

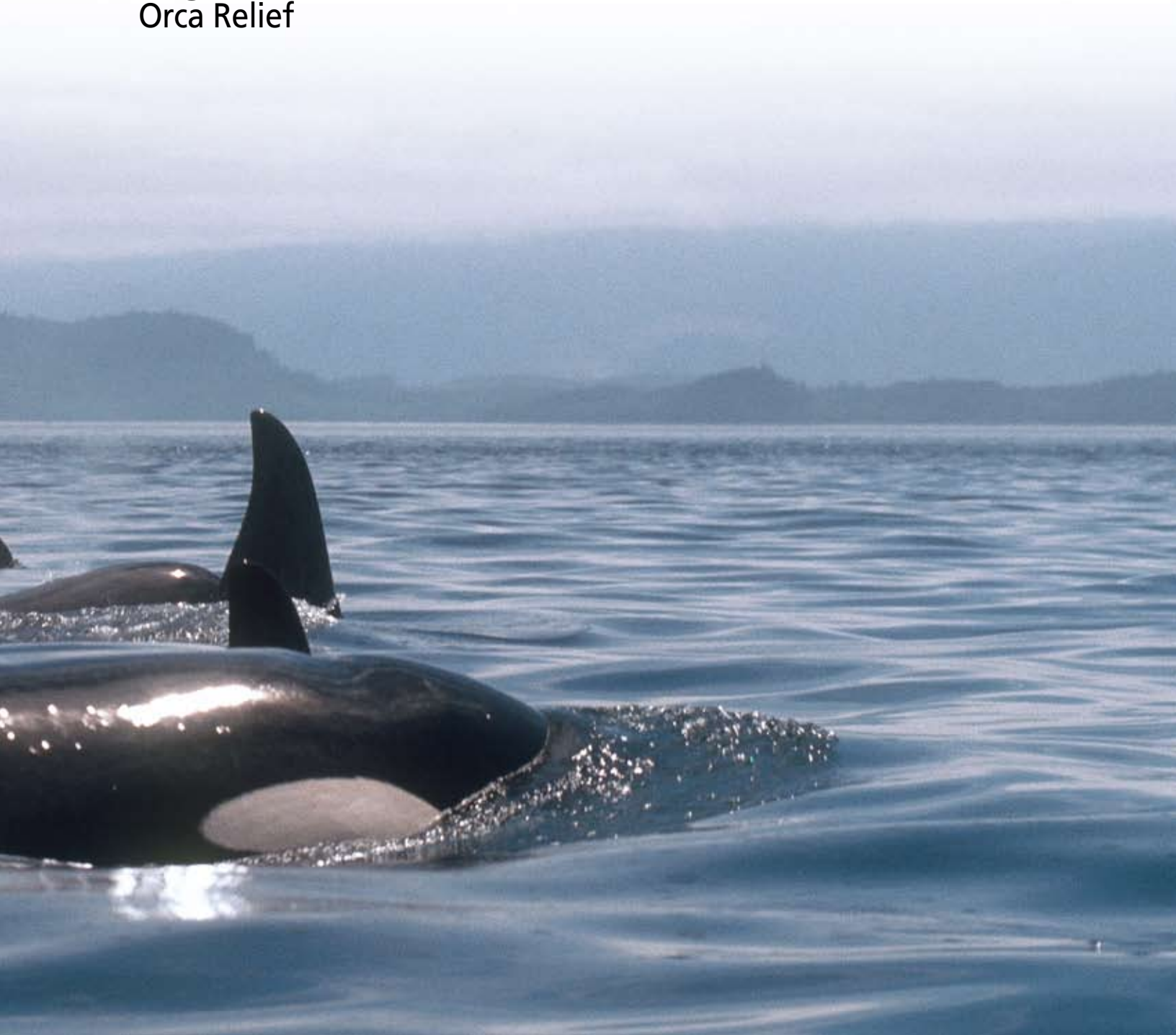
Technical Report 2007-01



Orcas in Puget Sound

Prepared in support of the Puget Sound Nearshore Partnership

Birgit Kriete
Orca Relief



Valued Ecosystem Components Report Series

PUGET SOUND
NEARSHORE
PARTNERSHIP



RESTORING OUR
ECOSYSTEM HEALTH

The Puget Sound Nearshore Partnership (PSNP) has developed a list of valued ecosystem components (VECs). The list of VECs is meant to represent a cross-section of organisms and physical structures that occupy and interact with the physical processes found in the nearshore. The VECs will help PSNP frame the symptoms of declining Puget Sound nearshore ecosystem integrity, explain

how ecosystem processes are linked to ecosystem outputs, and describe the potential benefits of proposed actions in terms that make sense to the broader community. A series of “white papers” was developed that describes each of the VECs. Following is the list of published papers in the series. All papers are available at www.pugetsoundnearshore.org.

Brennan, J.S. 2007. Marine Riparian Vegetation Communities of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-02. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Buchanan, J.B. 2006. Nearshore Birds in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Dethier, M.N. 2006. Native Shellfish in Nearshore Ecosystems of Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Eissinger, A.M. 2007. Great Blue Herons in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Fresh, K.L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Johannessen, J. and A. MacLennan. 2007. Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Kriete, B. 2007. Orcas in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-01. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Leschine, T.M. and A.W. Petersen. 2007. Valuing Puget Sound's Valued Ecosystem Components. Puget Sound Nearshore Partnership Report No. 2007-07. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Penttila, D. 2007. Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Front and back covers: Orcas in Puget Sound (courtesy of Washington Sea Grant)

Contents

Executive Summary.....	v
Preface	1
Nearshore Habitat Requirements	2
Ecosystem Processes Supporting Habitat Attributes	17
Major Gaps/Critical Uncertainties.....	19
Conclusions: Key Measures for Orca Restoration.....	19
References	20

Acknowledgments

First and foremost, thanks go to Dr. Megan Dethier and the Nearshore Science Team of PSNERP for giving me the opportunity to write this paper. Valuable unpublished papers and graphs were provided by Peter Olesiuk of Department of Fisheries and Oceans (DFO), Canada.

Recommended bibliographical citation:

Kriete, B. 2007. Orcas in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-01. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Available at www.pugetsoundnearshore.org.

The Puget Sound Nearshore Partnership Steering Committee initiated the concept of this paper and the others in this series. The Nearshore Partnership Project Management Team (PMT) — Tim Smith, Bernie Hargrave, Curtis Tanner and Fred Goetz — oversaw production of the papers. The Nearshore Science Team (NST) played a number of roles: they helped develop conceptual models for each valued ecosystem component (VEC), in collaboration with the authors; individual members were reviewers for selected papers; and members were also authors, including Megan Dethier, Tom Mumford, Tom Leschine and Kurt Fresh. Other NST members involved were Si Simenstad, Hugh Shipman, Doug Myers, Miles Logsdon, Randy Shuman, Curtis Tanner and Fred Goetz.

The Nearshore Partnership organization is especially grateful for the work done by series science editor Megan Dethier, who acted as facilitator and coach for the authors and liaison with the NST and PMT. We also thank the U.S. Army Corps of Engineers Public Affairs Staff — Patricia Grasser, Dick Devlin, Nola Leyde, Casandra Brewster and Kayla Overton — who, with Kendra Nettleton, assisted with publication of all the papers in the series.

Finally, the Nearshore Partnership would like to thank the Washington Sea Grant Communications Office — Marcus Duke, David Gordon, Robyn Ricks and Dan Williams — for providing the crucial editing, design and production services that made final publication of these papers possible.

This report was supported by the Puget Sound Nearshore Ecosystem Restoration Project through the U.S. Army Corps of Engineers and Washington Department of Fish and Wildlife.

For further information or printed copies of this report, contact Curtis Tanner, Local Project Manager, Puget Sound Nearshore Ecosystem Restoration Project, Washington Department of Fish and Wildlife, 600 Capital Way North, Olympia, Washington 98501-1091.
curtis_tanner@fws.gov.

To download PDF files of this and other reports in the series, visit our Web site at www.pugetsoundnearshore.org.

Executive Summary

The stock of southern resident killer whales (SRKW) in the eastern North Pacific declined by almost 20 percent in a five-year period to fewer than 80 individuals in 2001. Data suggest that the SRKW population might have previously numbered as many as 200 individuals during the 1800s, prior to human impact. The recent decline led the National Oceanic and Atmospheric Administration (NOAA) to list this resident group of orca as endangered under the Endangered Species Act (ESA) in November 2005. A combination of natural factors, including El Niño and La Niña but largely reductions in prey resources, disturbance from vessel traffic, and toxins, most likely contributed to the whales' decline. These factors cumulatively affect resident and transient whales' survival to the present. Data on previous numbers of transient killer whales are not available.

Ecologically, economically and recreationally, southern resident and transient killer whales have become greatly important to the local nearshore environment. Economically, whale watching in the San Juan Islands alone has become a \$10 million industry in the last few years. More than 500,000 visitors participate in whale watching on commercial vessels in the nearshore waters of Washington and British Columbia annually, not including visitors on an estimated 3,000 to 8,000 private vessels (The Whale Museum 2006).

Much biological information is available on these populations, due to 30 years of research and the animals' high visibility and individual identification. These top predators use nearshore locations for foraging and travel and are very susceptible to human disturbances and ecosystem decline. Their long life expectancy and position at the top of the food web contribute to the whales' accumulation of toxins, which can be dated back to the 1930s. Decreased reproductive success has also been linked with reduced prey availability.

The variety of human threats currently impacting orcas includes ecosystem deterioration, direct and indirect effects of contaminants on both prey and orca, 'loving the whales to death' by the constant presence of whale watch boats much of the year, and historical decline of salmon populations caused by habitat disturbance, overharvesting and inappropriate hatchery practices. Removal of nearly 40 percent of the SRKW population, as well as a number of transient orcas, during the late 1960s and early 1970s for public display also harmed the populations. While there is potential to restore the whales' environment by turning around various damaged processes, this will take decades to achieve. Local and regional efforts, as well as international agreements and laws, regarding toxics disposal will be necessary to achieve this goal.

Preface

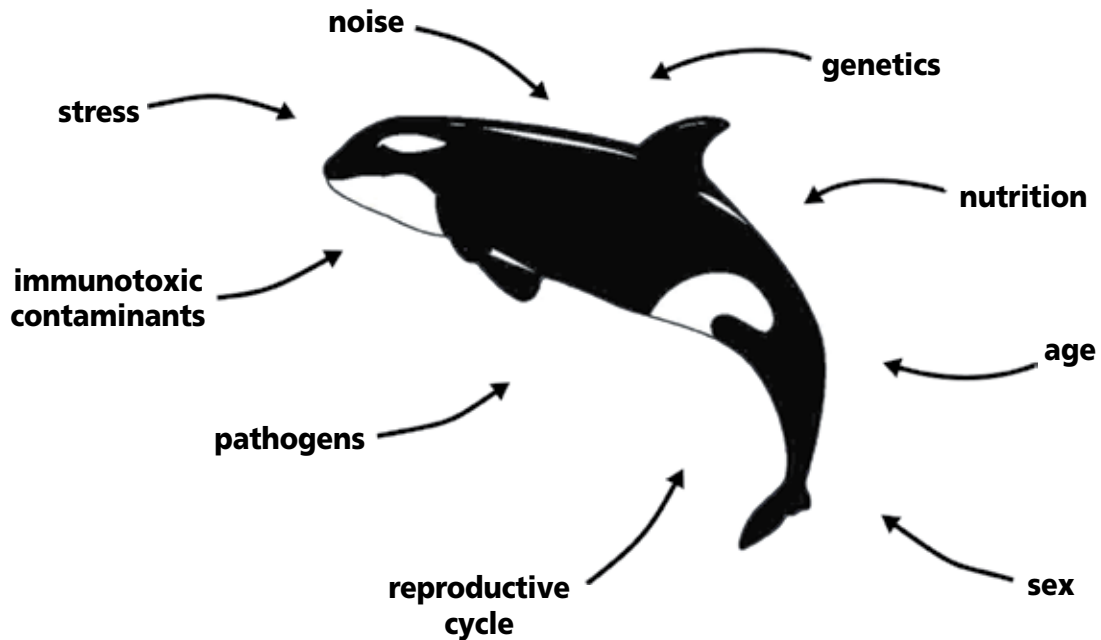
The southern resident population of orca is an extremely valuable resource to the Puget Sound area. Ecologically, the species inhabits the top of the food chain and serves as a sentinel species for environmental health. Being a top carnivore, resident killer whales consume primarily Chinook salmon, a smaller percentage of other local salmon species and some bottom fish, while transient orcas feed almost entirely on marine mammals.

Historically, killer whales were of cultural importance to native people but of no recreational or commercial importance to settlers. Rather, the whales were feared and killed because of their competition with the fishing industry for salmon. This view on orcas changed in the late 1960s and early 1970s when, within four years, approximately 40 percent of the

population was removed for display in aquaria worldwide. Orcas became a well-known and much-loved species.

Over the last 18 years, killer whales have been turned into 'superstars' and nowadays draw in tourists and researchers as well as local, national, and international businesses benefiting the local economy. They have become of great importance economically and recreationally. The status of the species, and the emotional bond that humans have developed with killer whales, due to similarities in social organization and culture and through movies, guarantees media attention. Annually, approximately 500,000 visitors watch this population of whales from boats in nearshore local waters (The Whale Museum 2006).

Many factors affect the health of free-ranging killer whales



Ross et al 2004

Nearshore Habitat Requirements

Distribution

Two distinct types of killer whales (*Orcinus orca*, Linnaeus 1758) are commonly found in Puget Sound: the southern resident (fish eating) and the transient (marine mammal eating). A third type of killer whale was recognized in the late 1980s and described as the offshore killer whale population (Ford et al. 1992, 1994, Walters et al. 1992). Offshore orca and northern residents rarely enter the protected waters of Puget Sound (Wiles 2004) and are therefore not extensively described in this paper.

The southern resident killer whale (SRKW) community consists of three pods, known as J, K, and L pods, numbering 86 whales as of the end of October 2006 (K. Balcomb, pers. comm., Center for Whale Research 2006). All reside in the inland waters of Washington State and southern British Columbia (Juan de Fuca Strait, Puget Sound and the Strait of Georgia) for a considerable time of the year, predominantly from early spring until late fall (Ford and Ellis 2002, Krahn et al. 2002) (Figure 1). Most often the resident pods are seen in Haro Strait, along the west side of San Juan Island, and in the southern part of Georgia Strait, Boundary Passage, the southern Gulf Islands and the eastern end of Juan de Fuca Strait (Heimlich-Boran 1988, Felleman et al. 1991, Olsen 1998, Ford et al. 2000, The Whale Museum 2006) (Figures 1 and 2).

During early autumn, southern resident pods, especially J pod, expand their routine movements into Puget Sound proper; probably to take advantage of Chinook and chum salmon runs (Osborne 1999). In recent years, it has become fairly common for K and L pods to feed in the sound. The resident pods are seen in Admiralty Inlet (Whidbey Island) and Puget Sound (Osborne 1999) (Figure 2), as well as along the Oregon and California coasts. All three pods travel outside the inshore waters throughout the year, venturing out to the west side of Vancouver Island and the outer coast of the Olympic Peninsula. During the late fall to late winter, the SRKW travel as far south as Monterey, California, and north to the Queen Charlotte Islands, British Columbia. SRKWs generally stay within 50 km of the shore (Ford et al. 2005a) (Figures 2 and 3).

Transient orcas' distribution encompasses a much larger geographic area, ranging from Los Angeles, California, to Icy Strait and Glacier Bay in Alaska (Goley and Straley 1994, Ford and Ellis 1999, Baird 2001a, Barrett-Lennard and Ellis 2001) (Figure 4a). Wiles (2004) reports that most transients along the Puget Sound and Vancouver Island shorelines are recorded during the summer and early fall, which coincides with seal pupping and more search effort.

Offshore killer whales' distribution ranges from Los Angeles, California, to the eastern Aleutian Islands (Ford and Ellis 1999) (Figure 4b). They generally stay more than 15 km offshore (Krahn et al. 2002). This group's distribution is poorly understood due to infrequent observations.

General Life History Description

Resident killer whales are long-lived, highly social marine mammals that live in stable matrilineal pods throughout their entire lives (Baird 2000, Ford et al. 2000, Ford 2002, Ford and Ellis 2002). Two juveniles who became separated from their pods, A73 and L98, are considered anomalies. Southern resident group sizes vary among the three pods: K-pod is the smallest with 18 whales, J-Pod follows with 24 individuals, and L-Pod is the largest group of the southern resident population with 41 animals (K. Balcomb, pers. comm., 2006). The pods aggregate temporarily throughout the year, and are often seen traveling and socializing together (Dahlheim and Heyning 1999, Baird 2000, Ford et al. 2000). Breeding must also take place during the social encounters, even though it has never reliably been observed in the wild. Pods have individual vocal dialects, as well as sharing some calls with other pods (Ford 1989).

Transient killer whales show much less stability in their social groupings. Wiles (2004) states that at least 225 transient killer whales have been photo-identified in Washington, British Columbia and Alaska, with an estimate of 300-400 transients for the entire North American west coast. About one-third of this population has been observed in Washington state. Due to transient whales' irregular occurrences, it is difficult to determine deaths over time; a complete number of transients and accurate population assessment cannot be given (Baird 2001a).

Transient pods are smaller in number than resident pods, ranging from 1 to 4 whales per pod (Baird and Dill 1996, Ford and Ellis 1999, Baird and Whitehead 2000). They also live in fairly stable maternal groups, generally consisting of an adult female and one or two of her offspring. However, dispersal of members from their natal pods is common. The smaller numbers of whales in transient groups very likely aid the whales in detecting and capturing their patchily distributed food, which includes seals, sea lions, harbor and Dall's porpoises, minke whales and particularly harbor seals (Hoyt 1990, Jefferson et al. 1991, Dahlheim and Heyning 1999, Baird and Dill 1996, Ford et al. 1998). A smaller transient pod minimizes competition and maximizes individual energy intake (Baird and Dill 1996, Ford and Ellis 1999, Baird and Whitehead 2000), while the larger numbers in a resident pod probably help in finding schools of fish (Ford et al. 2000).

Genetic evidence (Stevens et al. 1989, Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001) suggests that transient and resident killer whale populations in the Pacific Northwest have been isolated from each other for thousands of years (Bigg et al. 1987, Hoelzel et al. 1998). Genetic and morphological differences between northern and southern resident orca in Washington and British Columbia waters suggest that these two populations are reproductively isolated. While both types of orca belong to the

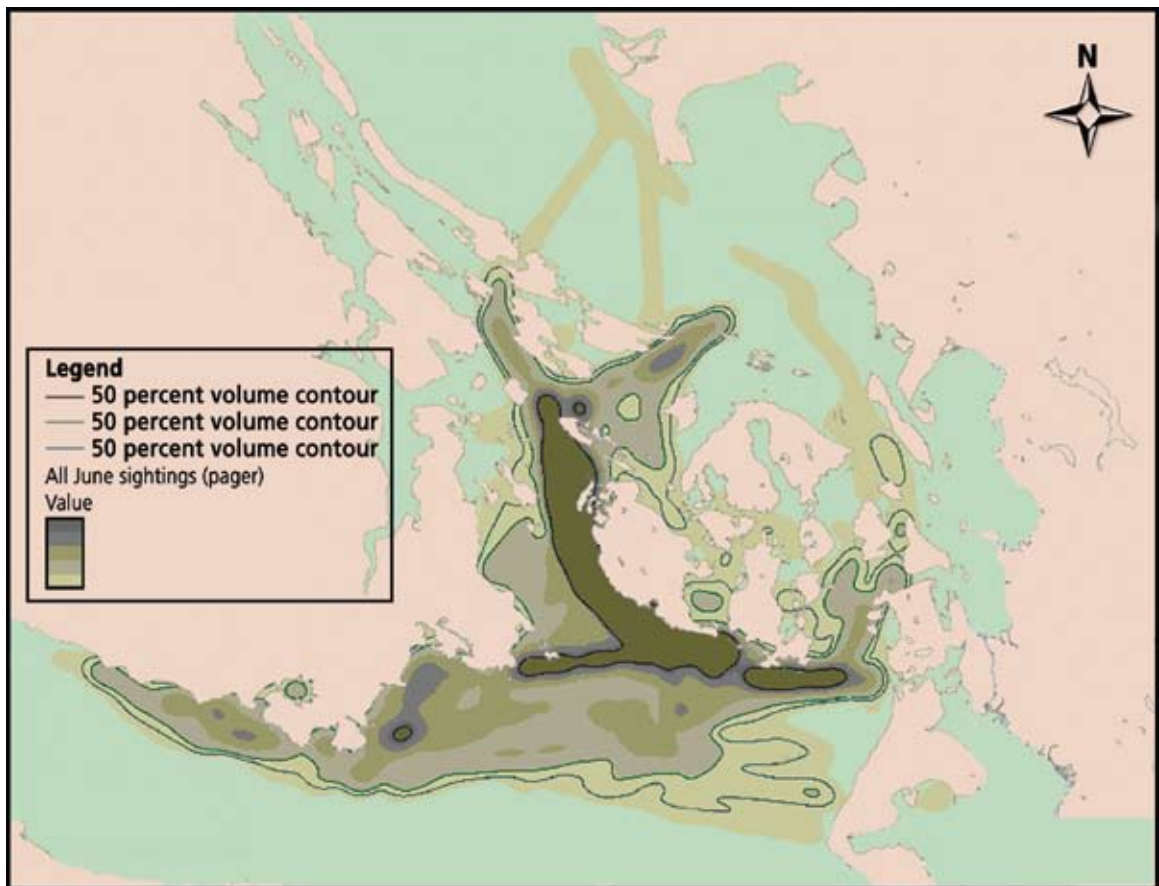


Figure 1. Typical distribution and relative occurrence of Southern Resident Killer Whales in northern Puget Sound during June, which is also representative of overall spring-fall occurrence (The Whale Museum 2006).

More readable color versions of this and all other graphics in this series are available at www.pugetsoundnearshore.org/.

same species and share considerable overlap in their range, mitochondrial DNA sequence data indicate that resident haplotypes are divergent from transient types. Southern residents satisfy all of the criteria necessary to delineate a separate stock under the Marine Mammal Protection Act (MMPA) (Krahn et al. 2002), while sharing similarities with other populations of killer whales in behavior, morphology and ecology. While no subspecies are recognized, Krahn et al. (2004) suggested that all resident orca in the northeast Pacific should be treated as a single unnamed subspecies, separate from transient killer whales.

Offshore killer whales are morphologically similar to the SRKW; i.e., their dorsal fins appear to be more rounded at the tip, and most saddle patches appear to be closed (National Marine Mammal Lab unpubl. data). They do not mix with residents or transients. Hoelzel et al. (1998) showed that offshores are genetically more closely related to the southern residents, yet are probably genetically isolated from local resident or transient orcas. Offshore orca groups ranging from 10 to 70 whales have been observed.

Genetic studies also indicate that local resident killer whales are polygamous, and males mate only with females outside their natal pod (Barrett-Lennard 2000, Barrett-Lennard and

Ellis 2001). Most births take place between October and March (Olesiuk et al. 1990). Calving intervals were estimated to range from 4.9 to 7.7 years (Olesiuk et al. 1990, Krahn et al. 2002, 2004, Matkin et al. 2003).

Since annual identification of each individual resident orca has been done for the last 32 years, long-term population dynamics of this group of whales are known. Despite this unusually large database, uncertainties persist because the studies only span about half the average lifetime of a female. As with other mammals, the SRKW population has differences in survival with age, with relatively low early survival, high adult survival, and declining survival in older individuals (Caughley 1966). Survival also differs between sexes. Olesiuk et al. (1990) determined that local females have an average life expectancy of about 50 years, which may extend to a maximum age of 80-90 years. The youngest known female to give birth was 11 years old, while the mean age of females at first birth was 15 years. On average, five viable calves (calves that survive to their first summer) are born to a single female over her 25-year reproductive lifespan. Since the mid 1990s, females' average age of first birth has been observed to occur one year later in SRKW females, to 16 years of age (Olesiuk et al. 2005 and 2006).



Figure 2. Distribution of SRKW during September 2006 in Puget Sound and the southern Strait of Georgia (Advanced Satellite Productions, Orca Network 2006) (T – indicates transient killer whales).

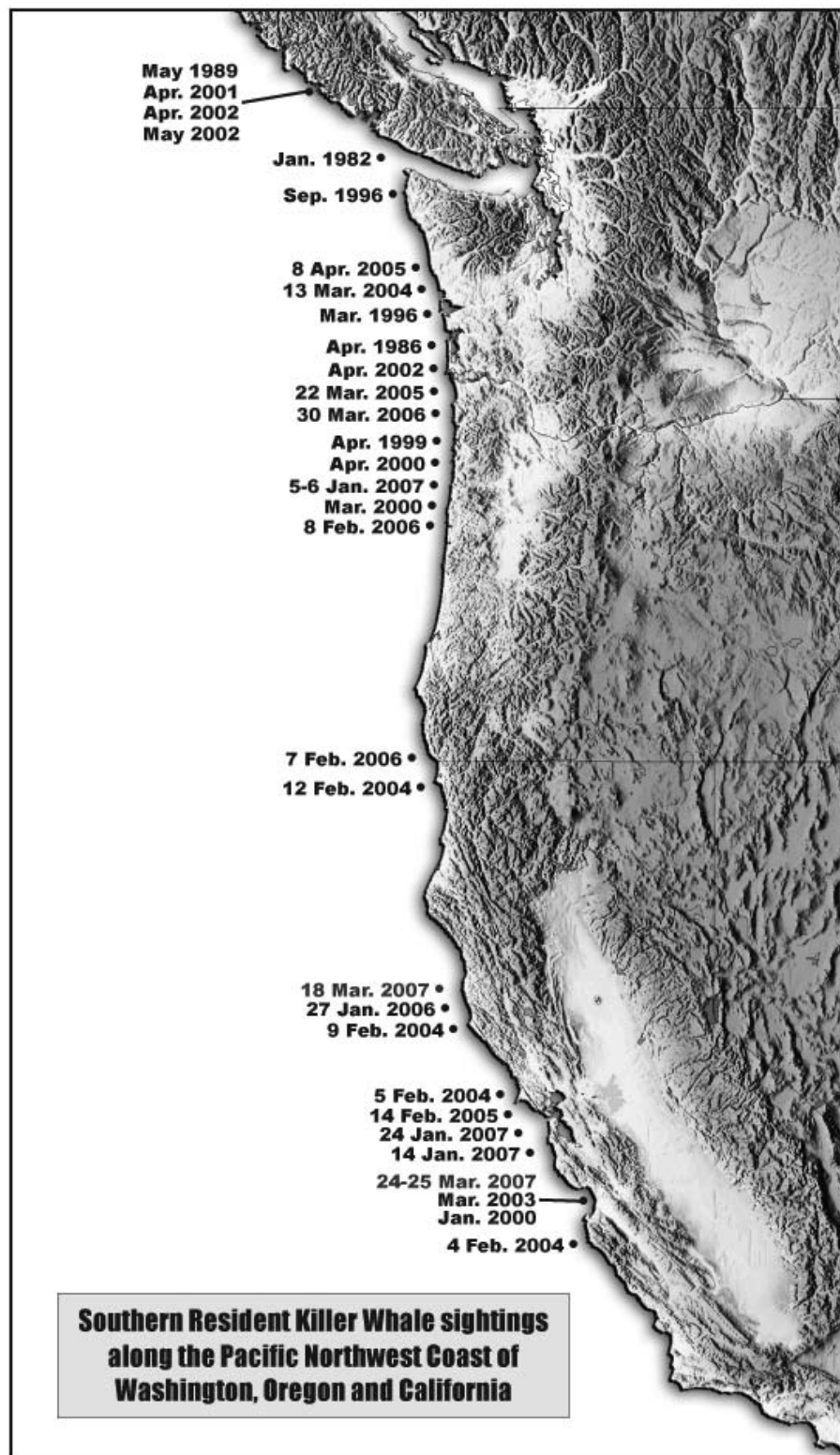


Figure 3: Coastal Marine Distribution of SKRWs 2003-2006 (Center for Whale Research and NOAA 2006).

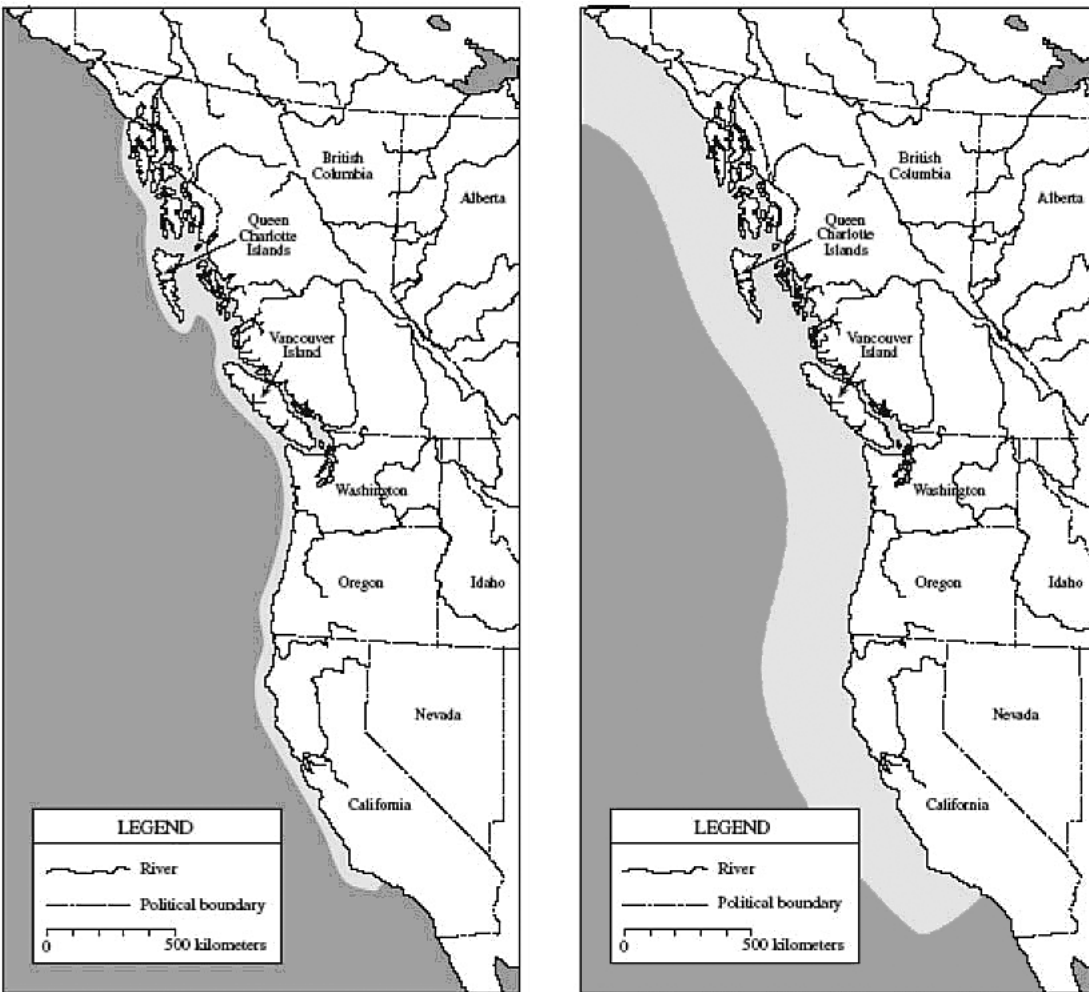


Figure 4a,b: Geographic ranges (light shading) of the west coast transient (left) and offshore (right) killer whale populations in the northeastern Pacific. The western pelagic boundary of the ranges is ill-defined. The northern range of the offshore population extends westward to the eastern Aleutian Islands. From Wiles (2004).

Males' life expectancy is about 29 years. They reach sexual maturity around age 15 and physical maturity around age 21. Table 1 shows the different age and sex classes determined through long-term photo-identification studies.

Resident populations are composed of about 50 percent juveniles, 19 percent mature males, 21 percent reproductive females, and 10 percent post-reproductive females (Olesiuk et al. 2005 and 2006).

Diet and Feeding

Resident and transient orcas are believed to have evolved specific diets and foraging strategies due to historically abundant prey resources that occurred year around (Ford and Ellis 2002). Strategies involve cooperative hunting, food sharing and passing information on to future generations (Felleman et al. 1991, Hoelzel 1991, Jefferson et al. 1991, Baird and Dill 1996, Guinet et al. 2000). Whales spend 50–67 percent of their daily time foraging (Heimlich-Boran 1988, Felleman et al. 1991, Kriete 1995). Resident orcas clearly prefer salmonids to any other prey items, which include 22 species of fish and one species of squid (Ford et al. 1998, 2000, Saulitis et al. 2000). Overall, salmon was found to be the main prey source, constituting 96 percent of all prey during spring, summer and fall. Residents show a distinct preference for Chinook salmon (*Oncorhynchus*

Table 1. Age and sex classes of killer whales.

Calves	Ages 0	Whales seen in first summer
Juveniles	Ages 1-10	
Females	Ages 11-41	Reproductive-age females
Females	Ages 42+	Post-reproductive-age females
Males	Ages 11-21	Young males
Males	Ages 22+	Old males

tshawytscha) over any other prey type during late spring through early fall, due to the Chinook's larger size and high fat content (Ford et al. 1998, Ford et al. 2005b), followed by chum salmon during the fall, probably because of their broad availability in the whales' coastal habitat (Figure 5). The SRKWs follow salmon runs that enter the sound and are pushed by the current up against the rocky shores of the San Juan Islands on their way to home rivers in the United States and Canada. (Figure 2). Salmon are an easy food source for resident killer whales. While few sightings of actual prey capture exist, several witnesses observed Chinook salmon being chased into crevices for easy capture (F. Felleman 1990, pers. comm.) This author has witnessed groups of four to six SRKW enter small bays along the west side of San Juan Island and circle around in tight formation while salmon jump out of the water within the whale circle. Several favorite foraging areas within 15 to 180 meters of the coastline of the west side of San Juan Island are used consistently, including the Pile Point/Hannah Heights area and Eagle Cove (Erbe 2002, B. Kriete, pers. obs.) The west side of San Juan Island provides a complicated acoustic environment due to deep channels dropping from shore to 300 meters very rapidly. Erbe (2002) has expressed concern about engine noise being reflected off the underwater shoreline, affecting the whales' ability to echolocate to find prey

and communicate with one another. Boat and ship noises at different locations are presently being investigated by John Hildebrand of the Scripps Institute of Oceanography in California.

Chinook salmon make up 65 percent of all salmonids consumed, even though this species was much less abundant than other salmonids. However, Chinook is larger in size, higher in caloric value and fat content, and occurs year around in the inland waters. Pink salmon (*O. gorbuscha*) made up 17 percent of the southern and northern resident killer whales' diet, coho (*O. kisutch*) 6 percent, chum (*O. keta*) 6 percent, sockeye (*O. nerka*) 4 percent, and steelhead salmon (*O. mykiss*) 2 percent (Ford et al. 2005). Other food items include rockfish (*Sebastes* spp.), halibut (*Hippoglossus stenolepis*), flatfish, lingcod (*Ophiodon elongates*) and Pacific herring (*Clupea pallasii*).

Recent toxicology studies (Krahn et al. 2002) confirmed that salmon are the main prey item; the patterns and component signature of PCB and DDT levels in the southern residents corresponded closely to those in Puget Sound salmonid species.

Transients spend 60-90 percent of daylight hours foraging, traversing seal haul-outs and nearshore areas by following the contours of the shoreline closely (Baird and Dill 1996,

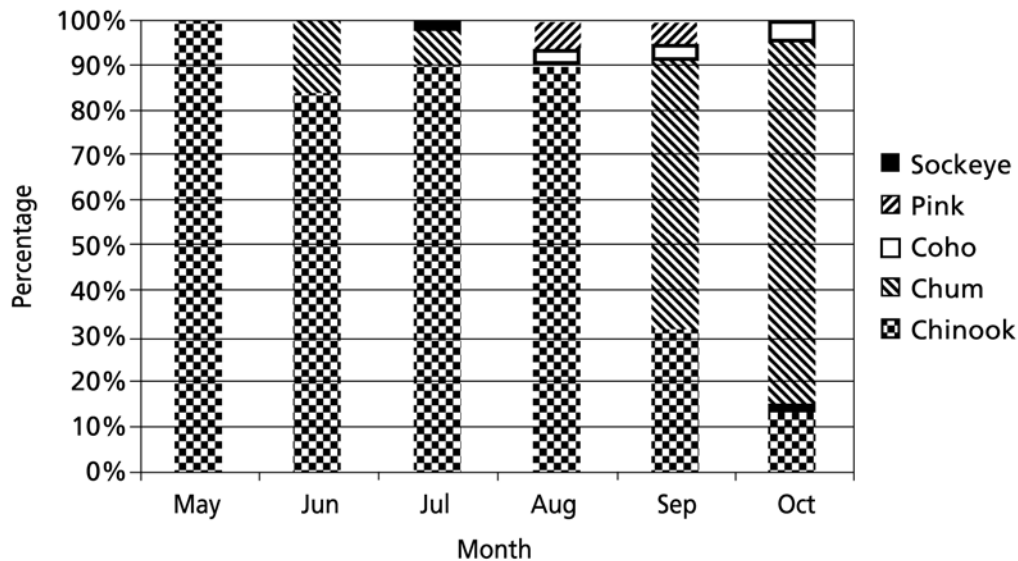


Figure 5: Frequency distribution of salmonid species in southern and northern resident killer whale population feeding events during May – October (Ford and Ellis 2005).

Ford and Ellis 1999). The animals' diet around Vancouver Island consists mainly of harbor seals (94 percent), harbor porpoises (2 percent), Dall's porpoises, sea lions and northern elephant seals (1 percent) (Baird and Dill 1996). Attacks on larger species, such as minke whales, are observed (Ford et al. 2005b), but rarely. Seals and sea lions are generally caught close to their haul-out sites, and smaller and larger cetaceans are attacked in more open waters and occasionally within close range of the shoreline. Offshore orcas are believed to prey mainly on fish and squid (Ford et al. 2000, Heise et al. 2003).

Food requirements for all different age and sex classes have been established as follows (Kriete 1995). This converts to approximately 62 Kcal/kg/day for a wild whale (Baird and Dill 1996):

Adult males	200,000 Kcal/day
Adult females.....	160,000 Kcal/day
Immatures	100,000 Kcal/day
Juveniles	85,000 Kcal/day

Status and Trends in Puget Sound

Based on microsatellite data, Barrett-Lennard (2000) and Barrett-Lennard and Ellis (2001) determined that SRKWs display the same number of alleles for genetic diversity as NRKWs, indicating that the southern resident population was most likely a much larger community fairly recently, perhaps close to the present size of the northern resident community. Krahn et al. (2004) argue that the southern resident community might have numbered more than 200 whales until the mid- to late-1800s.

Olesiuk et al. (1990) formed an age-specific life table for SRKWs with a 1.3 percent intrinsic growth rate for the

southern community in the early years (1974–1985), which was only half the expected rate of 2.6 percent. This discrepancy appeared to be due to: 1) a disproportionate number of females who became post-reproductive just prior to or early in the study (for unknown reasons); and 2) fewer females who became mature during the study because of live-captures of juvenile females in the late 1960s and early 1970's.

Overall, from 1972 to the early 1990's, the SRKW community increased at nearly 2.6 percent per year, experiencing the maximum intrinsic growth rate (Olesiuk et al. 1990, 2005; Krahn et al. 2004). Using a stage-structured model, Brault and Caswell (1993) estimated the intrinsic growth rate of the southern residents at 2.5 percent and the observed rate of increase of females at 0.7 percent, similar to the findings of Olesiuk et al. (2005 and 2006).

An 11-year growth phase lasted from 1985-1996, during which the population grew by 32 percent (2.9 percent mean annual growth rate) to 98 individuals (Trillmich et al. 2001). This was caused by an increase in birth rates due to juvenile maturation and a decrease in mortality rates (Figure 6). From 1996-2001, a period of decline occurred, decreasing the population by 17 percent to 79 animals, most likely resulting from poor survival in all age/sex classes and poor reproduction (Krahn et al. 2002, 2004). L-pod was of particular concern due to an even higher mortality rate and lower fecundity (Taylor 2004) (Figure 7). From 2002-2004, the SRKW community increased again by 6 percent. Presently, the southern resident population is essentially the same size that was estimated during the early 1960s (Olesiuk et al. 2005 and 2006).

Between 1974 and 2002, survival rates were comparatively consistent within two seven-year periods, but were different between consecutive periods (Krahn et al. 2004, Olesiuk et al. 2005 and 2006). Three time periods had above-average survival rates: 1974-1979, 1985-1992, and 2001-2002. Two

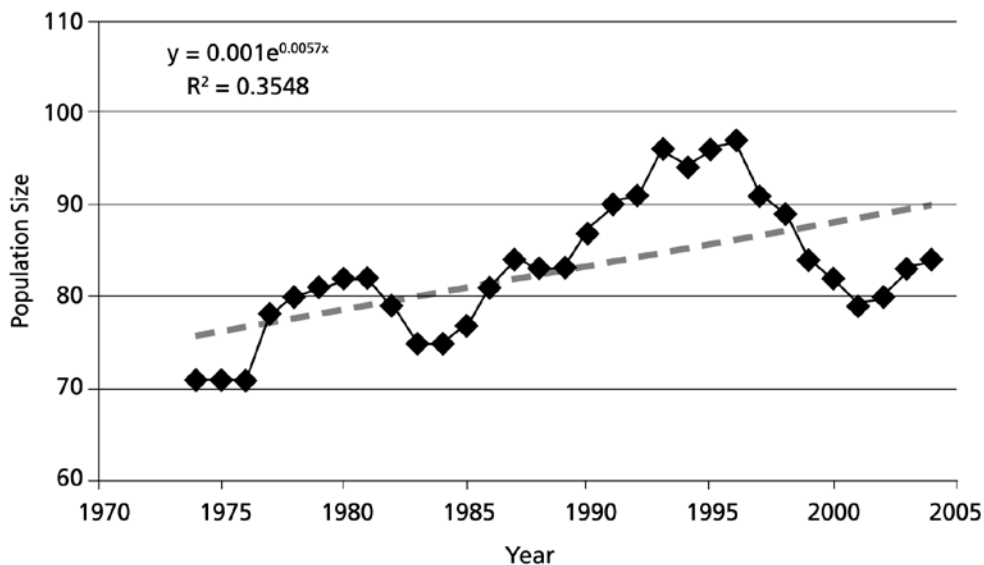


Figure 6: Population size of southern resident communities 1973-2004 (Ford et al. 2005).

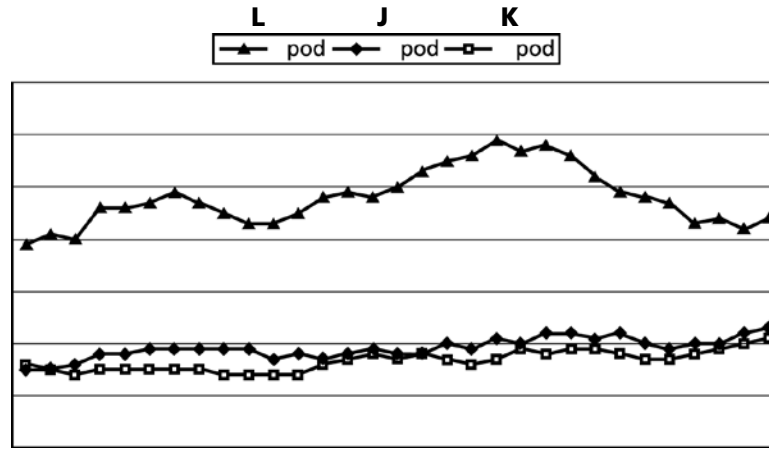


Figure 7. Visual population trends of the three southern resident killer whale pods (J, K, and L) from 1974-2003. Data were obtained through photo-identification surveys and were provided by the Center for Whale Research (unpubl. data).

intervals were well below average: 1980-1984 and 1993-2000 (Figure 8). Survival of SRKW is also positively correlated with years of high abundance of Chinook, although there is a time lag (Table 2) indicating that low Chinook salmon abundance precedes increased SRKW mortality rates. There was no correlation, however, between killer whale survival and abundance of chum salmon, again indicating the importance of Chinook for SRKW.

Krahn et al. (2002, 2004) modeled SRKW's future risk of extinction after modeling average estimates of survival (Figure 8). Their study showed distinct patterns, with relatively high survival rates from 1974 to 1979 and 1985 to 1992 and low survival rates from 1980 to 1984 and 1993 to 2000. While an increase in survival occurred again from 2001 to 2003, this increase was smaller than those observed during previous vacillations. Krahn et al.'s analysis indicated that the SRKWs have extinction probabilities of <0.1-3 percent in the next 100 years and 2-42 percent in the next 300 years under the scenario that the population's overall survival rates from 1974-2003 continue into the future. However, the likelihood of extinction is greater if future survival rates

are similar to those that the SRKW experienced from 1990-2003 or 1994-2003.

As pointed out earlier, resident killer whales have long life spans and remain in their natal pod throughout their entire life. One of the unusual features of their biology compared to other mammalian species is the large proportion of post-reproductive females. The few other species that have evolved this strategy include humans and elephants. It was recently shown (Parsons et al. 2006, McComb et al. 2001) that old female elephants serve the herd through their memory of interactions with neighboring herds (e.g., whether they were friend or foe). Similarly, the older whales in a pod may be a valuable resource because they carry social knowledge and perhaps pass on information on foraging sites from generation to generation (Krahn et al. 2002).

Human effects on habitat attributes (stressors)

The SRKWs' habitat in Puget Sound and the straits of Juan de Fuca and Georgia has changed significantly over the last 200 years with the arrival of European hunters, whalers and fisheries, followed by intense urbanization. The whales' environment has become noisier and more contaminated with toxins, and water temperatures have increased (University of Washington Friday Harbor Labs, unpublished data).

Changes in whale survival over time imply altered external conditions, such as changes in prey availability. The previous sections indicate that changes in whale survival were not due simply to demographic stochastic variation in small populations (random nature of births and deaths) or to fluctuations in survival from year to year. Fluctuations in survival can be caused by changes in environmental conditions, such as the Pacific Decadal Oscillation or El Niño, when prey becomes less available (Trillmich et al. 1991).

Reduction of prey is likely a significant factor in the decreased survival of SRKW in recent decades. Most West Coast salmon populations have declined significantly since the 19th century and more recently since the 1950s (Bledsoe

Table 2: Effect of varying time lags on strength or correlation between deviations in expected resident mortality rates and overall coastal abundance of Chinook salmon (Ford et al. 2005).

Lag (yrs)	r ²	Signif.
2	0.0183	0.510
1	0.1552	0.046
0	0.5089	<0.0001
1	0.7627	<0.0001
2	0.5788	<0.0001
3	0.2104	0.028
4	0.0620	0.264
5	0.0494	0.333

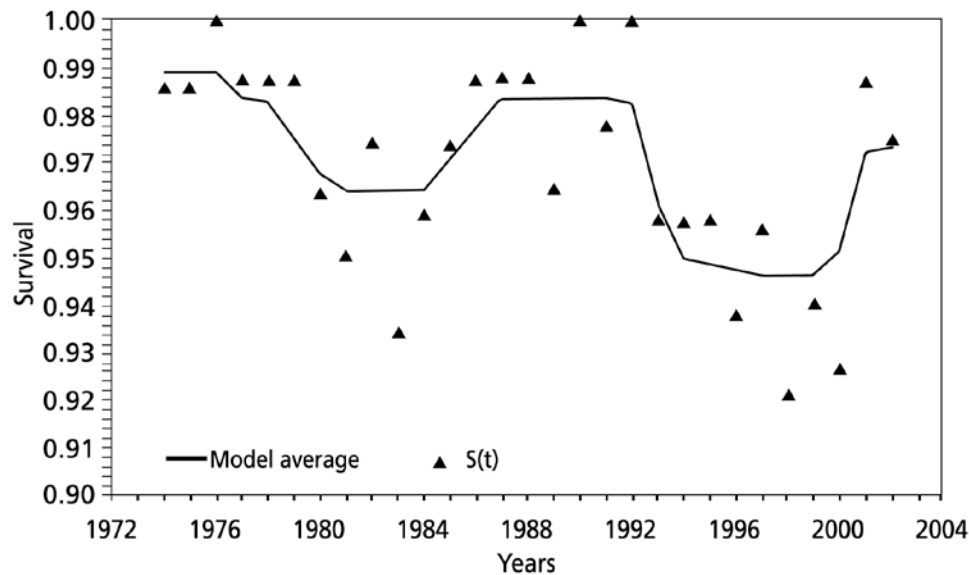


Figure 8: Model-average estimates of entire SRKW population survival (Krahn et al. 2004).

et al. 1989, Puget Sound example shown in Figure 9). Chinook salmon is the most important but also least abundant and most contaminated prey species for SRKW (Ford et al. 2005, Ford and Ellis 2005). Even though the Chinook fishery has been closed since 1995, the recreational Chinook fishery is still open for catching hatchery fish, and perhaps some wild fish, in the greater Puget Sound area (L. Weitkamp, Killer Whale Symposium, April 2006). Wild Chinook populations continue to decline due to dam construction, overall habitat loss, loss of prey and historical over-fishing. Sanford (2006) pointed out that current mean weight of adult Chinook salmon returning to their spawning grounds in Puget Sound is only 56 percent of the mean weight of fish collected during the 1950s.

Due to the limited available data for salmon abundance, it is difficult to make a quantitative estimate of the decline of potential prey for SRKWs. However, it seems likely that there has been a decline of 50 percent or more since the mid- to late 1800s. It is therefore possible that the carrying capacity of SRKWs, in terms of food availability, was at least double that of the present population size. If SRKWs are close to their current carrying capacity, the population might have been twice as large 150 years ago. If the SRKW population declined at the same time as salmon in the region, the decline would have occurred decades before the population was monitored.

Transients' prey base has not experienced a decline over the last three decades; seal and sea lion populations have grown since the late 1970s (NOAA 2003, Baird 2001b).

Other than the decline of salmon, two additional factors — toxic contaminants and whale watching activity — have been linked to the survival of the local killer whale population. The following provides an overview of these issues and their potential impact on whale populations.

Toxics

The Puget Sound region receives emissions and waste discharges from the activities of more than 7.5 million people and is exposed to global contaminants from as many as 2 billion humans directly or indirectly (Ross 2006). Pollutants (persistent organic, inorganic and bacterial pollutants from industry, sewage, stormwater and vessel activities, including PCBs, PBDEs, dioxins, and furans) enter aquatic systems through direct and indirect discharge and atmospheric transport and flow into the nearshore aquatic habitats (Ross et al. 2004) (Figures 10 and 11).

As a result of local and global pollution into Puget Sound's aquatic system, SRKW and, even more so, transient orca carry some of the highest contaminant burdens (PCBs and PBDEs) known in the animal kingdom. St. Lawrence beluga whales, thought until recently to be the most polluted species, carry much lower PCB loads than either SRKW or transient orca (Figure 12) (Ross 2006, Ross et al. 2004, Ross et al. 2000). This is true despite an estimated 2.5-fold decrease in PCBs since the 1970s, as measured by PCB concentration changes in harbor seals and California sea lions (Ross 2006). These results model the estimates on sediment core data (Hickie 2003, Figure 13).

SRKWs' relatively long life span and top food web position, as well as their use of feeding locations near urban centers and industrial sites (Figure 14), increase their exposure to contaminants through biomagnification. The combination of inadequate nutrition due to declining fish stocks and exposure to and accumulation of contaminants can increase susceptibility to infection and decrease reproductive rates, especially during years of low food abundance. Studies of

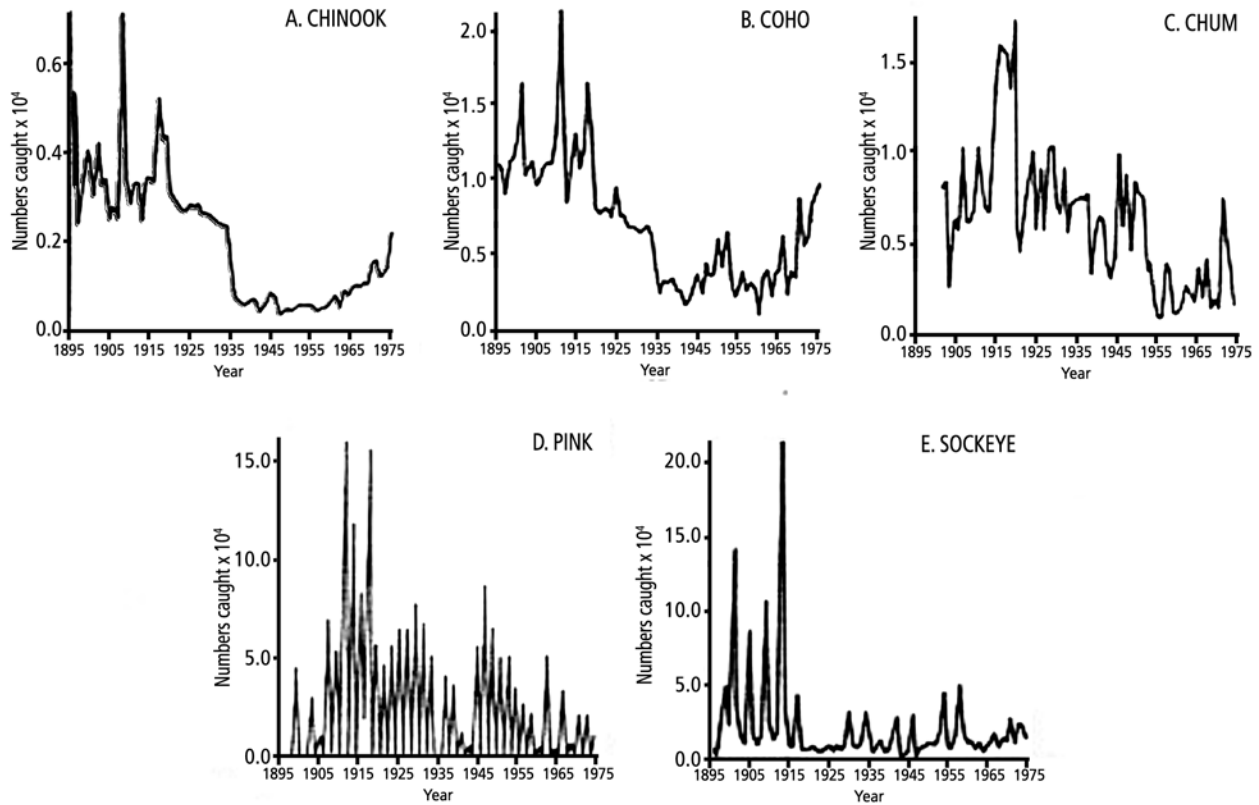


Figure 9. Puget Sound salmon catch (Chinook and coho), 1895 -1976 (Bledsoe et al. 1989); y axis is numbers caught in millions (10⁶).

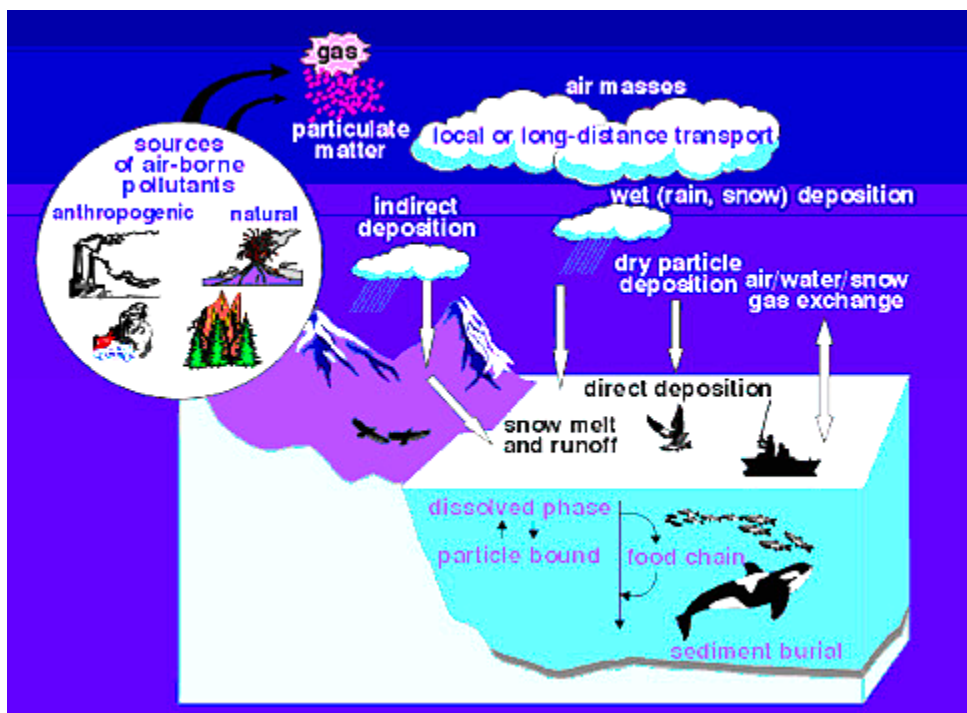


Figure 10. Point sources, atmospheric transport and food web considerations for mitigative strategies in exposure to SRKW (Ross et al. 2004).



Figure 11. Industrialized and urbanized Puget Sound and Georgia Basins, areas frequented by SRKW (Ross 2006).

captive killer whales show that food requirements increase significantly during the last month of pregnancy, and females doubled their normal food intake during lactation (Kriete 1995).

Studies have shown that exposure to PCBs results in adverse health effects in marine mammals. Controlled studies conducted on harbor seals showed a link between the intake of contaminated fish and reproductive impairment, immunotoxicity and endocrine disruption (Ross 2002). While these effects have not been measured directly in killer whales, it is likely that the effects of PCBs on cetacean species is similar to their effects on pinnipeds. PCBs are not well metabolized and are typically lost only through lactation by females. As a result, PCB levels in male orca continue to increase throughout their life span, while females transfer a large portion of their PCBs to their offspring through lactation.

While traditional PCBs have been banned in North America, fire retardants (polybrominated diphenyl ethers, or PBDEs) have recently attracted much concern and are becoming a common contaminant in nearshore waters (Ross 2006). PBDEs are spread as air pollutants across the Pacific Ocean by prevailing winds. The pollutants are deposited both in wet and dry form on the water surface and find their way into the pelagic food web (Ueno et al. 2004). These chemicals disrupt the endocrine system and mimic natural hormones, resulting in negative effects on the development and reproductive success of exposed individuals. They modify circulatory vitamin A and thyroid hormone levels, alter aryl hydrocarbon receptors, and suppress the immune system (Ross 2006). Both killer whales and Chinook salmon are at increased risk to retain PBDEs, as the chemicals are stored in lipid layers. A high level of PBDEs leads the individual to increase its food consumption, increasing its susceptibility to disease and making it more vulnerable in times of low prey availability (Ross 2006).

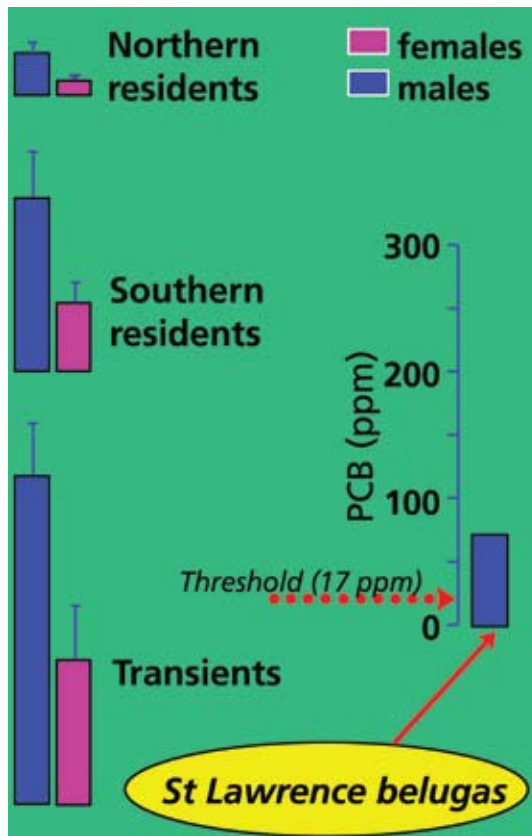


Figure 12: Graphic comparison of PCB levels (ppm) in 3 different killer whale populations with Beluga whales from the St. Lawrence River (Ross et al. 2004).

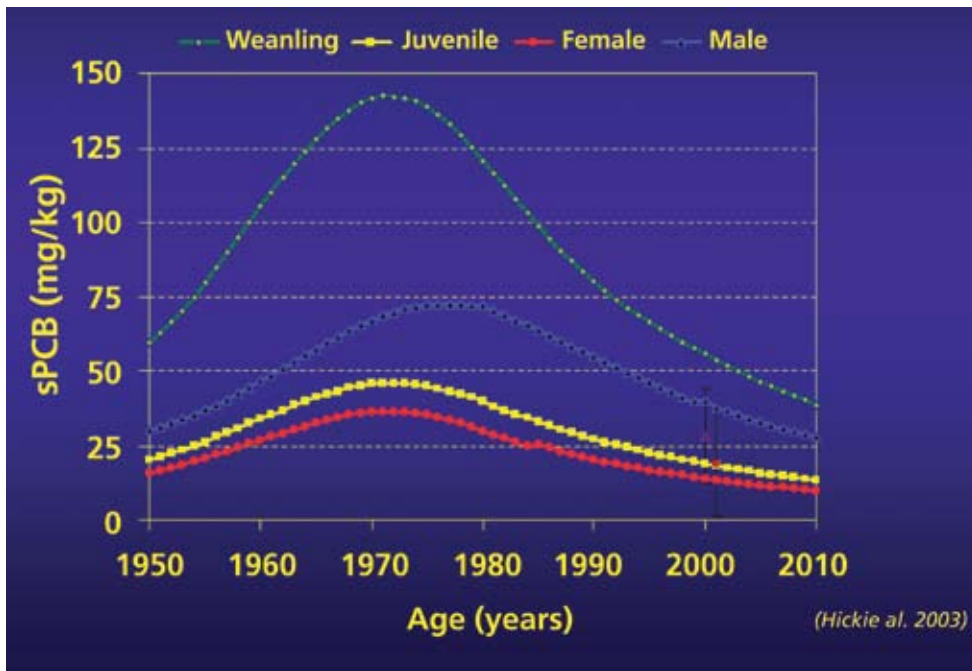


Figure 13: Model predicting that PCB levels have decreased in orcas (Hickie 2003). Data used are a combination of actual PCB levels found in stranded resident killer whales and data calculated based on PCB levels found in sediments.

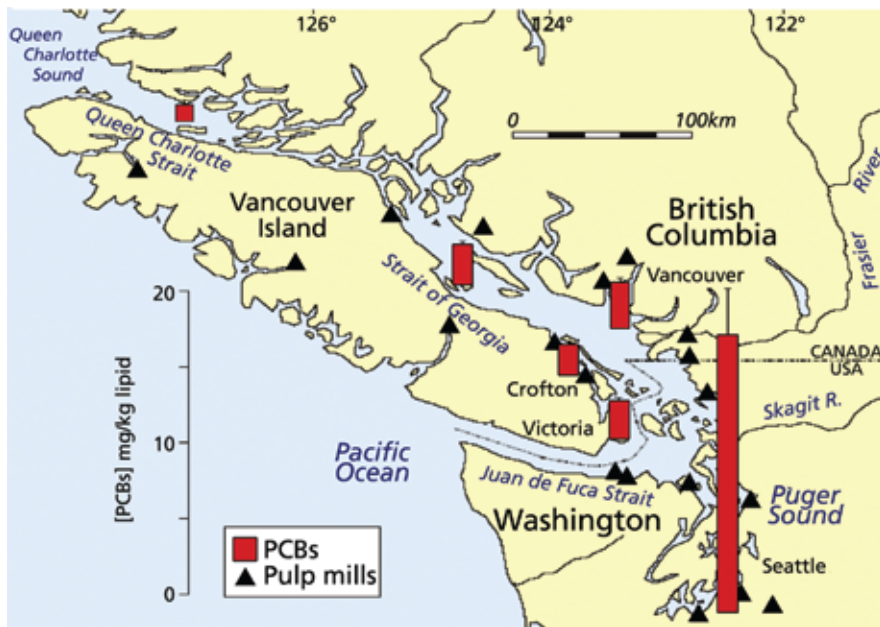


Figure 14: Puget Sound is a regional PCB ‘hotspot’ (Ross et al. 2004).

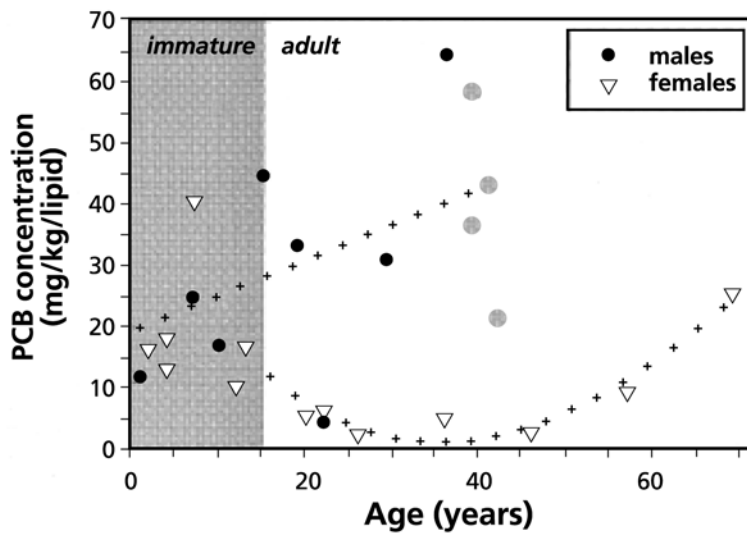


Figure 15: Total PCB concentration in northern resident killer whales plotted against age. Regression lines are plotted for males and immatures (circles, gray circles are for individuals for which minimum age estimates only are available) and females (triangles) Ross et al 2000. [Author’s note: these data are not yet available for SRKW. However, based on mammalian physiological principles, this phenomenon of total PCB concentration should apply equally to SRKW.]

Annual Population Change and Fleet Size

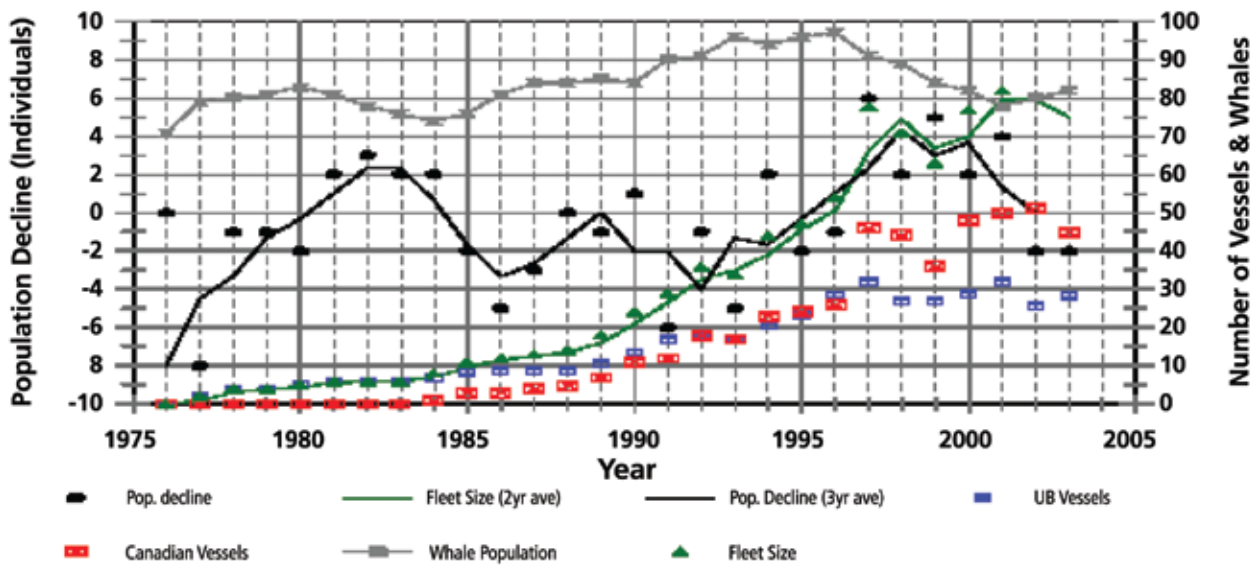


Figure 16: Correlation of fleet size with whale population dynamics (Bain 2005).

Whale Watching

Whale watching by commercial and private vessels has become increasingly popular, and whale-watch businesses have steadily increased over the last 20 years (Bain et al. 2005, Foote et al. 2004) (Figure 16). Boat impact is the most easily studied component of human impact on killer whales, so cetologists have made more recommendations on this issue than on other human disturbance factors.

Several studies have shown that whale-watching boats have a negative effect on killer whales, and that the increase in this activity might have contributed to the recent decline in the SRKW. Bain et al. (2005) determined a significant correlation between fleet size and SRKW population dynamics. Kriete (2002) determined that male and female orca increase swimming velocity and respiration rates by 19 percent and 17 percent respectively when followed by boats, compared to no boat traffic. This in turn increases the whales' energy expenditure; consequently, the animals need to consume more food, which may have serious consequences for a food-limited population. Whales also swam around the boats in an avoidance behavior, rather than from point A to point B in a direct line, leading to an increase of 13 percent in swimming distance. This study was performed both with northern and southern residents and produced very similar results. Other behavior changes linked to boats included (Bain et al. 2005):

- Whales spent significantly more time traveling when boats were within 400 meters than when the closest vessel was farther away.
- Whales were 13 percent less likely to forage when vessels were within 100 meters ($p < 0.05$) than when no vessels were within 1,000 meters.
- Whales followed an 11 percent less direct path when vessels were present ($p < 0.001$).
- Whales exhibited close to five times more surface active behavior when vessels were present ($p < 0.001$).
- Whales were much more likely to stop feeding after 15 minutes with boats present.

Marine vessel traffic has led to several documented collisions between boats and killer whales: Luna, a young male orca separated from his pod and residing in Nootka Sound, was killed by a tugboat in March 2006; a whale was hit near the west side of San Juan Island by a whale-watch boat in July 2005 (Walker 2005); a fatal incident involving a ferry occurred in the 1970s; and there are other, unofficially reported cases. Research is being considered to determine chemical effects, such as those associated with unburned fuel and exhaust, that may contribute to the whales' toxin load.

Noise in the whales' environment is also of considerable concern. Large numbers of whale-watch and private vessels surround the whales much of the time (Figure 17). In 2004, researchers counted as many as 145 vessels surrounding the whales on busy holiday weekends (Davies 2004).

Other sources of acoustic disturbance include mid-frequency sonar, low-frequency sonar, industrial noise, acoustic harassment/deterrent devices (used by salmon farms; Morten et al. 2004), explosives, acoustic tomography and airguns. As killer whales are almost entirely dependent on sound for hunting, communication, and navigation, the disruption of their ability to echolocate and communicate can lead to decreases in prey-finding success. Increased whale-watching traffic has been linked to longer call duration. Studies show that since 2001, the whales' call durations have

increased, and that this is linked to the increase in whale-watch traffic and corresponding increase in noise from boat engines (Foote et al. 2004). Erbe (2002) also predicted vessel noise would affect echolocation and communication, ranging from masking to temporary hearing threshold. Bain's (2002) models suggest that boat noise may decrease the whales' ability to echolocate by as much as 95 percent.

Noise disturbance and the presence of boats are also linked to transients' ability to catch pinnipeds. Transients use passive listening to find prey and even coordinate their respirations to be inconspicuous before attacking seals and sea lions (Baird and Dill 1996). Pinnipeds exit the water and haul out when disturbed by noise or physical presence of perceived danger, making them inaccessible as prey for transient orcas.

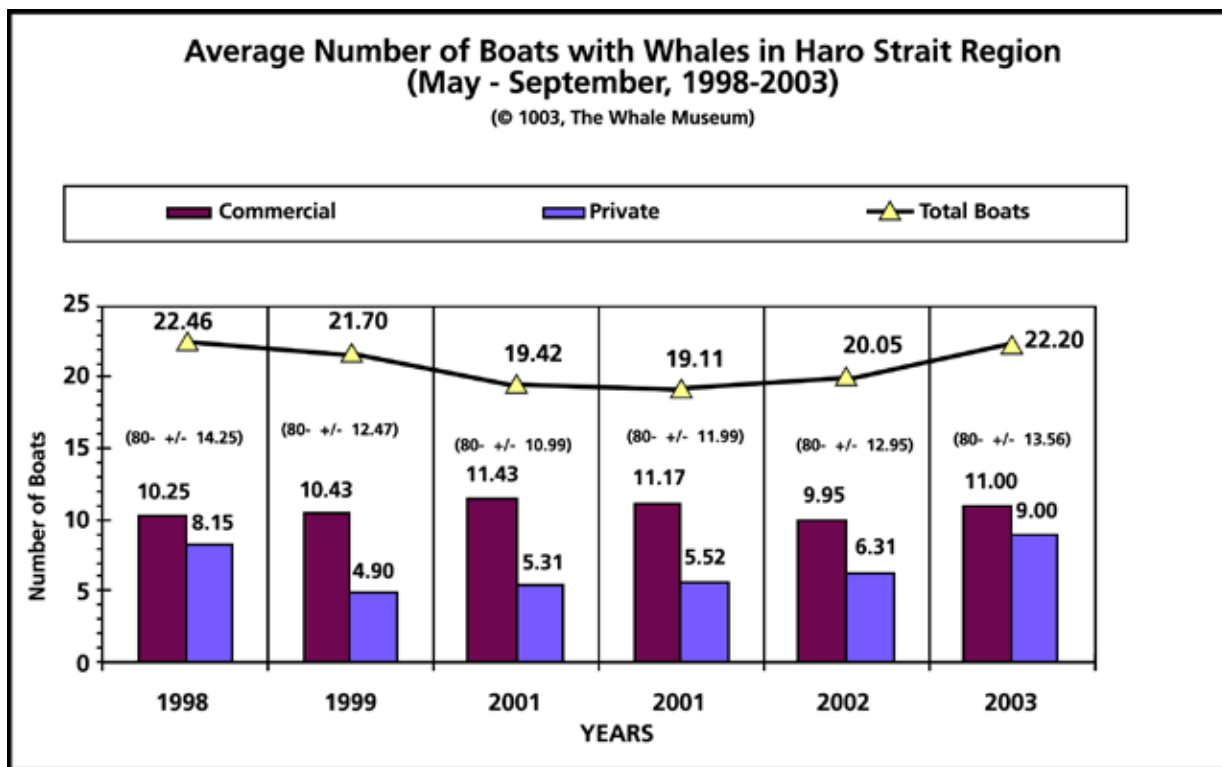


Figure 17. Private vs. commercial vessels in the vicinity of SRKW (The Whale Museum 2004).

Ecosystem Processes Supporting Habitat Attributes

As the top predator of the marine food chain, killer whales depend on a healthy ecosystem at every level, since their food supply in turn depends on ecosystem health at every lower level. The three main components for the survival of orca — year-around prey availability, a clean environment and the ability to echolocate and communicate in quiet waters — are all essential for their future survival.

A conceptual model (Figure 18) shows the ultimate positive effect of restoration actions at every ecological level below this species. By improving salmon habitat, and hence increasing the number of salmon accessible to resident orca, increased food sources will be available. At the same time, human harvests of species important to salmon populations must be limited, if these harvests are currently large enough to negatively affect orcas.

Disposal of toxic pollutants into the local and global marine environment affects marine life at every level, but has the greatest effect on the species at the top of the food chain due to biomagnification. New chemicals are constantly being developed and ultimately need to be disposed of. In addition, many already-disposed chemicals will take decades to decompose. To provide a healthy marine environment for killer whales, national and international laws and agreements will need to be established to:

- discontinue future deposits of chemicals into the aquatic system, both directly and indirectly;
- clean nearshore areas of present chemicals, if possible;
- discontinue sewage outflows into nearshore aquatic systems.

While all of the above-mentioned restoration processes will take decades to achieve, marine vessel traffic, particularly whale-watch boats surrounding the whales on a daily basis, can be regulated in a much shorter time frame. Federal laws will have to be established regulating vessel traffic around the whales. This will have an immediate effect leading to a quieter nearby marine environment for the whales and decreased exhaust and water pollution in the whales' feeding and traveling vicinity.

As a first step, on June 9, 2006, NOAA Fisheries proposed to designate a 2,500 square-mile area in and around Puget Sound and the Strait of Juan de Fuca (Figure 19) as critical habitat for killer whales. This area encompasses parts of Haro Strait and the waters around the San Juan Islands, the Strait of Juan de Fuca and all of Puget Sound. Excluded are 18 military sites covering nearly 112 square miles of habitat.

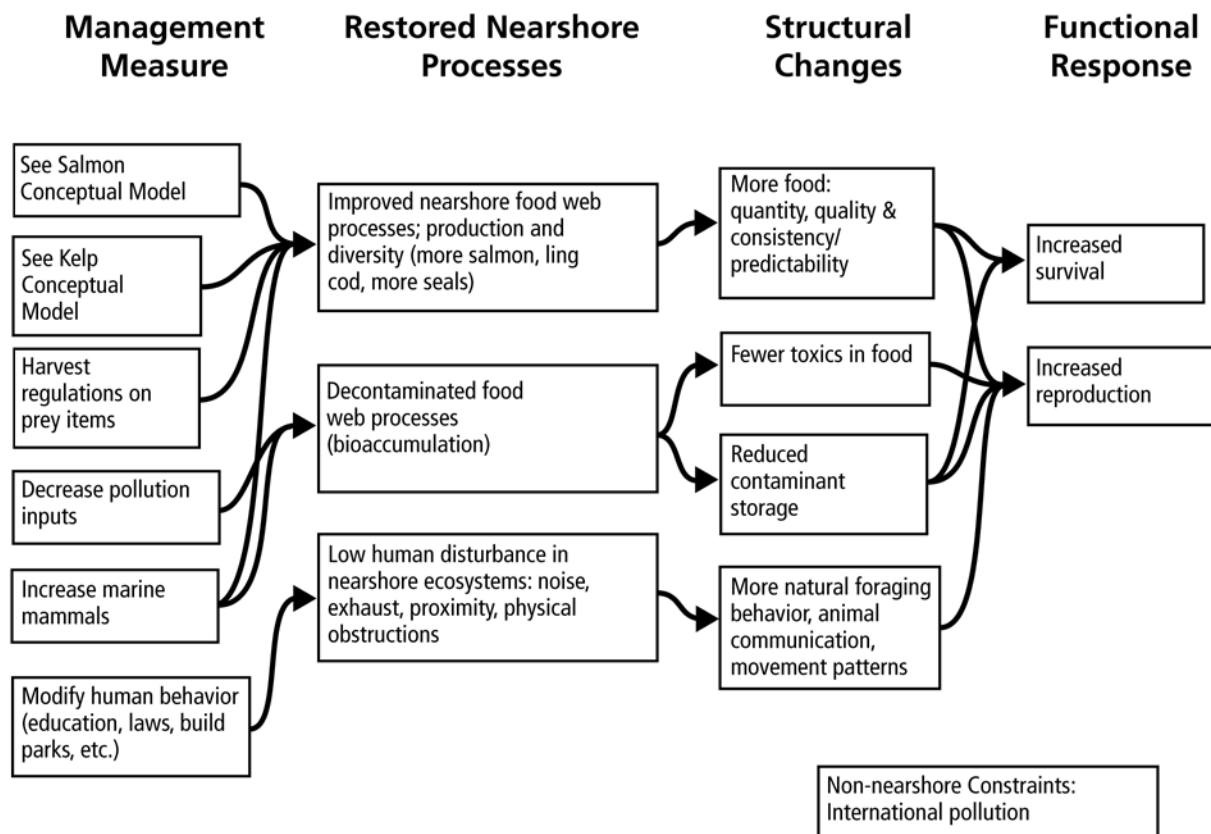


Figure 18. Orcas conceptual model.

**Proposed Critical Habitat for Southern Resident Killer Whales
May 2006
NOAA Fisheries, Northwest Region**

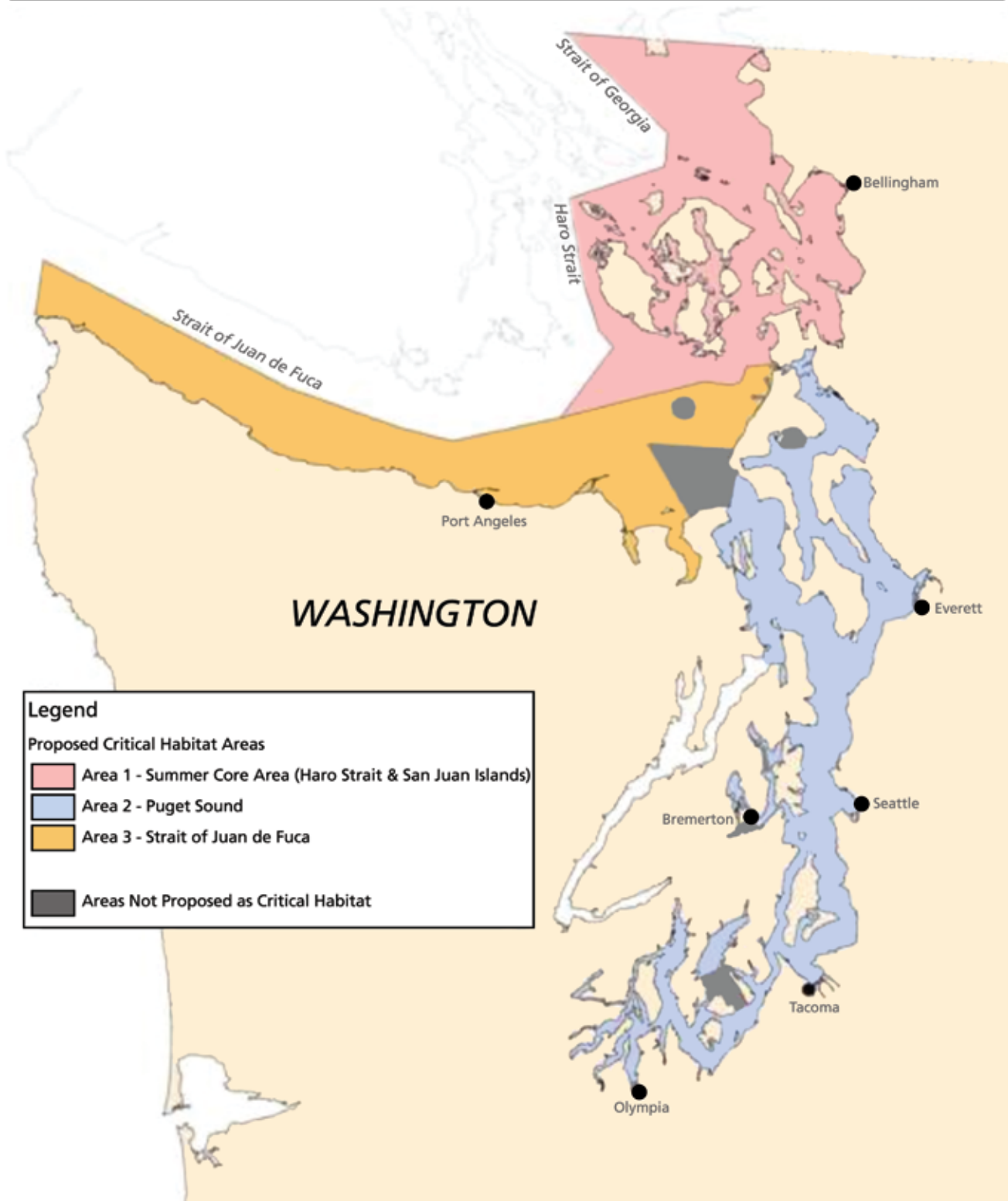


Figure 19. Proposed critical area for SRKW (NOAA 2006).

More readable color versions of this and all other graphics in this series are available at www.pugetsoundnearshore.org/.

Major Gaps/ Critical Uncertainties

Killer whales are not an easy species to study. An animal that spends only 5 percent of its time at the water surface provides only short glimpses into its life. However, because whales live long lives, can be identified individually by their markings and have a close social structure which remains consistent throughout their lives, population parameters can be determined through photo-identification. While scientists believe that the main reasons for the most recent SRKW decline have been identified, many questions remain and need to be addressed in order to protect the local orca population from extinction:

- Data on salmon, and especially Chinook abundance and quality, are needed to determine if the orca's prey abundance is adequate to support the population and meet the nutritional and energetic needs of the SRKW. Considerable more dietary data are also needed.
- Are toxicant pathways more evident and in higher concentration near the shoreline, and what effect could this have both on salmon and the SRKWs?
- What is the acoustic environment near the shoreline, as opposed to open water? Is there a distinction?
- To what extent do boats affect fish and fish dispersal, especially close to shore and in shallow areas such as Salmon Bank, where SRKW primarily feed? How does boat noise affect the whales' ability to hunt successfully and with the least energetic expenditure? What distance between whale-watch boats and orca is necessary to decrease or eliminate the impact on the whales?
- What are the causes for the variation in population growth and survival rates?
- Which factors affect reproductive success?
- Which factors affect survival of calves and neonates?

Conclusions: Key Measures for Orca Restoration

- Salmon habitat restoration (Fresh 2006).
- Safe salmon harvest and hatchery practices.
- Decrease (discontinue) dumping toxics such as persistent organic pollutants (PCBs, PBDEs, dioxins, furans) into the marine environment; clean up, if possible.
- International agreements regarding emission of toxics.
- Reduce the cumulative effect of whale watching:
 - current guidelines are inadequate, since vessels affect behavior at distances greater than 100 meters; hence laws must be established to protect SRKW from close contact with vessels
 - limited entry/individual transferable quotas for commercial vessels
 - time and area closures
 - zone space between resources and use
 - require operating license (including knowledge tests) with license fee to cover management costs
 - tax incentives for four-stroke engines (registered in San Juan County or statewide)
 - limit whale-watch to boats with trained guides, boat numbers, times, places (for all boats)
 - raise public awareness
 - encourage more land-based whale-watching.

References

- Advanced Satellite Productions. 2006. Available online: www.adsat.com/
- Bain, D.E. 2002. A model linking energetic effects of whale watching to killer whale (*Orcinus orca*) population dynamics. Friday Harbor Labs, University of Washington, Friday Harbor, WA.
- Bain, D.E., J.C. Smith, R. Williams and D. Lusseau. 2005. Effects of vessels on behavior of Southern Resident Killer Whales. Poster presented for the Society for Marine Mammal Meeting.
- Baird, R.W. 2000. The killer whale: foraging specializations and group hunting. Pages 127-153 in J. Mann, R.C. Connor, P.L. Tyack, and H. Whitehead (eds.). Cetacean societies: field studies of dolphins and whales. University of Chicago Press, Chicago, IL.
- Baird, R.W. 2001a. Status of killer whales, *Orcinus orca*, in Canada. Canadian Field-Naturalist 115:676-701.
- Baird, R.W. 2001b. Status of harbor seals, *Phoca vitulina*, in Canada. Canadian Field-Naturalist 115:663-675.
- Baird, R.W. and L.M. Dill. 1996. Ecological and social determinants of group size in transient killer whales. Behavioral Ecology 7:408-416.
- Baird, R.W. and H. Whitehead. 2000. Social organization of mammal-eating killer whales: group stability and dispersal patterns. Canadian Journal of Zoology 78:2096-2105.
- 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, B.C.
- Barrett-Lennard, L.G. and G.M. Ellis. 2001. Population structure and genetic variability in northeastern Pacific killer whales: towards an assessment of population viability. Research Document 2001/065, Fisheries and Oceans, Canada, Nanaimo, B.C.
- Bledsoe, L.J., D.A. Somerton, and C. M. Lynde. 1989. The Puget Sound runs of salmon: an examination of the changes in run size since 1896. Canadian Special Publication of Fisheries and Aquatic Sciences 105:50-61.
- Brault, S., and H. Caswell. 1993. Pod-specific demography of killer whales (*Orcinus orca*). Ecology 74:1444-1454.
- Caughley, G. 1966. Mortality patterns in mammals. Ecology 47:906-918.
- Center for Whale Research and NOAA. 2006. Pers. Comm., Figure 3 provided by K.C. Balcomb. Available online: www.whaleresearch.com.
- Dahlheim, M.E., and J.E. Heyning 1999. Killer whale *Orcinus orca* (L.1758). Pages 281-322 in S. Ridgway and R. Harrison (eds.). Handbook of marine mammals. Academic Press, San Diego, CA.
- Davies, P. 2004. The behavioral response of the Resident Killer Whale (*Orcinus orca*) to variation in local environmental conditions. B.Sc. Marine Sciences Dissertation, Dept. of Ocean and Earth Sciences, University of Southampton, UK.
- Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. Marine Mammal Science 18:394-418.
- Felleman, F.L., J.R. Heimlich-Boran, and R.W. Osborne. 1991. The feeding ecology of killer whales (*Orcinus orca*) in the Pacific Northwest. Pages 113-147 in K. Pryor and K.S. Norris (eds.). Dolphin societies: discoveries and puzzles. University of California Press, Berkeley, CA.
- 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. 1989. Acoustic behavior of resident killer whales (*Orcinus orca*) off Vancouver Island, B.C. Canadian Journal of Zoology 67:727-745.
- Ford, J.K.B. 2002. Killer whale *Orcinus orca*. Pages 669-676 in W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.). Encyclopedia of marine mammals. Academic Press, San Diego, CA.
- Ford, J.K.B., and G. M. Ellis. 1999. Transients: mammal-hunting killer whales of British Columbia, Washington and southeastern Alaska. University of British Columbia Press, Vancouver, B.C.
- Ford, J.K.B., and G. M. Ellis. 2002. Reassessing the social organization of resident killer whales in B.C. In Conference abstracts: 4th International Orca Symposium and Workshop, 23-28 Sept. 2002, 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. Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, 2005/041.
- Ford, J.K.B., G. M. Ellis, and K.C. Balcomb. 1994. Killer Whales: the natural history and genealogy of *Orcinus orca* in British Columbia and Washington State. University of British Columbia Press, Vancouver, B.C.
- Ford, J.K.B., G.M. Ellis, and K.C. Balcomb. 2000. Killer whales: the natural history and genealogy of *Orcinus orca* in B.C. and Washington State. University of British Columbia, Vancouver, B.C.

- Ford, J.K.B., G.M. Ellis, L.G. Barrett-Lennard, A.B. Morton, R.S. Palm, and K.C. Balcomb III. 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal B.C. and adjacent waters. *Canadian Journal of Zoology* 76:1456-1471.
- Ford, J.K.B., G.M. Ellis, and P.F. Olesiuk. 2005a. Linking prey and population dynamics: did food limitation cause recent declines of 'resident' killer whales (*Orcinus orca*) in British Columbia. Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, 2005/042.
- Ford, J.K.B., G.M. Ellis, D.R. Matkin, K.C. Balcomb, D. Briggs, and A.B. Morton. 2005b. Killer whale attacks on minke whales: prey capture and antipredator tactics. *Marine Mammal Science* 21:603-618.
- Ford, J.K.B., and L.M. Nichol. 1992. Killer whales of the Queen Charlotte Islands: A preliminary study of the abundance, distribution and population identity of *Orcinus orca* in the waters of Haida Gwaii. Prepared for South Moresby/Gwaii Haanas National Park Reserve, Canadian Parks Service, Vancouver Aquarium, Vancouver, B.C.
- Fresh, K.L. 2006. Juvenile Pacific salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, WA.
- Goley, P.D., and J.M. Straley. 1994. Attack on gray whales (*Eschrichtius robustus*) in Monterey Bay, California, by killer whales (*Orcinus orca*) previously identified in Glacier Bay, Alaska. *Canadian Journal of Zoology* 72:1528-1530.
- Guinet, C., L.G. Barrett-Lennard, and B. Loyer. 2000. Coordinated attack behavior and prey sharing by killer whales at Crozet Archipelago: Strategies for feeding on negatively-buoyant prey. *Marine Mammal Science* 16:829-834.
- Heimlich-Boran, J.R. 1988. Behavioral 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 B.C. *Aquatic Mammals* 29:325-334.
- Hickie, B. 2003. Model predicting that PCB levels have decreased in orcas. Figure In: Ross, P.S., S. Jeffries and J. Calambokides 2004. Southern Resident Killer Whales at risk: Contaminant-related health risks. Presentation at NMFS March 2004. Seattle, WA.
- Hoelzel, A.R. 1991. Killer whale predation on marine mammals in Punta Norte, Argentina: food sharing, provisioning, and foraging strategies. *Behavioral Ecology and Sociobiology* 29:297-304.
- Hoelzel, A.R., M. Dahlheim, and S.J. Stern. 1998. Low genetic variation among killer whales (*Orcinus orca*) in the eastern north Pacific and genetic differentiation between foraging specialists. *Journal of Heredity* 89:121-128.
- Hoyt, E. 1990. Orca: the whale called killer. Third edition, Camden House Publishing, North York, ON.
- Jefferson, T.A., P.J. Stacey, and R.W. Baird. 1991. A review of killer whale interactions with other marine mammals: predation to co-existence. *Mammal Review* 21:151-180.
- Koski, K., R. Osborne, and R. Tallmon. 2004. Soundwatch Public Outreach/Boater Education Project. Final Program Report, Whale Museum, Friday Harbor, Washington. Contract No. AB133F-03-SE-1126.
- Krahn, M.M., J.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. NOAA Technical Memorandum NMFS-NWF-SC-62, U.S. Dept. of Commerce, Seattle, WA.
- 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. NOAA Technical Memorandum NMFS-NWF-SC-54, U.S. Department of Commerce, Seattle, WA.
- Kriete, B. 1995. Bioenergetics in the killer whale, *Orcinus orca*. Ph.D. thesis, University of British Columbia, Vancouver, B.C.
- Kriete, B. 2002. Bioenergetic Changes from 1986 to 2001 in the southern resident killer whale population. Orca Relief Citizens' Alliance, Friday Harbor, WA.
- Matkin, C.O., G. Ellis, L. Barrett-Lennard, H. Yurk, El Saulitis, D. Scheel, P. Olesiuk, and G. Ylitalo. 2003. Photographic and acoustic monitoring of killer whales in Prince William Sound and Kenai Fjords. Restoration Project 030012 Final Report, Exxon Valdez Oil Spill Restoration Project, North Gulf Oceanic Society, Homer, AK.
- McComb, K., C. Moss, S.M. Durant, L. Baker, and S. Sayialel. 2001. Matriarchs as repositories of social knowledge in African elephants. *Science* 292:91-94.
- Morten, A. B., R. Routledge, C. Peet, and A. Ladwig. 2004. Sea lice (*Lepeophtheirus salmonis*) infection rates on juvenile pink (*O. gorbuscha*) and chum (*O. keta*) salmon in the near-shore marine environment of British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences* 61:147-157.
- National Oceanic and Atmospheric Administration (NOAA). 2006. Proposed recovery plan for Southern Resident Killer Whales (*Orcinus orca*). Northwest Region, Seattle, WA. 219 p.
- National Oceanic and Atmospheric Administration (NOAA). 2003. Harbor seals (*Phoca vitulina richardsi*) Oregon/Washington Coast stock. Available online: www.nmfs.noaa.gov/pr/species/mammals/pinnipeds.

- Olesiuk, P.F., M.A. Bigg, and G. M. Ellis. 1990. Life history and population dynamics of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission, Special Issue 12:209-243.
- Olesiuk, P.F., G.M. Ellis, and J.K.B. Ford. 2005. Life history and population dynamics of Northern Resident Killer Whales (*Orcinus orca*) in British Columbia. Canadian Science Advisory Secretariat, Research Document 1005/045.
- Olesiuk, P.F., G.M. Ellis, and J.K.B. Ford 2006. Life history and population dynamics of resident killer whales in B.C. and neighboring waters. Presentation given at the April 2006 Symposium on Southern Resident Killer Whales. Seattle, WA.
- Olsen, J.M. 1998. Temporal and spatial distribution patterns of sightings of Southern community and transient orcas in the inland waters of Washington and B.C. M.S. thesis, Western Washington University, Bellingham, WA.
- Orca Network. 2006. Website. Available online: www.orca-network.org.
- 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, B.C.
- Parsons, K.M., K.C. Balcomb, J.W. Durban, and J.K.B. Ford. 2006. Long-term social dynamics of fish-eating killer whales. Paper presented at the April 2006 Symposium on Southern Resident Killer Whales. Seattle, WA.
- Ross, P.S. 2002. The role of immunotoxic environmental contaminants in facilitating the emergence of infectious diseases in marine mammals. Human and Ecological Risk Assessment 8:277-292.
- Ross, P.S. 2006. Chemical Pollutants and Marine Mammals. JSKWICS. Available online: <http://www.killerwhalecentre.org/home/Conservation%20Issues/chemical%20pollutants%20and%20marine%20mammals.html>.
- Ross, P.S., G.M. Ellis, M.G. Ikononou, 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., S. Jeffries, and J. Calambokides. 2004. Southern Resident Killer Whales at risk: Contaminant-related health risks. Presentation at NMFS March 2004. Seattle, WA.
- Sanford, B. 2006. Washington Chinook salmon abundance. Paper presented at the April 2006 Symposium on Southern Resident Killer Whales (Abstract). Seattle, WA.
- Saulitis, E., C. Matkin, L. Barrett-Lennard, K. Heise, and G. Ellis. 2000. Foraging strategies of sympatric killer whales (*Orcinus orca*) populations in Prince William Sound, Alaska. Marine Mammal Science 16:94-109.
- Stevens, T.A., D.A. Duffield, E.D. Asper, K.G. Hewlett, A. Bolz, L.J. Gage, and G.D. Bossart. 1989. Preliminary findings of restriction fragment differences in mitochondrial DNA among killer whales (*Orcinus orca*). Canadian Journal of Zoology 67:2592-2595.
- Taylor, M. 2004. Southern resident orcas: population change, habitat degradation and habitat protection. Report No. SC/56/E32, International Whaling Commission, Cambridge, UK.
- The Whale Museum. 2006. Whale watching in the San Juan Islands. Available online: www.whale-museum.org.
- Trillmich, F., K.A. Ono, D.P. Costa, R.L. DeLong, S.D. Feldkamp, J.M. Francis, R.L. Gentry, C.B. Heath, B.J. LeBoeuf, P. Majluf, and A.E. York. 1991. The effects of El Niño on pinniped populations in the eastern Pacific. Pages 247-270 in F. Trillmich and K.A. Ono (eds.). Pinnipeds and El Niño: Responses to environmental stress. Springer-Verlag, Berlin, Germany. 293 p.
- Trillmich, F., K.A. Ono, D.P. Costa, R.L. DeLong, S.D. Feldkamp, J.M. Francis, M. Taylor, and B. Plater. 2001. Population viability analysis for the southern resident population of the killer whale (*Orcinus orca*). Center for Biological Diversity, Tucson, AZ.
- Ueno, D., N. Kajiwara, H. Tanaka, A. Subramanian, G. Fillmann, P.K.S. Lam, G.J. Zheng, M. Muchitar, H. Razak, M. Prudente, K.H. Chung, and S. Tanabe. 2004. Global pollution monitoring of polybrominated diphenyl ethers using skipjack tuna as a bioindicator. Environ. Sci. Technol. 38: 2312-2316.
- Walker, R. 2005. Orca bums boat. Journal of the San Juans. July 13, 2005.
- Walters, E.L., R.W. Baird, and T.J. Guenther. 1992. New killer whale 'pod' discovered near Victoria. Victoria Naturalist 49 (3):7-8.
- Wiles, G.J. 2004. Washington State status report for the killer whale. Washington Department of Fish and Wildlife, Olympia, WA.

PSNERP and the Nearshore Partnership

The **Puget Sound Nearshore Ecosystem Restoration Project** (PSNERP) was formally initiated as a General Investigation (GI) Feasibility Study in September 2001 through a cost-share agreement between the U.S. Army Corps of Engineers and the State of Washington, represented by the Washington Department of Fish and Wildlife. This agreement describes our joint interests and responsibilities to complete a feasibility study to “... *evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to these problems; and to recommend a series of actions and projects that have a federal interest and are supported by a local entity willing to provide the necessary items of local cooperation.*”

Since that time, PSNERP has attracted considerable attention and support from a diverse group of individuals and organizations interested and involved in improving

the health of Puget Sound nearshore ecosystems and the biological, cultural, and economic resources they support. The **Puget Sound Nearshore Partnership** is the name we have chosen to describe this growing and diverse group and the work we will collectively undertake, which ultimately supports the goals of PSNERP but is beyond the scope of the GI Study. We understand that the mission of PSNERP remains at the core of the Nearshore Partnership. However, restoration projects, information transfer, scientific studies and other activities can and should occur to advance our understanding and, ultimately, the health of the Puget Sound nearshore beyond the original focus and scope of the ongoing GI Study. As of the date of publication for this Technical Report, the Nearshore Partnership enjoys support and participation from the following entities:

King Conservation District	People for Puget Sound	U.S. Department of Energy – Pacific Northwest National Laboratory	Washington Department of Ecology
King County	Pierce County	U.S. Environmental Protection Agency	Washington Department of Fish and Wildlife
Lead Entities	Puget Sound Partnership	U.S. Geological Survey	Washington Department of Natural Resources
National Wildlife Federation	Recreation and Conservation Office	U.S. Fish and Wildlife Service	Washington Public Ports Association
NOAA Fisheries	Salmon Recovery Funding Board	U.S. Navy	Washington Sea Grant
Northwest Indian Fisheries Commission	Taylor Shellfish Company	University of Washington	WRIA 9
Northwest Straits Commission	The Nature Conservancy		
	U.S. Army Corps of Engineers		

Information about the Nearshore Partnership, including the PSNERP work plan, technical reports, the Estuary and Salmon Restoration Program, and other activities, can be found on our Web site at: www.pugetsoundnearshore.org.

PUGET SOUND NEARSHORE PARTNERSHIP



**RESTORING OUR
ECOSYSTEM HEALTH**

Puget Sound Nearshore Partnership/
Puget Sound Nearshore Ecosystem Restoration Project
c/o Washington Department of Fish and Wildlife

Mailing Address: 600 Capitol Way North,
Olympia, Washington 98501-1091

Contact: pugetsoundnearshore@dfw.wa.gov
or visit our website at: www.pugetsoundnearshore.org

