle seats, ubiquitous in environment. 2/3 product PBDEs banned in Europe. Same two products withdrawn from North American marketplace in 2005, but one (deca) product still used globally.	yes	yes	endocrine disruption, impairs liver and thyroid
PFOs (Perfluro-octane sulfonate)	stain, water and oil repellent (included in Scotchgard until recently), fire fighting foam, fire retardants, insecticides and refrigerants, ubiquitous in environment	yes	yes but in blood, liver, kidney and muscle	promotes tumour growth
TBT, DBT (Tributyltin Dibutyltin)	antifoulant pesticide used on vessels	yes	yes	unknown but recently associated with hearing loss
PCPs (Polychlorinated paraffins)	flame retardants, plasticizers, paints, sealants and additives in lubricating oils	yes	yes	endocrine disruption
PCNs (Polychlorinated napthalenes)	ship insulation, electrical wires and capacitors, engine oil additive, municipal waste incineration and chlor-alkali plants, contaminant in PCBs	yes	yes	endocrine disruption
APEs (Alkyl-phenol ethoxylates)	detergents, shampoos, paints, pesticides, plastics, pulp and paper mills, textile industry found in sewage effluent and sediments	moderate	moderate	endocrine disruption
PCTs (Polychlorinated terphenyls)	fire retardants, plasticizers, lubricants, inks and sealants, enters environment in runoff	yes	yes	endocrine disruption and reproductive impairment

References: Primarily Grant and Ross 2002, but also Lindstrom et al. 1999; Hooper and MacDonald 2000; Kannan et al. 2001; Hall et al. 2003; Van deVijver et al. 2003; Rayne et al. 2004; Song et al. 2005.

Table 2. Persistent organic pollutants that may pose a risk to Resident Killer Whales.

Pollutant	Use/Source	Persistent	Bio-accumulate	Risk
DDT (Dichlorodi-phenyl trichloroethane	pesticide used in some countries, banned in North America, persists in terrestrial runoff >30 years post ban, enters atmosphere from areas where still in use	yes	yes	reproductive impairment, immunosuppression, adrenal and thyroid effects
PCBs (Polychlorinated Biphenyls)	electrical transformer and capacitor fluid, limited use in North America but enters environment from runoff, spills, and incineration	yes	yes	reproductive impairment, skeletal abnormalities, immunotoxicity, and endocrine disruption
Dioxins and Furans	by-product of chlorine bleaching, wood product processing and incomplete combustion. Mills less of a source now. Current sources include burning of salt-laden wood, municipal incinerators, and residential wood and wood waste combustion; in runoff from sewage sludge, wood treatment	yes	yes	thymus and liver damage, birth defects, reproductive impairment, endocrine disruption, immunotoxicity, and cancer
PAHs (Persistent Polycyclic aromatic hydrocarbons)	by-product of fuel combustion, aluminium smelting, wood treatment, oil spills, metallurgical and coking plants, pulp and paper mills	yes	no	carcinogenic
flame retardants, esp. PBBs and PBDEs (Polybrominated diphenyl ethers)	flame retardants; in electrical components and backings of televisions and computers, in textiles and vehicle seats, ubiquitous in environment. 2/3 product PBDEs banned in Europe. Same two products withdrawn from North American marketplace in 2005, but one (deca) product still used globally.	yes	yes	endocrine disruption, impairs liver and thyroid
PFOs (Perfluro-octane sulfonate)	stain, water and oil repellent (included in Scotchgard until recently), fire fighting foam, fire retardants, insecticides and refrigerants, ubiquitous in environment	yes	yes but in blood, liver, kidney and muscle	promotes tumour growth
TBT, DBT (Tributyltin Dibutyltin)	antifoulant pesticide used on vessels	yes	yes	unknown but recently associated with hearing loss
PCPs (Polychlorinated paraffins)	flame retardants, plasticizers, paints, sealants and additives in lubricating oils	yes	yes	endocrine disruption
PCNs (Polychlorinated napthalenes)	ship insulation, electrical wires and capacitors, engine oil additive, municipal waste incineration and chlor-alkali plants, contaminant in PCBs	yes	yes	endocrine disruption
APEs (Alkyl-phenol ethoxylates)	detergents, shampoos, paints, pesticides, plastics, pulp and paper mills, textile industry found in sewage effluent and sediments	moderate	moderate	endocrine disruption
PCTs (Polychlorinated terphenyls)	fire retardants, plasticizers, lubricants, inks and sealants, enters environment in runoff	yes	yes	endocrine disruption and reproductive impairment

References: Primarily Grant and Ross 2002, but also Lindstrom et al. 1999; Hooper and MacDonald 2000; Kannan et al. 2001; Hall et al. 2003; Van deVijver et al. 2003; Rayne et al. 2004; Song et al. 2005.

Polybrominated diphenylethers (PBDEs)

Preliminary evidence suggests that flame retardants may be a significant and emerging concern for Resident Killer Whales (Ross 2006). Moderate levels of PBDEs were observed in 39 biopsy samples collected between 1993-1996 from Southern Resident and Transient Killer Whales, and relatively low levels were observed in Northern Residents (Rayne et al. 2004). Based on analysis of blubber samples from Harbour Seals in Puget Sound, concentrations of PBDEs doubled every 3.1 years between 1984 and 2003, but appeared to decline in 2009 (Ross et al. 2013). Regulations prohibiting the manufacture of all PBDEs in Canada came into effect in July 2009. Additionally, PBDEs have been added to the Prohibition of Toxic Substances Regulations, which prohibits all PBDEs unless present in a manufactured article.
Although the toxicity of PBDEs is not well understood, they have been associated with endocrine disruption in laboratory animals (Darnerud 2003). While no conclusive link could be established as a result of the numerous other lipophilic contaminants present, PBDE concentrations were negatively associated with thyroid hormones in Grey Seals (*Halichoerus grypus*, Hall et al. 2003). See Ross et al. (2009) for a review of research documenting some of the sources and properties, as well as the persistence and toxicity of PBDEs.

Numerous captive and semi-field studies of pinnipeds have provided evidence that POPs affect immune function (hence, resistance to disease), hormone levels, and reproductive health (Reijnders 1986; De Swart et al. 1996; Ross 2000; Nyman et al. 2003). Using this weight of evidence as a foundation, it is not possible to ignore the substantial risks that PCBs and other POPs present to Killer Whales in the northeast Pacific. Transient Killer Whales from Prince William Sound, Alaska (AT1 population) are highly contaminated, and have had no successful reproduction since 1984, providing perhaps a population-level glimpse into the effects of high POP burdens (Ylitalo 2001). High levels of toxic chemicals may also make Killer Whales more vulnerable to disease (Ross 2002). Jepson et al. (1999) found that Harbour Porpoises that died from infectious diseases had two to three times higher concentrations of PCBs than those that died from trauma.

Biological pollutants

Biological pollution may also threaten the health of Resident Killer Whales, their habitat and their prey. These pollutants may take the form of ‘spill-over’ pathogens from human activities (e.g. pets, livestock, migrations, habitat change), virulent, antibiotic- resistant bacterial strains arising as a result of the use of antibiotics or exotic species. Emerging infectious diseases are a growing concern for marine life, as naturally occurring host-pathogen relationships are altered through human activities such as disturbance, over-fishing, habitat destruction, climate change, or pollution (Ross 2002). Killer Whales whose immune system is compromised through chemical contaminants may be increasingly vulnerable to biological pollutants. Although no disease-related mass mortalities have been observed among BC’s marine mammals, *Morbillivirus* has been detected in marine-dwelling River Otters (Mos et al. 2003), highlighting the potential risk of this or related pathogens to Killer Whales. In other areas, *Morbillivirus* outbreaks have caused mass mortalities of seals (Grachev et al. 1989; Kennedy et al. 2000) and dolphins (Aguilar and Borrell 1994). Pathogens such as *Morbillivirus* are capable of spreading extremely quickly (3,000 km/year), likely because in the marine environment there are few barriers to dispersal (McCallum et al. 2003).

The introduction of exotic species has changed habitats in other areas (e.g. Zebra Mussels in the Great Lakes, Eurasian Milfoil into freshwater lakes) and introduced species have the potential to impact local ecosystems here. In BC, Atlantic Salmon that have escaped from aquaculture operations have successfully spawned in freshwater (Volpe et al. 2000). The extent to which this is occurring and how Atlantic Salmon would compete with Pacific salmon, the preferred prey of Residents (Ford et al. 1998), is not well known at this time.

Trace metals

Trace metals occur naturally in the marine environment, but elevated concentrations sufficient to be a concern to marine mammals may be found in localized areas such as urban and industrial centres (Grant and Ross 2002). Some, such as cadmium, mercury, copper and lead may have toxic effects even at relatively low concentrations, and could impact Killer Whales, although effects on their prey and/ or habitat are more likely.

Little information is available on the levels and effects of trace metals on marine mammals in the Pacific. However, in a small sample of stranded Killer Whales, Residents showed higher levels of mercury than Transients (Langelier et al. 1990). In the western Pacific, all odontocete meat sampled from Japanese markets contained amounts of mercury that exceeded the level permitted for human consumption (Endo et al. 2003). However, the historical exposure of high trophic level marine mammals to naturally elevated concentrations of mercury in prey has resulted in their evolved ability to detoxify this toxic metal through the formation of mercury-selenium crystals in the liver (Martoja and Berry 1980).

Sources of contaminants

Monitoring the sources and levels of environmental contaminants is particularly challenging given that each year, up to 1,000 new chemicals are released into the environment globally (Haggarty et al. 2003). The high contaminant levels found in Southern Residents may arise from consuming prey that are from industrialized areas near the BC-Washington border, which are more contaminated than the prey of Northern Residents (Ross et al. 2000; Cullon et al. 2009). In Japan, odontocetes that travelled in more industrialized areas carried higher contaminant loads than those found in more remote areas (Endo et al. 2003). In a study of Harbour Seals in BC and Washington, Ross et al. (2004) found that although PCB levels were a concern in all areas, seals from Puget Sound were seven times more PCB-contaminated than were seals from the Strait of Georgia. This suggests that the food web within Puget Sound has been contaminated with PCBs, such that Killer Whales consuming prey items from this region may be vulnerable to increased contaminant exposure. Chinook Salmon, one of the Resident Killer Whales' preferred prey species (Ford et al. 1998; Ford and Ellis 2005), feed in the upper trophic levels in the food web, and those from Puget Sound are relatively contaminated with PCBs (O'Neill et al. 1998; Cullon et al. 2009). Studies suggest that most salmonids are 'importing' contaminants from their time at sea, reflecting global environmental contamination (O'Neill et al. 1998; Ewald et al. 1998).

Although DDT was banned in Canada in 1989 and over 40 years ago in the United States, it continues to enter the ocean from terrestrial runoff (Hartwell 2004) as well as from atmospheric transport from countries where it is still in use. Dioxins (PCDDs) and furans (PCDFs) represent highly toxic by-products of chlorine bleaching and associated wood treatment, and incomplete combustion. Source controls and regulations have greatly reduced their input in to the coastal environments of BC and Washington.

Contaminants enter the marine environment from local, regional and international sources. These are discussed in detail in Haggarty et al. (2003). Local point sources of contaminants into the marine environment include:

- pulp and paper mills
- wood treatment facilities
- municipal effluent outfalls
- petrochemical facilities and
- mines

Indirect sources (non-point source pollutants) include:

- sewer overflows (e.g. organic wastes, household products, pharmaceuticals and personal care products)
- urban runoff and storm-water drainage (e.g. pesticides, metals, hydrocarbons, herbicides and animal wastes)
- agriculture (e.g. pesticides, herbicides, animal wastes and antibiotics)
- forestry (e.g. pesticides, herbicides, fire-control chemicals, anti-sapstain chemicals, log booms and storage areas) and
- aquaculture (e.g. organic wastes, chemical contaminants [antibiotics, feed additives, pharmaceuticals, pesticides and antifouling on nets])

Garrett and Ross (2010) describe the Canadian and U.S. federal, provincial and state agencies responsible for the monitoring, mitigation and regulation of environmental contaminants and their sources.

Shipping also represents a risk to the ecological integrity of coastal regions. Both intentional and unintentional discharge of chemicals and biological waste are added sources of pollution in all coastal areas, but particularly in high traffic zones. In addition, the introduction of exotic and invasive species carried on ship hulls and in ballast water have the potential to dramatically alter the habitats they have colonized (e.g. European Green Crabs, Zebra Mussels, the alga *Caulerpa taxifola*). Numerous invasive invertebrates have been found in the ballast water of ships at anchor in Vancouver Harbour (Levings et al. 2004), although the ecological significance of such introductions is unclear.

In addition, some pollutants such as PCBs, DDT and other chemicals are transported through atmospheric processes and ocean currents, and may travel to the west coast of North America from as far away as Asia in less than 5-8 days (Wilkening et al. 2000). Consequently, the northeastern Pacific may be a sink for globally produced POPs (Ross et al. 2000; 2004; 2006).

Certain ‘legacy’ POPs such as PCBs and DDT have been phased out of industrialized countries and their concentrations are slowly decreasing in the marine environment (Muir et al. 1999), although these declines have levelled off (Addison and Stobo 2001). However, levels of other ‘new’ POPs such as deca-PBDEs continue to increase globally, and represent the PCBs of the future (Ross 2006; Law et al. 2014). Unlike PCBs, which were generally used in a limited range of applications such as electrical transformers and capacitors, PBDEs have been widely used in many industrial and consumer applications and are incorporated into plastics, textiles and foam.

4.2.2. Reduced prey availability

Answering the question as to whether Killer Whales may be prey limited is complex. While the year-round diet of Resident Killer Whales is not well known, at certain times of the year salmon, particularly Chinook and Chum, are known to be important prey (see section 3.4.1. Diet). Ford et al. (2005) found that trends in the mortality rates of Southern and Northern Resident Killer Whales were correlated with each other, and that both were strongly related to fluctuations in the abundance of Chinook Salmon, but not Chum Salmon. Birth rates were also correlated with Chinook Salmon abundance, but more weakly than mortalities.

Less is known about the prey of Resident Killer Whales and their distribution and abundance during the months of November to April. This is due to the inherent challenges of studying whales during the winter months, and because the whales move from inshore areas where they are more concentrated during summer and range widely along the coast during the winter and early spring. Thus when considering the availability of prey to Resident Killer Whales, it should be noted that we have limited knowledge of what other prey species may be important to them, and the discussion below focuses on species that are known to be important.

Changes in salmon abundance and availability

Assessing the status of salmon stocks and their availability to Resident Killer Whales is challenging to interpret and often fraught with controversy. Until the middle of the 20th century, many wild salmon stocks experienced significant declines due to overfishing, habitat degradation, restrictions in access to spawning grounds due to landslides, and changes in ocean productivity (summarized in Krahn et al. 2002 and Wiles 2004). The situation changed between 1975 and 1993, and the total abundance of North Pacific salmon doubled (Bigler et al. 1996) due to hatchery enhancement, changes in fisheries management practices and a favourable climatic regime (Bigler et al. 1996; Beamish et al. 1997). Since the early 1990s many of these stocks have declined in number and specific causes have not been identified. Some studies have questioned the role of enhancement (Beamish et al. 1997, and reviewed in Gardner et al. 2004) but other potential problems such as marine survival appear to be a factor. At present 28 of 52 different wild Pacific salmon stocks in the lower 48 states of the U.S. are considered at risk under the U.S. ESA (NOAA 2017). In southwestern BC by 1990, salmon from one-third of the spawning rivers had been lost or were seriously depleted (Riddell 1993). Recognizing that many salmon stocks are under threat, Fisheries and Oceans Canada announced a new Wild Salmon Policy (WSP) in December 2004 (DFO 2005), designed to restore and maintain healthy and diverse wild salmon populations and their habitat. Since 2005, DFO has used the WSP to guide its work toward restoring healthy salmon populations, and development of a detailed implementation plan for the WSP is underway. If these and other actions are successful, salmon may gradually become more available to Resident Killer Whales.

Resident Killer Whales tend to be found in high concentrations in specific areas during the period when salmon are returning to rivers to spawn. This likely reflects the fact that salmon are not as widely dispersed at this time as they are during the rest of their life cycle. There is a great deal of diversity in the timing of the spawning period for salmon. For example, the Upper Columbia River has a spring run and a summer/fall run of Chinook. These runs are considered distinct stocks because they do not interbreed. The spring run is Endangered under the ESA in the U.S., yet the summer/ fall run is not at risk (NOAA 2017). This illustrates the need to consider the timing of the spawning period of each salmon stock when assessing the availability of salmon for Killer Whales, in order to ensure an adequate year-round food supply. Chinook Salmon are longer lived than other salmon species and spawn at different ages (Healey 1991). It is likely that their year-round availability in nearshore waters is a key factor, along with body size and lipid content, in Chinook being the preferred salmonid prey of Resident Killer Whales (Ford and Ellis 2005).

To address the scientific uncertainty regarding the impact of sea lice on salmon, and the relationship of this to Killer Whales, DFO and others are conducting scientific research to assess and protect the health of the wild Pink and Chum Salmon resource in the Broughton Archipelago.

Depressed Chinook stocks

Chinook Salmon, the principal prey of BC's Resident Killer Whales, is one of the least abundant species of salmon in BC (Riddell 2004). However, unlike other salmon, many populations of Chinook remain in nearshore waters during the ocean phase of their life cycle. As a result they are available on a more year-round basis to Killer Whales, but are also more vulnerable to pollution (discussed in section 4.2.1 Environmental contaminants).

Chinook abundance dropped in the 1970s and 1980s, but escapements increased until the early 1990s in some rivers, primarily due to hatchery production (Beamish et al. 1997). In Washington, hatchery fish now account for about 75% of all harvested Chinook (Mahnken et al. 1998 in Wiles 2004). In un-enhanced river systems in central and northern BC, Chinook numbers remain depressed (Riddell 2004) and nine of 17 Chinook stocks in Washington, Oregon and California are listed under the ESA (NOAA 2017). It is likely that Chinook is an important limiting factor in the population dynamics of Resident Killer Whales (Ford et al. 2005; Ward et al. 2009; Ford et al. 2010). This may explain why Southern Resident Killer Whales have appeared in places as distant as off the Columbia River and northern California to the south and off southeastern Alaska in the north (Ford et al. 2017). Their presence was associated with unusually large returns of Chinook Salmon, which they may have had to seek out because of less abundant prey within their traditional range. When prey availability is reduced, Killer Whales may be forced to spend more time and travel greater distances to forage for their food, or switch to less profitable prey, which could lead to lower reproductive rates and higher mortality rates.

In addition to reduced Chinook abundance, the quality of individual fish appears also to have declined over recent decades. Average weights of Chinook Salmon in nine populations from BC to California declined by up to 45% between 1975 and 1993 (Bigler et al. 1996). Thus, the nutritional yield of each Chinook Salmon may be significantly less today than it was in past years, which may have an impact on the overall foraging energetics of Resident Killer Whales.

4.2.3. Disturbance

All cetaceans, including Resident Killer Whales, are being subjected to increasing amounts of disturbance from vessels, aircraft, and anthropogenic noise (IWC 2004). Both private and commercial vessel traffic have increased dramatically in recent years, and Killer Whales must navigate in increasingly busy waters (Osborne 1999; Foote et al. 2004). Industrial activities such as dredging, drilling, construction, seismic testing and military sonar, and other vessel use of low and mid-frequency sonars also impact the acoustic environment (Richardson et al. 1995; NRC 2003). The means by which physical and/or acoustic disturbance can affect Resident Killer Whales at both the individual and population level are not well understood, but may depend on whether the disturbance is chronic (such as whale watching) or acute (such as seismic surveys). Other factors, including the animal's condition, previous exposure (potentially causing sensitization or habituation), age, sex, and behavioural state also influence how disturbance affects whales (e.g. Williams et al. 2014). In addition, environmental factors, such as El Niño events that may change the availability of prey, may make animals more vulnerable to disruption than they would be otherwise. The sources of both physical and acoustic disturbance and their potential impact on Resident Killer Whales are discussed in greater detail below.

A current challenge in studying the effects of disturbance is in finding informative ways to describe and measure them, and to date the question of whether a source of disturbance is likely to result in effects at the population level can be difficult to answer. Responses to disturbance may range from slight differences in surfacing and breathing rates to active avoidance of an area. Even if the disturbance causes immediate death, carcasses are rarely recovered (regardless of the cause of death, only 6% of Killer Whale carcasses are recovered, DFO-CRP unpublished data). As well, animals may show no obvious behavioural responses to disturbance, yet still be negatively affected. For example, Todd et al. (1996) found that Humpback Whales remained in the vicinity of underwater explosions, and showed no obvious behavioural responses to them. However they experienced significantly higher entanglement rates during this time, and necropsies of two whales that drowned in nets revealed acoustic trauma (Ketten et al. 1993). Thus a lack of a measurable behavioural response to a stimulus does not necessarily imply the disturbance does not have negative consequences. A parallel may exist with humans, since people exposed to chronic noise lose their hearing more quickly than those that are not exposed to chronic noise. The consequences of hearing loss for cetaceans are likely fatal.

Measures for changes in behaviour may also not be subtle enough to detect disturbance. Whitehead (2003) re-analyzed data that were reported to indicate that Sperm Whales did not show behavioural responses to surveys using high-intensity sound. He segregated the responses according to whale density in the area and found that contrary to earlier conclusions, when whale density was low, Sperm Whales avoided seismic activity. When densities were high, whales remained in the vicinity. He suggested that whales may have been reluctant to leave a rich feeding area despite the disturbance.

Whale watching

Commercial whale watching has grown dramatically in BC, with just a few boats carrying less than 1,000 passengers per year in the late 1970s and early 1980s to 80 boats carrying half a million passengers per year in 1998 (Osborne 1991; Baird 2002; Osborne et al. 2003). In 2015, there were 93 active commercial whale watching vessels in the Salish Sea alone (Seely et al. 2017). Whale watchers tend to focus on Resident Killer Whales in their most predictable locations, Haro Strait and Johnstone Strait. Vessels in the vicinity of whales include privately owned kayaks, sailboats and powerboats as well as commercial whale watch vessels. While the benefits of public education and increased awareness that can be achieved through guided whale watching are well established, concern over the effects of whale watching on Killer Whales has grown with the industry itself. This concern has prompted the development of industry initiated viewing guidelines and has resulted in studies that have attempted to measure responses of the whales to such focused attention (e.g. Kruse 1991; Williams et al. 2002a; b; Williams et al. 2014), as well as the behaviour of boaters around whales (e.g. Jelinski et al. 2002). Whale watching activities have the potential to disturb marine mammals through both the physical presence and activity of boats, as well as the increased underwater noise levels boat engines generate.

Under the Fisheries Act in Canada and the MMPA in the U.S., disturbance (harassment) of marine mammals, including Killer Whales, is prohibited. No special provisions or exemptions to this prohibition have been made for commercial whale watch operators and the commercial fleet is subject to the same regulatory restrictions as recreational boaters. Voluntary guidelines for viewing marine wildlife[3] were developed by DFO, the National Marine Fisheries Service (NMFS), and collaborators in 2002 to protect marine mammals, including Resident Killer Whales, from disturbance. These guidelines are reviewed and revised periodically. Additionally, industry associations, including the Pacific Whale Watch Association (PWWA) and the North Island Marine Mammal Stewardship Association (NIMMSA) have developed codes of conduct for marine mammal viewing by member businesses (NIMMSA 2016; PWWA 2017).

In 2011, the U.S. National Oceanic and Atmospheric Administration (NOAA) adopted federal vessel regulations to prohibit vessels from approaching Killer Whales within 200 yards (183 metres) and from parking in the path within 400 yards (366 metres) of Killer Whales. These regulations apply to all vessels in inland waters of Washington State, with exemptions for vessels that are actively engaged in commercial or First Nations fisheries, for research vessels under permit, ships in shipping lanes and government vessels in the course of official duties. Proposed amendments to the Canadian Marine Mammal Regulations under the Fisheries Act include minimum approach distances for all marine mammals as well as several other provisions aimed at reducing the risk of disturbance to marine mammals.

There are several projects that focus on educating the boating public both on and off the water about appropriate conduct in the vicinity of marine mammals. They also monitor vessel activity in the presence of whales. Current projects include the Soundwatch Boater Education Program in the San Juan Islands; Straitwatch in adjoining Canadian waters (Haro and Juan de Fuca Straits), Johnstone Strait, and occasionally off the west coast of Vancouver Island; and the Robson Bight Marine Warden Program in Johnstone Strait, while past projects include the Marine Mammal Monitoring Project in Victoria, BC. All of these programs are run by non-profit organizations that do not have guaranteed funding. Smith and Bain (2002) found that commercial operators increased their compliance with a voluntary 0.4 km ‘no boat’ zone in the San Juan Islands from less than 80% to over 90% when Soundwatch was present on the water.

Boat activity has been linked to short-term behavioural changes in Resident Killer Whales (Kruse 1991; Smith and Bain 2002; Williams et al. 2002a; 2002b). They have been known to swim faster, travel in less predictable paths, alter dive lengths, move into open water, and alter normal behaviour patterns at the surface in response to vessel presence (Kruse 1991; Williams et al. 2002a; 2002b). Foote et al. (2004) found that Southern Resident Killer Whales significantly increased the duration of their calls when boats were present, and suggested that this was an adaptation to the masking effects caused by increased noise levels. Additionally, Holt et al. (2009) found that Killer Whales increased the amplitude of their calls in response to increased vessel noise.

Although studies have shown short-term responses of Killer Whales to whale watching vessels, the long-term effects of whale watching on the health of Killer Whale populations are not known (Trites et al. 2002). Increased whale watching operations between the mid-1980s and 2001 may have resulted in a potential 20% increase in energetic expenditures of Killer Whales due to increased swimming velocity (Kriete 1995; 2002). Bain (2002) found that although the decline of Southern Residents followed the increase in commercial whale watching, the relationship was much more complex. He suggested that other variables, such as changes in the availability of prey, were also likely significant. Whether whale watching is a significant threat to Killer Whales or not, both the Northern and Southern Resident populations continue to return to their

[3] Be Whale Wise Guidelines for marine wildlife viewing are available at: http://www.bewhalewise.org/marine-wildlife-guidelines/

traditional summer ranges despite increased whale watching activity. This may reflect their strong cultural behaviours or the distribution of their prey.

Underwater noise

At the time the COSEWIC status report on Killer Whales was written (Baird 2001), relatively little was known about the effects of underwater noise on marine mammals. Previous research had focused primarily on powerful noise sources with the potential to cause immediate injury or death, rather than chronic lower level noise sources (Richardson et al. 1995). Since then, there has been a rapidly growing awareness that noise is a significant threat that degrades habitat and adversely affects marine life (IUCN 2004; IWC 2004). It is estimated that ambient (background) underwater noise levels have increased an average of 15 dB in the past 50 years throughout the world's oceans (NRC 2003).

Killer Whales have evolved in the underwater darkness using sound much the way terrestrial animals use vision: to detect prey, to communicate and to acquire information about their environment. Anthropogenic noise can interfere with all these activities in critically important ways, such as disrupting communication, reducing the distance over which social groups can detect each other, masking echolocation and hence reducing the distance over which the animals can detect their prey, potentially displacing them from preferred feeding habitats, displacing prey, impairing hearing, either temporarily or permanently and in extreme cases causing death (Bain and Dahlheim 1994; Barrett-Lennard et al. 1996; Bain 2002; Erbe 2002; NRC 2003; Au et al. 2004).

The challenges of using and interpreting behavioural responses of marine mammals to noise as a measure of disturbance are discussed above. Opportunities to measure physiological responses to anthropogenic noise are much rarer, but provide insight into the mechanisms by which noise could impact animals at the individual, and potentially population level. Physiological responses to anthropogenic noise that have been measured in marine mammals include both temporary and permanent hearing threshold shifts, the production of stress hormones and tissue damage, likely due to air bubble formation or as a result of resonance phenomena (Ketten et al. 1993; Crum and Mao 1996; Evans and England 2001; Finneran 2003; Jepson et al. 2003; Fernandez et al. 2004). Marine mammals, including Killer Whales, may be particularly vulnerable to resonance because of the air-filled cavities in their sinuses and middle ear, their lungs and small gas bubbles in their bowels. While the mechanism by which high-intensity sound can cause lethal and sub-lethal effects on cetaceans is not completely understood (Fernandez et al. 2004; Piantadosi and Thalmann 2004), loud anthropogenic sources of noise, particularly low and mid-frequency military sonars, have been implicated in mass stranding and mortality events around the world, and the subject urgently merits further study. Animals already affected by anthropogenic stressors such as environmental contaminants may be particularly vulnerable to additional stresses such as noise (Sih et al. 2004).

Sounds travel as waves much more quickly through water than air (1,530 vs. 340 m/s). The perceptual features of sound, "pitch" and "loudness," have physical analogues. How high or low-pitched a sound is can be described in terms of its frequency, and is measured in hertz (Hz). Human hearing ranges from approximately 20 to 20,000 Hz (20 kHz), and is best between 600 and 2,000 Hz. The peak hearing sensitivity of Killer Whales is at approximately 20 kHz, although they show behavioural responses to sound from 75 Hz to over 100 kHz (Hall and Johnson 1972; Syzmanski et al. 1999). Killer Whale calls contain energy throughout this frequency range, and many echolocation clicks are centered at 20 kHz.

The ‘loudness’ of a sound is described in terms of its pressure. For the purposes of consistency, the units of measure used here are dB_{RMS} re 1 μPa. By convention, noise sources are compared in terms of their “source levels” by estimating the level that would be measured at 1 m from the underwater sound source. In general, the further away from a sound source, the quieter the received sound level, although physical and oceanographic features of the marine environment can affect how quickly a sound attenuates (gets quieter). High frequency sounds attenuate much more rapidly than low frequency sounds under uniform conditions in the open ocean, but a number of factors influence sound propagation and high frequencies may propagate further than low frequencies in shallow water or places with complex bottom terrain. Temperature, salinity, depth, bottom topography and other physical factors must all be taken into account to accurately predict the intensity of sound reaching a whale.

The characteristics of some underwater noise sources are briefly described in Table 2. It is important to consider the length of time that animals are exposed to sounds, and sound loudness and frequency. As well, some sounds are continuous, whereas others are pulses of sound that are generated intermittently. The frequency composition also varies, ranging from broadband sounds such as seismic surveys, to narrowband sounds such as military sonar that are only broadcast across a limited range of frequencies.

Sounds at received levels of 120 dB typically disrupt the behaviour of 50% of exposed cetaceans (Richardson et al. 1995). Williams et al. (2002) found behavioural changes in Northern Residents at received levels estimated at about 105-110 dB. However, with increasing use of loud, low frequency noise in activities such as ocean acoustic tomography and low frequency active sonar, which are detectable at ranges of thousands of kilometres, there has been pressure to raise the threshold for regulatory intervention. In the United States, NMFS recently updated guidance on underwater acoustic threshold levels for avoiding permanent hearing threshold shifts (PTS) in marine mammals (NMFS 2016). This guidance expressed thresholds for hearing shifts for impulsive sounds in terms of both the cumulative sound exposure level and peak sound pressure level. Onset of PTS is considered to occur when either of the two metrics is exceeded. For cetaceans in the mid-frequency hearing group, including Killer Whales, the PTS acoustic thresholds (received levels) for impulsive sounds were identified as 230 dB for the peak sound pressure level and 185 dB for the cumulative sound exposure level. For non-impulsive sounds, the PTS onset acoustic threshold for mid-frequency cetaceans is 198 dB. It should be noted that these acoustic thresholds are just one tool for determining and mitigating the impacts of sound exposure on marine mammals. Behavioural impact thresholds and auditory masking assessments should also be considered (NMFS 2016).

Table 3 Signal structure, frequency range and source levels of anthropogenic noise. Modified from Table 2-1b in NRC (2003) and Table 6.8 in Richardson et al. (1995).

Source	Signal Structure	Frequency Range	Source Level (dB re 1 μPa at 1 m)
Seismic surveys	impulsive	broadband >0 Hz to >100kHz	>240
Military Sonar			
surveillance	pulsed tones	<1kHz	>230
tactical	pulsed tones	>1kHz to < 10kHZ	200 to 235+
weapon/ counter weapon	pulsed tones and wideband pulses	>10kHz to 100kHz	190 to 220
Construction	broadband and tones	<10kHz to 10+kHz	NA
Dredging	broadband and tones	<10Hz to <10kHz	NA
Explosions	impulsive	broadband	>240
Commercial shipping	continuous	10Hz to >1kHz	160 to 200
Commercial sonars	pulsed tones	28kHz to >200kHz	160 to 210

Military sonar

Military active sonar is used in military operations for target detection, localization and classification (NRC 2003). Unlike passive sonar systems, which listen for sounds, active sonar units transmit pulses of tones at frequencies from <1 to >100 kHz and source levels of 200-235 (or more) dB re 1 µPa at 1 m depending on the application (Evans and England 2001). There is now a growing weight of evidence that these sources of underwater noise may pose a significant threat to cetaceans. Active military sonar has been associated with increased strandings of beaked whales and Humpback Whales (numerous incidents summarized in IWC 2004). In October 2004, the European Parliament called on its member nations to suspend the use of all high-intensity military sonar until further research can determine what effects it may have on marine life (European Parliament Resolution P6 TA, 2004).

For security reasons, information on the specifications of military active sonar is difficult to obtain, and much of what is available is based on U.S. Navy equipment. Given that the U.S. Navy engages in joint operations with the Canadian military in both the Strait of Georgia and off the west coast of Vancouver Island, and that both Northern and Southern Resident Killer Whales travel in U.S. waters, the threat that active sonar may pose must be considered and precautionary measures should be considered by both navies. Southern Resident Killer Whales may be especially vulnerable because they spend significant time in the waters of Washington State, where a large naval exercise area runs parallel to the coast.

Military active sonars may be categorized as: surveillance (low frequency, <1 kHz), tactical (mid frequency, 1 to 10 kHz), and weapon/counter weapon (high frequency, >10 - 100 kHz, see Table 2). Tactical sonars can have detection ranges of 10s of kms, and surveillance low frequency active sonars can be detected at ranges of 100s of kms (NRC 2003). The use of SURTASS (Surveillance Towed Active Sensor System) LFA (Low Frequency Active) sonar has been controversial because of concerns about its potential effects on marine life (EIS 2007).

The Canadian Department of National Defence’s Research Agency (DRDC) conducted research to investigate low frequency active tactical sonar through the Towed Integrated Active Passive Sonar (TIAPS) off the Atlantic Coast (Bottomely and Theriault 2003). The maximum source level of the TIAPS system was 223 dB re 1μPa @ 1m (Theriault pers. comm. 2007). Mitigation measures were applied (see Bottomely and Theriault 2003 for details) and no incidents involving marine mammals were reported. There are no plans to acquire this particular sonar for Canadian military use, and present defence policy requires that any future acquisition and testing of sonar systems will include environmental considerations (Freeman pers. comm. 2007).

Mid-frequency tactical sonar systems operating at 1-10 kHz are used to detect mines and submarines. They have been associated with mass stranding events in the Bahamas, Canary Islands, Greece and the Gulf of California (IWC 2004). Mid-frequency sonar exercises conducted by the USS Shoup on May 5, 2003 in Haro Strait were reported to correspond with changes in behaviour in members of J pod that were foraging 47 km away at the time, and resulted in behaviour more extreme than observed in response to any other disturbance. The pod was observed trying to leave the area while the ship was 22 km away and ultimately pod members separated and left the area in different directions when the USS Shoup passed by at a range of 3 km (D. Bain, personal observation and personal communication; K.C. Balcomb, in Wiles 2004). Up to 100 Dall's Porpoises and a Minke Whale were also seen leaving the area at high speed. Extensive examination of the 11 concurrent Harbour Porpoise strandings found no definitive signs of acoustic trauma, but the cause of death could not be determined for six animals, and the possibility of acoustic trauma as a contributory factor in the deaths of the remaining five porpoises could not be ruled out (lesions consistent with both acoustic trauma and alternative explanations were observed; NMFS 2004). Further, all members of J pod were still alive more than two years after the incident.

The Canadian Navy has five principal types of military sonar emitters. The SQS 510 sonar is the primary mid-frequency sonar used for anti-submarine search and is the most powerful. It is currently fitted to six ships on the west coast. In comparison, the U.S. Navy's SQS 53C sonar, such as that used on the USS Shoup, emits ten times more energy than the Canadian 510 sonar. The Canadian Navy also uses helicopter dipping sonars and active sonobuoys, though these emit far less energy than the 510 (D. Freeman, Department of National Defence, pers. comm. 2007).

The Canadian Navy uses active sonar during training exercises and equipment testing in designated training areas. However, sonar operations may also take place in other waters along the Pacific coast. To mitigate the potential impacts of sonar use, Department of National Defence (DND) ship personnel receive training in marine mammal identification and detection. The current Maritime Command Order 46-13 for marine mammal mitigation is to avoid transmission of sonar any time a marine mammal is observed within the defined mitigation avoidance zone specific to each type of sonar. These zones were determined using the interim NMFS thresholds for potential behavioural disturbance (160 dB) and physical injury (180 dB) (Freeman pers. comm. 2007). Concerns remain that some impacts may occur beyond the visible horizon, and these will be difficult or impossible to observe or mitigate.

Canadian test ranges are also used by other navies to test equipment and train personnel. They follow Canadian procedures for use of these ranges, which includes marine mammal impact assessment and mitigation (Freeman pers. comm. 2005). When conducting joint exercises in Canadian waters, other navies are provided direction including sonar mitigation protocols, prior to and during exercises. As little is known about the offshore distribution of Resident Killer Whales, especially during the winter months, they may be vulnerable to the use of sonar in the offshore ranges.

Seismic surveys

Airguns are used in geophysical surveys and to detect and monitor earthquake faults and other structures such as oil and gas deposits beneath the sea floor. The following information on the characteristics of seismic surveys comes from NRC (2003) unless mentioned otherwise. Like military sonar, seismic surveys generate high intensity sounds. Most of their energy is concentrated at frequencies between 5-300 Hz and maximum pressure levels of 260 dB re 1μPa at 1 m. However, unlike military sonars, airgun arrays used for seismic surveys generate broadband noise that extends to over 100 kHz (Calambokidis et al. 1998).

Current survey methods use one or more airguns that are towed behind a ship. Airgun arrays range in size from 2,000-8,000 cu in, depending on the application. The pulses of noise fired from these guns penetrate the seafloor surface for distances of up to 10 km deep. The arrays are towed at approximately 2.6 m/s (5 knots) and the airguns are fired every 10-12 seconds. The question of whether Killer Whales could sustain swimming the long distance necessary to avoid these sound sources needs to be addressed. Seismic surveys using powerful airgun arrays have been detected at distances of over 3,000 km from their source (Niekurk et al. 2004).

DFO receives occasional applications for permits for geophysical surveys from industry, government agencies such as Natural Resources Canada, and from universities. Currently, however, a moratorium on offshore oil and gas exploration in BC remains in place. As awareness is growing on the potential threats of high intensity sound on marine life (IUCN 2004; IWC 2004), the potential impacts of broadband high energy noise on Killer Whales must be considered. DFO has developed the Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment, which is reviewed annually to allow for revisions to reflect new technologies, scientific findings, and industry practices (DFO 2016a). In the Pacific Region, each proposed seismic survey is reviewed and case by case mitigation measures are developed based on the species of concern in the area of the survey.

Systematic observations of cetaceans during seismic surveys have been carried out in UK waters, and have shown that Killer Whales and other cetaceans were generally seen further away during periods when airgun arrays were firing (Stone 2003). Behavioural studies in other areas have shown mixed responses to seismic surveys. Grey and Bowhead Whales appeared to avoid seismic surveys (Malme and Miles 1987; Ljungblad et al. 1988; Myrberg 1990). Male Sperm Whales and feeding Humpback Whales did not avoid seismic surveys (Malme et al. 1985; Madsen et al. 2002). A seismic survey in Puget Sound showed mixed results between species, with some, such as Grey Whales, exhibiting ambiguous responses to the survey while others, such as Harbour Porpoises, tolerating only relatively low exposure levels before leaving the area (Calambokidis et al. 1998).

For obvious ethical reasons, there are no experimental studies of the physical effects of seismic surveys on cetaceans. However the internal structure of the cetacean ear resembles that of both fish and terrestrial mammals (Fay and Popper 2000). A small (20 cu in) airgun has been shown to cause permanent hearing loss in caged fish (McCauley et al. 2003), so it is possible that airguns may be capable of damaging cetacean ears if the whales cannot avoid the sound source. Since Killer Whales are known to be exquisitely dependent on sound for orientation, navigation, locating and catching food, communication, and social interactions, the consequences of severe hearing loss could be fatal.

Commercial sonar

Commercial sonar systems are used in a wide variety of vessels for fishing, navigation (depth sounders), bottom-mapping and detecting obstacles (e.g. side scan sonars). They are generally standard equipment on any vessel over 5 m. These sonars typically generate narrowband sounds at higher frequencies and lower power than military sonars. High frequency sounds are more easily focused into narrow beams and attenuate more quickly than low frequency sounds. Thus the volume of water they influence is smaller. There are many models of commercial sonars, but it is only the units that operate below 100 kHz, the upper limit of Killer Whale hearing, that are of concern. Whales may be able to avoid these sources of sound when boats are widely dispersed, but when boats are concentrated in high traffic areas Killer Whales may have no choice but to travel through heavily ensonified areas.

Shipping

Commercial shipping has increased dramatically in recent years. For example, between 1995 and 1999 the worldwide commercial shipping fleet increased 12% (NRC 2003). There are few studies that have measured changes in the background underwater noise levels over time, but those that have suggest that increased vessel traffic is responsible for the increase in ambient noise over the last 100 years (e.g. Andrew et al. 2002). In the northern hemisphere, shipping noise is the dominant source of ambient noise between 10 to 200 Hz (NRC 2003). While shipping energy is concentrated at low frequencies, ships produce significant amounts of high frequency noise as well. Studies are currently underway to understand and mitigate the impacts of shipping activities and commercial vessel traffic noise on some marine mammal species at risk. For example, in 2017, the Enhancing Cetacean Habitat and Observation (ECHO) initiative led by the Vancouver Fraser Port Authority coordinated a vessel slowdown trial in Haro Strait to better understand and measure the level of noise reduction that can be achieved through reduced vessel speed.

Permitted close approaches

Certain activities have the potential to disturb and/or injure whales because they require physical contact with whales or close approaches by boats for extended periods of time. As a result, in both Canada and the U.S., researchers and filmmakers must obtain federal permits if their projects require close approaches or physical contact with Killer Whales. Close approaches can disturb whales both physically and acoustically. Much of the research on Killer Whales is conducted using boats ranging in size from a few metres to vessels over 30 m, although some is land-based (e.g. Orcalab on Hanson Island, the Robson Bight Marine Warden Program on West Cracroft Island, Johnstone Strait). A boat at 10 m from a whale will be approximately 20 dB louder than a boat at 100 m based on spherical spreading (Richardson et al. 1995).

Photo-identification studies require that all whales in the group be photographed before the encounter is considered complete, and good quality photographs typically mean that whales must be approached to within 30 m (approximately 10 dB louder than at 100 m). Prey fragment sampling, which is providing insight into the diet of Resident Killer Whales, involves approaching the area where a whale has surfaced after it has finished actively feeding. Biopsy darting, a method used in genetic and contaminant studies, also involves close approaches by boats, and recommendations arising from the NOAA Cetacean Systematics Workshop in La Jolla California, in April-May 2004 include darting juveniles (Waples and Clapham 2004). The possible health risks of darting young calves have not been evaluated.

Some satellite tags and time-depth recorders (TDRs) are applied externally to Killer Whales. They are used to monitor the movements of whales, but may disturb them during the initial application and /or during the time that they adhere to the skin. Newer technologies involving satellite tags and TDRs that are implanted in the skin or muscle pose the additional risk of injuring Killer Whales. From 2013 to 2016, NOAA used satellite tags that attach to Killer Whales through darts that implant into the skin and tissue of these whales. The tags provided information about movements and habitat use of Southern Resident Killer Whales and were used to address knowledge gaps regarding winter distribution of this population. This tagging effort was suspended in April 2016 following the death of Southern Resident L95, after the cause of death was determined to be an infection that was likely introduced through the tag wound (NOAA 2016).

Other forms of disturbance

The number of boats on the water has increased dramatically in recent years. This increase in traffic has the potential to disrupt Killer Whales simply because more vessels are passing through their habitat and potentially disturbing how whales move through the available space. This is most evident when whales are interrupted from their normal activities in order to avoid a collision. While collisions between whales and vessels are relatively rare, when they do occur they can cause significant injury or death (Ford et al. 2000). A science based review of the effectiveness of recovery measures for Southern Resident Killer Whales conducted in 2017 identified vessel strikes as an emerging threat to this population and measures have been suggested to address this threat. Refer to the Review of the Effectiveness of Recovery Measures for Southern Resident Killer Whales (DFO 2017c) for further information.

Personal watercraft (PWC) or ‘jet skis’ may be another potential source of disturbance or injury to Killer Whales. PWC are capable of much more erratic or unpredictable manoeuvres than traditional high speed vessels. As a result they pose a collision risk to Killer Whales and other wildlife. PWC have been banned in the San Juan Islands and in portions of the Monterey Bay National Marine Sanctuary, but they are not banned in the coastal waters of BC, with the exception of the inner waters of Vancouver Harbour. Underwater noise emissions of PWC are reported to consist of broadband energy between 100 Hz and 10 kHz (Erbe 2013).

While Resident Killer Whales must travel in high vessel traffic areas such as Johnstone Strait and the Strait of Georgia, they also must negotiate both commercial and recreational sports fishing boats specifically targeting salmon in ‘hot spots’ that are also good feeding areas for Killer Whales. This includes areas in the vicinity of sports fishing lodges. Conflict for space may force Killer Whales to alter their foraging behaviour in order to successfully capture prey or to avoid collision or entanglement (see section 4.2.5).

Certain industrial activities such as construction, drilling, pile driving, pipe laying and dredging may also disrupt Killer Whales. Construction is also a source of underwater noise. Physical structures, including net pens for aquaculture and permanent structures (e.g. wharves), may damage foraging habitat such as kelp beds, or physically displace Resident Killer Whales from areas they have historically travelled in. If the finfish aquaculture industry continues to expand on the north coast, the placement of net pens may become an issue for Northern Residents.

4.2.4. Oil spills

While the probability of either Northern or Southern Resident Killer Whales being exposed to a major oil spill is relatively low, the impact of such an event is potentially catastrophic. Both populations are at risk of exposure to an oil spill because of the large volume of tanker traffic that travels in and out of Puget Sound and the Strait of Georgia (Baird 2001; Grant and Ross 2002) and the proposed expansion of tanker traffic along the coast of BC. In 2003, 746 tankers and barges transported over 55 billion litres of oil and fuel through the Puget Sound (WDOE 2004). Though the moratorium on offshore oil and gas exploration and development remains in place in BC, if the moratorium is lifted, the extraction and transport of oil may put Resident Killer Whales at additional risk.

Killer Whales do not appear to avoid oil, as evidenced by the 1989 Exxon Valdez oil spill in Prince William Sound, Alaska. Less than a week after the spill, Resident Killer Whales from one pod were observed surfacing directly in the slick (Matkin et al. 1999). Seven whales from the pod were missing at this time, and within a year, 13 of them were dead. This rate of mortality was unprecedented, and there was strong spatial and temporal correlation between the spill and the deaths (Dahlheim and Matkin 1994; Matkin et al. 1999). The whales probably died from the inhalation of petroleum vapours (Matkin et al. 1999). Exposure to hydrocarbons can be through inhalation or ingestion and has been reported to cause behavioural changes, inflammation of mucous membranes, lung congestion, pneumonia, liver disorders, and neurological damage (Geraci and St. Aubin 1982).

4.2.5. Incidental mortality in fisheries

Killer Whales are rarely entangled in fishing gear, based on anecdotal accounts and an absence of net marks in identification photographs, but the actual numbers of whales caught are unknown (Baird 2001). Several stranded Killer Whales have been found with gear from commercial or recreational line fisheries in their stomachs and the possibility of mortality as a result is unknown (Ford et al. 1998). A few entanglements have been reported from BC, Alaska and California, but they usually have not resulted in death (Pike and MacAskie 1969; Barlow et al. 1994; Heyning et al. 1994; Guenther et al. 1995). In 2014, Northern Resident Killer Whale I103 became severely entangled in a gill net and despite being released quickly, died the following winter. It is likely that entanglement in fishing gear poses little direct threat to Killer Whale populations at present. However, there are areas in BC where Killer Whales have learned to take fish from fishing gear and once this behaviour is adopted, it can spread quickly throughout a population. This problem, referred to as depredation, is severe in many parts of the world (Donogue et al. 2002). Where depredation occurs, deterrent methods, entanglement and accidental hooking can increase the injury or mortality rates of whales.

5. Knowledge gaps

While Resident Killer Whales are among the best studied cetaceans in the world, significant gaps in knowledge about these populations remain. In part this is due to the fact that although studies of Killer Whales have been ongoing over the last 45 years, their whereabouts are poorly known during much of the year. As well, opportunities to learn from Killer Whale carcasses occur relatively infrequently. Only seven to eight carcasses are recovered around the world each year (Raverty et al. 2014). In a 30-year period, only 14 Resident carcasses were found and necropsied in BC (Ford et al. 1998), a recovery rate of 6%.

Some key areas where further knowledge is needed include:

- the year-round distribution and behaviour of Resident Killer Whales
- whether potential additional critical habitat areas are required for Resident Killer Whales
- the historical abundance of Resident Killer Whales
- the year-round diet and energetic requirements of Resident Killer Whales
- the consequences of changes in key prey populations on Resident Killer Whales, as well as their historic trends
- the population level consequences of low population size and its effects on the sustainability and viability of Resident Killer Whales
- the population size that is needed to maintain the cultural and genetic diversity of Resident Killer Whales
- the long- and short-term effects of physical disturbance (shipping, whale watching, aircraft, researchers and film makers) on Resident Killer Whales
- the long- and short-term effects of acoustic disturbance (whale watching, seismic surveys, military sonar, researchers and film makers) on Resident Killer Whales
- the full range of anthropogenic environmental contaminants to which Killer Whales and their prey are exposed, over time and in space, with special attention paid to the identification of sources and the resulting effects of environmental contaminants on Resident Killer Whales, their prey and their habitat
- diseases, pathogens, parasites and pathologies of Resident Killer Whales
- the effects of climate or environmental change on Resident Killer Whale prey and their habitat

6. Recovery

6.1 Recovery goal

The recovery goal for Northern and Southern Resident Killer Whales 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 goal reflects, to the extent possible, the complex social and mating behaviour of Resident Killer Whales and the key threats that may be responsible for their decline. In the absence of historical data, it does not identify a numerical target for recovery because our current understanding of Killer Whale population demographics is not adequate for setting a meaningful value at this time. However, because maintaining the demographic conditions that will preserve their reproductive potential, genetic variation, and cultural continuity is fundamental to these populations recovering, a number of demographic indicators are expressed herein that will serve as short-term measures of recovery success. The setting of a quantitative recovery goal will be revisited as new information becomes available.

Killer Whales are top-level predators, and as such will always be far less abundant than most other species in their environment. In addition, they are segregated into small populations that are closed to immigration and emigration, such as the Northern and Southern Resident communities. Furthermore, their capacity for population growth is limited by a suite of life history and social factors, including late onset of sexual maturity, small numbers of reproductive females and mature males, long calving intervals, and dependence on the cultural transmission of ecological and social information. Unfortunately, little is known concerning the historic sizes of

Killer Whale populations, or the factors that ultimately regulate them. Genetic diversity is known to be low in both populations, particularly the Southern Residents, but the consequences of this lack of diversity have not been examined.

6.1.1. Measures of recovery success

The following have been identified as measures of recovery success:

a) long-term maintenance of a steady or increasing size for populations currently at known historic maximum levels and an increasing size for populations currently below known historic maximum levels
b) maintenance of sufficient numbers of females in the population to ensure that their combined reproductive potential is at replacement levels for populations at known historic maximum levels and above replacement levels for populations below known historic maximum levels
c) maintenance of sufficient numbers of males in the population to ensure that breeding females have access to multiple potential mates outside of their own and closely related matrilines
d) maintenance of matrilines comprised of multiple generations to ensure continuity in the transmission of cultural information affecting survival

6.1.2. Monitoring and research strategies

The following monitoring and research programs are essential to define and evaluate the success of the indicators of recovery and will be vital to the establishment of a quantitative recovery goal:

a) routinely monitor Resident Killer Whale population numbers, sex and age composition, social structure and genetic diversity
b) develop models of Resident Killer Whale population dynamics and demographics, including social and genetic structure
c) develop a quantitative framework to better understand how key anthropogenic and naturally occurring factors, particularly those identified as threats, affect the dynamics of Resident Killer Whale populations
d) undertake studies to identify the role of cultural transmission in the foraging ecology, sociobiology and maintenance of genetic diversity in Resident Killer Whales

Because Killer Whale populations are closed to immigration and emigration, and animals individually identifiable, routine monitoring provides accurate, detailed life history information, which is used to determine trends, and to refine and test population models. These models will lead to a better understanding of achievable targets for population recovery. A better understanding of the anthropogenic and naturally occurring factors that regulate or limit Killer Whale populations, and of the role and importance of culture, will make it possible to rank threat factors and prioritize recovery actions.

6.2 Recovery objectives and strategies to achieve recovery

Given our current knowledge, the primary anthropogenic threats to the long-term survival of Northern and Southern Resident Killer Whales appear to be 1) reduced prey availability, 2) environmental contaminants, 3) disturbance, and 4) degradation of critical habitat. We have identified four objectives that directly address these threats and contribute to achieving the recovery goal of population viability and sustaining genetic diversity and maintaining cultural continuity (as stated above). The numerical values do not reflect any priority among the objectives. These objectives provide direction for the broad strategies that can be used to specifically mitigate and/or eliminate each of the threats facing Resident Killer Whales, and to better address gaps in our knowledge.

6.2.1 Objective 1

> Ensure that Resident Killer Whales have an adequate and accessible food supply to allow recovery.

This objective identifies the need to learn more about the year-round diet of Killer Whales, and to understand and mitigate the threats to key prey populations and their habitat. Food supply can limit the growth and recovery of any population, and there are concerns about the quality and quantity of Resident Killer Whale prey, as well as the prey's habitat. In some areas of the U.S., for example, runs of Chinook Salmon, a principal prey species for Resident Killer Whales, have been listed as either Endangered or Threatened (NOAA 2017). We know very little about what Killer Whales eat during the winter and spring, and this information is critical to understanding whether the quantity or quality of their food supply could be responsible for the recent decline in Killer Whale numbers, and may prevent their populations from recovering.

Objective 1 strategies

- Determine the seasonal and annual diet and energetic requirements of Resident Killer Whales
- Identify key prey populations and feeding areas for Resident Killer Whales
- Establish long-term monitoring programs capable of detecting changes in the abundance, distribution and quality of Resident Killer Whale prey
- Protect the access of Resident Killer Whales to important feeding areas
- Ensure that Resident Killer Whale prey populations and their (the prey's) habitat are adequately protected from anthropogenic factors such as exploitation and degradation, including contamination, which will allow for the recovery of Resident Killer Whales

6.2.2 Objective 2

> Ensure that chemical and biological pollutants do not prevent the recovery of Resident Killer Whale populations.

Ross et al. (2000) showed that Southern Resident Killer Whales are among the most contaminated mammals known, and that Northern Residents also carry significant pollutant loads. These pollutants are known to impair both immune responses and reproduction in other species at lower concentrations than currently seen in Killer Whales. The strategies listed below are intended to improve our understanding of, and mitigate, the contaminant risks that Resident Killer Whales and their prey are exposed to. They also acknowledge the serious risks that pathogens, introduced species and catastrophic events such as oil spills present to Killer Whales and their prey.

Objective 2 strategies

- Investigate the effects of chemical and biological pollutants on the health and reproductive capacity of Resident Killer Whales
- Monitor chemical and biological pollutant levels in Resident Killer Whales and their prey
- Identify (and prioritize) key chemical and biological contaminants and their sources
- Reduce the introduction into the environment of pesticides and other chemical compounds that have the potential to adversely affect the health of Killer Whales and/or their prey, through measures such as national and international agreements, education, regulation, and enforcement
- Mitigate the impacts of currently and historically used 'legacy' pollutants in the environment
- Investigate diseases, pathogens, parasites, and pathologies of Killer Whales
- Reduce the introduction of biological pollutants, including pathogens and exotic species, into the habitats of Killer Whales and their prey

In order for these strategies to be successful, it is important that contaminant levels be measured, so as to provide a baseline that can be used to monitor changes in contaminant profiles over time, and to quantify whether attempts at mitigation are successful. Mitigation must occur on scales that range from the local consumer to the international level, as many pollutants originate from sources outside of Canada. Regulations, guidelines and best practices for the manufacture, storage, transport, use and disposal of hazardous compounds must be followed, and evolve to reflect changing knowledge of contaminants and their adverse health effects on Resident Killer Whales, their prey and their habitat. Education at individual, corporate and government levels (again ranging from local to international) will play an important role in reducing the rate at which contaminants are introduced into the environment. International treaties, similar to the Stockholm Convention on Persistent Organic Pollutants, should be endorsed.

6.2.3 Objective 3

> Ensure that disturbance from human activities does not prevent the recovery of Resident Killer Whales.

Both physical and acoustic disturbance from human activities may be key factors causing depletion or preventing recovery of Resident Killer Whale populations. Sources of acoustic disturbance range from high-intensity sound produced by seismic surveys to chronic sources such as vessel traffic. During periods of high boating activity in the summer months, disturbance may occur from vessel congestion, impairing the ability of whales to move freely and/ or forage effectively. Physical disturbance can be caused by boat or air traffic close to whales, especially during certain behavioural states such as feeding or beach rubbing (Williams 1999). Research to date has identified various immediate responses of whales to disturbance; however, we know little about potential long-term effects on whale behaviour, health, and foraging efficiency. The National Research Council (NRC 2005) put forward a detailed listing of approaches to better understand how noise impacts marine mammals. The strategies listed here generally address the need for more knowledge about how noise and physical disturbance affect Resident Killer Whales and also provide for mitigation of disturbance as a precautionary measure.

Objective 3 strategies

- Determine the short and long-term effects of chronic and immediate forms of disturbance, including vessels and noise, on the physiology, foraging, and social behaviour of Resident Killer Whales
- Determine baseline ambient and anthropogenic noise profiles and monitor sources and changes in the exposure of Resident Killer Whales to underwater noise
- Develop and implement regulations, guidelines, sanctuaries and other measures to reduce or eliminate physical and acoustic disturbance of Resident Killer Whales
- Develop protocols, regulations, guidelines and/or other measures for the use of underwater seismic survey tools and high energy sonar testing, as most appropriate and in collaboration with stakeholders, to reduce disturbance or injury to Resident Killer Whales, where such activities are permitted

In order to be effective, these strategies will require education and stewardship activities promoting compliance with best practice guidelines, the protection of sanctuaries, and the enforcement of regulations. New technologies, such as those that reduce noise may also contribute to reductions in disturbance over the long-term. Existing regulations, guidelines, protocols and other measures should be evaluated for their efficacy in protecting Resident Killer Whales, particularly as new information becomes available.

6.2.4 Objective 4

> Protect critical habitat for Resident Killer Whales and identify additional potential areas for critical habitat designation and protection.

Four areas, used consistently by Resident Killer Whales, are designated as critical habitat as defined by SARA. One, the trans-boundary waters of Haro Strait and Boundary Pass, is used by Southern Residents year-round. The second, the waters of Johnstone and southeastern Queen Charlotte Straits and their adjoining channels, is used by many of the Northern Residents during the summer and fall. The third, which includes waters off southwestern Vancouver Island, is used by members of both the Southern and Northern Resident Killer Whale populations throughout most of the year. The fourth, waters in western Dixon Entrance, is used by Northern Resident Killer Whales year-round. These areas represent a relatively small proportion of the total range of each population and it is unknown whether additional critical habitat may be required to support Resident Killer Whale recovery objectives. Preliminary data suggest that key areas may exist in other locations and at different times of the year, but are not sufficient to warrant proposing these habitats as critical without further research. The strategies listed here provide measures for the protection of the critical habitats referred to above, as well as direction for the potential identification of additional critical habitat.

Objective 4 strategies

- Develop a year-round comprehensive survey program for Resident Killer Whales
- Identify key feeding areas and other critical habitat of Resident Killer Whales throughout the year
- Protect the access of Resident Killer Whales to their critical habitat
- Protect critical habitat areas through assessment and mitigation of human activities that result in contamination and physical disturbance

- Ensure that sufficient prey is available to Killer Whales in their critical habitat.
- Ensure trans-boundary cooperation in the identification and protection of critical habitat

The first two strategies listed above focus on determining whether additional areas should be proposed for critical habitat designation. The remaining strategies, as well as those in Objectives 1, 2 and 3, will help to preserve and protect designated critical habitat.

6.3 Effects on non-target species

The objectives outlined above are designed to protect Resident Killer Whale prey populations and their habitat from exploitation and degradation including contaminants and noise. The spin-off effects of this are likely to be widespread and will be beneficial to human health as well as to a wide variety of organisms ranging from fish to sea birds, since all are affected by contaminants and exploitation. It is likely this benefit will far exceed the increased mortality of prey species associated with increased Killer Whale numbers.

6.4 Evaluation and the status of strategies for recovery

The following are examples of performance measures that may be used to assess the effectiveness of the objectives and strategies, and to determine whether recovery remains feasible. Detailed recovery measures that provide the best chance of meeting the recovery goal and objectives for Northern and Southern Resident Killer Whales, and timelines for their implementation, were identified during the development of the action plan (DFO 2017a).

Progress towards meeting these objectives and strategies was detailed in the Report on the Progress of Recovery Strategy Implementation for Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada for the Period 2009-2014 (DFO 2016b) and will continue to be reported on every five years until the objectives have been achieved or until recovery of the species is no longer feasible.

Table 3. Examples of performance measures that may be used to assess the effectiveness of the broad strategies used to achieve the objectives of the recovery strategy for the Northern and Southern Resident Killer Whales in Canada

Objective no. /threat	Broad strategy	Status*	Examples of performance measures for broad strategies and objectives
Recovery Goal: Ensure long-term population viability	Monitor population dynamics and demography	Underway	Completion of annual censuses Genetic sampling and analyses completed Evaluation of population status to ensure growth
	Develop population models	Underway	Models developed that incorporate social and genetic structure and explain population trends
	Quantitative framework for understanding effects of threats on population dynamics	Proposed	Models completed that incorporate threats into population dynamic models

Objective no. /threat	Broad strategy	Status*	Examples of performance measures for broad strategies and objectives
	Studies to identify role of culture in foraging ecology and sociobiology	Proposed	Peer-reviewed publications on role of culture in Killer Whale foraging
	Studies to identify role of culture in maintaining genetic diversity	Underway	Biopsy samples collected and analyzed to identify paternity
1. Ensure adequate and accessible food supply	Determine seasonal/annual diet/ energetic requirements	Underway	Prey fragment samples collected year-round for multiple years
			Alternative diet sampling methods tested to confirm diet
			Winter and spring distribution and diet of Resident Killer Whales identified
	Identify key prey populations and feeding areas	Underway	Complete diet sampling of all members of population and during all seasons
			Prey identified to stock, not just species
	Monitoring prey populations to detect changes in abundance or availability	Underway	Population assessment completed for all stocks identified as important prey for Resident Killer Whales
	Protect access to important feeding areas	Proposed	Guidelines developed for human activities in important whale feeding areas
	Protection of prey populations	Underway	Incorporation of Killer Whale predation into fisheries management plans
2. Chemical and biological contaminants	Investigate effects of contaminants on health and reproductive capacity of Killer Whales	Underway	Peer reviewed publication on contaminants in Resident Killer Whales
			Develop and apply tests to measure the health of Killer Whales
	Monitor pollutants, diseases, pathogens, parasites and pathologies in Killer Whales	Underway	Extensive sampling of populations to establish baseline contaminant levels
			Completed analyses of contaminants in samples
			Complete necropsies of stranded Killer Whales.
	Identify and prioritize key chemical and biological pollutants	Underway	Completed sampling and analyses of contaminants in Killer Whale prey
	Identify and prioritize key sources of chemical and biological pollutants	Underway	Water quality sampling in areas throughout range of Resident Killer Whales
	Reduce introduction of chemical pollutants into environment	Underway	Measurable decline in contaminant levels in environment (prey, sediments etc.)
	Mitigate impacts of currently used pollutants	Underway	Evaluation of effectiveness of legislation completed

Objective no. /threat	Broad strategy	Status*	Examples of performance measures for broad strategies and objectives
	Mitigate impacts of ‘legacy’ pollutants	Underway	PCB sources identified
	Reduce introduction of biological pollutants	Underway	Evaluation of effectiveness of legislation completed
3. Acoustical and Physical Disturbance	Investigate short-term effects of chronic forms of disturbance	Underway	Controlled studies of whale/boat interactions completed
	Investigate short-term effects of acute forms of disturbance	Proposed	Complete controlled study of marine mammals in areas where seismic exploration is active
	Investigate long-term effects of chronic forms of disturbance	Proposed	Complete model that incorporates effects of increasing ambient noise levels on communication signals of Resident Killer Whales
	Investigate long-term effects of acute forms of disturbance	Proposed	Complete controlled study of marine mammals in areas where seismic exploration is active
	Determine baseline ambient and anthropogenic noise profiles	Proposed	Complete acoustic profiles of vessels most likely to be encountered by Resident Killer Whales
	Develop measures to reduce physical disturbance	Underway	Revised whale watching guidelines, and/ or regulations that reflect most recent understanding of effects of chronic physical disturbance
	Develop measures to reduce acoustic disturbance	Proposed	Establishment of acoustic sanctuaries in critical habitat areas
	Develop measures for reducing disturbance to high energy sources of sound	Proposed	Revised protocols for seismic and military sonar that reflect most recent understanding of physiological and behavioural responses to noise
4. Protection of critical habitat	Year-round comprehensive surveys to identify important areas for Killer Whales	Underway	Winter distribution of Resident Killer Whales well understood
	Identify key feeding areas and other critical habitat	Underway	Winter prey of Resident Killer Whales identified
	Protect access of whales to critical habitat	Underway	Sanctuaries within critical habitat established
	Protect critical habitat from contamination, and physical disturbance	Proposed	Measurable reduction in contaminants in critical habitat
	Ensure sufficient prey available to whales in critical habitat	Proposed	Key prey populations in critical habitat areas
	Ensure trans-boundary cooperation in identification and protection of critical habitat	Proposed	Formal identification of critical habitat recognized by international agreement

Note: A thorough listing of recovery measures was included in the action plan (DFO 2017a).

∗ The information presented in the status column of this table represents the status of each strategy at the time of the development of the original recovery strategy (2008). See Table 3 in the Report on the Progress of Recovery Strategy Implementation for Northern and Southern Resident Killer Whales (DFO 2016b) for more recent information regarding progress made toward each of these objectives and strategies.

7. Critical habitat

7.1 Identification of the species' critical habitat

7.1.1 General description of the species' critical habitat

Critical habitat is defined in SARA section 2(1) as "…the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in a recovery strategy or in an action plan for the species."

SARA defines habitat for aquatic species at risk as "… spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced" [s. 2(1)].

Partial critical habitat was identified for both Northern and Southern Resident Killer Whales in the 2008 recovery strategy. Northern Resident Killer Whale critical habitat included the waters of Johnstone Strait and southeastern Queen Charlotte Strait (Figure 4), while Southern Resident Killer Whale critical habitat included the transboundary waters in southern BC, including the southern Strait of Georgia, Haro Strait, and Juan de Fuca Strait (Figure 5). These critical habitat areas were protected through the making of a SARA Critical Habitat Order in 2009. In 2011, minor amendments were made to the critical habitat section of the 2008 recovery strategy. These amendments clarified that attributes of critical habitat identified in the 2008 recovery strategy are a part of critical habitat.

Two additional areas were identified for consideration as critical habitat for Resident Killer Whales in DFO (2017b).These areas include: i) waters on the continental shelf off southwestern Vancouver Island, including Swiftsure and La Pérouse Banks (Northern and Southern Resident Killer Whale critical habitat, Figures 4 and 5) and ii) the waters of western Dixon Entrance along the north coast of Graham Island from Langara Island to Rose Spit (Northern Resident Killer Whale critical habitat, Figure 4).

For Northern and Southern Resident Killer Whales, critical habitat is identified in this recovery strategy to the extent possible, using the best available information. A description of the functions, features, and attributes that support the identification of critical habitat is provided in section 7.1.3.

Under SARA, critical habitat must be legally protected within 180 days of being identified in a recovery strategy or action plan through a SARA Critical Habitat Order or under any other Act of Parliament, and through prohibitions to the destruction of any part of critical habitat.

This recovery strategy identifies critical habitat for Resident Killer Whales as four distinct geographic areas. These include: 1) the waters of Johnstone Strait and southeastern Queen Charlotte Strait (Northern Resident Killer Whale critical habitat); 2) transboundary waters in southern British Columbia, including the southern Strait of Georgia, Haro Strait, and Juan de Fuca Strait (Southern Resident Killer Whale critical habitat); 3) waters on the continental shelf off southwestern Vancouver Island, including Swiftsure and La Pérouse Banks (Northern and Southern Resident Killer Whale critical habitat); and 4) waters of west Dixon Entrance, along the north coast of Graham Island from Langara to Rose Spit (Northern Resident Killer Whale critical habitat).

It is unknown if the critical habitat identified in this recovery strategy is sufficient to achieve the species' recovery goal and objectives. The schedule of studies outlines the research required to identify additional critical habitat and to acquire more detail about the critical habitat identified to achieve the species' recovery goal and objectives. Additional critical habitat may be identified in future amendments to this recovery strategy.

7.1.2 Information and methods used to identify critical habitat

The movement patterns of Resident Killer Whales are influenced by the availability of their preferred prey. During the summer and fall months, Resident Killer Whale distribution is associated spatially and temporally with the migratory routes of Chinook Salmon as this important prey species returns to natal streams to spawn (Ford and Ellis 2005). For the rest of the year there is less information available on the diet, distribution, and movement patterns of Resident Killer Whales, though surveys, passive acoustic monitoring, and satellite tagging studies have been conducted to address these knowledge gaps (Riera 2012; Hanson et al. 2013; DFO 2017b). Determining whether there are additional habitats that the whales utilize during winter and spring that are critical for the survival or recovery of these populations has been and continues to be a priority. This will need to take into account the likelihood that changes in the availability of major stocks of key prey species may cause corresponding shifts in the geographic location of critical habitat for Resident Killer Whales.

Methods and rationale used to designate each of the four critical habitat areas identified to date are detailed below.

Northern Resident Killer Whale critical habitat: Johnstone Strait and southeastern Queen Charlotte Strait

Analyses of existing data on coast-wide occurrence patterns of Northern Resident Killer Whales provide quantitative documentation of the importance of Johnstone Strait and southeastern Queen Charlotte Strait (Figure 4) to these whales (Ford 2006). These analyses, along with previously published information, form the basis for this area's critical habitat designation.

One or more Northern Resident matrilines are sighted in this area on most days during July through October, with peak numbers generally in mid-July to mid-September (Nichol and Shackleton 1996; Ford 2006). Sightings become more sporadic in the area during November, are scarce from December through May. Although all Northern Resident pods have been identified in the area, different pods do not use the area equally (Ford et al. 2017). For example, 75% of encounters documented during 1990-2004 included all or part of A1 pod, while only 0.7% of encounters during this same period included I18 pod, a group of similar size. Northern Resident Killer Whales in the Johnstone Strait area spend the majority of time foraging for salmon, primarily Chinook during July-September and Chum in October (Ford 1989; Ford et al. 1998; Ford 2006; Ford et al. 2010; DFO 2017b). Other activities undertaken in the area include resting, socializing, and beach rubbing (Ford 1989; Ford et al. 2000; Ford 2006).

Beach rubbing appears to be an important activity for Northern Resident Killer Whales. More than 90% of the Northern Resident Killer Whales observed in Johnstone Strait visit the rubbing beaches, and spend about 10% of their time there (Briggs 1991). During this time they are very sensitive to disturbance. In recognition of the importance of this habitat to Resident Killer Whales, in 1982 the Province of British Columbia established the Robson Bight–Michael Bigg Ecological Reserve to protect a portion of western Johnstone Strait and the foreshore near Robson Bight, where the rubbing beaches are located. This Ecological Reserve includes the primary foraging areas for Killer Whales utilizing the Johnstone Strait area, as well as at least six beaches used to various degrees by these whales for rubbing, and is included as critical habitat within the Johnstone and southeastern Queen Charlotte Straits boundaries (see Table 4).

Given the importance of this area to a significant component of the Northern Resident community for a major portion of the salmon feeding season, and the traditional use of rubbing beaches located there, this area has been designated as critical habitat as defined in SARA.

Southern Resident Killer Whale critical habitat: transboundary waters of the southern Strait of Georgia, Haro Strait, and Juan de Fuca Strait

The transboundary waters of southern BC and Washington State (Figure 5) represent an important area of high concentration of Southern Resident Killer Whales. This area includes waters under both Canadian and U.S. jurisdiction. Analyses of existing data on coast-wide occurrence patterns of Southern Resident Killer Whales have been completed by NOAA as part of the ESA designation of critical habitat in collaboration with DFO (NMFS 2006a). This assessment provided quantitative documentation of the importance of these transboundary areas to these whales and forms, along with previously published information, the basis for the critical habitat identification.

This critical habitat area is utilized regularly by all three Southern Resident pods during June through October in most years (Osborne 1999; Wiles 2004). J pod appears to be present in the area throughout much of the remainder of the year, but two Southern Resident pods, K and L, are typically absent during December through April. This critical habitat is of great importance to the entire Southern Resident community as a foraging range during the period of salmon migration, and thus has been designated as critical habitat under SARA.

Northern and Southern Resident Killer Whale critical habitat: southwestern Vancouver Island; and Northern Resident Killer Whale critical habitat: western Dixon Entrance

Southwestern Vancouver Island and western Dixon Entrance were identified as habitats of special importance to Northern and Southern Resident Killer Whales based on photo-identification, predation, and acoustic data. Passive acoustic monitoring was used to supplement the boat-based photo-identification studies, as these areas are remote and exposed to open ocean conditions, making small boat studies difficult. Using both photo-identification and detections of Resident Killer Whale vocalizations on acoustic recording devices allowed for year-round assessment of Resident Killer Whale occurrence in these areas. Tissue samples and scales were collected at predation sites to identify prey and assess Resident Killer Whale diet. See DFO (2017b) for detailed information about the methods used to identify these two areas as Resident Killer Whale critical habitat.

Critical habitat off southwestern Vancouver Island (Figures 4 and 5) includes the Canadian portions of Swiftsure Bank, where acoustic monitoring between August 2009 and July 2011 indicated considerable habitat use by both Southern and Northern Resident Killer Whales over much of the year. Additionally, it encompasses several other relatively shallow banks, including La Pérouse Bank which, like Swiftsure Bank, is among the most productive fishing areas for Chinook Salmon on the west coast of North America. During this acoustic monitoring, all three Southern Resident Killer Whale pods were detected in this area, with L pod being the most frequently documented (Ford et al. 2017). The area is important for Southern Resident Killer Whales, both during summer, when groups of whales spend time west of the critical habitat area in the transboundary waters in southern BC, and in winter, when whales are mostly absent from the southern BC critical habitat area, but were detected frequently off southwestern Vancouver Island (DFO 2017b). Northern Resident Killer Whales were detected in all months of the year, especially in March and April. Fifteen of the 16 pods in the Northern Resident Killer Whale population were also encountered during boat surveys in this area. Given the importance of southwestern Vancouver Island to both Northern and Southern Resident Killer Whales throughout most of the year, it meets the definition for critical habitat under SARA for both of these populations.

Critical habitat in western Dixon Entrance (Figure 4) is an important foraging area for Northern Resident Killer Whales, and is situated on migratory routes for a wide variety of Chinook Salmon stocks. Northern Resident Killer Whales were detected during acoustic monitoring activities between September 2009 and June 2012 in this area in all months of the year, but most frequently during late winter and spring (DFO 2017b). Certain pods that are rarely encountered in Northern Resident Killer Whale critical habitat in Johnstone and eastern Queen Charlotte Straits at any time of year were frequently detected in western Dixon Entrance (DFO 2017b). As habitat needed for recovery, western Dixon Entrance appears to be far more relevant for these pods than the Johnstone /Queen Charlotte Straits critical habitat area. Pods belonging to G clan were documented in western Dixon Entrance most often, followed by R01 pod (R clan). The use of western Dixon Entrance by members of the population that are rarely documented in the Johnstone Strait area and during times of year when detections of this population in the Johnstone Strait area are infrequent indicates its importance to Northern Resident Killer Whales. This area thus meets the definition for critical habitat under SARA.

7.1.3 Identification of critical habitat

Geographic information

Four critical habitat areas have been identified for Resident Killer Whales. Critical habitat has been identified using the bounding box approach. This means that critical habitat is not composed of the entire area within the identified boundaries but only those areas within the identified geographical boundaries where the described biophysical features, attributes, and the functions they support occur, as described in Table 4 and defined by the coordinates in Appendix D. The critical habitat's biophysical functions, features, and attributes are described below and summarized in Table 4.

Northern Resident Killer Whale critical habitat: Johnstone Strait and southeastern Queen Charlotte Strait

The boundaries of the existing critical habitat area for Northern Resident Killer Whales include the waters of Johnstone Strait and southeastern Queen Charlotte Strait, and the channels connecting these straits as depicted in Figure 4. This area is approximately 905 km^2.

Southern Resident Killer Whale critical habitat: Transboundary waters of the southern Strait of Georgia, Haro Strait, and Juan de Fuca Strait

Critical habitat for Southern Resident Killer Whales includes the transboundary areas of southern BC and Washington State. The portion of this critical habitat that is in Canadian waters is approximately 3,390 km^2 in size, and includes the Canadian side of Haro and Juan de Fuca Straits, as well as Boundary Pass and adjoining areas in the Strait of Georgia, as depicted in Figure 5.

Much of the area that qualifies as critical habitat for Southern Resident Killer Whales falls within U.S. jurisdiction, and the identification of critical habitat under SARA only applies to the portion of the area that is within Canadian waters (Figure 5). In November 2005, the U.S. listed Southern Resident Killer Whales as Endangered under the ESA (NMFS 2006a). As a result, 6,630 km^2 of U.S. inland waters of Washington State and Juan de Fuca Strait were designated as critical habitat under the ESA in November 2006 (NMFS 2006b, see Figure 5).

Northern and Southern Resident Killer Whale critical habitat: Southwestern Vancouver Island

Critical habitat for Northern and Southern Resident Killer Whales located off southwestern Vancouver Island forms a contiguous westward extension of the critical habitat area for Southern Resident Killer Whales described above. The southern boundary is formed by the Exclusive Economic Zone of Canada and extends to the 200 m isobath, or depth contour. See Figures 4 and 5 for the boundaries of this critical habitat, which encompass an area of 5,025 km^2.

Northern Resident Killer Whale critical habitat: Western Dixon Entrance

Critical habitat for Northern Resident Killer Whales in western Dixon Entrance includes most of the coastal waters off the north side of Graham Island. The shallow waters of Naden Harbour, Massett Inlet, and McIntyre Bay are not included as critical habitat, due to limited use of these areas by Resident Killer Whales. See Figure 4 for the boundaries of this critical habitat, which encompass an area of 1,394 km^2.

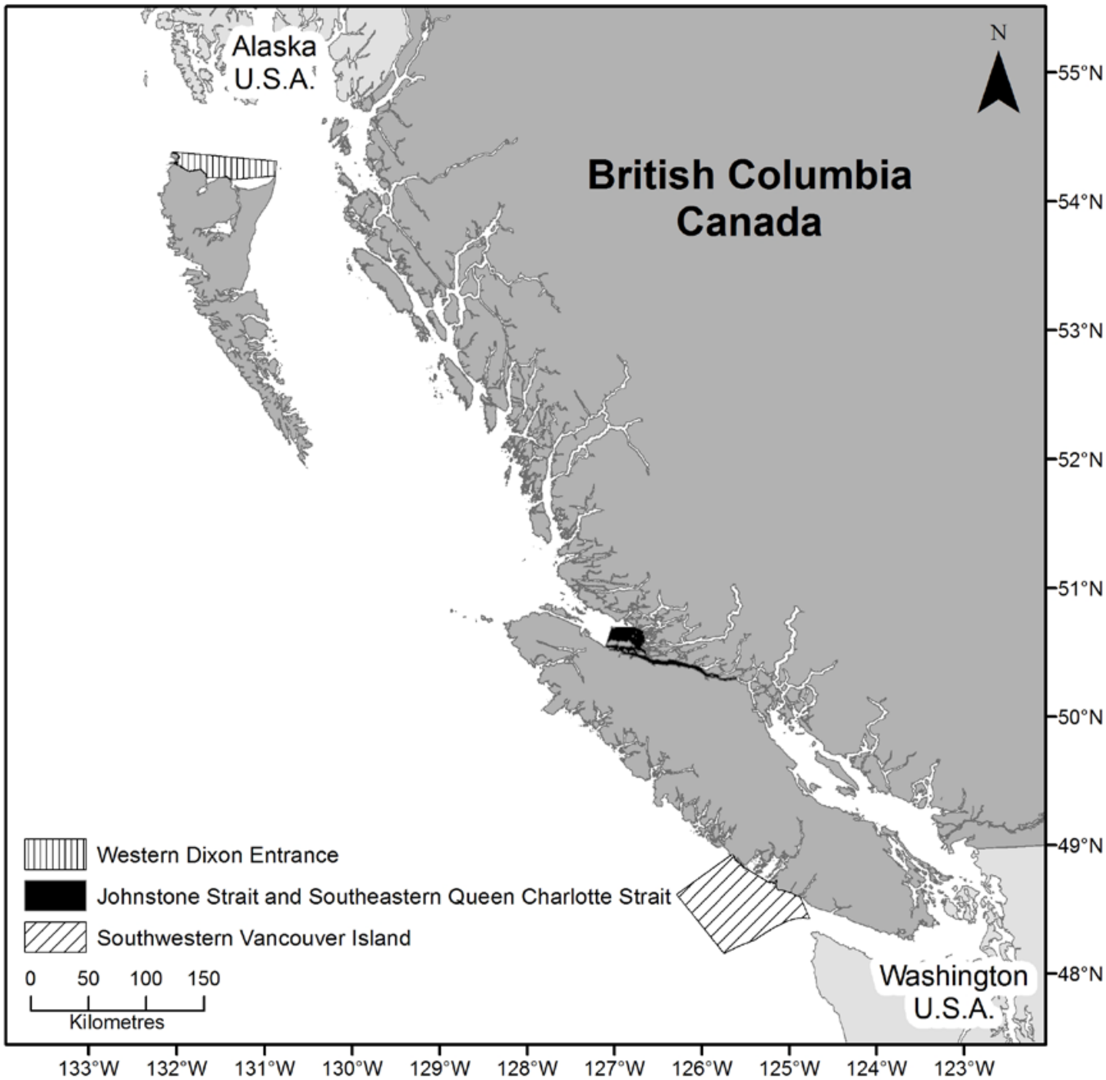

Figure 4. Critical habitat areas identified for Northern Resident Killer Whales. Critical habitat is not composed of the entire area within the identified boundaries but only those areas within the identified geographical boundaries where the described biophysical features and the functions they support occur, as described in Table 4.

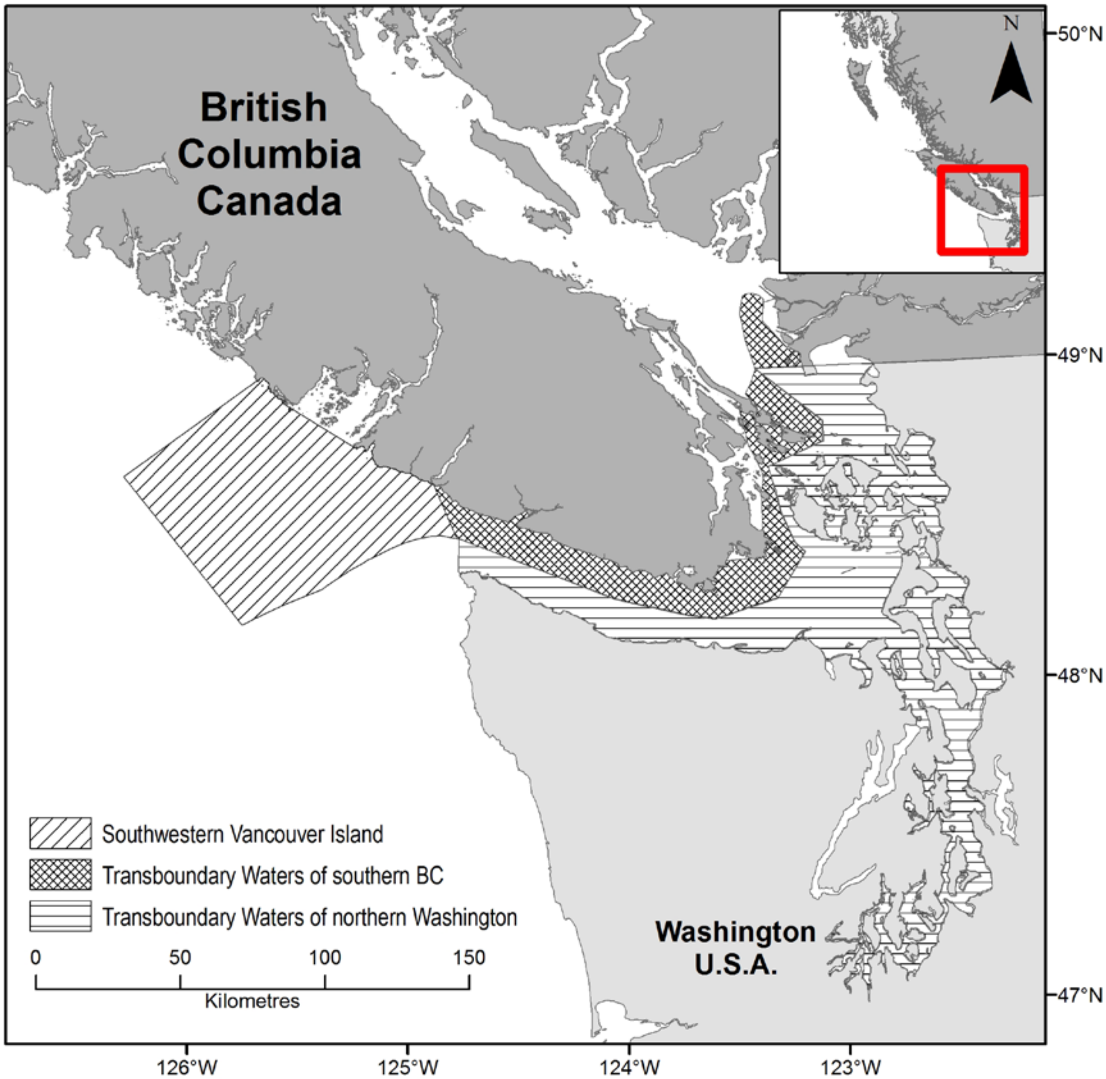

Figure 5. Critical habitat areas identified for Southern Resident Killer Whales. Critical habitat is not composed of the entire area within the identified boundaries but only those areas within the geographical boundaries where the described biophysical features and the functions they support occur, as described in Table 4. The hatched areas in the transboundary waters of southern BC and off southwestern Vancouver Island are the critical habitat areas in Canadian waters for Southern Resident Killer Whales, as designated under SARA. The hatched area in the transboundary waters of northern Washington State is designated as Southern Resident Killer Whale critical habitat under the U.S. ESA.

Biophysical functions, features, and attributes

Seasonal distribution and movement patterns of Resident Killer Whales in Canadian Pacific waters are strongly associated with the availability of their preferred prey, Chinook Salmon, and secondarily Chum Salmon (Ford 2006; Ford and Ellis 2006; Ford et al. 2010; Hanson et al. 2010). Habitats that are important for the survival or recovery of Resident Killer Whales are those that provide for profitable foraging on these key prey species, including the acoustic and physical space required to successfully pursue and capture prey. Other activities, including resting and socializing, similarly depend on an acoustic environment that does not impede effective communication among whales.

The only activity that is strictly associated with particular geographic locations is beach rubbing by Northern Resident Killer Whales, which only takes place at specific traditional sites. Several of these sites are included in the Northern Resident Killer Whale critical habitat located in Johnstone Strait (Ford 2006). These rubbing beaches are composed of small rounded pebbles approximately 1 – 5 cm in diameter and are usually situated along otherwise rocky shorelines (Ford pers. comm. 2018).

Table 4 summarizes the best available knowledge of the biophysical functions, features, and attributes for Northern and Southern Resident Killer Whales. Note that not all attributes in Table 4 must be present in order for a feature to be identified as critical habitat. If a feature as described in Table 4 is present and capable of supporting the associated functions, the feature is considered critical habitat for the species.

The features, functions, and attributes described in Table 4 are based on narrative provided in the 2011 recovery strategy and on Table 1 of DFO (2017b). They apply to all four critical habitat areas and to both populations, with the exception of those associated with beach rubbing, a function that is known to be important for Northern Resident Killer Whales but has not been documented for Southern Residents. As Resident Killer Whales travel with their matrilines throughout their lives, the features, functions, and attributes described also apply to all life stages of Resident Killer Whales.

There is currently insufficient information with which to quantify the levels of many of the attributes listed in Table 4 required to support the features and functions of critical habitat. For example, the density, quantity, and quality of prey needed to support Resident Killer Whale populations are unknown. Additionally, although it is assumed that Chinook remains the primary prey species of Resident Killer Whales throughout the year, the vast majority of Resident Killer Whale prey samples have been collected during summer and fall, and their year-round diet is not well-understood. It is therefore possible that additional important prey species may be identified in the future. Broad studies focused on identifying additional habitats that are important to Resident Killer Whales, and to better understand threats to critical habitat are included in section 7.2. In addition, the action plan for Northern and Southern Resident Killer Whales includes several recovery measures to refine knowledge of the functions, features and attributes of critical habitat. The descriptions of the attributes in Table 4 may be refined in the future, as additional information becomes available.

Table 4. Summary of the biophysical functions, features, and attributes of critical habitat necessary for the survival or recovery of Northern and Southern Resident Killer Whales

Function	Feature	Attribute
Feeding and foraging	Availability of Chinook Salmon, Chum Salmon, and other important prey species	Sufficient quantity and quality of Chinook Salmon to provide for profitable foraging Diversity of Chinook stocks with a variety of spatial and temporal migration patterns sufficient to maintain availability

		Sufficient quantity and quality of Chum Salmon and other species that comprise part of the Resident Killer Whale diet
Feeding and foraging Reproduction, socializing, resting Beach rubbing (Northern Resident Killer Whales)	Acoustic environment	Anthropogenic noise level that does not impede effective acoustic social signaling and echolocation to locate prey Anthropogenic noise level that does not result in loss of habitat availability or function
Feeding and foraging Reproduction, socializing, resting	Water quality	Water quality of a sufficient level to support Chinook stocks Water quality of a sufficient level to support Chum Salmon and other species that comprise part of the Resident Killer Whale diet Water quality of a sufficient level so as not to result in loss of function
Feeding and foraging Reproduction, socializing, resting	Physical space	Unimpeded physical space surrounding individual whales (minimum vessel approach distance 200m)
Beach rubbing (Northern Resident Killer Whales)	Rubbing beach	Suitable physical habitat to allow for beach rubbing behaviour

Summary of critical habitat relative to the recovery goal and objectives

Critical habitat areas identified in this recovery strategy are areas that, based on current best available information, the Minister of Fisheries and Oceans and the Minister responsible for the Parks Canada Agency consider necessary to partially achieve the recovery goal and objectives required for the survival or recovery of Northern and Southern Resident Killer Whales.

It is unknown if critical habitat identified in this recovery strategy is sufficient to achieve the species' recovery goal and objectives. The schedule of studies outlines the research required to identify additional critical habitat and to acquire more detail about the critical habitat identified to achieve the species' recovery goal and objectives. Additional critical habitat may be identified in future updates to the recovery strategy.

7.2 Schedule of studies to identify critical habitat

Further research is required to refine the understanding of the functions, features, and attributes of the currently identified critical habitat, to identify potential additional critical habitat necessary to support the species' recovery goal and objectives and to protect the critical habitat from destruction. This additional work includes the studies listed in Table 5. Refer to the report on the progress of recovery strategy implementation for the Northern and Southern Resident Killer Whales in Canada (DFO 2016b) for more details regarding the progress made and the status of the studies outlined in Table 5. In addition to the broad studies outlined in Table 5, the Action Plan for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada (DFO

2017a) includes more specific recovery measures focused on refining the understanding of the features, functions, and attributes outlined in Table 4, on threats to critical habitat and on supporting identification of additional areas for critical habitat identification.

Table 5. Schedule of studies to refine critical habitat and identify potential additional critical habitat areas for Northern and Southern Resident Killer Whales

Study	Status
Year-round comprehensive surveys to identify areas of occupancy	Underway
Identify key feeding areas throughout the year to determine whether they should be proposed as additional critical habitat	Underway
Identify activities other than foraging that may be important functions of critical habitat	Underway
Identify sources of acoustic disturbance that may negatively impact or affect access to critical habitat	Underway
Identify sources of physical disturbance that may negatively impact or affect access to critical habitat	Underway
Identify sources of biological and chemical contaminants that may negatively impact critical habitat	Underway
Identify factors that may negatively affect an adequate and accessible supply of prey in areas of critical habitat	Underway

7.3 Activities likely to result in the destruction of critical habitat

Under SARA, critical habitat must be legally protected within 180 days of being identified in a recovery strategy or action plan. Northern Resident Killer Whale critical habitat in Johnstone and southeastern Queen Charlotte Straits and Southern Resident Killer Whale critical habitat in the transboundary waters of southern BC has been protected through a SARA Critical Habitat Order since 2009. It is anticipated that protection of the four Resident Killer Whale critical habitat areas identified in this recovery strategy will be accomplished through a SARA Critical Habitat Order made under subsections 58(4) and (5), which will invoke the prohibition in subsection 58(1) against the destruction of any part of the identified critical habitat. The term "recovery strategy" is defined in subsection 2(1) of SARA as meaning "a recovery strategy included in the public registry under subsection 43(2), and includes any amendment to it included in the public registry under section 45". Thus, reading the definition of "critical habitat" in conjunction with the definition of "recovery strategy," the Critical Habitat Order will apply not only to the critical habitat identified in the recovery strategy, but also to any modification to the critical habitat subsequently made in an amended recovery strategy, without the need to amend the Critical Habitat Order.

The following examples of activities likely to result in the destruction of critical habitat are based on known human activities that are likely to occur in and around critical habitat and would result in the destruction of critical habitat if unmitigated. The list of activities is neither exhaustive nor exclusive and has been guided by the threats described in section 4 of this recovery strategy. The absence of a specific human activity does not preclude or restrict the Department or Parks

Canada Agency's ability to regulate that activity under SARA. Furthermore, the inclusion of an activity does not result in its automatic prohibition and does not mean the activity will inevitably result in destruction of critical habitat. Every proposed activity must be assessed on a case-by-case basis and site-specific mitigation will be applied where it is reliable and available. Where information is available, thresholds and limits have been developed for critical habitat attributes to better inform management and regulatory decision making. However, in many cases knowledge of a species and its critical habitat's thresholds of tolerance to disturbance from human activities is lacking and must be acquired.

Reduced prey availability

Availability of Chinook and Chum Salmon is key to the presence of Resident Killer Whales in critical habitat areas (Ford and Ellis 2005; DFO 2017b). Maintaining an adequate food supply for Resident Killer Whales depends on many factors, including the body size and condition of prey, as well as sufficient stock diversity of key prey species to maintain prey availability over time. Activities that result in insufficient abundance, quality, or availability of Chinook Salmon, Chum Salmon, or other Resident Killer Whale prey species could therefore lead to destruction of critical habitat. These include fishing for Chinook Salmon, Chum Salmon, and other important prey species, as well as activities that impact the survival and prey supply of these species such that they are not of sufficient abundance, quality, or availability for Resident Killer Whales.

Acoustic disturbance

There is growing awareness of the impacts of anthropogenic noise on cetaceans (Nowacek et al. 2007; Weilgart 2007). As Killer Whales rely on sound to carry out their life functions, including foraging and socializing, the acoustic environment is an important component of critical habitat. Threats to the acoustical integrity of critical habitat include both acute and chronic noise, and are discussed in detail in section 4.2.3 Underwater noise. Acute noise, including seismic surveys, military and commercial sonars, pile driving and underwater explosions, can result in behavioural changes and displacement from habitat for cetaceans (Morton and Symonds 2002; Weilgart 2007). Chronic noise is primarily associated with vessel traffic, and can result in masking of communication and echolocation signals of Killer Whales (Erbe 2002; Foote et al. 2004; Holt et al. 2009).

Environmental contaminants

Environmental contaminants pose a serious threat to Killer Whales. These contaminants and their sources are discussed in section 4.2.1. As high trophic level, long-lived animals, Killer Whales are particularly vulnerable to persistent bioaccumulating toxins (PBTs) that accumulate in their fatty tissues as they feed on already contaminated prey. The introduction of high levels of contaminants is therefore a threat to Resident Killer Whale critical habitat. While many contaminants are airborne and dispersed throughout the coastal waters of BC, the waters surrounding the lower mainland and Vancouver Island are particularly at risk due to their proximity to human settlement.

The threat of a spill of oil or other toxic material within the areas of critical habitat poses not only an immediate and acute risk to the health of Resident Killer Whale populations (see section 4.2.4), but has the potential to make critical habitat areas uninhabitable for an extended period of time.

Physical disturbance

Vessels in close proximity to Killer Whales have the potential to disrupt behaviours, including foraging and beach rubbing (Williams et al. 2006; Lusseau et al. 2009). Additionally, prey must be physically accessible to Resident Killer Whales and physical obstacles at the surface and underwater which interfere with whales' abilities to pursue and capture prey represent a threat to critical habitat.

Killer Whales are particularly sensitive to disturbance while beach rubbing (Williams et al. 2006); the physical presence of vessels and other obstacles can not only disrupt beach rubbing, but can also prevent Killer Whales from approaching rubbing beaches to initiate this behaviour.

Geophysical disturbance

A key feature of the Northern Resident Killer Whale critical habitat in Johnstone and southeastern Queen Charlotte Straits is the presence of several rubbing beaches. Activities associated with the geophysical destruction of rubbing beaches are therefore threats to critical habitat. Rubbing beaches may also be vulnerable to activities that alter stream flow and siltation; thus, activities that occur upstream of these beaches, even outside of the designated critical habitat area, can pose a threat to critical habitat.

Table 6. Examples of activities likely to result in the destruction of critical habitat of Northern and Southern Resident Killer Whales

Threat	Activity	Effect - pathway	Function affected	Feature affected	Attribute affected
Reduced prey availability	Fishing for Chinook Salmon, Chum Salmon, and other important prey species Other activities that are detrimental to habitat and survival of prey (e.g. fishing for forage fish species)	Loss of prey Loss of forage fish for prey species	Feeding and foraging	Availability of Chinook Salmon, Chum Salmon and other important prey species	Sufficient quantity and quality of Chinook Salmon to provide for profitable foraging Diversity of Chinook stocks with a variety of spatial and temporal migration patterns sufficient to maintain availability Sufficient quantity and quality of Chum Salmon and other species that comprise part of the Resident Killer Whale diet
Acoustic disturbance	Vessel traffic Seismic surveys, military, and commercial sonars Pile driving, underwater explosions	Chronic noise resulting in masking of communication and echolocation Acute and chronic acoustic disturbance resulting in disruption of behaviour or displacement from habitat	Feeding and foraging Reproduction, socializing, resting Beach rubbing (Northern Resident Killer Whales)	Acoustic environment	Anthropogenic noise level that does not impede effective acoustic social signaling and echolocation to locate prey Anthropogenic noise level that does not result in loss of habitat availability or function
Environmental contaminants	Release of deleterious substances Point source and non-point source pollution	Loss of prey or reduction in prey quality Loss of water quality	Feeding and foraging Reproduction, socializing, resting	Availability of Chinook Salmon, Chum Salmon, and other important prey species Water quality	Water quality of a sufficient level to support Chinook stocks Water quality of a sufficient level to support Chum Salmon and other species that comprise part of the Resident Killer Whale diet Water quality of a

					sufficient level so as not to result in loss of function
Physical disturbance	Vessel approach to whales (within 200m) Vessel anchoring in vicinity of rubbing beaches Activities that prevent approach of whales to rubbing beaches; or that displace or disrupt rubbing behaviour Human presence on rubbing beaches when whales present or nearby	Reduction of physical space available to whales Displacement of whales from rubbing beaches, prevention of use of rubbing beaches	Feeding and foraging Reproduction, socializing, resting Beach rubbing (Northern Resident Killer Whales)	Physical space	Unimpeded physical space surrounding individual whales (minimum vessel approach distance 200m)
Geophysical disturbance	Shore-based industrial activities that could alter beach substrate Activities that result in alteration of stream flow to rubbing beaches, beach sediment, and siltation	Geophysical disturbance resulting in loss of function	Beach rubbing (Northern Resident Killer Whales)	Rubbing beach	Suitable physical habitat to allow for beach rubbing behaviour

8. Statement on action plans

SARA’s approach to recovery planning is a two-part approach, the first part being the recovery strategy and the second part being the action plan. An action plan contains specific recovery measures or activities required to meet the objectives outlined in the recovery strategy.

An action plan for Northern and Southern Resident Killer Whales was completed and posted to the Species at Risk Public Registry in 2017 (DFO 2017a). Additionally, several multi-species action plans that include Resident Killer Whales have been developed by the Parks Canada Agency and posted to the Species at Risk Public Registry. These include the multi-species action plan for Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site (Parks Canada Agency 2016); the multi-species action plan for Pacific Rim National Park Reserve of Canada (Parks Canada Agency 2017a); and the proposed multi-species action plan for Gulf Islands National Park Reserve of Canada (Parks Canada Agency 2017b).

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Appendix A. Record of cooperation and consultation

Northern and Southern Resident Killer Whales are listed on Schedule 1 of the Species at Risk Act (SARA) and as an aquatic species are under federal jurisdiction and managed by Fisheries and Oceans Canada (DFO): 200 - 401 Burrard Street, Vancouver, BC. Southern Resident Killer Whales are a transboundary population and the United States has developed a recovery plan for Southern Resident Killer Whales as mandated under their Endangered Species Act.

To assist in the development of an initial draft of this recovery strategy, DFO brought together a diverse team of experts from various government, environmental, eco-tourism and non-governmental groups from both Canada and the United States. On the advice of the Species at Risk Coordinator at the BC Aboriginal Fisheries Commission, a letter of invitation followed up by phone calls was sent to all coastal First Nations seeking their interest in participating on the Recovery Team and/or Technical Workshop. No response was received from First Nations for inclusion on either initiative. Subsequent to the consultation process the Namgis First Nation has indicated an interest to be involved in future action planning and local implementation.
A Technical Workshop was hosted in March 2004 to provide a forum for the sharing of knowledge and expertise on Killer Whales with an invited group of scientific and technical stakeholders which was invaluable in assisting the Resident Killer Whale Recovery Team to formulate an effective recovery strategy.

Public news releases announcing the Recovery Team and development of the recovery strategy and a notice of Public Consultations were sent to a distribution list of whale-related contacts provided to DFO in recent years from environmental groups, the eco-tourism sector, non-governmental organizations, government agencies and private citizens. An announcement was also placed in the Vancouver Aquarium Aquanews newsletter.

Additional input was sought through the internet (March 2005) on the draft recovery strategy and a discussion guide and feedback form were available. Responses were received from eco-tourism and non-government organizations and the Mowachaht/Muchalaht First Nations. Input from the United States National Oceanic and Atmospheric Administration and the State of Washington Department of Fish and Wildlife was received through team participation. Feedback on the recovery strategy was also received from other government agencies including: the Department of National Defence, Province of BC, SARA Secretariat, Environment and Climate Change Canada and Natural Resources Canada. An external peer review was conducted by Volker Deecke, Ph.D., University of BC, and Christophe Guinet, Centre d'Etudes Biologiques de Chize, France. All feedback from both government agencies and peer reviewers was incorporated into the recovery strategy.

A proposed version of the original recovery strategy was posted on the SARA Public Registry for a 60-day public comment period, from June 21 to August 20, 2007. During this time, numerous comments were received from a wide variety of sources including government agencies, commercial and recreational fishing groups, ecotourism operators, non-governmental organizations, and private citizens. All feedback from this comment period was considered and incorporated into the recovery strategy as appropriate. Following the public comment period, the proposed Recovery Strategy was revised by DFO in order to address public comments and to reflect the responsibilities of the competent Minister.

A record of consultation for the amendments to the 2018 recovery strategy will be included prior to the document being posted to the Species at Risk Public Registry.

Appendix B. Recovery team members

The following individuals composed the Recovery Team for the development of the 2008 recovery strategy.

Marilyn Joyce	Co-Chair: Resident Killer Whale Recovery Team Fisheries & Oceans Canada, Fisheries Management Branch Pacific Region, 200-401 Burrard Street, Vancouver, B.C., V6C 3S4, phone: 604-666-9965, email: joycema@pac.dfo-mpo.gc.ca
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David Bain	Friday Harbor Laboratories, University of Washington, WA
Ken Balcomb	Centre for Whale Research, WA
Jim Borrowman	North Island Whale Watching Community, BC
John Durban	National Marine Fisheries Service, Alaska Fisheries Science Centre, National Marine Mammal Laboratory, WA
Graeme Ellis	Fisheries & Oceans Canada, Science Branch, Conservation Biology Section, BC
John Ford	Fisheries & Oceans Canada, Science Branch, Conservation Biology Section, BC
Christine Garrett	Environment and Climate Change Canada, Environmental Protection Branch, Commercial Chemicals Division , BC
Anna Hall	Whale Watch Operators Association North West, BC
Steve Jeffries	Washington Department of Fish and Wildlife, Marine Mammal Investigations, WA
Linda Jones	National Marine Fisheries Service, Northwest Fisheries Science Centre, National Marine Mammal Laboratory, WA
Brent Norberg	National Marine Fisheries Service, Protected Resources Division, WA
Peter Olesiuk	Fisheries & Oceans Canada, Science Branch, Conservation Biology Section, BC
Rich Osborne	The Whale Museum, WA
Rob Paynter	Ministry of Sustainable Resource Management, BC
Brian Reader	Western Canada Service Centre, Parks Canada Agency, BC
Peter Ross	Fisheries and Oceans Canada, Marine Environmental Quality Section, BC
Paul Spong	Orcalab, Hanson Island, BC
Andrew Trites	Marine Mammal Research Unit, Fisheries Centre, University of British Columbia, BC
Scott Wallace	(Alternate) Marine Conservation Caucus, Raincoast Conservation Society Sierra Club of Canada, B.C. Chapter, BC

Gary Wiles	(Alternate) Washington Department of Fish and Wildlife, Marine Mammal Investigations, WA
Rob Williams	Marine Conservation Caucus, Raincoast Conservation Society, BC
Brian Riddell	Fisheries & Oceans Canada, Science Branch, Salmon and Freshwater Ecosystems, BC

Resource Personnel:

Paul Cottrell	Fisheries & Oceans Canada, A/SARA First Nations Coordinator, Treaty & Aboriginal Policy Branch, BC
Carole Eros	Fisheries & Oceans Canada, Species at Risk Recovery Planning Coordinator, Resource Management Pacific Region, BC
Annely Greene	Fisheries & Oceans Canada, Marine Mammal Program Manager, Resource Management Pacific Region, BC
Kathy Heise	Department of Zoology, University of British Columbia, BC
Lara Sloan	Fisheries & Oceans Canada, Communications Officer, Fisheries Management Pacific Region, BC

Appendix C. Contaminant acronyms

APEs:	Alkylphenol ethoxylates
DBT:	Dibutyltin
DDT:	Dichlorodiphenyl trichloroethane
PAHs:	Persistent aromatic hydrocarbons
PBDEs:	Polybrominated diphenylethers
PBDTs:	Polybrominated trienylethers
PCBs:	Polychlorinated biphenyls
PCDDs:	Dioxins, polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
PCNs:	Polychlorinated napthalenes
PCPs:	Polychlorinated paraffins
PCTs:	Polychlorinated terphenyls
SPFOs:	Perfluoro-octane sulfonates
POPs:	Persistent organic pollutants
TBT:	Tributyltin

Appendix D. Description of critical habitat

Southern Resident Killer Whale critical habitat boundaries for transboundary waters of southern Georgia, Haro, and Juan de Fuca Straits. Described clockwise from the western boundary - all Latitudes are Decimal Degrees North; all Longitudes are Decimal Degrees West.

		Start and end coordinates			
	Point description	**Latitude Deg**	**Latitude Min**	**Longitude Deg**	**Longitude Min**
1	Western boundary	48	29.68	124	44.31
2		48	40.02	124	50.68
3	Excluding waters north of the line joining (Sooke Inlet)	48	21.30	123	44.32
4		48	20.33	123	42.90
5	Excluding waters north of the line joining (Royal Roads, Esquimalt Hbr, Victoria Hbr)	48	24.25	123	28.97
6		48	24.57	123	22.61
7	Excluding waters west of the line joining (Cordova Channel and Sidney Channel)	48	29.69	123	18.61
8		48	36.12	123	18.51
9	Excluding waters west of the line joining (western half of Miners Channel and the waters west of Gooch Island)	48	37.04	123	18.49
10		48	39.70	123	17.72
11	Excluding waters west of the line joining (western half of Prevost Channel and Moresby Passage)	48	39.88	123	17.68
12		48	42.96	123	19.63
13	Excluding waters west of the line joining (western portion of Swanson Channel between Moresby Island and Prevost Island)	48	43.34	123	19.88
14		48	48.86	123	22.70
15	Excluding waters west of the line joining (western portion of Trincomali Channel between Prevost Island and Parker Island)	48	50.66	123	23.33
16		48	52.61	123	23.92
17	Excluding waters west of the line joining (western portion of Trincomali Channel between Parker Island and Galiano Island)	48	52.85	123	23.92
18		48	53.08	123	23.76
19	Excluding waters west of the line joining (western portion of southern Strait of Georgia)	48	54.28	123	20.67
20		48	55.39	123	21.98
21		49	0.00	123	18.88
22		49	10.39	123	22.82
23		49	13.58	123	21.97
24	Excluding waters north of the line joining (portion of southern Strait of Georgia)	49	13.58	123	21.97
25		49	14.00	123	21.09
26		49	14.18	123	19.22
27		49	13.79	123	17.21
28	Excluding waters north and east of the line joining (portion of southern Strait of Georgia)	49	13.79	123	17.21
29		49	12.87	123	15.75
30		49	9.01	123	16.48
31		49	3.39	123	9.24
32		49	3.47	123	8.48
	And bounded on the east and south by Point Roberts and the United States Border				

Northern Resident Killer Whale critical habitat boundaries for Johnstone and southeastern Queen Charlotte Straits. Described clockwise from the western boundary - all Latitudes are Decimal Degrees North; all Longitudes are Decimal Degrees West.

		Start and end coordinates			
	Point Description	**Latitude Deg**	**Latitude Min**	**Longitude Deg**	**Longitude Min**
1	Western boundary (Vancouver Island to Numas Island)	50	36.98	127	11.00
2		50	46.24	127	6.76
3	Northern boundary (Numas Island to Broughton Island)	50	46.27	127	5.26
4		50	46.41	126	48.27
5	Northern boundary (Broughton Island to Screen Island / Eden Island)	50	46.13	126	47.30
6		50	44.95	126	43.55
7	boundary line running from Eden Island to Crib Island (including waters of Queen Charlotte Strait and excluding waters of Trainer Passage)	50	44.79	126	43.22
8		50	43.67	126	42.73
9	boundary line running from Crib Island to House Ilet (including waters of Queen Charlotte Strait and excluding waters of Arrow and Spring Passages)	50	43.33	126	42.58
10		50	40.16	126	41.21
11	boundary line running from House Ilet to Swanson Island (including waters of Queen Charlotte Strait and excluding waters of Knight Inlet)	50	40.16	126	41.21
12		50	37.75	126	43.86
13	boundary line running from Swanson Island to Compton Island (including waters of Blackfish Sound excluding waters of West Passage)	50	36.06	126	41.77
14		50	35.84	126	41.42
15	boundary line running from Compton Island to Harbledown Island (including waters of Blackfish Sound excluding waters of Whitebeach Passage)	50	35.50	126	40.86
16		50	35.38	126	40.68
17	boundary line running from Harbledown Island to Parson Island (including waters of Blackfish Sound excluding waters of Parson Bay)	50	35.19	126	40.93
18		50	34.43	126	40.73
19	boundary line running from Parson Island to West Cracroft Island (including waters of Blackfish Sound excluding waters of Baronet Passage)	50	33.65	126	39.95
20		50	32.98	126	39.73
	Waters of western Johnstone Strait bounded on the north by West Cracroft Island, the mainland, Hardwicke Island and West Thurlow Island with no exclusions except:				
24	boundary line running from West Cracroft Island to the mainland (including waters of western Johnstone Strait excluding waters of Havannah Channel)	50	31.32	126	20.35
25		50	31.09	126	17.05
26	boundary line running from the mainland to Hardwicke Island (including waters of western Johnstone Strait excluding waters of Sunderland Channel)	50	28.46	126	2.54
27		50	26.57	125	57.94
28	boundary line running from Hardwicke Island to Eden Point on West Thurlow Island (including waters of western Johnstone Strait excluding waters of Chancellor Channel)	50	24.58	125	48.29
29		50	23.91	125	47.38
30	boundary line running from Eden Point to Tyee Point on West Thurlow Island (including waters of western Johnstone Strait excluding waters of Vere Cove)	50	23.91	125	47.38
31		50	23.26	125	47.06
32	Eastern boundary line running from West Thurlow Island (including waters of western Johnstone Strait excluding waters of eastern Johnstone Strait and Mayne Passage)	50	23.42	125	34.39
33		50	21.88	125	34.23
	Waters of western Johnstone Strait bounded on the south by Vancouver Island - no exclusions except:				
35	boundary line running from Graveyard Point to Kelsey Bay Harbour on Vancouver Island (including waters of western Johnstone Strait excluding waters of Salmon Bay)	50	23.45	125	56.71
36		50	23.80	125	57.62

Northern and Southern Resident Killer Whale critical habitat boundaries off Southwestern Vancouver Island. Described counter-clockwise from the northern boundary - all Latitudes are Decimal Degrees North; all Longitudes are Decimal Degrees West.

	Point Description	Start and end coordinates Latitude Deg	Latitude Min	Longitude Deg	Longitude Min
1	Northern Boundary (Vancouver Island running southwest offshore)	48	59.7	-125	40.15
2		48	41.72	-126	17.88
3	Offshore Boundary	48	13.95	-125	44.61
4	Waters adjacent the U.S.A. Border	48	29.72	-124	44.32
5	Waters adjacent Southern Resident Killer Whale critical habitat in transboundary waters of southern Georgia, Haro, and Juan de Fuca Straits	48	40.04	-124	50.66
6	And bounded by Vancouver Island to the Northwest boundary				
7	Excluding waters north of the line joining (Nitinat Inlet)	48	40.05	-124	50.99
8		48	40.13	-124	51.3
9	Excluding waters northeast of the line joining Cape Beale and Amphitrite Point (Barkley Sound)	48	55.22	-125	32.391
10		48	47.174	-125	13.039

Northern Resident Killer Whale critical habitat boundaries in western Dixon Entrance. Described clockwise from the western boundary - all Latitudes are Decimal Degrees North; all Longitudes are Decimal Degrees West.

	Point Description	Start and end coordinates Latitude Deg	Latitude Min	Longitude Deg	Longitude Min
1	Western Boundary (Langara Island Northward)	54	15.38	-133	3.5
2		54	15.99	-133	3.5
3	Northern Boundary	54	16.05	-131	40.45
4	Eastern Boundary	54	9.13	-131	40.43
5	Excluding waters south of line (McIntyre Bay)	54	5.491	-132	15.97
6	Bounded by Graham Island on the Southern Boundary to	54	11.07	-133	1.55
7	Northward to Langara Island, excluding waters west of the line	54	11.43	-133	0.75
8	Bounded on the western Boundary by the eastern side of Langara Island up to Langara Light				
9	Excluding waters south of line (Virago Sound, Naden Harbour)	54	5.86	-132	26.26
10		54	5.57	-132	34.3