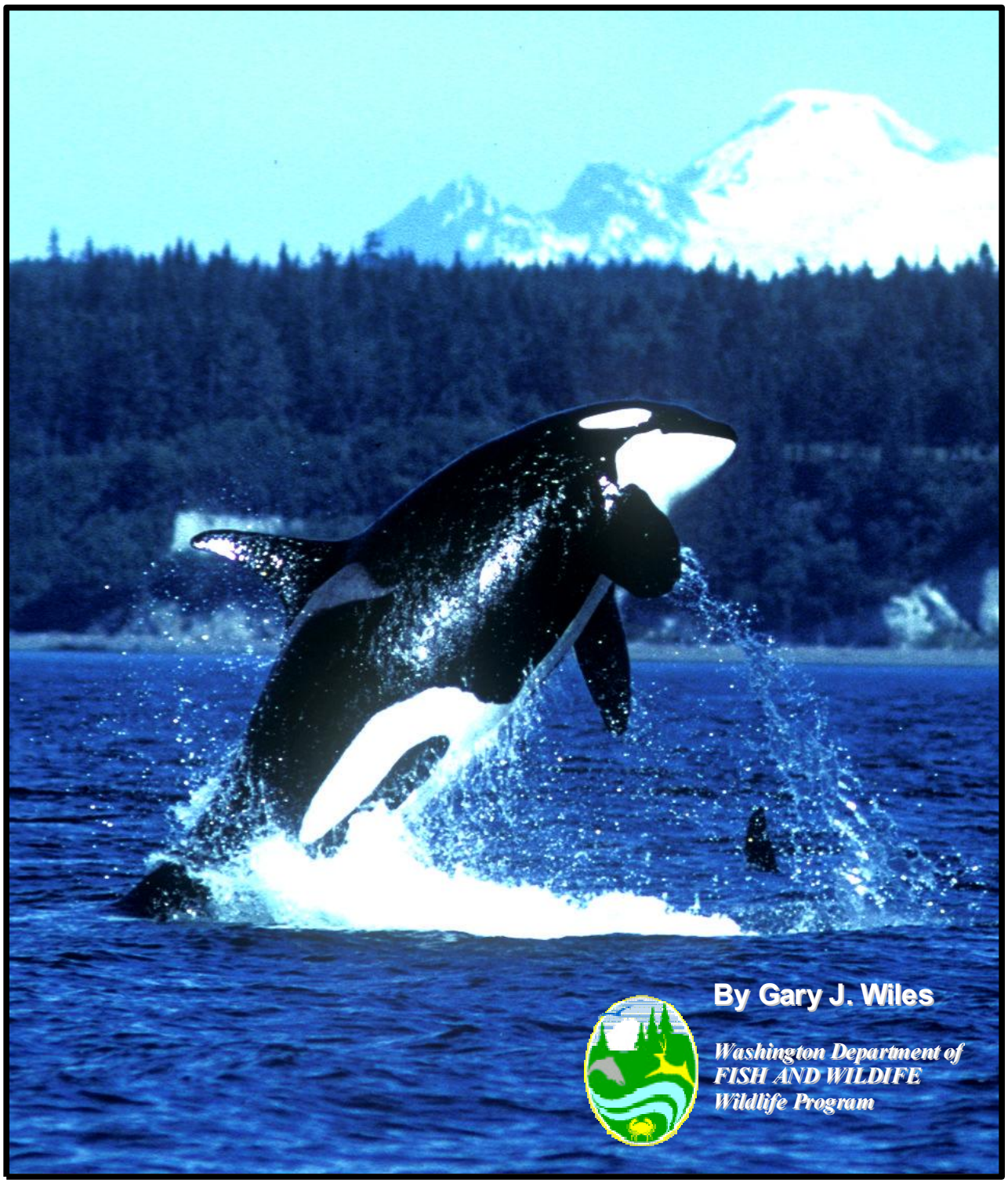
STATE OF WASHINGTON March 2004

Washington State Status Report for the Killer Whale



By Gary J. Wiles

Washington Department of
FISH AND WILDIFE
Wildlife Program

The Washington Department of Fish and Wildlife maintains a list of endangered, threatened, and sensitive species (Washington Administrative Codes 232-12-014 and 232-12-011, Appendix E). In 1990, the Washington Fish and Wildlife Commission adopted listing procedures developed by a group of citizens, interest groups, and state and federal agencies (Washington Administrative Code 232-12-297, Appendix E). The procedures include how species listings will be initiated, criteria for listing and delisting, public review, and recovery and management of listed species.

The first step in the process is to develop a preliminary species status report. The report includes a review of information relevant to the species' status in Washington and addresses factors affecting its status including, but not limited to: historic, current, and future species population trends, natural history including ecological relationships, historic and current habitat trends, population demographics and their relationship to long term sustainability, known and potential threats to populations, and historic and current species management activities.

The procedures then provide for a 90-day public review opportunity for interested parties to submit new scientific data relevant to the status report, classification recommendation, and any State Environmental Policy Act findings. During the 90-day review period, the Department may also hold public meetings to take comments and answer questions. At the close of the comment period, the Department completes the Final Status Report and Listing Recommendation for presentation to the Washington Fish and Wildlife Commission. The Final Report and Recommendation are then released 30 days prior to the Commission presentation for public review.

The draft status report for the killer whale was reviewed by researchers and state, provincial, and federal agencies. This review was followed by a 90-day public comment period from November 3, 2003-February 3, 2004. A public meeting was held in Mt. Vernon in January 2004. All comments received were considered in preparation of this Final Status Report for the Killer Whale. Submit written comments on this report by April 1, 2004 to: Endangered Species Section Manager, Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, Washington 98501-1091. The Department will present the results of this status review to the Fish and Wildlife Commission for action at the April 2-3, 2004 meeting in Spokane.

This report should be cited as:

Wiles, G. J. 2004. Washington State status report for the killer whale. Washington Department Fish and Wildlife, Olympia. 106 pp.

Cover photo: a member of L pod in the southern resident killer whale community breaches in Admiralty Inlet, Puget Sound, with Mt. Baker in the background (photo courtesy of the Center for Whale Research).
Other illustrations by Darrell Pruett.

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ACKNOWLEDGMENTS

Harriet Allen and Derek Stinson helped with many aspects of the preparation of this report. Ken Balcomb of the Center for Whale Research and John Ford of the Department of Fisheries and Oceans Canada kindly supplied their official count data for the southern and northern resident populations, respectively, and provided other information on killer whales, based on their extensive knowledge of the species. Kari Koski from the Soundwatch Boater Education Program of The Whale Museum was especially helpful during several discussions on whale watching. Rich Osborne of The Whale Museum allowed use of the data presented in Figure 5 and assisted with other information. John Calambokidis and Dave Ellifrit contributed information on regional movements and contaminants. Thanks also go to Jim Ames and Bruce Sanford for pointing out a few of the many intricacies of salmon occurrence.

Other useful information on killer whales or related topics was provided by Steve Jeffries, Robin Baird, Brent Norberg, Candi Emmons, Peter Ross, Gina Ylitalo, Brad Hanson, Joe Gaydos, Mike Bennett, Jodi Smith, Ingrid Visser, Sonja Kromann, Bill Wright, William Hoppe, Edward Bowlby, Jay Barlow, Trevor Branch, Ron Jameson, Jay Davis, Marilyn Dahlheim, Nancy Black, Pete Schroeder, Joe Shumacker, Ryan Karlson, Sanni Lustig, Charlie Stenvall, Gary Lee, Dan Doty, Jack Barfield, Rich Lincoln, Bruce White, Phil Anderson, Ian Guthrie, Greg Bargmann, Kyle Adicks, Tammy Mawani, Nancy Thomas, Fred Felleman, and Don Nelson. Sally Mizroch provided unpublished data from the Platforms of Opportunity Program database at the National Marine Mammal Laboratory. Darrell Pruett prepared the graphic illustrations and maps used in this report. Acknowledgment is also given to Peggy Krahn and her co-authors from the National Marine Fisheries Service, who published the agency's review of the status of southern resident killer whales in December 2002. Their report was the basis for much of the material appearing in this current document.

Thanks are extended to the following people who provided technical comments on preliminary drafts of the document: Jim Ames, Brad Hanson, Joe Buchanan, Robin Baird, John Ford, Peter Ross, Steve Jeffries, David Bain, Peggy Krahn, John Dohrmann, Dave Ellifrit, David Bain, Brent Norberg, Pete Schroeder, Toni Frohoff, Kari Koski, and Will Anderson.

EXECUTIVE SUMMARY

Killer whales are distributed throughout the marine waters of Washington. Four populations are recognized and are referred to as southern residents, northern residents, transients, and offshores. These populations rarely interact and do not interbreed despite having largely sympatric year-round geographic ranges that extend into British Columbia and other areas along the west coast of North America. Southern resident and transient killer whales are the only populations that regularly enter the state's coastal waters, whereas offshore whales mainly inhabit open ocean off the outer coast. Northern residents are rare visitors to the state. Resident killer whales are believed to feed almost exclusively on salmon, especially chinook, and other fish. They occur in small highly stable social units known as matrilines, in which all individuals are maternally related. Pods are larger social groups comprised of several matrilines and typically hold about 10 to 60 whales. In contrast, transient whales feed primarily on harbor seals and other marine mammals. They also travel in small matrilineal groups, which typically contain one to six animals. Although some matriline members maintain long-term bonds, the social organization of transients is generally more flexible than in residents. Few details are known about the biology of offshore killer whales, but they commonly occur in large groups of 20-75 individuals and are believed to be mainly fish-eaters.

The southern resident population is comprised of three pods (identified as J, K, and L pods) and is most familiar to the general public. It occurs primarily in the Georgia Basin and Puget Sound from late spring to fall, when it typically comprises the majority of killer whales found in Washington. The population travels more extensively during other times of the year to sites as far north as the Queen Charlotte Islands in British Columbia and as far south as Monterey Bay in California. Southern resident population trends are unknown before 1960, when roughly 80 whales were present, but it is quite likely that numbers were at a depleted level due to indiscriminant shooting by fishermen. The population is believed to have recovered somewhat during the early and mid-1960s, but live-captures for aquaria removed or killed at least 47 of the whales during the 1960s and 1970s. The population has been closely monitored since 1974, with exact numbers of animals and other demographic details learned through annual photo-identification surveys. Membership increased from 70 to 98 whales between 1974 and 1995, but this was followed by a rapid net loss of 18 animals, or 18% of the population, from 1996-2001. J and K pods have generally maintained their numbers during the decline, with both equaling or exceeding their largest recorded sizes in 2003. However, L pod, which comprises about half of the southern resident population, has been in sharp decline since 1994. This pod's decline is especially worrisome because it involves both increased mortality of members and a reduction in birth rates.

Population trends of transient and offshore killer whales are not known because of their greater mobility and more sporadic occurrence, making it difficult for researchers to maintain detailed photographic records of both groups. Both populations cover huge geographic ranges that extend from Alaska to southern California.

Killer whales in Washington face three main potential threats, plus other risk factors, that are unlikely to diminish in the future. First, the southern residents have experienced large historic declines in their main prey, salmon. Overall salmon abundance has remained relatively stable or been increasing in Puget Sound and the Georgia Basin during the past several decades and therefore may not be responsible for the decline in L pod since 1996. However, a lack of comprehensive information on the status of all salmon runs in the range of the southern residents makes the threat of reduced prey availability difficult to dismiss. Second, recent studies have revealed that transient and southern resident whales are heavily contaminated with organochlorine pollutants, primarily PCBs and DDT residues. Both populations are now considered as among the most highly contaminated marine mammals in the world. Lastly,

increasing public interest in killer whales has fueled tremendous growth in whale watching in and around the San Juan Islands during the past two decades. As a result, southern resident whales are now followed by significant numbers of commercial and private vessels during much or all of the day when residing in this portion of their range. An important short-term risk to killer whales and their prey in the Georgia Basin and Puget Sound is the threat of sizable oil spills. Despite the great increase in killer whale research in Washington and British Columbia since the early 1970s, researchers remain divided on which of these threats are most significant to the whales. It may well be that a combination of threats are working to harm the animals, especially L pod.

For these reasons, the Department recommends that the killer whale be listed as an endangered species in the state of Washington.

INTRODUCTION

Interest in placing killer whales (*Orcinus orca*) on the Washington list of endangered, threatened, or sensitive species began with a petition to the Department from the Progressive Animal Welfare Society on 11 November 1999, pursuant to WAC 232-12-297. Rationale for the request included a 17% decline in the southern resident whale population during the previous four years, the discovery of high contaminant levels in the whales, and historic declines in salmon, which are the main food of resident whales. The Department determined that there was adequate reason to be concerned about the biological status of killer whales in Washington and placed the species on the state's candidate species list in June 2000.

On 15 August 2001, Project SeaWolf petitioned the Department to emergency list the southern resident killer whale population as endangered in Washington. Because a status review needed to be conducted first, per WAC 232-12-297, the Department responded to the petitioners that, to avoid a duplication of effort, it would wait until after the National Marine Fisheries Service (NOAA Fisheries) had completed its own review of the southern residents, which was already being conducted to determine whether they should be federally listed as endangered. The Department provided technical information and advice from the state's perspective during the federal review. That assessment was completed in December 2002 and the Department initiated its own status review in March 2003. It should be noted that under the Department's listing procedures (WAC 232-12-297), only species and subspecies may be considered for listing. Subpopulations, such as the southern residents, are not eligible for separate listing.

This report fulfills the Department's requirement to evaluate all biological information regarding the status of killer whales in Washington. It summarizes the ecology, population status, and primary threats to transboundary populations of killer whales in the state and adjoining areas of British Columbia, with additional information about the species drawn from other localities in the northeastern Pacific Ocean and elsewhere around the world. The report begins with general descriptions of taxonomy and distribution of the species, as well as population types found in Washington and along the west coast of North America. This is followed by information on social organization, vocalizations, diet, behavior, movements, habitat use, reproduction, survival, and sources of mortality. Summaries of historic, recent, and future population trends are then presented, followed by a section on legal protection in the United States and internationally. The report identifies potential threats to killer whales in Washington and British Columbia and concludes with a listing recommendation.

TAXONOMY

Killer whales are members of the family Delphinidae, which includes 17-19 genera of marine dolphins (Rice 1998, LeDuc et al. 1999). Systematic classifications based on morphological comparisons have variously placed the genus *Orcinus* in the subfamilies Globicephalinae or Orcininae with other genera such as *Feresa*, *Globicephala*, *Orcaella*, *Peponocephala*, and *Pseudorca* (Slijper 1936, Fraser and Purves 1960, Kasuya 1973, Mead 1975, Perrin 1989, Fordyce and Barnes 1994). However, recent molecular work suggests that *Orcinus* is most closely related to the Irawaddy dolphin (*Orcaella brevirostris*), with both forming the subfamily Orcininae (LeDuc et al. 1999).

Orcinus has traditionally been considered monotypic, despite some variation in color patterns, morphology, and ecology across its distribution. No subspecies are currently recognized. In the early 1980s, Soviet scientists proposed two new species (*O. nanus* and *O. glacialis*) in Antarctica, based on their smaller sizes and other traits (Mikhalev et al. 1981, Berzin and Vladimirov 1983, Pitman and Ensor 2003). Similarly, Baird (1994, 2002) argued that resident and transient forms in the northeastern Pacific should be treated as separate species due to differences in behavior, ecology, and vocalizations. These designations have not

received wide acceptance (Hoelzel et al. 1998, Rice 1998, Barrett-Lennard 2000). Recent investigations have documented genetic distinctions among populations in the northeastern Pacific, but these were considered insufficient to warrant designation of discrete taxa (Hoelzel and Dover 1991, Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001). Worldwide populations show low diversity in mitochondrial DNA (Hoelzel et al. 2002), which is also suggestive of a lack of taxonomic differentiation within the species. Nevertheless, a number of authorities believe that the current classification of killer whales as a single species without subspecies is inaccurate (Krahn et al. 2002). For example, newly published evidence reveals the presence of three distinct forms of killer whales in Antarctica (Pitman and Ensor 2003). Thus, it seems likely that continued study, including broader application of the biological species concept, will eventually result in the recognition of additional species or subspecies of killer whales.

The name "killer whale" originates from early whalers and is appropriately based on the species' predatory habits, as well as its large size, which distinguishes it from other dolphins. Other common names currently or formerly used in North America include "orca," "blackfish," "killer," "grampus," and "swordfish." The name "orca" has become increasingly popular in recent decades as a less sinister alternative to "killer whale" (Spalding 1998). A variety of Native American names also exist, including *klasqo'kapix* (Makah, Olympic Peninsula), *ka-kow-wud* (Quillayute, Olympic Peninsula), *max'inux* (Kwakiutl, northern Vancouver Island), *qaqawun* (Nootka, western Vancouver Island), and *ska-ana* (Haida, Queen Charlotte Islands) (Hoyt 1990, Ford et al. 2000).

DESCRIPTION

Killer whales are the world's largest dolphin. The sexes show considerable size dimorphism, with males attaining maximum lengths and weights of 9.0 m and 5,568 kg, respectively, compared to 7.7 m and 3,810 kg for females (Dahlheim and Heyning 1999). Adult males develop larger pectoral flippers, dorsal fins, tail flukes, and girths than females (Clark and Odell 1999). The dorsal fin reaches heights of 1.8 m and is pointed in males, but grows to only 0.7 m and is more curved in females (Figure 1). Killer whales have large paddle-shaped pectoral fins and broad rounded heads with only the hint of a facial beak. The flukes have pointed tips and form a notch at their midpoint on the trailing edge. Ten to 14 teeth occur on each side of both jaws and measure up to 13 cm in length (Eschricht 1866, Scammon 1874, Nishiwaki 1972). Skull morphology and other anatomical features are described by Tomilin (1957) and Dahlheim and Heyning (1999).

Killer whales are easily identifiable by their distinctive black-and-white color pattern, which is among the most striking of all cetaceans. Animals are black dorsally and have a white ventral region extending from the chin and lower face to the belly and anal region (Figure 1). The underside of the tail fluke is white or pale gray, and may be thinly edged in black. Several additional white or gray markings occur on the flanks and back. These include a small white oval patch behind and above the eye, a larger area of white connected to the main belly marking and sweeping upward onto the lower rear flank, and a gray or white "saddle" patch usually present behind the dorsal fin. These color patterns exhibit regional and age variation (Carl 1946, Evans et al. 1982, Baird and Stacey 1988, Ford et al. 2000, Pitman and Ensor 2003). Infants feature yellowish, rather than white, markings. Each whale has a uniquely shaped and scarred dorsal fin and saddle patch, which permits animals to be recognized on an individual basis, as depicted in photo-identification catalogs, such as those compiled for Washington and British Columbia (e.g., van Ginneken et al. 1998, 2000, Ford and Ellis 1999, Ford et al. 2000). Shape and coloration of the saddle often differs on the left and right sides of an animal (Ford et al. 2000, van Ginneken et al. 2000). Eye-patch shape is also unique among individuals (Carl 1946, Visser and Mäkeläinen 2000). In the Antarctic, several populations of killer whales display grayish dorsal "capes" extending over large portions of the back

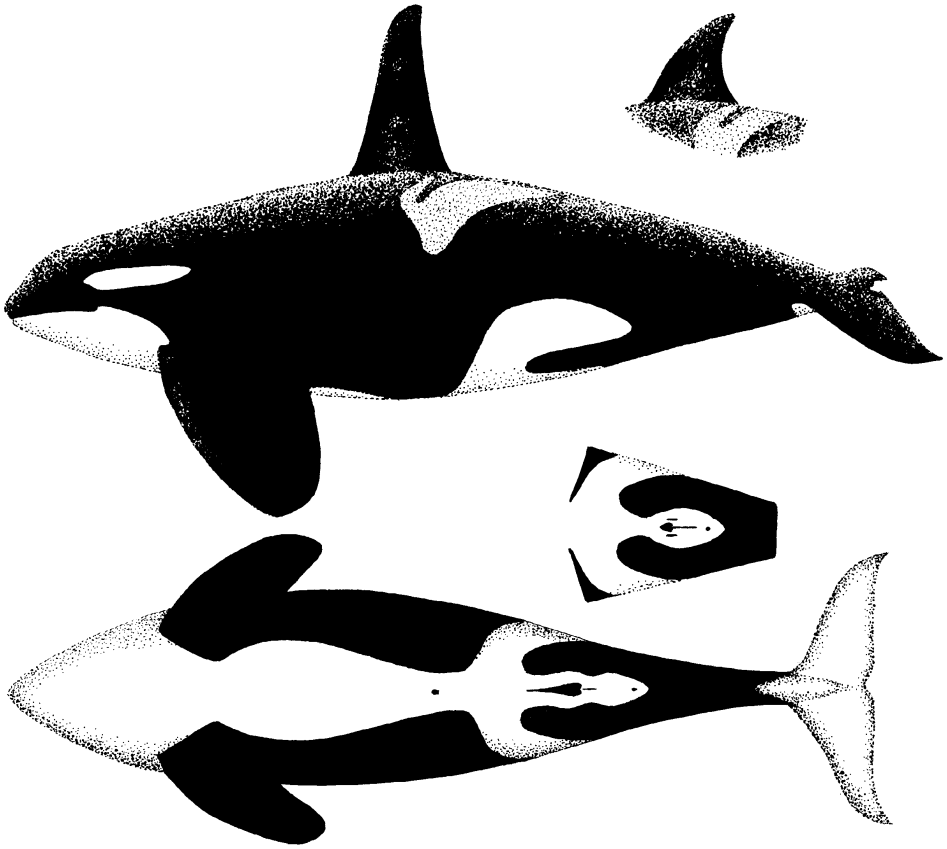

Figure 2. Lateral and ventral views of an adult male killer whale. Small insets show the dorsal fin and genital pigmentation of a female. Adapted from Dahlheim and Heyning (1999) and Ford et al. (2000).

and flanks (Evans et al. 1982, Visser 1999a, Pitman and Ensor 2003).

In addition to the characters mentioned above, male and female killer whales are distinguishable by pigmentation differences in the genital area (Figure 1; Ford et al. 2000). Females have a roughly circular or oval white patch surrounding the genital area. Within this patch, the two mammary slits are marked with gray or black and are located on either side of the genital slit, which also usually has a dark marking. Males have a more elongated white patch surrounding the genital area, a larger darker spot at the genital slit, and lack the darkly shaded mammary slits.

When viewed at long distances, false killer whales (*Pseudorca crassidens*) and Risso's dolphins (*Grampus griseus*) can be mistaken for female and immature killer whales (Leatherwood et al. 1988). Blows of killer whales are low and bushy-shaped, reaching a height of about 1.5-2 m (Scammon 1874, Scheffer and Slipp 1948, Eder 2001). Scheffer and Slipp (1948) described the sound of

blowing as "a quick breathy puff, louder and sharper and lacking the double gasp of the harbor porpoise" (*Phocoena phocoena*).

DISTRIBUTION

Global

Killer whales have a cosmopolitan distribution considered the largest of any cetacean (Figure 2). The species occurs in all oceans, but is generally most common in coastal waters and at higher latitudes, with fewer sightings from tropical regions (Dahlheim and Heyning 1999). In the North Pacific, killer whales occur in waters off Alaska, including the Aleutian Islands and Bering Sea (Murie 1959, Braham and Dahlheim 1982, Dahlheim 1994, Matkin and Saulitis 1994, Miyashita et al. 1995, Dahlheim 1997, Waite et al. 2002), and range southward along the North American coast and continental slope (Norris and Prescott 1961, Fiscus and Niggol 1965, Gilmore 1976, Dahlheim et al. 1982, Black et al. 1997, Guerrero-Ruiz et al. 1998). Populations are also present along the northeastern coast of Asia from eastern Russia to southern China (Tomilin 1957, Nishiwaki and Handa 1958, Kasuya 1971, Wang 1985, Miyashita et al. 1995). Northward occurrence in this region extends into the Chukchi and Beaufort Seas (Lowry et al. 1987). Sightings are generally infrequent to rare across the tropical Pacific, extending from Central and South America (Dahlheim et al. 1982, Wade and

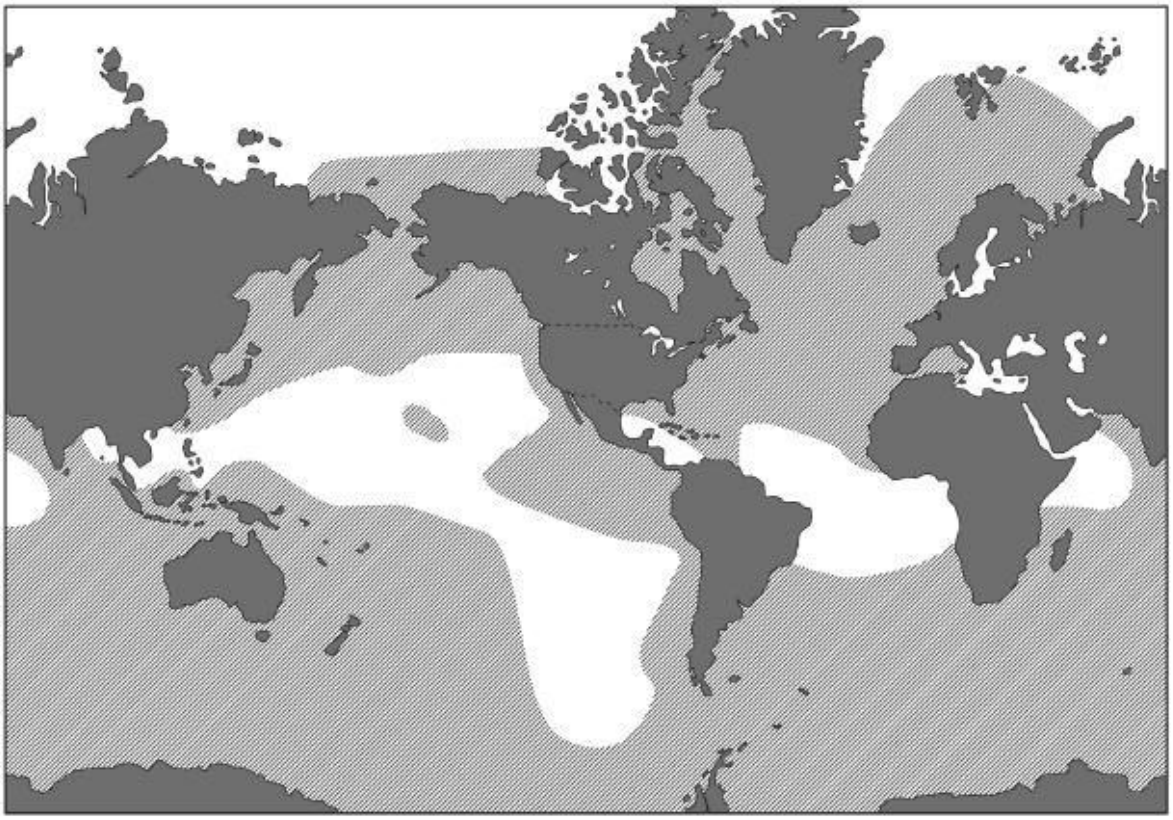

Figure 2. Worldwide range of killer whales. Hatched areas depict the distribution of known records. White areas are probably also inhabited, but documented sightings are lacking. Adapted from Miyashita et al. (1995) and Dahlheim and Heyning (1999), with additional information from Reeves and Mitchell (1988b), Wade and Gerrodette (1993), Andersen and Kinze (1999), and Reeves et al. (1999).

Gerrodette 1993) westward to much of the Indo-Pacific region (Tomich 1986, Eldredge 1991, Miyashita et al. 1995, Reeves et al. 1999, Mobley et al. 2001, Visser and Bonoccorso 2003). The species occurs widely in the North Atlantic, including the entire eastern coast of North America, parts of the Caribbean, Greenland, and from northwestern Russia and Scandinavia to Africa (Tomilin 1957, Evans 1988, Hammond and Lockyer 1988, Katona et al. 1988, Øien 1988, Mitchell and Reeves 1988, Reeves and Mitchell 1988a, 1988b, Baird 2001). Killer whales are broadly distributed in the southern oceans (Miyashita et al. 1995), being most common off Antarctica. Smaller populations are present in Australia, New Zealand, South America, and southern Africa (Jehl et al. 1980, Dahlheim 1981, Thomas et al. 1981, Dahlheim and Heyning 1999, Peddemors 1999).

Washington

Killer whales occur in marine waters throughout Washington. From late spring to fall, most whales can be found in the inland waters around the San Juan Islands, including Haro Strait, Boundary Passage, and the eastern portion of the Strait of Juan de Fuca (Heimlich-Boran 1988, Felleman et al. 1991, Olson 1998, Ford et al. 2000). Less time is generally spent elsewhere, including other parts of the Strait of Juan de Fuca, Puget Sound, and the outer coast. Movements during the winter and early spring are poorly known, but many animals shift their activity to outer coastal areas or depart the state. Accounts of the seasonal distribution of each killer whale population found in the state appear in greater detail in other sections of the text.

CLASSIFICATION OF KILLER WHALES IN THE NORTHEASTERN PACIFIC

Three distinct forms of killer whales, termed as residents, transients, and offshores, are recognized in the northeastern Pacific Ocean. Although there is considerable overlap in their ranges, these populations display significant genetic differences due to a lack of interchange of member animals (Stevens et al. 1989, Hoelzel and Dover 1991, Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001). Important differences in ecology, behavior, and morphology also exist (Baird 2000, Ford et al. 2000). Similar differences among overlapping populations of killer whales have been found in Antarctica (Berzin and Vladimirov 1983, Pitman and Ensor 2003) and may eventually be recognized in the populations of many localities (Ford et al. 1998). The names "resident" and "transient" were coined during early studies of killer whale communities in the northeastern Pacific (Bigg 1982), but continued research has shown that neither term is particularly descriptive of actual movement patterns (Dahlheim and Heyning 1999, Baird and Whitehead 2000, Baird 2001). Both names, plus "offshore," are currently applied only to killer whales occurring in this region, but may also be appropriate for some populations off eastern Asia (Krahn et al. 2002).

Resident Killer Whales

In the northeastern Pacific, resident killer whales are distributed from Alaska to California, with four distinct communities recognized: southern, northern, southern Alaska, and western Alaska (Krahn et al. 2002). Resident killer whales differ from transient and offshore animals by having a dorsal fin that is more curved and rounded at the tip (Ford et al. 2000). Residents also exhibit at least five patterns of saddle patch pigmentation (Baird and Stacey 1988). They feed primarily on fish, occur in large stable pods typically comprised of 10 to about 60 individuals, and also differ in vocalization patterns (Ford 1989, Felleman et al. 1991, Ford et al. 1998, 2000, Saulitis et al. 2000). A fifth resident community, known as the western North Pacific residents, is thought to occur off eastern Russia and perhaps Japan (Krahn et al. 2002).

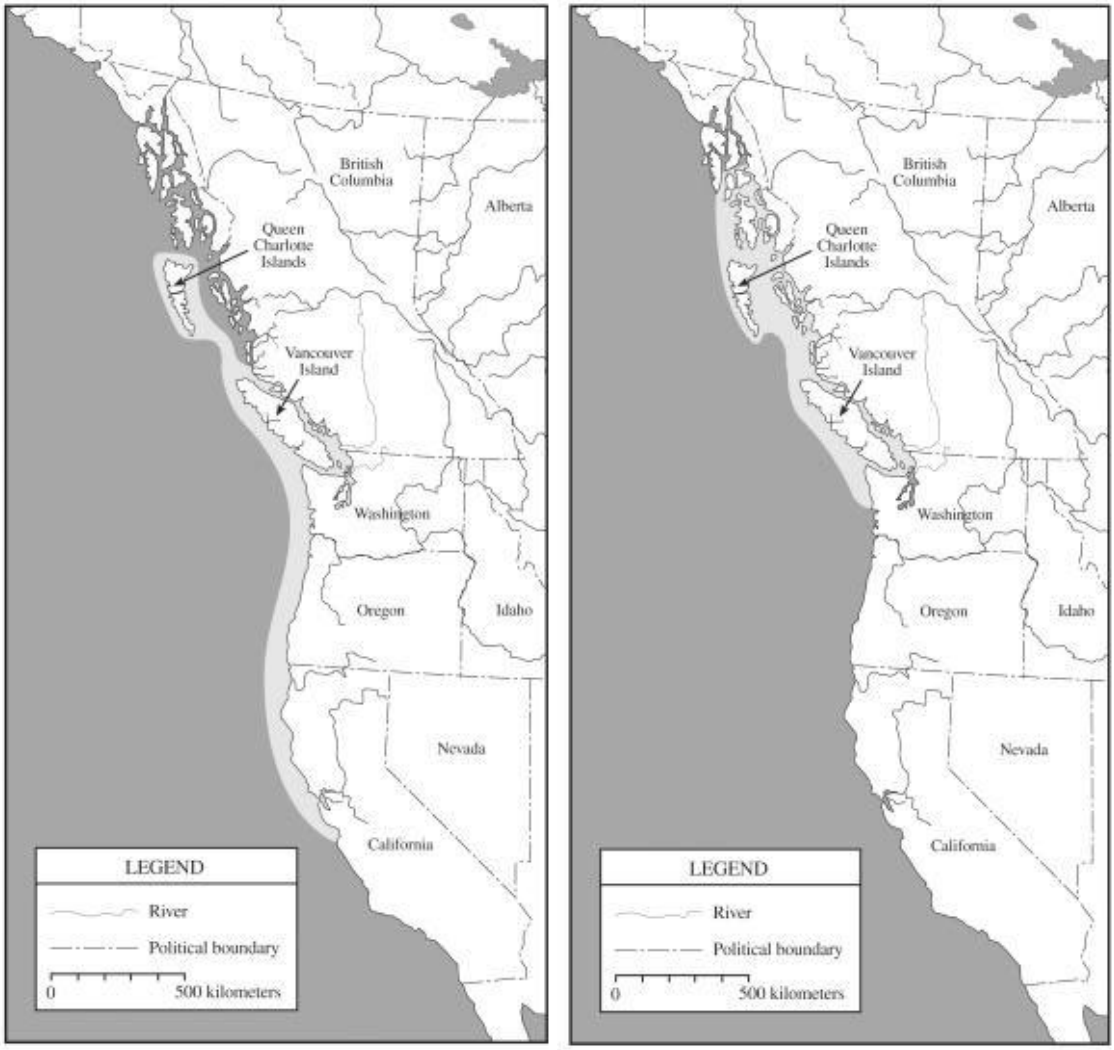

Figure 3. Geographic ranges (light shading) of the southern resident (left) and northern resident (right) killer whale populations in the northeastern Pacific. The western pelagic boundary of the ranges is ill-defined.

Southern residents. This population consists of three pods, identified as J, K, and L pods, that reside for part of the year in the inland waterways of the Strait of Georgia, Strait of Juan de Fuca, and Puget Sound, especially during the spring, summer, and fall (Krahn et al. 2002). Pods regularly visit coastal sites off Washington and Vancouver Island (Ford et al. 2000), and are known to travel as far south as central California and as far north as the Queen Charlotte Islands (Figure 3). Winter movements and distribution are poorly understood for the population. Although there is considerable overlap in the geographic ranges of southern and northern residents, pods from the two populations have not been observed to intermix (Ford et al. 2000). Genetic analyses using microsatellite (nuclear) DNA and mitochondrial DNA (mtDNA) further indicate that the two populations are reproductively isolated (Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001).

Northern residents. The northern resident killer whale community contains 16 pods that reside

primarily from central Vancouver Island (including the northern Strait of Georgia) to Frederick Sound in southeastern Alaska (Figure 3; Dahlheim 1997, Ford et al. 2000), although animals occasionally venture as far south as the Strait of Juan de Fuca, San Juan Islands, and probably the western Olympic Peninsula (Barrett-Lennard and Ellis 2001; J. Calambokidis, unpubl. data). From June to October, many northern resident pods congregate in the vicinity of Johnstone Strait and Queen Charlotte Strait off northeastern Vancouver Island, but movements and distribution during other times of the year are much less well known (Ford et al. 2000). In southeastern Alaska, northern residents have been seen once in association with pods from the southern Alaska resident community (Dahlheim et al. 1997) and limited gene flow may occur between these two populations (Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001).

Other residents. Southern Alaska resident killer whales inhabit the waters of southeastern Alaska and the Gulf of Alaska (including Prince William Sound and Kodiak Island), with at least 15 pods identified (Dahlheim 1997, Dahlheim et al. 1997, Matkin and Saulitis 1997). Distribution and abundance of the western Alaska residents are less understood, but their range includes coastal and offshore waters of the Bering Sea for at least part of the year (Krahn et al. 2002).

Transient Killer Whales

Transients do not associate with resident and offshore whales despite having a geographic range that is largely sympatric with both forms (Figure 4). Compared to residents, transients occur in smaller groups of usually less than 10 individuals (Ford and Ellis 1999, Baird 2000, Baird and Whitehead 2000), display a more fluid social organization, and have diets consisting largely of other marine mammals (Baird and Dill 1996, Ford et al. 1998, Saulitis et al. 2000). They also move greater distances and tend to have larger home ranges than residents (Goley and Straley 1994, Dahlheim and Heyning 1999, Baird 2000). Morphologically, the dorsal fins of transients are straighter at the tip than in residents and offshores (Ford and Ellis 1999, Ford et al. 2000). Two patterns of saddle pigmentation are recognized (Baird and Stacey 1988). Recent genetic investigations using both nuclear DNA and mtDNA have found significant genetic differences between transients and other killer whale forms, confirming the lack of interbreeding (Stevens 1989, Hoelzel and Dover 1991, Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001). These studies also indicate that up to three genetically distinct assemblages of transient killer whales exist in the northeastern Pacific. These are identified as 1) west coast transients, which occur from southern California to southeastern Alaska (Figure 4), 2) Gulf of Alaska transients, and 3) AT1 pod, which inhabits Prince William Sound and the Kenai Fjords in the northern Gulf of Alaska and is highly threatened with just nine whales remaining (Ford and Ellis 1999, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001). Genetic evidence suggests there is little or no interchange of members among these populations (Barrett-Lennard and Ellis 2001).

Offshore Killer Whales

Due to a scarcity of sightings, much less information is available for the offshore killer whale population, which was first identified in the late 1980s (Ford et al. 1992, 1994, Walters et al. 1992). Records are distributed from southern California to Alaska (Figure 4), including many from western Vancouver Island and the Queen Charlotte Islands (Ford and Ellis 1999, Krahn et al. 2002). Recent data from Alaska has extended the population's range to the western Gulf of Alaska and eastern Aleutians (M. E. Dahlheim, pers. comm.). Offshore killer whales usually occur 15 km or more offshore, but also visit coastal waters and occasionally enter protected inshore waters. Sightings have been made up to 500 km off the Washington coast (Krahn et al. 2002). Animals typically congregate in groups of 20-75 animals and are presumed to feed primarily on fish. Intermixing with residents and transients

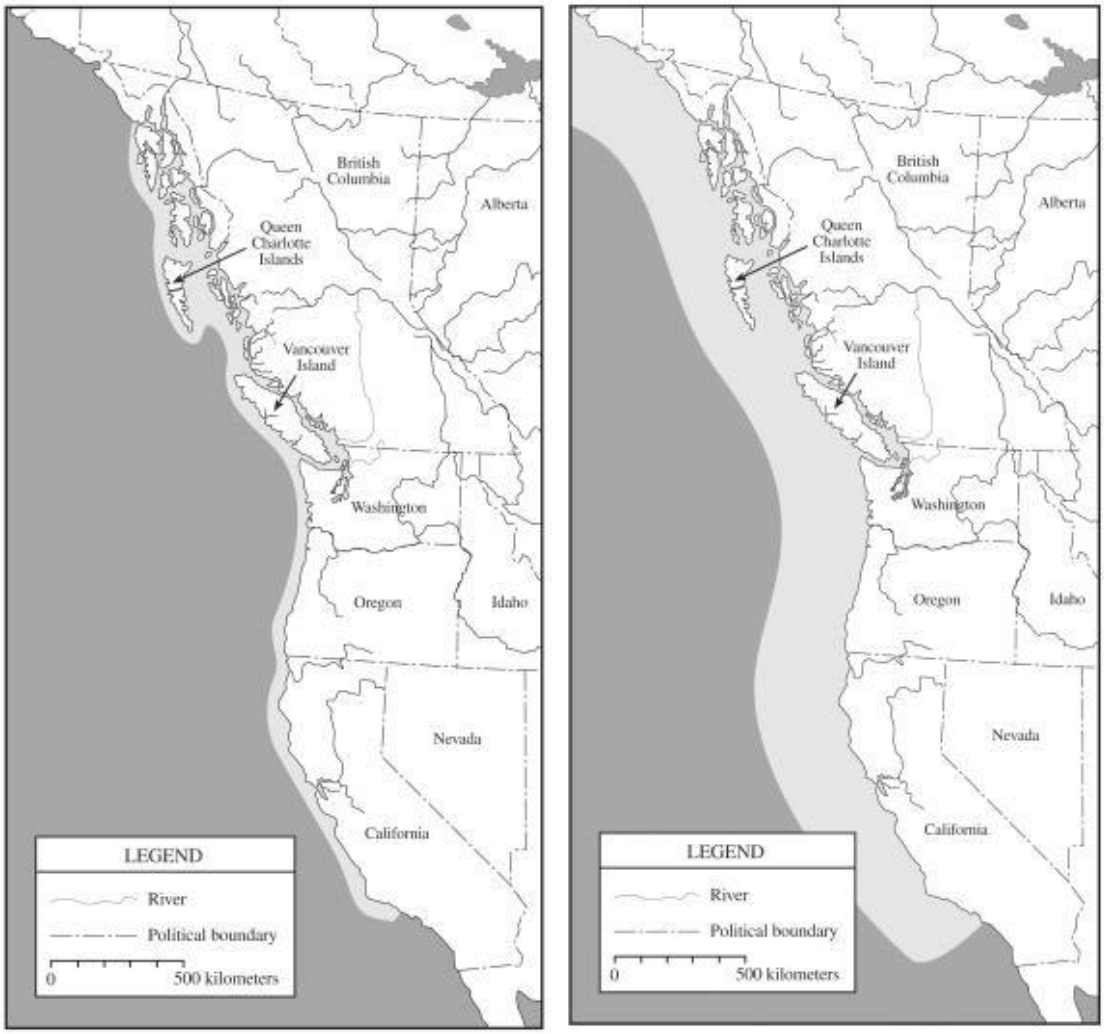

Figure 4. Geographic ranges (light shading) of the west coast transient (left) and offshore (right) killer whale populations in the northeastern Pacific. The western pelagic boundary of the ranges is ill-defined. The northern range of the offshore population extends westward to the eastern Aleutian Islands.

has not been observed. Genetic analyses indicate that offshore killer whales are reproductively isolated from other forms, but are more closely related to the southern residents (Hoelzel et al. 1998, Barrett-Lennard and Ellis 2001). Offshores are thought to be slightly smaller in body size than residents and transients, and have dorsal fins and saddle patches resembling those of residents (Walters et al. 1992, Ford et al. 2000).

Naming Systems of Killer Whales in the Northeastern Pacific

As previously noted, killer whales are individually recognizable by the unique markings and shapes of their dorsal fin, saddle patch, and eye patches. In the northeastern Pacific, researchers use several alphanumeric naming systems to maintain sighting records and other data for individual whales in each community. For resident whales in

Washington and British Columbia, animals are assigned their own alphanumeric names, based on their pod and the sequence in which they were identified (Ford and Ellis 1999, Ford et al. 2000). Thus, the whale known as "L7" was the seventh member to be documented in L pod. The system is more complicated for transients, which have a more flexible social system. All animals are assigned the letter "T" followed by a unique number (if the whale was born before the study began or has an unknown mother) or number-letter code (if the whale was born to an identified female) (Ford and Ellis 1999). Thus, "T10" was the tenth transient to be documented, "T49A" was the first known calf of "T49", and "T49B" was the second known calf of "T49." Offshores are designated by the letter "O" and a unique number signifying the order in which they were recorded. Thus, "O2" was the second offshore killer whale to be identified. Equivalent naming systems exist for transients and offshores in California and southeastern Alaska, with the prefix "CA" used for animals in California (Black et al. 1997) and various prefixes beginning with the letter "A" for Alaska (Dahlheim et al. 1997). Thus, individuals observed in multiple areas may have more than one name (Ford and Ellis 1999).

NATURAL HISTORY

Social Organization

Killer whales are highly social animals that occur primarily in groups or pods of up to 40-50 animals (Dahlheim and Heyning 1999, Baird 2000). Mean pod size varies among populations, but often ranges from 2 to 15 animals (Kasuya 1971, Condy et al. 1978, Mikhalev et al. 1981, Braham and Dahlheim 1982, Dahlheim et al. 1982, Baird and Dill 1996). Larger aggregations of up to several hundred individuals occasionally form, but are usually considered temporary groupings of smaller social units that probably congregate near seasonal concentrations of prey, for social interaction, or breeding (Dahlheim and Heyning 1999, Baird 2000, Ford et al. 2000). Single whales, usually adult males, also occur in many populations (Norris and Prescott 1961, Hoelzel 1993, Baird 1994). Differences in spatial distribution, abundance, and behavior of food resources probably account for much of the variation in group size among killer whale populations. For example, sympatric populations of resident and transient whales in Washington and British Columbia vary substantially in average pod size. Transients forage in small groups on wary and patchily distributed marine mammals and are presumably able to maximize their per capita energy intake through reduced competition over food (Baird and Dill 1996, Ford and Ellis 1999, Baird and Whitehead 2000). In contrast, the larger groups of resident whales may be better able to detect schools of fish, enabling individual members to increase food consumption (Ford et al. 2000).

The age and sex structure of killer whale social groups has been reported for populations at several locations. Olesiuk et al. (1990a) reported that pods in Washington and British Columbia were comprised of 19% adult males, 31% adult females, and 50% immature whales of either sex. In Alaska, 24% of the animals in pods were adult males, 47% were either adult females or subadult males, and 29% were younger animals (Dahlheim 1997, Dahlheim et al. 1997). For southern oceans, Miyazaki (1989) found that 16% of populations were adult males, 8% were adult females with calves, and 76% were immatures and adult females without calves. At Marion Island in the southern Indian Ocean, 29% of the population were adult males, 21% were adult females, 8% were calves, 25% were subadults, and 17% unidentified (Condy et al. 1978).

Some of the most detailed studies of social structure in killer whales have been made in British Columbia, Washington, and Alaska during the past few decades, with much information available on group size, structure, and stability, and vocal traits (Ford 1989, 1991, Bigg et al. 1990, Matkin et al. 1999b, Ford et al. 2000, Yurk et al. 2002). Social organization in this region is based on maternal kinship and may be characteristic of killer whale populations throughout the world (Ford 2002).

Residents. Four levels of social structure have been identified among resident killer whales. The basic social unit is the matriline, which is a highly stable hierarchical group of individuals linked by maternal descent (Baird 2000, Ford et al. 2000, Ford 2002). A matriline is usually composed of a female, her sons and daughters, and offspring of her daughters, and contains one to 17 (mean = 5.5) individuals spanning one to four (mean = 3) generations. Members maintain extremely strong bonds and individuals seldom separate from the group for more than a few hours. Permanent dispersal of individuals from resident matrilines has never been recorded (Bigg et al. 1990, Baird 2000, Ford et al. 2000, Barrett-Lennard and Ellis 2001).

Groups of related matrilines are known as pods. Matrilines within pods share a common maternal ancestor from the recent past, making them more closely related to one another than to those of other pods (Baird 2000, Ford et al. 2000). Pods are less cohesive than matrilines and member matrilines may travel apart for periods of weeks or months. Nonetheless, matrilines associate more often with others from their pod than with matrilines from other pods. Most pods are comprised of one to four matrilines, but one southern resident pod (L pod) holds 12 matrilines (Table 1). Resident pods contain two to 59 whales (mean = 18) (Bigg et al. 1987; Ford et al. 2000; Ford 2002; Center for Whale Research, unpubl. data). Gradual changes in pod structure and cohesion occur through time with the deaths and

Table 1. Social hierarchy and pod sizes of southern and northern resident killer whales in Washington and British Columbia (Ford et al. 2000; Center for Whale Research, unpubl. data).

Community	Clan	Pod[a]	Matrilines	No. of members per pod[b]
Southern residents	J	J	J2, J8, J9, J16	22
	J	K	K3, K4, K7, K18	21
	J	L	L2, L4, L9, L12, L21, L25, L26, L28, L32, L35, L37, L45	41
			Total	84
Northern residents	A	A1	A12, A30, A36	16
	A	A4	A11, A24	11
	A	A5	A8, A9, A23, A25	13
	A	B1	B7	7
	A	C1	C6, C10	14
	A	D1	D7, D11	12
	A	H1	H6	9
	A	I1	I1	8
	A	I2	I22	2
	A	I18	I17, I18	16
	G	G1	G3, G4, G17, G18, G29	29
	G	G12	G2, G12	13
	G	I11	I11, I15	22
	G	I31	I31	12
	R	R1	R2, R5, R9, R17	29
	R	W1	W3	3
			Total	216

[a] Southern resident pods are also known as J1, K1, and L1 pods (Ford et al. 2000).
[b] Pod sizes are based on annual census results from 2003 for southern residents (Center for Whale Research, unpubl. data) and from 1998 for northern residents (Ford et al. 2000).

births of members, as seen after the death of one matriarchal female, which appeared to prompt the fragmentation of her matriline (Ford et al. 2000). Such changes in association patterns caused some observers to believe that L pod had broken into three smaller pods during the 1980s (Hoelzel 1993). Within pods, some researchers recognize the existence of an intermediate type of association known as the subpod, which is defined as a grouping of matrilines that spends more than 95% of their time together (Baird 2000).

Clans are the next level of social structure and are composed of pods with similar vocal dialects and a common but older maternal heritage (Ford 1991, Ford et al. 2000, Yurk et al. 2002). Those pods with similar dialects are presumably more closely related to one another than those with greater differences in their dialects (Ford 1991). However, vocalizations known as pulsed calls are not shared between different clans, indicating a lack of recent common ancestry between clans. Clans overlap in their geographic ranges and pods from different clans frequently intermingle.

Pods (and clans) that regularly associate with one another are known as communities, which represent the highest level of social organization in resident killer whale societies (Ford et al. 2000, Ford 2002). Four communities (southern, northern, southern Alaska, and western Alaska) of resident whales exist in the northeastern Pacific. Communities are based solely on association patterns rather than maternal relatedness or acoustic similarity. Ranges of neighboring communities partially overlap and member pods may or may not associate on an occasional basis with those from other communities (Baird 2000). The southern resident community is comprised of three pods and one clan (J), whereas the northern resident community has 16 pods in three clans (A, G, and R) (Table 1, Ford et al. 2000). The A clan contains 10 pods (A1, A4, A5, B1, C1, D1, H1, I1, I2, and I18), G clan consists of four pods (G1, G12, I11, and I31), and R clan holds two pods (R1 and W1) (Table 1; Ford et al. 2000).

Transients. The social organization of transients is less understood than for resident whales. Transients also occur in fairly stable maternal groups, with some associations between individual animals exceeding 15 years (Baird 2000, Baird and Whitehead 2000). Groups are thought to usually comprise an adult female and one or two of her offspring (Ford and Ellis 1999, Baird and Whitehead 2000). Male offspring typically maintain stronger relationships with their mother than female offspring, and such bonds can extend well into adulthood. Unlike residents, extended or permanent dispersal of transient offspring away from natal matrilines is common, with juveniles and adults of both sexes participating (Ford and Ellis 1999, Baird 2000, Baird and Whitehead 2000). Some males depart to become "roving" males. These individuals do not form long-term associations with other whales, but live solitarily much of the time and occasionally join groups that contain potentially reproductive females (Baird 2000, Baird and Whitehead 2000). Roving males do not associate together in all-male groups. Females that disperse from their maternal matriline appear to be more gregarious than males, but remain socially mobile (Baird and Whitehead 2000).

Transient pods are smaller than those of residents, numbering just one to four individuals (mean = 2.4) (Baird and Dill 1996, Ford and Ellis 1999, Baird and Whitehead 2000). Ford and Ellis (1999) reported that about 70% of all transient groups contained two to six animals (median = four), 17% had 7-11 animals, 10% were lone animals (these are mostly males; Baird 1994), and 3% had 12-22 individuals. Larger groups result from matrilines temporarily joining each other to forage and socialize (Baird and Dill 1995, 1996, Ford and Ellis 1999, Baird and Whitehead 2000). In comparison with resident killer whales, transient matrilines generally maintain more flexible association patterns with one another (Baird and Dill 1995, Baird 2000). However, some matrilines associate preferentially with certain other matrilines, perhaps for reasons of enhanced foraging success (Baird and Dill 1995). As in resident clans, all members of the transient community share a related acoustic repertoire, although regional differences in vocalizations have been noted (Ford 2002).

Offshores. The social structure of offshore killer whales has not been studied in detail. These whales usually occur in large groups of 20-75 animals (Walters et al. 1992, Ford et al. 2000, Krahn et al. 2002). Membership patterns within groups appear to be dynamic, with considerable interchange of animals noted between sightings (K. C. Balcomb, unpubl. data).

Vocalizations

Vocal communication is particularly advanced in killer whales and is an essential element of the species' complex social structure. Like all dolphins, killer whales produce numerous types of vocalizations that are useful in navigation, communication, and foraging (Dahlheim and Awbrey 1982, Ford 1989, Barrett-Lennard et al. 1996, Ford et al. 2000). Sounds are made by air forced through structures in the nasal passage and are enhanced and directed forward by a fatty enlargement near the top of the head, known as the melon. Most calls consist of both low- and high-frequency components (Bain and Dahlheim 1994). The low-frequency component is relatively omnidirectional, with most energy directed forward and to the sides (Schevill and Watkins 1966). A fundamental tone between 250-1,500 Hz and harmonics ranging to about 10 kHz are present in this component. Most of the energy in the high-frequency component is beamed directly ahead of the animal. This component has a fundamental tone between 5-12 kHz and harmonics ranging to over 100 kHz (Bain and Dahlheim 1994).

Newborn calves produce calls similar to adults, but have a more limited repertoire (Dahlheim and Awbrey 1982). As young animals mature, complete call repertoires are most likely developed through vocal imitation and learning from association with closely related animals rather than being genetically inherited (Bowles et al. 1988, Bain 1989, Ford 1989, 1991, Yurk et al. 2002). Regional differences in call structure and vocalization patterns have been recorded from the North Pacific, North Atlantic, and Antarctica (Jehl et al. 1980, Thomas et al. 1981, Awbrey et al. 1982).

Killer whales produce three categories of sounds: echolocation clicks, tonal whistles, and pulsed calls (Ford 1989). Clicks are brief pulses of ultrasonic sound given singly or more often in series known as click trains. They are used primarily for navigation and discriminating prey and other objects in the surrounding environment, but are also commonly heard during social interactions and may have a communicative function (Barrett-Lennard et al. 1996). Barrett-Lennard et al. (1996) suggested that killer whales share information obtained from echolocation, but further clarification of this possible function is needed (Baird 2000). Individual clicks are highly variable in structure, lasting from 0.1 to 25 milliseconds and containing a narrow to broad range of frequencies that usually range from 4-18 kHz, but extend up to 50-85 kHz (Diercks et al. 1973, Awbrey et al. 1982, Ford 1989, Barrett-Lennard et al. 1996). Most click trains last 2-8 seconds and have repetition rates of 2-50 clicks per second, but some exceed 10 seconds or hold as many as 300 clicks per second (Jehl et al. 1980, Ford 1989, Barrett-Lennard et al. 1996, Ford et al. 2000). Slower click trains are probably used for navigation and orientation on more distant objects, such as other whales and features on the seafloor, whereas rapid click rates appear to be used for investigating objects within 10 m (Ford 1989).

Most whistles are tonal sounds of a fundamental frequency with the addition of several harmonics (Thomsen et al. 2001). Whistles have an average dominant frequency of 8.3 kHz (range = 3-18.5 kHz), an average bandwidth of 4.5 kHz (range = 0.5-10.2 kHz), and an average of 5.0 frequency modulations per whistle (range = 0-71 frequency modulations) (Thomsen et al. 2001). Mean duration is 1.8 seconds (range = 0.06-18.3 seconds). Whistles are the primary type of vocalization produced during close-range social interactions (Thomsen et al. 2002). They are given infrequently during foraging and most types of traveling.

Pulsed calls are the most common type of vocalization in killer whales and resemble squeaks, screams, and squawks to the human ear.

Most calls are highly stereotyped and distinctive in structure, being characterized by rapid changes in tone and pulse repetition rate, with some reaching up to 4,000 or more pulses per second (Jehl et al. 1980, Ford 1989). Duration is usually less than two seconds. Call frequencies often fall between 1-6 kHz, but may reach more than 30 kHz. Three categories of pulsed calls are distinguishable: discrete, variable, and aberrant (Ford 1989). Discrete calls have received considerable study and are especially noteworthy because they are used repetitively and have stable group-specific structural traits. Discrete calls are the predominant sound type during foraging and traveling, and are used for maintaining acoustic contact with other group members, especially those out of visual range (Ford 1989, Ford et al. 2000). Variable and aberrant calls are given more frequently after animals join together and interact socially. Representative sound spectrograms of discrete calls are presented in Ford (1989, 1991).

The vocal repertoires of killer whale pods are comprised of specific numbers and types of repetitive discrete calls, which together are known as a dialect (Ford 1991). Dialects are complex and stable over time, and are unique to single pods. Individuals likely learn their dialect through contact with their mother and other pod members (Ford 1989, 1991). Dialects are probably an important means of maintaining group identity and cohesiveness. Similarity in dialects likely reflects the degree of relatedness between pods, with variation building through time as pods grow and split (Ford 1989, 1991, Bigg et al. 1990). Researchers have thus far been unable to determine whether specific calls have particular meanings or are associated with certain activities. Deecke et al. (2000) reported that some calls undergo gradual modification in structure over time, probably due to cultural drift, maturational effects, or some combination thereof.

Dialects of resident killer whale pods contain seven to 17 (mean = 11) distinctive call types (Ford 1991). Transient dialects are much different, having only four to six discrete calls, none of which are shared with residents (Ford and Ellis 1999). All members of the west coast transient community possess the same basic dialect, as would be expected due to this population's fluid social system, although some minor regional variation in call types is evident (Ford and Ellis 1999). Preliminary research indicates that offshore killer whales have group-specific dialects unlike those of residents and transients (Ford et al. 2000).

Hearing and Other Senses

As with other delphinids, killer whales hear sounds through the lower jaw and other portions of the head, which transmit the sound signals to receptor cells in the middle and inner ears (Møhl et al. 1999, Au 2002). Killer whale hearing is the most sensitive of any odontocete tested thus far. Hearing ability extends from 1 to at least 120 kHz, but is most sensitive in the range of 18-42 kHz (Szymanski et al. 1999). The most sensitive frequency is 20 kHz, which corresponds with the approximate peak energy of the species' echolocation clicks (Szymanski et al. 1999). This frequency is lower than in many other toothed whales. Hearing sensitivity declines below 4 kHz and above 60 kHz. Killer whale vision is also considered well developed (White et al. 1971).

Diving and Swimming Behavior

Respiration rates of killer whales vary with activity level (Ford 1989). Dive cycles in transient whales average 5-8 minutes in total length and usually consist of three to five short dives lasting 10-35 seconds each followed by a longer dive averaging 4-7 minutes (range = 1-17 minutes) (Erickson 1978, Morton 1990, Ford and Ellis 1999). Surface blows following each of the short dives in a cycle last 3-4 seconds. Dive cycles in resident whales follow a similar pattern, but have long dives that are usually much briefer than in transients, averaging about 3 minutes and rarely exceeding 5 minutes (Morton 1990, Ford and Ellis 1999).

Southern residents spend 95% of their time underwater, nearly all of which is between the surface and a depth of 30 m (Baird et al. 1998, 2003, Baird 2000). Preliminary information

indicates that up to two dives per hour are made below 30 m. However, these represent fewer than 1% of all dives and occupy less than 2.5% of an animal's total dive time. In the vicinity of the San Juan Islands, maximum dive depths averaged 141 m per animal among seven individuals tagged with time-depth recorders in July 2002 (Baird et al. 2003). One juvenile whale twice exceeded 228 m, causing Baird et al. (2003) to speculate that members of this population are probably capable of diving to 350 m, which is the approximate maximum bottom depth of the core inland waters of their summer range. The deepest dive reported for a killer whale is 260 m by a trained animal (Bowers and Henderson 1972).

Killer whales normally swim at speeds of 5-10 km per hour, but can attain maximum speeds of 40 km per hour (Lang 1966, Erickson 1978, Kruse 1991, Williams et al. 2002a). Diving animals reach a velocity of 22 km per hour, or 6 m per second, during descents and ascents. Bursts in speed during dives commonly occur when prey are chased (Baird et al. 2003).

Diet and Foraging

As top-level predators, killer whales feed on a variety of marine organisms ranging from fish to squid to other marine mammal species. Some populations have specialized diets throughout the year and employ specific foraging strategies that reflect the behavior of their prey. Such dietary specialization has probably evolved in regions where abundant prey resources occur year-round (Ford 2002). Cooperative hunting, food sharing, and innovative learning are other notable foraging traits in killer whales (Smith et al. 1981, Lopez and Lopez 1985, Felleman et al. 1991, Hoelzel 1991, Jefferson et al. 1991, Hoelzel 1993, Similä and Ugarte 1993, Baird and Dill 1995, Guinet et al. 2000, Pitman et al. 2003). Cooperative hunting presumably increases hunting efficiency and prey capture success of group members and may also enhance group bonds. Additionally, group living facilitates knowledge of specialized hunting skills and productive foraging areas to be passed traditionally from generation to generation (Lopez and Lopez 1985, Guinet 1991, Guinet and Bouvier 1995, Ford et al. 1998). Some foraging styles require extensive practice and learning (e.g., Guinet 1991).

Dietary information was formerly derived primarily through examination of stomach contents from stranded whales or those killed during commercial whaling operations, but in recent years, direct observations of feeding behavior have added much new data on the species' food habits. Killer whales are the only cetacean to routinely prey on marine mammals, with attacks documented on more than 35 mammal species, including species as large as blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), and sperm whales (*Physeter macrocephalus*) (Tomilin 1957, Tarpy 1979, Hoyt 1990, Jefferson et al. 1991, Dahlheim and Heyning 1999, Pitman et al. 2001). Pinnipeds and cetaceans are major prey items for some populations (Tomilin 1957, Rice 1968, Hoelzel 1991, Jefferson et al. 1991, Baird and Dill 1996, Ford et al. 1998, Dahlheim and Heyning 1999). Because killer whales probably represent the most important predators of many marine mammals, their predation has presumably been a major evolutionary influence on the life history of these prey species (Jefferson et al. 1991, Corkeron and Conner 1999, Pitman et al. 2001, Deecke et al. 2002). Fish (including tuna, rays, and sharks) and squid are other major foods, with penguins, other seabirds, and sea turtles also taken (Tomilin 1957, Nishiwaki and Handa 1958, Caldwell and Caldwell 1969, Condy et al. 1978, Ivashin 1981, Hoyt 1990, Fertl et al. 1996, Similä et al. 1996, Ford et al. 1998, Dahlheim and Heyning 1999, Ford and Ellis 1999, Visser 1999b, Aguiar dos Santos and Haimovici 2001, Ainley 2002, Visser and Bonoccorso 2003). Killer whales also may steal fish from longlining vessels (Dahlheim 1988, Yano and Dahlheim 1995a, 1995b, Secchi and Vaske 1998, Visser 2000a), scavenge the discarded bycatch of fisheries operations (Sergeant and Fisher 1957, Dahlheim and Heyning 1999), and feed on harpooned whales under tow by whaling ships (Scammon 1874, Heptner et al. 1976, Hoyt 1990). There are no verified records of killer whales killing humans.

Residents. Fish are the major dietary component of resident killer whales in the northeastern Pacific, with 22 species of fish and one species of squid (*Gonatopsis borealis*) known to be eaten (Ford et al. 1998, 2000, Saulitis et al. 2000). Observations from this region indicate that salmon are clearly preferred as prey. Existing dietary data for southern and northern resident killer whales should be considered preliminary. Most information originates from a single study (Ford et al. 1998) in British Columbia, including southeastern Vancouver Island, that focused primarily on northern residents, relied on several field techniques susceptible to bias (e.g., surface observations and scale sampling), and reported on a relatively small sample of observations. With these limitations in mind, salmon were found to represent 96% of the prey during the spring, summer, and fall. Chinook salmon (*Oncorhynchus tshawytscha*) were selected over other species, comprising 65% of the salmonids taken. This preference occurred despite the much lower numerical abundance of chinook in the study area in comparison to other salmonids and is probably related to the species' large size, high fat and energy content (see Salmon Body Composition), and year-round occurrence in the area. Other salmonids eaten in smaller amounts included pink (*O. gorbuscha*, 17% of the diet), coho (*O. kisutch*, 6%), chum (*O. keta*, 6%), sockeye (*O. nerka*, 4%), and steelhead (*O. mykiss*, 2%) salmon (Ford et al. 1998). These data may underestimate the extent of feeding on bottom fish (Baird 2000). Species such as rockfish (*Sebastes* spp.), Pacific halibut (*Hippoglossus stenolepis*), a number of smaller flatfish, lingcod (*Ophiodon elongatus*), and greenling (*Hexagrammos* spp.) are likely consumed on a regular basis (Ford et al. 1998). Pacific herring (*Clupea pallasi*) also contribute to the diet. The conclusion that the southern residents feed largely on salmon is supported by the toxicology analyses of Krahn et al. (2002), who determined that the ratios of DDT (and its metabolites) to various PCB compounds in the whales correspond with those of Puget Sound salmon rather than those of other fish species. Resident whales have been seen to harass porpoises and harbor seals, but never kill and eat them (Ford et al. 1998). Little is known about the winter and early spring foods of residents or whether individual pods have specific dietary preferences. Future research on the food habits of both resident populations may find meaningful deviations from the pattern described above.

Resident whales spend about 50-67% of their time foraging (Heimlich-Boran 1988, Ford 1989, Morton 1990, Felleman et al. 1991). Groups of animals often disperse over several square kilometers while searching for salmon, with members moving at roughly the same speed (range of 3-10 km/hr, mean = 6 km/hr) and direction (Ford 1989, 2002, Ford et al. 1998). Foraging episodes usually cover areas of 3-10 km^2 and last 2-3 hours, but may extend up to 7 hours. Individual salmon are pursued, captured, and eaten by single animals or small subgroups, usually a mother and her young offspring (Jacobsen 1986, Osborne 1986, Felleman et al. 1991, Ford 1989, Ford et al. 1998). Foraging whales commonly make two or three brief shallow dives, followed by a longer dive of 1-3 minutes (Ford et al. 2000). Several whales may occasionally work together to corral fish near the shore, but coordinated encirclement of prey has not been observed in Washington or British Columbia (Ford 1989, Ford et al. 1998). The large sizes of resident pods may benefit members by improving the success rate of locating scattered salmon (Heimlich-Boran 1988, Bigg et al. 1990, Hoelzel 1993). Prey are detected through a combination of echolocation and passive listening (Barrett-Lennard et al. 1996), whereas vision and echolocation are probably used during prey capture. Foraging animals produce rapid series of evenly spaced echolocation clicks, but whistles and pulsed calls are also emitted during this activity (Ford 1989). Most foraging is believed to occur during the day (Baird et al. 1998). There is some evidence that adult resident males forage differently than females and immatures, possibly because the larger size of males makes them less maneuverable in shallow waters (Baird 2000). Adult males have been noted to hunt in deeper waters than females and spend more time foraging on the edges of pods (Ford et al. 1998). Females and subadults occasionally attempt to capture salmon hiding in rock crevices near shore, a behavior not seen in adult males.

Piscivorous killer whales in Norway use tail lobbing, porpoising, blasts of air bubbles, and flashing of their white undersides to herd herring into tight schools near the surface (Similä and Ugarte 1993, Nøttestad and Similä 2001). The whales then stun the fish for eating by hitting the edges of the school with their tail flukes. In New Zealand, bubble releases are sometimes used to dislodge rays from the ocean floor (Visser 1999b).

Transients. The diet of transient killer whales contrasts greatly from that of residents and is focused almost entirely on marine mammals. Harbor seals are clearly the most important prey item in Washington and British Columbia. One study of transient diets reported that harbor seals were pursued in 94% of 138 feeding observations on marine mammals around southern Vancouver Island (Baird and Dill 1996). Other species attacked included harbor porpoises (2%), Dall's porpoises (1%), unidentified sea lions (1%), and northern elephant seals (1%). In a second broader study covering British Columbia, Washington, and Alaska, harbor seals were killed or attacked in 53% of nearly 200 feeding events (Ford et al. 1998). Other regular prey species included Steller's sea lions (*Eumetopias jubatus*, 13%), Dall's porpoises (*Phocenoides dalli*, 12%), harbor porpoises (11%), and California sea lions (*Zalophus californianus*, 5%). Attacks were also noted on Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), gray whales (*Eschrichtius robustus*), northern minke whales (*Balaenoptera acutorostrata*), and northern river otters (*Lontra canadensis*). Capture success rates were highest when directed at harbor porpoises (100%, n = 16) and harbor seals (90%, n = 80), but were successful 50% or less of the time for other species. Seven species of seabirds were harassed and sometimes killed, but were seldom eaten. Fish were never observed to be hunted or consumed. As an example of the diversity of prey consumed by individual whales, Ford and Ellis (1999) described the stomach contents of three known or probable transients found dead on Vancouver Island. One animal contained the remains of several harbor seals, a northern elephant seal (*Mirounga angustirostris*), a white-winged scoter (*Melanitta fusca*), and a squid, although the squid may have originated from the stomach of the elephant seal. A second whale held nearly 400 harbor seal claws in its stomach, representing at least 20 seals eaten over an unknown time period, plus portions of two harbor porpoises and a sea lion. The remains of harbor seals, a gray whale, and a cormorant (*Phalacrocorax* sp.) were present in the stomach of the third individual. Additional information on predation on Steller's sea lions is provided by Heise et al. (2003). Larger cetaceans, including humpback whales (*Megaptera novaeangliae*), are seldom pursued in Washington and British Columbia (Jefferson et al. 1991, Ford 2002), but may have been hunted much more frequently in the past before overharvesting greatly reduced their populations (Springer et al. 2003). Terrestrial mammals, such as black-tailed deer (*Odocoileus hemionus*) and moose (*Alces alces*), are also preyed on in rare instances when caught while swimming between islands (Pike and MacAskie 1969, Dahlheim and Heyning 1999, Ford and Ellis 1999).

In Alaska, transients prey about equally on Dall's porpoises and harbor seals (Saulitis et al. 2000). Although highly controversial, a recent theory proposes that predation by mammal-eating killer whales, possibly transients, may have been responsible for a series of precipitous population declines in harbor seals, northern fur seals (*Callorhinus ursinus*), Steller's sea lions, and sea otters (*Enhydra lutris*) in southwestern Alaska between the 1960s and 1990s (Estes et al. 1998, Hatfield et al. 1998, Doroff et al. 2003, Springer et al. 2003). Such predation may have resulted after heavy commercial whaling decimated baleen and sperm whale numbers in the North Pacific after World War II, perhaps causing at least some killer whales to shift to other prey species (Springer et al. 2003). A recent increase in predation on belugas (*Delphinapterus leucas*) by probable transients in Cook Inlet, Alaska, may be due to similar reasons (Shelden et al. 2003).

Transients usually forage in smaller groups than residents. When hunting harbor seals, mean group size numbers three or four whales (Baird and Dill 1996, Ford et al. 1998, Saulitis et al. 2000). Individuals in groups of this size have

significantly higher energy intake rates compared to animals in smaller or larger groups, probably due to increased rates of prey encounter and capture and reduced rates of detection by prey (Baird and Dill 1996). Slightly larger groups have been recorded as prey size increases, averaging 5.0 animals when porpoises or dolphins are the target species and 5.4 animals for sea lions (Ford et al. 1998). Apparent cooperative hunting by two groups is occasionally observed, with all members of both groups sharing the prey (Baird 2000). This type of foraging association occurs most often when dangerous or difficult to capture prey are sought, but has also been noted among animals hunting seals.

Transients are stealthy hunters and often rely on surprise to capture unsuspecting prey. Unlike resident whales, they are much quieter while foraging, producing greater numbers of isolated clicks and far fewer and briefer click trains of lower intensity (Morton 1990, Felleman et al. 1991, Barrett-Lennard et al. 1996, Ford and Ellis 1999). This probably allows the whales to avoid acoustical detection by their wary mammalian prey. Experiments have shown that harbor seals recognize the calls of transients and respond by taking defensive action (Deecke et al. 2002). Transients may instead rely heavily on passive listening to detect the sounds of swimming prey (Barrett-Lennard et al. 1996). Vision may also be useful (Baird 2000). Vocalizations are given freely only in the process of killing or eating prey.

Transients spend 60-90% of daylight hours foraging and commonly hunt in both nearshore and open-water habitats (Heimlich-Boran 1988, Morton 1990, Baird and Dill 1995, Ford and Ellis 1999). When hunting for harbor seals close to shore, animals swim near one another and surface and dive in synchrony. During open-water foraging, the whales are more dispersed and usually swim abreast in a rough line and constant direction. Dall's and harbor porpoises, as well as other species, are commonly hunted in this manner. During both types of foraging, long dives of 7-10 minutes are separated by a series of three or four shallow dives, each lasting less than a minute. This pattern can continue for hours, broken only by the pursuit of prey (Ford and Ellis 1999). Transients of all ages and both sexes participate in marine mammal attacks (Jefferson et al. 1991) and prey sharing occurs as part of most successful events (Baird and Dill 1995, Baird 2000). Harbor seals may be seized with the mouth, struck from below with the top of the head or snout, or hit several times with the tail to immobilize an animal before it is eaten (Scheffer and Slipp 1944, Ford and Ellis 1999). Seal attacks and eating of the carcass typically last from a few minutes to about half an hour (Baird and Dill 1995, 1996, Ford and Ellis 1999). Pursuit and capture of larger prey sometimes requires considerably longer periods of up to several hours, but Baird and Dill (1995) found no statistical relationship between prey size and handling time. Sea lions are usually butted with the whales' heads and slapped repeatedly with the tail flukes until the animal is sufficiently weakened to be taken underwater and drowned. However, attacks on sea lions fail in about half of all instances, with the animal escaping or the pursuit abandoned (Ford and Ellis 1999). When hunting porpoises, whales may single out an individual and take turns chasing it until it tires, then ram it or jump on it to finish the kill (Ford et al. 1998). Dall's porpoises are swift enough to evade capture in more than half of all chases. Pacific white-sided dolphins are sometimes captured by direct pursuit (Dahlheim and Towell 1994) or driven in large schools into confined bays, where individuals are trapped against the shore and killed (Ford and Ellis 1999).

Although attacks on large whales are rarely witnessed in the northeastern Pacific, the hunting tactics used probably resemble those recorded elsewhere in the world. Techniques vary but often involve vigorous coordinated attacks in which the larger whales are repeatedly rushed and bitten on the flippers, flukes, underside, flanks, lower back, and head, and gradually immobilized through blood loss (Scammon 1874, Tomilin 1957, Morejohn 1968, Rice and Wolman 1971, Tarpy 1979, Whitehead and Glass 1985, Arnbom et al. 1987, Silber et al. 1990, Goley and Straley 1994, George and Suydam 1998, Pitman et al. 2001). This strategy may reduce the likelihood of injuries among the attacking killer whales (Pitman et al.

2001). In some cases, biting of the tail region may also be avoided for the same reason (Silber et al. 1990). Forcible holding underwater, body ramming, and leaping on the backs of larger whales may also be performed to induce internal injuries or drowning (Villiers 1925, Hancock 1965, Baldridge 1972, Hall 1986, Silber et al. 1990, Jefferson et al. 1991, Goley and Straley 1994). Only females and juveniles participate in some attacks, while males assist in others (Hancock 1965, Tarpy 1979, Whitehead and Glass 1985, Finley 1990, Silber et al. 1990, Jefferson et al. 1991, Pitman et al. 2001). Killer whales typically consume relatively small amounts of large cetacean carcasses before abandoning them, although this may partially result from the negative buoyancy of carcasses, which causes them to rapidly sink beyond reach (Hancock 1965, Martinez and Klinghammer 1970, Baldridge 1972, Silber et al. 1990, Guinet et al. 2000). Many accounts indicate that killer whales may preferentially feed on the tongues and lips of larger whales (Scammon 1874, Villiers 1925, Jefferson et al. 1991, George and Suydam 1998). This behavior is probably explained by the high fat content and large size (up to several metric tons) of large whale tongues (Heptner et al. 1976). Migrating gray whales with calves appear to be a favorite target, especially off California (Morejohn 1968, Jefferson et al. 1991, Goley and Straley 1994, Ford et al. 1998), with 18% of all animals (n = 316) bearing teeth marks from killer whales (Rice and Wolman 1971). According to an account by Andrews (1914), scars of this type were once present on the fins and flukes of "almost every [gray] whale." In the western North Atlantic, 33% of all humpback whales possess tooth rakes from killer whales (Katona et al. 1980). These observations indicate that many pursuits are not lethal, with such scarring perhaps resulting from killer whales testing the vulnerability of potential prey. Pitman et al. (2001) presented an especially vivid account from California of a loose aggregation of up to 35 killer whales attacking nine sperm whales aligned in a defensive rosette formation. The killer whales used a "wound and withdraw" strategy, with brief charging attacks made by four to 12 animals at a time over at least a five-hour period until two of the sperm whales eventually became isolated from the group. At least one sperm whale was killed during the attack and several others were likely mortally wounded.

Intentional stranding is a frequent hunting tactic employed by killer whales in Argentina and some islands in the southern Indian Ocean for the purpose of capturing pinnipeds in the surf zone of beaches (Lopez and Lopez 1985, Hoelzel 1991, Guinet 1991). This method has been observed only once among transients in the northeastern Pacific (Baird and Dill 1995). Scheffer and Slipp (1948) documented a novel instance of seal hunting in Washington in which a group of killer whales intentionally rammed a log boom to knock a number of hauled-out seals into the water. Killer whales are also known to deliberately strike or tilt ice floes for the purpose of spilling seals and penguins into the water (Villiers 1925, Fraser 1949, Tomilin 1957, Pitman and Ensor 2003). Smith et al. (1981) and Pitman and Ensor (2003) described pods of killer whales swimming in unison to create waves that tipped ice floes, pitching hauled-out seals into the water.

Offshores. Little is known about the diets of offshore killer whales. They are suspected to feed primarily on fish and squid, based on their frequent use of echolocation and large group sizes (Ford et al. 2000, Heise et al. 2003).

Food requirements. Captive killer whales consume about 3.6-4% of their body weight daily (Sergeant 1969, Kastelein et al. 2000). Food intake in captive animals gradually increases from birth until about 20 years of age (Kastelein et al. 2003). For example, a captive female ate about 22 kg of fish per day at one year of age, 45 kg per day at 10 years of age, and about 56 kg per day at 18 years of age (Kastelein and Vaughan 1989, Kastelein et al. 2000). Food consumption has also been noted to increase among captive females late in pregnancy or lactating (Kastelein et al. 2003). Due to their greater activity levels, wild killer whales presumably have greater food demands than captive individuals (Kastelein et al. 2003). The energy requirements of killer whales are about 85,000 kcal per day for juveniles, 100,000 kcal per

day for immatures, 160,000 kcal per day for adult females, and 200,000 kcal per day for adult males (Kriete 1995). Baird and Dill (1996) reported a mean energy intake of 62 kcal/kg/day among wild individuals. Based on these values and an average size value for five salmon species combined, Osborne (1999) estimated that adults must consume about 28-34 adult salmon daily and that younger whales (<13 years of age) need 15-17 salmon daily to maintain their energy requirements. Extrapolation of this estimate indicates that the southern resident population eats about 750,000-800,000 adult salmon annually (Osborne 1999).

Other Behavior

In addition to foraging, killer whales spend significant amounts of time traveling, resting, and socializing (Baird and Dill 1995, Ford 2002). Limited evidence from radio-tracking and acoustic monitoring indicates that most behavior patterns are similar during day and night (Erickson 1978, Osborne 1986).

Traveling. Whales swimming in a constant direction at a slow, moderate, or rapid pace without feeding are considered to be traveling (Jacobsen 1986, Baird and Dill 1995, Ford 1989, Ford and Ellis 1999, Ford et al. 2000). This behavior is usually seen among animals moving between locations, such as desirable feeding areas. Speeds of about 10 km/hr (range = 4-20 km/hr) are maintained, which is usually significantly faster than during foraging. Traveling whales often line up abreast in fairly tight formations and commonly surface and dive in synchrony, with individuals occasionally jumping entirely out of the water. Animals are usually quite vocal while traveling, but may at times be silent. Traveling occupies about 15-31% of the total activity budget of transients, but only about 4-8% of the time of northern residents (Ford 1989, Morton 1990, Baird and Dill 1995). Southern residents reportedly spend more time traveling than northern residents (Heimlich-Boran 1988), perhaps because of longer distances between their feeding sites (Ford et al. 2000).

Resting. This behavior often follows periods of foraging. In resident groups, whales usually gather together abreast in a tight formation, with animals diving and surfacing in subdued unison (Jacobsen 1986, Osborne 1986, Baird and Dill 1995, Ford 1989, Ford et al. 2000). Individuals often arrange themselves according to matriline or pod, and offspring usually swim near or touching their mother. Forward motion is slow (mean = 3 km/hr) or stops entirely, and vocalizations often cease. Dives and surfacings become characteristically regular, with a series of several short shallow surfacings lasting 2-3 minutes followed by a longer dive of 2-5 minutes. Resting whales are usually silent, except for occasional vocalizations. Resting periods average about 2 hours, but may last from 30 minutes to 7 hours (Osborne 1986, Ford 1989). Transient whales display similar resting behavior, but spend only 2-7% of their time resting, compared to 10-21% for residents (Heimlich-Boran 1988, Ford 1989, Morton 1990, Baird and Dill 1995, Ford and Ellis 1999).

Socializing. Killer whales perform numerous displays and interactions that are categorized as socializing behaviors (Ford 1989, Ford and Ellis 1999, Ford et al. 2000). During socializing, all members of a pod may participate or just a few individuals may do so while others rest quietly at the surface or feed. Socializing behaviors are seen most frequently among juveniles and may represent a type of play (Jacobsen 1986, Osborne 1986, Ford 1989, Rose 1992). They include chasing, splashing at the surface, spyhopping, breaching, fin slapping, tail lobbing, head standing, rolling over other animals, and playing with objects such as kelp or jellyfish. Descriptions and photographs of these behaviors are presented in Jacobsen (1986) and Osborne (1986). Wave riding occasionally takes place in the wakes of vessels and on naturally generated waves (Jacobsen 1986, Ford et al. 2000), as does bow-riding in the bow waves of boats (Dahlheim 1980). Socializing behavior may involve considerable physical contact among animals. All-male subgroups commonly engage in sexual behavior, such as penile erections and nosing of genital areas (Haenel 1986, Osborne 1986, Jacobsen 1986, Ford

1989, Rose 1992). Play and sexual behavior may help adolescents, especially males, gain courtship skills (Rose 1992). Whales become especially vocal while socializing and emit a wide range of whistles and calls heard infrequently during other activities, such as foraging and resting (Ford 1989, Thomsen et al. 2002). During the summer, residents spend about 12-15% of their time engaged in socializing (Heimlich-Boran 1988, Ford 1989). Transient whales socialize less than residents and do so most often after successful hunts (Heimlich-Boran 1988, Baird and Dill 1995, Ford and Ellis 1999).

Several differences in socializing behavior have been documented among killer whale communities in the northeastern Pacific (Ford 1989, Ford et al. 2000). Beach rubbing, which involves whales visiting particular beaches to rub their bodies on smooth pebbles in shallow water (Jacobsen 1986), is common among northern residents, but has never been observed in southern residents or transients (Ford 1989, Ford et al. 2000). Southern residents perform aerial displays more frequently and with greater vigor than northern residents. They also engage more often in a greeting ceremony that occurs when pods meet after being separated for a day or more (Osborne 1986, Ford et al. 2000). During this interaction, pods approach each other in two tight lines, stop for 10-30 seconds at the surface when 10-50 m apart, then merge underwater with considerable excitement, vocalizing, and physical contact.

Courtship and mating. Courtship and mating behavior remains poorly documented among wild killer whales. Jacobsen (1986) reported some preliminary observations. In captive situations, males may court a particular estrous female for 5-10 days and have been noted to copulate with anestrous and pregnant females as well (Duffield et al. 1995). It is unknown whether similar behavior occurs in the wild.

Parturition. Stacey and Baird (1997) described various behaviors associated with the birth of a resident killer whale, which took place within a pod of 11-13 animals. An individual presumed to be the mother was seen making several rapid rotations at the surface during a 30-second period. Birth then apparently took place underwater and was immediately followed by three pod members lifting the newborn entirely out of the water for several seconds. Unusual swimming behavior by the group, bouts of high-speed swimming and percussive activity, and additional lifting of the calf was seen during the next two hours. Bouts of nursing normally last about 5 seconds in the wild and take place both underwater and at the surface (Jacobsen 1986). In contrast, newborn calves in captivity have been observed to nurse an average of 32-34 times per day totaling 3.2-3.6 hours per day, with suckling bouts lasting a mean of 6.8-7.2 min (Kastelein et al. 2003).

Alloparental care. Non-reproductive female and male killer whales sometimes tend and give parental-like care to young animals that are not their own, a behavior known as alloparental care (Haenel 1986, Waite 1988). Older immatures are commonly the recipients of such care after their mothers give birth to new calves. Adult males have occasionally been seen to "baby-sit" groups of calves and juveniles (Haenel 1986, Jacobsen 1986).

Care-giving behavior. This behavior is directed at stricken individuals by other members of a group (Caldwell and Caldwell 1966, Tomilin 1957). Ford et al. (2000) published an account of one such incident involving a pod comprised of a male, female, and two calves in the Strait of Georgia in 1973. One of the calves was struck and severely injured by the propeller of a ferryboat. Captain D. Manuel of the ship described the event as follows:

> It was a very sad scene to see. The cow and the bull cradled the injured calf between them to prevent it from turning upside-down. Occasionally the bull would lose its position and the calf would roll over on its side. When this occurred the slashes caused by our propeller were quite visible. The bull, when this happened, would make a tight circle, submerge, and rise slowly beside the calf, righting it, and then proceed with the diving

and resurfacing. While this was going on the other calf stayed right behind the injured one.

Aggressive behavior. Aggressive interactions between killer whales are rarely witnessed. Bisther (2002) reported occasional agonistic encounters involving the displacement of one killer whale pod by another at herring feeding sites in Norway, but such behavior has never been seen in the northeastern Pacific. The parallel scarring patterns seen on the backs and dorsal fins of some killer whales are suggestive of intraspecific aggression (Scheffer 1968, Greenwood et al. 1974, Jacobsen 1986, Visser 1998). However, some of these markings possibly result instead from social interactions or the defensive responses of pinnipeds (Jacobsen 1986, Ford 1989, Dahlheim and Heyning 1999).

Interactions between transients and residents. Transient killer whales are not known to interact socially with resident whales. Baird (2000) summarized evidence that members of the two communities in fact deliberately avoid one another when traveling on intersecting routes. In 11 observations where a transient and resident group approached within several kilometers of each other, the transients responded by changing their travel direction eight times, while the residents did so in three instances. However, on eight other occasions when non-intersecting courses were involved, the groups passed within several kilometers of one another without altering their paths. Reasons for avoidance are speculative, but may be related to the usually smaller group sizes of transients or to perceived threats to vulnerable calves. Residents perhaps show less evasive behavior simply because they are unaware of the presence of transient groups, which usually forage quietly. A single aggressive interaction between the two forms has been witnessed and involved about 13 residents chasing and attacking three transients (Ford and Ellis 1999).

Movements and Dispersal

Killer whale movements are generally thought to be far ranging, but detailed information on year-round travel patterns is lacking for virtually all populations. Radio and satellite telemetry has not been used to track long-term movements because of the absence of benign techniques for restraining target animals and attaching transmitters. Researchers have instead relied on non-intrusive observational methods, especially photo-documentation and focal group following, to study population distribution and movements of individual whales. However, these techniques suffer from seasonal biases in viewing effort due to limitations in the distances that observers can travel, inclement weather, and seasonal availability of daylight (Baird 2001, Hooker and Baird 2001). A lack of photo-identification work in offshore areas is especially problematic for many monitored populations (Baird 2000). As a result, significant time gaps with few or no location data exist for all populations, including the well-studied southern and northern resident communities of Washington and British Columbia. This situation is probably responsible for some of the misperceptions regarding the migratory status of some populations.

Many killer whale populations appear to inhabit relatively well-defined seasonal home ranges linked to locations of favored prey, especially during periods of high prey abundance or vulnerability, such as fish spawning and seal pupping seasons (Jefferson et al. 1991, Reeves et al. 2002). Killer whale occurrence has been tied to migrating rorqua1 whales off eastern Canada (Sergeant and Fisher 1957), minke whale presence in southern oceans (Mikhalev et al. 1981, Pitman and Ensor 2003), sea lion and elephant seal pupping sites in the southwest Indian Ocean, Argentina, and North Pacific (Tomilin 1957, Norris and Prescott 1961, Condy et al. 1978, Lopez and Lopez 1985, Hoelzel 1991, Baird and Dill 1995), migrating herring (*Clupea harengus*) and other fish in the northeastern Atlantic (Jonsgård and Lyshoel 1970, Bloch and Lockyer 1988, Christensen 1988, Evans 1988, Similä et al. 1996), and returning salmon in the northeastern Pacific (Balcomb et al. 1980, Heimlich-Boran 1986a, 1988, Felleman et al. 1991, Nichol and Shackleton 1996). Defended territories have not been observed around these or other food

resources (Dahlheim and Heyning 1999, Baird 2000).

Clear evidence of annual north-south migrations has not been documented for any killer whale population (Baird 2001), although such movements are suspected among some animals visiting the Antarctic (Mikhalev et al. 1981, Visser 1999a, Pitman and Ensor 2003). Regional movement patterns are probably best known for populations in the northeastern Pacific and may be illustrative of movements occurring in other parts of the world. Both resident and transient killer whales have been recorded year-round in Washington, British Columbia, and Alaska (Heimlich-Boran 1988, Baird and Dill 1995, Olson 1998, Baird 2001). Many pods inhabit relatively small core areas for periods of a few weeks or months, but travel extensively at other times. Known ranges of some individual whales or pods extend from central California to the Queen Charlotte Islands off northern British Columbia (a distance of about 2,200 km) for southern residents, from southern Vancouver Island to southeastern Alaska (about 1,200 km) for northern residents, from southeastern Alaska to Kodiak Island (about 1,450 km) for southern Alaska residents, and from central California to southeastern Alaska (about 2,660 km) for transients (Goley and Straley 1994; Dahlheim and Heyning 1999; Krahn et al. 2002; J. K. B. Ford and G. M. Ellis, unpubl. data). Both types of whales can swim up to 160 km per day (Erickson 1978, Baird 2000), allowing rapid movements between areas. For example, members of K and L pods once traveled a straight-line distance of about 940 km from the northern Queen Charlotte Islands to Victoria, Vancouver Island, in seven days (J. K. B. Ford and G. M. Ellis, unpubl. data). Other resident pods in Alaska have journeyed 740 km in six days and made a 1,900-km round trip during a 53-day period (Matkin et al. 1997). Transients are believed to travel greater distances and have larger ranges than residents (Goley and Straley 1994, Dahlheim and Heyning 1999, Baird 2000), as reflected by maximum home range estimates of 140,000 km^2 for transients and 90,000 km^2 for residents suggested by Baird (2000). A linear distance of 2,660 km covered by three transients from Glacier Bay, Alaska, to Monterey Bay, California (Goley and Straley 1994), is the longest recorded movement by the species.

Scheffer and Slipp (1948) provided the earliest information on the areas occupied by killer whales in Washington, but were unaware at the time of the distinction between resident, transient, and offshore whales. Their report suggests that many currently preferred areas of use were also inhabited in the 1940s. They further noted that the whales moved into the waters surrounding Camano Island during salmon and herring runs, and entered Willapa Bay on rare occasions. Palo (1972) remarked that killer whales visited southern Puget Sound most often during the fall and winter. He added that the whales' preferred access route to this portion of the sound was through Colvos Passage along the west side of Vashon Island and that McNeil Island and Carr Inlet were visited annually. These sites were productive areas for salmon and herring in the 1960s (Palo 1972).

Southern residents. Photo-identification work and tracking by boats have provided considerable information on the ranges and movements of southern resident killer whales since the early 1970s. Ranges are best known from late spring to early autumn, when survey effort is greatest. During this period, all three southern resident pods are regularly present in the Georgia Basin (defined as the Georgia Strait, San Juan Islands, and Strait of Juan de Fuca) (Heimlich-Boran 1988, Felleman et al. 1991, Olson 1998, Osborne 1999), with K and L pods typically arriving in May or June and spending most of their time there until departing in October or November (Figure 5). However, during this season, both pods make frequent trips lasting a few days to the outer coasts of Washington and southern Vancouver Island (Ford et al. 2000). J pod differs considerably in its movements during this time and is present only intermittently in Georgia Basin and Puget Sound.

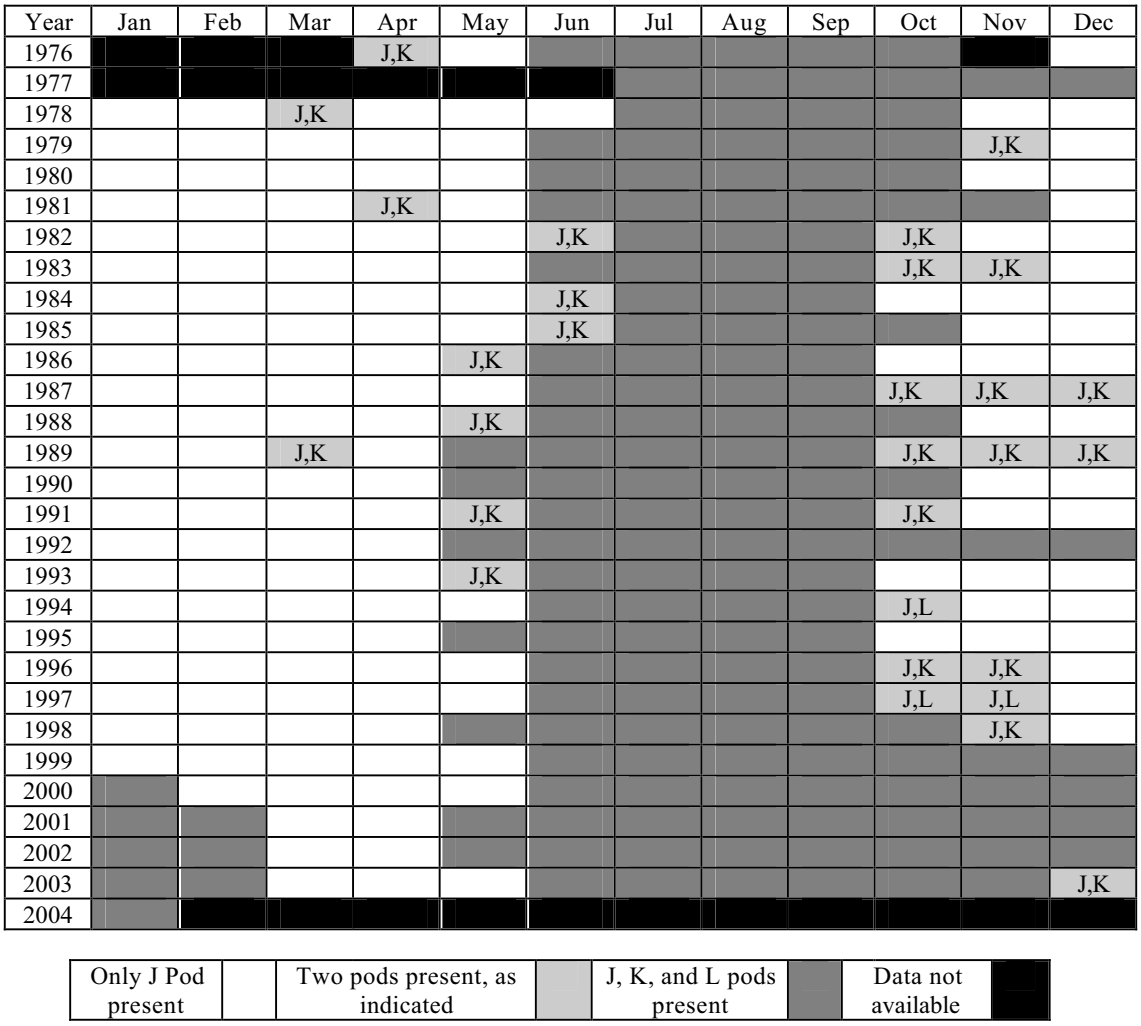

Figure 5. Monthly occurrence of the three southern resident killer whale pods (J, K, and L) in the inland waters of Washington and British Columbia, 1976-2004. This geographic area is defined as the region east of Race Rocks at the southern end of Vancouver Island and Port Angeles on the Olympic Peninsula. Data come from a historical sighting archive held at The Whale Museum (2003).

While in inland waters during warmer months, all of the pods concentrate their activity in Haro Strait, Boundary Passage, the southern Gulf Islands, the eastern end of the Strait of Juan de Fuca, and several localities in the southern Georgia Strait (Figure 6; Heimlich-Boran 1988, Felleman et al. 1991, Olson 1998, Ford et al. 2000). Less time is generally spent elsewhere, including other sections of the Georgia Strait, Strait of Juan de Fuca, and San Juan Islands, Admiralty Inlet west of Whidbey Island, and Puget Sound. Individual pods are fairly similar in their preferred areas of use (Olson 1998), although J pod is the only group to venture regularly inside the San Juan Islands (K. C. Balcomb, unpubl. data). Pods commonly seek out and forage in areas that salmon most commonly occur, especially those associated with migrating salmon (Heimlich-Boran 1986a, 1988, Nichol and Shackleton 1996). Notable locations of particularly high use include Haro Strait and Boundary Passage, the southern tip of Vancouver

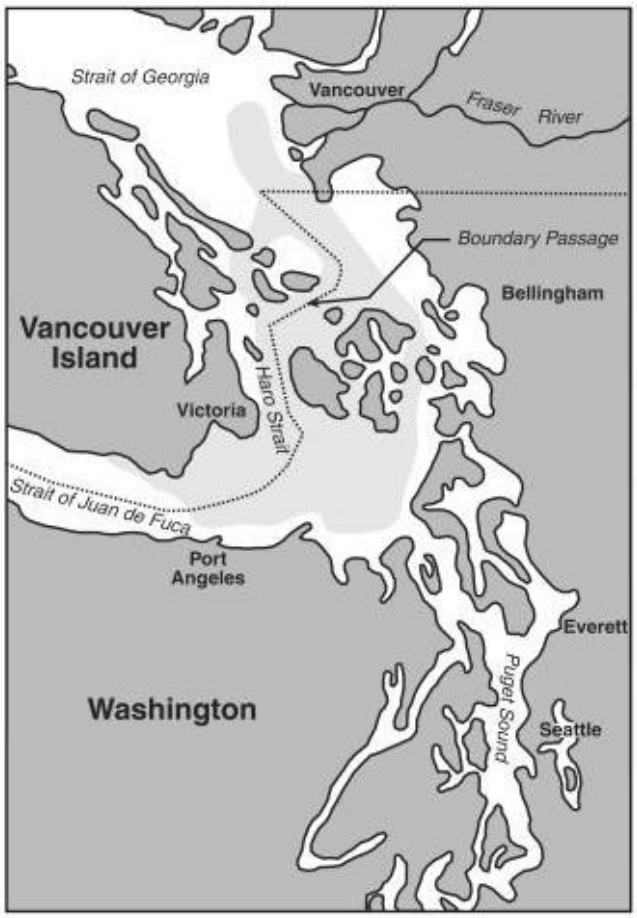

Figure 6. Primary area of occurrence (light shading) of southern resident killer whales (J, K, and L pods) when present in the Georgia Basin and Puget Sound. Adapted from Heimlich-Boran (1988), Olson (1998), and Ford et al. (2000), with additional information from D. K. Ellifrit (pers. comm.).

Island, Swanson Channel off North Pender Island, and the mouth of the Fraser River delta, which is visited by all three pods in September and October (Figure 6; Felleman et al. 1991; Ford et al. 2000; K. C. Balcomb, unpubl. data). These sites are major corridors of migrating salmon.

During early autumn, southern resident pods, especially J pod, expand their routine movements into Puget Sound to likely take advantage of chum and chinook salmon runs (Osborne 1999). In recent years, this has become the only time of year that K and L pods regularly occur in the sound. Movements into seldom-visited bodies of water may occur at this time. One noteworthy example of such use occurred in Dyes Inlet near Bremerton in 1997. Nineteen members of L pod entered the 19-km^2-sized inlet, which is surrounded by urban and residential development, on 21 October during a strong run of chum salmon into Chico Creek and remained there until 19 November, when salmon abundance finally tapered off. The reasons for this long length of residence are unclear, but may have been related to food abundance (K. C. Balcomb, pers. comm.; D. K. Ellifrit, pers. comm.) or a reluctance by the whales to depart the inlet because of the physical presence of a bridge crossing the Port Washington Narrows and associated road noise (J. Smith, pers. comm.).

Late spring to early fall movements of southern residents in the Georgia Basin have remained fairly consistent since the early 1970s, with strong site fidelity shown to the region as a whole. However, some areas of use have changed over time. Visitation of Puget Sound has diminished since the mid-1980s, whereas Swanson Channel receives noticeably more use now than in the past (K. C. Balcomb, unpubl. data). Long-term differences in the availability of salmon at particular sites are one possible explanation for these alterations. Another cause may be the deaths of certain older experienced whales that were knowledgeable of good feeding sites, but who are no longer present to direct the movements of their pods to these sites or along favored travel routes.

During the late fall, winter, and early spring, the ranges and movements of the southern residents are much more poorly known. J pod continues to occur intermittently in the Georgia Basin and Puget Sound throughout this time (Figure 5), but its location during apparent absences is unknown (Osborne 1999). Prior to 1999, K and L pods followed a general pattern in which they spent progressively smaller amounts of time in inland waters during October and November and departed them entirely by December of most years (Figure 5; Osborne 1999). Sightings of both groups passing through the Strait of Juan de Fuca in late fall suggested that activity shifted to the outer coasts of Vancouver Island and Washington, although it was unclear if the whales spent a substantial portion of their time in this area or were simply in transit to other locations (Krahn et al. 2002). Since the winter of 1999-2000, K and L pods have extended their use of inland waters until January or February each year (Figure 5). The causes behind this change are unknown, but may relate to greater food availability resulting from, for example, increased abundance of chum or hatchery chinook, or to reduced food resources along the outer coast (R. W. Osborne, pers. comm.). Thus, since 1999, both pods are completely absent from the Georgia Basin and Puget Sound only from about early or mid-February to May or June.

Areas of activity by K and L pods are virtually unknown during their absences. A small number of verified sightings of both pods have occurred along the outer coast from January to April 1976-2003, including one off Vancouver Island and two each off Washington, Oregon, and Monterey Bay, California (Black et al. 2001, Krahn et al. 2002, Monterey Bay Whale Watch 2003). There have also been several sightings of resident whales that were most likely these pods near the Columbia River mouth during April in recent years (K. C. Balcomb, unpubl. data). Almost all of these records have occurred since 1996, but this is perhaps more likely due to increased viewing effort along the coast rather than a recent change in the pattern of occurrence for this time of year. The southern residents were formerly thought to range southward along the coast only to about Grays Harbor (Bigg et al. 1990) or the mouth of the Columbia River (Ford et al. 2000). However, recent sightings of members of K and L pods in Oregon (L pod at Depoe Bay in April 1999 and Yaquina Bay in March 2000) and California (17 members of L pod and four members of K pod at Monterey Bay on 29 January 2000, and L71 and probably other L pod members at the same site on 13 March 2003) have considerably extended the southern limit of their known range (Black et al. 2001, Krahn et al. 2002, Monterey Bay Whale Watch 2003). Both Monterey sightings coincided with large runs of chinook salmon, with feeding on chinook witnessed in 2000 (K. C. Balcomb, unpubl. data).

Available information suggests that K and L pods travel to northern Vancouver Island and occasionally to the Queen Charlotte Islands during May and June. K pod has been sighted once near Tofino on the west-central coast of Vancouver Island in early May (Krahn et al. 2002). K and L pods sometimes make their initial spring entry into the Strait of Georgia via Johnstone Strait (Ford et al. 2000), implying regular movement around the northern end of Vancouver Island. On 28 May 2003, members of both pods were identified for the first time in the Queen Charlottes, when a group of 30 or more whales was viewed off Langara Island (54°15'N, 133°02'W) at the north end of the island group about 46 km south of

Alaska (J. K. B. Ford and G. M. Ellis, unpubl. data). Other records from this region include the carcass of an unidentified southern resident (recognized through genetic testing) that was found on the west coast of the Queen Charlottes in June 1995 (Ford et al. 2000) and another dead individual found off Cape Scott at the northwestern tip of Vancouver Island in May 1996 (J. K. B. Ford, pers. comm.).

Due to extensive changes in many salmon stocks along the North American west coast during the past 150 years, it is possible that the current movement patterns of the southern residents are somewhat different from those of several centuries ago. In particular, the whales may have once been regularly attracted to the Columbia River mouth, where immense numbers of salmon previously returned during their spawning migrations (K. C. Balcomb, pers. comm.).

Northern residents. This community is distributed from the Olympic Peninsula to southeastern Alaska. Some pods are seen most predictably from June to October in western Johnstone Strait and Queen Charlotte Strait, where occurrence is closely associated with salmon congregating to enter spawning rivers (Morton 1990, Nichol and Shackleton 1996, Ford et al. 2000). However, the majority of animals occur farther north during this season in passages and inlets of the central and northern British Columbia coast, in Hecate Strait and Queen Charlotte Islands, and reaching Frederick Sound in southeastern Alaska (Nichol and Shackleton 1996, Dahlheim 1997, Ford et al. 2000). Less information is available on the winter distribution of northern residents. Use of Johnstone Strait and neighboring areas declines markedly during this time (Morton 1990, Nichol and Shackleton 1996).

Most northern resident pods travel extensively within the community's overall range, as illustrated by the members of G12 pod, who moved between the Queen Charlotte Islands and Strait of Juan de Fuca from July to October 1999 (Ford et al. 2000). Some pods regularly enter the northern Georgia Strait, but movements into the southern Georgia Strait and Strait of Juan de Fuca are quite unusual. In the summer of 2000, about 50 northern residents from C, D, H, I1, I2, and I18 pods spent several days at the southern end of Vancouver Island (Barrett-Lennard and Ellis 2001; D. K. Ellifrit, unpubl. data). The animals ventured into Washington's waters when they transited the San Juan Islands and visited the eastern end of the Strait of Juan de Fuca (D. K. Ellifrit, unpubl. data). There have also been several verified and probable sightings of the northern residents in the transboundary region off the west coasts of the Olympic Peninsula and Vancouver Island between June and October from 1996 and 2001 (J. Calambokidis, unpubl. data). Neither of the two verified sightings (involving members of C, D, G1, G12, and I11 pods) actually occurred within Washington's waters, although one was just 10 km north of the border. However, both probable records were located inside Washington, with the southernmost made about 70 km west of Ocean Shores. Northern and southern residents normally maintain separate geographic ranges during much of the year. The two communities occur sympatrically at times during the spring, when some southern residents visit northern Vancouver Island and the Queen Charlotte Islands (Osborne 1999, Ford et al. 2000).

Transients. The west coast transient community is distributed from the Los Angeles area of southern California to the Icy Strait and Glacier Bay region of southeastern Alaska (Ford and Ellis 1999; Baird 2001; Barrett-Lennard and Ellis 2001; N. A. Black, pers. comm.). Transients are considered farther ranging and more unpredictable in their daily movements than residents, but detailed information on seasonal movements is not available because of the relatively few identifications made of nearly all individuals. In contrast to the southern residents, transient patterns of occurrence show less seasonal change in abundance and distribution, which probably relates to the year-round presence of their marine mammal prey (Ford and Ellis 1999). Most sightings in Washington and around Vancouver Island occur in the summer and early fall, when viewing effort is greatest and harbor seals pup. Smaller numbers of encounters continue through

the rest of the year (Morton 1990, Baird and Dill 1995, Olson 1998, Ford and Ellis 1999).

Photo-identification records indicate some transients are regularly seen in particular sub-regions, suggesting that they inhabit preferred seasonal or annual home ranges, whereas other individuals travel across much of the community's geographic range (Ford and Ellis 1999). For example, some transient groups are encountered almost entirely within moderately sized areas of British Columbia and southeastern Alaska, with few sightings made elsewhere (Ford and Ellis 1999). The extensive movements of the T49 group illustrate a sharp contrast with this pattern. From June 1995 to April 1996, this group traveled a minimum of 5,000 km from Glacier Bay, Alaska, to the Queen Charlotte Islands and southeastern Vancouver Island, then returned to Sitka, Alaska, and finally reappeared along the west-central coast of Vancouver Island. Regional-scale movements are evident in many of the transients identified in British Columbia or Washington, with slightly more than half (111 of 206 animals) having been sighted in southeastern Alaska (Dahlheim et al. 1997, Ford and Ellis 1999). About 13% of the individuals photographed off California have been observed in Washington, British Columbia, or Alaska (Black et al. 1997). Documented examples of movements of this scale include a trip of 1,445 km between Alaska and the San Juan Islands made by two adults and a three-year-old calf during a 3.5-month span (Leatherwood et al. 1984) and another of 2,660 km between Alaska and California made by three whales (T132, T134, and T135) over a nearly three-year period (Goley and Straley 1994). Observations that some groups enter the Georgia Basin primarily in August and September during the harbor seal pupping season, while others were present throughout the year (Baird and Dill 1995), are consistent with this travel scenario. These records further suggest that some transients move in relation to specific seasonal food sources. Long gaps of many years between sighting records indicates that some transients make long-term shifts in ranges (Ford and Ellis 1999).

Transient sightings in the Georgia Basin and Puget Sound are concentrated around southeastern Vancouver Island, the San Juan Islands, and the southern edge of the Gulf Islands, with reduced activity occurring in Puget Sound and elsewhere in the Strait of Juan de Fuca and Georgia Strait (Olson 1998; K. C. Balcomb, unpubl. data). Erickson (1978) described the movements of two radio-tagged individuals (T13, T14) in this region (also see Ford and Ellis 1999). The pair was originally captured at Budd Inlet near Olympia in March 1976 and held in captivity for seven weeks during which time they were transported to Kanaka Bay on San Juan Island. Upon release, the whales traveled extensively in and around the vicinity of the San Juan and Gulf Islands during a 10-day tracking period in April and May. Daily travel distances averaged 126 km (range = 107-138 km). The animals continued to be seen off and on in the same area through September, but were also viewed at Sequim Bay and the Fraser River mouth.

One of the most interesting observations of transient occurrence in recent years in Washington was an assemblage of 11 animals from the T13, T73, and T123 groups that inhabited Hood Canal from 2 January to 3 March 2003. Hood Canal is a natural fjord-like inlet that opens into northwestern Puget Sound and measures 108 km in length by 2-4 km in width. The whales repeatedly traveled up and down much of the canal during their stay, but concentrated their activity along a stretch of important harbor seal haulouts between the Skokomish River mouth and Quilcene Bay (S. Jeffries, unpubl. data). The whales' long period of residence was likely related to the canal's large population of seals, estimated at about 1,000-1,200 animals (S. Jeffries, unpubl. data). Predation by the whales is believed to have significantly reduced seal abundance during the two-month period (J. M. London, unpubl. data). Although there was some speculation that the Hood Canal bridge at the northern end of the canal may have impeded the whales' departure, this was doubtful given the abundance of prey in the area (K. C. Balcomb, pers. comm.; S. Jeffries, pers. comm.). Prior records of killer whales in the canal are rare and involved only a few transients that remained

for short periods (J. M. London, unpubl. data). Another noteworthy facet of the visit was that it involved an adult male (T14) captured at Budd Inlet in 1976 and fitted with a radio transmitter (Erickson 1978, Ford and Ellis 1999).

Offshores. The offshore community is distributed from the area north of Los Angeles in southern California to the eastern Aleutian Islands (Ford and Ellis 1999; M. E. Dahlheim, unpubl. data; N. A. Black, pers. comm.), but movements are poorly understood due to the small numbers of verified observations. At least 20 of the approximately 200 individuals photographed in Washington, British Columbia, and Alaska have been sighted in California (Black et al. 1997; M. E. Dahlheim, unpubl. data), indicating that extensive movements may be normal in some animals. Offshore killer whales primarily inhabit offshore locations, but are also seen in nearshore coastal waters and occasionally in inland waters. Sightings were made several times in the Georgia Basin up through the mid-1990s (e.g., Walters et al. 1992), but have become annual occurrences in the past few years (K. C. Balcomb, unpubl. data). Two separate groups of offshores were recorded in late April and early May 2003, with one group of about 40 animals seen near the San Juan Islands (D. K. Ellifrit, unpubl. data; K. C. Balcomb, unpubl. data) and the other off Johnstone Strait (J. K. B. Ford, unpubl. data). Similar types of sightings are known from the inland waters of southeastern Alaska (Dahlheim et al. 1997; M. E. Dahlheim, unpubl. data) and northwestern British Columbia (J. K. B. Ford, unpubl. data).

Dispersal among residents and transients. Social dispersal, in which an animal more-or-less permanently departs its natal group to live alone or in association with unrelated individuals while remaining part of the breeding population, is believed to occur commonly in transient killer whales, with juveniles and adults of both sexes participating (Ford and Ellis 1999, Baird 2000, Baird and Whitehead 2000). In doing so, dispersing transients continue to occupy their large natal geographic ranges throughout their lives.

By comparison, resident killer whales occur in highly stable social groups and dispersal away from natal groups has never been recorded (Bigg et al. 1990, Baird 2000, Ford et al. 2000). Several instances of young solitary resident killer whales found away from their natal pods have been recorded in Washington and British Columbia (Balcomb 2002), but likely represent orphaned or poorly nurtured individuals that became separated from their pods rather than true examples of dispersal. Animals such as these are believed to usually die rather than reestablish permanent bonds with other resident whales. A73, a one-year old northern resident female, appeared in Puget Sound in late 2001 or early 2002 far from its expected range and eventually took up residence near Seattle. It remained there until being captured in June 2002, after which it was translocated back to its natal pod in Johnstone Strait. This individual suffered from declining health prior to its capture and would have likely died without human intervention. L98, a southern resident male, was discovered in Nootka Sound on western Vancouver Island in July 2001 after apparently becoming separated from L pod at about 2 years of age and has since resided alone there. It has remained healthy throughout this time, but is more threatened by interactions with humans.

Habitat Use

Killer whales frequent a variety of marine habitats with adequate prey resources and do not appear to be constrained by water depth, temperature, or salinity (Baird 2000). Although the species occurs widely as a pelagic inhabitant of open ocean, many populations spend large amounts of time in shallower coastal and inland marine waters, foraging even in inter-tidal areas in just a few meters of water. Killer whales tolerate a range of water temperatures, occurring from warm tropical seas to polar regions with ice floes and near-freezing waters. Brackish waters and rivers are also occasionally entered (Scheffer and Slipp 1948, Tomilin 1957). Individual knowledge of productive feeding areas and other special habitats (e.g., beach rubbing sites in the Johnstone Strait) is probably an important determinant in the selection

of locations visited and is likely a learned tradition passed from one generation to the next (Ford et al. 1998).

Residents. Resident and transient killer whales exhibit somewhat different patterns of habitat use while in protected inland waters, where most observations are made (Heimlich-Boran 1988, Morton 1990, Felleman et al. 1991, Baird and Dill 1995). Residents generally spend more time in deeper water and only occasionally enter water less than 5 m deep (Heimlich-Boran 1988, Baird 2000, 2001). Distribution is strongly associated with areas of greater salmon abundance (Heimlich-Boran 1986a, 1988, Felleman et al. 1991, Nichol and Shackleton 1996), but research to date has yielded conflicting information on preferred foraging habitats. Several studies have reported that southern residents feed heavily in areas characterized by high-relief underwater topography, such as subsurface canyons, seamounts, ridges, and steep slopes (Heimlich-Boran 1988, Felleman et al. 1991). Such features may limit fish movements, thereby resulting in greater prey availability, and be used by the whales as underwater barriers to assist in herding fish (Heimlich-Boran 1988). The primary prey at greater depths may be chinook salmon, which swim at depths averaging 25-80 m and extending down to 300-400 m (Candy and Quinn 1999). Other salmonids mostly inhabit the upper 30 m of the water column (Quinn and terHart 1987, Quinn et al. 1989, Ruggerone et al. 1990).

In contrast, Hoelzel (1993) reported no correlation between the feeding behavior of residents and bottom topography, and found that most foraging took place over deep open water (41% of sightings), shallow slopes (32%), and deep slopes (19%). Ford et al. (1998) described residents as frequently foraging within 50-100 m of shore and using steep nearshore topography to corral fish. Both of these studies, plus those of Baird et al. (1998, 2003), have reported that most feeding and diving activity occurs in the upper 30 m of the water column, where most salmon are distributed (Stasko et al. 1976, Quinn and terHart 1987, Quinn et al. 1989, Ruggerone et al. 1990, Olson and Quinn 1993, Nichol and Shackleton 1996, Candy and Quinn 1999, Baird 2000). Additionally, chinook salmon occupy nearshore habitats more so than other salmonids (Stasko et al. 1976, Quinn et al. 1989). Reasons for the discrepancies between studies are unclear, but may result from interpod variation and differences in study methodology (Nichol and Shackleton 1996, Baird 2001).

Other behaviors, such as resting and socializing, are performed in open water with varied bathymetry (Heimlich-Boran 1988, Felleman et al. 1991). Habitat use patterns are poorly understood for southern resident pods visiting the outer coast.

Transients. Transient whales also occupy a wide range of water depths, including deep areas exceeding 300 m. However, transients show greater variability in habitat use than residents, with some groups spending most of their time foraging in shallow waters close to shore and others hunting almost entirely in open water (Heimlich-Boran 1988, Felleman et al. 1991, Baird and Dill 1995). Small bays and narrow passages are entered, in contrast to residents (Morton 1990). Groups using nearshore habitats often feed primarily on seals and sea lions, and concentrate their activity in shallow waters near haul-out sites. While foraging, these whales often closely follow the shoreline, entering small bays and narrow passages, circling small islets and rocks, and exploring inter-tidal areas at high tides. Transients that spend more time in open water probably prey more frequently on porpoises as well as pinnipeds.

Use of rivers. Killer whales in the northeastern Pacific occasionally enter the lower reaches of rivers while foraging. Several older instances of whales ascending up to 180 km up the Columbia River are known (Scheffer and Slipp 1948). These included a 4.1-m female that was present at Portland for several weeks in October 1931 before being killed (Shepherd 1932), two whales estimated at 6 m in length seen near Swan Island and Vancouver in October 1940, and a third possible record of a single individual near the St. John's district of Portland in March 1942. It is not known whether these animals were resident or transient whales. Use of the lower Fraser River by

resident killer whales has been reported (Baird 2001, pers. comm.) and may have involved animals in pursuit of salmon. Transients have been recently recorded in several rivers or river mouths in Oregon, including the Nehalem, Yaquina, and Coos Rivers (K. C. Balcomb, unpubl. data).

Reproduction and Growth

Much of the information on reproduction and growth in killer whales comes either from observations of animals held in captivity or from long-term photo-identification studies of the resident whale communities in Washington and British Columbia (Olesiuk et al. 1990a). Variation in these parameters can be expected in other populations (Ford 2002).

Mating system. Killer whales are polygamous (Dahlheim and Heyning 1999). Recent paternity analyses using microsatellite DNA indicate that males nearly always mate with females outside of their own pods, thereby reducing the risks of inbreeding (Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001). Differences in dialects very likely assist animals in determining the degree of relatedness among prospective mating partners, with female choice probably being the major factor in the mating success of males (Ford 1989, 1991, Ford et al. 2000, Yurk et al. 2002).

Mating season and estrous activity. Most mating in the North Pacific is believed to occur from May to October (Nishiwaki 1972, Olesiuk et al. 1990a, Matkin et al. 1997). However, small numbers of conceptions apparently happen year-round, as evidenced by births of calves in all months. Data on breeding dates are ambiguous for other parts of the world (Olesiuk et al. 1990a), but can be estimated from information on parturition period.

Captive adult females experience periods of multiple estrous cycling interspersed with intervals of non-cycling (Walker et al. 1988, Robeck et al. 1993, Duffield et al. 1995). The lengths of these periods are highly variable, both within an individual and a population. Estrous cycle lengths average 42-44 days (range = 18-91 days), with an average of four cycles (range = 1-12 cycles) during polyestrous. Non-cycling intervals last an average of 7-8 months (range = 3-16 months) (Robeck et al. 1993, Duffield et al. 1995). Profiles of reproductive hormones during ovarian cycles and pregnancy in captive females are presented by Walker et al. (1988) and Duffield et al. (1995).

Calving interval. Estimates of calving intervals, defined as the length of time between the births of surviving calves, average about 5.3 years (range = 2-14 years) in the northeastern Pacific (Olesiuk et al. 1990a, Matkin and Saulitis 1994) and range from 3.0-8.3 years in the North Atlantic and Antarctica (Christensen 1984, Perrin and Reilly 1984). Females in captivity have produced calves 2.7-4.8 years apart (Duffield et al. 1995), while Hoyt (1990) cited a captive female that gave birth 19 months after the death of her previous newborn calf. Jacobsen (1986) observed copulation in a wild female that had given birth to and then lost a calf the previous year. Several authors have suggested that birth rates in some populations may be density dependent (Fowler 1984, Kasuya and Marsh 1984, Brault and Caswell 1993, Dahlheim and Heyning 1999). However, no study has confirmed this trait among resident whales in Washington and British Columbia (Olesiuk et al. 1990a, Taylor and Plater 2001). Olesiuk et al. (1990a) reported mean annual pregnancy rates of 52.8% for females of reproductive age and 35.4% for all mature females in Washington and British Columbia. These rates are substantially higher than those published for Norway (26.3%) and the southern hemisphere (19.2%) by Dahlheim and Heyning (1999), which were calculated by different procedures.

Gestation period. Gestation periods in captive killer whales average about 17 months (mean ± SD = 517 ± 20 days, range = 468-539 days) (Asper et al. 1988, Walker et al. 1988, Duffield et al. 1995). Fetal development and morphology have been described in several studies (Turner 1872, Guldberg and Nansen 1894, Benirschke and Cornell 1987).

Calving season and characteristics of newborns. Among resident killer whales in the northeastern

Pacific, births occur largely from October to March, but may take place during any month (Olesiuk et al. 1990a). Parturition dates are thought to be mainly from November to February in the North Atlantic (Jonsgård and Lyshoel 1970, Evans 1988) and from January to April in the Antarctic, which corresponds there to the late austral summer (Anderson 1982). Only single calves are born. Several previous reports of twins (e.g., Olesiuk et al. 1990a, Baird 2000) have proven erroneous (Ford and Ellis 1999). Nearly all calves are born tail-first (Duffield et al. 1995). Newborns measure 2.2-2.7 m long and weigh about 200 kg (Nishiwaki and Handa 1958, Olesiuk et al. 1990a, Clark et al. 2000, Ford 2002). Heyning (1988) reported a mean length of 2.36 m in northeastern Pacific calves. Sex ratios at birth are probably 1:1 (Dahlheim and Heyning 1999). Taylor and Plater (2001) reported a sex ratio of 57% males among 65 southern resident calves born after 1973, but this did not differ significantly from a 1:1 sex ratio.

Development and growth of young. Calves remain close to their mothers during their first year of life, often swimming slightly behind and to the side of the mother's dorsal fin. Weaning age remains unknown, but nursing probably ends at 1-2 years of age (Haenel 1986, Kastelein et al. 2003). Tooth eruption begins from several to 11 weeks of age, which is about the time that calves begin taking solid food from their mothers (Haenel 1986, Asper et al. 1988, Heyning 1988, Kastelein et al. 2003). Asper et al. (1988) reported a captive calf that consumed 6.6 kg of fish per day at 5 months of age and 22 kg per day of fish and squid at 15 months of age. Another captive animal increased its food consumption from about 22 kg per day at one year of age to about 45 kg at 10 years of age (Kastelein and Vaughan 1989). As young killer whales grow older, they spend increasing amounts of time with siblings and other pod members (Haenel 1986). Juveniles are especially active and curious. They regularly join subgroups of several other youngsters and participate in chasing, leaping, and high-speed porpoising. Young males of 2-6 years of age also engage in displays of sexual behavior. Among resident whales, maternal associations slowly weaken as juveniles reach adolescence (Haenel 1986), but typically continue well into adulthood.

Studies to date have yielded somewhat contradictory information on growth patterns of killer whales, which may partially reflect population differences and whether or not the animals were wild or captive. Christensen (1984) indicated that males and females displayed similar growth rates up to about 15 years of age, but Clark et al. (2000) found that males had lower growth rates than females during the ages of one to six. Several studies have reported linear growth rates during the first nine to 12 years for females and first 12 to 16 years in males, after which growth slows in both sexes (Bigg 1982, Duffield and Miller 1988). Annual growth rates for captive juveniles originating from the northeastern Pacific averaged 38 cm per year (range = 26-52 cm per year), but fell into two categories for animals from the North Atlantic, averaging 21 cm per year (range = 17-25 cm per year) in one group and 39 cm per year (range = 31-48 cm per year) in a second group (Duffield and Miller 1988). For youngsters one to six years of age, Clark et al. (2000) reported mean growth rates of 28 cm and 182 kg per year for males and 36 cm and 248 kg per year for females. Based on whaling data, Christensen (1984) suggested that male killer whales enter a period of sudden growth during adolescence. The validity of this finding has been questioned (Duffield and Miller 1988, Baird 2000), but measurements taken by Clark and Odell (1999) support Christensen's (1984) hypothesis. Both sexes continue to grow until physical maturity is reached at about 19-25 years of age (Olesiuk et al. 1990a, Christensen 1984, Kastelein et al. 2000). Bigg and Wolman (1975) calculated the relationship between body length and weight in both sexes of killer whale as being: weight = $0.000208\ \text{length}^{2.577}$ (weight in kg, length in cm). Kastelein et al. (2003) noted a similar growth pattern among captive animals.

Characteristics of reproductive adults. Females achieve sexual maturity at lengths of 4.6-5.4 m, depending on geographical region (Perrin and Reilly 1984). Wild females from the northeastern Pacific give birth to their first surviving calf

between the ages of 12 and 16 years (mean = 14.9 years), but when adjusted for the high mortality rate among newborns, the probable mean age at first birth of either a viable or non-viable calf is reduced to 13.1 years (Olesiuk et al. 1990a). This latter age corresponds to a probable mean age at first conception of 11.7 years. Pubescent females may ovulate several times before conceiving, thus average age at first ovulation is probably even younger (Olesiuk et al. 1990a). Duffield et al. (1995) reported similar ages for initial births among captive females from this region, but noted a captive-born female that gave birth when 8 years old. Somewhat younger ages of 7-14 years have been reported for North Atlantic females becoming sexually mature or bearing their first calf (Christensen 1984, Duffield et al. 1995, Kastelein et al. 2003). Females produce an average of 5.4 surviving calves during a reproductive life span lasting about 25 years (Olesiuk et al. 1990a). Breeding ends at about 40 years of age. Females then enter a post-reproductive period that continues until their death. This averages about 10 years in length, but extends more than 30 years in a few individuals. Males become sexually mature at body lengths ranging from 5.2-6.4 m, which corresponds to ages of 10 to 17.5 years (mean = about 15 years) (Christensen 1984, Perrin and Reilly 1984, Duffield and Miller 1988, Olesiuk et al. 1990a). Males are presumed to remain sexually active throughout their adult lives (see Olesiuk et al. 1990a).

Survival, Longevity, and Natural Mortality

Survival. Population demography in the species is best understood for the two resident communities of Washington and British Columbia. The detailed information presented by Olesiuk et al. (1990a) was gathered when both populations were generally expanding in size. However, Krahn et al.'s (2002) recent investigation of the southern resident population, which included data from the most recent decline, demonstrated that some of these parameters are no longer accurate (see *Status in Washington and Southern British Columbia: 1974-2003*). Mortality curves are U-shaped for both sexes, although the curve is narrower for males (Olesiuk et al. 1990a). Mortality is extremely high during the first six months of life, when 37-50% of all calves die (Bain 1990, Olesiuk et al. 1990a). Annual death rates for juveniles decline steadily thereafter, falling to 0.5% for both sexes from 10.5 to 14.5 years of age, and an estimated 77% of viable calves reach adulthood. Death rates remain low among females of reproductive age, averaging just 0-1.7% per year between 15.5 and 44.5 years (Olesiuk et al. 1990a). Mortality increases dramatically among older females, especially those beyond 65 years of age. After reaching sexual maturity, death rates for males increase throughout life, reaching 7.1% annually among individuals older than 30 years. Life history tables for the resident populations of Washington and British Columbia are presented in Olesiuk et al. (1990a).

Seasonal mortality rates among resident whales have not been analyzed, but are believed to be highest during the winter and early spring, based on the numbers of animals missing from pods returning to inland waters each spring (J. K. B. Ford, pers. comm.; K. C. Balcomb, pers. comm.).

Comparable data for transients are not available because of the difficulty in closely monitoring their population, but death rates are perhaps similar to those of residents (Ford and Ellis 1999). Killer whales held in captivity suffer considerably higher overall rates of mortality of 6.2-8.9% per year (DeMaster and Drevenak 1988, Duffield and Miller 1988, Small and DeMaster 1995).

Longevity. At birth, the average life expectancy of resident killer whales is about 29 years for females and 17 years for males (Olesiuk et al. 1990a). However, for animals that survive their first six months, mean life expectancy increases to about 50-60 years for females and 29 years for males. Life expectancy at sexual maturity (about 15 years of age in both sexes) averages about 63 years for females and 36 years for males. Maximum life span is estimated to be 80-90 years for females and 50-60 years for males (Olesiuk et al. 1990a). Reasons for the shorter longevity of males are unknown, but are probably linked to sexual selection (Baird 2000).

Natural mortality. Natural causes of death in killer whales remain largely unidentified, even in the well-investigated resident populations of Washington and British Columbia. Animals usually sink after dying, giving researchers little opportunity to conduct post-mortem examinations of carcasses. Thus, reasons for the high mortality rates among calves are not known (Baird 2000). Killer whales have no predators other than humans (Baird 2000, Ford 2002). Field observations and the lack of shark-induced scars, such as those seen on some dolphin species (Corkeron et al. 1987, Heithaus 2001), suggest that shark predation is insignificant even on young animals (Baird 2000). Visible signs of emaciation are rarely seen among resident and transient whales in Washington and British Columbia (K. C. Balcomb, pers. comm.; J. K. B. Ford, pers. comm.; R. W. Baird, pers. comm.), thus it is unknown whether these populations experience annual periods of food scarcity that might contribute to increased mortality.

Individual and mass strandings of killer whales are considered rare (Dahlheim and Heyning 1999) and usually end in the deaths of the animals. Strandings are sometimes caused when whales foraging in shallow waters become accidentally trapped by a receding tide, but other problems such as disease, parasitism, and intense human-generated sound may be involved in some cases (Perrin and Geraci 2002). Only about a dozen records of mass strandings existed worldwide through the mid-1980s, but four of these occurred in British Columbia during the 1940s (Pike and MacAskie 1969, Mitchell and Reeves 1988). These included 11 whales stranded near Masset in the Queen Charlotte Islands in January 1941 (Cameron 1941), "a number" of whales temporarily stranded at Cherry Point on Vancouver Island in September 1944 (Carl 1946), 20 whales stranded near Estevan Point on western Vancouver Island in June 1945 (Carl 1946), and five whales stranded in Von Donnop Lagoon on Cortez Island near Campbell River, Vancouver Island, in March 1949 (Pike and MacAskie 1969). Mass strandings have never been reported from Washington, but live strandings of one or two individuals occur on a rare basis. In recent years, these have included a 2.8-m female at Port Madison in August 1970, a 4.8-m female at Ocean City in March 1973, and two adult transients (one was rescued) at Dungeness Spit in January 2002.

Killer whales inhabiting high latitudes occasionally become entrapped by wind-blown or fast-forming ice. This can force animals to remain in small pools of open water for prolonged periods (Taylor 1957, Reeves et al. 2002) and probably results in some deaths (Mitchell and Reeves 1988).

Diseases. Causes of death have been reported for killer whales held in captivity, but may not be representative of mortality in the wild. Deaths of 32 captive individuals were attributed to pneumonia (25%), systemic mycosis (22%), other bacterial infections (16%), mediastinal abscesses (9%), and undiagnosed causes (28%) (Greenwood and Taylor 1985). Little is known about infectious diseases of wild killer whales or the threat that they pose to populations. Sixteen pathogens have been identified from captive and free-ranging animals, including nine types of bacteria, four viruses, and three fungi (Gaydos et al., in press). Three of these, marine *Brucella*, *Edwardsiella tarda*, and cetacean poxvirus, were detected in wild individuals. Marine *Brucella* and cetacean poxvirus have the potential to cause mortality in calves and marine *Brucella* may cause abortion (Miller et al. 1999, Van Bressem et al. 1999). Cetacean poxvirus also produces skin lesions, but probably does not cause many deaths in cetaceans (Van Bressem et al. 1999). Antibodies to *Brucella* spp. were detected in a female transient that stranded at Dungeness Spit in January 2002 (Gaydos et al., in press). In 2000, a male southern resident died from a severe infection caused by *E. tarda* (Ford et al. 2000). Gaydos et al. (in press) identified an additional 27 pathogens (12 fungi, 11 bacteria, and four viruses) from other species of toothed whales that are sympatric with the southern residents and considered these as potentially transmittable to killer whales. Several, including porpoise morbillivirus, dolphin morbillivirus, and herpesviruses, are highly virulent and have the capacity to cause large-scale disease outbreaks in some related species. Disease epidemics have never been reported in killer

whales in the northeastern Pacific (Gaydos et al., in press).

Killer whales are susceptible to other forms of disease, including Hodgkin's disease and severe atherosclerosis of the coronary arteries (Roberts et al. 1965, Yonezawa et al. 1989). Tumors and bone fusion have also been recorded (Tomilin 1957). Jaw abscesses and dental disease are common problems caused by heavy tooth wear down to the gum line, resulting in exposure and infection of the pulp cavity and surrounding tissue (Carl 1946, Tomilin 1957, Caldwell and Brown 1964). Noticeable tooth wear can occur even in some younger animals (Carl 1946). Captive animals commonly suffer from abscessed vestigial hair follicles on the rostrum, a condition that can eventually spread over the entire skin surface (Simpson and Gardner 1972).

A genetic disorder known as Chediak-Higashi syndrome was diagnosed in a young transient killer whale from southern Vancouver Island in the early 1970s (Haley 1973, Taylor and Farrell 1973, Hoyt 1990, Ford and Ellis 1999). The syndrome causes partial albinism, susceptibility to infections, and a reduction in life span. Occasional reports of albino killer whales in British Columbia and Washington prior to 1960 (Scheffer and Slipp 1948, Carl 1959), including another juvenile associated with the same transient pod (Ford and Ellis 1999), likely involved other individuals with this disorder (Matkin and Leatherwood 1986).

The collapsed dorsal fins commonly seen in captive killer whales (Hoyt 1992) do not result from a pathogenic condition, but are instead thought to most likely originate from an irreversible structural change in the fin's collagen over time (B. Hanson, pers. comm.). Possible explanations for this include (1) alterations in water balance caused by the stresses of captivity or dietary changes, (2) lowered blood pressure due to reduced activity patterns, or (3) overheating of the collagen brought on by greater exposure of the fin to the ambient air. Collapsed or collapsing dorsal fins are rare in most wild populations (Hoyt 1992, Ford et al. 1994, Visser 1998, Ford and Ellis 1999) and usually result from a serious injury to the fin, such as from being shot or colliding with a vessel. Matkin and Saulitis (1997) reported that the dorsal fins of two male resident whales in Alaska began to fold soon after their pod's exposure to oil during the *Exxon Valdez* spill in 1989 and were completely flattened within two years. Both animals were suspected to be in poor health and subsequently died.

Parasites. Relatively little information is available on the parasites of killer whales. Known endoparasites include *Fasciola skrjabini*, *Leucasiella subtilla*, and *Oschmarinella albamarina* (Trematoda), *Trigonocotyle spasskyi* and *Phyllobothrium* sp. (Cestoda), *Anasakis simplex* and *A. pacificus* (Nematoda), and *Bolbosoma physeteris* and *B. nipponicum* (Acanthocephala) (Dailey and Brownell 1972, Heptner et al. 1976, Heyning 1988, Gibson and Bray 1997). These are transmitted primarily through the ingestion of infected prey (Baird 2000). An estimated 5,000 unidentified nematodes were reported in the stomach of a resident whale from Washington (Scheffer and Slipp 1948). The forestomach of a calf estimated at 1-2 months of age in California contained numerous *Anasakis simplex* worms, indicating that infections can begin at an early age (Heyning 1988). Ectoparasites are infrequently found and include the whale lice *Cyamus orcini*, *C. antarcticensis*, and *Isocyamus delphinii* (Amphipoda) (Leung 1970, Berzin and Vlasova 1982, Wardle et al. 2000). Most external parasites are probably transmitted through body contact with other individuals, such as during social encounters and mother-young interactions (Baird 2000). No severe parasitic infestations have been reported in killer whales in the northeastern Pacific.

Several types of commensal organisms associate with killer whales. Barnacles (*Xenobalanus globicipitis* and *Cryptolepas rhachianecti*) growing on the rostrum and trailing edges of the flukes and dorsal fin are rare in most populations (Samaras 1989, Dahlheim and Heyning 1999), but are present on many Mexican killer whales (Guerrero-Ruiz 1997, Black et al. 1997). Remoras

rarely attach themselves to killer whales (Fertl and Landry 1999, Guerrero-Ruiz and Urbán 2000). Diatoms have also been found on the skin (Hart 1935, Nemoto et al. 1980).

Human-Related Sources of Mortality and Live-Captures

Aboriginal harvest. The extent that indigenous peoples hunted killer whales in the past is poorly documented. There is no tradition of hunting killer whales in the Canadian Arctic (Reeves and Mitchell 1988b) or along the Pacific coast (Olesiuk et al. 1990a). Hoyt (1990) stated that a general taboo against killing the species was widespread among coastal North American tribes, based on the fear that surviving whales would avenge the deaths of pod members. Nevertheless, the Makah in Washington are known to have occasionally caught killer whales and considered their meat and fat superior to that of baleen whales (Scammon 1874). The species was not hunted by the neighboring Quillayute (Scheffer and Slipp 1948). Carl (1946) reported that the Nootka on Vancouver Island ate the meat and oil from killer whales, but it was unclear whether these were obtained through active hunting or only from beached animals. Small-scale harvesting of killer whales continues in Greenland (Heide-Jørgensen 1988, MacLean et al. 2002), Indonesia (Ellis 2002), St. Vincent and the Grenadines in the Caribbean (International Whaling Commission 2003), and perhaps elsewhere (Reeves and Leatherwood 1994). This is generally accepted as a form of subsistence harvest even though native hunters have increasingly adopted modern weaponry and forms of transport and sold their products for cash.

Commercial exploitation. The first records of commercial hunting of killer whales date back to the 1700s in Japan (Ohsumi 1975). During the 19th and early 20th centuries, the global whaling industry harvested immense numbers of baleen and sperm whales, but largely ignored killer whales because of their limited amounts of recoverable oil, their smaller populations, and the difficulty that whalers had in capturing them (Scammon 1874, Scheffer and Slipp 1948, Budker 1958, Reeves and Mitchell 1988a). Killer whales were taken once in a while during lulls in the hunting of other species, mainly to keep whaling crews active or to help offset the financial loss of a voyage (Bockstoce 1986, Reeves and Mitchell 1988a). No killer whales were reported among the nearly 25,000 whales processed by coastal whaling stations in British Columbia from 1908-1967 (Gregr et al. 2000). Similarly, none were among the 2,698 whales handled at the Bay City whaling plant in Grays Harbor, Washington, during its 14 years of operation from 1911-1925 (Scheffer and Slipp 1948, Crowell 1983).

Tomilin (1957) reported that medium to large-sized killer whales produce 750-950 kg (4.4-5.6 barrels) of oil per animal. However, as pointed out by Reeves and Mitchell (1988a), this was the amount obtained from the processing of an entire carcass, as performed on Russian whaling ships in the 20th century. Whalers during the 19th century were capable of rendering only the blubber into oil, resulting in a more typical yield of two barrels per whale. Both amounts were far less than the average of 30-45 barrels of whale oil derived from sperm whales and most baleen whales in the 1800s (Bockstoce 1986).

From the 1920s to 1940s, small whaling fisheries were developed or became more sophisticated in several countries, primarily Norway, the Soviet Union, and Japan, resulting in greater hunting pressure on smaller whales, dolphins, and killer whales (Jonsgård and Lyshoel 1970, Mitchell 1975, Ohsumi 1975, Øien 1988). Available harvest statistics indicate that each of these countries killed an average of about 43-56 killer whales annually from the 1940s to 1981, with most animals taken from the North Atlantic (total = 2,435 whales), Antarctic and southern oceans (1,681 whales), Japanese coastal waters (1,534 whales), and Soviet far east (301 whales) (Ohsumi 1975, Øien 1988, Hoyt 1990). An exceptional harvest of 916 whales in the Antarctic by the Soviets during the 1979-1980 whaling season (Berzin and Vladimirov 1983) resulted in the International Whaling Commission (IWC) establishing a moratorium on the taking of killer whales by factory ships the following year

(Anonymous 1981). It should be noted that some of the official harvest data from this era are erroneous. Between the late 1940s and early 1970s, the Soviet Union over-reported the number of killer whales harvested (482 animals reported as taken versus 124 animals actually taken) to conceal massive illegal catches of more desirable baleen species (Brownell and Yablokov 2002). Japan also falsified (i.e., probably under-reported) catch statistics on a smaller scale for some species, which may have included killer whales. Furthermore, catch data would likely exclude any wounded animals that escaped and eventually died. Norway and Russia discontinued their harvests in the early 1980s and Japan did so in the early 1990s. The only killer whales reported as commercially taken in the northeastern Pacific from the 1940s to early 1980s were a single animal in British Columbia in 1955 (Pike and MacAskie 1969) and five whales in California between 1962 and 1967 (Carretta et al. 2002). Although the commercial harvests of this period likely reduced killer whale abundance in some regions of the world, they probably had no impact on most populations in the northeastern Pacific. The current numbers of killer whales hunted for profit are probably quite small (Reeves and Leatherwood 1994, Baird 2001), but documentation is lacking. Several countries belonging to the IWC, such as Japan, may not include killer whales in their harvest reports because they are considered "small cetaceans" outside the jurisdiction of the IWC (Baird 2001). A few animals may also be killed by non-IWC countries and go unreported.

Killer whales taken by small whale fisheries generated several products of minor economic importance. In Norway and Russia, the meat was used as animal feed, while the oil and skin had other uses (Tomilin 1957, Jonsgård and Lyshoel 1970). In Japan, the fresh meat was utilized for human consumption, whereas aged meat and viscera were used as fertilizer and bait (Nishiwaki and Handa 1958, Ohsumi 1975).

Mortality associated with killer whale depredation. As with other large and highly visible predators, killer whales historically generated a variety of negative emotions among people, ranging from general dislike to fear and outright hatred. Such feelings were most prevalent among fishermen, whalers, sealers, and sportsmen, and largely stemmed from perceived competition over prey resources, damage caused to fishing gear and captured baleen whales, and the belief that killer whales scared off other marine mammals that were potentially harvestable. As a result, killer whales were widely persecuted to varying extents. Shooting was probably the most popular method of responding to nuisance animals (Bennett 1932, Budker 1958, Heptner et al. 1976) and likely resulted in the loss of substantial numbers of whales in some localities so that significant population declines may have occurred (Lien et al. 1988, Olesiuk et al. 1990a). Governments sometimes supported the use of lethal control measures on killer whales, as seen in the establishment of a bounty in Greenland from 1960-1975 (Heide-Jørgensen 1988), the recommendations of Russian scientists to conduct large-scale culling programs to protect seal populations for human harvest (Tomilin 1957), and the opportunistic shooting of whales by fisheries department personnel in British Columbia (Ford et al. 2000, Baird 2001). Animosity against killer whales reached an extreme in the mid-1950s, when the U.S. military reportedly killed "hundreds" over a several-year period in Icelandic waters at the request of the Icelandic government in an effort to reduce predation on herring and damage to fishing equipment (Anonymous 1954, 1956, Vangstein 1956, Dahlheim 1981, Hoyt 1990). Hoyt (1990) also reported that the U.S Air Force practiced strafing runs against killer whales in the North Atlantic in 1964.

Negative attitudes toward killer whales have abated in recent decades, but often persist where interference with fishing activities occurs (Klinowska 1991, Matkin and Saulitis 1997). Conflicts with longline fishing operations are common in a number of regions (Rice and Saayman 1987, Yano and Dahlheim 1995a, 1995b, Ashford et al. 1996, Secchi and Vaske 1998, Visser 2000a, Whale and Dolphin Conservation Society 2002), but net fisheries are also affected,

including gillnetting and purse seining (Young et al. 1993). Longline losses to whales can be extensive and reach 50-100% of the catch in extreme cases. As a result, fishermen frequently resort to shooting at killer whales or harassing them with small underwater explosives ("seal bombs") in an effort to drive off the whales (Matkin 1986, Hoyt 1990, Dahlheim and Matkin 1994, Yano and Dahlheim 1995a, Visser 2000a). Many bullet wounds are probably non-fatal, but accurate information on wounding and killing rates is difficult to obtain.

Deaths from deliberate shooting were probably once relatively common in Washington and British Columbia (Scheffer and Slipp 1948, Pike and MacAskie 1969, Haley 1970, Olesiuk et al. 1990a, Baird 2001). As an indication of the intensity of shooting that occurred until fairly recently, about 25% of the killer whales captured in Puget Sound for aquaria through 1970 bore bullet scars (Hoyt 1990). Shootings have tapered off since then (Hoyt 1990, Olesiuk et al. 1990a, Baird 2001) and only several resident animals currently show evidence of bullet wounds to their dorsal fins (Bigg et al. 1987, Ford et al. 2000). One northern resident, a matriarchal female, died from being shot in 1983 (Ford et al. 2000). Deliberate killings associated with fishery interactions are currently considered insignificant at a population level throughout the northeastern Pacific (Young et al. 1993, Carretta et al. 2001), but may be more prevalent than reported.

Incidental human-related mortality. Drowning from accidental entanglement in nets and longlines is an additional minor source of fishing-related mortality in killer whales. Scheffer and Slipp (1948) documented several deaths of animals caught in gillnets and salmon traps in Washington between 1929 and 1943. Whales are occasionally observed near fishing gear in Washington, British Columbia, and much of Alaska, but current evidence indicates that entanglements and deaths are rare (Bigg and Wolman 1975, Barlow et al. 1994, Matkin and Saulitis 1994, Pierce et al. 1996, Carretta et al. 2001, 2002). One individual is known to have contacted a salmon gillnet in British Columbia in 1994, but did not entangle (Guenther et al. 1995). Typically, killer whales are able to avoid nets by swimming around or underneath them (Jacobsen 1986). Not all entanglements result in death.

In rare instances, killer whales are injured or killed by collisions with passing ships and powerboats, primarily from being struck by the propeller blades (Visser 1999c, Visser and Fertl 2000, Baird 2001, Carretta et al. 2001). Some animals with severe injuries eventually make full recoveries, such as a female described by Ford et al. (2000) that showed healed wounds extending almost to her backbone. Only one mortality from a vessel collision is known to have occurred in Washington and British Columbia during the past 40 years (Baird 2002). Two accidents between vessels and killer whales were documented in the region during the 1990s (Baird 2001). One took place on the Washington side of Haro Strait in 1998 and involved a slow moving boat that apparently did not injure the whale. In 1995, a northern resident was struck by a speedboat, causing a wound to the dorsal fin that quickly healed.

Major oil spills are potentially catastrophic to killer whales and their environment. During the three years following the massive *Exxon Valdez* oil spill in Prince William Sound, Alaska, in 1989, the main resident pod frequenting the spill area lost 14 of its 36 members, a mortality rate that is unprecedented for the northeastern Pacific (Dahlheim and Matkin 1994, Matkin et al. 1994). However, because carcasses of missing animals were never located and other causes of death, such as natural mortality and killing by fishermen, could not be ruled out, researchers were unable to directly attribute the deaths to oil contamination. A transient group (the AT1 pod) that lived near the spill also lost at least nine of its members within 1-2 years (Matkin and Saulitis 1997). However, five other resident pods seen swimming through oil-sheened waters did not experience losses during the same period.

Live-captures for aquaria. Interest in the live-capture of killer whales for public display in aquaria began in southern California in 1961, when Marineland of the Pacific captured a

disoriented individual in California, which died shortly after (Bigg and Wolman 1975). An attempt to obtain a replacement animal followed at Haro Strait in 1962, but this ended in the deaths of a female and possibly an accompanying male (Hoyt 1990). However, in 1964 and 1965, single whales were caught and held for periods of 3 and 12 months at the Vancouver Public Aquarium and Seattle Marine Aquarium, respectively, resulting in much publicity and demonstrating the species' highly appealing qualities when held in captivity. The development of a netting technique in 1965, the initiation of commercial netting operations in 1968, and an immediate demand for captive animals led to large increases in capture effort in Washington and British Columbia beginning in 1967 (Bigg and Wolman 1975).

Operators captured most whales by following a pod until it entered an appropriate bay, where netting could be done (Bigg and Wolman 1975). Nets were then quickly placed across the bay's entrance or pursed around the pod. The whales were held for several days or longer, which allowed them to calm down and be sorted for permanent keeping or release. Puget Sound was preferred as a capture site because it offered fewer escape routes and a number of bays with shallower waters, both of which aided netting efforts, and it had a large network of shore-based observers that provided movement updates on the whales (Bigg and Wolman 1975). Important capture sites (Table 2) included Penn Cove on Whidbey Island (102-113 whales captured), Carr Inlet at the southern end of the Kitsap Peninsula (60-70 whales captured), and Yukon Harbor on the eastern side of the Kitsap Peninsula (40-48 whales captured). During these efforts, many individual whales were caught multiple times.

From 1962-1977, 275-307 whales were captured in Washington and British Columbia, of which 55 were transferred to aquaria, 12 or 13 died during capture operations, and 208-240 were released or escaped back into the wild (Table 2). However, these figures exclude a few additional deaths that were never made public (K. C. Balcomb, pers. comm.). Most (224-256) of the captures occurred in Washington, with 31 whales collected for aquaria and at least 11 dying (Table 2). Peak harvest years occurred from 1967-1971, when 80% of the retained whales were caught. Due to public opposition (e.g., Haley 1970), capture operations declined significantly after 1971, with only eight whales removed beyond this date. The British Columbia provincial government prohibited further live-captures in 1975, although an injured female calf was sent to an aquarium for permanent rehabilitation in August 1977 (Hoyt 1990, Dahlheim and Heyning 1999). In 1982, the British Columbia government issued a final license to capture killer whales in Pedder Bay, but the license holder was unable to catch any whales because none entered the bay (R. W. Baird, pers. comm.). The Washington State Senate passed a resolution (Senate Resolution 1976-222) requesting the U.S. federal government to establish a moratorium on harassment, hunting, and live-capture of the species in 1976 after six transient whales were caught in Budd Inlet, Olympia (see Hoyt [1990] for an account of the events surrounding this capture). The total revenue generated from the sale of captured whales probably exceeded $1,000,000, with the prices of individual animals ranging from about $8,000 in 1965 to $20,000 in 1970 (Bigg and Wolman 1975).

Based on slightly updated information from that presented by Olesiuk et al. (1990a), 70% (47 or 48 animals) of the whales retained or killed were southern residents, 22% (15 animals) were northern residents, and 7% (5 animals) were transients. For the southern resident community, collections and deaths were biased toward immature animals (63% of the total) and males (57% of identified animals). Removed whales included 17 immature males, 10 immature females, nine mature females, seven or eight mature males, and four (three immatures, one adult) individuals of unknown sex. Only 15 of the whales were subsequently identified by pod, with nine animals coming from K pod, five from L pod, and one from J pod (Bigg 1982). These removals substantially reduced the size of the southern resident population, which did not recover to estimated precapture numbers until 1993 (Baird 2001). Furthermore, selective removal of younger

Table 2. Number of killer whales captured, retained for captivity, and killed during capture from 1962-1977 in Washington and British Columbia (Bigg and Wolman 1975, Asper and Cornell 1977, Hoyt 1990, Olesiuk et al. 1990a).

Date[a]	Location	No. of whales caught[b]	No. of whales retained	No. of whales dying
Southern residents				
Sept 1962	Haro Strait, Wash.[c]	1[d,e]	0	1-2[d,e]
Oct 1965	Carr Inlet, Wash.	15	1	1
Feb 1967	Yukon Harbor, Wash.	15[e]	5	3
Feb 1968	Vaughn Bay, Wash.	12-15	2	0
Oct 1968	Yukon Harbor, Wash.	25-33	5	0
Apr 1969	Carr Inlet, Wash.	11[e]	2	0
Oct 1969	Penn Cove, Wash.	7-9[e]	0	1
Feb 1970	Carr Inlet, Wash.	6-14[e]	1	0
Aug 1970	Penn Cove, Wash.	80	7	4
Aug 1970	Port Madison, Wash.	1[e,f]	1	0
Aug 1971	Penn Cove, Wash.	15-24	3	0
Nov 1971	Carr Inlet, Wash.	19	2	0
Mar 1972	Carr Inlet, Wash.	9-11	1	0
Mar 1973	Ocean City, Wash.	1[f]	1	0
Jul 1964	Saturna Island, B.C.	1	1	0
Jul 1966	Steveston, B.C.	1[e]	0	1
Aug 1973	Pedder Bay, B.C.	2	1	0
Aug 1973	Pedder Bay, B.C.	2	2	0
Aug 1977	Menzies Bay, B.C.	1[e]	1	0
Subtotal		224-256	36	11-12
Northern residents				
Jun 1965	Namu, B.C.	2	1	0
Jul 1967	Port Hardy, B.C.	1	1	0
Feb 1968	Pender Harbour, B.C.	1	0	0
Apr 1968	Pender Harbour, B.C.	7	6	0
Jul 1968	Malcolm Island, B.C.	11[g]	1	0
Dec 1969	Pender Harbour, B.C.	12	6	0
Subtotal		34	15	0
Transients				
Mar 1976	Budd Inlet, Wash.	6	0	0
Mar 1970	Pedder Bay, B.C.	5	2[h]	1
Aug 1975	Pedder Bay, B.C.	6	2	0
Subtotal		17	4	1
Total		275-307	55	12-13

[a] Captures are listed chronologically for Washington, followed by British Columbia.

[b] The exact numbers of whales caught in Washington were often not known due to poor record keeping and the difficulty in counting the numbers of individuals present in large groups (M. A. Bigg in Hoyt 1990).

[c] The exact location in Haro Strait is not known (Hoyt 1990), but is presumed here to have been in Washington.

[d] An adult female was shot and killed after being captured, but an adult male was also shot once during the incident (Hoyt 1990). Olesiuk et al. (1990a) presumed that the male also died, but based on Hoyt's (1990) account, there is no conclusive evidence of this.

[e] Presumed to be southern residents (Olesiuk et al. 1990a).

[f] Captured after stranding (Bigg and Wolman 1975).

[g] Presumed to be northern residents (Olesiuk et al. 1990a).

[h] Bigg and Wolman (1975) and Asper and Cornell (1977) listed three whales as being retained from this capture, but the accounts of Hoyt (1990) and Ford and Ellis (1999) disclosed the death of an adult female from apparent malnutrition in its holding pen. Her carcass was then secretly disposed of.

animals and males produced a skewed age- and sex-composition in the population, which probably worked to slow later recovery (Olesiuk et al. 1990a).

Although live-captures of killer whales ceased in the northeastern Pacific after 1977, the demand for captive individuals by aquaria continued. From 1976-1997, 55 whales were taken from the wild in Iceland, 19 from Japan, and three from Argentina (Sigurjónsson and Leatherwood 1988, Hoyt 1990, OrcaInfo 1999). These figures exclude any animals that may have died during capture. The value of captured animals rose to $200,000-300,000 per whale by 1980 (Hoyt 1990) and is now estimated at up to $1 million (Whale and Dolphin Conservation Society 2003). Live-captures fell dramatically in the 1990s, and by 1999, about 40% of the 48 animals on display in the world were captive born (OrcaInfo 1999). Captures temporarily ended in 1997, but resumed in September 2003, when one young whale was caught and another accidentally killed in the Russian Far East (Whale and Dolphin Conservation Society 2003). The Russian government authorized the capture of up to 10 killer whales from this region in 2003. Currently, killer whales are reported to be the third most widely kept species of toothed whale in the worlds' aquaria after bottlenose dolphins (*Tursiops truncatus*) and belugas (Kastelein et al. 2003).

POPULATION STATUS

Global Status: Past and Present

Little information on the former abundance of killer whales is currently available from any portion of their range. Scammon (1874), who worked primarily in the northeastern Pacific, considered the species as "not numerous" in comparison to other delphinids, but anecdotal remarks such as this provide little basis for recognizing even gross changes in population levels during the past 200 years. Nevertheless, it is likely that many populations have declined significantly since 1800 in response to greatly diminished stocks of fish, whales, and pinnipeds in the world's oceans (Reeves and Mitchell 1988a).

Killer whales have proven difficult to census in many areas because of their general scarcity as well as their widespread and often unpredictable movement patterns (Ford 2002). Many older characterizations of relative abundance may well reflect the amount of observation effort rather than actual differences in density among sites (Matkin and Leatherwood 1986). During the past few decades, populations have been surveyed primarily through the use of photo-identification studies or line-transect counts. Photo-identification is capable of providing precise information on population size, demographic traits, and social behavior (Hammond et al. 1990), making it the preferred method in locations where the species is regularly seen. It requires intensive effort spread over multi-year periods and, due to the species' mobility, should be conducted over large geographic areas to obtain accurate results. Photo-identification catalogs for killer whales were first established in the early 1970s for the resident communities of Washington and British Columbia (Balcomb et al. 1980, Sugarman 1984, Bigg et al. 1987, van Ginneken et al. 1998, 2000, Ford and Ellis 1999, Ford et al. 2000) and have since been initiated for most areas where population studies have been undertaken. Other published catalogs exist for Alaska (Heise et al. 1991, Dahlheim 1997, Dahlheim et al. 1997, Matkin et al. 1999a), California and parts of Mexico (Black et al. 1997), and Patagonia (Bubas 2003). All photographic surveys rely on recognition of individual animals through their distinctive dorsal fins and saddle patches, although eye-patch traits are sometimes used to supplement identification (Baird 1994, Visser and Mäkeläinen 2000). Line-transect surveys from ships or aircraft have generally been undertaken in large areas of open ocean where photo-identification is impractical. The results of line-transect surveys are almost always accompanied by large confidence limits, making it difficult to establish true population sizes and to compare trends over time. Furthermore, the technique is unsuited for gathering most demographic data.

As top-level predators, killer whales occur in low densities throughout most of their geographic range. Densities are considered greater in colder waters than in tropical regions. Reeves and Leatherwood (1994) reported the worldwide population as probably exceeding 100,000 whales, based on information presented in Klinowska (1991), but this was undoubtedly an overestimate influenced by preliminary count data from the Antarctic. A number of regional abundance estimates have been made in recent years, with emerging evidence suggesting that many populations are relatively small (Whale and Dolphin Conservation Society 2002). In the northeastern Pacific, about 1,150-1,500 resident, transient, and offshore whales are currently thought to exist from California to the eastern Aleutian Islands of Alaska (Ford et al. 2000, Barrett-Lennard and Ellis 2001). Other estimates for northern populations include about 400-650 animals in the Bering Sea (Waite et al. 2002), 1,900 animals in Japan (Miyashita cited in Dahlheim and Heyning 1999), 500-1,500 animals in Norwegian coastal waters (Christensen 1988), and about 190 whales off Iceland (Klinowska 1991). New Zealand's entire population is believed to number fewer than 200 animals (I. N. Visser, unpubl. data). A recent population estimate of about 25,000 killer whales in Antarctica (Branch and Butterworth 2001) is considered much more accurate than earlier projections (Hammond 1984; Butterworth et al. 1994; T. A. Branch, pers. comm.). Densities in this region are highest near the ice edge (Kasamatsu et al. 2000). An estimate of 8,500 killer whales for the eastern tropical Pacific, as derived from shipborne surveys (Wade and Gerrodette 1993), is probably too large, given the general opinion that densities are substantially reduced at lower latitudes. Abundance in many other areas remains poorly investigated (Whale and Dolphin Conservation Society 2002). Trend information is lacking for virtually all populations other than the resident communities of the northeastern Pacific.

Status in Washington and Southern British Columbia: Before 1974

Several lines of evidence argue that the southern resident community may have numbered more than 200 whales until perhaps the mid- to late-1800s (Krahn et al. 2002), when Euro-American settlement began to impact the region's natural resources. Recent genetic investigations using microsatellite DNA reveal that the population retains a somewhat similar amount of genetic diversity as the northern residents (Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001), indicating that the two were possibly once similar in size. This scenario would be unlikely if the southern resident population had remained small for many generations, which would have caused a gradual loss of genetic diversity. The presence of relatively few acoustic clans and pods in the southern residents (1 clan, 3 pods), as compared to the northern (3 clans, 16 pods) and southern Alaska residents (2 clans, 11 pods), also infers that the southern population was once larger (Krahn et al. 2002). Finally, reductions in salmon and other prey along much of the west coast of North America during the past 150 years, especially from Washington to California (Nehlson 1997, Kope and Wainwright 1998), have very likely lessened the region's carrying capacity for resident killer whales (Krahn et al. 2002) and caused a decline in southern resident abundance.

Efforts to determine killer whale population trends in Washington and southern British Columbia during the past century are hindered by an absence of empirical information prior to 1974. A report by Scheffer and Slipp (1948) is the only older account to mention abundance in Washington. It noted that the species was "frequently seen" in the Strait of Juan de Fuca, northern Puget Sound, and off the coast of the Olympic Peninsula, with smaller numbers occurring farther south along the outer coast. Palo (1972) put forth a tentative estimate of 225-300 whales for Puget Sound and the Georgia Basin in 1970, but was admittedly unsure of the figure's validity. Olesiuk et al. (1990a) modeled population sizes of the southern and northern resident communities for the periods between 1960 and 1973 or 1974. Both

populations were projected as increasing from 1960 to 1967 or 1968, with the southern residents expanding from about 78 to 96 whales and the northern residents growing from about 97 to 120 whales (Figure 7, Appendix A). This was probably a result of both populations recovering from the opportunistic shooting that was widespread before 1960 (see *Mortality Associated with Killer Whale Depredation*) and other human impacts, or may have been caused by some unidentified improvement in the region's capacity to support the whales (Olesiuk et al. 1990a). A second but much cruder method of estimating population size in the mid-1960s is to add the numbers of whales collected and killed during the live-capture fishery to the numbers of animals tallied in the initial censuses of the southern and northern resident communities in the mid-1970s. This would produce estimates of roughly 117 and 147 whales in the two populations, respectively.

Beginning in about 1967, removals of whales by the live-capture fishery caused immediate declines in both populations (see *Live-Captures for Aquaria*). Southern resident numbers were most affected, falling an estimated 30% to about 67 whales by 1971, whereas the northern residents decreased by an estimated 10% to about 108 whales by 1970 (Olesiuk et al. 1990a). Removals from the southern resident community are known to have included nine animals from K pod, five from L pod, and one from J pod (Bigg 1982). Northern resident takings included six known and six suspected whales from A5 pod, one from C1 pod, and one from I11 pod (Bigg 1982).

Transient whales also suffered serious prey losses between the late 1800s and late 1960s, and very likely experienced a sizable decrease in abundance as a result (Ford and Ellis 1999, Springer et al. 2003). During this period, overhunting caused dramatic declines or extirpations in pinniped and large whale populations in British Columbia and adjacent areas. By about 1970, it is estimated that harbor seal and Steller's sea lion populations in the province had fallen to about 10% and 25-33%,

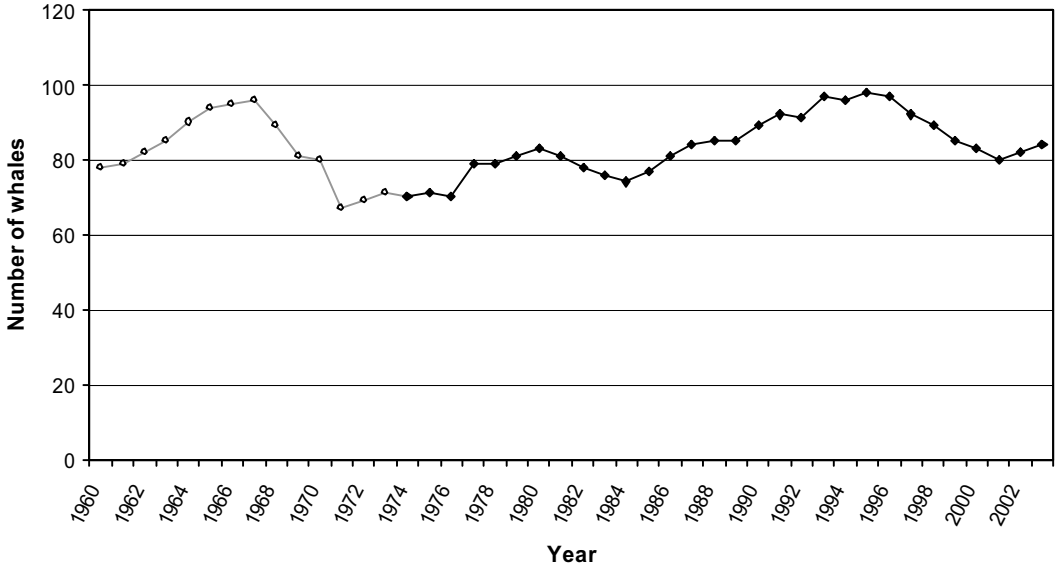

Figure 7. Population size and trend of southern resident killer whales, 1960-2003. Data from 1960-1973 (open circles, gray line) are number projections from the matrix model of Olesiuk et al. (1990a). Data from 1974-2003 (diamonds, black line) were obtained through photo-identification surveys of the three pods (J, K, and L) in this community and were provided by the Center for Whale Research (unpubl. data). Data for these years represent the number of whales present at the end of each calendar year.

respectively, of historic levels (Olesiuk et al. 1990b, Ford and Ellis 1999). Similar reductions in pinniped numbers occurred elsewhere between southeastern Alaska and California (Scheffer 1928, Bonnot 1951, Newby 1973, Jeffries et al. 2003). Whale populations crashed even more severely and have never recovered in most cases. Historical whaling data show that resident humpback and possibly fin whale populations formerly existed in the coastal waters of British Columbia and Washington, sei and blue whales once migrated past Vancouver Island, and sperm whales previously mated and calved in the region (Scheffer and Slipp 1948, Gregr et al. 2000).

Status in Washington and Southern British Columbia: 1974-2003

Southern residents. Photo-identification studies have been the foundation of all killer whale population research in Washington and British Columbia since the early 1970s. Annual censuses of the southern residents were initiated by Michael Bigg of Canada's Department of Fisheries and Oceans in 1974 (Bigg et al. 1976). The Center for Whale Research assumed responsibility for the counts in 1976 (Balcomb et al. 1980) and has directed them since then. The surveys are typically performed from May to October, when all three pods reside near the San Juan Islands, and are considered complete censuses of the entire community. It should be noted that small discrepancies in the annual count totals of the southern residents (e.g., see Ford et al. [2000], Baird [2001], Taylor and Platt [2001], Krahn et al. [2002], and Appendix A of this report) are due in part to differences in the reporting times of yearly numbers and whether or not whales that died were tallied during the year of their death. The count criteria used in this report appear in Figures 7 and 8 and Appendix A.

The population has gone through several periods of growth and decline since 1974 (Figure 7, Appendix A), when live-captures were ending and numbers were judged as beneath carrying capacity (Olesiuk et al. 1990a). Between 1974 and 1980, total whale numbers expanded 19% (mean annual growth rate of 3.1%) from 70 to 83 animals. J and L pods grew 27% and 26%, respectively, during this period, whereas K pod decreased by 6%.

This was followed by four consecutive years of decrease from 1981-1984, when count results fell 11% (mean annual decline rate of 2.7%) to 74 whales. The decline coincided with periods of fewer births and greater mortality among adult females and juveniles (Taylor and Plater 2001). A distorted age- and sex-structure, likely caused by the selective cropping of animals during live-captures 8-17 years earlier, also appears to have been a significant factor in the decline (Olesiuk et al. 1990a). This resulted in fewer females and males maturing to reproductive age and a reduction in adult males that was possibly below the number needed for optimal reproduction. An unusually large cohort of females that stopped bearing young also played a role in the decline (Olesiuk et al. 1990a). Pod membership during this period dropped by 12% for L pod, 11% for J pod, and 7% for K pod.

In 1985, the southern residents entered an 11-year growth phase, which began with a drop-off in deaths and a pulse in births caused partly by the maturation of more juveniles (Taylor and Plater 2001). Total numbers eventually peaked at 98 animals in 1995 (Figure 7, Appendix A), representing an increase of 32% (mean annual growth rate of 2.9%) in the population. Pod growth during the period was 37% in L pod, 36% in K pod, and 29% in J pod.

The southern resident community entered yet another period of decline in 1996, with an 18% reduction (mean annual decline rate of 3.1%) in numbers occurring by 2001, when 80 whales remained (Figure 7, Appendix A). This decline appears to have resulted more from an unprecedented 9-year span of relatively poor survival in nearly all age classes and both sexes than from an extended period of poor reproduction (Krahn et al. 2002). All three pods suffered reductions in membership during this period, with L pod falling 28%, J pod 14%, and K pod 11%. The population increased slightly to 82 whales in 2002 and 84 whales in 2003. Growth in J and K pods account for this gain and both pods now

equal or exceed their largest sizes achieved in the 1990s. By comparison, L pod appears to be continuing its decline and fell to just 41 members in 2003. This pod has experienced means of 3.1 deaths and 1.4 births per year since 1994 (Center for Whale Research, unpubl. data).

At present, the southern resident population has declined to essentially the same size that was estimated during the early 1960s, when it was considered as likely depleted (Olesiuk et al. 1990a). Since censusing began in 1974, J and K pods have increased their sizes by 47% (mean of 1.6% per year) and 31% (mean of 1.1% per year), respectively. The largest pod, L pod, has grown only 5.1% (mean of 0.2% per year) during this period, but more importantly, is in a 10-year decline that threatens to reduce the pod's size below any previously recorded level. From 1974-2003, there was an average of 3.3 births and 2.7 deaths per year in the community as a whole (Center for Whale Research, unpubl. data).

Olesiuk et al. (1990a) used data from 1974-1987 to estimate an intrinsic growth rate of 2.92% per year for both resident populations combined. However, observed rates of increase differed substantially for the two communities (1.3% annually from 1974-1987 for the southern residents vs. 2.9% annually from 1979-1986 for the northern residents). Brault and Caswell (1993) also examined growth rates for both populations during the same periods, but used a stage-structured model and based their calculations on females only. Intrinsic and observed rates of growth among the southern residents were 2.5% and 0.7% per year, respectively, with the observed rate being much lower than in the northern residents. Non-significant differences in intrinsic growth rates existed among the three southern pods (J pod, 3.6% per year; K pod, 1.8% per year; and L pod, 1.5% per year). This study concluded that population growth rates in killer whales were more sensitive to changes in adult survival, as would be expected in any long-lived species, than to changes in juvenile survival and fertility.

Using data from 1974-2000, Krahn et al. (2002) recently presented a new analysis of the population dynamics of the southern residents in an effort to identify demographic factors contributing to the population's latest decline. For their analyses, six age and sex classes were defined as follows: calves in their first summer (<1 year of age), juveniles of both sexes (1-10 years of age), females of reproductive age (11-41 years of age), post-reproductive females (42 years of age and older), young adult males (11-21 years of age), and older males (22 years of age and older). The study found sizable differences in annual survival among age and sex classes, with an overall mean of 0.969. Modeling of annual survival data determined that overall survival was relatively constant within approximately six-year periods, but differed greatly between consecutive periods. Greater than average survival rates were detected from 1974-1979 and 1985-1992, but rates were below average from 1980-1984 and 1993-2000. Changes in survival were not related to stochastic variation caused by the population's small size (e.g., random patterns in births or deaths) or to annual fluctuations in survival. Krahn et al. (2002) therefore suggested that survival patterns were more likely influenced by an external cause, such as periodic changes in prey availability or exposure to environmental contaminants. The study also discovered declining rates of survival in five of the population's six age and sex categories from 1992-2000. Survival fell most sharply in older males in contrast to reproductive females, which showed almost no decline in survival. From 1993-2001, the percentage of males 15 years of age or older in the population fell from 17% to 11%, placing it much lower than the 19% necessary for a stable age and sex distribution (Olesiuk et al. 1990a). Investigation of temporal patterns in survival rates found no differences among the three pods (Krahn et al. 2002). Each pod experienced similar reductions in survival during the declines of the early 1980s and the late 1990s.

Krahn et al. (2002) also examined fecundity levels in the southern resident population. Based on numbers of calves that survived to their first summer, average fecundity of reproductive-aged females was estimated at 12% from 1974-2000, which corresponded to a mean interval of 7.7

years between surviving calves. Modeling revealed that annual birth rates best fit a periodic function with about eight years between peaks. Low points in the numbers of recruited calves were observed in 1981, 1989, and 1997 and peaks occurred in 1977, 1985, and 1993. Krahn et al. (2002) noted considerable variability in the annual fecundity rate of the population, as expected in a small population with few reproductively active females. However, because the data fit a periodic function, reproductive output also appeared to be partially synchronized between females. Such a pattern might result from occasional poor environmental years causing high calf mortality, which might then lead to a pulse in births after conditions recovered (Krahn et al. (2002). Birthing synchrony might then be retained for a certain period of time thereafter.

Recent birthing data for the community as a whole indicate that births did not increase between 2000 and 2003, as predicted by Krahn et al.'s (2002) model. During the past decade, J and K pods appear to have slightly increased their calf productivity when compared to the previous decade (Center for Whale Research, unpubl. data). In contrast, calf productivity in L pod has dropped by half in the past 10 years, with only 13 calves born. Additionally, L pod has experienced much higher calf mortality (6 of 13 calves born during the past decade) than either J pod (0 of 10 calves) or K pod (2 of 9 calves) (Center for Whale Research, unpubl. data).

Brief histories of each of the three southern resident pods are provided below. At the end of 2003, the community as a whole was comprised of seven mature males (8.3% of the population), 21 reproductive females (25.0%), 14 post-reproductive females (16.7%), 17 juvenile males (20.2%), 12 juvenile females (14.3%), and 13 immature animals of unknown sex (15.5%) (van Ginneken et al. 2000; Center for Whale Research, unpubl. data). Older demographic information on the pods can be found elsewhere (Balcomb et al. 1980, 1982, Balcomb 1982, Bigg 1982, Balcomb and Bigg 1986, Bigg et al. 1987).

J pod. This pod's overall expansion from 15 whales in 1974 to 22 whales at the end of December 2003 has been mixed with several minor declines and increases during intervening years (Figure 8, Appendix A). The pod is currently comprised of four matrilines totaling one adult male, six reproductive females, two post-reproductive females, five immature males, five immature females, and three immature animals of unknown sex (van Ginneken et al. 2000; Center for Whale Research, unpubl. data). The oldest member is J2, which is estimated to be in her eighties or early nineties (Ford et al. 2000). J1 is the only adult male and is considered to be in his early fifties.

K pod. Membership in K pod has varied from 14 to 21 whales since 1974, with 21 animals present at the end of 2003 (Figure 8, Appendix A). The pod currently holds four matrilines consisting of one mature male, five reproductive females, four post-reproductive or non-reproductive females, three immature males, three immature females, and five immature whales of unknown sex (van Ginneken et al. 2000; Center for Whale Research, unpubl. data). The oldest member is K7, which is believed to be in her eighties or early nineties (Ford et al. 2000). The pod was without an adult male for several years in the late 1990s, following the death of K1 in 1997. The oldest male (K21) is now 17 years of age. This pod was cropped especially heavily during the live-capture era (Bigg 1982).

L pod. This is the largest of the three southern resident pods and grew from 39 whales in 1974 to a peak of 59 whales in 1993 (Figure 8, Appendix A). Pod membership has been in decline since then and totaled just 41 animals at the end of 2003. L pod currently contains 12 matrilines comprised of five adult males, 10 reproductive females, eight post-reproductive females, 10 immature males, four immature females, and four immature animals of unknown sex (van Ginneken et al. 2000; Center for Whale Research, unpubl. data). The percentage of immatures (43.9%) is currently the lowest of any pod. Three matrilines are represented by single whales, either males or post-reproductive females, and are destined to

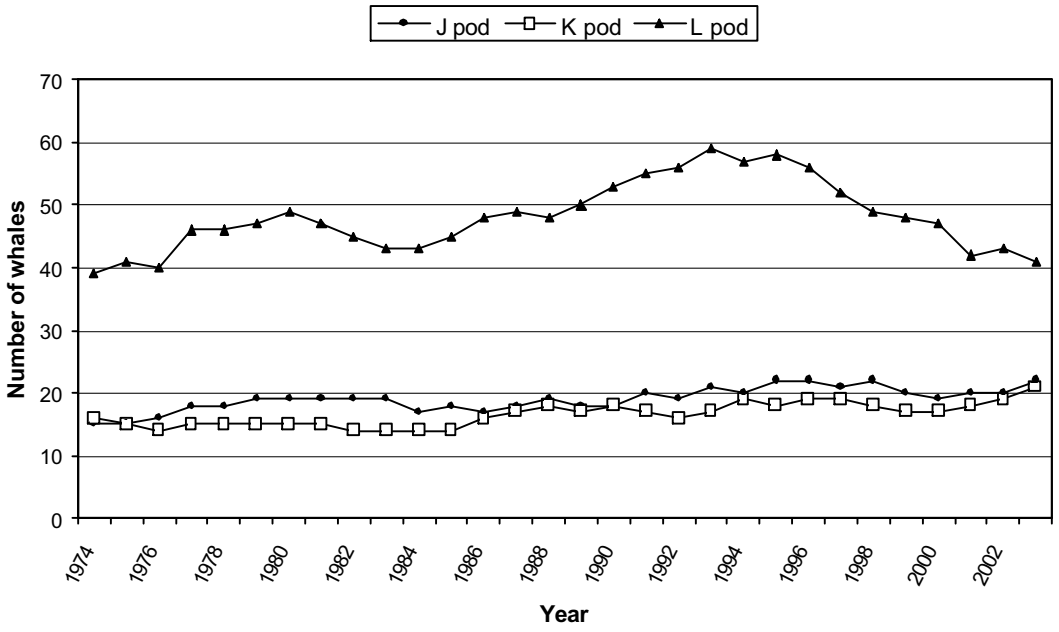

Figure 8. Population sizes and trends of the three southern resident killer whale pods (J, K, and L) from 1974-2003. Data were obtained through photo-identification surveys and were provided by the Center for Whale Research (unpubl. data). Data represent the number of whales present in each pod at the end of a calendar year (K. C. Balcomb, pers. comm.).

eventually die out. The oldest females are L25 and L12, which are estimated to be 75 and 70 years old, respectively (Ford et al. 2000). L41 and L57 are the oldest males and were both born in 1977. An additional member of L pod, a four-year-old male (L98), has lived solitarily in Nootka Sound on the west side of Vancouver Island since July 2001 after becoming separated from the pod. Canadian officials are currently assessing different methods to reunite the whale with the pod. L98 is excluded from annual census results because it is not considered a contributing member of the population. During the 1980s, Hoelzel (1993) believed that L pod had separated into three smaller pods, which were identified as L8, L10, and L 35 pods.

Northern residents. Canadian researchers have conducted annual censuses of the northern resident community since 1975 (Bigg et al. 1990, Ford et al. 2000). The population contains 16 pods and grew fairly steadily at a rate of 3.0% per year from 1975-1997, when numbers expanded from 132 to 220 whales (Figure 9, Appendix A) (Ford et al. 2000; J. K. B. Ford, unpubl. data). This rate of growth was similar to the predicted intrinsic rate of the population and was substantially higher than the observed rate of the southern residents during the same time (Olesiuk et al. 1990a, Brault and Caswell 1993). Several factors were presented as possible reasons for the relatively stable growth of the northern residents through 1997, including 1) the population's larger size in comparison to the southern residents, which made it less sensitive to stochastic events in births and deaths, 2) the smaller amount of cropping that occurred during the live-capture fishery (Olesiuk et al. 1990a), and 3) possibly fewer environmental changes in the community's geographic range in recent decades. The population experienced an 8.6% decline in numbers from 1997-2001, falling to 201 whales. Possible explanations for this decrease are similar to those put forth for the southern residents (J. K. B. Ford, pers. comm.). Abundance has increased slightly since then, with 204 whales counted in 2003. Individuals from A1, A4, C, D, G1, G12, H,

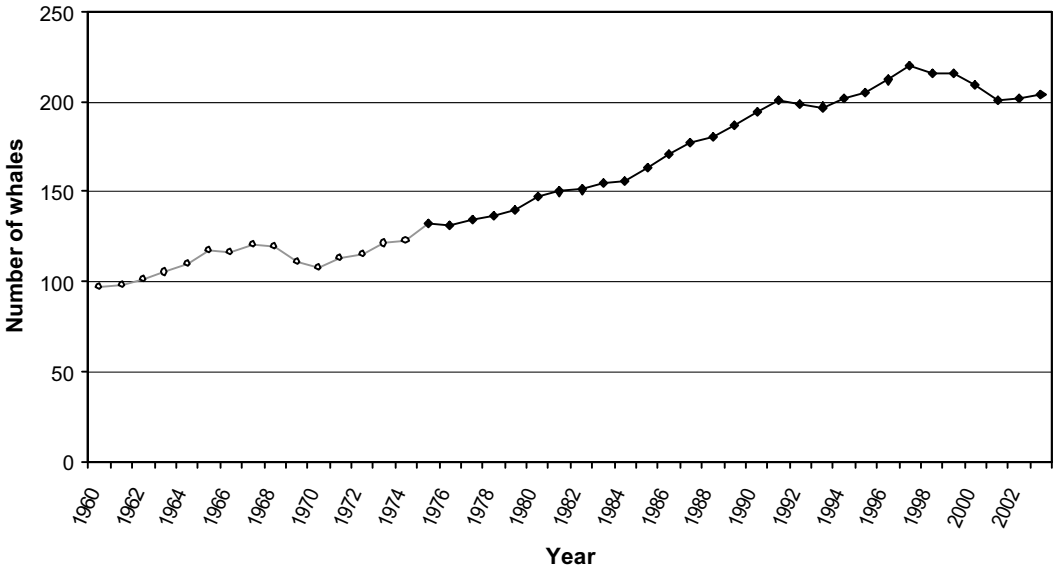

Figure 9. Population size and trend of northern resident killer whales, 1975-2003. Data from 1960-1974 (open circles, gray line) are number projections from the matrix model of Olesiuk et al. (1990a). Data from 1975-2003 (diamonds, black line) were obtained through photo-identification surveys of the 16 pods in this community and were provided by J. K. B. Ford (unpubl. data). Data for these years represent whale numbers for entire calendar years; animals are counted through their last year seen.

I1, I2, I11, and I18 pods have been identified in or near Washington's waters (D. K. Ellifrit, unpubl. data; J. Calambokidis, unpubl. data).

Transients. Cumulative numbers of photographically identified killer whales in the west coast transient community expanded throughout the 1980s and 1990s as efforts to document the population continued (Bigg et al. 1987, Black et al. 1997, Ford and Ellis 1999). To date, about 320 individuals have been identified in the population, which includes about 225 transients in Washington, British Columbia, and southeastern Alaska (Ford and Ellis 1999; J. K. B. Ford, unpubl. data) and 105 animals off California (Black et al. 1997). At least 10 whales have been seen in both regions. Efforts to determine population size are complicated by two problems (Ford and Ellis 1999, Baird 2001, Carretta et al. 2001). Small numbers of new transients continue to be documented each year, indicating that a complete registry of individuals has not yet been achieved. Secondly, some identified whales have undoubtedly died over time, but their numbers have been difficult to establish because of the long intervals between sightings for some individuals. Given the current level of knowledge, the population probably totals about 300-400 whales. Trend information is lacking for the population because accurate assessments of abundance have not been made. The number of transient whales in Washington's waters at any one time is speculative, but is probably fewer than 20 individuals (K. C. Balcomb, pers. comm.; D. K. Ellifrit, pers. comm.). Roughly one-third to half of the entire population has been detected in the state (K. C. Balcomb, unpubl. data; D. K. Ellifrit, unpubl. data).

Offshores. No firm estimates of total population size or changes in numbers have been established for the offshore community. About 235 offshore killer whales were catalogued for the northeastern Pacific through about 2002 (J. K. B. Ford, unpubl. data). As with transients, this is considered an underestimate of total numbers because of the

continued detection of new individuals over time and the difficulty in substantiating mortalities. Carretta et al. (2002) calculated a minimum estimate of 285 offshore whales along the coasts of Washington, Oregon, and California, based on shipboard line-transect surveys conducted in the 1990s and the percentage of offshore animals among all killer whales photographed off California (Black et al. 1997). This is believed to be an underestimate of true numbers because of biases in sampling. Based on the documented movements of some photographed individuals, it is likely that much of this community occurs in Washington's waters on a regular or irregular basis. Because offshores often occur in large groups and travel widely, their abundance in the state probably varies from a few to perhaps as many as 75-100 animals at any one time (D. K. Ellifrit, pers. comm.).

Status along Washington's coast. Abundance patterns of killer whales are not well known for Washington's outer coast. Several studies have reported relatively low encounter rates during shipborne and aerial surveys, with most sightings made along the continental shelf within about 50 km of land (Green et al. 1992, 1993, Shelden et al. 2000). Very few observations during these studies were identifiable to community type. However, killer whales were encountered somewhat more often during another study by J. Calambokidis and others (unpubl. data), who conducted summer ship surveys off the Olympic Peninsula from 1995-2002. These researchers detected transient whales most frequently, but members of both resident communities and the offshore population were also observed. Sightings were made predominantly at mid-shelf depths averaging 100-200 m and at distances of 40-80 km from land. An additional source of information is the Platforms of Opportunity Program database maintained by the National Marine Mammal Laboratory. It contains 76 killer whale records from the outer coast between 1958 and 1997. These sightings, which were obtained in a non-systematic manner, indicate that killer whales can be found along the entire coast during all seasons and at distances of up to at least 200 km from land (Platforms of Opportunity Program Database, National Marine Mammal Laboratory, unpubl. data).

Shore sightings of killer whales are relatively rare along the outer coast. There is at least one record from the mouth of Grays Harbor and several others from just outside the bay's entrance during the past decade (Cascadia Research, unpubl. data). Few if any records are known from Willapa Bay during the past several decades (K. C. Balcomb, pers. comm.). Any sightings from either embayment would most likely involve transients.

Status in Washington and Southern British Columbia: Future Predictions

Southern residents. Two recent studies have used a technique known as population viability analysis (PVA) to assess the future risk of extinction of the southern resident population. PVAs rely on known life history parameters to reach their conclusions and usually assume that conditions observed in the past will continue in the future. Limitations in models can produce unreliable results for a variety of reasons, such as the use of inaccurate demographic data and failure to correctly consider environmental variables and parameter uncertainty (Beissinger and Westphal 1998, Reed et al. 1998). Thus, PVA forecasts should often be viewed with some caution.

Taylor and Plater (2001) made two series of simulations for the southern residents using a VORTEX software program. The first employed mortality and fecundity rates from 1974-2000 and assumed that these were representative of the rates expected in the future. The second scenario used survival rates only from the most recent decline (1996-2000) and assumed that these would continue in the future. Using a number of parameter hypotheses, the initial set of models predicted median times to extinction to all exceed 265 years and determined that the population had a 36-64% chance of extinction within 300 years. The second group of analyses utilized a wider range of assumptions and risk levels, resulting in greatly increased risk estimates that ranged from a 1.5-28.5% chance of extinction in the next 100 years. Regardless of the assumptions used, this

scenario predicted extinction to occur at a median time ranging from 113-213 years. Taylor and Platt (2001) considered the second set of analyses to be more plausible than the first because it better reflected an expected continuation of habitat degradation in the future.

Krahn et al. (2002) measured extinction risk in the southern residents with a more complex, customized PVA model that they considered more reflective of the true biology of the southern residents. Their simulations incorporated data for the periods of 1974-2000 and 1992-2000 and considered eight values of carrying capacity for the population set between 100 and 400 whales. Analyses were performed at two population levels, with one characterizing the southern residents as a single unit and the second combining them with the northern and western Alaska residents into a larger northeastern Pacific resident population. The results of this model were more optimistic than those of Taylor and Platt (2001). Nevertheless, they indicated that the southern residents still have extinction risks of 12-30% in the next 100 years and greater than 85% over 300 years under the scenario that the population's survival rates from 1992-2000 continue into the future. However, if future survival rates match those from 1974-2000, then the probability of extinction fell to 1-4% in 100 years and 5-50% in 300 years, with the higher values associated with increased rates and magnitudes of catastrophes, such as oil spills and disease outbreaks. The model determined the risk of extinction for the larger northeastern Pacific resident population as negligible over 100 years and less than 5% over 300 years.

Other communities. PVAs have not been conducted for other killer whale communities occurring in Washington. However, the transient population may be just as threatened as the southern residents because of its elevated levels of toxic contaminants (see *Environmental Contaminants*).

LEGAL STATUS

Federal laws. Killer whales and most other marine mammal populations in the United States are protected under the Marine Mammal Protection Act of 1972 (MMPA), which placed a moratorium on the taking (defined as harassing, hunting, capturing, killing, or attempting to harass, hunt, capture, or kill) and importation of these animals and products derived from them. The MMPA exempts some native harvest for subsistence purposes and for creating and selling native handicrafts and clothing, but no tribe currently has a harvest permit approved for killer whales. Some incidental take associated with commercial fisheries is also allowed. The MMPA allows permits to be issued for research, public display, and commercial educational photography. In late 2003, the Department of Defense was granted an exemption from the take and harassment provisions of the MMPA during times of national emergency. In May 2003, the southern resident community was declared a depleted stock under the MMPA by the National Marine Fisheries Service. This status will allow the agency to develop conservation measures aimed at improving the population's habitat and elevating public awareness. In response to a petition filed by a number of environmental organizations in 2001 (Center for Biological Diversity 2001), the Service determined that it was unwarranted to list the southern residents as threatened or endangered under the U.S. Endangered Species Act because the population did not meet the criteria of being a distinct population segment (Krahn et al. 2002, National Marine Fisheries Service 2002). However, this decision was rejected in federal court in December 2003, meaning that the agency must re-evaluate its determination and issue a new finding within one year. Cetaceans also receive protection through the Packwood-Magnuson Amendment of the Fisheries and Conservation Act. This law allows observers to be placed on fishing vessels that have a high probability of killing marine mammals and provides for limited monitoring and enforcement activities regarding marine mammal and vessel interactions. The Pelly Amendment of the Fisherman's Protective Act allows trade sanctions to be imposed on countries

that violate international laws protecting marine mammals. The importation of wildlife and associated products taken illegally in foreign countries is prohibited under the Lacey Act.

State laws. Killer whales are covered under several Washington laws and regulations. Killer whales are listed as protected under the category of "other protected wildlife" in the Washington Administrative Code (WAC 232-12-011). This prohibits the hunting, malicious killing, and possession of killer whales, but does not protect the species from harassment. Violations of this law are a misdemeanor offense (RCW 77.15.130), with penalties ranging up to 90 days imprisonment and a $1,000 fine. The species also receives protection under WAC 232-12-064, which prohibits the capture, importation, possession, transfer, and holding in captivity of most wildlife in state. In June 2000, killer whales were named a "state candidate species" by the Washington Department of Fish and Wildlife, meaning that they will receive future consideration for state listing as endangered, threatened, or sensitive. Species of candidate status receive no direct protection. Killer whales are also listed as a "Criterion Two" priority species on the Department's Priority Habitat and Species List, which catalogs animals and plants that are priorities for conservation and management, especially at the county level. Criterion Two species include those species or groups of animals susceptible to significant population declines within a specific area or statewide by virtue of their inclination to aggregate. This status also provides no mandatory protection for killer whales. In some situations, federal laws may preempt the regulatory protections provided by Washington State.

Canadian laws. Killer whales received federal protection from disturbance under Canada's Marine Mammal Regulations of the Fisheries Act in 1994, when a change in definitions extended coverage to all cetaceans and pinnipeds (Baird 2001). Although these regulations allow killer whales to be hunted with the purchase of a fishing license at a nominal fee, the license is granted at the discretion of the Minister of Fisheries and Oceans and no such licenses have ever been approved. The regulations broadly prohibit the disturbance of killer whales (except when being hunted), but give no definition of "disturbance." Penalties include fines and imprisonment. The Department of Fisheries and Oceans is currently amending the regulations to make them more stringent and relevant to conservation needs (Fisheries and Oceans Canada 2002). The department has also developed a set of voluntary guidelines to limit interactions between whale-watching vessels and northern resident killer whales. Until recently, there has been little enforcement of the Marine Mammal Regulations or monitoring of the viewing guidelines by authorities (Baird 2001, Lien 2001). However, in 2004, an American whale-watching operator was prosecuted under the Marine Mammal Regulations and fined CA$6,500 (US$4,875) for approaching two groups of southern resident whales in the Gulf Islands too closely. In 2001, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) categorized the four populations of killer whales in the country's Pacific waters, as follows: southern residents, endangered; northern residents, threatened; transients, threatened; and offshores, special concern. COSEWIC had no legal mandate and served only in an advisory role. The Species at Risk Act (SARA) became federal law in June 2003, with killer whale populations maintaining their same status as under COSEWIC. Under this regulation, the killing, harassment, and possession of killer whales will become prohibited in June 2004. Important habitats of listed species will also eventually receive protection. Lastly, SARA requires the preparation of recovery plans for all listed species. Such plans are now being drafted for southern and northern resident killer whales. The province of British Columbia does not have any laws currently protecting killer whales (Baird 2001).

International laws. International trade in killer whales and their body parts is regulated and monitored by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Killer whales were placed on Appendix II in 1979, which requires all international shipments of the species to be

accompanied by an export permit issued by the proper management authority of the country of origin. The International Whaling Commission categorizes killer whales and most other odontocetes as "small cetaceans," but there is disagreement among member countries as to whether the Convention applies to this group of species. The Commission officially included killer whales in their moratorium on factory ship whaling (Anonymous 1981), but other management measures (e.g., the Southern Ocean Sanctuary and the moratorium on commercial whaling) do not apply to killer whales (Baird 2001). In 2002, killer whales were added to Appendix II of the U.N. Convention on the Conservation of Migratory Species of Wild Animals. This designation is given to migratory species that "have an unfavorable conservation status and require international agreements for their conservation and management, as well as those which have a conservation status which would significantly benefit from the international cooperation that could be achieved by an international agreement." The World Conservation Union (IUCN) lists killer whales as a species of "Lower Risk/Conservation Dependent" on its Red List.

POTENTIAL THREATS TO POPULATIONS IN WASHINGTON AND SOUTHERN BRITISH COLUMBIA

Marine mammal populations are often exposed to many forms of environmental degradation, including habitat deterioration, changes in food availability, increased exposure to pollutants, and human disturbance. All of these factors have been identified as potential threats to killer whales in Washington and British Columbia (Ford and Ellis 1999, Ford et al. 2000, Baird 2001, Krahn et al. 2002). Unfortunately, despite much study since the early 1970s and great advances in knowledge of the species, researchers remain unsure which threats are most significant to the region's whales. Three primary factors are discussed in this section: reductions in prey availability, disturbance by underwater noise and whale-watching vessels, and exposure to environmental contaminants. None have yet been directly tied to the recent decline of the southern resident population (Krahn et al. 2002), but continued research should provide further insight into relationships. Perhaps most likely, two or more of these factors may be acting together to harm the whales. For example, disturbance from whale-watching craft may be most problematic when combined with the stresses of reduced prey availability or increased contaminant loads (Williams et al. 2002a). Under such a scenario, reduced foraging success resulting from interference from whale-watching boats and declining salmon abundance may lead to chronic energy imbalances and poorer reproductive success, or all three factors may work to lower an animal's ability to suppress disease.

Reduction of Prey Populations

Healthy killer whale populations are dependent on adequate prey levels. Reductions in prey availability may force whales to spend more time foraging and might lead to reduced reproductive rates and higher mortality rates. Human influences have had profound impacts on the abundance of many prey species in the northeastern Pacific during the past 150 years. Foremost among these, many stocks of salmon have declined significantly due to overfishing and degradation of freshwater and estuarine habitats through urbanization, dam building, and forestry, agricultural, and mining practices (National Research Council 1996, Gregory and Bisson 1997, Lichatowich 1999, Pess et al. 2003). Populations of some other known or potential prey species, such as marine mammals and various fish, have similarly declined or fluctuated greatly through time. Status assessments of the food resources available to killer whales in the region are complicated by numerous considerations, including a lack of detailed knowledge on the food habits and seasonal ranges of the whales, uncertainties in the historical and current abundance levels of many localized populations of prey, and the cyclic nature of large-scale changes in ocean conditions.

Reduction of Prey Populations: Residents

Information on the diets of resident killer whales in Washington and British Columbia is very limited, but it is generally agreed that salmon are the principal prey in spring, summer, and fall (Heimlich-Boran 1986, Felleman et al. 1991, Ford et al. 1998). Current data suggest that chinook salmon, the region's largest salmonid, are the most commonly targeted prey species (Ford et al. 1998). Other salmonids appear to be eaten less frequently, as are some non-salmonids such as rockfish, halibut, lingcod, and herring. Unfortunately, conclusions about resident diets are limited by a number of observational biases (Ford et al. 1998, Baird 2000). Most information originates from a single published study (Ford et al. 1998) that focused on the northern residents from late spring to early fall. Few feeding data exist for the winter months for either resident population or for whales found away from inland waters. There has also been a reliance on surface feeding observations, which may underrepresent predation on bottom fish or other species. Further complicating an adequate understanding of whale-prey relationships is the possibility of dietary differences among pods and between sexes (Nichol and Shackleton 1996, Ford et al. 1998, Baird 2000).

Another poorly understood facet of diet is the extent to which resident killer whales have depended on specific salmon runs, both in the past and currently (Krahn et al. 2002). Several researchers have compared southern resident distribution with salmon sport catch records, but none have attempted to identify targeted runs. The population's annual presence in the vicinity of the San Juan Islands and Fraser River mouth from late spring to early fall suggests a dependence on salmon returning to this river system (Osborne 1999). This hypothesis is reasonable given the river's immense production of salmon (Northcote and Atagi 1997) and that its sockeye and pink runs pass through Haro Strait and surrounding waters. Heimlich-Boran (1986) correlated killer whale occurrence with salmon sport catch in the San Juan Islands and portions of Puget Sound, but did not describe the species or runs selected. Felleman et al. (1991) added that some small-scale winter occurrences of the whales were related to the presence of juvenile chinook, adult steelhead, and adult cutthroat trout (*Salmo clarkii*). Autumn movements of southern resident pods into Puget Sound roughly correspond with chum and chinook salmon runs (Osborne 1999), as illustrated by the presence of whales in Dyes Inlet during a strong run of chum in 1997. Both California sightings coincided with large runs of chinook salmon (K. C. Balcomb, unpubl. data). Northern resident occurrence in Johnstone Strait has been tied more strongly to the large seasonal runs of sockeye and pink salmon, as well as chum salmon to a lesser extent (Nichol and Shackleton 1996).

Without better knowledge of selected salmon runs, the effects on resident killer whales of changing salmon abundance in key runs cannot be judged. In former times, the whales may have simply moved to other areas with adequate food or shifted their diets to alternate fish stocks in response to the reduction of a heavily used run (Ford et al. 2000). These options may be less viable now due to broader declines of various fish populations in the region.

As already noted, there is an absence of comprehensive and accurate estimates of salmon abundance for significant portions of the ranges of southern and northern residents. In many cases, salmon population estimates from the 1800s to mid-1900s are crude or non-existent. Furthermore, estimates originate from a variety of sources and methods (i.e., catch data, escapement, or both) and therefore may not be comparable among or within locations (Bisson et al. 1992). Some include both wild and hatchery fish, whereas others tallied only one of these groups. Substantial interannual variability is also inherent in many stocks. Finally, concise summaries of specific run size information can be dauntingly difficult to locate within fisheries agency records. Despite these limitations, some general trends are apparent. Of greatest significance are the overall major reductions in the natural breeding populations of most species between the 1800s to mid-1900s (Table 3). Many runs have continued

to decrease since then, but others have partially recovered. Declines are particularly prevalent in Washington, Oregon, Idaho, and California due to greater human impacts on freshwater habitats as well as ocean productivity cycles, whereas populations in Alaska have been little affected (Nehlsen 1997, Wertheimer 1997, Kope and Wainwright 1998). Among naturally spawning salmon, 30 of the 49 evolutionarily significant population units (ESUs) in the western contiguous U.S. are currently listed as threatened (22 ESUs), endangered (4), or candidates for listing (4) under the federal Endangered Species Act. Half or more of all chinook, steelhead, and chum ESUs are listed. Some of the remaining 19 ESUs are predicted to become endangered unless specific recovery actions can be accomplished. Despite this overall pattern, an assessment of natural salmon stocks in Washington during the late 1980s and early 1990s found that of 309 stocks with sufficient data to assess current status, 60.5% were in fact healthy and 39.5% were depressed or of critical status (WDF et al. 1993). A disproportionately greater number of healthy stocks were located in Puget Sound, whereas more depressed and critical stocks occurred in the Columbia River basin.

Many wild salmon runs have been supplemented by significant numbers of hatchery-reared salmon since the 1950s and 1960s, when modern hatchery programs began being widely implemented (Mahnken et al. 1998). In Washington, hatchery fish now account for about 75% of all chinook and coho salmon and nearly 90% of all steelhead harvested. In Puget Sound, the amounts of artificially reared salmon are variable with species, but significant numbers of hatchery chinook and coho are present in many runs. The extent that resident whales consume hatchery salmon is unknown, but hatchery fish may represent an important part of the diet for southern residents.

For southern resident killer whales, salmon population levels are particularly crucial in and around the Georgia Basin and Puget Sound, which are the core area for these whales during much of the year. Overall salmon abundance in Puget Sound has been roughly stable or increasing for the past several decades, due largely to the strong performance of pink and chum salmon. Both species have been at or near historic levels of abundance for the past 20-25 years (Hard et al. 1996; Johnson et al. 1997; WDFW 2004; J. Ames, unpubl. data). No recent changes in salmon populations are obviously apparent that may be responsible for the decline of L pod.

Population trends of salmon stocks in the ranges of southern and northern resident killer whales are summarized below, along with those of several other known prey species. Brief discussions of additional factors affecting salmon abundance and productivity are also presented. Detailed accounts of the life history of Pacific salmon can be found in Groot and Margolis (1991), with summaries of occurrence in Washington presented in Wydoski and Whitney (2003).

Chinook salmon. Chinook are the least common species of salmon in the northeastern Pacific (Wydoski and Whitney 2003). Long- and short-term trends in the abundance of wild stocks are predominantly downward, with some populations exhibiting severe recent declines (Table 3). However, total abundance in Puget Sound, the eastern Strait of Juan de Fuca, and the lower Columbia River basin has been relatively high in recent decades due to production from hatcheries (Myers et al. 1998; B. Sanford, pers. comm.). All spring-run populations in these areas are depressed and most are likely to become endangered in the foreseeable future. Many of the formerly vast populations in the mid- to upper Columbia and Snake River basins have declined considerably or virtually disappeared, although some (e.g., fall runs in the upper Columbia) remain moderately large (WDF et al. 1993, Myers et al. 1998, WDFW and ODFW 2002). Total abundance along the Washington and Oregon coasts is relatively high and long-term population trends are generally upward, but a number of runs are experiencing severe recent declines. In British Columbia, chinook escapements were higher in the early 1990s than at any other time dating back to the 1950s, but concern remains over the depressed status of stocks in southern British Columbia

(Northcote and Atagi 1997, Henderson and Graham 1998). The status of stocks from southern

Table 3. Summary of historical and recent estimates of salmon numbers (in thousands) produced by western North American river systems between the Strait of Georgia and central California (adapted and updated from Krahn et al. 2002)[a].

Region	Period of time	Species					
		Chinook	Pink	Coho	Chum	Sockeye	Steelhead
Fraser River	Late 1800s to mid-1900s	750[b]	23,850[b]	1,230[b]	800[b]	925-40,200[c]	-
	Mid-1900s to early 1980s	150[b]	1,900-18,700[d]	160[b]	390[b]	967-18,800[c]	-
	Mid-1980s to early 1990s	140-280[e]	7,200-22,180[d]	40-100[b]	about 1,300[f]	3,770-22,000[c]	-
	Early 1990s to current	140-350[e]	3,600-21,200[d]	increasing[f]	13x greater since 1997[f]	3,640-23,600[c]	-
Puget Sound	Late 1800s to early 1900s	250-700[g]	1,000-16,000[g]	700-2,200[g]	500-1,700[g]	1,000-22,000[g]	-
	Mid-1900s	40-100[g]	350-1,000[h]	200-600[g]	300-600[h]	150-400[h]	-
	Mid-1980s to early 1990s	80-140[h]	1,000-1,930[i]	300-800[h]	1,040-2,030[j]	92-622[i]	-
	Early 1990s to current	40-170[h, k]	440-3,550[i]	200-500[h]	570-3,390[j]	37-555[i]	-
Coastal Washington	Mid- to late 1800s	190[l]	-	-	-	-	-
	Mid-1900s	-	-	-	80-100[h]	20-130[h]	-
	Mid-1980s to early 1990s	30-115[h]	-	40-130[h]	10-325[h]	15-80[h]	25-50[h]
	Early 1990s to current	50-65[h]	-	30-70[h]	60-175[h]	20-80[h]	30-40[h]
Columbia River	Mid- to late 1800s	5,000-9,000[m]	-	2,600-2,800[m]	500-1,400[m]	900-1,700[m]	570-1,350[m]
	Mid-1900s	565-1,410[n]	-	21-272[n]	2-59[n]	43-335[n]	250-440[n]
	Mid-1980s to early 1990s	410-1,140[n]	-	100-1,530[n]	1-5[n]	47-200[n]	254-560[n]
	Early 1990s to current	311-515[n]	-	74-550[n]	1-3[n]	9-94[n]	240-335[n]
Mid- to northern coastal Oregon	Mid- to late 1800s	300-600[o]	-	1,700[p]	-	-	-
	Mid-1900s	-	-	-	-	-	-
	Mid-1980s to early 1990s	30-50% decline[o]	-	100[p]	-	-	-
	Early 1990s to current	-	-	-	-	-	-
Northern coastal California	Mid- to late 1800s	300[l]	-	1,200[q]	-	-	-
	Mid-1900s	250[q]	-	200-500[r]	-	-	-
	Mid-1980s to early 1990s	-	-	13[r]	-	-	-
	Early 1990s to current	about 10-50[s]	-	-	-	-	-
Central Valley, California	Mid- to late 1800s	1,000-2,000[t]	-	-	-	-	-
	Mid-1900s	400-500[t]	-	-	-	-	-
	Mid-1980s to early 1990s	200-1,300[t]	-	-	-	-	-
	Early 1990s to current	300-600[t]	-	-	-	-	-

[a] Estimates may represent catch data, escapement, or estimated run size, and therefore may not be comparable between or within sites. Some estimates include hatchery fish. Early catch records for sockeye and pink salmon in Puget Sound are especially problematic because they include Fraser River salmon caught by American fishermen and landed in Puget Sound ports (J. Ames, pers. comm.).

[b] Northcote and Atagi (1997), catch and escapement; [c] I. Guthrie (unpubl. data); [d] B. White (unpubl. data); [e] DFO (1999), catch and escapement; [f] DFO (2001); [g] Bledsoe et al. (1989), catch only; [h] Johnson et al. (1997b), wild run sizes only; [l] J. Ames, unpubl. data; [j] WDFW (2004); [k] B. Sanford (unpubl. data) in Krahn et al. (2002); [l] Myers et al. (1998); [m] Northwest Power Planning Council (1986); [n] WDFW and ODFW (2002); [o] Nicholas and Hankin (1989); [p] Nickelson et al. (1992); [q] California Department of Fish and Game (1965); [r] Brown et al. (1994); [s] Mills et al. (1997); [t] Yoshiyama et al. (1998).

Oregon to California's Central Valley is variable, with a number of runs in poor condition or extirpated (Yoshiyama et al. 2000). Others (e.g., Rogue River, fall runs in the upper Klamath and Trinity Rivers and the Central Valley) remain fairly abundant, although hatchery fish tend to be a large component of escapements (Myers et al. 1998, Yoshiyama et al. 2000).

Pink salmon. Pink salmon are the most abundant species of Pacific salmon (Wydoski and Whitney (2003) and reach the southern limit of their primary spawning range in Puget Sound. Most odd-year populations in the sound and southern British Columbia appear healthy and current overall abundance is close to historical levels or increasing (Hard et al. 1996; Northcote and Atagi 1997; J. Ames, pers. comm.), whereas even-year runs are naturally small. Numbers in Puget Sound have been high (mean odd year run size = 1.47 million fish, range = 440,000-7.4 million) in most years since at least 1959 (J. Ames, unpubl. data). However, several populations along the Strait of Juan de Fuca and in Hood Canal are declining or possibly extinct. Considerable variation in run size can occur, as seen in the Fraser River, where odd-year runs varied from about 3.6 to 22.2 million between 1991 and 2001 (B. White, unpubl. data). Stocks in Puget Sound and British Columbia are comprised almost entirely of naturally spawning fish.

Coho salmon. Abundance south of Alaska has declined despite the establishment of large hatchery programs (Kope and Wainwright 1998). A number of risk factors, including widespread artificial propagation, high harvest rates, extensive habitat degradation, a recent dramatic decline in adult size, and unfavorable ocean conditions, suggest that many wild stocks may encounter future problems (Weitkamp et al. 1995). Populations supplemented with large numbers of hatchery fish are considered near historical levels in Puget Sound and the Strait of Georgia, with overall trends considered stable (Weitkamp et al. 1995). Natural coho populations in British Columbia have been in decline since the 1960s (Northcote and Atagi 1997, Henderson and Graham 1998), while those in the lower Columbia River basin and along the coasts of Oregon and northern California are in poor condition (Weitkamp et al. 1995). Most coho in the Columbia basin originate from hatcheries.

Chum salmon. Chum salmon are abundant and widely distributed in Puget Sound and the Strait of Georgia, and currently comprise the majority of wild salmon in many river systems. Autumn runs are prevalent in both areas. Recent numbers in Puget Sound are at or near historic levels (Table 3), fluctuating between about 0.6 and 2.6 million fish (including hatchery fish) from the early 1980s to 1998 (WDFW 2004). Numbers dropped to fewer than 700,000 fish in 1999 and 2000 due to unfavorable ocean conditions, but rebounded strongly in 2001 and 2002, with run size estimated at nearly 3.4 million fish in 2002 (WDFW 2002, 2004). Hatchery fish comprise 19-47% of the total population in any given year. Although chum abundance in British Columbia is characterized by large annual fluctuations, overall escapements have been slowly increasing since the 1950s (Henderson and Graham 1998). However, numbers remain lower than those observed in the early 1900s (Henderson and Graham 1998). The Columbia River once supported commercial landings of hundreds of thousands of chum salmon, but returning numbers fell drastically in the mid-1950s and never exceeded 5,000 fish per year in the 1990s (WDFW and ODFW 2002). Stock sizes are variable along the Washington coast, but are low relative to historic levels on the Oregon coast.

Sockeye salmon. Sockeye are the second most common species of salmon in the northeastern Pacific (Wydoski and Whitney 2003). Only three of Washington's nine sockeye salmon populations are considered healthy (WDF et al. 1993) and many are naturally small (Gustafson et al. 1997). Declines are especially noticeable in the Columbia basin (Table 3; WDFW and ODFW 2002). From 1993-2002, run size of the introduced stock in the Lake Washington system averaged 230,000 fish (range = 35,000-548,000) (J. Ames, unpubl. data). Sockeye numbers have been recovering in British Columbia since the 1920s (Northcote and Atagi 1997, Henderson and Graham 1998). The Fraser

River holds the largest run, usually accounting for more than half of all sockeye production in the province. Huge runs occur cyclically every four years in the river and elsewhere in southern British Columbia, which may have a substantial effect on annual food availability for southern resident killer whales. Between 1990 and 2002, run sizes varied from about 3.6 to 23.6 million fish (I. Guthrie, unpubl. data).

Steelhead. More than half of the assessed wild populations in Washington are considered depressed (WDF et al. 1993) and many are declining (Busby et al. 1996). However, stocks throughout the state are heavily supplemented with hatchery fish. Populations are largest in the Columbia River basin (Table 3), where summer runs have generally increased since the 1970s and winter runs have declined (WDFW and ODFW 2002). Wild coastal steelhead populations are considered healthy in Washington (WDFW 2002), but are largely in decline in Oregon and northern California (Busby et al. 1996).

Hatchery production. Hatchery production has partially compensated for declines in many wild salmon populations and therefore has likely benefited resident killer whales to some undetermined extent. However, hatcheries are also commonly identified as one of the factors responsible for the depletion of wild salmon stocks. Competition for food and other resources between hatchery and wild fish may reduce the number of wild fish that can be sustained by the habitat (Flagg et al. 1995, Levin et al. 2001). Physical and genetic interactions between wild and hatchery fish can weaken wild stocks by increasing the presence of deleterious genes (Reisenbichler 1997, Reisenbichler and Rubin 1999). Predation by hatchery fish may also harm wild populations.

Salmon size. Many North Pacific populations of five salmon species have declined in physical size during the past few decades (Bigler et al. 1996). For example, mean weights of adult chinook and coho salmon from Puget Sound have fallen by about 30% and 50%, respectively (Weitkamp et al. 1995; Quinn et al. 2001; B. Sanford, pers. comm.). In the Columbia River, chinook weighing 50-60 lb were once a small but regular component of runs, but are now a rarity. Size reductions have been linked to abundance levels and ocean condition (Bigler et al. 1996, Pyper and Peterman 1999), but other factors such as harvest practices, genetic changes, effects of fish culture, and density-dependent effects in freshwater environments attributable to large numbers of hatchery releases may also play a role (Weitkamp et al. 1995). Heavy fishing pressure often produces younger age distributions in populations, resulting in fewer salmon maturing in older age classes and a smaller overall average adult size (Pess et al. 2003; J. Ames, pers. comm.). Hatcheries also have a tendency to produce returning adults that are younger and smaller (B. Sanford, pers. comm.). Reduced body size not only poses a number of risks to natural salmon populations, but may also impact killer whales and other predators. Smaller fish may influence the foraging effectiveness of killer whales by reducing their caloric intake per unit of foraging effort, thus making foraging more costly. A combination of smaller body sizes and declines in many stocks means an even greater reduction in the biomass of salmon resources available to killer whales.

Salmon body composition. In at least a few populations, hatchery salmon differ from wild salmon in their energy value for killer whales by lacking the heavier fat deposits of the wild fish. This is seen in Puget Sound, where wild spring run chinook salmon possess higher fat levels than their hatchery counterparts (B. Sanford, pers. comm.). Larger amounts of fat are required by wild fish for swimming to spawning sites located farther upstream and to survive their naturally long residency period in rivers prior to spawning. Energy value and possibly nutritional quality differ among salmon species. Osborne (1999) reported the caloric content of five Pacific salmon species as follows: chinook, 2,220 kcal/kg; sockeye, 1,710 kcal/kg; coho, 1,530 kcal/kg; chum, 1,390 kcal/kg; and pink, 1,190 kcal/kg. Thus, prey switching from a preferred but declining salmon species to a more abundant alternate species may result in lowered energy intake for resident killer whales.

Salmon distribution. Habitat alteration, hatchery and harvest practices, and natural events have combined to change regional and local patterns of salmon distributions during the past 150 years, but especially since about 1950 (Bledsoe et al. 1989, Nehlsen 1997). Some historically productive populations are no longer large, whereas other runs may have increased in abundance through hatchery production. Limited evidence indicates that hatcheries do not greatly change the pelagic distribution of coho salmon (Weitkamp et al. 1995), but they can strongly influence the nearshore presence of salmon and thus the availability of salmon for predators (Krahn et al. 2002). Within Puget Sound and the Strait of Georgia, it is unknown whether changes in salmon distribution have accompanied long-term changes in abundance. However, salmon distribution is believed to have remained consistent in this region since at least the 1960s. In particular, pink and chum salmon currently occupy nearly all of the habitat that would have been available historically (J. Ames, pers. comm.).

Perhaps the single greatest change in food availability for resident killer whales since the late 1800s has been the decline of salmon in the Columbia River basin. Estimates of predevelopment run size vary from 10-16 million fish (Table 3; Northwest Power Planning Council 1986) and 7-30 million fish (Williams et al. 1999), with chinook salmon being the predominant species present. Since 1938, annual runs have totaled just 750,000 to 3.2 million salmon (WDFW and ODFW 2002). Returns during the 1990s averaged only 1.1 million fish, representing a decline of 90% or more from historical levels. With so many salmon once present, the Columbia River mouth may well have been a highly attractive feeding site for southern resident whales. Furthermore, with several recent suspected records of northern residents traveling as far south as Grays Harbor, it is conceivable that this community visited the river mouth as well.

Seasonal availability. Even though salmon are currently considered relatively numerous in a number of areas (when hatchery fish are included), patterns of seasonal availability differs from historical patterns in some instances. Thus, resident killer whales may have lost some seasonally important sources of prey, while perhaps gaining others, as seen in the examples that follow. Natural salmon runs throughout the region have always been greatest from August to December, but there may have been more spring and summer runs in the past (J. Ames, pers. comm.). In particular, spring and summer chinook salmon were abundant in the Columbia River until about the late 1800s (Lichatowich 1999). Populations of spring chinook have also declined severely in Puget Sound so that most runs now occur in the late summer and fall (B. Sanford, pers. comm.). This problem may be partially offset by the relatively recent presence of "blackmouth" salmon, which are a hatchery-derived form of chinook that reside year-round in Puget Sound. Through deliberate management programs, these fish have been present in large enough numbers to support a recreational fishing season since the 1970s. Contractions in run timing can also affect food availability for killer whales, as seen in several Washington populations of hatchery coho salmon, where return timing was condensed from about 14 weeks to 8 weeks during a 14-year period even though total fish numbers remained about the same (Flagg et al. 1995).

Climatic variability. A naturally occurring climatic pattern known as the Pacific Decadal Oscillation has recently been identified as a major cause of changing marine productivity and salmon abundance in the North Pacific (Mantua et al. 1997, Beamish et al. 1999, Hare et al. 1999, Benson and Trites 2002). The system is characterized by alternating 20-30-year shifts in ocean temperatures across the region, which produced cooler water temperatures from 1890-1924 and 1947-1976 and warmer water temperatures from 1925-1946 and 1977 to at least 2001. Cooler periods promote coastal biological productivity off the western contiguous U.S. and British Columbia, but inhibit productivity in Alaska, whereas warmer phases have the opposite effect (Hare et al. 1999). Salmon are probably most affected through changes in food availability and survival at sea (Benson and Trites 2002), but associated terrestrial weather patterns may also be

a factor. Higher rainfall at certain times of the year during warm regimes can cause greater stream flow and flooding in western Washington, thereby reducing salmon egg survival (J. Ames, pers. comm.). The most recent warm period has been strongly tied to lower salmon production south of Alaska (Hare et al. 1999). Greater salmon numbers in Washington during the past several years indicate that the latest warm phase has concluded. Evidence suggests that the Pacific Decadal Oscillation has existed for centuries, which implies that sizable fluctuations in salmon abundance are a natural pattern in the North Pacific (Beamish et al. 1999, Benson and Trites 2002).

Although not necessarily related to the Pacific Decadal Oscillation, changes in ocean temperature also directly influence salmon abundance in the Strait of Juan de Fuca and the vicinity of the San Juan Islands. In years when ocean conditions are cooler than usual, the majority of sockeye salmon returning to the Fraser River do so via this route, but when warmer conditions prevail, migration is primarily through Johnstone Strait (Groot and Quinn 1987).

Other fish species. Declines in abundance have also been recorded in some of the other known prey of resident killer whales. The Pacific herring stock in the Georgia Basin and Puget Sound collapsed from overharvesting in the 1960s, but recovered to high levels by the late 1970s through better management practices (DFO 2002a). However, some subpopulations, such as those at Cherry Point and Discovery Bay in Puget Sound, have fallen so low that they may now be threatened (Stout et al. 2001). Herring abundance has also decreased off western Vancouver Island since 1989, probably because of warm ocean temperatures (DFO 2001). Heavy fishing pressure was responsible for decreases in lingcod populations throughout British Columbia during the 1970s (DFO 2002b). Numbers generally responded to improved management and rebounded during the 1980s and early 1990s, but have again declined in subsequent years. Abundance has remained low in the Strait of Georgia since the 1980s. Excessive exploitation has also caused rockfish stocks to plummet along much of the Pacific coast in recent decades (Bloeser 1999, Love et al. 2002). Copper, brown, and quillback rockfishes are among the most affected species in Puget Sound. In contrast to the species mentioned above, catch data suggest significant growth in Pacific halibut populations in British Columbia and Washington from the mid-1970s to late 1990s (International Pacific Halibut Commission 2002).

Prey availability summary. Resident killer whales have likely been exposed to natural changes in the availability of salmon and some other prey for millennia. During the past century and a half, human harvest pressures and alterations to the environment have undoubtedly caused important changes in food availability for resident whales. Due to a lack of information on many topics, especially which species runs are important, it is unknown whether current fish stocks are a limiting factor for either population of resident whales. Favorable ocean conditions across the region in the next decade or two may temporarily alleviate possible food limitations by boosting overall salmon numbers. Nevertheless, the long-term prognosis for salmon recovery in the region is unclear. Improved management programs will undoubtedly benefit some salmon populations, but continued human population growth and urbanization will place greater pressure on freshwater and marine ecosystems and challenge the efforts of managers seeking to achieve meaningful recovery (Langer et al. 2000).

Reduction of Prey Populations: Transients

Harbor seals and other marine mammals are the preferred prey of transient killer whales (Baird and Dill 1996, Ford et al. 1998, Ford and Ellis 1999), but the extent that transients rely on specific seasonal and local sources of prey is less understood. In a few instances, some transients are known to take advantage of specific seasonal food sources, such as harbor seal pupping sites (Baird and Dill 1995). As with resident whales, transients also experienced serious historical declines in their prey base. From the late 1800s to late 1960s, overhunting caused large declines or

extirpations in seal, sea lion, and large whale populations between southeastern Alaska and California (Scheffer 1928, Bonnot 1951, Newby 1973, Ford and Ellis 1999, Gregr et al. 2000, Jeffries et al. 2003, Springer et al. 2003). Numbers of harbor seals and Steller's sea lions were reduced as much as 90% in British Columbia (Olesiuk et al. 1990b, Ford and Ellis 1999). Seal numbers in the region have grown 7 to 12-fold since about 1970 and are now close to or at carrying capacity (Olesiuk 1999, Jeffries et al. 2003). Regional whale populations crashed even more severely, but have not recovered in most cases (Gregr et al. 2000). Recovery of the gray whale population is one notable exception (National Marine Fisheries Service 1993). Partial recovery of regional humpback whale populations has also occurred (Carretta et al. 2002). With the recovery of some pinniped populations, Ford et al. (2000) believed that transient whales no longer face a scarcity of prey.

The following recent population estimates have been made for marine mammals that are important prey of transient killer whales. Population sizes of harbor seals are estimated to number 24,732 (CV = 0.12) animals along the Washington and Oregon coasts, 14,612 (CV = 0.15) animals in Washington's inland waters, 108,000 animals in British Columbia, 30,293 animals in California, and 37,450 (CV = 0.073) animals in southeastern Alaska (Olesiuk 1999, Angliss and Lodge 2002, Carretta et al. 2002). The eastern Pacific stock of Steller's sea lions contains an estimated minimum of 31,028 individuals from southeastern Alaska to California (Angliss and Lodge 2002). The estimated U.S. population of California sea lions ranges from 204,000 to 214,000 animals (Carretta et al. 2002). The estimated abundance of the Dall's porpoise stock from California to Washington is 117,545 (CV = 0.45) individuals (Carretta et al. 2002). Stocks of harbor porpoise are estimated to be 39,586 (CV = 0.38) animals for the Washington and Oregon coasts and 3,509 (CV = 0.40) animals for Washington's inland waters (Carretta et al. 2002). The estimated abundance of the eastern North Pacific stock of gray whales is 26,635 (CV = 0.10) animals (Angliss and Lodge 2002). Population estimates of humpback whale stocks in the eastern and central North Pacific are 856 (CV = 0.12) animals and 4,005 (CV = 0.095) animals, respectively (Angliss and Lodge 2002, Carretta et al. 2002).

Disturbance by Underwater Noise and Vessel Traffic

Many marine mammal populations are experiencing ever-increasing amounts of indirect harassment through expanding contact with human-made sources of marine noise and vessel traffic. Underwater noise pollution originates from a variety of sources, including general shipping and boating traffic, industrial activities such as dredging, drilling, marine construction, and seismic testing of the sea bottom, and military and other vessel use of sonar (Richardson et al. 1995, Gordon and Moscrop 1996, National Research Council 2003). Many of these activities are prevalent in coastal areas, coinciding with the preferred habitat of most killer whale populations. Killer whales rely on their highly developed acoustic sensory system for navigating, locating prey, and communicating with other individuals. Excessive levels of human-generated noise have the potential to mask echolocation and other signals used by the species, as well as to temporarily or permanently damage hearing sensitivity. Loud sounds may therefore be detrimental to survival by impairing foraging and other behavior, resulting in a negative energy balance (Bain and Dahlheim 1994, Gordon and Moscrop 1996, Erbe 2002, Williams et al. 2002a, 2002b). Such noise may also alter the movements of prey, further affecting foraging efficiency. Furthermore, chronic stress from noise exposure, as well as repeated disturbance from vessel traffic, can induce harmful physiological conditions, such as hormonal changes, lowered immune function, and pathology of the digestive and reproductive organs (Gordon and Moscrop 1996). In extreme cases, high-intensity sounds (e.g., those from certain types of sonar) are potentially lethal by directly damaging lungs, sinuses, the gastro-intestinal tract, and other body tissues, or by causing hemorrhages (Gordon and Moscrop 1996). The threshold levels at which underwater noise

becomes harmful to killer whales remain poorly understood (Krahn et al. 2002).

In addition to the problem of noise, the physical presence of vessels can disrupt killer whale movements and normal behavioral patterns, especially when encounters are frequent. Commercial shipping and recreational boating traffic has expanded in many regions in recent decades, increasing the likelihood of interactions between whales and vessels. In Washington, both types of vessel traffic have grown over time with the state's expanding economy and human population.

Whale watching, naval sonar use, and deployment of acoustical harassment devices at salmon farms have drawn the most attention in Washington and British Columbia as being activities that are potentially disruptive and harmful to killer whale populations.

Whale watching. Whale watching has become an important tourist industry in many localities around the world since the early 1980s (Hoyt 2001, 2002). In addition to boosting the economies of coastal communities and providing an economic basis for preserving whale populations, whale watching has also proven beneficial by increasing public awareness of marine mammals and the environmental issues confronting them (Barstow 1986, Tilt 1986, Duffus and Deardon 1993, Lien 2001). In Washington and British Columbia, killer whales are the main target species of the commercial whale-watching industry, easily surpassing other species such as gray whales, porpoises, and pinnipeds (Hoyt 2001). Killer whale watching in the region is centered primarily on the southern and northern residents, which can be found more reliably than transients or offshores. Viewing activity occurs predominantly in and around Haro and Johnstone Straits, which are the summer core areas of the two resident communities. However, Haro Strait supports a considerably greater industry because of its proximity to urban areas. Both commercial and private vessels engage in whale watching, as well as kayaks and small numbers of aircraft. In addition, land-based viewing is popular at locations such as Lime Kiln State Park, San Juan County Park, and the San Juan County land bank on San Juan Island, Turn Point on Stuart Island, and East Point on Saturna Island (K. Koski, pers. comm.). Lime Kiln State Park was established in 1985 by the Washington State Parks and Recreation Commission for the purpose of watching killer whales (Ford et al. 2000) and receives about 200,000 visitors per year, most of whom hope to see whales (W. Hoppe, pers. comm.).

Commercial viewing of killer whales began in Washington and southern British Columbia in 1977 and persisted at a small scale through the early 1980s, with just a few boats operating and fewer than 1,000 passengers serviced per year (Osborne 1991, Baird 2002, Osborne et al. 2002). The first full-time commercial whale-watching vessel began frequent service in 1987 (Baird 2002). Activity expanded to about 13 active vessels (defined as making more than one trip per week) and 15,000 customers by 1988 (Osborne 1991), then jumped sharply from 1989 to 1998, when vessel numbers grew to about 80 boats and passenger loads increased to about half a million customers per year (Osborne et al. 2002). Small reductions in the numbers of companies, active boats, and passengers have occurred since then. About 37 companies with 73 boats were active in 2003; passenger levels were estimated at 450,000 people in both 2001 and 2002 (K. Koski, unpubl. data). Most companies belong to an industry organization known as the Whale Watch Operators Association Northwest, which was formed in 1994 to establish a set of whale viewing guidelines for commercial operators and to improve communication among companies (Whale Watch Operators Association Northwest 2003). The majority of commercial vessels were based in Washington during the 1980s, but this has gradually shifted so that Canadian boats comprised 65% of the industry in 2002 (Osborne et al. 2002). Most companies are based in Victoria or the San Juan Islands, but others operate from Bellingham, La Conner, Everett, Port Townsend, and Vancouver. Commercial whale-watching boats range in size and configuration from open vessels measuring under 7 m in length and capable of

holding 6-16 people to large 30-m-long passenger craft that can carry up to 280 customers. Many boats routinely make two or three trips per day to view whales. Commercial kayaking operations include about six active companies that are focused on whale watching, plus another 18 companies or so that occasionally view whales (K. Koski, pers. comm.). At least one business offers occasional airplane viewing. The San Juan Islands and adjacent waters also attract large numbers of private boaters for recreational cruising and fishing. Many of these participate in viewing whales whenever the opportunity arises. Currently, about 64% of the craft seen with whales are commercially operated, with the remainder privately owned (Marine Mammal Monitoring Project 2002, Osborne et al. 2002). Additionally, private floatplanes, helicopters, and small aircraft take regular advantage of opportunities to view whales (Marine Mammal Monitoring Project 2002).

Hoyt (2001) assessed the value of the overall whale-watching industry in Washington at US$13.6 million (commercial boat-based viewing, $9.6 million; land-based viewing, $4.0 million) and in British Columbia at US$69.1 million (commercial boat-based viewing, $68.4 million; land-based viewing, $0.7 million) in 1998, based on estimated customer expenditures for tours, food, travel, accommodations, and other expenses. An estimated 60-80% of this value likely originated from the viewing of killer whales in the Georgia Basin and Puget Sound (R. W. Osborne, pers. comm.). More recent estimates of the economic value of whale watching in the region are unavailable. Expenditures by the users of private whale-watching vessels are also unknown.

The growth of whale watching during the past few decades has meant that killer whales in the region are experiencing unprecedented contact with vessels. Not only do greater numbers of boats accompany the whales for longer periods of the day, but there has also been a gradual lengthening of the viewing season. Commercial viewing activity during the summer now routinely extends from 9:00 a.m. to 9:00 p.m., with the heaviest pressure between 10:00 a.m. and 5:00 p.m. (Osborne et al. 2002; K. Koski, pers. comm.). However, some viewing may begin as early as 6:00 a.m. (Bain 2002). Thus, many resident whales are commonly accompanied by boats throughout much or all of the day. The commercial whale-watching season now usually begins in April, is heaviest during the warmer summer months, and largely winds down in October, but a small amount of traffic occurs throughout the winter and early spring whenever whales are present (K. Koski, pers. comm.). Viewing by private craft follows a similar seasonal pattern. J pod is considered the most commonly viewed pod, with L pod being the least viewed (Bain 2002; K. Koski, pers. comm.; R. W. Osborne, pers. comm.).

The mean number of vessels following groups of killer whales at any one time during the peak summer months increased from five boats in 1990 to 18-26 boats from 1996-2002 (Osborne et al. 1999, 2002, Baird 2001, Erbe 2002, Marine Mammal Monitoring Project 2002). However, the whales sometimes attract much larger numbers of vessels. Annual maximum counts of 72-120 boats were made near whales from 1998-2002 (Osborne et al. 2002). In these cases, commercial vessels totaled no more than 35 craft, thus the majority of boats present were privately owned. Baird (2002) described one instance of a small fleet of 76 boats that simultaneously viewed about 18 members of K pod as they rested along the west side of San Juan Island in 1997. The ring of boats surrounding the whales included kayaks, sailboats, and a wide assortment of different-sized powerboats measuring up to about 30 m. Unusual occurrences of whales have the potential to draw even greater numbers of vessels. The month-long presence of killer whales at Dyes Inlet in Bremerton in the autumn of 1997 attracted up to 500 private whale-watching boats on weekends.

Worries that whale watching may be disruptive to killer whales date back to the 1970s and early 1980s, when viewing by relatively small numbers of vessels became routine (Kruse 1991). The tremendous expansion of commercial and private viewing in recent years has greatly added to concerns (Osborne 1991, Duffus and Deardon

1993, Lien 2001, Erbe 2002, Williams et al. 2002a, 2002b). The southern residents in particular have been exposed to large amounts of noise generated by whale-watching vessels since the early 1990s (Bain 2002). This has caused whale-watching activity to be cited as possibly an important contributing factor in the recent decline of this population (Baird 2001, Bain 2002, Krahn et al. 2002). Whale-watching vessels can produce high levels of underwater sound in close proximity to the animals. Noise levels vary with vessel and engine type and become louder as speed increases (Bain 2002, Erbe 2002). Outboard-powered vessels operating at full speed produce estimated noise levels of about 160-175 decibels with reference to one microPascal at one meter (dB re 1 µPa at 1 m hereafter) (Bain 2002, Erbe 2002). Inflatables with outboard engines are slightly louder than rigid-hull powerboats with inboard or stern-drive engines (Erbe 2002). Bain (2002) reported that the shift in predominance from American to Canadian-owned commercial craft during the 1990s has likely led to greater noise exposure for the whales. Many Canadian boats are small outboard powered craft, whereas most American vessels are larger and diesel powered. By modeling vessel noise levels, Erbe (2002) predicted that the sounds of fast boats are audible to killer whales at distances of up to 16 km, mask their calls up to 14 km away, elicit behavioral responses within 200 m, and cause temporary hearing impairment after 30-50 minutes of exposure within 450 m. For boats moving at slow speeds, the estimated ranges fall to 1 km for audibility and masking, 50 m for behavioral reactions, and 20 m for temporary hearing loss. It should be noted that underwater sound propagation can vary considerably depending on water depth and bottom type, thus noise measurements may not be applicable between locations (Richardson et al. 1995).

Several studies have linked vessel noise and traffic with short-term behavioral changes in northern and southern resident killer whales (Kruse 1991; Jelinski et al. 2002; Williams et al. 2002a, 2002b; J. Smith, unpubl. data). Individuals can react in a variety of ways to the presence of whale-watching vessels. Responses include swimming faster, adopting less predictable travel paths, making shorter or longer dives, moving into open water, and altering normal patterns of behavior at the surface (Kruse 1991; Jelinski et al. 2002; Williams et al. 2002a; J. Smith, unpubl. data), while in some cases, no disturbance seems to occur (R. Williams, unpubl. data). Avoidance tactics often vary between encounters and the sexes, with the number of vessels present and their proximity, activity, size, and loudness affecting the reaction of the whales (Williams et al. 2002a, 2002b). Avoidance patterns often become more pronounced as boats approach closer. Kruse (1991) observed that northern resident whales sometimes reacted even to the approach of a single boat to within 400 m. This study also reported a lack of habituation to boat traffic over the course of one summer. However, further research by Williams et al. (2001, 2002a, 2002b) indicated a reduction in the intensity of northern resident responses to vessels between the mid-1980s and mid-1990s, possibly because of gradual habituation, changes in the avoidance responses of the whales, or sampling differences between the two studies. Disturbance by whale-watching craft has also been noted to cause newborn calves to separate briefly from their mothers' sides, which may lead to greater energy expenditures by the calves (J. P. Schroeder, pers. comm.).

Transient killer whales also receive considerable viewing pressure when they venture into the Georgia Basin and Puget Sound (Baird 2001). No studies have focused on their behavioral responses to whale-watching vessels to determine whether they resemble those of residents. Because transients may depend heavily on passive listening for prey detection (Barrett-Lennard et al. 1996), their foraging success is more likely affected by vessel presence than with residents (Ford and Ellis 1999, Baird 2001).

Whale-watching vessels generally employ one of two methods for approaching and viewing killer whales. "Paralleling" involves a boat that slowly cruises alongside the whales, preferably at a distance of greater than 100 m, as specified under current guidelines (see below). This style usually allows the passengers to see more of the whales

and their behavior, but keeps them farther from the animals. The second technique is known as "leapfrogging" and involves a vessel that moves ahead of the whales by paralleling them for some distance at a faster speed (Williams et al. 2002b). The vessel then turns 90º to place itself directly in the whales' anticipated path and waits for their approach while sitting in a stationary position with its engines put in idle or turned off. If the whales maintain their approximate travel course, they often swim closely past the boat or even underneath it, giving passengers a better close-up viewing opportunity. Private boaters usually engage in leapfrogging more than commercial operators (William et al. 2002b). Both styles of watching induce similar evasive responses by the whales, but leapfrogging appears to cause greater path deviation (Williams et al. 2002a, 2002b). Vessels speeding up to leapfrog also emit greater noise levels that are of higher frequency, and therefore have greater potential to mask communication in the whales than paralleling craft (Bain 2002). Furthermore, masking is more likely to occur from vessels placed in front of the whales (Bain and Dahlheim 1994, Bain 2002).

Researchers and photographers during the 1970s suspected that their own vessels affected killer whale behavior and developed an unofficial code of conduct intended to reduce the impacts of their activity on the whales (Bain 2002). These initial rules addressed the proximity between vessels and whales, vessel speeds, and the orientation of vessels relative to whales. As whale watching in Washington and southern British Columbia became increasingly popular, a set of voluntary guidelines was eventually established in the late 1980s by The Whale Museum in Friday Harbor to instruct commercial operators and recreational boaters on appropriate viewing practices. These also functioned as a proactive alternative to stricter legal enforcement of American and Canadian regulations (i.e., the Marine Mammal Protection Act and Fisheries Act, respectively), which prohibit harassment of the whales. In 1994, the newly formed Whale Watch Operators Association Northwest prepared an improved set of guidelines aimed primarily at commercial operators (Whale Watch Operators Association Northwest 2003). Regular review and updating of the guidelines has occurred since then. The current "Be Whale Wise" guidelines (Appendix B) were issued in 2002 with input from the operator's association, whale advocacy groups, and governmental agencies. These guidelines suggest that boaters parallel whales no closer than about 100 m, approach the animals slowly from the side rather than from the front or rear, and avoid putting their vessel within about 400 m in front of or behind the whales. Vessels are also recommended to reduce their speed to about 13 km/hr within about 400 m of the whales and to remain on the outer side of whales near shore. A variety of other recommendations are also provided. Commercial operators have also agreed not to accompany whales into two areas off San Juan Island, an action that many private boaters follow as well. The first is a ½-mile (800 m)-wide zone along a 3-km stretch of shore centered on the Lime Kiln lighthouse. The area was designated in 1996 to facilitate shore-based viewing of whales and to reduce vessel presence in an area used preferentially by the whales for feeding, traveling, and resting. The second is a ¼-mile (400 m)-wide zone along much of the west coast of San Juan Island from Eagle Point to Mitchell Point. This was established in 1999 for the purpose of giving whales uninterrupted access to inshore habitats.

Most commercial whale-watching boats generally appear to honor the guidelines, with overall adherence rates improving over time (K. Koski, pers. comm.). However, infractions persist (Table 4). A greater problem lies with recreational boaters, who are much less likely to know about the guidelines and proper viewing etiquette (Lien 2001, Erbe 2002). As a result, several programs have been established to improve the awareness and compliance of private whale watchers, but these have had a beneficial impact on commercial operators as well. They include the Soundwatch Boater Education Program, which The Whale Museum has operated since 1993 largely through private grants and donations. A Canadian counterpart program known as the Marine Mammal Monitoring Project (M3) began in 2001 through the Veins of Life Watershed Society, with principal funding from the Canadian federal

Table 4. Types and relative occurrence of infractions of voluntary whale-watching guidelines witnessed by the Soundwatch Boater Education Program in Washington and southern British Columbia, 1998-2002 (data provided by The Whale Museum's Soundwatch Boater Education Program). Infractions were committed by commercial and recreational vessels and aircraft in the act of whale watching.

Type of infraction	Percent of infractions[a]
Parked in path of whales[b]	31.6
Within the 400-m-wide San Juan Island no-boat zone	21.4
Inshore of whales	20.8
Other[c]	7.6
Aircraft within 300 m of whales	6.4
Under power within 100 m of whales	5.0
Crossing the path of whales	3.6
Chasing or pursuing whales	2.0
Within the 800-m-wide Lime Kiln no-boat zone	1.8
Total	100.2

[a] Based on 2,634 infractions observed from 1998-2002.
[b] Includes leapfrogging and repositioning.
[c] Includes a variety of infractions, such as repeated circling by aircraft, operating a vessel at fast speeds within 400 m of whales, drifting into the path of whales, and operating a vessel within the protected zone around seabird nesting areas and marine mammals haul-out sites.

government. Both programs work cooperatively in the waters of both countries. A third program known as Straitwatch has operated in the vicinity of Johnstone Strait under the guidance of the Johnstone Strait Killer Whale Interpretive Centre Society since 2002. The programs educate the boating public through several methods, the most visible of which is the use of small patrol boats that are on the water with whale-watching vessels on a daily basis during the peak whale-watching season. Crews do not have enforcement capability, but monitor and gather data on boater activities and inform boat operators of whale-watching guidelines and infractions. Monitoring of commercial craft is also performed. Program staff also distribute informational materials and give public presentations to user groups. These programs have been very successful in improving the overall behavior of recreational and commercial whale watchers, especially when their patrol craft are operating on the scene (J. Smith, unpubl. data; K. Koski, pers. comm.).

Aircraft are not specifically mentioned in the "Be Whale Wise" guidelines. However, recommendations for aircraft are incorporated into a broader set of regional whale-watching guidelines prepared by the National Marine Fisheries Service. These advise aircraft to maintain a minimum altitude of 300 m (1,000 ft) above all marine mammals, including killer whales, and to not circle or hover over the animals. Violations of these recommendations have dramatically risen in the past four years and now represent about 10% of all infractions observed (Marine Mammal Monitoring Project 2002; K. Koski, unpubl. data).

The potential impacts of whale watching on killer whales remain controversial and inadequately understood. Although numerous short-term behavioral responses to whale-watching vessels have been documented, no studies have yet demonstrated a long-term adverse effect from whale watching on the health of any killer whale population in the northeastern Pacific. Both resident populations have shown strong site fidelity to their traditional summer ranges despite more than 25 years of whale-watching activity. Furthermore, northern resident abundance increased throughout much of this period, suggesting that this population was not affected to any great extent until perhaps recently. The

current decline of the southern resident population does not appear to follow a simple cause-and-effect relationship with the expansion of whale watching. Indeed, the statistical analyses of Bain (2002) most strongly indicated that the whale-watching fleet's buildup tracked the decline of the population from 1991-2001. Bain (2002) therefore speculated that a complex relationship with additional variables might be at work. Further confounding the matter is the fact that the heaviest watched pod (J pod) has shown an overall increasing trend in numbers since the 1970s and is currently at its highest recorded number. In contrast, L pod is considered the least viewed pod, but is the only one to undergo a substantial and continuing decline since 1996. It is important to note that research findings on the responses of the northern residents to vessel traffic are not necessarily applicable to the southern residents, which are exposed to much heavier viewing pressure (Williams et al. 2002a). Some researchers believe that the southern residents are more habituated to vessel traffic and have perhaps adapted to some of its adverse impacts. Nevertheless, concerns remain that populations may be experiencing subtle cumulative detrimental effects resulting from frequent short-term disturbance caused by whale watching. If recent levels of whale watching are indeed problematic for the southern residents, the population has much less opportunity than the region's other killer whale communities to relocate to other productive feeding areas with less disturbance (Bain 2002).

Military sonar use and other activities. The intense sound levels generated by some military sonar, when coupled with certain types of sea bottom, may sometimes be harmful to marine mammals (Balcomb and Claridge 2001). Current sonar designs produce signals of greater than 235 dB re 1 µPa at 1 m and can be heard underwater for up to 30 km. The signals are loud enough to damage the hearing of marine mammals and, in severe cases, can cause hemorrhaging around the brain and ear bones, resulting in death. Injuries (e.g., severe congestion and hemorrhaging in blood vessels and some tissues) in deep-diving species are consistent with gas bubble formation resulting from rapid decompression (Jepson et al. 2003). Strandings of cetaceans have been linked to naval sonar use at a number of locations (see summary in Balcomb and Claridge 2001). Animals appear to be especially vulnerable in confined waterways, where opportunities for escape are limited.

A clear example of the disruptive effects that military sonar use can have on killer whales and other marine mammals was seen in Haro Strait on 5 May 2003. A U.S. Navy guided-missile destroyer (*USS Shoup*) passed through the strait while operating its mid-frequency (3 kHz) AN/SQS-53C sonar during a training exercise. This type of sonar is widely used on Navy ships and has been linked to marine mammal strandings elsewhere. The test lasted about 4 hours and the sonar's pulses were loud enough to be heard above water by witnesses in the area. Twenty-two members of J pod happened to be at a preferred foraging area in the strait and performed a number of unusual behaviors in response to the sound (K. C. Balcomb, pers. comm.). Observers noted that the whales quickly stopped foraging and bunched up in a defensive manner. They then swam in close to shore at the surface, moved about in several different directions and appeared confused, and finally split apart and fled the area in opposite directions. As many as 100 Dall's porpoises were seen high-speed swimming over a long distance while rapidly departing the strait and a minke whale was observed porpoising over a distance of at least 4.5 km (K. C. Balcomb, pers. comm.). During the month after the incident, eight dead harbor porpoises and one Dall's porpoise washed ashore in the vicinity of the San Juan Islands and eastern Strait of Juan de Fuca (National Marine Fisheries Service 2004). Necropsies performed on seven of the harbor porpoises indicated that causes of death were due to blunt-force injury or illness (four animals) or could not be determined (three animals) (National Marine Fisheries Service 2004). No definite evidence of acoustic trauma was noted, but such injury could not be ruled out as a contributing factor in the deaths of any of the porpoises.

Naval exercises using mid-frequency sonar are infrequent in Washington's inland waters, but may occur with greater regularity off the outer coast. It is unknown whether such tests have previously affected killer whales or other marine mammals along the coast or elsewhere in the northeastern Pacific.

Canadian military authorities maintain a munitions testing area near Bentinct Island and Pedder Bay at the southern tip of Vancouver Island. Underwater detonations are sometimes performed at the site and occurred on one occasion when J pod was less than 1.5 km away, which caused the whales to suddenly change their direction of travel (R. W. Baird, pers. comm.). The U.S. Navy operates at least four ordnance training locations in Puget Sound, including sites at Crescent Harbor and Holmes Harbor off eastern Whidbey Island, Port Townsend Bay off Indian Island, and Hood Canal at Subase Bangor. Similar sites probably occur elsewhere in Washington and other U.S. waters with killer whales. Their operations likely have little impact on the species unless they take place when animals happen to be in the vicinity.

Civilian sonar use. Commercial sonar systems widely used on civilian vessels are often characterized by higher operating frequencies, lower power, narrower beam patterns, and shorter pulse lengths than military sonar (National Research Council 2003). Frequencies fall between 1 and 200 kHz or more, thus many systems function within the hearing range of marine mammals. Source levels of some units can reach 250 dB re 1 µPa at 1 m. Commercial depth sounders and fish detectors usually focus their sound downward and therefore may be less disruptive to killer whales than forward-looking sonars. Little information is currently available on the impacts of civilian sonar on killer whales and other marine mammals, but there is potential for conflicts under some circumstances.

Underwater acoustic harassment devices. The use of acoustic harassment devices at salmon aquaculture farms represents another source of disruptive noise for killer whales in Washington and British Columbia. The devices emit loud signals that are intended to displace harbor seals and sea lions away from the farms, thereby deterring predation, but can cause strong avoidance responses in cetaceans as well (Olesiuk et al. 2002). Morton and Symonds (2002) described one model that broadcast a 10 kHz signal at 194 dB re 1 µPa at 1 m and was potentially audible in open water for up to 50 km. During the early 1990s, the devices were installed at a number of salmon farms in Washington (including Cypress Island, Port Angeles, Rich Passage off Bainbridge Island, and Squaxin Island) and British Columbia, but were phased out of operation in Washington after just a few years (B. Norberg, pers. comm.; D. Swecker, pers. comm.; J. K. B. Ford, pers. comm.). Activation of the devices at a farm near northeastern Vancouver Island corresponded with drastic declines in the use of nearby passages and inlets by both resident and transient whales (Morton and Symonds 2002). It is unknown whether the devices ever produced similar impacts on killer whales in Washington or elsewhere in British Columbia. The only device still in use in Washington operates at the Ballard locks in Seattle, where the National Marine Fisheries Service utilizes it primarily during the spring steelhead run (B. Norberg, pers. comm.).

Environmental Contaminants

Organochlorines. Another primary factor in the decline of killer whales in the northeastern Pacific may be exposure to elevated levels of toxic chemical contaminants, especially organochlorine compounds (Ross et al. 2000, Center for Biological Diversity 2001, Krahn et al. 2002). Organochlorines comprise a diverse group of chemicals manufactured for industrial and agricultural purposes, such as polychlorinated biphenyls (PCBs), DDT, as well as unintentional by-products of industrial and combustion processes, such as the dioxins (PCDDs) and furans (PCDFs). Many organochlorines are highly fat soluble (lipophilic) and have poor water solubility, which allows them to accumulate in the fatty tissues of animals, where the vast majority of storage occurs (O'Shea 1999, Reijnders and Aguilar 2002). Some are highly persistent in the environment and resistant to metabolic

degradation. Vast amounts have been produced and released into the environment since the 1920s and 1930s. The persistent qualities of organochlorines mean that many are ultimately transported to the oceans, where they enter marine food chains. Bioaccumulation through trophic transfer allows relatively high concentrations of these compounds to build up in top-level marine predators, such as marine mammals (O'Shea 1999). The toxicity of several organochlorines has led to bans or restrictions on their manufacture and use in northern industrial countries (Barrie et al. 1992). Most agriculture uses of DDT ended in the U.S. in 1972 and in Canada from 1970-1978. Production of PCBs stopped in the U.S. in 1977 and importation into Canada was prohibited in 1980. However, these compounds continue to be used widely in other parts of the world, including Asia and Latin America. Organochlorines enter the marine environment through several sources, such as atmospheric transport, ocean current transport, and terrestrial runoff (Iwata et al. 1993, Grant and Ross 2002). As a result, these compounds have become distributed throughout the world, including seemingly pristine areas of the Arctic and Antarctic (Barrie et al. 1992, Muir et al. 1992). Much of the organochlorine load in the northern Pacific Ocean originates through atmospheric transport from Asia (Barrie et al. 1992, Iwata et al. 1993, Tanabe et al. 1994).

Killer whales are candidates for accumulating high concentrations of organochlorines because of their position atop the food chain and long life expectancy (Ylitalo et al. 2001, Grant and Ross 2002). Their exposure to contaminants occurs only through diet (P. S. Ross, pers. comm.). Mammal-eating populations appear to be especially vulnerable to accumulation of contaminants because of the higher trophic level of their prey, as compared to fish-eating populations (Ross et al. 2000).

Several studies have examined contaminant levels in killer whales from the North Pacific (Table 5). It should be noted that variable sample quality, limited background information, and different analytical techniques make direct comparisons between study results difficult (Ross et al. 2000, Ylitalo et al. 2001, Reijnders and Aguilar 2002). Organochlorine concentrations are also known to vary in relation to an animal's physiological condition (Aguilar et al. 1999). Most marine mammals lose weight during certain stages of their normal life cycles, such as breeding and migration, or from other stresses, including disease and reduced prey abundance and quality. The depletion of lipid reserves during periods of weight loss can therefore alter detected organochlorine concentrations, depending on whether a compound is redistributed to other body tissues or is retained in the blubber (O'Shea 1999). Perhaps most importantly, caution should be used when comparing contaminant levels between free-ranging presumably healthy whales and stranded individuals, which may have been in poor health before their deaths. Sick animals commonly burn off some of their blubber before stranding. Furthermore, stranded killer whales tend to be older individuals and therefore may be more contaminated (P. S. Ross, pers. comm.).

Ross et al. (2000) have recently described the contaminant loads of killer whale populations occurring in British Columbia and Washington. Male transient whales were found to contain significantly higher levels of total PCBs (SPCBs hereafter) than southern resident males, whereas females from the two communities carried similar amounts (Table 5). Both populations had much higher SPCB concentrations than northern resident whales. A similar pattern exists in Alaska, where transients from the Gulf of Alaska and AT1 communities contained SPCB levels more than 15 times higher than residents from the sympatric Prince William Sound pods of the southern Alaska community (Ylitalo et al. 2001). Profiles of specific PCB congeners were similar among the three killer whale communities from British Columbia and Washington, with congeners 153, 138, 52, 101, 118, and 180 accounting for nearly 50% of SPCB load (Ross et al. 2000).

Relatively low amounts of SPCDDs and SPCDFs were detected in these whales, possibly because these compounds are more easily metabolized or excreted than many PCB congeners (Ross et al. 2000). PCDD and PCDF levels in whales from

Table 5. SPCB, SDDT, and *p,p'*-DDE concentrations (mean ± SE, mg/kg, wet weight or lipid weight) reported in tissue samples from killer whale populations in the North Pacific.

Reference	Popula-tion[a]	Age and sex[b]	Sample size[c]	Sample locations[d]	Sample years	SPCBs[e]	SDDTs[e]	*p,p'*-DDE[e]
Studies of free-ranging animals that were biopsied or otherwise tested[f]								
Ross et al.	WCT	M	5	BC	1993-96	251 ± 55 (l)	-	-
(2000)	WCT	F	5	BC	1993-96	59 ± 21 (l)	-	-
	SR	M	4	BC	1993-96	146 ± 33 (l)	-	-
	SR	F	2	BC	1993-96	55 ± 19 (l)	-	-
	NR	AM	8	BC	1993-96	37 ± 6 (l)	-	-
	NR	AF	9	BC	1993-96	9 ± 3 (l)	-	-
Ylitalo et al.	AT	M, F	13	AK	1994-99	59 ± 12 (w)	83 ± 17 (w)	71 ± 15 (w)
(2001)	AT	M, F	13	AK	1994-99	230 ± 36 (l)	320 ± 58 (l)	280 ± 50 (l)
	SAR	M, F	64	AK	1994-99	3.9 ± 0.6 (w)	3.8 ± 0.6 (w)	3.1 ± 0.5 (w)
	SAR	M, F	64	AK	1994-99	14 ± 1.6 (l)	13 ± 1.8 (l)	11 ± 1.5 (l)
Ono et al. (1987)	U	AM	1	JA	1986	410 (w)	-	-
	U	AF	2	JA	1986	355 ± 5 (w)	-	-
Studies of stranded animals								
Calambokidis	WCT	AM	1	BC	1979	250 (w)	-	640 (w)
et al. (1984)	SR	AM	1	WA	1977	38 (w)	-	59 (w)
Jarman et al. (1996)	U	JM, AM, AF	6	WA, BC	1986-89	22 (w)	32 (w)	28 (w)
Hayteas and	U	JM	3	OR	1988-97	146 ± 135 (w)	-	174 ± 106 (w)
Duffield (2000)	U	AF	1	OR	1996	276 (w)	-	494 (w)
	U	JF	1	OR	1995	117 (w)	-	519 (w)

[a] WCT, west coast transients; SR, southern residents; NR, northern residents; AT, Gulf of Alaska and AT1 transients; SAR, southern Alaska residents; and U, not identified.
[b] M, males; F, females; A, adults; and J, juveniles.
[c] Number of animals sampled.
[d] BC, British Columbia; AK, Alaska; JA, Japan; WA, Washington; and OR, Oregon.
[e] Concentrations expressed on the basis of wet weight (w) or lipid weight (l).
[f] The animals studied by Ono et al. (1987) were accidentally caught and killed by commercial fishermen.

this area also appear in Jarman et al. (1996). No detailed studies of SDDT concentrations in killer whales have been conducted to date in Washington or surrounding areas. However, preliminary evidence from stranded individuals in Oregon and Washington suggests that high levels of the metabolite *p,p'*-DDE may be present (Calambokidis et al. 1984, Hayteas and Duffield 2000). High concentrations of SDDTs, primarily *p,p'*-DDE, have also been detected in transient whales from Alaska (Ylitalo et al. 2001). Results from these studies establish the transient and southern resident populations of the northeastern Pacific as among the most chemically contaminated marine mammals in the world (Ross et al. 2000, Ylitalo et al. 2001). This conclusion is further emphasized by the recent discovery of extremely high levels of SPCBs (about 1,000 mg/kg, wet weight) in a reproductively active adult female transient (CA189) that stranded and died on Dungeness Spit in January 2002 (G. M. Ylitalo, unpubl. data). While alive, this whale was recorded most frequently off California, thus its high contaminant load may largely reflect pollutant levels in prey from that region (M. M. Krahn, pers. comm.). It should be noted that organochlorine levels have not yet been established for the three southern resident pods. It is unknown whether L pod has higher contaminant

levels than J or K pods, thus accounting for its decline.

No direct temporal data are available to indicate whether contaminant concentrations have changed over time in the region's killer whales. Populations visiting Puget Sound have been exposed to PCBs and DDT for a number of decades. Sediment analyses indicate that large amounts of PCBs began entering marine ecosystems in the sound during the late 1930s, whereas inputs of DDT date back to the 1920s (Mearns 2001). The presence of both chemicals peaked in about 1960. Since then, environmental levels of many organochlorines (e.g., PCBs, dioxins, furans, organochlorine pesticides, and chlorophenols) have substantially declined (Gray and Tuominen 2001, Mearns 2001, Grant and Ross 2002). Mean SPCB concentrations in harbor seal pups from Puget Sound fell from more than 100 mg/kg, wet weight in 1972 to about 20 mg/kg, wet weight in 1990, but have since leveled off (Calambokidis et al. 1999). Recent modeling of PCB levels in killer whales from British Columbia and Washington suggests that concentrations have declined by about 2.5 times since 1970 (B. Hickie and P. S. Ross, unpubl. data).

Concentrations of most organochlorine residues in killer whales are strongly affected by an animal's age, sex, and reproductive status (Ross et al. 2000, Ylitalo et al. 2001). Levels in juveniles of both sexes increase continuously until sexual maturity. Males continue to accumulate organochlorines throughout the remainder of their lives, but reproductive females sharply decrease their own burden by transferring much of it to their offspring during gestation and nursing. Because organochlorines are fat-soluble, they are readily mobilized from the female's blubber to her fat-rich milk and passed directly to her young in far greater amounts during lactation than through the placenta during pregnancy (Reijnders and Aguilar 2002). As a result, mothers possess much lower levels than their weaned offspring, as well as adult males of the same age bracket (Ylitalo et al. 2001). After females become reproductively senescent at about 40 years old, their organochlorine concentrations once again begin to increase (Ross et al. 2000). Similar patterns of accumulation have been reported in other marine mammals (Tanabe et al. 1987, 1994, Aguilar and Borrell 1988, 1994a, Borrell et al. 1995, Beckmen et al. 1999, Krahn et al. 1999, Tilbury et al. 1999).

Birth order also influences the organochlorine burdens of killer whales. First-born adult male resident whales contain significantly higher levels of SPCBs and SDDTs than non-first-born males of the same age group (Ylitalo et al. 2001, Krahn et al. 2002). This pattern presumably exists among immature females as well. In other delphinids, females pass as much as 70-100% of their organochlorine load to their offspring during lactation, with the first calf receiving by far the largest burden (Tanabe 1988, Cockcroft et al. 1989, Borrell et al. 1995). Thus, females that have gone through previous lactation cycles carry substantially lower organochlorine loads and transfer reduced amounts to subsequent young (Aguilar and Borrell 1994a, Ridgway and Reddy 1995). These observations indicate that first-born killer whales are the most likely to suffer from any organochlorine toxicity effects (Ylitalo et al. 2001).

The effects of chronic exposure to moderate to high contaminant levels have not yet been ascertained in killer whales. There is no evidence to date that high organochlorine concentrations cause direct mortality in this species or other cetaceans (O'Shea and Aguilar 2001). However, a variety of more subtle physiological responses in marine mammals has been linked to organochlorine exposure, including impaired reproduction (Béland et al. 1998), immunotoxicity (Lahvis et al. 1995, de Swart et al. 1996, Ross et al. 1995, 1996a, 1996b, Ross 2002), hormonal dysfunction (Subramanian et al. 1987), disruption of enzyme function and vitamin A physiology (Marsili et al. 1998, Simms et al. 2000), and skeletal deformities (Bergman et al. 1992). PCB-caused suppression of the immune system can increase susceptibility to infectious disease (Ross 2002, Ross et al. 1996b) and was implicated in morbillivirus outbreaks that caused massive die-offs of dolphins in the Mediterranean Sea during the early 1990s (Aguilar and Borrell 1994b) and

harbor seals and gray seals (*Halichoerus grypus*) in the North Sea in the late 1980s (de Swart et al. 1994, Ross et al. 1995, 1996a). Immune suppression may be especially likely during periods of stress and resulting weight loss, when stored organochlorines are released from the blubber and become redistributed to other tissues (Krahn et al. 2002). Several studies have attempted to establish threshold levels at which organochlorines become toxic to marine mammals. However, susceptibility to PCBs varies substantially among mammal species, even within a genus, making it difficult to generalize about sensitivity (O'Shea 1999). Nevertheless, it is likely that all males from the three tested killer whale communities in Washington and British Columbia, as well as most female transients and southern residents, exceed the toxicity levels believed to cause health problems in other marine mammals (Ross et al. 2000).

Toxic elements. The three elements usually considered of greatest concern to cetaceans are mercury, cadmium, and lead (O'Shea 1999). Mercury, cadmium, and other metals accumulate primarily in the liver and kidneys, whereas lead is deposited mostly in bones (Reijnders and Aguilar 2002). Concentrations of most metals tend to increase throughout an animal's life. Because metals are not lipophilic, females cannot significantly reduce their loads via reproductive transfer. Many marine mammal species are able to tolerate high amounts of metals or detoxify them (Reijnders and Aguilar 2002) and published accounts of metal-caused pathology are scarce (O'Shea 1999). To date, there has been little investigation of metals in killer whales in Washington and British Columbia. Small numbers of animals have been tested, with one 17-year old male resident (L14) having high liver concentrations of mercury (reported as >600 mg/kg, wet weight, of which 14% was in the toxic methylated form, J. Calambokidis, unpubl. data; also reported as 1,272 mg/kg, wet weight, Langelier et al. 1990). An adult female transient (CA189) that stranded at Dungeness Spit in January 2002 carried the following metal levels (wet weight) in its liver: mercury, 129 mg/kg; cadmium, <0.15 mg/kg; and lead, <0.15 mg/kg (G. M. Ylitalo, unpubl. data). Stranded resident whales appear to carry higher amounts of mercury than transients (Langelier et al. 1990, cited in Baird 2001). With the exception of mercury, most metals do not bioaccumulate and are therefore unlikely to directly threaten the health of killer whales (Grant and Ross 2002). However, their greatest impact may be on prey populations and habitat quality.

Contaminant levels in prey. Relatively few studies have measured organochlorine loads in known or potential prey species of killer whales in Puget Sound and adjacent areas. Pinnipeds and porpoises carry far greater amounts of PCBs and DDTs than baleen whales and fish (Table 6) because of their higher positions in food chains (O'Shea and Aguilar 2001, Reijnders and Aguilar 2002). Among five species of fish in which muscle tissue has been sampled, chinook salmon possess the highest mean SPCB and SDDT levels and coho salmon have the lowest (Table 6). Whole-body testing of two species indicates that Pacific herring are more contaminated than coho salmon. Returning adult chinook and coho salmon carry substantially higher SPCB levels than smolts, indicating that the vast majority of these compounds are obtained during the marine phase of life in Puget Sound or the Pacific Ocean (O'Neill et al. 1998). Studies reveal that adult coho salmon returning to spawn in central and southern Puget Sound have higher SPCB concentrations than those returning to northern Puget Sound (West et al. 2001a). In English sole, rockfish, and herring, SPCB levels are influenced by the contaminant levels of local sediments. Thus, sole and rockfish living near contaminated urban areas often have higher burdens than those from non-urban sites (O'Neill et al. 1995, West et al. 2001b) and herring from central and southern Puget Sound possess greater burdens than those from northern Puget Sound and the Strait of Georgia (O'Neill and West 2001). Recent analyses of PCB levels in harbor seals indicate that seals and their prey in Puget Sound are seven times more contaminated than those in the Strait of Georgia (Cullon et al. in press). In some long-lived fish species, PCB concentrations accumulate with age so that older individuals carry

Table 6. Summary of SPCB and SDDT concentrations (mean ± SE, mg/kg, wet weight) in tissue samples from various mammal and fish species that are known or potential prey of killer whales in Washington and neighboring areas. Results are combined for both sexes.

Species	Location	Age[a]	Tissue analyzed	Sample size	SPCBs	SDDTs	Reference
Harbor seal	s. Puget Sound, Wash.	P	blubber	7	17.1 ± 2.1	2.2 ± 0.3[b]	Calambokidis et al. (1991)
Harbor seal	e. Strait of Juan de Fuca, Wash.	P	blubber	7	4.0 ± 2.5	1.5 ± 0.8[b]	Calambokidis et al. (1991)
Harbor seal	s. Puget Sound, Wash.	P	blubber	4	13.1	2.9[b]	Hong et al. (1996)
Harbor seal	e. Strait of Juan de Fuca, Wash.	P	blubber	4	1.7	0.8[b]	Hong et al. (1996)
Harbor seal	s. Puget Sound, Wash.	P	blubber	57	13.4 ± 1.1	2.0 ± 0.2	Calambokidis et al. (1999)
Harbor seal	s. Puget Sound, Wash.	P	blubber	17	18.1 ± 3.1	-	Ross et al. (2004)
Harbor seal	Georgia Strait, British Columbia	P	blubber	38	2.5 ± 0.2	-	Ross et al. (2004)
Harbor seal	Queen Charlotte Strait, B.C.	P	blubber	5	1.1± 0.3	-	Ross et al. (2004)
Sea lion sp.	outer coast, Wash.	-	blubber	1	2.6	4.8[b]	Calambokidis et al. (1984)
Harbor porpoise	s. Puget Sound, Wash.	-	blubber	1	55.0	14.0[b]	Calambokidis et al. (1984)
Harbor porpoise	Washington[c]	I,A	blubber	8	17.3 ± 3.9	14.4 ± 3.2[b]	Calambokidis and Barlow (1991)
Harbor porpoise	British Columbia[d]	C,I,A	blubber	7	8.4[e]	8.2[e]	Jarman et al. (1996)
Harbor porpoise	Oregon	C,I,A	blubber	13	10.9 ± 3.7	19.2 ± 4.5[b]	Calambokidis and Barlow (1991)
Harbor porpoise	central California	C,I,A	blubber	22	12.3 ± 2.0	41.5 ± 7.2[b]	Calambokidis and Barlow (1991)
Harbor porpoise	Monterey Bay, California	I,A	blubber	3	10.0[e]	15.0[e]	Jarman et al. (1996)
Dall's porpoise	San Juan Islands, Wash.	-	blubber	1	9.0	5.0[b]	Calambokidis et al. (1984)
Dall's porpoise	s. British Columbia[d]	I,A	blubber	3	4.5[e]	5.5[e]	Jarman et al. (1996)
Minke whale	s. Puget Sound, Wash.	-	blubber	1	.150	.550[b]	Calambokidis et al. (1984)
Gray whale	Washington	-	blubber	38	.220 ± .042	.130 ± .026	Krahn et al. (2001)
Chinook salmon	Puget Sound, s. Georgia Str, Wash.	4	muscle	66	.050 ± .005	.022 ± .001	O'Neill et al. (1995)
Chinook salmon	s. and c. Puget Sound, Wash.	-	muscle	34	.074	-	O'Neill et al. (1998)
Chinook salmon	Puget Sound, Wash.	4	whole body	35	.042 ± .003	.023 ± .001	G. M. Ylitalo (unpubl. data, in Krahn et al. 2002)
Coho salmon	s. and c. Puget Sound, Wash.	-	muscle	32	.035	-	O'Neill et al. (1998)
Coho salmon	Puget Sound, Wash.	3	muscle	47	.019 ± .002	.011 ± <.001	West et al. (2001a)
Pacific herring	Puget Sound, s. Georgia Str, Wash.	3	whole body	50	.102 ± .012	.029 ± .004	West et al. (2001a)
English sole	c. Puget Sound, Wash.[f]	-	muscle	18	.071	-	Landolt et al. (1987)
English sole	Puget Sound, s. Georgia Str, Wash.	6	muscle	113	.022 ± .002	.001 ± <.001	West et al. (2001a)
Quillback rockfish	Puget Sound, San Juan Isl., Wash.	14	muscle	83	.028 ± .003	.001 ± <.001	West et al. (2001a)
Brown rockfish	Puget Sound, San Juan Isl., Wash.	22	muscle	35	.027 ± .004	.002 ± <.001	West et al. (2001a)

[a] Expressed as age category (P, pups; C, calves; I, immatures; and A, adults) or years of age.
[b] Only *p,p'*-DDE was measured.
[c] Collected primarily from the outer coast.
[d] Collected primarily from southern Vancouver Island.
[e] Results expressed as a geometric mean.
[f] Collected from Edmonds, Elliott Bay, Commencement Bay, and Bremerton.

significantly higher burdens than younger individuals (O'Neill et al. 1995, 1998). In rockfish, this type of accumulation occurs only in males (West et al. 2001b).

Sources of contaminants. Marine ecosystems in the northeastern Pacific receive pollutants from a variety of local, regional, and international sources (Grant and Ross 2002), but the relative contribution of these sources in the contamination of killer whales is unknown. Because resident killer whales carry increasingly higher chemical loads from Alaska to Washington (Ross et al. 2000, Ylitalo et al. 2001), pollutants originating within Puget Sound and the Georgia Basin may play a greater role in contamination than those from other sources. Ross et al. (2000) has suggested that elevated organochlorine concentrations in southern residents might result from their consumption of small amounts of highly contaminated prey near industrialized areas. However, the high PCB loads of chinook salmon, which are a major prey item of killer whales, illustrate that pelagic contaminant sources may also be involved. Chinook spend most of their life in the open Pacific Ocean and their high trophic level relative to other salmonids may result in greater accumulation of PCBs. In this case, atmospheric deposition of PCBs in the North Pacific may be an important route for food chain contamination (Ross et al. 2000). Sources of pollutants in transient whales are also difficult to decipher. Transients are highly contaminated throughout much of their distribution, but this very likely results from the higher trophic level and biomagnification abilities of their prey, as well as possibly from the widespread movements of many of these whales.

PCBs, polycyclic aromatic hydrocarbons (PAHs), and a number of other pollutants appear to occur at substantially higher levels in Puget Sound than elsewhere in Washington and southern British Columbia, including the Strait of Georgia, based on studies of contaminant loads in harbor seals, herring, and mussels (Hong et al. 1996, Mearns 2001, O'Neill and West 2001, Grant and Ross 2002, Ross et al. 2004, Cullon et al. in press). This geographic pattern undoubtedly stems from greater contaminant inputs into Puget Sound due to human activities as well as the sound's lower rates of flushing and sedimentation (O'Neill et al. 1998, West et al. 2001a). Recent analyses indicate that 1% of the marine sediments in Puget Sound are highly degraded by chemical contamination, whereas 57% show intermediate degrees of deterioration and 42% remain relatively clean (Long et al. 2001). Hotspots for contaminated sediments are centered near major urban areas, where industrial and domestic activities are concentrated. Locations of particular concern include Bellingham Bay, Fidalgo Bay, Everett Harbor and Port Gardner, Elliott Bay, Commencement Bay, Sinclair Inlet and other sites near Bremerton, and Budd Inlet (Long et al. 2001, Grant and Ross 2002), but contamination can extend widely into even some rural bays. Analyses of contaminants in fish and mussels suggest that some pollutants are most abundant in central and southern Puget Sound (Mearns 2001, O'Neill and West 2001, West et al. 2001a). However, sediment testing indicates that the extent of contamination is broadly similar throughout the sound (Long et al. 2001).

Marine pollutants originate from a multitude of urban and non-urban activities, such as improper disposal of manufacturing by-products, processing and burning of fossil fuels, discharge of leachate from landfills and effluent from wastewater treatment plants (Appendix C), agricultural use of pesticides, and non-source terrestrial runoff. During the past few decades, regulatory actions, improved waste handling, and on-going cleanup efforts have led to marked improvements in regional water quality. Important actions taken include the cessation of PCB production and DDT use in the 1970s and the elimination of most dioxin and furan emissions from pulp and paper mills during the 1980s and early 1990s. Significant progress has also been made in the cleaning and containment of the 31 Superfund sites in the Puget Sound basin, of which at least 11 leaked contaminants into coastal waters (Appendix D). Environmental levels of many organochlorine residues (e.g., PCBs, dioxins, furans, organochlorine pesticides, and chlorophenols) have declined significantly during this period

(Gray and Tuominen 2001, Mearns 2001, Grant and Ross 2002). For example, mean SPCB concentrations in harbor seal pups from Puget Sound fell from more than 100 mg/kg, wet weight in 1972 to about 20 mg/kg, wet weight in 1990 (Calambokidis et al. 1999). Despite these improvements, the presence of some chemicals (e.g., PCBs and DDE) in coastal habitats and wildlife has stabilized since the early 1990s and is not expected to decline further for decades to come (Calambokidis et al. 1999, Grant and Ross 2002).

Atmospheric transport of pollutants is another important contaminant source for marine ecosystems. Due to the prevailing wind patterns of the Northern Hemisphere, a number of substances (e.g., PCBs, DDT, other pesticides, dioxins, furans, and metals) are carried in this manner from Asia to the northeastern Pacific (Iwata et al. 1993, Tanabe et al. 1994, Blais et al. 1998, Ewald et al. 1998, Jaffe et al. 1999, Ross et al. 2000, Grant and Ross 2002, Lichota et al. 2004). Such contamination particularly affects the open North Pacific Ocean, where migratory salmon populations spend much of their lives maturing, but also impacts the coastal waters and land areas of Washington and British Columbia. Locally produced airborne pollutants (e.g., certain PCBs, dioxins, and furans) also enter coastal marine waters (Lichota et al. 2004).

Increased human population growth, urbanization, and intensified land use are projected for western Washington and southern British Columbia during the coming decades (Transboundary Georgia Basin-Puget Sound Environmental Indicators Working Group 2002) and will undoubtedly subject coastal ecosystems to greater contaminant input (Gray and Tuominen 2001, Grant and Ross 2002). Emissions from Asian sources are also expected to gradually expand and continue to reach the open North Pacific and mainland of northwestern North America. In particular, PCBs will likely remain a health risk for at least several more decades due to their persistence, their continued cycling in the environment through atmospheric processes, and the relative inability of marine mammals to metabolize them (Ross et al. 2000, Calambokidis et al. 2001). Thus, exposure of the region's killer whales to contaminants is not expected to change appreciably in the foreseeable future (Grant and Ross 2002, Krahn et al. 2002).

Oil spills

Exposure to petroleum hydrocarbons released into the marine environment via oil spills and other discharge sources represents another potentially serious health threat for killer whales in the northeastern Pacific. Marine mammals are generally able to metabolize and excrete limited amounts of hydrocarbons, but acute or chronic exposure poses greater toxicological risks (Grant and Ross 2002). Unlike humans, cetaceans have a thickened epidermis that greatly reduces the likelihood of petroleum toxicity from skin contact with oiled waters (O'Shea and Aguilar 2001). Inhalation of vapors at the water's surface and ingestion of hydrocarbons during feeding are more likely pathways of exposure. Transient killer whales may be especially vulnerable after consuming prey debilitated by oil (Matkin and Saulitis 1997). In marine mammals, acute exposure to petroleum products can cause changes in behavior and reduced activity, inflammation of the mucous membranes, lung congestion, pneumonia, liver disorders, and neurological damage (Geraci and St. Aubin 1982). Evidence of direct mortality in killer whales from spills is described elsewhere in this report (see *Incidental Human-Related Mortality*). Oil spills are also potentially destructive to prey populations and therefore may adversely affect killer whales by reducing food availability.

The Georgia Basin and Puget Sound are among the busiest waterways in the world, with a mean of about 39 large cargo ships, tankers, and oil barges passing daily through Puget Sound alone in 2000 (Puget Sound Action Team 2002). Due to its proximity to Alaska's crude oil supply, the sound is also one of the leading petroleum refining centers in the U.S., with about 15 billion gallons of crude oil and refined petroleum products transported through it annually (Puget Sound Action Team 2002). Inbound oil tankers carry crude oil to four major refineries in Puget Sound,

Table 7. Oil spills of 100,000 gallons or more from vessels, production facilities, and pipelines in Washington from the 1960s to 2003 (from Neel et al. 1997, Puget Sound Action Team 2002).

Year	Incident name	Location	Amount spilled (gallons)	Type of product
Vessels				
1972	*General M. C. Meiggs*	Cape Flattery	2,300,000	Heavy fuel oil
1964	United Transportation barge	n. Grays Harbor Co.	1,200,000	Diesel fuel
1985	*ARCO Anchorage*	Port Angeles	239,000	Crude oil
1988	*Nestucca* barge	Ocean Shores	231,000	Heavy fuel oil
1971	United Transportation barge	Skagit County	230,000	Diesel fuel
1984	*SS Mobil Oil* tanker	Columbia R., Clark Co.	200,000	Heavy fuel oil
1978	Columbia River barge	Klickitat County	100,000	Diesel fuel
1991	*Tenyo Maru*	Strait of Juan de Fuca[a]	100,000	Heavy fuel oil, diesel
Refineries				
1991	US Oil	Tacoma	600,000	Crude oil
1993	US Oil	Tacoma	264,000	Crude oil
1991	Texaco	Anacortes	210,000	Crude oil
1990	Texaco	Anacortes	130,000	Crude oil
Pipelines				
1973	Trans-Mountain	Whatcom County	460,000	Crude oil
1999	Olympic	Bellingham	277,000	Gasoline
1983	Olympic	Skagit County	168,000	Diesel fuel

[a] Spill occurred in Canadian waters at the mouth of the Strait of Juan de Fuca and flowed into Washington.

while outbound tankers move refined oil products to destinations along the U.S. west coast (Neel et al. 1997). In 2002, a total of 759 oil tankers passed through Washington's waters bound for ports in Puget Sound, Canada, and along the Columbia River (Washington Department of Ecology 2003). This volume of shipping traffic puts the region at risk of having a catastrophic oil spill. The possibility of such a spill is considered one of the most important short-term threats to killer whales and other coastal organisms in the region (Krahn et al. 2002).

Neel et al. (1997) reported that shipping accidents were responsible for the largest volume (59%; 3.4 million gallons [12.9 million liters]) of oil discharged during major spills in Washington from 1970-1996. Other sources were refineries and associated production facilities (27%; 1.5 million gallons [5.7 million liters]) and pipelines (14%; 800,000 gallons [3.0 million liters]). There have been eight major oil tanker spills exceeding 100,000 gallons (378,500 liters) in the state's coastal waters and on the Columbia River since the 1960s, with the largest estimated at 2.3 million gallons (8.7 million liters) (Table 7). Grant and Ross (2002) did not report any major vessel spills from British Columbia during this same period, but at least one of 100,000 gallons (379,000 liters) is known to have occurred in Canadian waters at the mouth of the Strait of Juan de Fuca in 1991 (Neel et al. 1997). In addition to these incidents, there have been a number of near accidents resulting from vessel groundings, collisions, power loss, or poor vessel condition (Neel et al. 1997).

Puget Sound's four oil refineries are coastally located at Anacortes (Shell Oil and Texaco), Ferndale (Mobil Oil), and Tacoma (US Oil). Four major spills have occurred at two of these facilities (Table 7), with each causing some discharge of petroleum into marine waters (D. Doty, pers. comm.). Pipelines connecting to refineries and oil

terminals at ports represent another potential source of coastal spills. Pipeline leaks have caused several major spills in western Washington, but only the 1999 Olympic spill resulted in any discharge to marine waters (Neel et al. 1997; G. Lee, pers. comm.).

During the late 1980s and early 1990s, Washington significantly upgraded its efforts to prevent oil spills in response to increased numbers of spills in the state and the *Exxon Valdez* accident in Alaska. A number of state, provincial, and federal agencies now work to reduce the likelihood of spills, as does the regional Oil Spill Task Force, which was formed in 1989. National statutes enacted in the early 1990s, including the U.S.'s Oil Pollution Act in 1990 and the Canada Shipping Act in 1993, have also been beneficial in creating spill prevention and response standards. Since 1999, Washington State has maintained a rescue tugboat at Neah Bay for about 225 days per year during the winter months to aid disabled vessels and thereby prevent oil spills. These measures appear to have been helpful in reducing the number and size of spills since 1991, but continued vigilance is needed (Neel et al. 1997). In general, Washington's outer coast, the Strait of Juan de Fuca, and areas near the state's major refineries are considered the locations most at risk of major spills (Neel et al. 1997).

Disease

Infectious diseases are not known to limit any killer whale population, nor have epidemics been recorded in the species. Nevertheless, a variety of pathogens have been identified in killer whales, while others occur in sympatric marine mammal species and may therefore be transmittable to killer whales (Gaydos et al., in press). Several highly virulent diseases have emerged in recent years as threats to marine mammal populations. Of particular concern are several types of virus of the genus *Morbillivirus*. These include 1) dolphin morbillivirus, which killed several thousand striped dolphins (*Stenella coeruleoalba*) in the Mediterranean Sea during the early 1990s (Aguilar and Borrell 1994b) and unknown numbers of bottlenose dolphins in the western Atlantic during the late 1980s and Gulf of Mexico in the mid-1990s (Kennedy 1999, 2001), 2) phocine distemper virus, which produced large die-offs of harbor seals and gray seals in Europe in the late 1980s and 2002 (Hall et al. 1992, Jensen et al. 2002), and 3) canine distemper virus, which caused mass mortalities among Baikal seals (*Phoca sibirica*) in the late 1980s and Caspian seals (*P. caspica*) in 2000 (Kennedy et al. 2000, Kennedy 2001). PCB-caused suppression of the immune system is thought to have increased susceptibility to the virus in many of these cases (de Swart et al. 1996, Ross et al. 1996b, Ross 2002), although this conclusion is the subject of debate (O'Shea 2000a, 2000b, Ross 2000). Morbillivirus infections have been diagnosed in a variety of other marine mammals from the Atlantic, but caused little mortality in most instances (Kennedy 2001). Antibodies to dolphin morbillivirus have also been detected in common dolphins (*Delphinus delphis*) from southern California (Reidarson et al. 1998), placing the virus inside the ranges of transient and offshore killer whales and near the known southern limit of the southern resident community (Gaydos et al., in press). Additionally, there have been recent detections of canine distemper virus in river otters in British Columbia (Mos et al. 2003) and evidence of exposure to a canine- or phocine-like morbillivirus in sea otters from the Olympic Peninsula (J. Davis, unpubl. data). Because of the mutation capabilities and species-jumping history of morbilliviruses, there is a possibility that these forms could infect killer whales even if they are not the dolphin type (J. Gaydos, pers. comm.). Limited testing evidence suggests that killer whales have not yet been affected by morbilliviruses in Washington, British Columbia, or elsewhere in the world (Van Bressem et al. 2001), although small sample sizes precludes a thorough assessment of this issue. The fact that southern resident killer whales are likely seronegative suggests that they may be vulnerable if exposed to such a virus (P. S. Ross, pers. comm.). Other diseases such as *Brucella* spp. and cetacean poxvirus may impact killer whale populations by lowering reproductive success or causing greater mortality among calves (Gaydos et al., in press). The southern resident community is

perhaps the most vulnerable of the four populations in Washington and British Columbia to a serious disease outbreak due to its gregarious social nature, smaller population, seasonal concentration near the San Juan Islands, and high levels of PCB contamination (Gaydos et al., in press).

Inbreeding

Small population sizes often increase the likelihood of inbreeding, which can lead to the accumulation of deleterious alleles and thereby heighten the risk of a population's extinction. Inbreeding depression can cause decreased reproductive rates, reduced adaptability to environmental hazards such as disease and pollution, and other problems (Barrett-Lennard and Ellis 2001). Such effects are highly variable among species, with some strongly impacted and others much less so. Killer whale communities in the northeastern Pacific each contain fewer than 400 individuals, which is usually considered very small for discrete populations of most species (Barrett-Lennard and Ellis 2001, Frankham et al. 2002). Nevertheless, these communities appear adept at avoiding matings between members of the same pod. This may be an adaptation to small group size and suggests that the populations are genetically more viable when small than those of most species (Barrett-Lennard and Ellis 2001). If inbreeding depression is indeed a threat, the southern resident community is probably the most vulnerable due to its small size and lower gene diversity than other populations (Barrett-Lennard and Ellis 2001). Because of its recent decline, this community now contains just 28 reproductively active individuals. The deaths of several adult males in J and K pods between 1995 and 1998 have left the females of L pod with only one fully adult male (J1) to mate with during the past five years. This situation could lead to further loss of genetic variability in the population (Center for Biological Diversity 2001). Thus, inbreeding depression should not be ruled out as a future possibility in the southern residents.

CONCLUSION AND RECOMMENDATIONS

Four populations of killer whales occur in Washington: southern residents, northern residents, transients, and offshores. Only two of these communities, southern residents and transients, are regularly present in the state's coastal waters, while offshore whales are mainly inhabitants of the open ocean. These populations maintain large geographic ranges and none live exclusively in the state. Northern resident killer whales occur primarily in British Columbia and have been recorded in Washington on only a few occasions.

The southern resident population, which is composed of J, K, and L pods, is most familiar to the general public and is usually encountered in and around the San Juan Islands. This population comprises the majority of killer whales found in Washington at any one time during the spring, summer, and fall. The historical size of the southern resident population is unknown, but the best available scientific information suggests that it totaled about 200 whales. By 1960, the population was estimated to have declined to roughly 80 whales, due probably to indiscriminant shooting by fishermen and possibly decreasing salmon abundance. Numbers are believed to have increased somewhat during the early and mid-1960s, but live-captures for aquaria removed or killed at least 47 of the whales during the 1960s and 1970s. The population increased from 70 to 98 whales between 1974 and 1995, but this was followed by a rapid net loss of 18 animals, or 18% of the population, from 1996 to 2001. J and K pods have generally maintained their numbers since 1996, ranging between 19 and 22 animals and 17 and 21 animals, respectively. However, L pod, which comprises about half of the southern resident population, has experienced a 31% loss since 1994. This rate of decline is unprecedented since annual censuses began in 1974 and is especially worrisome because it involves both increased mortality among most sex and age classes and a substantial reduction in birth rates. At present, the southern resident population has declined to essentially the same size that was

estimated during the early 1960s, when it was considered as likely depleted. In contrast, northern resident killer whales have more than doubled their population between 1960 and 2003, increasing from an estimated 97 to 204 whales. Population trends for transient and offshore killer whales are not known because of the greater mobility and more sporadic occurrence of these whales, making it difficult for researchers to maintain detailed records of both populations.

Killer whales in Washington face three main potential threats, plus other risk factors, that are unlikely to diminish in the future. These are particularly applicable to the southern residents, which are considered the most urbanized population of killer whale in the world. The southern residents have experienced large historic declines in their main prey, salmon. Although overall salmon abundance has remained relatively stable or been increasing in Puget Sound and the Georgia Basin during the past few decades, there is a lack of comprehensive information on the status of all salmon runs in the population's range, which is currently known to extend from central California to northern British Columbia. Furthermore, a number of issues associated with human harvest practices, hatchery production, and stream habitat alteration may have reduced salmon quality (i.e., size and fat content) and changed localized patterns of salmon occurrence for whales. Organochlorine pollutants, primarily PCBs and DDT residues, are a second threat. Both southern resident and transient populations are now considered among the most highly contaminated marine mammals in the world and exceed the chemical toxicity concentrations believed to cause health problems in other marine mammals. Although environmental levels of some contaminants have declined in the region during the past few decades, many pollutants are still widely present and are foreseen to remain a health risk well into the future. A third potential factor, whale watching, has grown tremendously in and around the San Juan Islands during the past two decades. As a result, southern resident whales residing in this portion of their range are now followed during much or all of the day by significant numbers of commercial and private vessels. Whale watching vessels are known to cause a variety of short-term behavioral changes in killer whales. These, and possible interference with foraging, may have a cumulative negative effect on the whales. An important short-term risk to killer whales and their prey in the Georgia Basin and Puget Sound is the threat of sizable oil spills. These factors, singly, or in combination, pose a risk for southern residents and the other populations. The factors responsible for the recent, rapid decline in the L pod are unknown.

As a top-level predator, killer whales occur at naturally low densities, are long-lived, have low reproductive rates and long generation times, and invest large amounts of parental effort in each offspring. These characteristics mean that the loss of relatively few individuals can have serious consequences for their populations, as well as hinder recovery rates. Several population viability models using different assumptions and data sets have been recently used to estimate extinction risks for the southern resident population. Models considered most plausible by Taylor and Plater (2001) estimated there was a 1.5-28.5% chance of extinction in the next 100 years and predicted median extinction times to range from 113-213 years. The most conservative PVA models used by Krahn et al. (2002) predicted 1-4% probabilities of extinction in 100 years and 5-50% in 300 years. During recent discussions convened by the National Marine Fisheries Service, marine mammals scientists reviewed the subject of thresholds of extinction risk in whales and recommended that endangered status was appropriate for species with probabilities of extinction exceeding 1% in 100 years (Angliss et al. 2002).

Because of the combination of low population numbers, the recent steep decline in L pod, and continued threats to the population, the Department believes that killer whales in Washington, predominantly the southern residents, are at risk of extinction from all or a significant portion of their range in Washington and recommends that the species be listed as endangered in the state.

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Appendix A. Population and pod sizes of southern and northern resident killer whales in Washington and British Columbia, 1960-2003.

	Southern residents[a]				Northern residents[b]
Year	J pod	K pod	L pod	Total	Total
1960	-	-	-	78	97
1961	-	-	-	79	98
1962	-	-	-	82	101
1963	-	-	-	85	105
1964	-	-	-	90	110
1965	-	-	-	94	117
1966	-	-	-	95	115
1967	-	-	-	96	119
1968	-	-	-	89	120
1969	-	-	-	81	111
1970	-	-	-	80	108
1971	-	-	-	67	113
1972	-	-	-	69	115
1973	-	-	-	71	121
1974	15	16	39	70	123
1975	15	15	41	71	132
1976	16	14	40	70	131
1977	18	15	46	79	134
1978	18	15	46	79	137
1979	19	15	47	81	140
1980	19	15	49	83	147
1981	19	15	47	81	150
1982	19	14	45	78	151
1983	19	14	43	76	155
1984	17	14	43	74	156
1985	18	14	45	77	163
1986	17	16	48	81	171
1987	18	17	49	84	177
1988	19	18	48	85	180
1989	18	17	50	85	187
1990	18	18	53	89	194
1991	20	17	55	92	201
1992	19	16	56	91	199
1993	21	17	59	97	197
1994	20	19	57	96	202
1995	22	18	58	98	205
1996	22	19	56	97	212
1997	21	19	52	92	220
1998	22	18	49	89	216
1999	20	17	48	85	216
2000	19	17	47	83	209
2001	20	18	42	80	201
2002	20	19	43	82	202
2003	22	21	41	84	204

[a] Southern resident data from 1960-1973 are estimates based on projections from the matrix model of Olesiuk et al. (1990a). Data from 1974-2003 were determined through photo-identification surveys and were provided by the Center for Whale Research (unpubl. data). Data for these years represent the number of whales present at the end of each calendar year. Whales verified as missing are assumed to have died and may be removed from count totals within a calendar year, depending on date of disappearance (K. C. Balcomb, pers. comm.).

[b] Northern resident data from 1960-1974 are estimates based on projections from the matrix model of Olesiuk et al. (1990a). Data from 1975-2003 were determined through photo-identification surveys and were provided by J. K. B. Ford (unpubl. data). Count data represent the number of whales believed to be alive during a calendar year. Whales are counted through their last year of being seen (J. K. B. Ford, pers. comm.).

Appendix B. The current "Be Whale Wise" guidelines recommended for vessels, kayaks, and other craft watching killer whales in Washington and British Columbia by the Soundwatch Boater Education Program and Marine Mammal Monitoring Project (M3).

Whale Watching

1. Be cautious and courteous: approach areas of known or suspected marine mammal activity with extreme caution. Look in all directions before planning your approach or departure.
2. Slow down: reduce speed to less than 7 knots when within 400 meters/yards of the nearest whale. Avoid abrupt course changes.
3. Avoid approaching closer than 100 meters/yards from any whale.
4. If your vessel is unexpectedly within 100 meters/yards, stop immediately and allow the whales to pass.
5. Avoid approaching whales from the front or from behind. Always approach and depart whales from the side, moving in a direction parallel to the direction of the whales.
6. Keep clear of the whales' path. Avoid positioning your vessel within the 400 meter/yard area in the path of the whales.
7. Stay on the offshore side of the whales when they are traveling close to shore. Remain at least 200 meters/yards offshore at all times.
8. Limit your viewing time to a recommended maximum of 30 minutes. This will minimize the cumulative impact of many vessels and give consideration to other viewers.
9. Do not swim with or feed whales.

Porpoises and Dolphins

1. Observe all guidelines for watching whales.
2. Do not drive through groups of for the purpose of bow-riding.
3. Should dolphins or porpoises choose to ride the bow wave of your vessel, reduce speed gradually and avoid sudden course changes.

Seals, Sea Lions and Birds on Land

1. Avoid approaching closer than 100 meters/yards to any marine mammals or birds.
2. Slow down and reduce your wake/wash and noise levels.
3. Pay attention and back away at the first sign of disturbance or agitation.
4. Be cautious and quiet when around haul-outs and bird colonies, especially during breeding, nesting and pupping seasons (generally May to September).
5. Do not swim with or feed any marine mammals or birds.

Viewing Wildlife within Marine Protected Areas, Wildlife Refuges, Ecological Reserves and Parks

1. Check your nautical charts for the location of various protected areas.
2. Abide by posted restrictions or contact a local authority for further information.

To Report a Marine Mammal Disturbance or Harassment:

Canada: Fisheries and Oceans Canada: 1-800-465-4336
U.S.: National Marine Fisheries Service, Office for Law Enforcement: 1-800-853-1964

To Report Marine Mammal Sightings:

BC Cetacean Sightings Network: www.wildwhales.org or 1-604-659-3429
The Whale Museum Hotline (WA state): 1-800-562-8832 or hotline@whalemuseum.org
Orca Network: info@orcanetwork.org

Appendix C. List of major sewage treatment plants and pulp and paper mills in the Puget Sound and Georgia Basin region[A]

Sewage treatment plants

Washington

Bellingham STP	Lakota STP, Federal Way
Anacortes WWTP	Tacoma Central No. 1
Mt. Vernon STP	Tacoma North No. 3
Everett STP	Chambers Creek, University Place
Lynnwood STP	Puyallup STP
Edmonds STP	Sumner STP
Metro Alki Point, Seattle	Enumclaw STP
Metro West Point, Seattle	LOTT, Olympia area
Salmon Creek WWTP, Burien	Port Angeles STP
Metro Renton, Renton	Kitsap County Central Kitsap, Poulsbo
Miller Creek WWTP, Normandy Park	Bremerton STP
Midway Sewer District, Des Moines	Shelton STP
Redondo STP, Des Moines	

British Columbia

Campbell River	Chilliwick
Comox Valley Regional	Northwest Langley
Powell River	Nanaimo
Westview	French Creek, Nanaimo
Squamish	Ladysmith
Lion's Gate, Vancouver	Salt Spring Island
Iona Island, Vancouver	Sydney
Lulu Island, Vancouver	Clover Point, Victoria
Annacis Island, Vancouver	Macaulay Point, Victoria

Pulp and paper mills

Washington

Georgia Pacific, Bellingham	Kimberley-Clark, Everett
Daishowa America, Port Angeles	Simpson Tacoma Kraft, Tacoma
Rayonier[b], Port Angeles	Sonoco, Sumner
Port Townsend Paper, Port Townsend	Stone Consolidated (Abitibi)[a], Steilacoom

British Columbia

Norske Skog Canada, Elk Falls	Western Pulp Limited Partnership, Squamish
Pacifica Papers, Port Alberni	Howe Sound Pulp & Paper, Port Mellon
Pope & Talbot, Harmac	Norampac Paper, New Westminster
Norske Skog Canada, Crofton	Scott Paper, New Westminster
Pacifica Papers, Powell River	

[a] Adapted from Grant and Ross (2002), with additional information from the Washington Department of Ecology. Many of these sites discharge their effluent directly into marine waters and may have once been significant polluters.

[b] Now closed.

Appendix D. Superfund sites located in the Puget Sound region, with a listing of primary contaminants (U.S. Environmental Protection Agency 2003).

Site name	Location	Contaminated media	Major contaminants
Northwest Transformer, Mission Pole[a]	Everson, Whatcom Co.	Soils, sludges	PCBs, others
Northwest Transformer, S. Harkness St.[a]	Everson, Whatcom Co.	Soils, sludges	PCBs, heavy metals
Oeser Company	Bellingham, Whatcom Co.	Soils, sludges	Others
Whidbey Island Naval Air Station, Ault Field	Whidbey Island, Island Co.	Soils, marine and freshwater sediments, groundwater	PCBs, pesticides, dioxins, heavy metals, others
Whidbey Island Naval Air Station, Seaplane Base[a]	Whidbey Island, Island Co.	Soils, sludges, groundwater, surface water	Pesticides, heavy metals, others
Tulalip Landfill	Marysville, Snohomish Co.	Surface water, soils, marine and freshwater sediments, groundwater	PCBs, DDT, heavy metals, others
Harbor Island	Seattle, King Co.	Soils, marine and freshwater sediments, sludges, groundwater	PCBs, heavy metals, petroleum products, others
Lower Duwamish Waterway	Seattle, King Co.	Freshwater sediments, surface water	PCBs, others
Pacific Sound Resources	Seattle, King Co.	Marine and freshwater sediments, groundwater	PCBs, heavy metals, others
Pacific Car and Foundry (PACCAR)	Renton, King Co.	Soils	PCBs, heavy metals, petroleum products, others
Midway Landfill	Kent, King Co.	Groundwater	Heavy metals, others
Seattle Municipal Landfill	Kent, King Co.	Groundwater	Heavy metals, others
Western Processing Company	Kent, King Co.	Soils, freshwater sediments, groundwater	PCBs, dioxins, heavy metals, others
Queen City Farms	Maple Valley, King Co.	Soils, sludges, groundwater, surface water	PCBs, heavy metals, others
Port Hadlock Detachment, U.S. Navy	Indian Island, Jefferson Co.	Marine sediment, shellfish, soils, groundwater	PCBs, pesticides, heavy metals, others
Naval Undersea Warfare Center	Keyport, Kitsap Co.	Soils, marine sediments, shellfish, groundwater	PCBs, heavy metals, petroleum products, others
Bangor Naval Submarine Base	Silverdale, Kitsap Co.	Soils, sludges, surface water, groundwater	Others
Bangor Ordnance Disposal, U.S. Navy	Silverdale, Kitsap Co.	Soils, sludges, surface water, groundwater	Others

Appendix D. Superfund sites in the Puget Sound region (cont'd).

Site name	Location	Contaminated media	Major contaminants
Wyckoff Company/Eagle Harbor	Bainbridge Island, Kitsap Co.	Soils, marine sediments, groundwater	Dioxins, furans, heavy metals, others
Jackson Park Housing Complex, U.S. Navy	Bremerton, Kitsap Co.	Soils, sludges, surface water	Heavy metals, others
Puget Sound Naval Shipyard Complex	Bremerton, Kitsap Co.	Soils, sludges, marine sediments, groundwater	PCBs, heavy metals, petroleum products, others
Old Navy Dump/Manchester Lab	Manchester, Kitsap Co.	Soils, sludges, marine sediments, surface water, shellfish	PCBs, heavy metals, petroleum products, others
Commencement Bay Nearshore/ Tideflats	Tacoma, Pierce Co.	Surface water, soils, marine sediments, groundwater	PCBs, heavy metals, others
Commencement Bay South Tacoma Channel	Tacoma, Pierce Co.	Surface water, soils, marine sediments, groundwater	PCBs, heavy metals, petroleum products, others
American Lake Gardens, McChord AFB	Tacoma, Pierce Co.	Groundwater	Others
McChord AFB (Wash Rack/Treat)[a]	Tacoma, Pierce Co.	Groundwater	Petroleum products, others
Lakewood Site	Lakewood, Pierce Co.	Soils, sludges, groundwater	Others
Hidden Valley Landfill (Thun Field)	Puyallup, Pierce Co.	Groundwater	Heavy metals, others
Fort Lewis (Landfill No. 5)[a]	Fort Lewis, Pierce Co.	Groundwater	Heavy metals, others
Fort Lewis Logistics Center	Fort Lewis, Pierce Co.	Groundwater	Heavy metals, others
Palermo Well Field	Tumwater, Thurston Co.	Soils, surface water, groundwater	Others

[a] Cleanup activities considered complete.

Appendix E. Washington Administrative Code 232-12-011, 232-12-014, and 232-12-297.

WAC 232-12-011 Wildlife classified as protected shall not be hunted or fished.

Protected wildlife are designated into three subcategories: threatened, sensitive, and other.
(1) Threatened species are any wildlife species native to the state of Washington that are likely to become endangered within the foreseeable future throughout a significant portion of their range within the state without cooperative management or removal of threats. Protected wildlife designated as threatened include:

Common Name	Scientific Name
western gray squirrel	*Sciurus griseus*
Steller (northern) sea lion	*Eumetopias jubatus*
North American lynx	*Lynx canadensis*
Aleutian Canada goose	*Branta canadensis leucopareia*
bald eagle	*Haliaeetus leucocephalus*
ferruginous hawk	*Buteo regalis*
marbled murrelet	*Brachyramphus marmoratus*
green sea turtle	*Chelonia mydas*
loggerhead sea turtle	*Caretta caretta*
sage grouse	*Centrocercus urophasianus*
sharp-tailed grouse	*Phasianus columbianus*

(2) Sensitive species are any wildlife species native to the state of Washington that are vulnerable or declining and are likely to become endangered or threatened in a significant portion of their range within the state without cooperative management or removal of threats. Protected wildlife designated as sensitive include:

Common Name	Scientific Name
gray whale	*Eschrichtius gibbosus*
common Loon	*Gavia immer*
peregrine falcon	*Falco peregrinus*
Larch Mountain salamander	*Plethodon larselli*
pygmy whitefish	*Prosopium coulteri*
margined sculpin	*Cottus marginatus*
Olympic mudminnow	*Novumbra hubbsi*

(3) Other protected wildlife include:

Common Name	Scientific Name
cony or pika	*Ochotona princeps*
least chipmunk	*Tamius minimus*
yellow-pine chipmunk	*Tamius amoenus*
Townsend's chipmunk	*Tamius townsendii*
red-tailed chipmunk	*Tamius ruficaudus*
hoary marmot	*Marmota caligata*
Olympic marmot	*Marmota olympus*
Cascade golden-mantled ground squirrel	*Spermophilus saturatus*
golden-mantled ground squirrel	*Spermophilus lateralis*
Washington ground squirrel	*Spermophilus washingtoni*
red squirrel	*Tamiasciurus hudsonicus*
Douglas squirrel	*Tamiasciurus douglasii*
northern flying squirrel	*Glaucomys sabrinus*
wolverine	*Gulo gulo*
painted turtle	*Chrysemys picta*
California mountain kingsnake	*Lampropeltis zonata*

All birds not classified as game birds, predatory birds or endangered species, or designated as threatened species or sensitive species; all bats, except when found in or immediately adjacent to a dwelling or other occupied building; mammals of the order Cetacea, including whales, porpoises, and mammals of the order Pinnipedia not otherwise classified as endangered species, or designated as threatened species or sensitive species. This section shall not apply to hair seals and sea lions which are threatening to damage or are damaging commercial fishing gear being utilized in a lawful manner or when said mammals are damaging or threatening to damage commercial fish being lawfully taken with commercial gear.

[Statutory Authority: RCW 77.12.047, 77.12.655, 77.12.020. 02-11-069 (Order 02-98), § 232-12-011, filed 5/10/02, effective 6/10/02. Statutory Authority: RCW 77.12.047. 02-08-048 (Order 02-53), § 232-12-011, filed 3/29/02, effective 5/1/02; 00-17-106 (Order 00-149), § 232-12-011, filed 8/16/00, effective 9/16/00. Statutory Authority: RCW 77.12.040, 77.12.010, 77.12.020, 77.12.770. 00-10-001 (Order 00-47), § 232-12-011, filed 4/19/00, effective 5/20/00. Statutory Authority: RCW 77.12.040, 77.12.010, 77.12.020, 77.12.770, 77.12.780. 00-04-017 (Order 00-05), § 232-12-011, filed 1/24/00, effective 2/24/00. Statutory Authority: RCW 77.12.020. 98-23-013 (Order 98-232), § 232-12-011, filed 11/6/98, effective 12/7/98. Statutory Authority: RCW 77.12.040. 98-10-021 (Order 98-71), § 232-12-011, filed 4/22/98, effective 5/23/98. Statutory Aut hority: RCW 77.12.040 and 75.08.080. 98-06-031, § 232-12-011, filed 2/26/98, effective 5/1/98. Statutory Authority: RCW 77.12.020. 97-18-019 (Order 97-167), § 232-12-011, filed 8/25/97, effective 9/25/97. Statutory Authority: RCW 77.12.040, 77.12.020, 77.12.030 and 77.32.220. 97-12-048, § 232-12-011, filed 6/2/97, effective 7/3/97. Statutory Authority: RCW 77.12.020. 93-21-027 (Order 615), § 232-12-011, filed 10/14/93, effective 11/14/93; 90-11-065 (Order 441), § 232-12-011, filed 5/15/90, effective 6/15/90. Statutory Authority: RCW 77.12.040. 89-11-061 (Order 392), § 232-12-011, filed 5/18/89; 82-19-026 (Order 192), § 232-12-011, filed 9/9/82; 81-22-002 (Order 174), § 232-12-011, filed 10/22/81; 81-12-029 (Order 165), § 232-12-011, filed 6/1/81.]

WAC 232-12-014 Wildlife classified as endangered species. Endangered species include:

Common Name	Scientific Name
pygmy rabbit	*Brachylagus idahoensis*
fisher	*Martes pennanti*
gray wolf	*Canis lupus*
grizzly bear	*Ursus arctos*
sea otter	*Enhydra lutris*
sei whale	*Balaenoptera borealis*
fin whale	*Balaenoptera physalus*
blue whale	*Balaenoptera musculus*
humpback whale	*Megaptera novaeangliae*
black right whale	*Balaena glacialis*
sperm whale	*Physeter macrocephalus*
Columbian white-tailed deer	*Odocoileus virginianus leucurus*
woodland caribou	*Rangifer tarandus caribou*
American white pelican	*Pelecanus erythrorhynchos*
brown pelican	*Pelecanus occidentalis*
sandhill crane	*Grus canadensis*
snowy plover	*Charadrius alexandrinus*
upland sandpiper	*Bartramia longicauda*
spotted owl	*Strix occidentalis*
western pond turtle	*Clemmys marmorata*
leatherback sea turtle	*Dermochelys coriacea*
mardon skipper	*Polites mardon*
Oregon silverspot butterfly	*Speyeria zerene hippolyta*
Oregon spotted frog	*Rana pretiosa*
northern leopard frog	*Rana pipiens*

[Statutory Authority: RCW 77.12.047, 77.12.655, 77.12.020. 02-11-069 (Order 02-98), § 232-12-014, filed 5/10/02, effective 6/10/02. Statutory Authority: RCW 77.12.040, 77.12.010, 77.12.020, 77.12.770, 77.12.780. 00-04-017 (Order 00-05), § 232-12-014, filed 1/24/00, effective 2/24/00. Statutory Authority: RCW 77.12.020. 98-23-013 (Order 98-232), § 232-12-014, filed 11/6/98, effective 12/7/98; 97-18-019 (Order 97-167), § 232-12-014, filed 8/25/97, effective 9/25/97; 93-21-026 (Order 616), § 232-12-014, filed 10/14/93, effective 11/14/93. Statutory Authority: RCW 77.12.020(6). 88-05-032 (Order 305), § 232-12-014, filed 2/12/88. Statutory Authority: RCW 77.12.040. 82-19-026 (Order 192), § 232-12-014, filed 9/9/82; 81-22-002 (Order 174), § 232-12-014, filed 10/22/81; 81-12-029 (Order 165), § 232-12-014, filed 6/1/81.]

WAC 232-12-297 Endangered, threatened, and sensitive wildlife species classification.

PURPOSE

1.1 The purpose of this rule is to identify and classify native wildlife species that have need of protection and/or management to ensure their survival as free-ranging populations in Washington and to define the process by which listing, management, recovery, and delisting of a species can be achieved. These rules are established to ensure that consistent procedures and criteria are followed when classifying wildlife as endangered, or the protected wildlife subcategories threatened or sensitive.

DEFINITIONS

For purposes of this rule, the following definitions apply:

2.1 "Classify" and all derivatives means to list or delist wildlife species to or from endangered, or to or from the protected wildlife subcategories threatened or sensitive.

2.2 "List" and all derivatives means to change the classification status of a wildlife species to endangered, threatened, or sensitive.

2.3 "Delist" and its derivatives means to change the classification of endangered, threatened, or sensitive species to a classification other than endangered, threatened, or sensitive.

2.4 "Endangered" means any wildlife species native to the state of Washington that is seriously threatened with extinction throughout all or a significant portion of its range within the state.

2.5 "Threatened" means any wildlife species native to the state of Washington that is likely to become an endangered species within the foreseeable future throughout a significant portion of its range within the state without cooperative management or removal of threats.

2.6 "Sensitive" means any wildlife species native to the state of Washington that is vulnerable or declining and is likely to become endangered or threatened in a significant portion of its range within the state without cooperative management or removal of threats.

2.7 "Species" means any group of anim als classified as a species or subspecies as commonly accepted by the scientific community.

2.8 "Native" means any wildlife species naturally occurring in Washington for purposes of breeding, resting, or foraging, excluding introduced species not foun d historically in this state.

2.9 "Significant portion of its range" means that portion of a species' range likely to be essential to the long-term survival of the population in Washington.

LISTING CRITERIA

3.1 The commission shall list a wildlife species as endangered, threatened, or sensitive solely on the basis of the biological status of the species being considered, based on the preponderance of scientific data available, except as noted in section 3.4.

3.2 If a species is listed as endangered or threatened under the federal Endangered Species Act, the agency will recommend to the commission that it be listed as endangered or threatened as specified in section 9.1. If listed, the agency will proceed with development of a recovery plan pursuant to section 11.1.

3.3 Species may be listed as endangered, threatened, or sensitive only when populations are in danger of failing, declining, or are vulnerable, due to factors including but not restricted to limited numbers, disease, predation, exploitation, or habitat loss or change, pursuant to section 7.1.

3.4 Where a species of the class Insecta, based on substantial evidence, is determined to present an unreasonable risk to public health, the commission may make the determination that the species need not be listed as endangered, threatened, or sensitive.

DELISTING CRITERIA

4.1 The commission shall delist a wildlife species from endangered, threatened, or sensitive solely on the basis of the biological status of the species being considered, based on the preponderance of scientific data available.

4.2 A species may be delisted from endangered, threatened, or sensitive only when populations are no longer in danger of failing, declining, are no longer vulnerable, pursuant to section 3.3, or meet recovery plan goals, and when it no longer meets the definitions in sections 2.4, 2.5, or 2.6.

INITIATION OF LISTING PROCESS

5.1 Any one of the following events may initiate the listing process.

5.1.1 The agency determines that a species population may be in danger of failing, declining, or vulnerable, pursuant to section 3.3.

5.1.2 A petition is received at the agency from an interested person. The petition should be addressed to the director. It should set forth specific evidence and scientific data which shows that the species may be failing, declining, or vulnerable, pursuant to section 3.3. Within 60 days, the agency shall either deny the petition, stating the reasons, or initiate the classification process.

5.1.3 An emergency, as defined by the Administrative Procedure Act, chapter 34.05 RCW. The listing of any species previously classified under emergency rule shall be governed by the provisions of this section.

5.1.4 The commission requests the agency review a species of concern.

5.2 Upon initiation of the listing process the agency shall publish a public notice in the Washington Register, and notify those parties who have expressed their interest to the department, announcing the initiation of the classification process and calling for scientific information relevant to the species status report under consideration pursuant to section 7.1.

INITIATION OF DELISTING PROCESS

6.1 Any one of the following events may initiate the delisting process:

6.1.1 The agency determines that a species population may no longer be in danger of failing, declining, or vulnerable, pursuant to section 3.3.

6.1.2 The agency receives a petition from an interested person. The petition should be addressed to the director. It should set forth specific evidence and scientific data which shows that the species may no longer be failing, declining, or vulnerable, pursuant to section 3.3. Within 60 days, the agency shall either deny the petition, stating the reasons, or initiate the delisting process.

6.1.3 The commission requests the agency review a species of concern.

6.2 Upon initiation of the delisting process the agency shall publish a public notice in the Washington Register, and notify those parties who have expressed their interest to the department, announcing the initiation of the delisting process and calling for scientific information relevant to the species status report under consideration pursuant to section 7.1.

SPECIES STATUS REVIEW AND AGENCY RECOMMENDATIONS

7.1 Except in an emergency under 5.1.3 above, prior to making a classification recommendation to the commission, the agency shall prepare a preliminary species status report. The report will include a review of information relevant to the species' status in Washington and address factors affecting its status, including those given under section 3.3. The status report shall be reviewed by the public and scientific community. The status report will include, but not be limited to an analysis of:

7.1.1 Historic, current, and future species population trends.

7.1.2 Natural history, including ecological relationships (e.g. food habits, home range, habitat selection patterns).

7.1.3 Historic and current habitat trends.

7.1.4 Population demographics (e.g. survival and mortality rates, reproductive success) and their relationship to long term sustainability.

7.1.5 Historic and current species management activities.

7.2 Except in an emergency under 5.1.3 above, the agency shall prepare recommendations for species classification, based upon scientific data contained in the status report. Documents shall be prepared to determine the environmental consequences of adopting the recommendations pursuant to requirements of the State Environmental Policy Act (SEPA).

7.3 For the purpose of delisting, the status report will include a review of recovery plan goals.

PUBLIC REVIEW

8.1 Except in an emergency under 5.1.3 above, prior to making a recommendation to the commission, the agency shall provide an opportunity for interested parties to submit new scientific data relevant to the status report, classification recommendation, and any SEPA findings.

8.1.1 The agency shall allow at least 90 days for public comment.

FINAL RECOMMENDATIONS AND COMMISSION ACTION

9.1 After the close of the public comment period, the agency shall complete a final status report and classification recommendation. SEPA documents will be prepared, as necessary, for the final agency recommendation for classification. The classification recommendation will be presented to the commission for action. The final species status report, agency classification recommendation, and SEPA documents will be made available to the public at least 30 days prior to the commission meeting.

9.2 Notice of the proposed commission action will be published at least 30 days prior to the commission meeting.

PERIODIC SPECIES STATUS REVIEW

10.1 The agency shall conduct a review of each endangered, threatened, or sensitive wildlife species at least every five years after the date of its listing. This review shall include an update of the species status report to determine whether the status of the species warrants its current listing status or deserves reclassification.

10.1.1 The agency shall notify any parties who have expressed their interest to the department of the periodic status review. This notice shall occur at least one year prior to end of the five year period required by section 10.1.

10.2 The status of all delisted species shall be reviewed at least once, five years following the date of delisting.

10.3 The department shall evaluate the necessity of changing the classification of the species being reviewed. The agency shall report its findings to the commission at a commission meeting. The agency shall notify the public of its findings at least 30 days prior to presenting the findings to the commission.

10.3.1 If the agency determines that new information suggests that classification of a species should be changed from its present state, the agency shall initiate classification procedures provided for in these rules starting with section 5.1.

10.3.2 If the agency determines that conditions have not changed significantly and that the classification of the species should remain unchanged, the agency shall recommend to the commission that the species being reviewed shall retain its present classification status.

10.4 Nothing in these rules shall be construed to automatically delist a species without formal commission action.

RECOVERY AND MANAGEMENT OF LISTED SPECIES

11.1 The agency shall write a recovery plan for species listed as endangered or threatened. The agency will write a management plan for species listed as sensitive. Recovery and management plans shall address the listing criteria described in sections 3.1 and 3.3, and shall include, but are not limited to:

11.1.1 Target population objectives.

11.1.2 Criteria for reclassification.

11.1.3 An implementation plan for reaching population objectives which will promote cooperative management and be sensitive to landowner needs and property rights. The plan will specify resources needed from and impacts to the department, other agencies (including federal, state, and local), tribes, landowners, and other interest groups. The plan shall consider various approaches to meeting recovery objectives including, but not limited to regulation, mitigation, acquisition, incentive, and compensation mechanisms.

11.1.4 Public education needs.

11.1.5 A species monitoring plan, which requires periodic review to allow the incorporation of new information into the status report.

11.2 Preparation of recovery and management plans will be initiated by the agency within one year after the date of listing.

11.2.1 Recovery and management plans for species listed prior to 1990 or during the five years following the adoption of these rules shall be completed within 5 years after the date of listing or adoption of these rules, whichever comes later. Development of recovery plans for endangered species will receive higher priority than threatened or sensitive species.

11.2.2 Recovery and management plans for species listed after five years following the adoption of these rules shall be completed within three years after the date of listing.

11.2.3 The agency will publish a notice in the Washington Register and notify any parties who have expressed interest to the department interested parties of the initiation of recovery plan development.

11.2.4 If the deadlines defined in sections 11.2.1 and 11.2.2 are not met the department shall notify the public and report the reasons for missing the deadline and the strategy for completing the plan at a commission meeting. The intent of this sect ion is to recognize current department personnel resources are limiting and that development of recovery plans for some of the species may require significant involvement by interests outside of the department, and therefore take longer to complete.

11.3 The agency shall provide an opportunity for interested public to comment on the recovery plan and any SEPA documents.

CLASSIFICATION PROCEDURES REVIEW

12.1 The agency and an ad hoc public group with members representing a broad spectrum of interests, shall meet as needed to accomplish the following:

12.1.1 Monitor the progress of the development of recovery and management plans and status reviews, highlight problems, and make recommendations to the department and other interested parties to improve the effectiveness of these processes.

12.1.2 Review these classification procedures six years after the adoption of these rules and report its findings to the commission.

AUTHORITY

13.1 The commission has the authority to classify wildlife as endangered under RCW 77.12.020. Species classified as endangered are listed under WAC 232-12-014, as amended.

13.2 Threatened and sensitive species shall be classified as subcategories of protected wildlife. The commission has the authority to classify wildlife as protected under RCW 77.12.020. Species classified as protected are listed under WAC 232-12-011, as amended.

[Statutory Authority: RCW 77.12.047, 77.12.655, 77.12.020. 02-02-062 (Order 01-283), § 232-12-297, filed 12/28/01, effective 1/28/02. Statutory Authority: RCW 77.12.040. 98-05-041 (Order 98-17), § 232-12-297, filed 2/11/98, effective 3/14/98. Statutory Authority: RCW 77.12.020. 90-11-066 (Order 442), § 232-12-297, filed 5/15/90, effective 6/15/90.]

Washington State Status Reports and Recovery Plans

Status Reports

2004	Killer Whale	✓
2002	Peregrine Falcon	✓
2001	Bald Eagle	✓
2000	Common Loon	✓
1999	Northern Leopard Frog	✓
1999	Olympic Mudminnow	✓
1999	Mardon Skipper	✓
1999	Lynx Update	
1998	Fisher	✓
1998	Margined Sculpin	✓
1998	Pygmy Whitefish	✓
1998	Sharp-tailed Grouse	✓
1998	Sage-grouse	✓
1997	Aleutian Canada Goose	✓
1997	Gray Whale	✓
1997	Olive Ridley Sea Turtle	✓
1997	Oregon Spotted Frog	✓
1993	Larch Mountain Salamander	
1993	Lynx	
1993	Marbled Murrelet	
1993	Oregon Silverspot Butterfly	
1993	Pygmy Rabbit	
1993	Steller Sea Lion	
1993	Western Gray Squirrel	
1993	Western Pond Turtle	

Recovery Plans

2004	Greater Sage-Grouse	✓
2003	Pygmy Rabbit: Addendum	✓
2002	Sandhill Crane	✓
2000	Sea Otter (Draft)	✓
2001	Pygmy Rabbit: Addendum	✓
2001	Lynx	✓
1999	Western Pond Turtle	✓
1996	Ferruginous Hawk	✓
1995	Pygmy Rabbit	✓
1995	Upland Sandpiper	
1995	Snowy Plover	

✓ These reports are available in pdf format on the Department of Fish and Wildlife's web site:
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