

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

## KILLER WHALE



March 2008



## About the Species at Risk Act Recovery Strategy Series

### What is the *Species at Risk Act* (SARA)?

SARA is the Act developed by the federal government as a key contribution to the common national effort to protect and conserve species at risk in Canada. SARA came into force in 2003 and one of its purposes is “*to provide for the recovery of wildlife species that are extirpated, endangered or threatened as a result of human activity.*”

### What is recovery?

In the context of species at risk conservation, recovery is the process by which the decline of an endangered, threatened, or extirpated species is arrested or reversed, and threats are removed or reduced to improve the likelihood of the species’ persistence in the wild. A species will be considered recovered when its long-term persistence in the wild has been secured.

### What is a recovery strategy?

A recovery strategy is a planning document that identifies what needs to be done to arrest or reverse the decline of a species. It sets goals and objectives and identifies the main areas of activities to be undertaken. Detailed planning is done at the action plan stage.

Recovery strategy development is a commitment of all provinces and territories and of three federal agencies — Environment Canada, Parks Canada Agency, and Fisheries and Oceans Canada — under the Accord for the Protection of Species at Risk. Sections 37–46 of SARA ([http://www.sararegistry.gc.ca/the\\_act/default\\_e.cfm](http://www.sararegistry.gc.ca/the_act/default_e.cfm)) outline both the required content and the process for developing recovery strategies published in this series.

Depending on the status of the species and when it was assessed, a recovery strategy has to be developed within one to two years after the species is added to the List of Wildlife Species at Risk. Three to four years is allowed for those species that were automatically listed when SARA came into force.

### What’s next?

In most cases, one or more action plans will be developed to define and guide implementation of the recovery strategy. Nevertheless, directions set in the recovery strategy are sufficient to begin involving communities, land users, and conservationists in recovery implementation. Cost-effective measures to prevent the reduction or loss of the species should not be postponed for lack of full scientific certainty.

### The series

This series presents the recovery strategies prepared or adopted by the federal government under SARA. New documents will be added regularly as species get listed and as strategies are updated.

### To learn more

To learn more about the *Species at Risk Act* and recovery initiatives, please consult the SARA Public Registry (<http://www.sararegistry.gc.ca/>) and the web site of the Recovery Secretariat ([http://www.speciesatrisk.gc.ca/recovery/default\\_e.cfm](http://www.speciesatrisk.gc.ca/recovery/default_e.cfm)).

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

**March 2008**

**Recommended citation:**

Fisheries and Oceans Canada. 2008. Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada. *Species at Risk Act Recovery Strategy Series*, Fisheries & Oceans Canada, Ottawa, ix + 81 pp.

**Additional copies:**

You can download additional copies from the SARA Public Registry (<http://www.sararegistry.gc.ca/>)

**Cover illustration:** Graeme Ellis, Fisheries & Oceans Canada

Également disponible en français sous le titre :  
« Programme de rétablissement des épaulards résidents (*Orcinus orca*) du nord et du sud au Canada »

© Her Majesty the Queen in Right of Canada, represented by the Minister of Fisheries & Oceans, 2008. All rights reserved.

ISBN 978-0-662-47242-1

Catalogue no. En3-4/46-2007E-PDF

*Content (excluding the cover illustration) may be used without permission, with appropriate credit to the source.*

## **DECLARATION**

This recovery strategy for the Northern and Southern Resident Killer Whales has been prepared in cooperation with jurisdictions responsible for the species, as described in the Preface. Fisheries and Oceans has taken final editorial responsibility for the strategy. This revised document constitutes the Minister of Fisheries and Oceans' final recovery strategy for the northern and southern resident killer whale populations as required by the *Species at Risk Act*.

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 & Oceans Canada or any other jurisdiction alone. In the spirit of the Accord for the Protection of Species at Risk, the Minister of Fisheries & Oceans invites all Canadians to join Fisheries & Oceans Canada in supporting and implementing this strategy for the benefit of the northern and southern resident killer whales and Canadian society as a whole. Fisheries & Oceans Canada will endeavour to support implementation of this strategy, given available resources and varying species at risk conservation priorities. The Minister will report on progress within five years.

This strategy will be complemented by one or more action plans that will provide details on specific recovery measures to be taken to support conservation of the species. The Minister will take steps to ensure that, to the extent possible, Canadians directly affected by these measures will be consulted.

## **RESPONSIBLE JURISDICTIONS**

Under the Species-At-Risk Act, the Minister of Fisheries and Oceans (the competent minister) is responsible for preparing and finalizing the Recovery Strategy with respect to Northern and Southern Resident Killer Whales.

These populations occur off the coast of the province of British Columbia and within the proposed Gwaii Haanas and Southern Strait of Georgia National Marine Conservation Areas. The Province of British Columbia, Environment Canada and Parks Canada also cooperated in the development of this recovery strategy. In addition, both populations are considered trans-boundary in United States waters. The US National Oceanic and Atmospheric Administrations also participated in its preparation.

## **ACKNOWLEDGMENTS**

Fisheries and Oceans Canada wishes to thank the Resident Killer Whale Recovery Team for its efforts in developing the proposed Recovery Strategy for the Northern and Southern Resident Killer Whale 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 Figures 1-3.

The proposed Recovery Strategy received from the Recovery Team was posted on the Species-At-Risk Public Registry for public comment on June 21, 2007. Following the public comment period, the proposed Recovery Strategy has been revised by DFO in order to address public comments and to reflect the responsibilities of the competent Minister.

# 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 summarized also below.

While this recovery strategy will clearly benefit the environment by promoting the recovery of the northern and southern 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 and its functions. 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 will be evaluated and detailed in the action plan for these populations along with an evaluation of effects and costs for each activity or measure. Therefore, taking into account the general nature of the recommendations for new 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.

## RESIDENCE

SARA defines residence as: “*a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating*” [SARA S2(1)].

Residence descriptions, or the rationale for why the residence concept does not apply to a given species, are posted on the SARA public registry: [http://www.sararegistry.gc.ca/plans/residence\\_e.cfm](http://www.sararegistry.gc.ca/plans/residence_e.cfm)

## PREFACE

The northern and southern resident populations of killer whales are marine mammals and are under the jurisdiction of the federal government. The *Species at Risk Act* (SARA, Section 37) requires the competent minister to prepare recovery strategies for listed extirpated, endangered or threatened species. The northern and southern resident populations of killer whales were listed as threatened and endangered, respectively under SARA at proclamation on June 5, 2003. Fisheries and Oceans Canada – Pacific Region led the development of this recovery strategy. The strategy meets SARA requirements in terms of content and process (Sections 39-41). This Recovery Strategy was developed in cooperation or consultation with many individuals, organizations and government agencies, in particular:

- Environment Canada, Parks Canada, Department of National Defence, Natural Resources Canada, the Province of British Columbia, the US National Oceanic and Atmospheric Administration and Washington State Department of Fisheries and Wildlife.
- Marine Centre for Whale Research, The Whale Museum, The Vancouver Aquarium, and the University of British Columbia
- Whale Watch Operators Association NW and the North Vancouver Island Whale Watch Operators

Please see the Record of Cooperation and Consultations -Appendix D for further details.



## EXECUTIVE SUMMARY

Two distinct populations of killer whales (*Orcinus orca*), known as the northern and southern residents, occupy the waters off the west coast of British Columbia. In 2001, 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.

Resident killer whale populations in British Columbia 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 experienced declines of 3% per year between 1995 and 2001, and has increased since then to 85 members in 2003<sup>1</sup>. During the summer and fall, southern residents are primarily found in the trans-boundary waters of Haro Strait, Boundary Pass, the eastern portion of the Strait of Juan de Fuca, and southern portions of the Strait of Georgia. This area is designated as ‘critical habitat’ based on consistent and prolonged seasonal occupancy. Some members of the population typically remain in the same general area in winter and spring, but others appear to range over much greater distances, and have been reported as far south as Monterey Bay, California, and as far north as Haida Gwaii (the Queen Charlotte Islands). Winter and spring critical habitat has not been identified for the latter group. During the summer and fall, the principal prey of southern residents appears to be chinook and chum salmon (*Oncorhynchus tshawytscha* and *O. keta*); little is known of their diet in the winter and spring. The lack of information about winter diet and distribution of the southern residents is a major knowledge gap that impedes our understanding of the principal threats facing the population.

The northern resident killer whale population experienced a decline of 7% between 1997 and 2003, and similar to southern residents, has since increased to 205 members in 2003. 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 (C.M. Gabriele, personal communication). A portion of the population is regularly found in Johnstone Strait and southeastern portions of Queen Charlotte Strait (and adjoining channels) during the summer and fall, and this area is identified as critical habitat based on this consistent seasonal occupancy. Other areas are likely very important to northern residents during this time but they have yet to be clearly identified. Similarly, areas that may constitute critical habitat during the winter and spring are not yet known. Northern residents also appear to feed primarily on chinook and chum salmon during the summer and fall. However, like southern residents, very little is known of their winter distribution and diet, and this knowledge gap must be addressed to fully understand the principal threats affecting the population.

---

<sup>1</sup> Note that there are also 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. For example Krahn et al. (2004) report 83 southern residents in 2003.

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<sup>2</sup>.*

In order to achieve this goal, four principal objectives have been identified. These include:

*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.*

Numerous broad strategies are outlined herein to achieve these objectives. 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. Action plans are recommended to address the threats and issues of knowledge gaps regarding 1) resident killer whale population dynamics and demographics, 2) reduced prey availability, 3) environmental contaminants, 4) physical disturbance, 5) acoustic disturbance, and 6) critical habitat. Action plans will be developed before March 31, 2013.

---

<sup>2</sup> Culture refers to a body of information and behavioural traits that are transmitted within and between generations by social learning

# TABLE OF CONTENTS

DECLARATION .....	i
RESPONSIBLE JURISDICTIONS .....	i
ACKNOWLEDGMENTS .....	ii
STRATEGIC ENVIRONMENTAL ASSESSMENT STATEMENT .....	iii
RESIDENCE .....	iii
PREFACE .....	iv
EXECUTIVE SUMMARY .....	v
LIST OF TABLES .....	ix
LIST OF FIGURES .....	ix
1. BACKGROUND .....	1
1.1. Species Information .....	1
1.1.1. Species Description .....	1
1.2. Distribution .....	3
1.2.1. Global Range .....	3
1.2.2. Canadian Pacific Range .....	3
1.3. Population Size and Trends .....	5
1.3.1. Global .....	5
1.3.2. British Columbia .....	6
1.4. Natural Factors Affecting Population Viability and Recovery .....	9
1.4.1. Biological Limiting Factors .....	9
1.4.2. Other Natural Limiting Factors .....	14
2. THREATS .....	15
2.1. Historic Threats .....	15
2.1.1. Harvest and Live Captures .....	15
2.1.2. Intentional Shootings .....	16
2.1.3. Acoustic Harassment Devices .....	16
2.2. Current Threats .....	16
2.2.1. Environmental Contaminants .....	17
2.2.2. Reduced Prey Availability .....	23
2.2.3. Disturbance .....	25
2.2.4. Oil Spills .....	34
2.2.5. Incidental Mortality in Fisheries .....	35
3. CRITICAL HABITAT .....	35
3.1. Identification of the species' critical habitat .....	36
3.1.1. Southern Residents .....	37
3.1.2. Northern Residents .....	38
3.2. Examples of activities likely to result in destruction of critical habitat .....	40

3.2.1. Geophysical Disturbance	40
3.2.2. Chemical and Biological Contamination	41
3.3. Schedule of studies to identify critical habitat.....	42
3.4. Mechanisms for the protection of critical habitat .....	42
4. KNOWLEDGE GAPS.....	46
5. RECOVERY .....	47
5.1. Recovery Feasibility .....	47
5.2. Recovery Goal .....	48
5.2.1. Interim Measures of Recovery Success	48
5.2.2. Monitoring and Research Strategies	49
5.3. Recovery Objectives and Strategies to Achieve Recovery.....	49
5.3.1. Objective 1	49
5.3.2. Objective 2	50
5.3.3. Objective 3	51
5.3.4. Objective 4	52
5.4. Effects on Non-Target Species .....	52
5.5. Evaluation and the Status of Strategies for Recovery .....	53
5.6. Recommended Approach for Recovery .....	56
5.7. Target Date for Completion of Action Plans .....	56
6. REFERENCES.....	57
APPENDIX A - Glossary.....	74
APPENDIX B - Legal description of critical habitat.....	76
APPENDIX C - Recovery Team Members.....	78
APPENDIX D - Record of Cooperation and Consultation.....	80

## LIST OF TABLES

Table 1. Persistent organic pollutants that may pose a risk to resident killer whales.....	20
Table 2 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).....	29
Table 3 Schedule of studies to identify additional areas of critical habitat and its threats .....	42
Table 4 Current and recommended measures for the protection of critical habitat.....	43
Table 5 Examples of performance measures that may be used to assess the effectiveness of the broad strategies used to achieve the objectives of the Proposed Recovery Strategy for the Northern and Southern Resident Killer Whales in Canada.....	53

## LIST OF FIGURES

Figure 1 The coast of British Columbia showing the general ranges of northern and southern resident killer whales .....	4
Figure 2 Population size and trends for southern resident killer whales from 1974-2003. Source: Unpublished data from the Centre for Whale Research.....	7
Figure 3 Population size and trends for northern resident killer whales from 1974 to 2003. Values reflect the minimum, maximum and estimated number of animals alive as of July 1 in each year. Source: Unpublished data, Cetacean Research Program-DFO, Nanaimo.....	9
Figure 4 The known critical habitat for southern resident killer whales in late spring summer and fall, in British Columbia. The hatched area shows suggested critical habitat for Washington State.. ..	37
Figure 5 The known critical habitat for northern resident killer whales in summer and fall in British Columbia. ....	39

# 1. BACKGROUND

## 1.1. Species Information

The status report and assessment summary for resident killer whales is available from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) Secretariat ([www.COSEWIC.gc.ca](http://www.COSEWIC.gc.ca)).

<b>COSEWIC Assessment Summary</b>	
Common Name:	killer whale, orca,
Scientific Name:	<i>Orcinus orca</i>
Assessment Summary:	Assessed in 1999, reviewed and revised in 2001
COSEWIC Status:	'Southern resident' killer whales are designated as endangered, 'northern resident' killer whales as threatened
SARA Status:	'Southern resident' killer whales, endangered, on Schedule 1 'Northern resident' killer whales, threatened on Schedule 1
Reason for Designation:	The southern resident killer whale population is small, with recent declines of 17% between 1995 and 2001, and currently contains 85 members. The northern resident killer whale population is small at 205 members, with recent declines of 7% between 1997 and 2003. Seasonally, they are exposed to high levels of boat traffic. The availability of their prey is reduced relative to historic levels. High levels of persistent organic pollutants may be compromising their reproductive and immune systems, leading to reduced calving and/ or increased mortality rates.
Range in Canada:	Pacific Ocean
Status History:	In April 1999, the two North Pacific 'resident' killer whale populations were designated threatened. In November 2001, the southern resident population was designated endangered while the northern resident population remained threatened.

### 1.1.1. Species 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 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, but they are thought to feed on fish (Ford et al. 2000, Heise et al. 2003). They 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 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 has 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 matriline that travel, forage, socialize and rest with each other at least 50% of the time, and predicted that pods, like matriline, 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. 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 matriline.

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 1.4.1. 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. They have not been observed interacting and genetic studies have revealed that the two populations rarely if ever interbreed (Barrett-Lennard and Ellis 2001). 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 US governments. In 2001 COSEWIC assigned northern residents ‘threatened’ status, and southern residents ‘endangered’ status. 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.

## **1.2. Distribution**

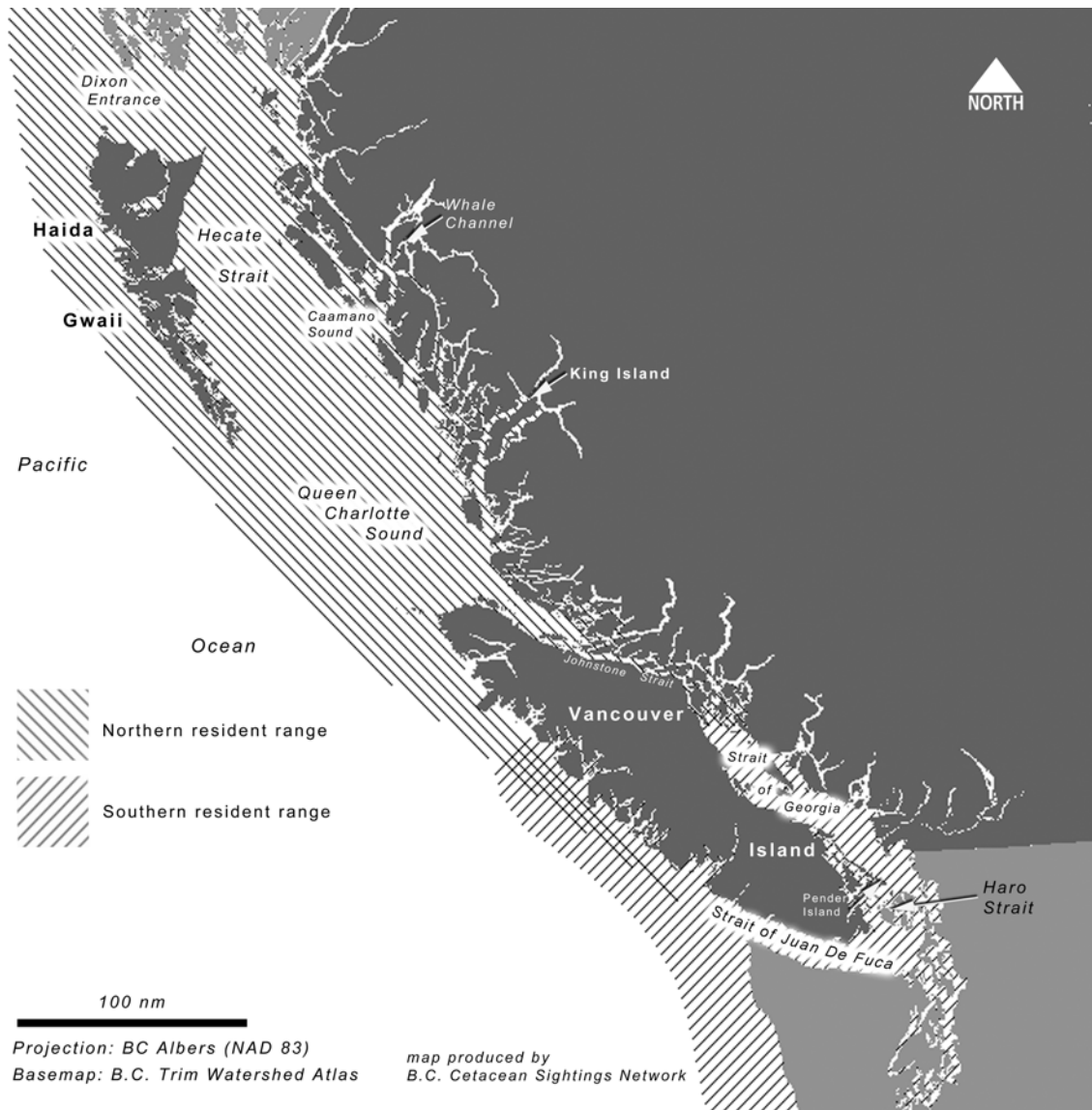
### **1.2.1. Global Range**

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 in press). 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).

### **1.2.2. 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, but they appear to be uncommon in the Atlantic and the Arctic (COSEWIC 2003). In British Columbia (BC), they 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

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 matriline (Ford et al. 2000). The known range of this community is from northern British Columbia to central California (Ford et al. 2000; unpublished data, Cetacean Research Program, Fisheries & Oceans Canada, Pacific Biological Station, Nanaimo, BC [CRP-DFO]). 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-Strait of Juan de Fuca region (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 Langara Island, off Haida Gwaii (Ford et al. 2000, Black et al. 2001, unpublished data (CRP-DFO)).

### *Northern Residents*

The northern resident killer whale community comprises three acoustic clans (A, G, and R) containing 34 matriline, which range from Glacier Bay, Alaska to Grays Harbour, Washington (Ford et al. 2000, unpublished data CRP-DFO). From June to October, they frequent areas from mid Vancouver Island to southeastern Alaska, particularly 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 poorly 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).

## **1.3. Population Size and Trends**

### **1.3.1. 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, British Columbia, 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 Gerodette 1993). As such, the worldwide abundance of killer whales is probably between 40,000 and 60,000 whales (Forney and Wade in press). Trend data for killer whales are generally not available, with the exception of resident populations of whales in British Columbia (discussed below) and southern Alaska (population increasing, Craig Matkin, North Gulf Oceanic Society personal communication,

November 2005) and for a small population of transients in Prince William Sound (AT1s, currently in decline, not likely to recover, Saulitis et al. 2002).

### **1.3.2. British Columbia**

There are no population estimates for killer whales in British Columbia 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 Centre 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 Cetacean Research Program, DFO Nanaimo, BC (CRP-DFO), were used to describe the northern resident killer whale population. Whales are censused slightly differently by each research group.<sup>3</sup>

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 members of the southern resident community are photographed annually, so the count is reasonably precise.

The northern resident count includes all whales that are known to be alive on July 1 of each year. However, not all members of the resident community are seen each year, so the count data are generally less precise than for the southern residents.

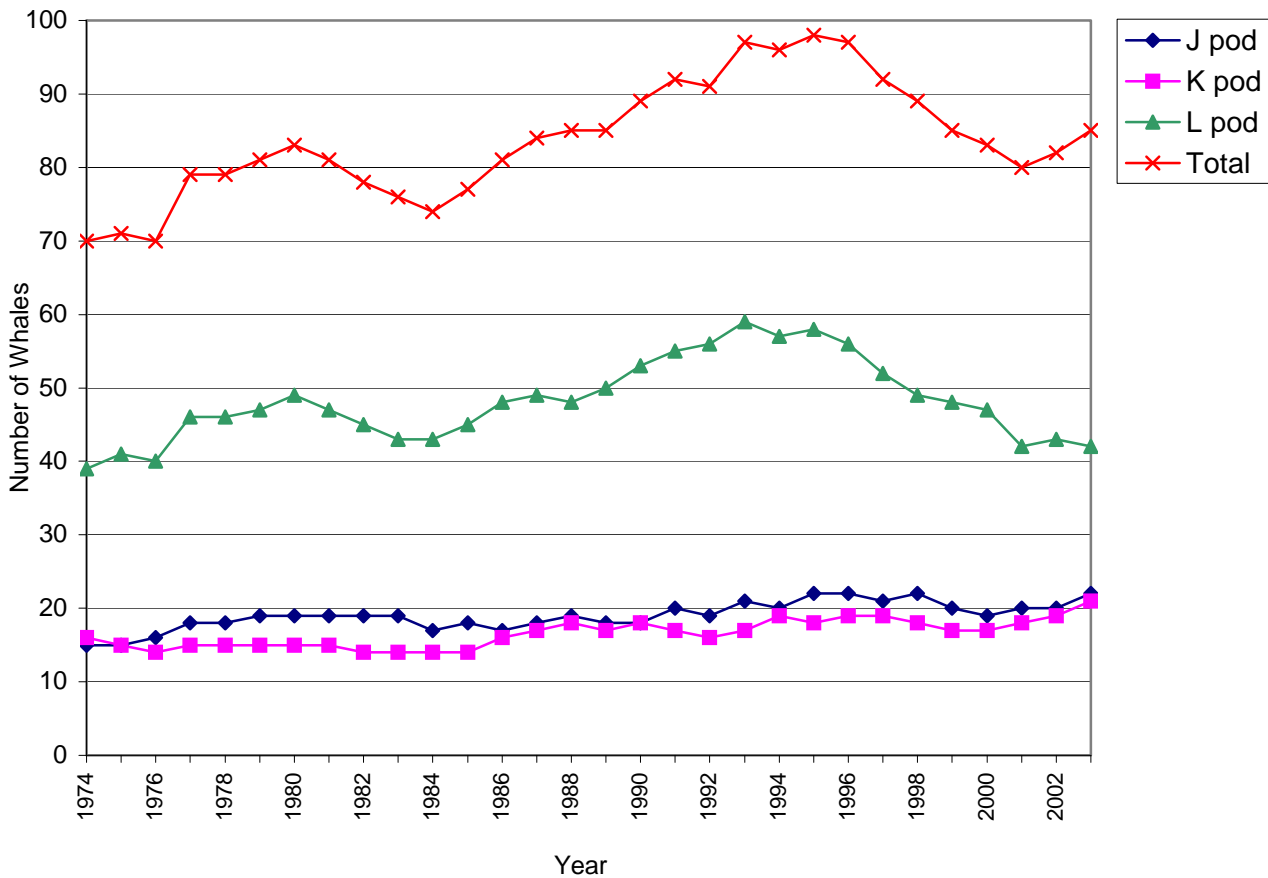
In 2003, there were a total of 290 northern and southern resident killer whales (unpublished data, CWR, and CRP-DFO). By comparison there are approximately 220 transient and 200 offshore killer whales, although these numbers are less precise than the resident counts, because not all individuals are encountered 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, and was estimated for the years prior to that (Olesiuk et al. 1990, unpublished data CWR). Figure 2 shows the size of each pod as well as the fluctuation in the total population of the southern resident community from 1974-2003.

---

<sup>3</sup> 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. For example Krahn et al. (2004) report 83 southern residents in 2003



**Figure 2** Population size and trends for southern resident killer whales from 1974-2003.  
Source: Unpublished data from the Centre for Whale Research

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 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. The latest 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 number of southern residents has increased slightly to 85

in 2003<sup>4</sup> (unpublished data CWR). The growth has been in J and K pods, whereas L pod has continued to decline.

Population viability analyses (PVA) have been used to estimate the extinction risk of southern resident killer whales (Taylor and Plater 2001, and 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 is elevated. The 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. However, 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.

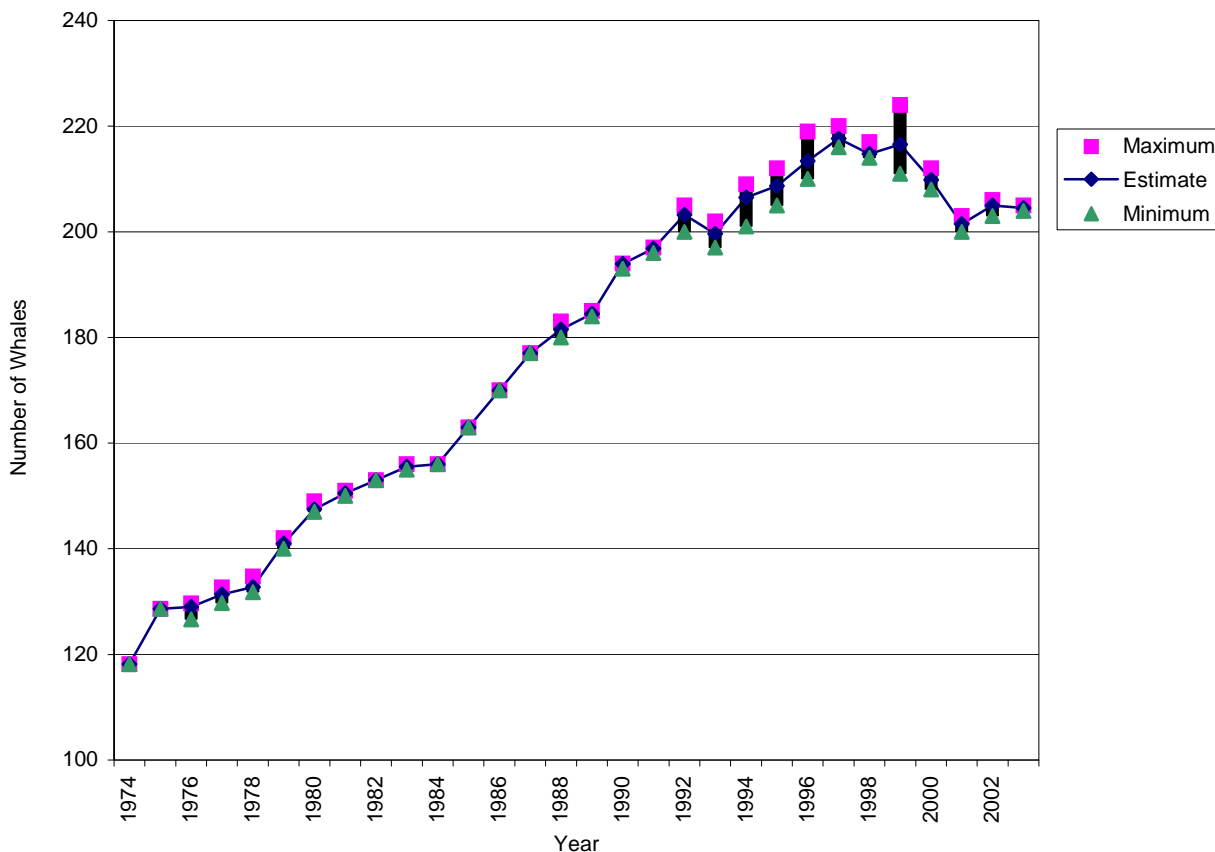
In addition to analyses focused solely on the southern residents, Krahn et al. (2002) ran simulations assuming that the southern resident population was part of a larger breeding population including northern and southern Alaskan resident killer whales, which greatly decreased its extinction risk. However this scenario does not reflect present evidence that suggests that southern residents are genetically isolated from other populations (Barrett-Lennard 2000; Barrett-Lennard and Ellis 2001).

### *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 matriline are seen each year, it appears that the northern community grew steadily during the period 1974 to 1991 (approximately 3.4% per year, Figure 3). The census method used for northern residents is to estimate the population size based on the number of animals that are known to be alive on July 1 of each year. The population increased to a peak of 220 animals in 1997 (growth of 3.0% per year, unpublished data CRP-DFO). 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 (unpublished data CRP-DFO, Figure 3). As with southern resident killer whales, the cause(s) of the decline are not known. No population viability analysis has yet been conducted for the northern resident killer whales exclusively.

---

<sup>4</sup> This estimate includes L98 or Luna, discussed in section 3.2.2. Social Organization



**Figure 3** Population size and trends for northern resident killer whales from 1974 to 2003. Values reflect the minimum, maximum and estimated number of animals alive as of July 1 in each year. Source: Unpublished data, CRP-DFO, Nanaimo.

## 1.4. Natural Factors Affecting Population Viability and Recovery

It is important to appreciate 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 poorly known.

### 1.4.1. 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 whales have shown that these whales forage selectively for certain salmonids regardless of their abundance (Ford and Ellis 2005). Chinook salmon (*Oncorhynchus tshawytscha*) is the predominant prey species taken by both northern and southern resident communities during May-August, but chum salmon (*O. keta*) is more prevalent in September-October. Coho salmon (*O. 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 whale diet during May-October.

Resident 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 the Skeena River near Prince Rupert and as far south as the Columbia River in Oregon (unpublished data CRP-DFO).

Despite over 30 years of study in British Columbia, only 14 stomachs from resident killer whales have been recovered and examined (Ford et al. 1998, unpublished data CRP-DFO). The extent to which stranded individuals provide accurate insight into the dietary preferences of healthy, free-ranging killer whales is not certain. However, salmon was identified in all seven stomachs that contained prey, including four in which chinook was positively identified. Two contained squid and one also contained bottom fish. It is possible that bottom fish (including ling cod, kelp greenling and sablefish), as well as squid, comprises a significant component of killer whale diet in some areas or during certain times of the year, but more research is needed to determine the year-round diet of killer whales.

It is not known whether resident killer whales depend on specific salmon runs, but their occurrence has been correlated with the abundance of various salmonid species in several past studies (Heimlich-Boran 1986, Nichol and Shackleton 1996, Osborne 1999). The role of these geographical correlations with regard to prey selection is uncertain, since some of these species (sockeye and pink salmon) are not taken in significant numbers compared to chinook salmon (Ford et al. 1998, Ford and Ellis 2005). It is likely that whale occurrence in such areas is driven primarily by the availability of migrating chinook salmon, especially in summer months, and correlations with pink and sockeye salmon are an incidental result of their great abundance during the same period. In fall, the presence of chum salmon appears to influence the movements of resident 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 British Columbia 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 matriline may contain up to four 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 whales leaving their matriline 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, sisters often begin to spend more and more time apart after their mother dies, and their own matriline may eventually become socially independent (Bigg et al. 1990, Ford et al. 2000, Ford and Ellis 2002).

### *Reproductive Parameters*

Females reach sexual maturity, defined as the age of first successful pregnancy, at 14.9 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 -17.4 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 number 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 1.0-1.5 to two years of age. The interval between calving is usually about 5.2 years for northern residents and 6.2 years for southern residents (unpublished data CRP-DFO). However the interval is highly variable, and ranges from two to 12 years, and increases with age until menopause (Olesiuk et al. 1990). Overall, females have an average of 5.25 viable calves in a 25.2 year reproductive lifespan (Olesiuk et al. 1990). Calving occurs year-round in the northern resident community, but appears to peak between fall and spring. Southern residents do not appear to calve in the summer (unpublished data CWR).



### *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 50.2 years for females and 29.2 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 2.2.1. 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 2.

### *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 transients 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). In African elephants, older matriarchs are better able to discriminate between threatening and non-threatening disturbances than younger animals, and pass this knowledge on to other members of their group (McComb et al. 2001).

Culture may help animals to learn to 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).

### *Depensation*

Resident killer whale populations are at risk simply by virtue of their low population size. In general, small populations generally 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 85 southern residents in 2003<sup>5</sup> (unpublished data, CWR), and 205 northern residents in 2003 (unpublished data, CRP-DFO). If either resident population continues to decline, 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.

---

<sup>5</sup> including L98 or Luna, discussed in section 3.2.2. Social Organization.

Inbreeding appears to be less of a risk for resident killer whales than might be expected based on the small size of their populations. They may avoid inbreeding and its inherent risks through non-random mate selection. Resident killer whales select mates from outside their natal pod, which may make small populations of killer whales more genetically viable than would be expected from population size alone (Barrett-Lennard and Ellis 2001).

### *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). The proximate cause of death, stranding, is a natural source of mortality, but the death is ultimately human-caused.

#### **1.4.2. 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 (Carl 1946, Pike and MacAskie 1969, Mitchell and Reeves 1988, Cameron 1941). 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, nineteen 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 Bressemer 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 killer whales in BC (Baird 2001). Internal parasites of killer whales

include various trematodes, cestodes, and nematodes (Heyning and Dahlheim 1988, Raverty and Gaydos 2004). 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 brevetoxin. 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.

## **2. THREATS**

### **2.1. 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.

#### **2.1.1. 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 aquariums. 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 likely affected productivity of the community for many years after the live captures ended in 1975.

### **2.1.2. 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.

### **2.1.3. 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). AHDs are no longer used at fish farms 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).

## **2.2. Current Threats**

A variety of threats may directly impact northern and southern resident killer whale populations in British Columbia, particularly because of their small population size. Threats include environmental contaminants (including oil spills), reduced prey availability, disturbance, and

noise pollution, each of which is discussed in more detail below. 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.

### **2.2.1. 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 A) 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. Such an extrapolative approach encompassed using a ‘weight of evidence’ 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. Recent 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). 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. The acronyms used for many of the contaminants are listed in Appendix I.

### *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 or 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).

Pollutant	Use/Source	Persistent	Bio-accumulate	Risk
DDT <i>(Dichlorodiphenyl trichloroethane)</i>	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 <i>Polychlorinated Biphenyls</i>	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 <i>Persistent Polycyclic aromatic hydrocarbons</i>	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 <i>Polybrominated diphenyl ethers</i>	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 <i>Perfluoro-octane sulfonate</i>	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 <i>Tributyltin Dibutyltin</i>	antifoulant pesticide used on vessels	yes	Yes	unknown but recently associated with hearing loss
PCPs <i>(Polychlorinated paraffins)</i>	flame retardants, plasticizers, paints, sealants and additives in lubricating oils	yes	yes	endocrine disruption
PCNs <i>Polychlorinated naphthalenes</i>	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 <i>Polychlorinated terphenyls</i>	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 de Vijver et al. 2003, Rayne et al. 2004, Song et al. 2005.



**Table 1.** Persistent organic pollutants that may pose a risk to resident killer whales.*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 the as-yet largely unregulated 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). Unlike an earlier study on PCB levels in resident killer whales (Ross et al. 2000), Rayne et al. (2004) did not find any significant age-related trends in PBDE levels, but that may have been an artefact of their small sample size or the fact that PBDEs were relatively new in the environment in the 1990s. In a sample of 70 long-finned pilot whales in the North Atlantic, Lindstrom et al. (1999) found that juveniles had two to three times higher levels of PBDEs than did adults (Lindstrom et al. 1999), suggesting that reproductive females may pass PBDEs on to their offspring during gestation and lactation.

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). As more than 10 years have passed since some of the killer whale samples were collected, and since PBDE levels persist in the environment and their use has been increasing exponentially (Hooper and McDonald 2000), it is likely that killer whales today in 2007 are carrying significantly higher concentration loads of these contaminants than were found in whales sampled in the mid 1990s. Numerous captive and semi-field studies of pinnipeds provide evidence that POPs are affecting immune function (hence, resistance to disease), hormone levels, and reproductive health (Ross 2000; Reijnders 1986; Nyman et al. 2003; De Swart et al., 1996).

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. Transients 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 (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 (3000 km/yr), 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 British Columbia, 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 centers (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 1000 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 may be more contaminated than the prey of northern residents (Ross et al. 2000). 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 British Columbia and Washington, Ross et al. (2004) found that although PCB levels were a concern in all areas, seals from Puget Sound are 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). 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 30 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 over the past 15 years.

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 (in press) describe the Canadian and US 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 taxifolia*). 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 the flame retardant PBDEs have increased exponentially over the past 25 years, and represent the PCBs of the future (Hooper and McDonald 2000; Ross 2006). Unlike PCBs, which were generally used in a limited range of applications such as electrical transformers and capacitors, PBDEs are widely used in many industrial and consumer applications and are incorporated into plastics, textiles and foam.

### **2.2.2. Reduced Prey Availability**

Answering the question as to whether killer whales may be prey limited is complex. While the complete diet of resident killer whales is not known, at certain times of the year salmon, particularly chinook and chum, appear to be important prey (see Section 1.5.1. 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.

Unfortunately, there is very little 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 their Summer concentrated areas and range widely along the exposed 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 very little 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 20<sup>th</sup> 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 26 of 52

different wild Pacific salmon stocks in the lower 48 states of the US are considered at risk under the US *Endangered Species Act* (NWR 2004). In British Columbia, salmon from one-third of the spawning rivers in southwestern BC had been lost or were seriously depleted by 1990 (Riddell 1993). Recognizing that many salmon stocks are under threat, Fisheries and Oceans Canada announced a new wild salmon policy in December 2004 (DFOb 2005), designed to restore and maintain healthy and diverse wild salmon populations and their habitat. If these actions are successful, salmon may gradually become more available to resident killer whales.

Resident killer whales tend to be found in concentrated 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 US, yet the summer/ fall run is not at risk (NWR 2004). 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 (e.g., Pacific Salmon Forum) 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 2.2.1 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 British Columbia, chinook numbers remain depressed (Riddell 2004) and 10 of 17 chinook stocks in Washington, Oregon and California are listed under the ESA (NWR 2004). Thus it is plausible that chinook may be limiting for killer whales (Ford et al. 2005). This may explain why southern resident killer whales have appeared in places as distant as off the Columbia River and off northern California to the south and off Langara Island in the north (unpublished data CRP-DFO). 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 British Columbia to California declined by up to 45% between 1975 and 1993 (Bigler et al. 1996). Thus, the nutritional yield of each chinook salmon is significantly less today than it was in past years, which may have an impact on the overall foraging energetics of resident killer whales.

### **2.2.3. 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 boat 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 influences how disturbance affects whales. 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, unpublished data CRP-DFO). 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 show 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 British Columbia, 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). Whale watchers tend to target resident killer whales in their most predictable locations, Haro Strait and Johnstone Strait. In the summer, an average of 19-22 boats have been observed near southern resident killer whales in Haro Strait, commonly from 9 am to 9 pm (Osborne et al. 2003) although some begin as early as 6 am (personal communication David Bain, February 2005). These 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 watching guidelines and has resulted in studies that have attempted to measure responses of the whales to such focused attention (Kruse 1991, Williams et al. 2002a, b), as well as the behaviour of boaters around whales (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 US, disturbance (harassment) of marine mammals, including killer whales, by the public 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. It is not known what the biological significance of disturbance is to resident killer whales, but voluntary whale watching guidelines for Canadian vessels have been developed (Be Whale Wise, DFO 2004). From June through to November, an additional set of guidelines has been developed to minimize disturbance to whales when whales are in the Special Management Zone in Johnstone Strait (see [www.straitwatch.org](http://www.straitwatch.org) for details). The Whale Watch Operators Association Northwest (WWOANW) has developed an even more comprehensive 'Best Practices Guidelines' for commercial operators to follow when observing southern residents (WWOAN 2004). These guidelines have evolved over a 10 year period to reflect new knowledge and minimize the negative effects of vessel traffic. They remain a work in progress and will evolve as further research reveals if and how whale watching may have population level consequences for resident killer whales.

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, and *Straitwatch* in Johnstone Strait, while past projects include the

*Marine Mammal Monitoring Project* in Victoria, BC,. All 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, b). 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, b). 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.

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 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; Erbe 2002, Bain 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 (Piantadosi and Thalmann 2004, Fernandez et al. 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 (1530 vs. 340 m/s). The perceptual features of sound, “pitch” and “loudness,” have physical analogs. 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 2000 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, Szymanski 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<sub>RMS</sub> 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, their loudness and their 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 is currently developing comprehensive guidance on what levels of sound exposure are likely to cause behavioral responses or injury, in the context of the *Marine Mammal Protection Act* (MMPA). Until formal guidance is available, NMFS is using an interim sound exposure level for impulsive sources of 180 dB<sub>RMS</sub> re 1µPa, as a threshold for temporary or permanent hearing loss of cetaceans, and 160 dB<sub>RMS</sub> re 1µPa for behavioural disruption (NMFS 2005b).

**Table 2** 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  $\mu$ Pa 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 US Navy equipment. Given that the US 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 whales travel in US 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 km (NRC 2003; Tomaszewski 2004). 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 US Navy is now forbidden from deploying these units except in an area in the western Pacific Ocean and during periods of war (Malakoff 2003), but this ruling is currently being appealed by the US government.

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 1 $\mu$ Pa @ 1m (J. Theriault, Defence Research and Development Canada, personal communication 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 (D. Freeman, Department of National Defence, personal communication, 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 6 ships on the west coast. In comparison, the US Navy's SQS 53C sonar, such as that used on the *USS Shoup*, emits 10 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, personal communication, 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. However, an evaluation of the effectiveness of the Maritime Command Order, particularly the ability of observers to detect marine mammals in the zone of influence, has not been completed to date. These zones are determined using the interim NMFS thresholds for potential behavioural disturbance (160 dB) and physical injury (180 dB) (D. Freeman, DND, personnel communication 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 (D. Freeman, DND, personal communication 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. There are no military active sonar exercise ranges within the proposed critical habitat areas that have been identified to date.

## 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 1 $\mu$ Pa 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 2000-8000 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. At the time the COSEWIC status report on killer whales was written (Baird 2001) both the federal and provincial moratorium on oil and gas exploration was in place. Since 2001, the BC provincial government has lifted the moratorium on oil and gas exploration and has requested that the federal government do the same. 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 is currently developing standards for seismic surveys, and a draft policy for the mitigation of seismic surveys (DFO, 2005a) is currently being revised following public consultation. 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. Gray 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 gray 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 do 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. The consequences of these chronic sources of noise on killer whales have not been assessed.

### *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 United States, 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 meters to vessels over 30 m, although some is land based (e.g. Orcalab on Hanson Island, the 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 recent 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. Satellite tags and the use of 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.

### *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).

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 British Columbia, with the exception of the inner waters of Vancouver Harbour. The underwater noise levels of PWC have not been reported.

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 2.2.5).

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.

### **2.2.4. Oil Spills**

While the probability of either northern or southern resident killer whales being exposed to an oil spill is low, the impact of such an event is potentially catastrophic. Both populations are at risk of 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 in the north and central coast of BC. In 2003, 746 tankers and barges transported over 55 billion litres of oil and fuel through the Puget Sound (WDOE 2004). If the moratorium on oil and gas exploration and development is lifted in British Columbia, the extraction and transport of oil may put northern 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 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).

### 2.2.5. 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 (Pike and MacAskie 1969, Guenther et al. 1995, Barlow et al. 1994, Heyning et al. 1994), but they usually have not resulted in death. It is likely that fisheries pose little direct threat to killer whale populations at present. However, killer whales in other areas are known to 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) and could affect resident killer whales in the future. Where depredation occurs, deterrent methods, entanglement, or accidental hooking, increases the injury or mortality rates of whales.

## 3. Critical Habitat

“Critical habitat” is defined under *SARA* as “*the habitat that is necessary for the survival or recovery of a listed wildlife species that is identified as the species’ critical habitat in the recovery strategy or in an action plan for the species*” (*SARA* s.2 (1)). Under *SARA*, defining critical habitat for killer whales to the extent possible is a legal requirement (*SARA* s.41 (1) (c)). Once critical habitat is identified by the Minister, no person shall destroy any part of the critical habitat (*SARA* S.58 (1) and the minister must describe in the public registry how the critical habitat is legally protected (*SARA* S.58 (5))

Defining critical habitat for any species is challenging, but especially so for mobile marine animals such as killer whales. Resident killer whales travel over large geographical distances and members of the northern and the southern resident communities may be spread over



hundreds of kilometres at any given point in time. As well, much of what we know about killer whales comes from the very short period of time they spend at the surface where we can see them, and the ways in which they travel and utilize their three dimensional underwater habitat are not at all well understood. The underwater vocalizations of resident killer whales provide some insight into their behavioural state, but tell us little about how geographic features of the environment are used. According to the best knowledge at this time, the habitat most important to killer whales in the summer and fall are channels, shorelines, or other topographic or oceanographic features that concentrate their migratory prey, salmon.

There is little evidence to suggest that killer whales require or are limited by specific physical features of their environment, other than features that make prey available to them. Indeed, as top level predators, killer whales in general are not known to require refugia, and they inhabit a wide range of both nearshore and pelagic habitats worldwide and tolerate a wide range of temperature, salinity and turbidity levels. The presence of resident killer whales is closely associated with the presence of salmon (Heimlich-Boran 1988, Felleman et al. 1991, Osborne 1999, Nichol and Shackleton 1996, Ford et al. 1998), and it is this overwhelming feature of the environment that affects their distribution, although knowledge is limited temporally to summer and fall months. For the rest of the year there is much less information available on their diet or distribution and movement patterns. Clearly, determining whether there are additional habitats, that the whales utilize during the winter and spring, which are critical for recovery, must be a specific objective for the action plan. Such criteria will need to take into account the likelihood that changes in the relative strength of major salmon stocks may cause corresponding shifts in the geographic location of critical habitat for resident killer whales.

### **3.1. Identification of the species' critical habitat**

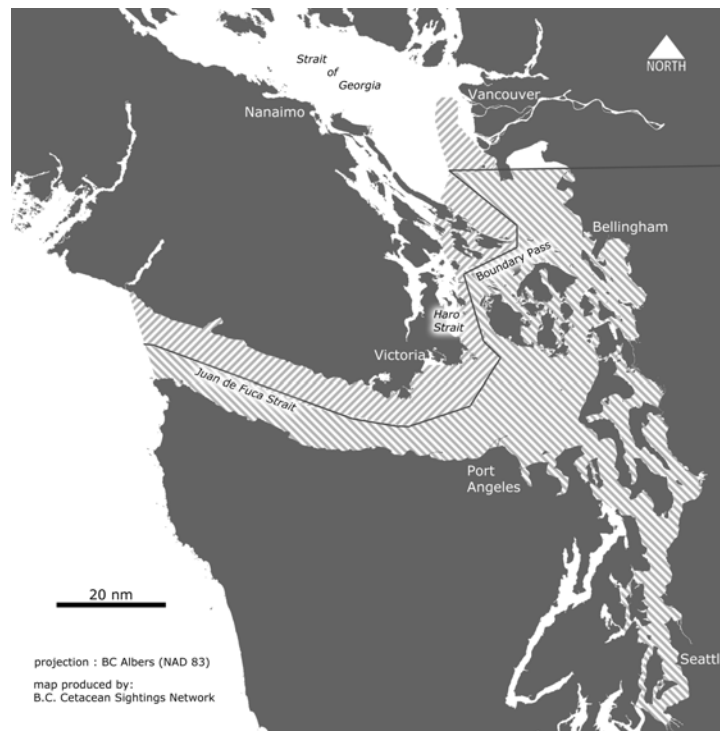
Two seasonal concentration areas for resident killer whales off northeastern and southeastern Vancouver Island have been well documented and meet the requirements for designation as critical habitat under *SARA*. Critical habitat (Figures 4 and 5) is described by coordinates for each population (see Appendix B). Both of these areas are characterized by narrow channels with strong currents, and appear to be geographical 'funnels' that tend to concentrate migrating salmon bound for the Fraser River, which has the largest salmon production in the region (Northcote and Larkin 1989), and other smaller river systems flowing into the Strait of Georgia and Puget Sound. Rational for the designation of critical habitat and a general description of the habitat and its features is presented in Section 3.1.1 and 3.1.2 for northern and southern residents respectively.

There are likely other areas that are important for killer whales at various times, but these have not yet been studied in sufficient detail to be identified with confidence. Measures to identify and effectively protect other critical habitat areas will be described in the action plan that follows this recovery strategy.

### 3.1.1. Southern Residents

The critical habitat for southern resident killer whales includes the transboundary areas of southern British Columbia and Washington State. These include Haro Strait and Boundary Pass and adjoining areas in the Strait of Georgia and the Strait of Juan de Fuca, as depicted in Figure 4 (see Appendix B for description of the area designated). This area represents a very important concentration area for southern resident killer whales. Analyses of existing data on coast-wide occurrence patterns of southern resident killer whales has been completed by the US, NOAA as part of the ESA designation of critical habitat in collaboration with DFO (NMFS, 2006). This assessment provides quantitative documentation of the importance of these transboundary areas to these animals and forms, along with previously published information, the basis for the critical habitat identification. The following provides a general summary of the rationale for the identification and the important aspects of the habitat for southern resident killer whales.

The occurrence of southern residents in this area is strongly correlated with the timing of salmon migration through these waters (Heimlich-Boran 1988, Felleman et al. 1991, Osborne 1999). Within this area, locations that are particularly important for foraging are the nearshore waters along the west and southwest sides of San Juan Island, the southern tip of Vancouver Island, Swanson Channel off North Pender Island, and off the mouth of the Fraser River (Heimlich-Boran 1988, Hoelzel 1993, Ford et al. 2000; unpublished data CWR and CRP-DFO).



**Figure 4** Critical habitat for southern resident killer whales. The hatched area in US waters shows the approximate areas designated as southern resident critical habitat under the US *Endangered Species Act* (ESA).

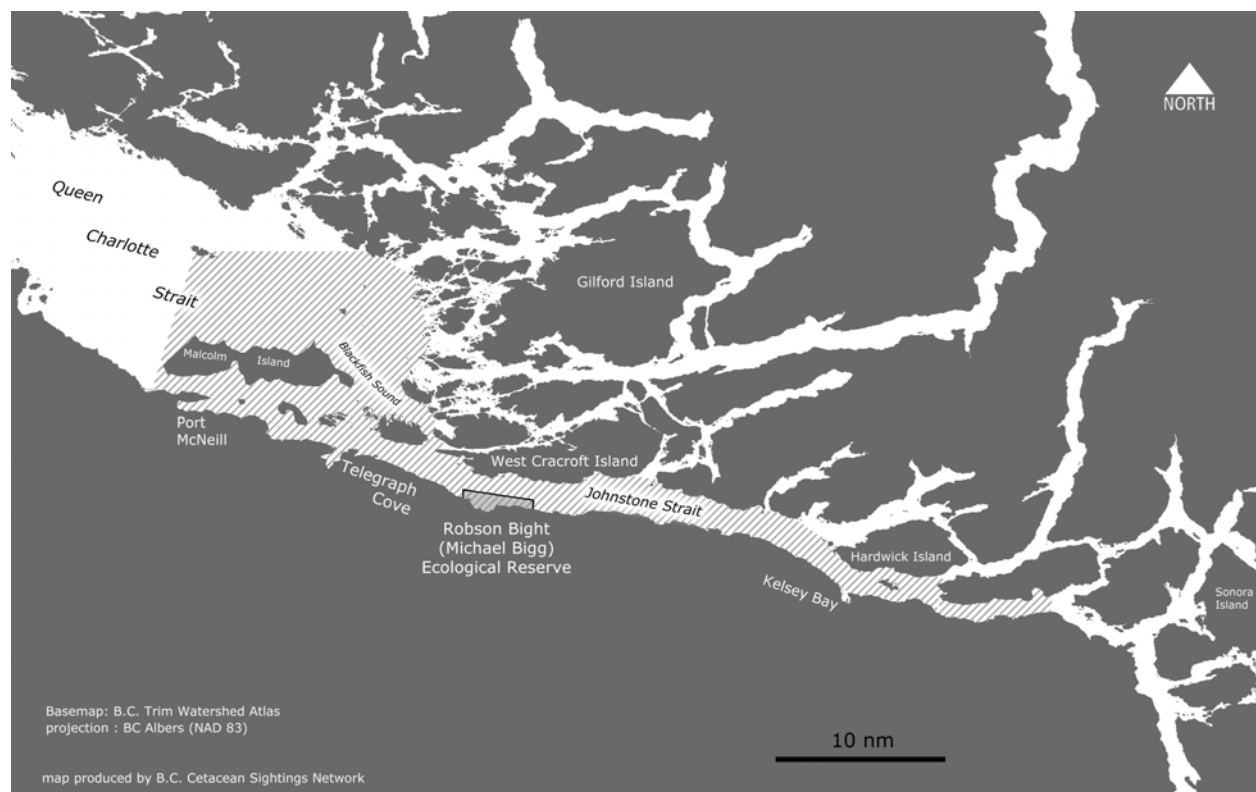
The critical habitat area is utilized regularly by all three southern resident pods during June through October, in most years (Osborne 1999, Wiles 2004). J pod appears to be present in the area throughout much of the remainder of the year, but two southern resident pods, K and L, are typically absent during December through April. This critical habitat is clearly of great importance to the entire southern resident community as a foraging range during the period of salmon migration, and thus meets the definition of critical habitat as described in the *Species at Risk Act*.

Much of the area that qualifies as critical habitat for southern resident killer whales falls within US jurisdiction, and thus the identification of critical habitat under SARA only applies to the portion of the area that is within Canadian waters (Figure 4). In November 2005, the United States listed southern resident killer whales as endangered under the *Endangered Species Act* (ESA), (NMFS 2005a). As a result 6,630 square km of US inland waters of Washington State and the Strait of Juan de Fuca were designated as critical habitat under the ESA in November 2006 (see Figure 4), (NMFS, 2006b).

### **3.1.2. Northern Residents**

The critical habitat for northern resident killer whales includes the waters of Johnstone Strait and southeastern Queen Charlotte Strait, and the channels connecting these straits as depicted in Figure 5 (see Appendix B for legal description of the area designated). This area represents a very important concentration area for northern resident whales. Analyses of existing data on coast-wide occurrence patterns of northern resident killer whales has been completed (Ford, 2006) which provides quantitative documentation of the importance of Johnstone Strait to these animals and forms, along with previously published information, the basis for the critical habitat designation. Hereafter, the area designated as critical habitat is referred to as the ‘Johnstone Strait critical habitat’, and has long been the focus of research and whale watching activity involving the northern resident community (JSKWC 1991). The following provides a general summary of the rationale for identification and the important aspects of the habitat for northern resident killer whales.

Northern residents frequent the area on most days during July through October, with peak numbers generally in mid-July to mid-September (JSKWC 1991, Nichol and Shackleton 1996). Whales become more sporadic in the area during November, and are scarce, but nevertheless occasionally seen, from December through May. Although all northern resident pods have been identified in the area, it is used most frequently by only part of the community, particularly groups belonging to A Clan (Ford 1984, Nichol and Shackleton 1996). Members of G Clan tend to be seen in the area more often in September and October than during summer in some years (Nichol and Shackleton 1996, unpublished data CRP–DFO). 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, unpublished data CRP-DFO). Other activities undertaken in the area include resting, socializing, and beach rubbing (Ford 1989, Ford et al. 2000).



**Figure 5** The critical habitat for northern resident killer whales in summer and fall in British Columbia.

Beach rubbing appears to be an important activity for northern resident killer whales. Ninety percent of whales 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 killer whales, the province of British Columbia in 1982 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 (Figure 5). However, in response to growing concerns about the impacts of human activities in and around Robson Bight, in 1990 the British Columbia and Canadian governments jointly appointed the Johnstone Strait Killer Whale Committee to develop management recommendations to ensure the conservation and protection of killer whales (JSKWC 1991, 1992). One of the key recommendations of the Committee called for the establishment of a Special Management Zone to encompass a larger marine area than the existing Ecological Reserve, and establish a seasonal patrol vessel program to monitor whale-oriented vessel activity and mitigate potential disturbance. The area identified as critical habitat encompasses the area recommended as a Special Management Zone.

The Special Management Zone 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 within the shaded area in Figure 5. 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 is designated as critical habitat as defined in the *Species at Risk Act*.

There may be additional areas that will qualify as critical habitat for northern residents during other parts of the year, and for northern resident groups that infrequently utilize the Johnstone Strait area during summer and fall, but there is insufficient information to characterize them at present. Analyses of existing data on coast-wide occurrence patterns of northern resident killer whales outside the designated areas are currently underway, which will identify additional candidate areas for consideration as critical habitat (Ford 2006). These areas might include portions of Dixon Entrance, Caamano Sound, Whale Channel, and the channels surrounding King Island on the central BC mainland coast. Northern resident whales frequent all these locations in at least some years, especially during May to early July (Nichol and Shackleton 1996, unpublished data CRP-DFO). Several rubbing beaches have also been identified in other locations on northern Vancouver Island and the mainland coast, and might also warrant protection as critical habitats because of the importance of this behavioural tradition to the cultural diversity of resident populations.

### **3.2. Examples of activities likely to result in destruction of critical habitat and its function**

Many of the threats that face resident killer whales also affect their habitat, and this is of particular concern for the critical habitat. The threats to critical habitat and its function are briefly listed here, but the reader is referred to Section 2.2 for a more thorough discussion on threats identified below. As previously mentioned, it is important to recognize that the definition and identification of critical habitat for resident killer whales is complex. While for the purposes of SARA the critical habitat itself is a defined geophysical area (see above), other ecosystem features such as the availability of prey for foraging and the quality of the environment must be managed as threats so as to not compromise the function of the critical habitat and thus potentially impede survival and recovery. It is also important to note that there are many gaps in our understanding of critical habitat, and that this will be a focus for research in the action plan.

#### **3.2.1. Geophysical Disturbance**

A key physical feature of both the northern and southern resident killer whale's critical habitat is that these areas by virtue of their underwater topography funnel salmon into areas where they concentrate before spawning. Thus, any large scale physical disturbance, such as an earthquake, could significantly alter the channelling of salmon and could be considered a serious threat. However, such catastrophic events are not predictable and have a low probability of occurrence. Industrial activities such as construction, drilling, pile driving, pipe-laying and dredging are the most likely sources of critical habitat destruction. Fisheries using nets that drag along the bottom (accidentally or intentionally) also damage habitat. Vessel anchors damage the seabed and may serve to alter a rubbing beach or cause displacement. Physical structures such as wharves and net pens for aquaculture may displace killer whales. Both the placement of individual structures and the cumulative effect of multiple structures should be assessed against the needs of killer whales in critical habitat.

A key feature of the northern resident killer whale critical habitat is the presence of several rubbing beaches. Any destruction of rubbing beaches, or disturbance of the animals while in these areas should be considered a threat. Rubbing beaches may also be vulnerable to disturbance through flooding and landslides in areas adjacent to the beach.

### *Acoustic Degradation*

There is growing awareness that the underwater acoustic environment is extremely important to cetaceans (IUCN 2004, IWC 2004) and it is important that the threat of a degraded underwater acoustic environment be managed in critical habitat, in order that killer whales can maintain communication, and detect and capture prey while in the area. There are many threats to the acoustical integrity of critical habitat, and these are discussed in detail in Section 2.2.3. Underwater Noise. These include seismic surveys, military and commercial sonars, vessel noise, construction and dredging.

### **3.2.2. Chemical and Biological Contamination**

The degradation of water quality due to environmental contaminants poses a particularly serious threat to killer whales, their prey and their habitat. These contaminants and their sources are discussed in Section 2.2.1. While many contaminants are airborne and dispersed throughout the coastal waters of British Columbia, the waters surrounding the lower mainland and Vancouver Island are particularly at risk due to their proximity to human settlement. This includes the risks to habitat associated with the introduction of exotic species. Urban land use represents a significant concern for the health of coastal ecosystems (Grant and Ross 2002) and a growing population makes this situation unlikely to improve. By 2020 the Canadian portion of this area is predicted to have a population of over 3.8 million (BC Statistics 2004), and the State of Washington, which borders this area is projected to have over 7.7 million people (OFM 2004).

The threat of a spill of oil or other toxic material within the areas of critical habitat pose not only an immediate and acute risk to the health of resident populations (see Section 2.2.4), but have the potential to make critical habitat areas un-inhabitable for an extended period of time.

### **3.2.3. Diminished Prey Availability**

As the presence of salmon is key to the presence of killer whales in the critical habitat (Heimlich-Boran 1988, Nichol 1990, Nichol and Shackleton 1996, Osborne 1999), significant reduction to the quantity, quality and availability of salmon within critical habitat are a threat to its very function.

Prey must be physically accessible to resident killer whales in critical habitat, yet killer whales and fishing vessels targeting the same prey compete with each other for space, particularly in fishing hotspots. The presence of fishing vessels also alters fish behaviour (Mitson and Knudsen 2003) potentially making them less accessible to killer whales, although this is an area for further research.

### 3.3. Schedule of studies to identify critical habitat

While it is clear that protection of the habitat that serves as the primary foraging grounds for these populations during a portion of the year, through designation as critical habitat, is necessary at this time, there may be additional areas that will qualify as critical habitats for both resident populations during other parts of the year, and for northern resident groups that infrequently utilize the Johnstone Strait area during summer and fall. However, there is insufficient information to characterize these areas at present. The following table identifies these studies that are necessary to identify any additional areas for critical habitat designation.

**Table 3** Schedule of studies to identify additional areas of critical habitat and its threats

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	Proposed
Identify sources of acoustic disturbance that may negatively impact or affect access to critical habitat	Proposed
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 (due to salmon initiatives)

### 3.4. Mechanisms for the protection of critical habitat and its functions

There are various mechanisms for the protection of resident killer whale critical habitat and its functions, including legislative tools such as acts, regulations, government policy and programs, as well as best practices, education and stewardship programs (see Table 4) that, given the current understanding of the nature and extent of the identified threats to critical habitat and its functions can provide the necessary protection. As the critical habitat for southern resident killer whales borders the waters of Washington State, where additional Critical Habitat exists, it is important that transboundary cooperation in protecting habitat is fostered. The following provides a summary of the applicability of the mechanisms outlined.

Within Canada, the *Fisheries Act* provides for the protection of habitat from physical alteration and the introduction of deleterious substances. The *Marine Mammal Regulations (MMR, Section 7)* of the *Fisheries Act* prohibit the disturbance of marine mammals; this includes activities such as the emission of high energy sounds (seismic surveys, low-mid frequency sonars) or sounds associated with various industrial activities. Garrett and Ross (In press) provide a thorough summary of the existing legislation and regulations regarding contaminants into the marine environment. Proactive efforts, to ensure that activities are assessed and controls and/or mitigative measures are implemented, are vital to the protection of the critical habitat and its

functions identified for killer whales. Screening activities, such as those required under the *Canadian Environmental Assessment Act (CEAA)* and *Integrated Management (IM)* as described by the *Oceans Act (OA)* are essential mechanisms for protecting critical habitat and its functions. Monitoring and enforcement of all regulations is essential and complements the legislation and regulations listed above to ensure compliance.

Measures to manage threats to the foraging function of the critical habitat, primarily for salmon, can be accomplished through management activities under the *Fisheries Act*, directed by annual Integrated Fisheries Management Plans (IFMPs). A comprehensive approach to the management of salmon stocks that explicitly accounts for the dietary needs of killer whales should be evaluated and considered as one approach to protecting food resources.

Non-government education and stewardship programs (such as the Green Boater Program and Toxic Smart) will complement government programs and engage Canadians to take action at an individual level to protect critical habitat and its functions. In areas where critical habitat falls within a reserve or any other lands that are set apart for the use and benefits of a band under the *Indian Act*, the *Species at Risk Act (SARA)* states in Sections 58(7), 59(5) that the band must be consulted before the prohibition on the destruction of critical habitat is triggered or regulations are made to protect critical habitat on federal lands.

The following table summarizes the most understood potential threats to the critical habitat and its functions, along with a description of measures to protect it currently in place, and recommends additional measures that may be needed for the explicit protection of resident killer whale critical habitat and its functions, based on the current understanding of critical habitat and the associated threats. It is anticipated that the additional measures recommended will be evaluated in greater detail and articulated within the action plan for these populations. In addition, as a greater understanding develops of the important features of the habitat necessary to ensure the survival of these populations and the threats to this habitat, the mechanisms and measures needed to protect it will require revision.

**Table 4** Current and recommended measures for the protection of critical habitat and its function.

Threat	Current Mechanisms	Recommended Additional Measures
Geophysical Disturbance	<i>Fisheries Act</i> and the <i>Canadian Environmental Assessment Act (CEAA)</i> screening Integrated management (IM) planning in northern resident critical habitat	Ensure all habitat alterations and marine use planning incorporate assessment of killer whale critical habitat Consider IM planning for southern resident critical habitat Apply precautionary approach in areas where critical habitat have not yet been identified



Threat	Current Mechanisms	Recommended Additional Measures
Geophysical Disturbance at Rubbing Beaches	HPR CEAA screening BC Parks Ecological Reserve & Monitoring program (Robson Bight) Remote surveillance technology (e.g. Orcalab)	Prohibit habitat alteration at rubbing beaches Establish Marine Protected Areas ( <i>Oceans Act</i> ) at Robson Bight Fisheries management actions ( <i>Fisheries Act</i> ) within rubbing beach areas Evaluate need for protection at other rubbing beaches Ensure all habitat alterations and marine use planning (e.g. fishing) incorporates assessment of rubbing beaches.

Threat	Current Mechanisms	Recommended Additional Measures
Acoustic Degradation - Seismic	CEAA screening for some seismic programs and mitigation required Non-CEAA seismic programs reviewed regionally Marine Mammal Regulations (MMR) on disturbance	Evaluate recently developed draft standards for mitigation of seismic exploration Apply precautionary approach in areas where critical habitat has not yet been identified Amend MMR to provide for licensing (control) of disturbance activities Require screening and authorization for all seismic activities Encourage trans-boundary cooperation in mitigation measures
Acoustic Degradation- Sonar	Protocols for military sonar use MMR regulations on disturbance	Review existing military sonar use and protocols to ensure adequacy, revise as necessary Amend MMR to provide for licensing (control) of disturbance activities Encourage trans-boundary cooperation in mitigation measures Apply precautionary approach in areas where critical habitat has not yet been identified
Acoustic Degradation – Industrial Activity	MMR disturbance regulations DFO policy prohibits use of acoustic harassment devices	Consider and limit, as necessary, acoustic alteration from construction/development projects Amend MMR to provide for licensing (control) of disturbance activities
Chemical & Biological Contaminants in Canadian waters <sup>6</sup>	Stockholm Convention on POPs Georgia Basin Action Plan (Environment Canada) NGO environmental education programs (e.g. Green Boater Program, Toxic Smart etc.) <i>BC Environmental Management Act</i> <i>CEPA and Fisheries Act</i> Industry initiatives (e.g. Clean Print BC) <i>Integrated Pest Management Act</i> (IPMA, Health Canada) Canada-Wide Standards of Canadian Council of Ministers of the Environment <i>Fertilizers Act</i>	Better identification and understanding of key contaminants and their sources Increased enforcement of existing regulations Increased funding for education at the individual, municipal and sector level Evaluate and strengthen <i>BC Environmental Management Act</i> Evaluate and strengthen the <i>Canadian Environmental Protection Act</i> Continue to upgrade water treatment plants Evaluate and strengthen the <i>Integrated Pest Management Act, Fertilizers Act</i>
Biological and Chemical Contaminants in US waters	Numerous acts to protect critical habitat from contamination are listed in Garrett and Ross (In Press)	Strengthen transboundary cooperation in reducing contaminants Detailed recommendations in EVS (2003) including actions
Oil & Toxic Chemical Spills	HPR regulations for deleterious substances Canadian/ US spill response plan (CANUSPAC) in southern transboundary waters CANUSDIX joint response plan in	Develop and incorporate into existing oil spill response plans measures specific to killer whales

<sup>6</sup> Source: Garrett and Ross. In press.

Threat	Current Mechanisms	Recommended Additional Measures
Presence & Availability of Salmon	<p>northern transboundary waters (Dixon Entrance)</p> <p>BC Marine Oil Spill Contingency Plan 1992 (OSRIS)</p> <p>Federal Marine Spills Contingency Plan Regional Environmental Emergencies Team (REET)</p> <p>Washington State Department of Ecology</p> <p>Integrated Salmon Management Plan (FA authority) provides for conservation of salmon</p> <p>Regulations under the <i>Fisheries Act</i> to manage harvest activities</p>	Evaluate resident killer whale prey and ensure that management plans incorporate adequate supply of prey for resident killer whales, even in changing climate scenarios

## 4. KNOWLEDGE GAPS

While resident killer whales are among the best studied cetaceans in the world, it is clear that key information is still needed to assist their recovery. In part this is due to the fact that although studies of killer whales have been ongoing over the last 30 years, killer whales spend the majority of time underwater, and their whereabouts are unknown 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 and Gaydos 2004). In a 30 year period, only 14 resident carcasses have been found and necropsies in British Columbia (Ford et al. 1998), a recovery rate of 6%.

Listed below are the key areas where further knowledge is needed:

- The year-round distribution and behaviour of resident killer whales
- Critical and important habitat for resident killer whales, in addition to the areas identified in this strategy
- 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

## **5. RECOVERY**

### **5.1. Recovery Feasibility**

Resident killer whale populations are not expected to achieve high abundances that might automatically trigger 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 1.4.2 in Population Status and Trends). Growth is unlikely to exceed these levels due to the low reproductive rate of the species, and the recovery of northern and southern resident killer whales can be expected to take more than one generation. The southern resident killer whale population will be 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, completing the 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. Effective implementation of initiatives such as Environment Canada's Georgia Basin Action Plan (EC-GBAP 2005) and Fisheries and Oceans Canada's Wild Salmon Policy (DFO 2005) will complement the objectives in this recovery strategy, to improve both the quality and abundance of killer whale prey and their habitat. There are also individuals and interest groups that have already shown initiatives in mitigating threats to killer whales, such as the 'Best Practices Guidelines' developed by the industry based Whale Watch Operators Association- Northwest (WWOANW 2004). These are designed to reduce the impact of whale watching on southern resident killer whales. As killer whales travel regularly across international borders, it is timely that both the Washington State and the United States federal governments are engaged in developing a conservation plan for the southern resident population that should complement and enhance Canadian efforts towards population recovery.

## 5.2. Recovery Goal

*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 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 interim measures of recovery success. The setting of a quantitative recovery goal will be revisited in five years, when the recovery strategy is re-evaluated.

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. In light of these inherent characteristics and uncertainties, the following have been identified as interim measures of recovery success:

### 5.2.1. Interim 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 matriline;
- d) Maintenance of matriline comprised of multiple generations to ensure continuity in the transmission of cultural information affecting survival.

### 5.2.2. Monitoring and Research Strategies

The following monitoring and research programs are essential to define and evaluate the success of the interim indicators of recovery success and will be vital to the establishment of a quantitative recovery goal in five years' time.

- 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 and animals individually identifiable, routine monitoring provides accurate, detailed life history information, which will be used to determine trends, and to refine and test populations 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.

### 5.3. Recovery Objectives and Strategies to Achieve Recovery

Given our current knowledge, the prime 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.

#### 5.3.1. 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 US, for example, runs of chinook salmon, a principal prey species for residents during the summer, have

been listed as either endangered or threatened (NWR 2004). 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.

#### **5.3.2. 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.

These strategies are intended to protect and restore the prey populations and habitat of resident killer whales. In order for them 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. New international treaties, similar to the Stockholm Convention on Persistent Organic Pollutants, which Canada ratified in 2001 (but the US has not), should be endorsed.

### 5.3.3. 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) has recently put forward a detailed listing of approaches to better understand how noise impacts marine mammals, which will be worth examining as the resident killer whale action plan moves forward. The strategies listed here more 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.

#### **5.3.4. Objective 4**

*Protect critical habitat for resident killer whales and identify additional potential areas for critical habitat designation and protection.*

Two coastal 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 other, the waters of Johnstone and Queen Charlotte Straits and their adjoining channels, is used by many of the northern residents during the summer and fall. These areas represent a relatively small proportion of the total range of each population. Preliminary data suggest that other 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 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 2, 3 and 4, will help to preserve and protect designated critical habitat and its functions.

#### **5.4. Effects on Non-Target Species**

Objectives 2, 3 and 4 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.

## 5.5. Evaluation and the Status of Strategies for Recovery

*The competent Minister must report on the implementation of the recovery strategy, and the progress towards meeting its objectives, within five years after it is included in the public registry... [SARA, S.46].*

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 performance measures will be identified more fully during the development of the action plan.

**Table 5** Examples of performance measures that may be used to assess the effectiveness of the broad strategies used to achieve the objectives of the Proposed 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
	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

Objective No. /Threat	Broad Strategy	Status	Examples of Performance Measures for Broad Strategies and Objectives
2. Chemical and biological contaminants	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
	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 Compete 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
	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

Objective No. /Threat	Broad Strategy	Status	Examples of Performance Measures for Broad Strategies and Objectives
	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 performance measures will be included in an action plan.

## **5.6. Recommended Approach for Recovery**

The recommended approach for recovery of northern and southern resident killer whales is a single species, but multi-population approach that encompasses a variety of strategies focused on the threats to resident killer whales, their prey and their habitat. At present, the recovery strategy for northern and southern resident killer whales does not directly link to any single species recovery strategies currently in progress in Canada. However, US agencies (NOAA and Washington State) have developed a proposed recovery plan for southern resident killer whales that will likely complement Canadian efforts on recovery (NMFS, 2006c). As well, initiatives such as Environment Canada's Georgia Basin Action Plan, DFO's Wild Salmon Policy and Parks Canada's Southern Strait of Georgia National Marine Conservation Area proposal and numerous Provincial Parks, including the Robson Bight-Michael Bigg Ecological Reserve established specifically to protect northern resident killer whales and their habitat will help to effect recovery by protection of at least a portion of resident killer whale habitat and their prey.

## **5.7. Target Date for Completion of Action Plans**

Action Plans will be necessary to successfully achieve the objectives and approaches of the resident killer whale recovery strategy. Action plans addressing the issues of 1) population dynamics and demographics, 2) reduced prey availability, 3) contaminants, 4) physical disturbance, 5) acoustic disturbance, and 6) critical habitat, will be completed by March 31, 2013. Further examination of prey availability and acoustic disturbance may be necessary due to the complex nature of these issues.

## 6. REFERENCES

- Addison, R.F. and W.T. Stobo. 2001. Trends in organochlorine residue concentrations and burdens in grey seals (*Halichoerus grypus*) from Sable Is., N.S., Canada, between 1974 and 1994. *Environmental Pollution* 112: 505-513.
- Aguilar, A. and A. Borrell. 1994. Abnormally high polychlorinated biphenyl levels in striped dolphins (*Stenella coeruleoalba*) affected by the 1990-92 Mediterranean epizootic. *Science of the Total Environment* 154: 237-247.
- Amos, B., C. Schloetterer, and D. Tautz. 1993. Social structure of pilot whales revealed by analytical DNA profiling. *Science* 260: 670-672.
- Andrew, R.K., B.M. Howe, J.A. Mercer, and M.A. Dzieciuch. 2002. Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast. *Acoustic Research Letters Online (ARLO)* 3: 65-70.
- Au, W. W. L., J. K. B. Ford, and K. A. Newman Allman. 2004. Echolocation signals of free-ranging killer whales (*Orcinus orca*) and modeling of foraging for chinook salmon *Oncorhynchus tshawytscha*. *Journal of the Acoustical Society of America* 221:559-564.
- Bain, D.E. 1990. Testing the validity of inferences drawn from photo-identification data, with special reference to the studies of the killer whales (*Orcinus orca*) in British Columbia. *Report of the International Whaling Commission Special Issue* 12: 93-100.
- Bain, D. 1996. Sound level contours produced by the 1995 acoustic barrier at the Hiram M. Chittenden Locks. NMFS Contract Report No. 40ABNF502019. 18pp
- Bain, D.E. 2002. A model linking energetic effects of whale watching to killer whale (*Orcinus orca*) population dynamics. Unpublished manuscript accessed January 17, 2005 at <http://www.saveorcawhales.org>
- Baird, R.W. 2000. The killer whales, foraging specializations and group hunting. Pages 127-153 in J. Mann, R.C. Connor, P.L. Tyack, and H. Whitehead (editors). *Cetacean societies: field studies of dolphins and whales*. University of Chicago Press, Chicago, Illinois.
- Baird, R.W. 2001. Status of killer whales, *Orcinus orca*, in Canada. *Canadian Field Naturalist* 115:676-701.
- Baird, R.W. 2002. *Killer whales of the world: natural history and conservation*. Voyageur Press, Stillwater, Minnesota.
- Baker, C.S., G.M. Lento, F. Cipriano, and S.R. Palumbi. 2000. Predicted decline of protected whales based on molecular genetic monitoring of Japanese and Korean markets. *Proceedings of the Royal Society of London Series B: Biological Sciences* 267: 1191-1199.
- Barlow, J., R.W. Baird, J.E. Heyning, K. Wynne, A. M. Manville, L.F. Lowry, D. Hanan, J. Sease, and V.N. Burkanov. 1994. A review of cetacean and pinniped mortality in coastal fisheries along the west coast of the USA and Canada and the east coast of the Russian Federation. *Report of the International Whaling Commission Special Issue* 15:405-425.

- Barrett-Lennard, L.G. 2000. Population structure and mating patterns of killer whales as revealed by DNA analysis. Ph.D. Thesis, University of British Columbia, Vancouver, British Columbia.
- Barrett-Lennard, L.G., J.K.B. Ford and K. Heise. 1996. The mixed blessing of echolocation: Differences in sonar use by fish-eating and mammal-eating killer whales. *Animal Behaviour* 51: 553-565.
- Barrett-Lennard, L.G. and G.M. Ellis. 2001. Population structure and genetic variability in Northeastern Pacific killer whales: toward an assessment of population viability. CSAS Res. Doc. 2001/065. 35 pp. Accessed January 4, 2005 at [http://www.dfo-mpo.gc.ca/csas/Csas/English/Research\\_Years/2001/2001\\_065e.htm](http://www.dfo-mpo.gc.ca/csas/Csas/English/Research_Years/2001/2001_065e.htm)
- Barrett-Lennard, L.G., V.B. Deecke, H. Yurk, and J.K.B. Ford. 2001. A sound approach to the study of culture. *Behavioural and Brain Sciences* 24: 325-326.
- BC Statistics 2004. Population projections. Accessed February 6, 2005 at <http://www.bcstats.gov.bc.ca/data/pop/popproj.htm#bc>
- Beamish, R.J., C. Mahnken, and C.M. Neville. 1997. Hatchery and wild production of Pacific salmon in relation to large-scale, natural shifts in the productivity of the marine environment. *ICES Journal of Marine Science* 54: 1200-1215
- Benson, A.J. and A. W. Trites. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific Ocean. *Fish and Fisheries* 3: 95-113.
- Berzin, A.A. and V.L. Vladimorov. 1983. A new species of killer whale (Cetacea, Delphinidae) from Antarctic waters. *Zoologicheskii Zhurnal* 62: 287-295.
- Bigg, M.A. and A.A. Wolman. 1975. Live-capture killer whales (*Orcinus orca*) fishery, British Columbia and Washington, 1962-73. *Journal of the Fisheries Research Board of Canada* 32:1213-1221.
- Bigg, M.A., G.M. Ellis, J.K.B. Ford, and K.C. Balcomb. 1987. Killer whales: a study of their identification, genealogy, and natural history in British Columbia and Washington State. Phantom Press, Nanaimo, British Columbia.
- Bigg, M.A., P.F. Olesiuk, G.M. Ellis, J.K.B. Ford, and K.C. Balcomb. 1990. Social organization and genealogy of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission Special Issue 12:383-405.
- Bigler, B.S., D.W. Welch, and J.H. Helle. 1996. A review of size trends among North Pacific salmon (*Oncorhynchus* spp.). *Canadian Journal of Fisheries and Aquatic Science* 53: 455-465.
- Bjorn, P.A., B. Finstad, and R. Kristoffersen. 2001. Salmon lice infection of wild sea trout and Arctic char in marine and freshwaters: the effects of salmon fumes. *Aquaculture Research* 32: 947-962.
- Black, N.R., A. Schulman-Janiger, R.L. Ternullo, and M. Guerrero-Ruiz. 1997. Killer whales of California and western Mexico: a catalogue of photo-identified individuals. US Dept. of Commerce NOAA-TM-NMFS-SWFSC-247.

- Black, N., R. Ternullo, A. Schulman-Janiger, A.M. Hammers, and P. Stap. 2001. Occurrence, behaviour, and photo-identification of killer whales in Monterey Bay, California. *In* 14<sup>th</sup> Biennial Conference on the Biology of Marine Mammals, Vancouver, British Columbia. Society for Marine Mammalogy, San Francisco, California.
- Borrell, A., D. Block, and G. Desportes. 1995. Age trends and reproductive transfer of organochlorine compounds in long-finned pilot whales from the Faroe Islands. *Environmental Pollution* 88: 283-292.
- Bosch, X. 2004. European parliament urges sonar moratorium. *Science* 306: 957.
- Bottomley, J.A., and J. Theriault. 2003. DRDC Atlantic Q-273 Sea Trial Marine Mammal Impact Mitigation Plan. DRDC Atlantic TM 2003-044, Defence Research and Development Canada – Atlantic. Accessed February 14, 2005 at <http://cradpdf.drdc-rddc.gc.ca/PDFS/unc31/p522682.pdf>
- Branch, T.A. and D.S. Butterworth. 2001. Estimates of abundance south of 60°S for cetacean species sighted frequently on the 1978/79 to 1997/98 IWC/IDCR-SOWER sighting surveys. *Journal of Cetacean Research and Management* 3: 251-270.
- Briggs, D.A. 1991. Impact of human activities on killer whales at the rubbing beaches in the Robson Bight Ecological Reserve and adjacent waters during the summers of 1987 and 1989. Unpublished. Report, BC Parks, Government of BC.
- Calambokidis, J., D. E. Bain and S. D. Osmek. 1998. Marine mammal research and mitigation in conjunction with air gun operation for the USGS "SHIPS" seismic surveys in 1998. Contract Report submitted to the Minerals Management Service. DRAFT accessed February 14, 2005 at <http://faculty.washington.edu/dbain/>
- Cameron, W.M. 1941. Killer whales stranded near Masset. Progress Report, Biological Station, Nanaimo, British Columbia and Pacific Experiment Station, Prince Rupert, British Columbia 49:16-17.
- Carl, G.C. 1946. A school of killer whales stranded at Estevan Point, Vancouver Island. Report of the Provincial Museum of Natural History and Anthropology B21-28.
- COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003. COSEWIC Species Database. Accessed January 4, 2005 at [http://www.cosewic.gc.ca/eng/sct1/searchform\\_e.cfm](http://www.cosewic.gc.ca/eng/sct1/searchform_e.cfm)
- Crum, L.A. and Y. Mao 1996. Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. *Journal of the Acoustical Society of America* 99: 2898-2907.
- Dahlheim, M.E. and J.E. Heyning. 1999. Killer whale *Orcinus orca* (Linnaeus, 1758). Pages 281-322 *in* S. Ridgway and R. Harrison (editors). Handbook of marine mammals, Volume 6. Academic Press, San Diego, California.
- Dahlheim, M.E. and C.O. Matkin. 1994. Assessment of injuries to Prince William Sound killer whales. Pages 163-171 *in* T.R. Loughlin (editor). Marine mammals and the Exxon Valdez. Academic Press, San Diego, California.



- Dahlheim, M., D.K. Ellifrit, and J.D. Swenson. 1997. Killer whales of southeast Alaska: a catalogue of photo-identified individuals. National Marine Mammal Laboratory, National Marine Fisheries Service, U.S. Department of Commerce, Seattle, Washington.
- Darnerud, P.O. 2003. Toxic effects of brominated flame retardants in man and in wildlife. *Environment International* 29: 841-853.
- Deecke, V.B., J.K.B. Ford, and P. Spong. 2000. Dialect change in resident killer whales: implications for vocal learning and cultural transmission. *Animal Behaviour* 60: 629-638.
- De Swart, R.L., Ross, P.S., Vos, J.G., and Osterhaus, A.D.M.E. 1996. Impaired immunity in harbour seals (*Phoca vitulina*) exposed to bioaccumulated environmental contaminants: review of a long-term study. *Environ. Health Perspect.* 104 (suppl. 4): 823-828.
- DFO. (Fisheries and Oceans Canada). 2004. Viewing Guidelines. Accessed March 9, 2006 at [http://www.pac.dfo-mpo.gc.ca/species/marinemammals/view\\_e.htm](http://www.pac.dfo-mpo.gc.ca/species/marinemammals/view_e.htm)
- DFO 2005a. Statement of Canadian practice on the mitigation of seismic noise in the marine environment. Accessed February 21, 2005 at [http://www.dfo-mpo.gc.ca/canwaters-eauxcan/infocentre/media/seismic-sismique/intro\\_e.asp](http://www.dfo-mpo.gc.ca/canwaters-eauxcan/infocentre/media/seismic-sismique/intro_e.asp)
- DFOb. 2005. Canada's Policy on the Conservation of Wild Pacific Salmon. Vancouver, DFO available at [http://www-comm.pac.dfo-mpo.gc.ca/publications/wsp/wsp\\_e.pdf](http://www-comm.pac.dfo-mpo.gc.ca/publications/wsp/wsp_e.pdf)
- Donague, M., Reeves, R., and G.S. Andrews. 2002. Report of the Workshop On Interactions Between Cetaceans And Longline Fisheries. Apia, Samoa: November 2002. New England Aquarium Aquatic Forum Series Report 03-1, New England Aquarium, Boston, MA, USA.
- Duffield, D.A., D.K. Odell, J.F. McBain, and B. Andrews. 1995. Killer whale (*Orcinus orca*) reproduction at Sea World. *Zoo Biology* 14:417-430.
- EC-GBAP (Environment Canada Georgia Basin Action Plan). 2005. Georgia Basin Action Plan. Accessed February 22, 2005 at [www.pyr.ec.gc.ca/georgiabasin/Index\\_e.htm](http://www.pyr.ec.gc.ca/georgiabasin/Index_e.htm)
- Endo, T. Y. Hotta, K. Haraguchi, and M. Sakata. 2003. Mercury contamination in the red meat of whales and dolphins marketed for human consumption in Japan. *Environmental Science and Technology* 37: 2681-2685.
- Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. *Marine Mammal Science* 18:394-418.
- European Parliament. 2004. European Session Document, Motion for a Resolution. B60089/04, Resolution P6 TA, 2004
- Evans, D.L., and G.R. England. 2001. Joint interim report Bahamas marine mammal stranding event of 15-16 March 2000. NOAA, US Dept. of Commerce and Dept. of the Navy. Accessed January 4, 2005 at [http://www.nmfs.noaa.gov/prot\\_res/overview/Interim\\_Bahamas\\_Report.pdf](http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf)

- EVS (Environmental Consultants). 2003. Status trends and effects of toxic contaminants in the Puget Sound environment: recommendations. Prepared for Puget Sound Action Team, Olympia WA. Accessed February 23, 2005 at [http://www.psat.wa.gov/shared/PSAT\\_Recommendations\\_Final\\_10\\_03.pdf](http://www.psat.wa.gov/shared/PSAT_Recommendations_Final_10_03.pdf)
- Ewald,G., Larsson,P., Linge,H., Okla,L., and Szarzi,N. 1998. Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (*Oncorhynchus nerka*). *Arctic* 51: 40-47.
- Fay, R.R. and A.N. Popper. 2000. Evolution of hearing in vertebrates: the inner ears and processing. *Hearing Research* 149: 1-10.
- Felleman, F.L., J.R. Heimlich-Boran, and R.W. Osborne. 1991. The feeding ecology of killer whales (*Orcinus orca*) in the Pacific Northwest. Pages 113-147 in K. Pryor and K.S. Norris (editors). *Dolphin societies: discoveries and puzzles*. University of California Press, Berkeley, California.
- Fernandez, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, R. Degolloada, H.M. Ross, P. Herraez, A.M. Pocknell, E. Rodrigez, F.E. Howie, A. Espinosa, R.J. Reid, R. Jaber, V. Martin, A.A. Cunningham, and P.D. Jepson. 2004. Whales, sonar and decompression sickness (reply). *Nature* 428: 1-2.
- Finneran, J.J. 2003. Whole lung resonance in a bottlenose dolphin (*Tursiops truncatus*) and white whale (*Delphinapterus leucas*). *Journal of the Acoustical Society of America* 114: 529-535.
- Fleeger, J.W., K.R. Carman and R.M. Nisbet. 2003. Indirect effects of contaminants in aquatic ecosystems. *The Science of the Total Environment* 317: 207-233.
- Foote, A.D., R.W. Osborne, and A. R. Hoelzel. 2004. Whale-call response to masking boat noise. *Nature* 428: 910.
- Ford, J.K.B. 1984. Call traditions and dialects of killer whales (*Orcinus orca*) in British Columbia. Ph.D. dissertation, University of British Columbia. 435 p.
- Ford, J.K.B. 1989. Acoustic behaviour of resident killer whales *Orcinus-orca* off Vancouver Island, British Columbia, Canada. *Canadian Journal of Zoology* 69: 1454-1483.
- Ford, J.K.B. 1991. Vocal traditions among resident killer whales, *Orcinus-orca*, in coastal waters of British Columbia, Canada. *Canadian Journal of Zoology* 69: 1454-1483.
- Ford, J.K.B. 2006. An Assessment of critical habitats of resident killer whales in waters off the Pacific Coast of Canada. Canadian Science Advisory Secretariat, Research Document 2006/072.
- Ford, J.K.B. and G.M. Ellis. 1999. *Transients: Mammal-Hunting Killer Whales*. UBC Press, Vancouver, British Columbia. 96 pp.
- Ford, J.K.B. and G.M. Ellis. 2002. Reassessing the social organization of resident killer whales in British Columbia. Pages 72-75 in the Fourth International Orca Symposium and Workshop, September 23-28, 2002. CEBC-CNRS, France.

- Ford, J.K.B., and G.M. Ellis. 2005. Prey selection and food sharing by fish-eating 'resident' killer whales (*Orcinus orca*) in British Columbia. Canadian Science Advisory Secretariat, Research Document 2005/041.
- Ford, J.K.B., G.M. Ellis, P.F. Olesiuk. 2005. Linking prey and populations dynamics: did food limitation cause recent declines of 'resident' killer whales (*Orcinus orca*) in British Columbia. Canadian Science Advisory Secretariat, Research Document 2005/042.
- Ford, J.K.B., G.M. Ellis, and K.C. Balcomb. 2000. Killer Whales: the natural history and genealogy of *Orcinus orca* in British Columbia and Washington, second edition. UBC Press, Vancouver, British Columbia. 104 pp.
- Ford, J.K.B., G.M. Ellis, L.G. Barrett-Lennard, A.B. Morton, R.S. Palm, and K.C. Balcomb. 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters. Canadian Journal of Zoology 76:1456-1471.
- Forney, K. A. and P. Wade. In press. Worldwide distribution and abundance of killer whales. In J. A. Estes, R. L. Brownell, Jr., D. P. DeMaster, D. F. Doak, and T. M. Williams (editors). Whales, whaling and ocean ecosystems. University of California Press, Berkeley, California.
- Frances, R.C., S.R. Hare, A.B. Hallowed and W.S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fisheries Oceanography 7: 1-21.
- Gardner, J. and D.L. Peterson. 2003. Making sense of the salmon aquaculture debate: analysis of issues related to netcage salmon farming and wild salmon in British Columbia. Prepared for the Pacific Fisheries Resource Conservation Council, Vancouver, BC. 159 pp. Accessed December 18, 2004 at [www.fish.bc.ca](http://www.fish.bc.ca).
- Gardner, J., D.L. Peterson, A. Wood, and V. Maloney. 2004. Making sense of the debate about hatchery impacts: interactions between enhanced and wild salmon on Canada's Pacific coast. Prepared for the Pacific Fisheries Resource Conservation Council, Vancouver, BC. 187 pp. Accessed December 18, 2004 at [www.fish.bc.ca](http://www.fish.bc.ca).
- Garrett and Ross. In press. Resident killer whale Recovery Planning Technical Workshop: Environmental contaminant source scoping document. Canadian Technical Reports of Fisheries and Aquatic Sciences. Approx. 58 pp.
- Gaydos, J.K., K.C. Balcomb, R.W. Osborne, and L. Dierauf. 2004. Evaluating potential infectious disease threats for southern resident killer whales, *Orcinus orca*: a model for endangered species. Biological Conservation 117: 253-262.
- Geraci, J.R. and D.J. St. Aubin. 1982. Sea mammals and oil: confronting the risks. Academic Press, New York, New York.
- Geraci, J.R., D.M. Anderson, R.J. Timperi, D.J. St. Aubin, G.A. Early, J.H. Prescott, and C.A. Mayo. 1989. Humpback whales (*Megaptera novaeangliae*) fatally poisoned by dinoflagellate toxin. Canadian Journal of Fisheries and Aquatic Science 46:1895-1898.

- Grachev, M.A., V.P. Kumarev, and L. V. Mamaev. 1989. Distemper virus in Baikal seals. *Nature* 338: 209.
- Grant, S.C.H. and P.S. Ross. 2002. Southern resident killer whales at risk: toxic chemicals in the British Columbia and Washington environment. Canadian Technical Report of Fisheries and Aquatic Science 2412:1-111.
- Greenwood, A.G. and D.C. Taylor. 1985. Captive killer whales in Europe. *Aquatic Mammals* 1:10-12.
- Guenther, T.J., R.W. Baird, R.L. Bates, P.M. Willis, R.L. Hahn, and S.G. Wischniowski. 1995. Strandings and fishing gear entanglements of cetaceans on the west coast of Canada in 1994. Report submitted to the International Whaling Commission, SC/47/06.
- Haenel, N.J. 1986. General notes on the behavioural ontogeny of Puget Sound killer whales and the occurrence of allomaternal behaviour. Pages 285-300 in B.C. Kirkevold and J.S. Lockard (editors). *Behavioural Biology of Killer Whales*. Alan R. Liss, New York, New York.
- Hagen, M.E., A.G. Colodey, W.D. Knapp, and S.C. Samis. 1997. Environmental response to decreased dioxin and furan loadings from British Columbia coastal pulp mills. *Chemosphere* 34: 1221-1229.
- Haggarty, D.R., B. McCorquodale, D.I. Johannessen, C.D. Levings, and P.S. Ross. 2003. Marine environmental quality in the central coast of British Columbia, Canada: A review of contaminant sources, types and risks. Canadian Technical Report of Fisheries and Aquatic Sciences 2507. 153 pp.
- Hall, J.D., and C.S. Johnson. 1972. Auditory thresholds of a killer whale *Orcinus orca* Linnaeus. *Journal of the Acoustical Society of America* 51: 515-517.
- Hall, A.J., O.I. Kalantzi, and G.O. Thomas. 2003. Polybrominated diphenyl ethers (PBDEs) in grey seals during the first year of life – are they thyroid hormone endocrine disrupters? *Environmental Pollution* 126: 29-37.
- Hartwell, S.I. 2004. Distribution of DDT in sediments off the central California coast. *Marine Pollution Bulletin* 49: 299-305.
- Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 313-393 in C. Groot and L. Margolis (editors). *Pacific salmon life histories*. UBC Press, Vancouver, British Columbia.
- Heimlich-Boran, J.R. 1986. Fishery correlations with the occurrence of killer whales in Greater Puget Sound. Pages 113-131 in B.C. Kirkevold and J.S. Lockard (editors). *Behavioural biology of killer whales*. Alan R. Liss, New York, New York.
- Heimlich-Boran, J.R. 1988. Behavioural ecology of killer whales (*Orcinus orca*) in the Pacific Northwest. *Canadian Journal of Zoology* 66:565-578.
- Heise, K., L. G. Barrett-Lennard, E. Saulitis, C. Matkin, and D. Bain. 2003. Examining the evidence for killer whale predation on Steller sea lions in British Columbia and Alaska. *Aquatic Mammals* 29: 325-334.

- Heyning, J.E. and M.E. Dahlheim. 1988. *Orcinus orca*. Mammalian Species 304:1-9.
- Heyning, J.E., T.D. Lewis, and C.D. Woodhouse. 1994. A note on odontocete mortality from fishing gear entanglements off southern California. Reports of the International Whaling Commission Special Issue 15:439-442.
- Hoelzel, A.R. 1993. Foraging behaviour and social group dynamics in Puget Sound killer whales. Animal Behaviour 45:581-591.
- Hoelzel, A.R., A. Natoli, M.E. Dahlheim, C. Olavarria, R.W. Baird, and N.A. Black. 2002. Low worldwide genetic diversity in the killer whale (*Orcinus orca*): implications for demographic history. Proceedings of the Royal Society of London, Biological Sciences, Series B. 269:1467-1473.
- Hooper, K. and T.A. McDonald. 2000. The PBDEs: an emerging environmental challenges and another reason for breast-milk monitoring programs. Environmental Health Perspectives 108: 387- 392.
- IUCN. 2004. RESWCC3.068 Undersea noise pollution Congress reference: GR3.RES053.Rev1. Accessed February 9, 2005 at [www.iucn.org](http://www.iucn.org)
- IWC (International Whaling Commission). 2004. Annex K. Report of the Standing Working Group on Environmental Concerns. Report of the Scientific Committee of the International Whaling Commission. Meeting held in Sorrento Italy, 29 June – 10 July 2004. Accessed December 17, 2004 at [www.iwcoffice.org/ documents/sci\\_com/SCRepFiles2004/56annexk.pdf](http://www.iwcoffice.org/documents/sci_com/SCRepFiles2004/56annexk.pdf)
- Jelinski, D.E., C.C. Krueger, and D.A. Duffus. 2002. Geostatistical analyses of interactions between killer whales (*Orcinus orca*) and recreational whale-watching boats. Applied Geography 22: 393-411.
- Jepson, P.D., C.R. Allchin, R.J. Law, T. Kuiken, J.R. Baker, E. Rogan, and J.T. Kirkwood. 1999. Investigating potential associations between chronic exposure to polychlorinated biphenyls and infectious disease mortality in harbour porpoises from England and Wales. Science of the Total Environment 243-244: 339-348.
- Jepson, P.D., M. Arbelo, R. Deaville, I. A. P. Patterson, P. Castro, J. R. Baker, E. Degollada, H. M. Ross, P. Herráez, A. M. Pocknell, F. Rodríguez, F. E. Howie, A. Espinosa, R. J. Reid, J. R. Jaber, V. Martin, A. A. Cunningham, and A. Fernández. 2003. Gas bubble lesions in stranded cetaceans. Nature 425: 575.
- JSKWC (Johnstone Strait Killer Whale Committee). 1991. Background Report. BC Ministry of Lands and Parks, and Dept. of Fisheries and Oceans. 76 p. + appendices.
- JSKWC (Johnstone Strait Killer Whale Committee). 1992. Management Recommendations. BC Ministry of Lands and Parks, and Dept. of Fisheries and Oceans. 18 p. + appendices.
- Kannan, K., J. Koistinen, K. Beckmen, T. Evans, J.F. Gorzelany, K.J. Hansen, P.D. Jones, E. Helle, M. Nyman, and J.P. Giesy. 2001. Accumulation of perfluorooctane sulfonate in marine mammals. Environmental Science and Technology 35: 1593-1598.
- Kennedy, S., T. Kuiken, and P.D. Jepson. 2000. Mass die-off of Caspian seals caused by canine distemper virus. Emerging Infectious Diseases 6: 637-639.

- Ketten, D.R., J. Lien, and S. Todd. 1993. Blast injury in humpback whales: evidence and implications. *Journal of the Acoustical Society of America* 94: 1849-1850.
- Krahn, M.M., P.R. Wade, S.T. Kalinowski, M.E. Dahlheim, B.L. Taylor, M.B. Hanson, G.M. Ylitalo, R.P. Angliss, J.E. Stein, and R.S. Waples. 2002. Status review of Southern Resident killer whales (*Orcinus orca*) under the *Endangered Species Act*. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-54. 133p.
- Krahn, M.M., M.J. Ford, W.F. Perrin, P.R. Wade, R.P. Angliss, M.B. Hanson, B.L. Taylor, G.M. Ylitalo, M.E. Dahlheim, J.E. Stein, and R.S. Waples. 2004. 2004 Status review of southern resident killer whales (*Orcinus orca*) under the *Endangered Species Act*. U.S. Dept. Commer, NOAA Tech. Memo. NMFSNWFS- 62, 73 p. Accessed January 4, 2005 at <http://www.nwr.noaa.gov/mmammals/whales/srkwstatusreview.pdf>
- Kriete, B. 1995. Bioenergetics in the killer whale, *Orcinus orca*. Ph.D. Thesis, University of British Columbia, Vancouver, British Columbia.
- Kriete, B. 2002. Bioenergetic changes from 1986 to 2002 in southern resident killer whales (*Orcinus orca*). Page 88 in Fourth international orca symposium and workshops, September 23-28, 2002, CEBC-CNRS, France.
- Kruse, S. 1991. The interactions between killer whales and boats in Johnstone Strait, B.C. Pages 149-159 in K. Pryor and K.S. Norris, editors. *Dolphin societies: discoveries and puzzles*. University of California Press, Berkeley, California.
- Langlier, K.M., P.J. Stacey, and R.W. Baird. 1990. Stranded whale and dolphin program of BC – 1989 report. *Wildlife Veterinary Report* 3(1): 10-11.
- Levings, C.D., J.R. Cordell, S. Ong, and G.E. Piercey. 2004. The origin and identify of invertebrate organisms being transported to Canada's Pacific coast by ballast water. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 1-11.
- Lindstrom, G., H. Wingfors, M.Dam, and B. von Bavel. 1999. Identification of 19 polybrominated diphenyl ethers (PBDEs) in long-finned pilot whale (*Globicephala melas*) from the Atlantic. *Archives of Environmental Contamination & Toxicology* 36: 355-363.
- Ljungblad, D.K.B., B. Wursig, S.L. Swartz and J.M. Keene. 1988. Observations on the behavioural responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. *Arctic* 41: 183-194.
- Madsen, P.T., B. Mohl, B.K. Nielsen, and M. Wahlberg. 2002. Male sperm whale behaviour during exposures to distant seismic survey pulses. *Aquatic Mammals* 28: 231-240.
- Mahnken, C., G. Ruggerone, W. Waknitz and T. Flagg. 1998. A historical perspective on salmonid production from Pacific Rim hatcheries. *North Pacific Anadromous Fish Commission Bulletin* 1: 38-53.
- Malakoff, D. 2003. Judge blocks navy sonar plan. *Science* 301: 1305.
- Malme, C.I., P.R. Miles, P. Tyack, C.W. Clark, and J.E. Bird. 1985. Investigation of the potential effects of underwater noise from petroleum industry activities on feeding



- humpback whale behaviour. BBN Rep. 5851: OCS Study MMS 85-0019 for US Minerals Management Service, Anchorage, Alaska.
- Malme, C.I. and P.R. Miles 1987. The influence of sound propagation conditions on the behavioural responses of whales to underwater industrial noise. *Journal of the Acoustical Society of America* 1: 97
- MARPAC. 2005. Capabilities. Accessed February 10, 2005 at [http://www.navy.forces.gc.ca/marpac/base-units/marpac\\_base-units\\_e.asp?category=2&title=16](http://www.navy.forces.gc.ca/marpac/base-units/marpac_base-units_e.asp?category=2&title=16)
- Matkin, C. O., and E. L. Saulitis. 1994. Killer whale (*Orcinus orca*) biology and management in Alaska. Report for the Marine Mammal Commission, Washington, D.C.
- Matkin, C.O., G. M. Ellis, E. L. Saulitis, L. G. Barrett-Lennard, and D. R. Matkin. 1999. Killer Whales of Southern Alaska. North Gulf Oceanic Society, Homer, Alaska.
- Martoja, R. & Berry, R.J. 1980. Identification of tiemannite as a probable product of demethylation of mercury by selenium in cetaceans, a complement scheme of the biological cycle of mercury. *Vie Milieu* 30: 7-10.
- McCallum, H., D. Harvell, and A. Dobson. 2003. Rates of spread of marine pathogens. *Ecological Letters* 6: 1062-1067.
- McComb, K., C. Moss, S.M. Durant, L. Baker, and S. Sayialel. 2001. Matriarchs as repositories of social knowledge in African elephants. *Science* 292: 491-494.
- McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. *Journal of the Acoustic Society of America* 113:638-642.
- Miller, P.O. and D.E. Bain. 2000. Within-pod variation in the sound production of a pod of killer whales, *Orcinus orca*. *Animal Behaviour* 60: 617-628.
- Mikhaley, Y.A., M.V. Ivashin, V.P. Savusin, and F.E. Zelenaya. 1981. The distribution and biology of killer whales in the Southern hemisphere. Report of the International Whaling Commission 31:551-566.
- Mitchell, E. and R.R. Reeves. 1988. Records of killer whales in the western North Atlantic, with emphasis on eastern Canadian waters. *Rit Fiskideildar* 11:161-193.
- Mitson, R.B. and H.P. Knudsen. 2003. Causes and effects of underwater noise on fish abundance estimation. *Aquatic Living Resources* 16: 255-263.
- Morton, A.B. and H.K. Symonds. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. *ICES Journal of Marine Science* 59:71-80.
- Morton, A. and R. Williams. 2003. First report of the sea louse (*Lepeophtheirus salmonis*), infestation on juvenile pink salmon (*Oncorhynchus gorbuscha*) in nearshore habitat. *Canadian Field Naturalist* 117: 634-641.
- Morton, A., R. Routledge, C. Peet and A. Ladwig. 2004. Sea lice (*Lepeophtheirus salmonis*) infection rates on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in the nearshore marine environment of British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Science* 61: 147-157.

- Mos, L., Ross, P.S., McIntosh, D., and Raverty, S. 2003. Canine distemper virus in river otters in British Columbia as an emergent risk for coastal pinnipeds. *Veterinary Record* 152: 237-239.
- Muir, D., B. Braune, B. De March, R. Norstrom, R. Wagemann, L. Lockhart, B. Hargrave, D. Bright, R. Addison, J. Payne and K. Reimer. 1999. Spatial and temporal trends and effects of contaminants in the Canadian Arctic marine ecosystem: a review. *Science of the Total Environment* 230: 83-144.
- Myrberg Jr., A.A. 1990. The effects of man-made noise on the behaviour of marine animals. *Environment International* 16: 575-586.
- Nichol, L.M. 1990. Seasonal movements and foraging behaviour of resident killer whales (*Orcinus orca*) in relation to the inshore distribution of salmon (*Oncorhynchus sp.*). M.Sc. Thesis, University of British Columbia, Vancouver.
- Nichol, L.M. and D.M. Shackleton. 1996. Seasonal movements and foraging behaviour of northern resident killer whales (*Orcinus orca*) in relation to the inshore distribution of salmon (*Oncorhynchus spp.*) in British Columbia. *Canadian Journal of Zoology* 74:983-991.
- Nishiwaki, M., and C. Handa. 1958. Killer whales caught in the coastal waters off Japan for recent 10 years. *Scientific Report of the Whales Research Institute, Tokyo*. 13: 85-96
- Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R. P Dziak, and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. *Journal of the Acoustical Society of America* 115: 1832-1843.
- Nyman, M., Bergknut, M., Fant, M.L., Raunio, H., Jestoi, M., Bengs, C., Murk, A., Koistinen, J., Bäckman, C., Pelkonen, O., Tysklind, M., Hirvi, T., and Helle, E. 2003. Contaminant exposure and effects in Baltic ringed and grey seals as assessed by biomarkers. *Mar. Environ. Res.* 55: 73-99.
- NMFS (National Marine Fisheries Service). 2004. Preliminary report: multidisciplinary investigation of harbour porpoises (*Phocoena phocoena*) stranded in Washington State from 2 May-2 June 2003 coinciding with the mid-range sonar exercises of the USS Shoup, February, 2004. 109 pp.
- NMFS 2005a. Endangered and Threatened Wildlife and Plants: Endangered Status for Southern Resident Killer Whales, Federal Register, 70 FR 69903.
- NMFS. 2005b. Endangered Fish and Wildlife; Notice of Intent to Prepare an Environmental Impact Statement. Federal Register (Vol. 70, Num. 7) January 11, 2005. pp 1871-1875.
- NMFS. 2006a. Designation of critical habitat for southern resident killer whales, biological report, October 2006, 44 pp. Accessed March 9, 2007 at <http://www.nwr.noaa.gov/Marine-Mammals/Whales-Dolphins-Porpoise/Killer-Whales/ESA-Status/upload/SRKW-CH-Bio-Rpt.pdf>
- NMFS. 2006b. Endangered and Threatened Species: Designation of Critical Habitat for Southern Resident Killer Whale, Federal Register, 71 FR 69054.



- NMFS. 2006c. Proposed Recovery Plan for Southern Resident Killer Whales (*Orcinus orca*), November 2006, 219pp. <http://www.nwr.noaa.gov/Marine-Mammals/Whales-Dolphins-Porpoise/Killer-Whales/ESA-Status/Orca-Recovery-Plan.cfm>
- Northcote, T.G. & P.A. Larkin. 1989. The Fraser River: A major salmonine production system. P.172-204 IN: Dodge, D.P. (ed.). Proceedings of the International Large River Symposium. Can. Spec. Publ. in Fish. Aquat. Sci. 106.
- NRC (National Research Council). 2003. Ocean Noise and Marine Mammals. National Research Council, National Academies Press, Washington, D.C.
- NRC. 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. National Academies Press, Washington, D.C.
- NWR (Northwest Regional Office, NOAA). 2004. *Endangered species act* status of west coast salmon and steelhead. Accessed December 18, 2004 at [www.nwr.noaa.gov](http://www.nwr.noaa.gov)
- Øien, N. 1988. The distribution of killer whales (*Orcinus orca*) in the North Atlantic based on Norwegian catches, 1938-1981, and incidental sightings, 1967-1987. Rit Fiskideildar11: 65-78.
- OFM (Office of Financial Management, State of Washington). 2004. Forecast of the state population. Accessed February 6, 2005 at <http://www.ofm.wa.gov/pop/stfc/index.htm>
- Olesiuk, P.F., M.A. Bigg, and G.M. Ellis. 1990. Life history and population dynamics of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission Special Issue 12:209-243.
- Olesiuk, P.F., L.M. Nichol, M.J. Sowden, and J.K.B. Ford. 2002. Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbour porpoises (*Phocoena phocoena*) in Retreat Passage, British Columbia. Marine Mammal Science 18:843-862.
- O'Neill, S.M., J.E. West, and J.C. Hoeman. 1998. Spatial trends in the concentration of polychlorinated biphenyls (PCBs) in chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) in Puget Sound and factors affecting PCB accumulation: results from the Puget Sound Ambient Monitoring Program. Puget Sound Research '98:312-328. Accessed January 4, 2005 at [http://www.psat.wa.gov/Publications/98\\_proceedings/pdfs/2b\\_oneill.pdf](http://www.psat.wa.gov/Publications/98_proceedings/pdfs/2b_oneill.pdf)
- Osborne, R.W. 1991. Trends in killer whale movements, vessel traffic, and whale watching in Haro Strait. Pages 672-688 in Puget Sound Research '91 Proceedings. Puget Sound Water Quality Authority, Olympia, Washington.
- Osborne, R.W. 1999. A historical ecology of Salish Sea "resident" killer whales (*Orcinus orca*): with implications for management. Ph.D. Thesis, University of Victoria, Victoria, British Columbia.
- Osborne, R.W., K. Koski, and R. Otis. 2003. Trends in whale watching traffic around southern resident killer whales. PowerPoint presentation from The Whale Museum, Friday Harbor, Washington.

- Penston, M.J., M.A. McKibben, D.W. Hay and P.A. Gillibrand. 2004. Observations on open-water densities of sea lice larvae in Loch Shildaig, Western Scotland. *Aquaculture Research* 35: 793-805.
- Perrin, W.F. and J.R. Geraci. 2002. Stranding. Pages 1192-1197 *in* W.F. Perrin, B. Würsig, and J.G.M. Thewissen (editors). *Encyclopedia of marine mammals*. Academic Press, San Diego, California.
- Piantadosi, C.A., and E.D. Thalman. 2004. Whales, sonar and decompression sickness. *Nature* 428: 1.
- Pike, G.C. and I.B. MacAskie. 1969. Marine mammals of British Columbia. *Bulletin of the Fisheries Research Board of Canada* 171:1-54.
- Pitman, R.L. and P. Ensor. 2003. Three forms of killer whales (*Orcinus orca*) in Antarctic waters. *Journal of Cetacean Research and Management* 5: 131-139.
- Raverty, S.A. and J.K. Gaydos. 2004. Killer whale necropsy and disease testing protocol. Accessed Sept. 16, 2004 at <http://mehp.vetmed.ucdavis.edu/pdfs/orcanecropsyprotocol.pdf>
- Rayne, S., M.G. Ikonomou, P.S. Ross, G. M. Ellis, and L.G. Barrett-Lennard. 2004 PBDEs, PBBs, and PCNs in three communities of free-ranging killer whales (*Orcinus orca*) from the northeastern Pacific Ocean. *Environmental Science and Technology* 38: 4293-4299.
- Reeves, R.R. and E. Mitchell. 1988. Distribution and seasonality of killer whales in the eastern Canadian Arctic. *Fis Riskideildar* 11:136-160.
- Reeves, R.R., W.F. Perrin, B.L. Taylor, C.S. Baker, and S.L. Mesnick. 2004. Report of the Workshop on Shortcomings of Cetacean Taxonomy in Relation to Needs of Conservation and Management April 30-May 2, 2004, La Jolla, California. NOAA Technical Memorandum NOAA-NMFS-SWFSC-363. 94 pp. Accessed January 4, 2005 at [http://swfsc.nmfs.noaa.gov/cmhc\\_reg/workshopreport22jul.pdf](http://swfsc.nmfs.noaa.gov/cmhc_reg/workshopreport22jul.pdf)
- Reijnders, P.J.H. 1986. Reproductive failure in common seals feeding on fish from polluted coastal waters. *Nature* 324: 456-457.
- Rendell, L., and H. Whitehead. 2001. Culture in whales and dolphins. *Behavioural and Brain Sciences* 24: 309-382.
- Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. *Marine mammals and noise*. Academic Press, San Diego, California.
- Riddell, B.E. 1993. Spatial organization of Pacific salmon: what to conserve? Pages 22-41 *in* Genetic Conservation of Salmonid Fishes. J.G. Cloud and G.H. Thorgaard (editors). Plenum Press, New York.
- Riddell, B. 2004. Pacific salmon resources in central and north coast British Columbia. Prepared for the Pacific Fisheries Resource Conservation Council, Vancouver, BC. 23 pp. Accessed December 18, 2004 at [www.fish.bc.ca](http://www.fish.bc.ca)
- Ross, P.S. 2000. Marine mammals as sentinels in ecological risk assessment. *Humans and Ecological Risk Assessment* 6: 29-46.

- Ross, P.S. 2002. The role of immunotoxic environmental contaminants in facilitating the emergence of infectious diseases in marine mammals. *Humans and Ecological Risk Assessment* 8: 277-292.
- Ross, P.S., G.M. Ellis, M.G. Ikonumou, L.G. Barrett-Lennard and R.F. Addison. 2000. High PCB concentrations in free-ranging Pacific Killer Whales, *Orcinus orca*: effects of age, sex and dietary preference. *Marine Pollution Bulletin* 40:504-515.
- Ross, P.S., G. Ellis, J.K.B. Ford, and L.G. Barrett-Lennard. 2002. Toxic chemical pollution and Pacific killer whales (*Orcinus orca*). Pages 126-130 in *Fourth International Orca Symposium and Workshops*, September 23-28, 2002, CEBC-CNRS, France.
- Ross, P.S., S.J. Jeffries, M.B. Yunker, R.E. Addison, M.G. Ikonomou, and J. C. Calambokidas. 2004. Harbour seals (*Phoca vitulina*) in British Columbia, Canada, and Washington State, USA, reveal a combination of local and global polychlorinated biphenyl, dioxin and furan signals. *Environmental Toxicology and Chemistry* 23: 157-165.
- Ross, P.S. 2006. Fireproof killer whales (*Orcinus orca*): Flame retardant chemicals and the conservation imperative in the charismatic icon of British Columbia, Canada. *Can.J.Fish.Aquat.Sci.* 63: 224-234.
- Saulitis, E., C. Matkin, L. Barrett-Lennard, K. Heise and G. Ellis. 2000. Foraging strategies of sympatric killer whale (*Orcinus orca*) populations in Prince William Sound. *Marine Mammal Science* 16:94-109.
- Saulitis, E., C.O. Matkin and G. Ellis. 2002. The biology and status of an endangered transient killer whale population in Prince William Sound, Alaska. Pages 131-132 in *Fourth International Orca Symposium and Workshops*, September 23-28, 2002, CEBC-CNRS, France.
- Scammon, C.M. 1874. The marine mammals of the northwestern coast of North America, together with an account of the American whale fishery. J.H. Carmany and Company, San Francisco, California.
- Scholin, C.A., F. Gulland, G.J. Doucette, S. Benson, M. Busman, F.P. Chavez, J. Cordaro, R. DeLong, A.D. Vogelaere, J. Harvey, M. Haulena, K. Lefebvre, T. Lipscomb, S. Loscutoff, L.J. Lowenstine, R. Marin, P.E. Miller, W.A. McLellan, P.D.R. Moeller, C.L. Powell, T. Rowles, P. Silvagni., M. Silver, T. Spraker, V. Trainer, and F.M.V. Dolah. 2000. Mortality of sea lions along the central California coast linked to a toxic diatom bloom. *Nature* 403:80-84.
- Shore, V. 1995. Do killer whales get trapped often? *Blackfish Sounder* (Vancouver Aquarium) 3:3.
- Shore, V. 1998. Southern residents go a 'bridge too far'. *Blackfish Sounder* (Vancouver Aquarium) 6:3.
- Sih, A., A.M. Bell, and J.L. Kerby. 2004. Two stressors are far deadlier than one. *Trends in Ecology and Evolution* 19: 274-276.
- Smith, J.C. and D.E. Bain. 2002. Theodolite study of the effects of vessel traffic on killer whales (*Orcinus orca*) in the near-shore waters of Washington State, USA. Pages 143-

- 145 in Fourth international orca symposium and workshops, September 23-28, 2002, CEBC-CNRS, France.
- Song, L., A. Seeger, and J. Santos-Such. 2005. On membrane motor activity and chloride flux in the outer hair cell: lessons learned from the environmental toxin tributyltin. *Biophysical Journal* 88 (3): 2350-2362.
- Stone C.J. 2003. The effects of seismic activity on marine mammals in UK waters, 1998-2000. Joint Nature Conservation Committee Report No. 323. Aberdeen, UK.
- Szymanski, M.D., D. E. Bain, K. Kiehl, S. Pennington, S. Wong and K. R. Henry. 1999. Killer whale (*Orcinus orca*) hearing: Auditory brainstem response and behavioral audiograms. *Journal of the Acoustical Society of America* 106: 1134-1141.
- Tanabe, S. and R. Tatsukawa. 1992. Chemical modernization and vulnerability of cetaceans: increasing toxic threat of organochlorine contaminants. Pages 161-177 in C.H. Walker and D.R. Livingstone (editors). *Persistent Pollutants in Marine Ecosystems*. Pergamon Press, New York, New York.
- Taylor, M. and B. Plater. 2001. Population viability analysis for the southern resident population of the killer whale (*Orcinus orca*). Centre for Biological Diversity, Tucson, Arizona. 30 p.
- Theriault, James A. DREA Q258 Sea Trial Marine Mammal Impact Mitigation Report," DREA Technical Note TN 2001-041. Informal Report.
- Todd, S., P. Stevick, J. Lien, F. Marques, and D. Ketten. 1996. Behavioural effects of exposure to underwater explosions in humpback whales (*Megaptera novaengliae*). *Canadian Journal of Zoology* 74: 1661-1672.
- Tomaszeski, T. 2004. Navy generated sound in the ocean. Presentation at the First Plenary Meeting of the Advisory Committee on Acoustic Impacts on Marine Mammals 3-5 February 2004 Bethesda, Maryland Accessed February 14, 2005 at [http://www.mmc.gov/sound/plenary1/pdf/plenary%201\\_tomaszeski.pdf](http://www.mmc.gov/sound/plenary1/pdf/plenary%201_tomaszeski.pdf)
- Trainer, V.L. and D.G. Baden. 1999. High affinity binding of red neurotoxins to marine mammal brain. *Aquatic Toxicology* 46:139-148.
- Trites, A.W., D.E. Bain, R.M. Williams, and J.K.B. Ford. 2002. A review of short- and long-term effects of whale watching on killer whales in British Columbia. Pages 165-167 in the Fourth International Orca Symposium and Workshop, September 23-28, 2002. CEBC-CNRS, France.
- US Navy (US Pacific Fleet Commander, Department of the Navy). 2004. Report of the results of the inquiry into allegations of marine mammal impacts surrounding the use of active sonar by USS Shoup (DDG 86) in the Haro Strait on or about 5 May 2003. 52 pp. Accessed January 4, 2005 at <http://www.acousticecology.org/docs/SHOUPNavyReport0204.pdf>
- Van Bresseem, M.F., K. Van Waerebeek, and J.A. Raga. 1999. A review of virus infections of cetaceans and the potential impact of morbilliviruses, poxviruses and papillomaviruses on host population dynamics. *Diseases of Aquatic Organisms* 38:53-65.

- Van de Vijver, K.I., P.T. Hoff, K. Das, W. Van Dongen, E. L Esmans, T. Jauniaux, J. Bouquegenau, R. Blust, and W. de Coen. 2003. Perfluorinated chemicals infiltrate ocean waters: link between exposure levels and stable isotope ratios in marine mammals. *Environmental Science and Technology* 37: 5545-5550.
- Volpe, J.P., E.B. Taylor, D.W. Rimmer, and B.W. Glickman. 2000. Natural reproduction of aquaculture escaped Atlantic salmon (*Salmo salar*) in a coastal British Columbia River. *Conservation Biology* 14: 899-903.
- Wade, P.R. and T. Gerrodette. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. Report of the International Whaling Commission 43:477-493.
- Wainwright, P., G.F. Searing, and S. Carr. 1998. Environmental assessment of military training in Maritime forces Pacific exercise areas. Prepared for Canadian Forces Base Esquimalt, Environmental Risk Management Office, Victoria, British Columbia.
- Walker, L.A., L.A. Cornell, K.D. Dahl, N.M. Czekala, C.M. Dargen, B. Joseph, A.J.W. Hsueh, and B.L. Lasley. 1988. Urinary concentrations of ovarian steroid hormone metabolites and bioactive follicle-stimulating hormone in killer whales (*Orcinus orca*) during ovarian cycles and pregnancy. *Biology of Reproduction* 39: 1013-1020.
- Waples, R. and P. Clapham. 2004. Appendix 6: Report of the working group on killer whales as a case study. Pages 62-73 in R.R. Reeves, W.F. Perrin, B.L. Taylor, C.S. Baker, and S.L. Mesnick (editors). Report of the Workshop on Shortcomings of Cetacean Taxonomy in Relation to Needs of Conservation and Management April 30-May 2, 2004, La Jolla, California. NOAA Technical Memorandum NOAA-NMFS-SWFSC-363. 94 pp. Accessed January 4, 2005 at [http://swfsc.nmfs.noaa.gov/cmhc\\_reg/workshopreport22jul.pdf](http://swfsc.nmfs.noaa.gov/cmhc_reg/workshopreport22jul.pdf)
- WDOE (Washington Department of Ecology). 2004. Vessel entry and transit for Washington waters VEAT 2003. WDOE Publication 04-08-002. Olympia Washington. Accessed on December 18, 2004 at <http://www.ecy.wa.gov/pubs/0408002.pdf>
- Whitehead, H. 2003. Sperm whales: social evolution in the ocean. University of Chicago Press, Chicago.
- Whitehead, H. and L. Rendell. 2004. Movements, habitat use and feeding success of cultural clans of South Pacific sperm whales. *Journal of Animal Ecology* 73: 190-196.
- Whitehead, H., L. Rendell, R.W. Osborne, and B. Wursig. 2004. Culture and conservation of non-humans with reference to whales and dolphins: review and new directions. *Biological Conservation* 120: 431-441.
- Wilkening, K.E., L.A. Barrie and M. Engle. 2000. Trans-Pacific air pollution. *Science* 290: 65-66
- Wiles, G.J. 2004. Washington state status report for the killer whale. Washington Department of Fish and Wildlife, Olympia. 106 p.
- Williams, R. 1999. Behavioural responses of killer whales to whale-watching: opportunistic observations and experimental approaches. M.Sc. Thesis, University of British Columbia, Vancouver, BC, Canada.

- Williams, R., A.W. Trites, and D.E. Bain. 2002a. Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats; opportunistic observations and experimental approaches. *Journal of the Zoological Society of London* 256:255-270.
- Williams, R., D.E. Bain, J.K.B. Ford, and A.W. Trites. 2002b. Behavioural responses of male killer whales to a 'leapfrogging' vessel. *Journal of Cetacean Research and Management* 4(3): 305-310.
- WWOAN (Whale Watch Operators Association Northwest). 2004. Best Practices Guidelines. Accessed December 18, 2004 at <http://www.nwwhalewatchers.org/guidelines.html>
- Ylitalo, G.M., C.O. Matkin, J. Buzitis, M.M. Krahn, L.L. Jones, T. Rowles, and J.E. Stein. 2001. Influence of life-history parameters on organochlorine concentrations in free-ranging killer whales (*Orcinus orca*) from Prince William Sound, AK. *Science of the Total Environment* 281:183-203.
- Yurk, H., L. Barrett-Lennard, J.K.B. Ford and C.O. Matkin. 2002. Cultural transmission within maternal lineages: vocal clans in resident killer whales in southern Alaska. *Animal Behavior* 63: 1103-1119.

## APPENDIX A - Glossary

Abiotic:	Non-living factors in the environment (e.g. water, air, rocks)
Allee effect:	The reduced likelihood of finding a mate when population numbers are low
Anthropogenic:	Caused or produced by humans
Bioaccumulation:	The process by which (toxic) substances from prey and the environment crease over time in concentration in living organisms.
Biotic:	Living components of the environment (e.g. fish, plankton)
Biotoxin	Toxin produced by a living organism
Culture:	A body of information and behavioural traits that are transmitted within and between generations by social learning
dB (decibel):	A unit for measuring the relative intensity of a sound. In this document the sources of sounds are consistently referenced to 1 $\mu$ Pa at 1 m. The sounds that marine mammals hear (received level) depend on their distance from the source of the sound.
Depensation:	When a decline in population numbers leads to reduced survival (due to increased mortality) or reduced reproduction (due to the Allee effect)
Ecotype:	A population that is genetically different from other populations of the same species
Lipophilic:	A substance that dissolves more easily in lipids (fats) than water. Chemicals that are lipophilic tend to bioaccumulate.
Matriline:	Comprises all surviving members of a female lineage. A typical matriline comprises an adult female, her offspring, and the offspring of her daughters.
Mediastinal:	Part of the thoracic cavity between the lungs that contains the heart, aorta, esophagus, trachea and thymus
Odontocete:	Toothed whales, dolphins and porpoises
Systemic mycoses:	Fungal infection that affects the whole body
$\mu$ Pa (micro Pascal):	A unit of acoustic pressure
Sympatric:	Closely related populations or ecotypes that overlap in their range but do not interbreed

**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- <i>p</i> -dioxins
PCDFs:	Polychlorinated dibenzofurans
PCNs:	Polychlorinated naphthalenes
PCPs:	Polychlorinated paraffins
PCTs:	Polychlorinated terphenyls
SPFOs:	Perfluoro-octane sulfonates
POPs:	Persistent organic pollutants
TBT:	Tributyltin



## APPENDIX B - Description of critical habitat

### Southern Resident Killer Whale Critical Habitat Boundaries

(Described clockwise from the western boundary-all Latitudes are Decimal Degrees North; all Longitudes are Decimal Degrees West)

	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,	48	24.25	123	28.97
6	Esquimalt Hbr, Victoria Hbr)	48	24.57	123	22.61
7	Excluding waters west of the line joining (Cordova Channel	48	29.69	123	18.61
8	and Sidney Channel)	48	36.12	123	18.51
9	Excluding waters west of the line joining (western half of	48	37.04	123	18.49
10	Miners Channel and the waters west of Gooch Island)	48	39.70	123	17.72
11	Excluding waters west of the line joining (western half of	48	39.88	123	17.68
12	Prevost Channel and Moresby Passage)	48	42.96	123	19.63
13	Excluding waters west of the line joining (western portion of	48	43.34	123	19.88
14	Swanson Channel between Moresby Island and Prevost	48	48.86	123	22.70
15	Island)	48	50.66	123	23.33
16	Excluding waters west of the line joining (western portion of	48	52.61	123	23.92
17	Trincomali Channel between Prevost Island and Parker	48	52.85	123	23.92
18	Island)	48	53.08	123	23.76
19		48	54.28	123	20.67
20		48	55.39	123	21.98
21	Excluding waters west of the line joining (western portion of	49	0.00	123	18.88
22	southern Strait of Georgia)	49	10.39	123	22.82
23		49	13.58	123	21.97
24		49	13.58	123	21.97
25	Excluding waters north of the line joining (portion of southern	49	14.00	123	21.09
26	Strait of Georgia)	49	14.18	123	19.22
27		49	13.79	123	17.21
28		49	13.79	123	17.21
29		49	12.87	123	15.75
30	Excluding waters north and east of the line joining (portion of	49	9.01	123	16.48
31	southern Strait of Georgia)	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

(Described clockwise from the western boundary-all Latitudes are Decimal Degrees North; all Longitudes are Decimal Degrees West)

	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		50	46.27	127	5.26
4	Northern boundary (Numas Island to Broughton Island)	50	46.41	126	48.27
5		50	46.13	126	47.30
6	Northern boundary (Broughton Island to Screen Island / Eden Island)	50	44.95	126	43.55
7		50	44.79	126	43.22
8	boundary line running from Eden Island to Crib Island (including waters of Queen Charlotte Strait and excluding waters of Trainer Passage)	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

## APPENDIX C - Recovery Team Members

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: <a href="mailto:joycema@pac.dfo-mpo.gc.ca">joycema@pac.dfo-mpo.gc.ca</a>
Lance Barrett-Lennard	Co-Chair: Resident Killer Whale Recovery Team Vancouver Aquarium Marine Service Center Stanley Park, Vancouver, BC V6B 3X8, phone: 604-659-3428, email: <a href="mailto:Lance.Barrett-Lennard@vanaqua.org">Lance.Barrett-Lennard@vanaqua.org</a>
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 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 D - 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 is concurrently developing a recovery plan 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 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 has been incorporated into the final recovery strategy.

A proposed version of the recovery strategy was posted on the SARA Public Registry for a 60-day public comment period, from June 21<sup>st</sup> to August 20<sup>th</sup>, 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 final recovery strategy as appropriate.

**Recovery Team:**

Marilyn Joyce, Chair: Fisheries & Oceans Canada, Lance Barrett-Lennard, Vancouver aquarium  
John Ford, Fisheries & Oceans Canada, Graeme Ellis, Fisheries & Oceans Canada, Peter Ross,  
Fisheries and Oceans Canada, Peter Olesiuk, Fisheries & Oceans Canada, Brian Reader, Parks  
Canada Agency, Christine Garrett, Environment Canada, Ken Balcomb, Centre for Whale  
Research, Brent Norberg, National Marine Fisheries Service, Steve Jeffries, Washington  
Department of Fish and Wildlife, John Durban, National Marine Fisheries Service, Linda Jones,  
National Marine Fisheries Service, Rich Osborne, The Whale Museum, David Bain, Friday  
Harbor Laboratories, University of Washington, Paul Spong, Orcalab, Andrew Trites, University  
of British Columbia, Anna Hall, Whale Watch Operators Association NW, Jim Borrowman,  
North Island Whale Watching Community, Rob Williams, Marine Conservation Caucus, Scott  
Wallace, Sierra Club of Canada, B.C. Chapter (Alternate), Gary Wiles, Washington Department  
of Fish and Wildlife (Alternate), Brian Riddell, Pacific Fisheries Resource Conservation Council,  
Rob Paynter, Ministry of Water, Land and Air Protection, Kathy Heise, University of British  
Columbia

**External Review:**

Dr. Volker Deecke of the University of British Columbia and Dr. Christophe Guinet, Centre  
d'Etudes Biologiques de Chize, France.