NOAA Technical Memorandum NMFS-NWFSC-62

2004 Status Review of Southern Resident Killer Whales *(Orcinus orca)* under the Endangered Species Act

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2004 Status Review of Southern Resident Killer Whales *(Orcinus orca)* under the Endangered Species Act

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December 2004

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National Marine Fisheries Service
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Table of Contents

List of Figures

List of Tables

Executive Summary

Background

On 18 December 2002, the Center for Biological Diversity and other plaintiffs initiated a motion for summary judgment in U.S. District Court, Western District of Washington, challenging the National Marine Fisheries Service (NMFS) 2002 decision indicating that listing of Southern Resident killer whales (*Orcinus orca*) as threatened or endangered under the Endangered Species Act (ESA) was not warranted at that time. The plaintiffs asserted that NMFS's policy that considers the population's "significance" in determining whether a population should be considered a distinct population segment (DPS) is not permitted by the ESA. In addition, the plaintiffs stated that NMFS's reliance on the "outdated and discredited" species *O. orca* as the taxon violated the best available science standard.

On 17 December 2003, U.S. District Court Judge Robert Lasnik found that the DPS policy is not contrary to congressional intent regarding the ESA and that including an assessment of a population's "significance" is one component of a reasonable interpretation of the term DPS. Judge Lasnik also held that NMFS erred by using the "inaccurate" global species *O. orca* when considering whether the Southern Resident killer whales are a DPS. The court set aside NMFS's "not warranted" finding and remanded the matter back to NMFS for determining whether the Southern Resident killer whales should be listed under the ESA. NMFS was required to issue a new finding consistent with Judge Lasnik's order by 17 December 2004.

NMFS decided that, in order to address the court order in a timely manner, the Biological Review Team (BRT) should be reconvened (referred to as the 2004 BRT).

Status of the Southern Resident Killer Whale Population

In May and June of each year since 1973/74, the Center for Whale Research, Friday Harbor, Washington, has taken photographs that identify every Southern Resident individual. As a result, the annual survey amounts to a census of the entire population. This census allows a detailed examination of the population dynamics of the Southern Resident community, including the survival and fecundity of individual animals of known age. In 1974 the population comprised 71 whales, whereas the most recent census in the summer of 2003 counted 83 whales, representing an overall annual increase of 0.4% per year. However, the population has fluctuated considerably over the 29 years of the study (Figure ES-1). Using the maximum recorded population size of 97 animals in 1996, the Southern Resident killer whale population declined by 2% per year between 1996 and 2003.

Large differences exist in survival rates of Southern Residents among different age and sex categories. Reproductive-age females had the highest survival rate, followed by juveniles, post-reproductive-age females, and young males. Calves and old males had the lowest survival

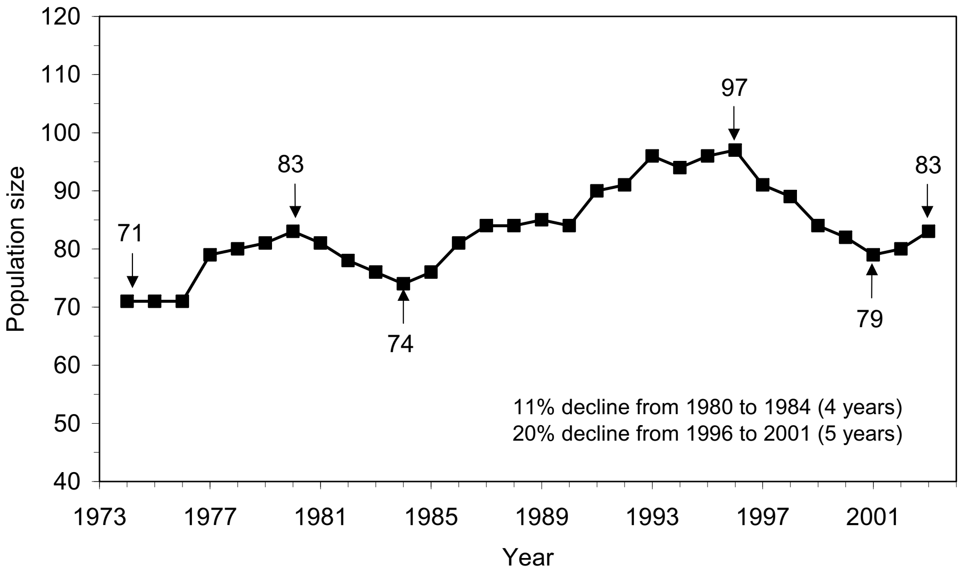

Figure ES-1. Southern Resident killer whale population size through time. (Note: The number 78 for year 2001 in Figure ES-1 of Krahn et al. 2002 was revised to 79 above to include L98, the juvenile male separated from his pod and living in Canadian waters.)

rates. In addition, there have also been large changes in survival rates through time for all age and sex categories. Survival has shifted from relatively high levels in the 1970s, to low levels in the early 1980s, to high levels again in the late 1980s and early 1990s, then returned to low levels through 2000. Survival rates improved in 2001 and 2002, but they were not as high as in previous periods of relatively high survival.

Genetic Data

The understanding of killer whale population genetic structure has expanded considerably since the last status review in 2002. In particular, the mitochondrial DNA (mtDNA) differentiation among eastern North Pacific resident, transient, and offshore populations can now be seen in the context of variation worldwide (shown in the mtDNA haplotype tree in Figure 2 of this status review). The most notable result from the new mtDNA data is the lack of strong mtDNA structure worldwide, suggesting that the current distribution of killer whales populations may be relatively young on an evolutionary scale (e.g., several hundred thousand years compared to the ≈5-million-year-old age of the *Orcinus* genus and possibly associated with a population bottleneck followed by a worldwide expansion). With regard to identifying conservation units, one of the implications of the new data is that the relative degree of mtDNA divergence among populations is not necessarily a good predictor of the length of time that the populations have evolved independently. For example, animals with the "southern resident" haplotype have been found in populations from Washington (the Southern Residents), Alaska, Russia, Newfoundland, and the United Kingdom. Evolutionarily, these populations are almost certainly more closely related to other geographically proximate populations than to each other (a hypothesis supported by the microsatellite data), and therefore share an mtDNA haplotype purely by chance. Thus it would be inappropriate to rely heavily on simple mtDNA divergence as a criterion for identifying conservation units, especially on a global scale. On a local scale, however, mtDNA remains useful for helping to identify populations, especially when combined with other types of information.

In addition to more mtDNA data, the amount of nuclear microsatellite data has expanded greatly in the last 2 years, both in terms of numbers of whales and loci analyzed (shown in the summary of new genetic data in Table 2 of this report). Within the eastern North Pacific, both the mtDNA and microsatellite data remain consistent with a hypothesis of 4–5 resident populations, at least 2–3 transient populations, and at least 1 offshore population. The issue of whether any contemporary gene flow occurs among eastern North Pacific populations remains unresolved, but the microsatellite data are consistent with low levels of gene flow (at most a few mating events among populations per generation). Despite some uncertainty about the evolutionary history that produced the current patterns of variation, both the mtDNA and the microsatellite data indicate a high degree of contemporary reproductive isolation among eastern North Pacific killer whale populations.

Taxonomic Information

The taxonomy of the killer whales is in a state of flux, as viewed by experts at the recent Workshop on the Shortcomings of Cetacean Taxonomy in Relation to Needs of Conservation and Management, April 30–May 2, 2004, La Jolla, California (referred to as the Cetacean Taxonomy Workshop). The previous prevailing concept of a single species has recently evolved into a diversity of views that include the possibility of multiple species. Recent new observations and data on morphology and genetics of both the Antarctic and North Pacific killer whales have reopened the question, and two divergent bodies of expert opinion have emerged. Under one line of reasoning, killer whales comprise a single highly variable species, with locally differentiated ecotypes representing recently evolved and relatively ephemeral forms not deserving species status. According to the opposing body of opinion, congruence of several lines of evidence for the distinctness of sympatrically occurring forms speaks for multiple species.

For the Antarctic, new observations of color pattern, size, habitat, and feeding ecology have led to the conclusion that there are three types of killer whales—one in open waters (the "ordinary" killer whale), one in the pack ice, and a third in leads in the fast ice. The types are distinguishable on the basis of body size, the size and shape of a white patch behind the eye, habitat, and feeding habits. Genetic relationships among the three forms, determined from mtDNA from biopsy samples, are congruent with their morphological and ecological distinctiveness.

A similar situation occurs for killer whales in the North Pacific. The seasonally sympatric resident and transient forms show consistent differences in mitochondrial and nuclear genetic markers, coloration, acoustic calls, and foraging habits. Preliminary data show differences in their cranial skeletons as well, although sample sizes remain small. The majority of experts participating in the killer whale working group at the Cetacean Taxonomy Workshop believed that the three Antarctic forms, as well as the resident and transient ecotypes in the North Pacific, may be distinct species or subspecies.

Determination of the Taxon

Species

The 2004 BRT first considered whether killer whales comprise a single species or multiple species, reviewing new information and the competing lines of evidence cited during the Cetacean Taxonomy Workshop. After discussion of this information, the BRT reached consensus that—although multiple species may exist and may be confirmed in the future—the present data do not adequately support designation of any new species. In particular, the BRT concluded that, provisionally, North Pacific transients and residents should be considered to belong to a single species.

Subspecies

The 2004 BRT next considered the question of whether Southern Residents and transients belong to different subspecies. A number of differences between residents and transients have been suggested to support subspecific separation.

- Residents and transients differ on average in external morphology, including dorsal-fin size and shape, saddle-patch shape, and pigmentation.
- Differences between the two ecotypes have been found in skull features, although the sample size is still small and uncontrolled for age and sex.
- Residents and transients are sympatric in the summer range, but no intermingling or interbreeding has ever been observed.
- The two groups have markedly different feeding specializations and social organization.
- The two ecotypes exhibit markedly different acoustic dialects and acoustic practices that may relate to differences in feeding ecology.
- The two forms are genetically divergent at both mtDNA and nuclear DNA markers. The level of divergence between the residents and transients is higher than the average level of divergence within populations of either group.
- Residents and transients fall into two different global mtDNA clades.

The 2004 BRT agreed that if the Southern Residents belong to a subspecies separate from that of the transients, the subspecies would include the Southern Residents and the Northern Residents, as well as the resident killer whales of Southeast Alaska, Prince William Sound, Kodiak Island, the Bering Sea and Russia. In short, the subspecies would include all of the resident, fish-eating killer whales of the North Pacific. The rationale for this decision was that all of these groups are apparently fish-eating specialists, occupy relatively similar habitats, and appear to be genetically more closely related to each other than to sympatric transient populations.

The BRT also considered whether the offshore form would be included in a subspecies with the residents (if such a subspecies were agreed to exist). A number of differences exist between North Pacific residents and offshores, including distribution, diet (as indicated by analyses of stable isotopes, fatty acids and contaminants, and differential tooth wear in whales with sharks in stomach contents), mtDNA haplotypes, nuclear DNA, external morphology (saddle patch and degree of sexual dimorphism, although data have not yet been well quantified), group size, and acoustic dialects.

The possible inclusion of killer whales of the eastern Tropical Pacific with North Pacific residents in a potential subspecies was also discussed. Differential characteristics of these whales include small group size (up to 20, but mostly 3–8), indistinct saddles, multiple haplotypes within sampled groups, vocal patterns that do not match those of the North Pacific, and prey that include large baleen whales.

After considering the arguments for existence of subspecies and the conclusions of the Cetacean Taxonomy Workshop, the BRT decided (by a 5-to-1 margin) that the taxon to use for determining a DPS under the ESA should be the North Pacific residents, an unnamed subspecies of *O. orca*. Including the North Pacific offshore or eastern Tropical Pacific killer whales in the same taxon as the North Pacific residents was rejected by a 3:2 and a 7:3 margin, respectively.

Determination of DPS

Evaluation of ESA Discreteness

The 2004 BRT unanimously concluded that the Southern Residents are discrete from other North Pacific resident killer whale populations. In particular, all available data—including behavior, demography, and core and summer ranges, as well as genetics—indicated that the Southern Residents are an independent population that is distinct from other populations.

Evaluation of ESA Significance

The BRT discussed at length the significance of the Southern Residents with respect to the North Pacific resident taxon. The BRT concluded by a 2-to-1 margin that the Southern Residents are significant with regard to the North Pacific resident taxon and therefore should be considered a DPS. The BRT also concluded by a 3-to-2 margin that the Southern Residents would be a DPS of a taxon consisting of both North Pacific residents and offshores. The arguments favoring significance under both taxonomic scenarios were as follows.

Ecological setting

The Southern Residents appear to occupy an ecological setting distinct from the other North Pacific resident populations. In particular, the Southern Residents are the only North Pacific resident population to spend a substantial amount of time in the California Current ecosystem, an ocean habitat that differs considerably from the Alaskan Gyre occupied by the Alaska Residents and Northern Residents. There is some evidence of differences in prey utilization, with Southern and Northern Residents favoring Chinook salmon (*Oncorhynchus tshawytscha*) and certain Alaska Residents also eating groundfish such as halibut and turbot.

Range

The BRT discussed data related to both the Southern Residents' year round and summer core ranges and concluded that loss of the Southern Residents would result in a significant gap in the range of the North Pacific resident taxon. In particular, the Southern Residents are the only North Pacific resident population to be sighted in the coastal areas off of California, Oregon, and Washington, and are the only population to regularly inhabit Puget Sound. Based on knowledge of other cetaceans, the BRT found little reason to believe that these areas would be repopulated by other North Pacific resident populations in the foreseeable future should the Southern Resident population become extinct.

Genetic differentiation

The Southern Residents differ markedly from other North Pacific resident populations at both nuclear and mitochondrial genes. The Southern Residents also differ from other North Pacific resident populations in the frequency of certain saddle-patch variants, a trait believed to have a genetic basis.

Behavioral and cultural diversity

The BRT noted that culture (knowledge passed through learning from one generation to the next) is likely to play an important role in the viability of killer whale populations. For example, the Southern Residents may possess unique knowledge of the timing and location of salmon runs in southern part of the North Pacific residents' range. The BRT also noted that there was some evidence that cultural traditions, such as greeting behavior, beach rubbing, and utilization of prey from longlines, differed among the resident populations.

Conclusions for DPS Determination

The BRT concluded that the Southern Residents are likely to be a DPS of the North Pacific resident taxon. Despite some uncertainty, the 2004 BRT was considerably more confident than the 2002 BRT about its conclusion. For example, the 2002 BRT was almost evenly split on the question of whether or not the Southern Residents are a DPS of the North Pacific resident taxon and gave only minor support to the idea that Southern Residents would be a DPS of a taxon consisting of North Pacific residents and offshores. In contrast, the 2004 BRT was fairly confident that the Southern Residents should be considered a DPS under both of these scenarios. The 2004 BRT discussed this increase in support for the Southern Residents as a DPS and attributed it primarily to the amount of new information that has been collected over the last couple of years. For example, knowledge about worldwide patterns of genetic variation in killer whales has increased dramatically and has demonstrated that sharing a similar mtDNA haplotype does not necessarily indicate a close evolutionary relationship between two populations. This is important, because the offshores and Southern Residents are characterized by very similar mtDNA haplotypes, a factor that influenced the conclusions of the 2002 BRT. In addition, the 2004 BRT was aware of recently collected information about the social structure, morphology, behavior, and diet of offshore killer whales that was unavailable at the time of the 2002 status review. This information tends to suggest that the offshores are more distinct from resident killer whales than was appreciated by the 2002 BRT. Finally, knowledge about ecological and behavioral diversity within killer whales has increased as a result of ongoing studies in British Columbia, Alaska, and the Russian Far East. The BRT generally concluded that this new information tended to suggest substantial ecological differentiation between the Southern Residents and other populations.

Risk Assessment

Risk Factors

The 2004 BRT considered whether factors that currently pose a risk for Southern Residents might continue in the future. Concern remains about whether reduced quantity or quality of prey are affecting the Southern Resident population. In addition, levels of organochlorine contaminants are not declining appreciably and those of many newly emerging contaminants (e.g., brominated flame retardants) are increasing, so Southern Residents are likely at risk for serious chronic effects similar to those demonstrated for other marine mammal species (e.g., immune and reproductive system dysfunction). Other important risk factors that may continue to impact Southern Residents are oil spills and noise and disturbance from vessel traffic.

Population Viability Analysis

A population viability analysis (PVA) was conducted to synthesize the potential biological consequences of a small population size, a slowly increasing or a declining population trend, and potential risk factors. The probability of the Southern Resident population going extinct was estimated using demographic information from the yearly census. Both the probability of extinction (defined as <1 male or female) as well as the probability of "quasi-extinction" (defined as $\leq$ 10 males or females) were determined, because the BRT believed that a population at the quasi-extinction level would be "doomed" to extinction, even though literal extinction might still take decades for long-lived killer whales. Under the assumption that growth rates in the future will accurately be predicted by the full 29-year time series of available data (the most optimistic scenario considered), the model predicted the probability that Southern Resident would become extinct was <0.1–3% in 100 years and 2–42% in 300 years (Figure ES-2). If a quasi-extinction threshold was used instead of actual extinction, the predicted probability of meeting the threshold ranged 1–15% in 100 years and 4–68% in 300 years. For both scenarios, the higher percentages in each range were associated with higher probability and magnitude of catastrophic mortality events (e.g., oil spills), as well as with a smaller carrying capacity (i.e., K = 100). When it was assumed that the population survival for the last 10 years would best predict the future (most pessimistic model), the analysis predicted a probability of extinction of 6–19% in 100 years and 68–94% in 300 years. If a quasi-extinction threshold was used in lieu of actual demographic extinction, the predicted probability of meeting the threshold ranged from 39–67% in 100 years to 76–98% in 300 years (Figure ES-2).

Summary of BRT Concerns

The population dynamics of the Southern Residents describe a population that is at risk for significant decrease, due either to incremental small-scale impacts over time (e.g., reduced fecundity or subadult survivorship) or to a major catastrophe (e.g., disease outbreak or oil spill).

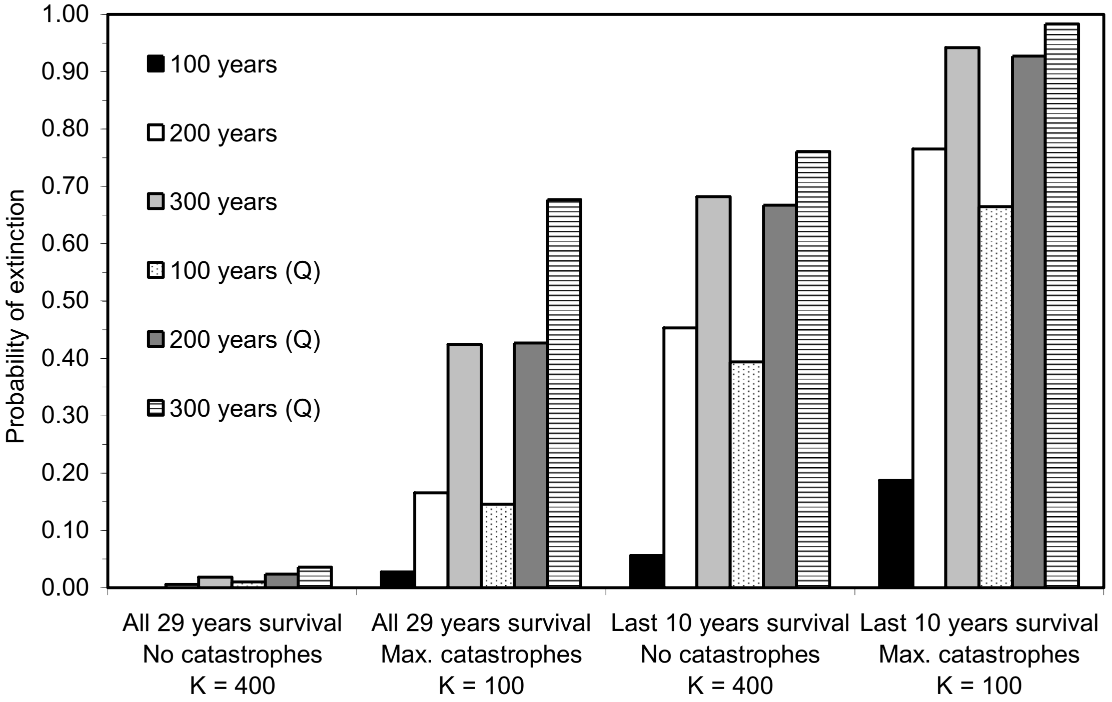

Figure ES-2. Estimated risk of extinction (<1 male or female) or quasi-extinction (Q; $\leq$10 males or females) at 100, 200, and 300 years for the Southern Resident population, assuming 1974–2003 (29-year) survival rates continue, with no catastrophes and with the maximum probability of catastrophe (two catastrophes every 100 years, with a 20% decline in the population following the catastrophes); or assuming survival rates for the last 10 years continue, with no catastrophes and with the maximum probability of catastrophe.

Additionally, the small size of this killer whale population makes it potentially vulnerable to Allee effects (e.g., inbreeding depression) that could cause a major decline. Furthermore, the small number of breeding males, as well as possible reduced fecundity and subadult survivorship in L Pod, may limit the population's potential for rapid growth in the near future. Although the Southern Resident population has demonstrated the ability to recover from lower levels in the past, the factors responsible for the recent decline are unclear, may still exist, and may continue to persist, precluding a substantial population increase.

Conclusions of the Status Review

- Although multiple species of killer whales may exist and may be confirmed in the future, the 2004 BRT concluded that present data do not adequately support designation of any new species, so North Pacific transients and residents should be considered to belong to a single species.

- The BRT agreed (by a 5-to-1 margin) that Southern Residents belong to a subspecies separate from that of the transients and this subspecies includes the Southern and Northern Residents, as well as the resident killer whales of Southeast Alaska, Prince William Sound, Kodiak Island, the Bering Sea, and Russia (but not the offshores). Thus the taxon to use for determining a DPS under the ESA would be resident killer whales in the North Pacific, an unnamed subspecies of *O. orca*.

- The BRT unanimously concluded that the Southern Residents are discrete from other North Pacific resident killer whale populations. The BRT also concluded (by a 2-to-1 margin) that the Southern Residents are significant with respect to the North Pacific resident taxon and therefore should be considered a DPS.

- Factors that might pose a future risk to the Southern Resident population are: reduced quantity and quality of prey, persistent pollutants that could cause immune or reproductive system dysfunction, oil spills, and noise and disturbance from vessel traffic.

- A PVA was conducted and the most optimistic model (29-year data set) predicted that the probability that Southern Resident would become extinct was <0.1–3% in 100 years and 2–42% in 300 years. Using the most pessimistic model (the last 10 years; quasi-extinction threshold), the probability of meeting the threshold ranged from 39–67% in 100 years to 76–98% in 300 years.

- Overall, the BRT was concerned about the viability of the Southern Resident population. The population is at risk for extinction, due either to small-scale impacts over time (e.g., reduced fecundity or subadult survivorship) or to a major catastrophe (e.g., disease outbreak or oil spill). Additionally, the small size of this killer whale population makes it potentially vulnerable to Allee effects (e.g., inbreeding depression).

1. Introduction

1.1. Scope and Intent of the Status Review Update

Following a 2002 review of the status of the Southern Resident population of killer whales (*Orcinus orca*) in the eastern North Pacific, the National Marine Fisheries Service (NMFS) determined that listing this killer whale population as a threatened or endangered species was not warranted because Southern Resident killer whales did not constitute a species, subspecies or distinct population segment (DPS) as defined by the Endangered Species Act (ESA). A legal challenge of the determination followed. Then the U.S. District Court, Western District of Washington, issued an order that set aside the NMFS finding and remanded the matter back to NMFS for redetermination of whether the Southern Resident killer whales should be listed under the ESA. NMFS reconvened a Biological Review Team (referred to as the 2004 BRT) to review and evaluate the most recent scientific and commercial information available on Southern Resident killer whales. This technical memorandum details the 2004 BRT's evaluation of the status of the Southern Resident killer whale population under the ESA.

1.2. History of the Status of Southern Resident Killer Whales

1.2.1. Petition to List—2001

On 2 May 2001, NMFS received a petition from the Center for Biological Diversity and 11 co-petitioners (Plater 2001) to list Southern Resident killer whales as threatened or endangered and to designate critical habitat for them under the ESA. The petitioned whale population, consisting of three pods (J, K, and L), inhabits the inland waterways of Puget Sound, Strait of Juan de Fuca, and Georgia Strait during the spring, summer, and fall. The primary impetus behind the petition was a rapid decline in the population from 97 animals in 1996 to 78 animals in 2001.

The petition highlighted key issues for NMFS's consideration, including: 1) genetic, behavioral, and ecological evidence indicating that Southern Resident killer whales might meet the criteria for being a DPS as defined by the ESA, 2) population data documenting a recent decline in Southern Resident killer whales and analyses indicating that these whales might be at risk of extinction, and 3) an array of threats that might account for the decline in Southern Resident killer whales. On 26 July 2001, NMFS received additional information from the lead petitioner, including an updated population viability analysis (PVA) and a report on the July 2001 census of Southern Resident killer whales returning to the inland waters of Washington and southern British Columbia (Taylor and Plater 2001).

On 13 August 2001, NMFS (2001) provided notice of its determination that the petition presented substantial information indicating that a listing might be warranted and that it would initiate a status review to determine if Southern Resident killer whales would warrant listing under the ESA.

1.2.2. Status Review—2001/2002

To conduct the status review, NMFS formed a BRT (referred to as the 2002 BRT) consisting of scientists from the agency's Alaska, Northwest, and Southwest Fisheries Science Centers. Because the ESA requires that NMFS make a listing determination based upon the best available scientific and commercial information, the agency solicited pertinent information on killer whales (NMFS 2001) and convened a meeting on 26 September 2001 to gather technical information from co-managers, scientists, and individuals having research or management expertise pertaining to killer whale stocks in the North Pacific Ocean. In addition, in March 2002 the BRT received comments from the Marine Mammal Commission and Washington, Tribal, and Canadian co-managers on a preliminary draft of the BRT's status review findings. These comments were evaluated by the BRT, which then prepared a final status review document for Southern Resident killer whales (NMFS 2002c) that was subsequently published as a NOAA technical memorandum (Krahn et al. 2002).

1.2.3. NMFS's "Not Warranted" Decision under ESA—2002

NMFS reviewed the petition, the 2002 BRT report (NMFS 2002c), co-manager comments, and other available information, and consulted with species experts and other individuals familiar with killer whales. The best available scientific and commercial information was inconclusive regarding a determination about whether the petitioned group of killer whales constituted a DPS of the currently recognized species *O. orca*.

NMFS found that the status review revealed uncertainties regarding the taxonomic status of killer whales worldwide. The taxonomy of killer whales published in the scientific literature described only a single species that included all killer whales globally. The BRT had discussed the more recent but inconclusive evidence that the cosmopolitan species *O. orca* should be subdivided into two or more species or subspecies. The BRT had recognized that taxonomists might be conservative or liberal in assigning new species and that the relevance of the new information would have to be debated widely before it could be generally accepted by the scientific community. Because the recent information related to the taxonomy of killer whales had not been subjected to that scientific debate, NMFS considered that the published standard (Rice 1998) of a single, global species was the best available scientific information. NMFS found that Southern Resident killer whales were not a species under the ESA. Consequently, NMFS found that listing Southern Resident killer whales as threatened or endangered was not warranted at that time (NMFS 2002a).

As noted in the 2002 BRT report, the BRT also investigated alternative DPSs to which Southern Residents might belong. Although a DPS could not be identified clearly, the BRT evaluated the risk of extinction for potential DPSs by aggregating logical units. As a first logical step in aggregating units of killer whales, the BRT combined the Southern, Northern, and Alaska Residents as a potential DPS to which the Southern Resident killer whales might belong and estimated the risk of extinction for this aggregation. Simulation results predicted that the extinction risk of that initial aggregation was negligible. Therefore, NMFS could not identify a

DPS to which Southern Residents might belong that was in danger of extinction throughout all or a significant portion of its range or likely to become endangered in the foreseeable future.

NMFS noted at the time of the "not warranted" decision that the agency was concerned about the recent decline in the Southern Residents[1] and would continue to seek new information on the taxonomy, biology, and ecology of these whales, as well as potential threats to their continued existence. In addition, NMFS stated that the agency would reconsider the taxonomy of killer whales within 4 years. If after 4 years the species *O. orca* had been subdivided in a manner that might allow Southern Resident killer whales to be identified as a DPS, NMFS indicated it would reconvene a BRT to reassess the status of these whales under the ESA.

1.2.4. Legal Challenge in the U.S. District Court—2002

On 18 December 2002 the Center for Biological Diversity and other plaintiffs initiated a motion for summary judgment in U.S. District Court challenging the NMFS "not warranted" finding. The plaintiffs asserted that NMFS's policy that considers the population's "significance" in determining whether a population should be considered a DPS is not permitted by the ESA. In addition, the plaintiffs stated that NMFS's reliance on the "outdated and discredited" species *O. orca* as the taxon violated the best available science standard.

1.2.5. Court's Decision—2003

On 17 December 2003, U.S. District Court Judge Robert Lasnik found that the DPS policy (see subsection 1.3 below) is not contrary to congressional intent regarding the ESA and that including an assessment of a population's "significance" is one component of a reasonable interpretation of the ambiguous DPS term. Judge Lasnik also held that NMFS erred by using the "inaccurate" global species *O. orca* when considering whether the Southern Resident killer whales are a DPS. The court set aside the NMFS "not warranted" finding and remanded the matter back to NMFS for determining whether the Southern Resident killer whales should be listed under the ESA. NMFS was required to issue a new finding consistent with Judge Lasnik's order by 17 December 2004.

The decision upheld the DPS policy—particularly the "significance" inquiry. However, the decision also mandated that NMFS consider the classification of Southern Resident killer whales using the best data available on the global species taxonomy, regardless of whether the scientific debate about killer whale taxonomy has been concluded, instead of defaulting to the currently recognized global species.

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[1] The scientific information evaluated during the ESA status review indicated that Southern Resident killer whales might be depleted under the Marine Mammal Protection Act (MMPA). NMFS initiated consultation with the Marine Mammal Commission (Commission) in a letter dated 25 June 2002 and published an advance notice of proposed rulemaking on 1 July 2002 (NMFS 2002b) to request pertinent information regarding the status of the stock and potential conservation measures that might benefit these whales. After considering comments received in response to the advance notice and from the Commission, NMFS published a proposed rule to designate the Southern Resident stock of killer whales as depleted (NMFS 2003a) and solicited comments on the proposal. Based on the best scientific information available and consultation with the Commission, NMFS determined that the Southern Resident stock of killer whales was depleted under the MMPA (NMFS 2003b) and announced its intentions to prepare a conservation plan.

1.2.6. BRT Reconvened—2004

NMFS decided that, in order to address the court order in a timely manner, the BRT should be reconvened. Most of the 2002 BRT members also served on this new panel, the 2004 BRT. Returning panel members and their areas of expertise were: NWFSC—Dr. Peggy Krahn (Team Leader; contaminants/feeding ecology), Dr. John Stein (toxicology), Gina Ylitalo (contaminants), Dr. Robin Waples (genetics), Dr. Brad Hanson (habitat/foraging ecology/whale watching); AFSC—Dr. Paul Wade (Lead, risk assessment; population dynamics/risk modeling), Dr. Robyn Angliss (conservation biology) and Dr. Marilyn Dahlheim (conservation biology/photo-identification/killer whale biology); and SWFSC—Dr. Barbara Taylor (genetics/risk modeling). Dr. Michael Ford (Lead, DPS; genetics) replaced a former panel member, Dr. Steven Kalinowski, who had taken a position outside NOAA. In addition, Dr. William Perrin from the SWFSC (Lead, cetacean taxonomy), joined the BRT to provide additional expertise on cetacean taxonomy and biology.

1.3. Key Questions in ESA Evaluations

1.3.1. The "Species" Question

For the purpose of the ESA, Congress has defined a species as "any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature." As amended in 1978, the ESA allows listing of "distinct population segments" of vertebrates, as well as named species and subspecies. Guidance on what constitutes a DPS is provided by the joint NMFS-U.S. Fish and Wildlife Service (USFWS) interagency policy on vertebrate populations (USFWS and NMFS 1996). To be considered "distinct," a population, or group of populations, must be "discrete" from other populations and "significant" to the taxon (species or subspecies) to which it belongs. Details of this joint DPS policy, including the specific considerations necessary for a population to be designated a DPS, are reviewed in subsection 4.3.

1.3.2. The "Extinction Risk" Question

The ESA defines the term endangered species as "any species which is in danger of extinction throughout all or a significant portion of its range." The term threatened species is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." The ESA states that a variety of information should be used in evaluating the level of risk faced by a species or a DPS. Important considerations include:

- the present or threatened destruction, modification, or curtailment of its habitat or range,
- overutilization for commercial, recreational, scientific, or educational purposes,
- disease or predation,
- the inadequacy of existing regulatory mechanisms, or
- other natural or man-made factors affecting its continued existence.

According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific information available on its current status, after taking into consideration conservation measures that are proposed or are in place. The BRT's mandate was to identify the DPS to which the Southern Residents belong and to evaluate the risk of extinction of that DPS. Evaluation of conservation measures and making a final listing recommendation for Southern Residents will be done by the NMFS Northwest Regional Office.

Additional details on ESA evaluations can be found in subsection 4.3 of this report, as well as in subsection 1.2, "Key Questions in ESA Evaluations," in the 2002 Status Review report (NMFS 2002c) and NOAA technical memorandum (Krahn et al. 2002).

2. Updates on the Biology, Taxonomy, Habitat, Ecology, and Potential Risk Factors for Southern Resident Killer Whales

This section has been limited to new information that was not reviewed by the 2002 BRT. Additional information on each topic can be found in section 2 of Krahn et al. (2002) or in Wiles (2004).

2.1. General Killer Whale Biology

2.1.1. Identifying Characteristics

Color patterns

Recently, Pitman and Ensor (2003) described three forms of killer whales in the Antarctic based on field observations and a review of available photographs. Identifications were based on the relative size and orientation of the white eyepatch and the presence of a dorsal cape. They concluded that, in addition to *O. orca*, two different types of killer whales occur in Antarctic waters. Visser (2000) also described variations in the eye-patch shape of killer whales in New Zealand waters.

Internal anatomy—skeleton

Killer whale skulls and associated skeletal material from a number of different museum collections have recently been measured. A preliminary comparison of these measurements suggested anatomical differences between resident and transient ecotypes (Fung and Barrett-Lennard 2004), but the sample size was small and uncontrolled for age and sex.

2.1.2. North Pacific Killer Whale Populations

Resident killer whales

The BRT recognized that there are five populations of resident killer whales in the North Pacific: Southern, Northern, Southern Alaska (to include Southeast Alaska and Prince William Sound), and Western Alaska Residents (Figure 1). Resident killer whales from Russian waters have also been described (Wiles 2004).

Southern Residents—The occurrence of Southern Residents has been documented in the coastal waters off Washington State, Vancouver Island, and more recently off the coast of central California and the Queen Charlotte Islands.

Northern Residents—Northern Resident killer whales are frequently seen in the waters of Southeast Alaska. Although Northern Residents are seen in close proximity to Southeast

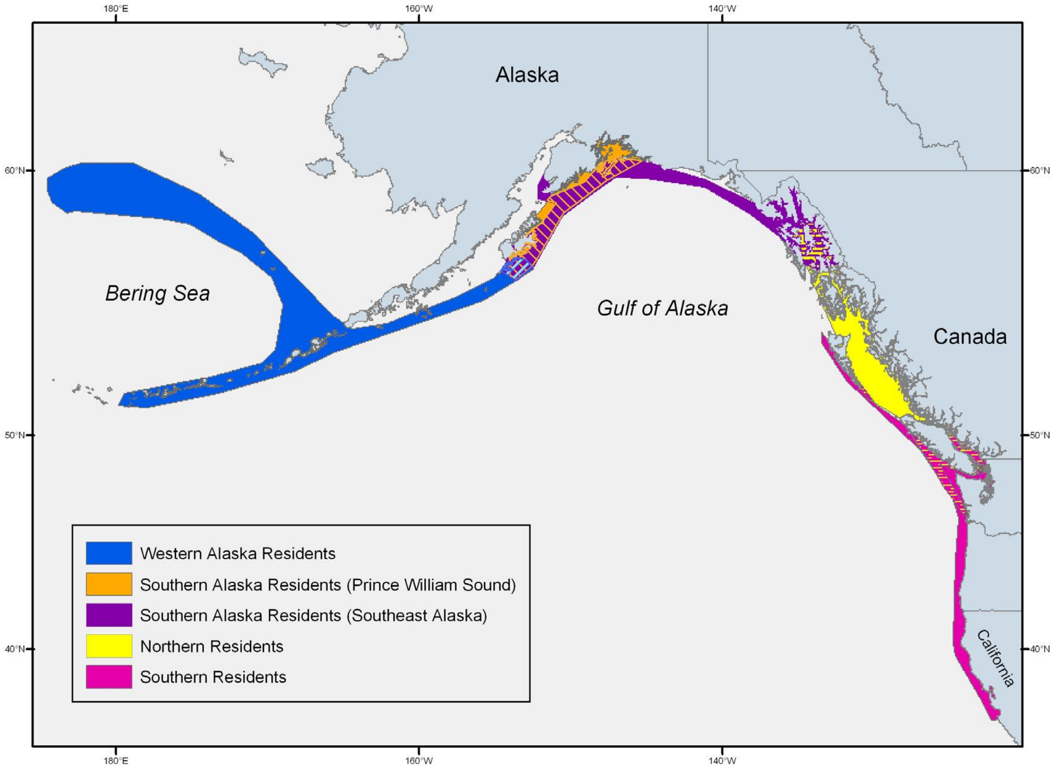

Figure 1. Ranges of resident killer whales in the eastern North Pacific (map from National Marine Mammal Laboratory).

Alaska Residents (less than ¼ nautical mile), the two groups have never been seen to intermix. Southeast Alaska whales have never been observed to the south in British Columbian waters.

Southern Alaska Residents—Southern Alaska Residents include those whales from both the Southeast Alaska and Prince William Sound/Kenai Fjords areas. Southeast Alaska whales frequently travel north and west into the waters of Prince William Sound. Intermixing between Prince William Sound and Southeast Alaska Residents has been documented. On one occasion in July 2001, a large group of killer whales was seen just south of Kodiak Island (Dahlheim unpubl. data). This grouping contained whales from Southeast Alaska, Gulf of Alaska, and the Bering Sea (Figure 1).

Western Alaska Residents—In 1992/93, large groups of resident whales from Kodiak Island westward to the Aleutian Islands and the Bering Sea shelf were first described (Dahlheim 1997). Recent studies (2001 to present) verified the resident form through genetic investigations. Preliminary counts, based on photo-identification studies, suggest a minimum of 800 individual resident whales inhabiting this region.

Western North Pacific Residents—Photo-identification studies conducted by the National Marine Mammal Laboratory (V. Burkanov and M. E. Dahlheim), as well as independent data collected and analyzed by the Alaska SeaLife Center (Seward, S. Burdin), have documented the presence of resident killer whales off the coast of Russia. Genetic data from Russian killer whales collected through the efforts of V. Burkanov also confirm this resident ecotype (Hoelzel et al. 2002b). It is likely that resident killer whales also occur along the coastline of Japan, but additional information is required to confirm this hypothesis.

Transient killer whales

Information on transient whales is provided in Krahn et al. (2002).

Offshore killer whales

Offshore killer whales can be distinguished from resident and transient whales (Dahlheim unpubl. data), because offshores appear to be smaller in overall size and their dorsal fins typically are more rounded than that of the resident form. In addition, less sexual dimorphism has been observed between adult males and females (Dahlheim unpubl. data), but this needs to be quantified. Offshore whales have multiple nicks on the trailing edge of the dorsal fin, possibly a result of the type of prey being targeted or the social interactions that may occur among members of this offshore group. Offshore group size is considerably larger—up to 200 whales—than reported for resident and transient whales. Offshore whales have not been seen to intermix with the resident or transient ecotypes, but there does appear to be a considerable amount of mixing of individual whales within the offshore groups. When comparing the overall range of the three ecotypes, offshore whales have significantly larger home ranges (Dahlheim unpubl. data). They also have suggested distinct differences in acoustical behavior.[2]

2.1.3. Feeding Ecology and Food Requirements

Information about the feeding ecology of the Southern and Northern Residents can be found in Krahn et al. (2002) and Wiles (2004).

When observed within inland waterways of Southeast Alaska and Prince William Sound, Southern Alaska Resident whales were primarily targeting salmon (Dahlheim unpubl. data). These feeding observations have been limited to the months of May to October, so the feeding habits of Southern Alaska Resident whales are not known for the winter periods. Little is known about the feeding habits of Western Alaska Resident whales. Given that major runs of salmon occur in this region, Western Alaska Resident whales may also be targeting salmon. Again, our data are limited to a 3–4 month period and nothing is known about feeding ecology in the fall to early spring period. However, in every month of the year, Western Alaska Resident whales have been documented to feed on fish from longlines (Yano and Dahlheim 1995). Based on a few observations, Russian resident killer whales also appear to be targeting salmon as prey.[3]

Based on only a few direct observations, offshore whales appear to be targeting fish. Sharks may also be consumed by this offshore ecotype. If offshore whales are following migratory fish, this may provide an explanation for the extensive movements of these whales between California and Alaska (Dahlheim unpubl. data).

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[2] J. K. Ford, DFO Canada, Science Branch, Conservation Biology Section, Pacific Biological Station, Nanaimo, BC. Pers. commun., 2004.

[3] V. Burkanov, AFSC, National Marine Mammal Laboratory, Seattle. Pers. commun., 2004.

2.1.4. Diving Behavior

From 1993 to 2002, 40 time-depth recorder tags were attached by suction cups to Southern Resident killer whales and these data from the study are still being analyzed (Baird and Hanson 2004). Although whales regularly dive to greater than 150 m, there appears to be a trend toward a greater frequency of shallower dives in recent years. In addition, the data have shown that males dive deeper than females do.

2.1.5. Social Structure

Ford and Ellis (2004) recently suggested that the most useful definitions of social structure within a resident killer whale community are the matriline and clan. The term pod should perhaps be used as a generic description of any aggregation of whales without implication of structure, or alternatively as a synonym for the matriline.

2.1.6. Behavioral and Cultural Diversity

When Southern Resident pods approach each other after being separated for some time, the pods have a unique "greeting" behavior that has not been described for other populations. The pods will form two tight lines and approach each other head on. When the groups are within 10–20 m of each other, they stop motionless at the surface and hover, facing each other for 10–30 seconds (Osborne 1986). Intermingling typically follows this greeting ceremony. Intermingling is characterized by slow-moving and tight-milling concentrations of whales. Many of the whales are in physical contact and roll and brush against each other at or near the surface.

Northern Residents also exhibit a somewhat unusual behavior. Northern Resident whales have entered shallow water along the coast and rubbed against the rocks along the bottom (Dahlheim unpubl. data). It is believed that this "beach rubbing" behavior aids the whales in sloughing dead skin. Because Northern Residents are frequently seen exhibiting this behavior, the beach rubbing areas are protected by the Canadian government. Beach rubbing by other resident whales, although extremely rare, has also been seen in Prince William Sound (Angliss unpubl. data).

In western Alaska, along the Aleutian Islands and Bering Sea shelf break, several pods of killer whales are known to actively depredate on longline-caught fish (Yano and Dahlheim 1995). These whales target sablefish and Greenland turbot. The extent and magnitude of these interactions appears to be expanding into the central and western Aleutians (Yano and Dahlheim 1995). In Prince William Sound, two killer whale pods (AB and AI Pods) are also known to depredate on longline-caught fish. In the late 1990s, AF Pod (resident pod from southeast Alaska) damaged longline-caught fish (Dahlheim unpubl. data). Given that AF Pod has been seen in association with the Prince William Sound resident pods, it is possible that AF Pod learned this behavior from observing the Prince William Sound resident whales.

2.2. Genetics of Killer Whales

2.2.1. Summary of the 2002 Status Review

The genetic information evaluated by the 2002 status review consisted primarily of mitochondrial DNA (mtDNA) sequences and microsatellite genotypes from samples collected in the eastern North Pacific and a small number of samples from other parts of the world (Table 1). The then current understanding of patterns of killer whale genetic variation was as follows: the resident and transient killer whale ecotypes in the eastern North Pacific were clearly differentiated by multiple (5-6/1000) fixed base pair differences in the mtDNA control region and relatively high divergence at nuclear microsatellite loci (F_{ST} estimates ranged from 0.23 to 0.43) depending on the specific populations compared (Barrett-Lennard 2000).

Only two mtDNA haplotypes had been found among eastern North Pacific residents, which differed from each other by a single base pair substitution. The Northern Residents were fixed for one haplotype and the Southern Residents for the other. The Southern Alaska Residents had both haplotypes, split along acoustical clans. The AB clan had the “northern resident” haplotype and the AD clan the “southern resident” haplotype. Offshores had only one haplotype, which differed from the southern resident haplotype by a single base pair substitution. Resident populations were strongly differentiated from offshores at microsatellite loci (estimates of F_{ST} were ≈ 0.30), and moderately differentiated from each other (F_{ST} estimates ranged from 0.076 to 0.187). The small number of Atlantic samples that had been analyzed had mtDNA haplotypes more similar to residents than to transients. The 2002 status review also noted that the level of microsatellite diversity in the small sample (n = 8) of Southern Residents that had been analyzed was similar to that observed in a much larger sample of Northern Residents (n = 126), suggesting the possibility that the Southern Resident population had once been much larger than its current size.

2.2.2. Additional Genetic Information Available to the 2004 BRT

Since the 2002 status review, additional mtDNA and microsatellite data have been collected for killer whales from various places around the world (Table 2), including one published paper (Hoelzel et al. 2002a) and five unpublished reports prepared as part of the NOAA-sponsored Workshop on Shortcomings of Cetacean Taxonomy in Relation to Needs of

Table 1. Summary of genetic analyses prior to 2002.

Study	Geographic focus	Number of samples	Type of data
Stevens et al. 1989	Eastern North Pacific, Atlantic	20	mtDNA[a]
Hoelzel and Dover 1991	Eastern North Pacific, Atlantic, southeastern Pacific	17	MtDNA,[b] nuclear fingerprinting
Hoelzel et al. 1998	Eastern North Pacific	73	MtDNA,[b] microsatellites
Barrett-Lennard 2000	Eastern North Pacific	130	MtDNA,[b] microsatellites

[a] Restriction fragment length polymorphism

[b] Control region sequence

Table 2. Summary of new genetic data considered by the BRT.

Study	Geographic focus	Number of samples	Type of data
Hoelzel et al. 2002a	Worldwide	102	mtDNA, microsatellites
Hoelzel 2004	Worldwide	211	mtDNA, microsatellites
LeDuc and Pitman 2004	Antarctic	49	mtDNA
LeDuc and Taylor 2004	Worldwide	219	mtDNA
Morin et al. 2004	Eastern North Pacific (historic samples)	30	mtDNA
Mesnick and Escorza-Treviño 2004	Eastern Tropical Pacific	13	mtDNA, microsatellites

Conservation and Management, April 30–May 2, 2004, La Jolla, California (designated the Cetacean Taxonomy Workshop). Each of these documents is summarized below.

Hoelzel et al. (2002a) sequenced the mtDNA control region from 102 whales, including 47 from the eastern North Pacific, 45 from the eastern North Atlantic, 5 from the western North Atlantic (Argentina), 3 from the western South Pacific (New Zealand), 1 from the western North Atlantic (Newfoundland), and one from Antarctica (Ross Sea). The total level of variation within the worldwide samples was low compared to other cetacean species. On average, randomly selected pairs of killer whale mtDNA control region sequences differed by only 5/1000 base pairs, a value near the low end of the range observed among marine mammals (Hoelzel et al. 2002b). The study found little evidence of geographic structure on a global scale. For example, the southern resident haplotype was observed not only in Southern and Alaskan Residents, but was also found in animals from the Atlantic sampled off the British Isles and Newfoundland. Similarly, another haplotype was shared between samples from New Zealand and Iceland. The overall pattern of variation is described by a “star phylogeny,” in which most sequences are more or less equally divergent from most other sequences. The distribution of differences among all pairs of sequences was unimodel, a pattern often associated with an expanding population. Hoelzel et al. (2002a) concluded that the low levels of diversity, lack of geographic structure, and distribution of pairwise differences all suggested that killer whales had gone through a genetic bottleneck. Based on the level of divergence among haplotypes, they suggested that if such a bottleneck occurred, it probably happened around 145,000 to 210,000 years ago. The study also examined microsatellite variation at eight loci, and found low levels of heterozygosity compared to other cetacean species. Patterns of microsatellite variation among the three groups of eastern North Pacific whales in the study (Southern and Alaskan Residents and transients) were generally similar to those reported by Barrett-Lennard (2000).

Hoelzel (2004) expanded his earlier study to include 211 samples, primarily from the eastern North Pacific, southeast Alaska, the Bering Sea, Kamchatka Peninsula in Russia, and southeast Iceland. In addition to mtDNA analysis (conducted on a subset of 188 samples), these samples were scored for 17 microsatellite loci. The increased number of mtDNA samples contained several additional haplotypes, including three previously unknown transient haplotypes. Patterns of mtDNA variation remained largely as described above, however, with the transients haplotypes forming one divergent group and all other haplotypes from around the world another group. Patterns of microsatellite divergence among eastern North Pacific population were largely consistent with Barrett-Lennard (2000), although the absolute level of divergence was lower (F_{ST} ranged from 0.03 between Bering Sea and Alaskan Residents to 0.25 between the samples from Russia and Iceland) (Table 3). The estimates of F_{ST} among pairs of resident populations were on average lower than estimates between resident and transient populations (0.03–0.125 within residents compared to 0.122–0.168 between residents and transients). Average heterozygosity and allelic richness (number of alleles corrected for sample size) were similar among the four resident populations in the study (Southern, Southeast Alaskan, Bering Sea, and Russian), and all four of the resident samples were less variable than the transient samples (heterozygosities ranged 0.387–0.507 for the residents and 0.652–0.668 for the transients). There was no evidence that the Southern Residents were less genetically diverse than other resident populations.

Hoelzel (2004) conducted several analyses aimed at estimating the level of migration among populations. These included estimating the number of migrants per generation under an equilibrium island migration model using the private allele method of Slatkin (1985) and an asymmetric migration model (Beerli and Felsenstein 2001, Beerli 2002). Both models produced roughly similar estimates of migration rate, ranging from less than one migration per generation between Icelandic samples and the Pacific samples (private alleles method, Table 3) to approximately eight migrants per generation from the Southern Residents to the Alaskan transients (Beerli method). It is important to note these estimates were obtained using models that are not designed to distinguish between current and historical gene flow, and the data could therefore potentially also be consistent with models assuming no contemporary migration but varying divergence times among populations (see extensive discussion of this issue in Nielsen and Wakeley 2001).

Hoelzel (2004) also approached the migration question by employing a population assignment method developed by Pritchard and Donnelly (2000). The method works by

Table 3. Estimates of genetic divergence (F_{ST}) and gene flow (migrants per generation, private allele method) among eight killer whale populations based on microsatellite DNA divergence. (Reproduced with permission from Hoelzel 2004.)

	SR[a]	**RU**	**AR**	**BS**	**OS**	**AT**	**CT**	**ICE**
SR	–	1.69	2.53	2.07	0.45	1.50	1.59	0.98
RU	0.125^{***b}	–	2.18	2.06	0.48	0.90	0.79	0.48
AR	0.061****	0.095****	–	3.38	1.06	1.34	0.97	0.69
BS	0.089***	0.052***	0.029**	–	0.53	1.21	0.72	0.62
OS	0.122*	0.201*	0.186**	0.208	–	1.34	0.93	0.68
AT	0.122****	0.132****	0.156****	0.143***	0.106*	–	2.56	0.94
CT	0.131****	0.152****	0.168****	0.166**	0.130*	0.035****	–	1.03
ICE	0.141****	0.245****	0.154****	0.205***	0.148**	0.145****	0.136****	–

[a] Abbreviations are: SR = Southern Resident, RU = Russian, AR = Southeast Alaskan Resident, BS = Bering Sea Resident, OS = offshore, AT = Alaskan transient, CT = California transient, ICE = Iceland.

[b] Asterisks indicate degree of statistical significance: **** = $p < 0.001$, *** = $p < 0.005$, ** = $p < 0.01$, * = $p < 0.05$. (See Hoelzel 2004 for details.)

partitioning the entire sample set into a preselected number of populations by maximizing the fit to multi-locus Hardy-Weinberg equilibrium expectations. Each individual sampled can then be assigned to its most likely population of origin. Individuals that assign with high probability to a population different from their sampling population can be identified as possible migrants or recent descendants of migrants. Hoelzel applied this analysis to the microsatellite data from the eastern North Pacific and Icelandic samples, and found that each initially identified population was strongly supported except for the Bering Sea Resident sample, which appeared to be a mixture of two or more populations. The analysis identified only three potential migrants—one Southeast Alaska Resident that genetically appeared to be Russian, an offshore sample that genetically appeared to be a California transient, and an Alaskan transient that genetically appeared to be a California transient.

Morin et al. (2004) reported on preliminary findings of a study examining patterns of mtDNA diversity in historical (pre-1980) samples of killer whales from California and Washington. The purpose of the study was to determine if there is evidence that the Southern Residents may have historically inhabited the California coast, especially the Sacramento River estuary, to take advantage of the historically large runs of Chinook salmon (*Oncorhynchus tshawytscha*) in that area. The presence of whales with the southern resident mtDNA haplotype would suggest that historically the Southern Residents inhabited the area, whereas the absence of this haplotype would tend to suggest they did not. The preliminary analyses from 30 samples, some dating from as early as the mid-1800s, found no evidence of haplotypes outside of their contemporary ranges. The whales sampled from the California coast all contained haplotypes currently associated with transients or offshores, and haplotypes currently associated with Southern Residents were found only in Puget Sound or the Strait of Juan de Fuca. Neither outcome was expected to be conclusive, however, because the absence of southern resident haplotypes in a small sample does not prove they were not there, and the presence of the southern resident haplotype does not conclusively prove that the whales carrying the haplotype were part of what is now considered the Southern Resident population.

LeDuc and Taylor (2004) reported on a large (n = 219) data set of killer whale mtDNA control region sequences. In addition, they combined their data with the published mtDNA sequences of Hoelzel et al. (2002b) to create the largest existing data set of killer whale mtDNA sequences. Their results can be summarized as follows:

1. The number of unique haplotypes has grown dramatically since the last status review was conducted as sample sizes have increased and new areas have been sampled. In total, 54 different haplotypes have now been found.
2. A large number of new haplotypes have been found in samples from Antarctica and the eastern Tropical Pacific.
3. The haplotypes form two major clades, named the R and T clades by LeDuc and Taylor (Figure 2).

The R clade is more diverse, and contains a large number of haplotypes from around the world, including the southern resident and northern resident haplotypes and the offshore haplotype. The T clade is limited to the Pacific Ocean and Antarctica, and contains the original transient haplotypes as well as many previously unsampled haplotypes. All known fish specialists (such as the eastern North Pacific residents) are found in the R clade, but both clades contain animals

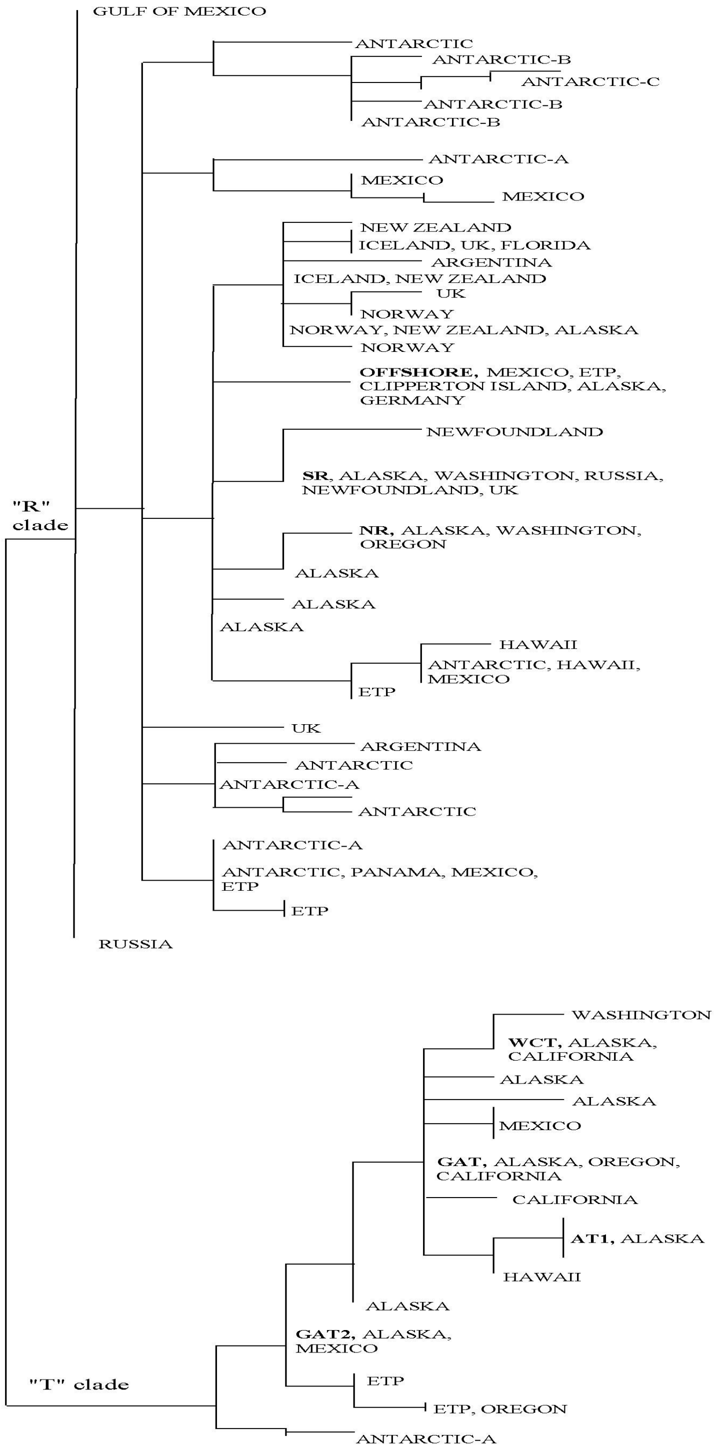

Figure 2. MtDNA haplotype tree (provided by R. LeDuc based on data described in LeDuc and Taylor 2004). ETP = eastern Tropical Pacific, NR = Northern Residents, SR = Southern Residents, WCT = West Coast transients, GAT = Gulf of Alaska transients, and AT1 = the AT1 Pod of transients in Alaska.

observed to feed on either fish or marine mammals or both (i.e., the two clades do not cleanly correspond to any known ecological specialization). LeDuc and Taylor (2004) did not report levels of nucleotide diversity, but as all of the new haplotypes are closely related to previously known haplotypes, it appears unlikely that the low levels of diversity found by Hoelzel (2002b) will change substantially. On a global scale, there is little geographic structure apparent in the data, but some local structure is apparent. In particular, the B and C forms from Antarctica share a group of closely related haplotypes, as do some animals from the eastern Tropical Pacific (Figure 2).

LeDuc and Pitman (2004) described recent mtDNA sequence data from Antarctic killer whales. They analyzed 49 samples, which included 7 samples identified a priori as Type A, 15 as Type B, and 18 as Type C. The 49 samples contained 24 variable sites, yielding 16 unique haplotypes. The ice inhabiting forms (B and C) were characterized by a group of closely related haplotypes, differing from Type A forms by three fixed differences. The Type A forms contained a large number of highly diverse haplotypes similar to others found from throughout the world (Figure 2). The total diversity present in Antarctica alone is comparable to what is found throughout the rest of the world.

Mesnick and Escorza-Treviño (2004) analyzed microsatellite and mtDNA variation within 13 killer whales sampled from five groups, defined as animals seen swimming together in a coordinated manner. Four of the groups were from the eastern Tropical Pacific, and one was a transient group from the Bering Sea. The goal of the study was to use patterns of genetic variation within groups to infer characteristics of their social structure. For example, the well-studied eastern North Pacific resident groups are characterized by a lack of mtDNA variation within pods, consistent with observations of no dispersal from natal groups. In contrast, at least one transient pod from the Gulf of Alaska has been found with two mtDNA haplotypes within the pod (Barrett-Lennard 2000). Killer whales in the eastern Tropical Pacific are much less studied than the eastern North Pacific whales, and could potentially have quite different social structures than have been previously observed. In their preliminary study, Mesnick and Escorza-Treviño found that animals within groups shared on average twice as many microsatellite alleles as animals compared from different groups, consistent with a high degree of relatedness within groups. Two of the eastern Tropical Pacific samples were each fixed for a single mtDNA haplotype, similar to what has been observed among eastern North Pacific resident groups. The other two eastern Tropical Pacific groups, however, each contained two mtDNA haplotypes, similar to what has been observed in some transient groups. In one of these groups, one of the two haplotypes was from the R side of the haplotype tree and the other from the T side (Figure 2). These results are preliminary and Mesnick and Escorza-Treviño are reanalyzing some samples to confirm the results, but they do provide some suggestion that the eastern Tropical Pacific killer whales may exhibit at least two of the social structures that have been observed in the eastern North Pacific.

2.2.3. Summary and Conclusions

The understanding of killer whale population genetic structure has expanded considerably since the 2002 status review. In particular, the mtDNA differentiation among eastern North Pacific resident, transient, and offshore populations can now be seen in the context of variation worldwide. The most notable result from the new mtDNA data is the lack of strong mtDNA structure worldwide, suggesting that the current distribution of killer whales populations may be relatively young on an evolutionary scale (e.g., several hundred thousand years compared to the ≈5-million-year-old age of the *Orcinus* genus [Waples and Clapham 2004]) and possibly associated with a population bottleneck followed by a worldwide expansion. With respect to identifying conservation units, one of the implications of the new data is that the relative degree of mtDNA divergence among populations is not necessarily a good predictor of the length of time that the populations have evolved independently. For example, killer whales with the same haplotype as in Southern Residents have also been found in Alaska, Russia, Newfoundland, and the United Kingdom (Figure 2). Evolutionarily, these whales with the southern resident haplotype are almost certainly more closely related to other geographically proximate populations than to each other (a hypothesis supported by the microsatellite data, Table 3) and therefore, share a mtDNA haplotype purely by chance. Because of this finding, it would be inappropriate to rely heavily on simple mtDNA divergence as a criterion for identifying conservation units, especially on a global scale. On a local scale, however, mtDNA clearly remains useful for helping to identify populations, especially when combined with other types of information.

In addition to more mtDNA data, the amount of nuclear microsatellite data has expanded greatly in the last 2 years, both in terms of whales and loci analyzed. Within the eastern North Pacific, both the mtDNA and microsatellite data remain consistent with a hypothesis of four to five resident populations, at least two to three transient populations and at least one offshore population (Figure 1). The issue of whether any contemporary gene flow occurs among eastern North Pacific populations remains unresolved, but the microsatellite data are consistent with either low levels of gene flow (at most a few mating events among populations per generation) or divergence times of at least several hundred to several thousand years (M. Ford 2004, Hoelzel 2004). Despite some uncertainty about the evolutionary history that produced the current patterns of variation, both the mtDNA and the microsatellite data indicate a high degree of contemporary reproductive isolation among eastern North Pacific killer whale populations.

2.3. Taxonomy of Killer Whales

2.3.1. Current Status

The taxonomy of the killer whales is in a state of flux. The previous prevailing concept of a single species has recently evolved into a diversity of views that include the possibility of multiple species. In 1758, Linnaeus described the species *O. orca*. Subsequently, some 25 additional species were described. Following a century or so of general “lumping” of zoological species described in Victorian times, the consensus of scientific opinion—until recently—was that a single global killer whale species exists (Rice 1998). Despite this consensus, new “species” of killer whales occasionally continue to be described. For example, in 1982 two Russian whale biologists described *Orcinus glacialis* based on large numbers of a small and distinctively patterned killer whale they encountered in the pack ice of Antarctica (Berzin and Vladimirov 1982, 1983). This “species” was not generally accepted by the scientific community because of the then-prevailing consensus of a single global species of killer whale and because of the loss of the holotype specimen. However, recent new observations and data on morphology and genetics of both the Antarctic and North Pacific killer whales have reopened the question and two divergent bodies of expert opinion have emerged (Waples and Clapham 2004). Under one line of reasoning, killer whales comprise a single highly variable species, with locally differentiated ecotypes representing recently evolved and relatively ephemeral forms not deserving species status. According to the opposing body of opinion, congruence of several lines of evidence for the distinctness of sympatrically occurring forms speaks for multiple species.

For the Antarctic, new observations of color pattern, size, habitat, and feeding ecology have led to the conclusion that there are three types of killer whales—one in open waters (the "ordinary" killer whale), one in the pack ice, and a third in leads in the fast ice (Pitman and Ensor 2003). The types are distinguishable on the basis of body size, size and shape of a white patch behind the eye, habitat, and feeding habits. Genetic relationships among the three forms, determined from mtDNA from biopsy samples, are congruent with their morphological and ecological distinctiveness (see subsection 2.2). Although loss of the holotype specimen of *O. glacialis* will complicate determining the correct nomenclature for the three forms (Perrin and Reeves 2004), the majority opinion in an expert working group on killer whales at the recent Cetacean Taxonomy Workshop was that, although more data are needed to evaluate species status, the three forms may represent two or possibly three species or subspecies (Reeves et al. 2004, Waples and Clapham 2004).

A similar situation occurs for killer whales in the North Pacific. The seasonally sympatric resident and transient forms show consistent differences in mitochondrial and nuclear genetic markers, coloration, acoustic calls, and foraging habits (Waples and Clapham 2004 and also subsections 2.1 and 2.2). Preliminary data show osteological differences as well, although sample sizes remain small (Fung and Barrett-Lennard 2004). The offshore form is also distinct, but shares some characteristics with the resident form. Similar to the case for the Antarctic killer whales, the majority of experts participating in the killer whale working group at the Cetacean Taxonomy Workshop believed that the resident and transient killer whales in the North Pacific may be distinct species or subspecies (Reeves et al. 2004, Waples and Clapham 2004).

Participants in the Cetacean Taxonomy Workshop agreed on guidelines for recognition of a cetacean subspecies:

> In addition to the use of morphology and genetics to define subspecies, the subspecies concept should be understood to embrace groups of organisms that appear to have been on independent evolutionary trajectories (with minor continuing gene flow), as demonstrated by morphological evidence or at least one line of appropriate genetic evidence. Geographical or behavioral differences can complement morphological and genetic evidence for establishing subspecies. As such, subspecies could be geographical forms or incipient species.

The Cetacean Taxonomy Workshop recognized that applying these standards may result in cases where subspecies status is given to entities that later prove to be full species, as has often happened in the past. Under the guidelines proposed, the participants concluded that recognition and formal description of subspecies of killer whales in the Antarctic (types A, B, and C) and North Pacific (residents and transients) would be appropriate, with the understanding that further research may result in elevation of some or all of them to the species level, or alternatively, in the determination that species status is not warranted.

2.3.2. Nomenclature

If it is decided that the resident killer whales of the North Pacific should be considered a subspecies of *O. orca* (see subsection 3.2), naming this taxon (and other killer whale taxa identified in a potential global review) becomes a problem. It must be emphasized that the nomenclatural work, if any is required, cannot commence until the biological work is completed, that is, after globally identifying the number of valid species or subspecies and their diagnostic characters.

The first step in assigning the various nominal species and subspecies names (some 25 in the literature since 1758, draft list in Perrin 2004) to biologically determined species or subspecies is determining the species or subspecies identity of type specimens. Some holotype specimens may be identifiable to species or subspecies from the figures and characters given in the description or from data published by earlier workers who examined the specimen. Others may require a visit to the collection holding the specimen to measure and photograph it. If the morphological characters are not fully diagnostic (including at all life stages in the case of an immature holotype), or if the specimen is incomplete or damaged such that the diagnostic characters cannot be examined, it may be necessary to collect a tooth or bone sample for genetic analysis. Alternatively, it may be possible to obtain a tooth or bone sample from the specimen without visiting the collection. In this case, the identification would hinge entirely on the molecular diagnosis. If all attempts to identify the holotype specimen to species or subspecies fail, the nominal species (the name) must be relegated to uncertain status (*nomen dubium*). If future, more powerful, analyses are able to identify the specimen, then the name will come back into play as a valid (junior or senior) synonym.

Holotype specimens of killer whales are thought to be held in the following collections:

1. Museum of the College of Surgeons, (may now be at British Museum), London, United Kingdom: *Orca capensis.*
2. British Museum, London, United Kingdom: *Orca stenorhynchus, O. latirostris, O. pacifica.*
3. Muséum National d'Histoire Naturelle, Paris, France: *O. gladiataor europoeus.*
4. Copenhagen Museum, Denmark: *Orca eschrichtii, O. gladiator arcticus.*
5. Bergen Museum, Norway: *Orca schlegelii.*
6. Naturistorika Museum, Göteborg, Sweden: *Orca minor.*
7. Buenos Aires Museum, Argentina: *Orca magellanica.*

As noted above, some of these may be identifiable to species based on information in the description or data published by earlier workers who examined the specimen.

If it is decided (as recommended by the Cetacean Taxonomy Workshop) that the North Pacific resident form constitutes a subspecies (see subsection 3.2), until a global review of holotypes and species descriptions can be accomplished, this subspecies would best remain unnamed. There is a precedent for such provisional recognition of cetacean subspecies (Rice 1998). For example, the dwarf southern-hemisphere form of the common minke whale (*Balaenoptera acutorostrata*) and the Kerguelen Island form of Commerson's dolphin (*Cephalorhynchus commersonii*) are recognized and managed by the International Whaling Commission as "unnamed subspecies."

2.4. Ecology of Southern Resident Killer Whales

2.4.1. Current Range and Distribution

Since the early 1970s, the range of Southern Resident killer whales has been determined from strandings or opportunistic resightings of photo-identified individuals. Some Southern Resident killer whale pods use different summer and winter habitats, and the amount of information available to determine the extent of their seasonal ranges is very limited. For example, over a 20-year period, only 27 confirmed sightings of Southern Residents have been documented outside the Puget Sound region (Table 4).

Summer

Additional studies in 2003 demonstrated that there are seasonal and temporal differences in habitat use by the three Southern Resident pods in Puget Sound (Hauser unpubl. data). The west side of San Juan Island and Haro Strait is the most commonly used area among all three pods, but other regions (e.g., the south end of Vancouver Island) are used in varying extents by the pods.

Fall, winter, and spring

Although the range of the Southern Residents outside Puget Sound is not well documented, recent studies indicate that, during nonsummer months, J Pod is sighted more frequently in Puget Sound than the other two pods (Wiles 2004). Expanded volunteer sighting efforts along the coasts of Washington, Oregon, and northern California, and a dedicated NMFS research cruise in February–March 2004 resulted in seven new confirmed Southern Resident sightings from April 2002 to April 2004 (Table 4). From these data, it appears that the current range of Southern Residents extends further south and north than previously documented. For example, the March 2003 sighting of K and L Pods off Monterey Bay, California[4]—in addition to the previously reported sighting there in January 2000—suggests that their current range may extend to central California. The sighting of L Pod off Langara Island in the northern Queen Charlotte Islands in May 2003 extended the northern range of the Southern Residents. This sighting, combined with earlier sightings of the pods returning to Georgia Strait through Johnstone Strait, suggests that this region may be a customary part of their range.

Multiple sightings have occurred over the years in a few locations and may provide new information on the habitat use and prey resources that are important to the Southern Residents during the winter and spring months. A sighting of L Pod off Tofino on the west coast of Vancouver Island in May 2004 was the fifth occurrence of Southern Residents in this area. During the 2004 research cruise, J Pod was observed at the entrance of the Strait of Juan de Fuca, heading toward the outer coast, and L Pod was sighted off Westport, Washington, the fourth occurrence in this area. The L Pod sighting coincided with the start of the spring Chinook salmon run in the Columbia River, but it is not known if salmon or other potential prey were in the area at the time of the J Pod sighting.

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[4] N. A. Black, Monterey Bay Cetacean Project, Pacific Grove, CA. Pers. commun., 2004.

Table 4. Summary of known and potential sightings of Southern Resident killer whales along the outer Pacific Ocean coast. Also listed are known sightings of Southern Resident killer whales in "winter" (December–April) in the inside waters of British Columbia and Washington (the Strait of Juan de Fuca and east).[*]

Date	Location	Identification	Source	Comments
British Columbia outer coast				
31 Jan 1982	Barkley Sound, west coast of Vancouver Island	L Pod	Ford et al. 2000 and J. Ford, PBS/DFO	Off shore of Sound
21 Oct 1987	Coal Harbor, north Vancouver Island	Part of L Pod	J. Ford, PBS/DFO	Were way up inlet a long distance from open ocean
3 May 1989	Tofino, west coast of Vancouver Island	K Pod	WMSA	
Jun 1995	Hippa Is., south Queen Charlotte Islands	Southern resident haplotype	J. Ford, PBS/DFO	Carcass found on beach, ID only by genetics
May 1996	Cape Scott, north Vancouver Island	Southern resident haplotype	J. Ford, PBS/DFO	Carcass found on beach, ID only by genetics
4 Sep 1997	Off Carmanah Point	L Pod	Observed by P. Gearin, NMML	Identified by D. Ellifret
14 Apr 2001	Tofino, west coast of Vancouver Island	L Pod	J. Ford, PBS/DFO	
27 Apr 2002	Tofino, west coast of Vancouver Island	L Pod	J. Ford, PBS/DFO	
12 May 2002	Tofino, west coast of Vancouver Island	L Pod	J. Ford, PBS/DFO	
30 May 2003	Langara Is., Queen Charlotte Islands	L Pod	M. Joyce, DFO	
17 May 2004	Tofino, west coast of Vancouver Island	L Pod	M. Joyce, DFO	
Washington outer coast				
4 Apr 1986	Westport/Grays Harbor	L Pod	Bigg et al. 1990 and J. Ford, PBS/DFO	
13 Sep 1989	Off Cape Flattery	L Pod	J. Calambokidis, Cascadia Research	Photos were sent to K. Balcomb
17 Mar 1996	Grays Harbor	L Pod	R. Osborne, WMSA	2 mi. off outer coast
20 Sep 1996	Off Sand Point	L Pod	Observed by P. Gearin, NMML	Identified by D. Ellifret
15 Apr 2002	Long Beach	L60	D. Duffield, Portland State Univ.	Stranded whale identified by K. Balcomb, CWR
11 Mar 2004	Grays Harbor	L Pod	B. Hanson, NWFSC	
Oregon				
Apr 1999	Depoe Bay	L Pod	J. Ford, PBS/DFO	
Mar 2000 (week of 20th)	Yaquina Bay	L Pod	J. Ford, PBS/DFO	
14 Apr 2000	Depoe Bay	Southern Residents	K. Balcomb, CWR	

Table 4 continued. Summary of known and potential sightings of Southern Resident killer whales along the outer Pacific Ocean coast. Also listed are known sightings of Southern Resident killer whales in "winter" (December–April) in the inside waters of British Columbia and Washington (the Strait of Juan de Fuca and east).*

Date	Location	Identification	Source	Comments
California				
29 Jan 2000	Monterey Bay	K and L Pods	N. Black, MBWW	Seen and photographed feeding on fish (Chinook?)
13 Mar 2002	Monterey Bay	L Pod	N. Black, MBWW	
Inside waters of Washington and British Columbia				
26 Feb 1975	Chatham Point, BC, central east coast Vancouver Island	L Pod	J. Ford, PBS/DFO	
1 Feb 1976	Beecher Bay, BC, Strait of Juan de Fuca, 10 mi. west of Victoria, BC	K and L Pods	J. Ford, PBS/DFO	
17 Apr 1976	Victoria, BC	K and L Pods	J. Ford, PBS/DFO	Off Victoria
3 Feb 1982	Victoria, BC	K and L Pods	J. Ford, PBS/DFO	Off Victoria
13 Mar 2004	Off Cape Flattery	J Pod	B. Hanson, NWFSC	Whales were outbound
Possible sightings of Southern Residents on outer coast				
15 Aug 1994	10–20 mi. off Westport, WA	3–5 whales	R. Osborne, WMSA	Photos taken
11 Apr 1997	Mouth of the Columbia River	Large pod	R. Osborne, WMSA	
18 Apr 1997	Off La Push, WA	18 whales	R. Osborne, WMSA	
20 Jul 2000	14 mi. west of Ucluelet, west coast Vancouver Island	50+ whales	R. Osborne, WMSA	No Southern Residents were known to be in inland waters at the time
26 Jul 2001	Off La Push, WA	10–20 whales	R. Osborne, WMSA	Possible Southern Resident
29 Jul 2001	Off Cape Flattery, WA	20–30 whales	R. Osborne, WMSA	

[*] Dates of new sightings (since the 2002 status review) are in bold. Observations are from a variety of sources. PBS/DFO is the Pacific Biological Station, Dept. Fisheries and Oceans Canada, Nanaimo, BC. NMML is the AFSC's National Marine Mammal Laboratory, Seattle, WA. WMSA is the Whale Museum Sighting Archives (1978–2001), Friday Harbor, WA. CWR is the Center for Whale Research, Friday Harbor, WA. MBWW is Monterey Bay Whale Watch, Pacific Grove, CA.

2.4.2. Population Dynamics

Since 1973/74, the Southern Resident killer whale pods have been photo-identified annually by the Center for Whale Research (Hammond et al. 1990). In order to identify individual whales, photographs are taken of a lateral view of a whale's dorsal fin and saddle patch. The shape of the dorsal fin and the coloration pattern of the saddle patch, as well as distinctive scratches, nicks or other marks, allows individual whales to be identified. In May and June of each year, sufficient photographs are taken to identify every Southern Resident individual, so the annual survey amounts to a census of the entire population. This census allows a detailed examination of the population dynamics of the Southern Resident community, including the survival and fecundity of individual animals of known age.

Age-specific information on survival and fecundity of individuals in the Southern Resident pods was analyzed to determine patterns in vital rates and to provide parameters for a PVA that examined possible population trajectories, given certain initial conditions and a range of plausible environmental parameters. The analyses of population dynamics here, as well as the PVA presented in subsection 5.1, update the analyses documented in the previous status review (Krahn et al. 2002).

Results from new analyses

Annual counts of the total population size showed fluctuations in the Southern Resident population from 1974 to 2003 (Figure 3). With a time series of 29 years, it is possible to look for changes in survival and fecundity rates (conditional on the survival of the adult female) over time and among age and sex classes, thus allowing an investigation into demographic factors that may have contributed to the fluctuations.

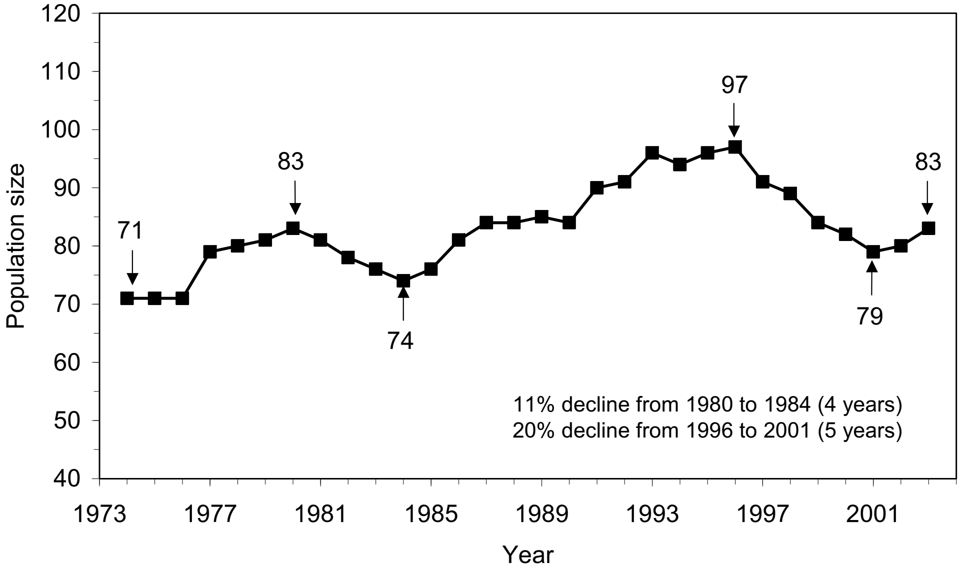

Figure 3. Southern Resident killer whale population size through time. (Note: The number 78 for year 2001 in Figure 3 of Krahn et al. 2002 was revised to 79 above to include L98, the juvenile male separated from his pod and living in Canadian waters.)

Population abundance and trends

In the 1974 census, the population comprised 71 whales, whereas the most recent census in the summer of 2003 counted 83 whales, representing an overall annual increase of 0.4% per year. However, the population has fluctuated over the 29 years of the study: increasing from 1974 to 1980 at 2.6% per year, then declining at –2.8% per year until 1984, then increasing again at 2.3% per year until 1996, declining at –4.3% per year through 2001, and finally increasing by 2.5% per year in 2002–2003 (Figure 3). On average, there have been 3.0 births and 2.7 mortalities per year. The whale L98 (known to be alive, but separated from L Pod) was included in these analyses.

Estimates of survival

A complete census of the population is made each year. Therefore, the realized survival rate of the population can be examined by calculating the fraction of animals that survive from one year to the next. Survival rate in year t is defined here as the probability of surviving from the summer of year t until the summer of year t + 1. For example, the survival rate in year 1990 is the proportion of animals that survived from the summer of 1990 until the summer of 1991. With 30 years of census data available, a total of 29 survival rates (for the years 1974–2002) can be calculated.

Crude (total population) survival rates

When every animal is seen in each year, the mark-recapture literature refers to this situation as “known fate” data. The survival rate in any given year is estimated as the number of animals in the group that survive from time t to t + 1 divided by the number alive in the group at time t. The “known fate” option in the program MARK (White and Burnham 1999) was used to analyze the data. This allowed a comparison between different models of survival and the selection of the model that provided the best fit to the data. Survival can be modeled over time in several different ways. A particular survival model is described by whether survival is different among groups (the six age and sex categories given in the “Age- and sex-specific survival models” subsection below) and how it changes over time. Models for survival over time included:

1. S(.) = a constant survival rate over all 28 years (1 parameter)
2. S(T) = a trend in survival (2 parameters)
3. S(t) = different survival rate in each year (29 parameters)
4. S(mt) = a different constant survival rate for each of m consecutive years (e.g., S(5t) would have one survival rate for the first 5 years, another survival rate for the second 5 years and so forth, for a total of 5 different parameters)

Values of m from 2 to 10 were used, ranging from a 14-parameter model to a 3-parameter model. As an additional complication, all possible starting permutations were considered: a full period starting in 1974 was given the letter “a” designation, a starting period 1 year less than a full period was given the letter “b” designation, and so on. For example, S(7t a) was a five-parameter model that had constant survival for five periods of 7, 7, 7, 7, and 1 year duration, S(7t b) had constant survival for five periods of 6, 7, 7, 7, and 2 years duration, and S(7t c) had constant survival for five periods of 5, 7, 7, 7, and 3 years duration.

The models were compared using Akaike's Information Criterion (AIC), which is based on the maximum likelihood estimates for the parameters. AIC provided a measure of which model best fits the data.

The best fitting models for crude survival were, in order, S(7t b), S(7t c), S(8t f), and S(4t b). Although these appear to be different models, in reality they provided a very similar picture of trends in survival through time, with the exception of some differences in single years. The best model, S(7t b), showed the overall pattern with alternating periods of relatively high and relatively low survival rates, ending with higher survival rates in the last 2 years (Figure 4). However, the three other models mentioned fit the data nearly as well. One was another model with constant 7-year periods, starting with a 5-year period in 1974, and the other was a model with 8-year constant periods, starting with a 3-year period in 1974. Both model S(8t f) and model S(4t b) started with a 3-year initial period in 1974; the difference between the two models was that the model S(4t b) allowed the 8-year periods in S(8t f) to be broken into 4-year periods with slightly different survival rates.

In cases where several models fit the data well, it is appropriate to average across models, where each model is weighted by its AIC value. Model averaging was done using the program MARK. The model-averaged estimates of survival show the distinct patterns through time (Figure 5). Survival rates were relatively high from 1974 to 1979, relatively low from 1980 to 1984, relatively high from 1985 to 1992, and relatively low again from 1993 to 2000 (Figure 4). Recent data showed an increase in survival from 2000 to 2003, but the observed increase was less than that seen during previous oscillations in survival rates.

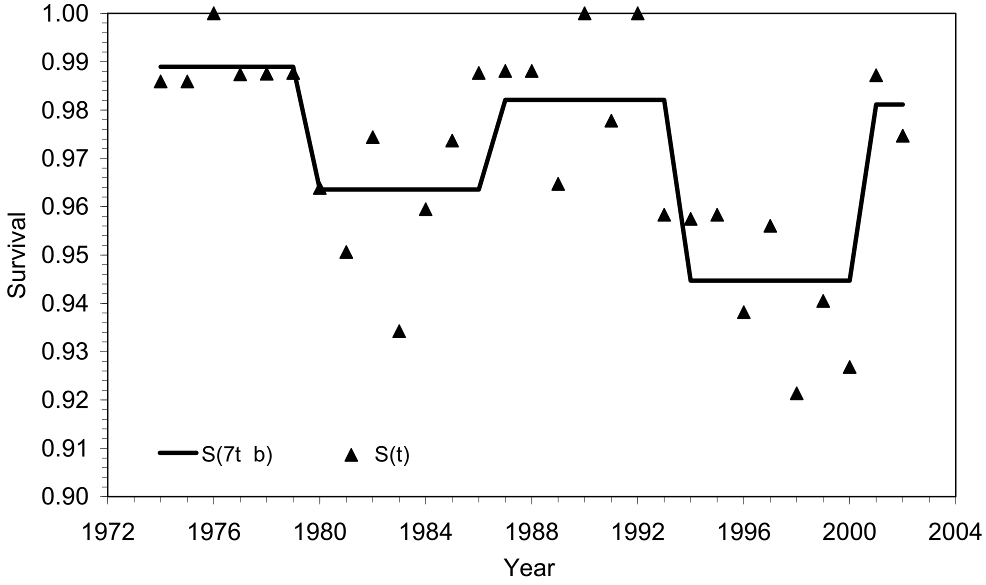

Figure 4. Best fitting model S(7t b) of crude (total population) survival (line), 7-year periods of constant survival, starting with a 6-year period in 1974. Also shown are annual estimates of survival (triangles).

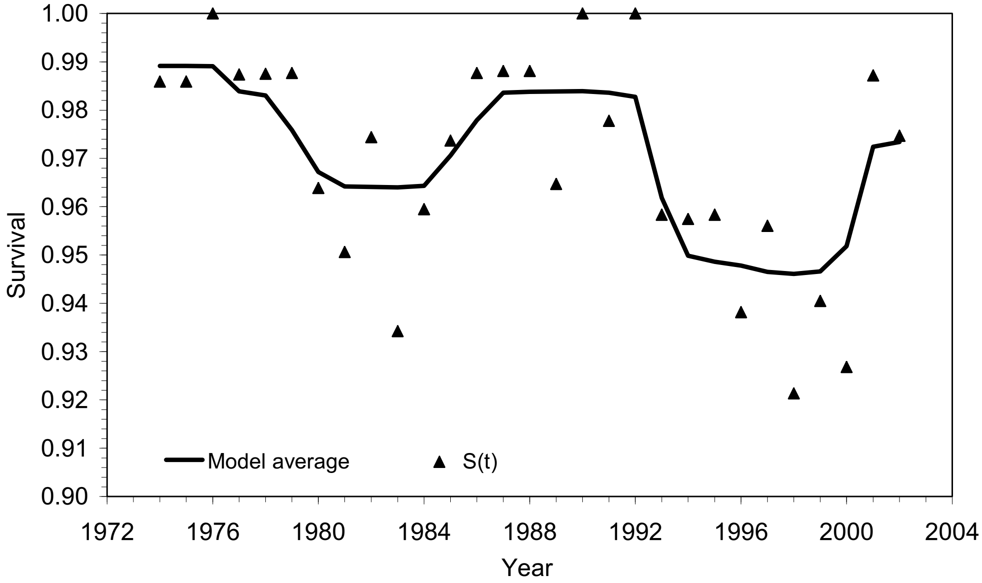

Figure 5. Model-averaged estimates of crude (total population) survival.

Crude survival by pod

An additional analysis was done to investigate whether there were differences in survival rates among J, K, and L Pods of Southern Residents (Figure 6). No differences in temporal patterns were found among the pods, and all three pods showed the same temporal trends seen in the crude survival analysis described above. Indeed, the decline in survival in the early 1980s, as well as in the 1990s, can be seen in each pod. However, L Pod has consistently had lower

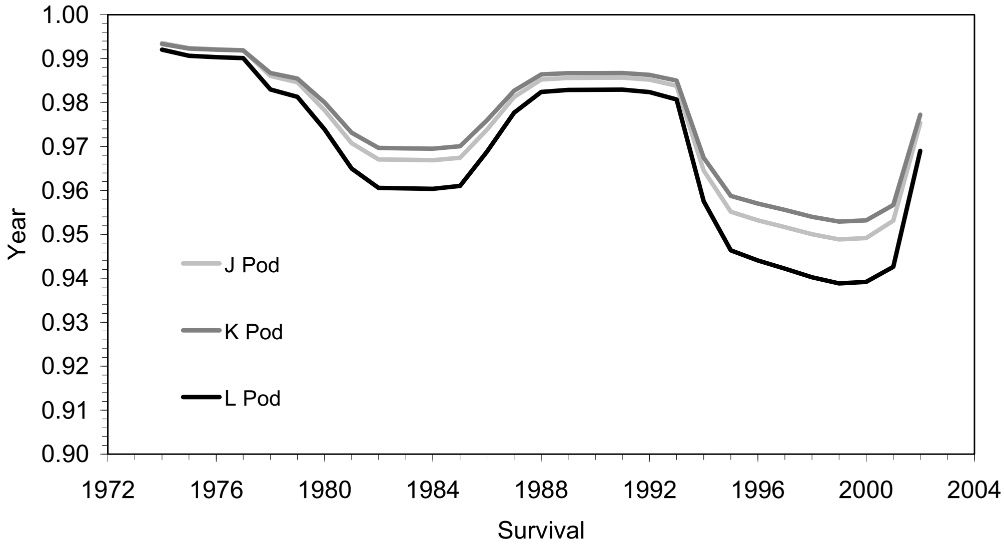

Figure 6. Southern Resident killer whale annual survival estimates by pod.

survival rates than either J or K Pod. The difference in the magnitude of survival among pods was sufficiently large that the AIC value considered the best pod survival model to be a better fit to the data than the best crude survival model that ignored pods.

Age- and sex-specific survival models

All mammals tend to have differences in survival with age, with relatively low early survival (infants and young juveniles), high adult survival and declining survival in older individuals (Caughley 1966). Killer whales have been shown to follow this pattern, as well as to exhibit differences in survival between sexes (Olesiuk et al. 1990). Olesiuk et al. (1990) reported that most births take place from October to March. Newly born whales are not counted until they are seen during the summer field season (typically May and June). The "calf" survival rate estimated here is for survival from the first summer to the second summer. For example, calf survival for a six-month old calf first seen in June will be survival from six months to 18 months of age.

Some individual killer whales do not have their sex identified until they are approximately 10 years old, although other individuals are identified at a much earlier age. Therefore, all males, females, and unknown sex whales aged 1 to 10 were assigned to the "juvenile" age class. Age 10 also provides a useful break point for females, because the youngest female to give birth in this population was age 12, meaning she was sexually mature at age 11. Whales older than age 10 were considered "adult" for this study, even though it is recognized that males do not reach sexual maturity until age 15 (on average) and may not reach physical maturity until age 20 or greater (Olesiuk et al. 1990). The oldest female to give birth was estimated to be 41 years old. Therefore, females from age 11 to 41 were placed into a single category "reproductive-age females" and those 42 and older were designated "post-reproductive-age females." However, a few females in this category have not been observed with a calf, so membership in this category does not imply that the animal is reproductively active or successful. Males from age 11 to 21 were placed into another category, called "young males." The age 21 was chosen as the upper bound because this is the average age at which physical maturity is attained. Males aged 22 and older were designated "old males." Six different age and sex classes were examined for survival:

- calves (age 0, whales seen in their first summer),
- juveniles (ages 1–10),
- females (ages 11–41, reproductive-age females),
- females (ages 42+, post-reproductive-age females),
- males (ages 11–21, young males), and
- males (ages 22+, old males).

The influence of the different age and sex classes was investigated by two different types of models for group effects. In the "times" models, each of the six groups had their own survival parameters that were independent from the other groups. This allowed for the possibility of each class (group) having its own unique temporal trend in survival. These models allowed more flexibility, but had more parameters to estimate than did simpler models. For example, combining a “times” model with a S(7t) temporal survival model led to 5 × 6 = 30 total parameters for estimating survival.

The second type of group effect models were “additive” models, where each age and sex class would have the same temporal trend (not independent), but each class could be scaled differently to account for different average survival rates seen between different age and sex classes. These models require the parameters that describe the temporal trend and just one additional parameter to scale each group (except for the first group). For example, an additive model with an S(7t) temporal survival model leads to five parameters for the temporal trend and then five more parameters to scale the other five groups, for a total of 10 parameters.

The results showed that “additive” models had the best (lowest) AIC values and these were much lower than models that ignored sex and age structure. In other words, the large differences in average survival among the age and sex classes was an important difference to take into account. The “additive” model also indicated that all the age and sex classes were experiencing similar patterns in survival through time, so more than one or two age and sex classes were affected when survival rates declined.

In this sex and age structured analysis, the best fitting models provided temporal trends similar to those from the best models in the crude survival analysis. The best four models all had similar AIC values—models S(7t c), S(7t b), S(8t f), and S(4t b). The model-averaged estimates of survival by age and sex class are shown in Figure 7. Although the averaging was done across all models, the results were dominated by the best four models mentioned above. Reproductive-age females had the highest survival rate, followed by juveniles, post-reproductive-age females and young males. Calves and old males had the lowest survival rates.

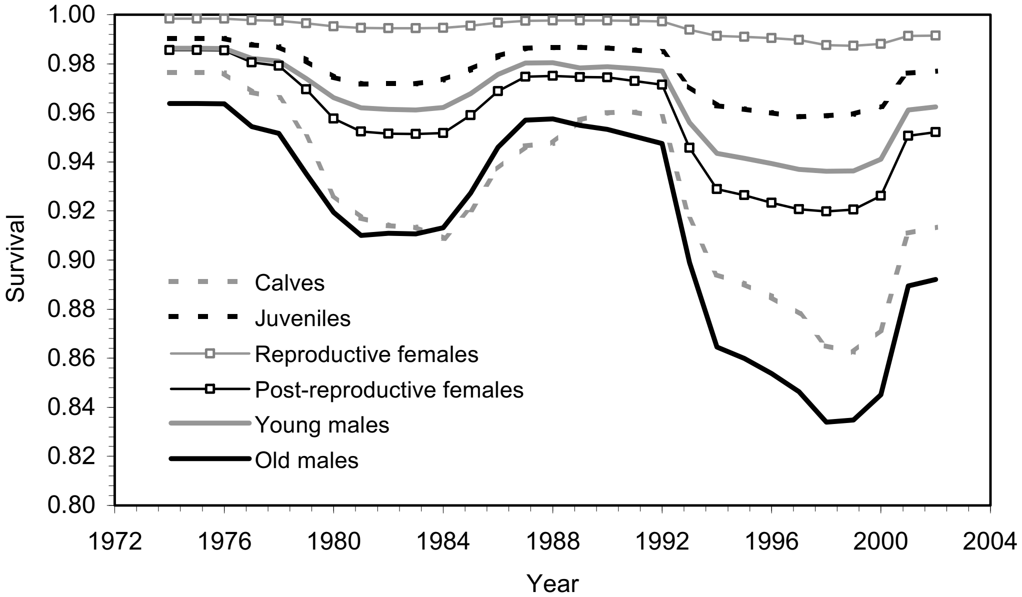

Figure 7. Southern Resident killer whale annual survival estimates by age and sex category over the years 1974 to 2002. These are the model-averaged estimates of survival.

Thus there were large differences in survival rates of Southern Resident killer whales among different age and sex categories, but there have also been large changes in survival rates through time. These changes have been characterized by periods of relatively constant survival for approximately 7 years, followed by a shift to a different, relatively constant, level of survival for the next 7 years, and so on. Survival has shifted from relatively high levels in the 1970s, to low levels in the early 1980s, to high levels in the late 1980s and early 1990s, then back to low levels through 2000, when survival began to improve. Although survival rates improved in 2001 and 2002, they were not as high as in previous periods of relatively high survival.

The risk factors that might account for differential survival among the age and sex classes were detailed in the previous status review (Krahn et al. 2002) and have been updated in subsection 2.5.

Estimates of fecundity

All calculations of fecundity were made for "recruited" calves (Olesiuk et al. 1990), which are defined as calves that survive until their first summer. Therefore, the fecundity rates reported here are likely to be much less than the true birth rate, because the fecundity rate is a product of the birth rate and the neonate survival rate.

The number of recruited calves as a percent of total population size (the gross annual reproductive rate, or GARR) was on average 3.5%, with a high of 11.3% (8 calves in 1976) and a low of 0%. From 1974 to 2000, the average observed calving interval (years between recruited calves) was 5.65. The reciprocal of the calving interval can be used to estimate the fecundity rate (Olesiuk et al. 1990). However, in this case it would overestimate the fecundity rate of reproductive age females (11–41), because it is based on the observed calving intervals that eliminate the years before and after the first and last observed calves. Fecundity was directly estimated from the number of recruited calves per reproductive-age female as 12%, with a high of 38% and a low of 0%. The reciprocal of 12% (0.12) is 7.7 years, which represents the average interval between recruited calves for every female from age 11 to 41.

To investigate temporal trends in fecundity, various models were fit to the fecundity data and compared using AIC, in a similar way as for the survival analysis. The two models that fit the data best were models with 3- or 4-year constant periods (the 3-year model was slightly better and is shown in Figure 8). However, given that several models had similar AIC values, it is again most appropriate to consider a model averaged across the best models as the best representation of fecundity through time for this population. The model-averaged estimates of fecundity represent a roughly periodic function that ranged between 0.052 and 0.187, with approximately 8 years between peaks (Figure 8). This corresponded well to the estimated calving interval of 7.7 years calculated above. Low points in the periodic model occurred in 1981, 1987, and 1996 and high points occurred in 1976, 1984, and 1992–1995.

A trend model was considered but did not provide a good fit to the data. Therefore, there was no evidence of a decline in fecundity rates over the study period. Two of the low periods in fecundity were coincident with the two low periods in survival rates. These drops in survival and fecundity in the early 1980s and the late 1990s suggested that environmental factors, such as a reduced supply of prey (Krahn et al. 2002), might have been responsible.

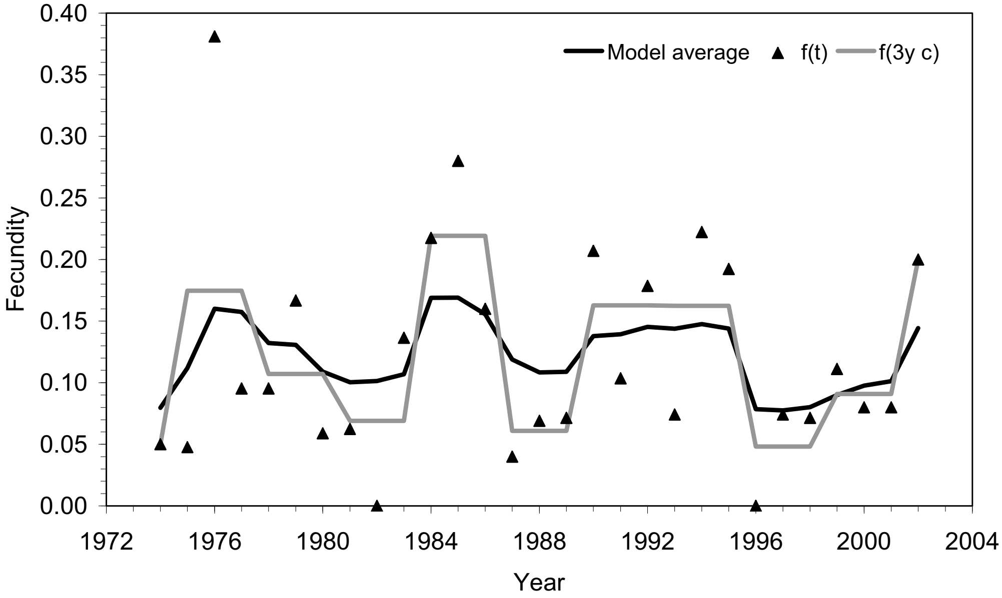

Figure 8. Best fitting model of fecundity (recruited calves per reproductive-age female), a periodic function with 3 years constant periods (gray line). Also shown are annual fecundity (triangles) and the model average fecundity from 1974 to 2002 (black line).

2.5. Potential Risk Factors

2.5.1. Prey Resources

There is little new information on the diet of Southern Resident killer whales since the Washington State Status Report for the Killer Whale (Wiles 2004) and the previous NMFS status review (Krahn et al. 2002). Salmon, particularly Chinook, are considered the major prey of Southern Residents, although information on food habits outside the Puget Sound region is very limited. There is some new unpublished information on the presence of Southern Residents during certain salmon runs in coastal waters. In 2003, the whales were observed in the Monterey Bay area feeding on Chinook salmon.[5] In March 2004, L Pod was foraging on salmon off Westport, Washington, during the spring Chinook salmon run in the Columbia River (Hanson unpubl. data).

Trends in salmon abundance

Most West Coast salmon populations have declined significantly since the 1950s. Currently 26 evolutionarily significant units (ESUs) on the West Coast are listed as threatened (21) or endangered (5) out of the 52 recognized ESUs. Adult returns for some populations have increased since 2000 (see Table 5 for updated information on salmon abundance), but it is unclear if these reflect a long-term trend.

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[5] See footnote 4.

Table 5. Summary of historical and recent estimates of numbers of salmon produced by North American west coast river systems between the Strait of Georgia and Central California (numbers in thousands, ND = no data).

		Species					
Region	**Time period**	**Chinook**	**Coho**	**Sockeye**	**Pink**	**Chum**	**Steelhead**
Fraser River	Mid–late 1800s	750[a]	1,230[a]	925–40,200[n]	23,850[a]	800[a]	ND
	Mid 1900s	150[a]	160[a]	967–18,800[n]	1,900–18,700[o]	390[a]	ND
	Mid 1980s–early 1990s	140–280[b]	40–100[a]	3,770–22,000[n]	7,200–22,180[o]	≈1,300[d]	12[v]
	Mid 1990s–current	140–350[b]	Increasing[c]	3,640–23,600[n]	3,600–21,200[o]	13× greater since 1997[d]	ND
Puget Sound	Mid–late 1800s	250–700[e]	700–2,200[e]	1,000–22,000[e]	1,000–16,000[e]	500–1,700[e]	ND
	Mid 1900s	40–100[e]	250–600[e, f]	150–400[f]	350–1,000[f]	300–600[f]	ND
	Mid 1980s–early 1990s	80–140[f]	300–800[f]	92–621[p]	1,000–1,930[p]	1,040–2,030[q]	120[t]
	Mid 1990s–current	56–92[f, r, x]	200–500[f]	35–548[p]	440–3,550[p]	570–3,390[q]	>45[t]
Coastal Washington	Mid–late 1800s	190[w]	ND	ND		ND	ND
	Mid 1900s	ND	ND	20–130[f]		80–100[f]	ND
	Mid 1980s–early 1990s	30–115[f]	40–130[f]	15–80[f]		10–325[f]	25–50[f]
	Early 1990s–current	50–65[f]	30–70[f]	20–80[f]		60–175[f]	30–40[f]
Columbia River	Mid–late 1800s	5,000–9,000[g]	900–1,700[g]	2,600–2,800[g]		500–1,400[g]	570–1,350[g]
	Mid 1900s	565–1,410[s]	21–272[s]	43–335[s]		1–425[s]	250–440[s]
	Mid 1980s–early 1990s	410–1,140[s]	43–1,575[s]	47–201[s]		1–5[s]	264–560[s]
	Mid 1990s–current	360–630[s]	89–624[s]	9–94[s]		1–3[s]	240–335[s]
Mid-north coastal Oregon	Mid–late 1800s	300–600[i]	1,000–2,000[i]			ND	ND
	Mid 1900s	192[h]	ND			130[i]	ND
	Mid 1980s–early 1990s	200–300[i]	100[i]			29[i]	330[t]
	Mid 1990s–current	ND	ND			ND	129[t]
North coast California	Mid–late 1800s	300[w]	1,200[j]				ND
	Mid 1900s	256[j]	200–500[l]				248[t]
	Mid 1980s–early 1990s	ND	13[l]				ND
	Mid 1990s–current	≈10–50[k]	ND				110[u]

Table 5 continued. Summary of historical and recent estimates of numbers of salmon produced by North American west coast river systems between the Strait of Georgia and Central California (numbers in thousands, ND = no data).

		Species					
Region	**Time period**	**Chinook**	**Coho**	**Sockeye**	**Pink**	**Chum**	**Steelhead**
Central Valley California	Mid–late 1800s	1,000–2,000[m]	ND				ND
	Mid 1900s	121–610[m]	ND				27[t]
	Mid 1980s–early 1990s	125–386[m]	ND				ND
	Mid 1990s–current	207–415[m]	ND				9[u]

[a] Northcote and Atagi 1997; catch and escapement
[b] DFO 1999; catch and escapement
[c] DFO 2002a
[d] DFO 2001
[e] Bledsoe et al. 1989; catch only
[f] Johnson et al. 1997; wild run sizes only
[g] Northwest Power Planning Council 1986
[h] Nicholas and Hankin 1989
[i] Nickelson et al. 1992
[j] California Dept. Fish and Game 1965
[k] Mills et al. 1997
[l] Brown et al. 1994
[m] Yoshiyama et al. 1998
[n] I. Guthrie unpubl. data
[o] B. White unpubl. data
[p] J. Ames unpubl. data
[q] WDFW no date; escapement
[r] B. Sanford unpubl. data
[s] WDFW and ODFW 2001
[t] Busby et al. 1996
[u] California Trout no date
[v] Simon Fraser Univ. 1998
[w] Meyers et al. 1998
[x] S. Thiesfeld unpubl. data

Chinook salmon—Chinook salmon is the least abundant species in the Northwest region. Total abundance of Chinook salmon along the Washington and Oregon coasts is relatively high and long-term population trends are generally upward, but a number of runs have had severe declines recently. In British Columbia, Chinook escapements in the early 1990s were higher than at any time since the 1950s, but concern still exists about the depressed status of stocks in southern British Columbia (Northcote and Atagi 1997, Henderson and Graham 1998). The status of California stocks is variable, with some in poor condition and others fairly abundant.

Chum salmon—In British Columbia, chum salmon (*Oncorhynchus keta*) populations have large annual fluctuations. Overall, the populations have been slowly increasing since the 1950s (Henderson and Graham 1998). Puget Sound runs are at or near historical levels, with about 3.4 million fish returning in 2002 (WDFW no date). Columbia River runs have been extremely low (<1% of historical) since the 1950s (WDFW and ODFW 2001). Stocks along the Washington coast remain variable and Oregon stocks are low.

Coho salmon—Coho (*O. kisutch*) populations in British Columbia, the Columbia River, and coastal waters of Washington and Oregon remain low. In contrast, Puget Sound and Strait of Georgia populations are near historical high levels, due to large numbers of hatchery fish (Weitkamp et al. 1995).

Sockeye salmon—Sockeye (*O. nerka*) is the second most common species of salmon in the eastern Pacific (Wydoski and Whitney 2003). Populations in British Columbia are increasing, with runs as large as 23.6 million fish. The largest run is in the Fraser River. In contrast, the run size in the Lake Washington system has averaged 230,000 fish. In addition, Columbia River and other Washington runs are low.

Pink salmon—Pink (*O. gorbuscha*) is the most abundant salmon species. Runs in Puget Sound have been high (up to 7.4 million fish), whereas those in the Fraser River have been higher (up to 22 million fish). The southern limit of their spawning range is Puget Sound.

Steelhead—Although Columbia River steelhead (*O. mykiss*) summer runs have increased since the 1970s, winter runs have declined (WDFW and ODFW 2001). Wild coastal populations are considered healthy in Washington (WDFW 2002), but Oregon and northern California populations are in decline (Busby et al. 1996). Stocks in Washington are heavily supplemented with hatchery fish.

Trends in herring abundance

Herring have been identified as prey of Southern Resident killer whales.[6] Stocks in Georgia Basin and Puget Sound recovered in the late 1970s (DFO 2002b), but certain subpopulations in Puget Sound and off Vancouver Island have declined (DFO 2001, Stout et al. 2001).

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[6] See footnote 2.

2.5.2. Marine Noise/Disturbance

Marine mammal populations are experiencing ever-increasing amounts of disturbance through contact with anthropogenic sources of marine noise and presence of vessel traffic (see detailed review in Wiles 2004). Underwater noise pollution originates from a variety of sources, including general shipping and boating traffic, industrial activities (e.g., 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, NRC 2003). Many of these activities occur in coastal areas and overlap with the habitat used by most resident and transient killer whale populations.

Killer whales rely on their highly developed acoustic sensory system for navigating, locating prey, and communicating with other individuals. Loud sounds are hypothesized to impair foraging and also to alter the movements of prey, which could affect foraging efficiency (Bain and Dahlheim 1994, Gordon and Moscrop 1996, Erbe 2002, Williams et al. 2002a, Williams et al. 2002b). Furthermore, chronic stress from noise exposure, as well as repeated disturbance from vessel traffic, can induce harmful physiological conditions (Gordon and Moscrop 1996), as well as increase energetic expenditures and cause temporary hearing threshold shifts. In extreme cases, high-intensity sounds (e.g., those from certain types of sonar) are potentially lethal by directly damaging body tissues (Gordon and Moscrop 1996). The threshold levels at which underwater noise becomes harmful to killer whales are unknown. In addition to the problem of noise, the physical presence of vessels can disrupt killer whale movements and normal behavioral patterns, resulting in increased energetic costs. Of the three pods, J Pod has the most exposure to whale watching and private vessels and L Pod has the least (Bain 2002, Koski[7]).

Commercial vessel traffic

The Strait of Juan de Fuca and Haro Strait are primary shipping lanes for vessels entering the Strait of Georgia and Puget Sound, and these areas are used by Southern Resident killer whales. This commercial traffic—on the order of several thousand trips per month—is typified by large freighters, tugs, and barges.

Commercial whale watching

In Washington and British Columbia, killer whales are the focal species of the commercial whale-watching industry (Hoyt 2001). Killer whale watching in the transboundary region is centered primarily on the Southern Residents, which can be found more reliably than transients or offshores. Viewing activity occurs predominantly in and around Haro Strait, which is the summer core area of this resident community.

There was a sharp increase in the number of whale-watching vessels between 1989 and 1998, reaching a peak of 80 vessels. However, in 2003 there were about 37 commercial whale-watching companies with 73 boats; passenger levels were estimated at 450,000 people in both 2001 and 2002.[8] Commercial whale-watching boats vary in size (7–30 m) and configuration

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[7] K. L. Koski, The Whale Museum, Friday Harbor, WA. Pers. commun., 2004.

[8] See footnote 7.

(6–280 passengers) and many routinely make two or three trips per day to view whales. In addition, at least one business offers airplane viewing. The San Juan Islands and adjacent waters also attract large numbers of private boaters for recreational cruising and fishing. Additionally, private floatplanes, helicopters, and small aircraft take regular advantage of opportunities to view whales (MMMP 2002).

In recent years, not only do large numbers of boats accompany the whales for long periods of the day (9 a.m. to 9 p.m.), but there has also been a gradual lengthening of the viewing season (April–October), with some vessels present even in the winter and early spring. The mean number of vessels following groups of killer whales increased from five boats in 1990 to 18–26 boats from 1996 to 2002 (Osborne 1999, Baird 2001, Erbe 2002, MMMP 2002, Osborne et al. 2002). Annual maximum counts of 72–120 boats were made near whales from 1998 to 2002 (Osborne et al. 2002). Of these, as many as 35 were commercial whale-watching vessels with privately owned vessels comprising the remainder. Whale-watching vessels were mainly U.S.-based in the 1980s, but currently about 65% of the vessels are Canadian (Osborne et al. 2002).

Whale-watching vessels have the potential to produce high levels of underwater sound in close proximity to the animals. Noise levels vary with vessel engine or propulsion system and become louder as speed increases (Bain 2002, Erbe 2002). The Whale Watch Operators Association Northwest was established in 1994 to establish guidelines for commercial operators to ensure consistency in practices and reduce impacts on the whales.

Recreational boating

Protected inland waters of Washington and British Columbia are popular cruising and recreational boating destinations for the general public. Opportunistic encounters between private boaters and whales are common (Osborne et al. 2002). Private boaters are more likely than commercial operators to approach too closely or otherwise operate their vessel in a manner that would potentially harass the whales.[9]

Commercial fishing

The summer range of Southern Resident killer whales was historically a region of intense fishing operations, particularly for salmon. Changes in fishing regulations and declines in salmon abundance have resulted in a significant reduction of commercial fishing vessels in this region.

Recreational fishing

Although reductions in many salmon populations have occurred, there are still seasonal openings for salmon sport fishing within the Southern Residents’ summer range. Although the boats are likely to co-occur in areas that the whales frequently use, they are relatively few and their activity (slow idle) generally does not appear to disrupt whale behavior.

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[9] See footnote 7.

Military operations

The Puget Sound area is home to a large number of naval vessels. Although naval vessels represent a small fraction of the total traffic and are designed to operate quietly, these ships are large and some are equipped with high-output sonar equipment. A mid-frequency "sonar incident" occurred with the USS *Shoup* in Haro Strait in May 2003 when J Pod was present. Biologists there reported unusual behavior patterns of J Pod, including surface behaviors (e.g., tail slapping and spy hopping), less surfacing, and changing direction/milling.[10]

Effects of vessel noise/traffic

In a model of vessel noise levels relative to killer whales' hearing detection capabilities, Erbe (2002) predicted that the sounds of fast boats are audible to killer whales at distances of up to 16 km, can mask their calls up to 14 km away, can elicit behavioral responses within 200 m, and may cause temporary hearing impairment after 30–50 min of exposure within 450 m.

Several other 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, Williams et al. 2002b, Foote et al. 2004). Individuals can react in a variety of ways to the presence of whale-watching vessels. Some of these responses include increased swimming speed, unpredictable travel paths, alteration of dive times, movement into open water, and unusual surface pattern behaviors (Kruse 1991, Jelinski et al. 2002, Williams et al. 2002a). In a recent study, Foote et al. (2004) found an increase in call duration of Southern Resident whales associated with the increase in whale-watching traffic.

2.5.3. Disease

As a baseline for developing standard necropsy protocols, Gaydos et al. (2004) provided a review of the potentially important infectious diseases that occur in other marine mammals and may impact Southern Resident killer whales. Among the identified diseases, four high priority pathogens (marine *Brucella*, cetacean poxvirus, cetacean morbillivirus and herpesvirus) were targeted for further study.

2.5.4. Environmental Contaminants

Southern Resident killer whales are exposed to relatively high levels of persistent organochlorine contaminants (OCs, e.g., PCBs and DDTs) (Ross et al. 2000) and may be exposed to other classes of emerging contaminants that have been documented in freshwater and marine environmental samples. These new contaminants of concern include brominated flame retardants (BFRs), perfluorooctanoic sulfate (PFOS) and related compounds, endocrine disruptors (e.g., synthetic estrogens, phthalates, steroids) and current use pesticides (e.g., carbamates, chlorpyrifos) (Richardson 2003, Schnoor 2003). These contaminant classes vary in their chemical structures, half-lives in the environment, input sources (e.g., atmospheric transport, input from sewage treatment plants) and uses (e.g., pesticides, flame retardants, industrial compounds). Even though many of these chemicals have been found to be toxic to

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[10] K. Balcomb, the Center for Whale Research, Friday Harbor, WA; R. Osborne, The Whale Museum, Friday Harbor, WA; and D. Bain, Univ. Washington, Seattle. Pers. commun., 2004.

wildlife, most are still being manufactured and used as agricultural and industrial chemicals in many countries throughout the world (de Wit et al. 2004).

Polybrominated diphenyl ethers (PBDEs) are a class of environmental BFRs that are quickly gaining the attention of regulatory agencies. These compounds are added to plastics, textiles, clothing, electronic circuit boards, and other materials as flame retardants. Similar to PCBs, PBDEs are ubiquitous lipophilic compounds that have been shown to bioaccumulate, especially in top-level predators such as marine mammals. The European Union has banned the use of two PBDE mixtures (penta- and octa-BDEs) and California will ban products that contain these two mixtures in 2008 (Raloff 2003). However, until PBDEs are discontinued globally, humans and wildlife will continue to be exposed to increasing levels of these compounds.

Boon et al. (2002) found that largest biomagnification of PBDEs occurred from predatory fish (cod) to marine mammals (harbor porpoise and harbor seal) in the North Sea food web. Furthermore, in North America and northern Europe, concentrations of PBDEs have been increasing since the 1970s in humans, as well as in freshwater and marine biota (de Wit 2002, Hites 2004). For example, levels of summed PBDEs measured in pooled human breast milk samples of Swedish mothers from the Stockholm region collected from 1972 through 1997 doubled every 5 years (Noren and Meironyte 2000).

Various studies have shown that some PBDE congeners may induce various toxicological effects in laboratory animals, including immune dysfunction, liver toxicity, and thyroid disruption (de Wit 2002). Hall et al. (2003) investigated the relationship between PBDE exposure and circulating levels of albumin, thyroid hormones, and cholesterol in gray seal pups from the east coast of the United Kingdom. The results suggested a link (although not a cause-and-effect relationship) between serum thyroid hormone, albumin, and cholesterol concentrations and exposure to PBDEs (approximate range: 56–1,600 ng/g, lipid) in the gray seals during their first year of life. Blubber of a reproductive female Southern Resident killer whale (L60) that stranded near Long Beach, Washington, in April 2001 was recently analyzed and found to contain a ∑PBDE concentration (1,300 ng/g, lipid, Ylitalo unpubl. data) in the same range that was associated with thyroid hormone disruption in the gray seal pups (Hall et al. 2003).

Exposure to various classes of contaminants, including OCs, PBDEs, and endocrine disrupters, may compromise the health of Southern Resident killer whales. Although these whales may be exposed to various classes of new contaminants of concern, measuring exposure in free-ranging whales is difficult because many of these contaminants are not as lipophilic as OCs and therefore are not stored in their blubber. In addition, some of these emerging contaminants have shorter half-lives and are more readily metabolized than OCs, so measuring the parent compounds in tissues is difficult. For example, steroids and pharmaceuticals are routinely measured in wastewater constituents and sediment samples in relatively low concentrations (low ng/L) (Richardson 2003, Vanderford et al. 2003), but few analytical methods have been developed to measure these compounds or their metabolites in tissues of wildlife.

2.5.5. Oil Spills

On 30 December 2003, approximately 4,800 gallons of #6 fuel oil (Bunker C) was spilled at the Chevron Texaco terminal at Point Wells, Washington. No Southern Resident killer whales were seen in the vicinity during this recent spill.

3. Determination of the Taxon

3.1. Species

The BRT first considered whether killer whales comprise a single species or multiple species, reviewing new information and the competing lines of evidence cited in the recent Cetacean Taxonomy Workshop (Reeves et al. 2004, Waples and Clapham 2004).

3.1.1. Arguments for a Single Species

- Patterns of divergence in mtDNA (the Antarctic [LeDuc and Pitman 2004], North Pacific [LeDuc and Taylor 2004], and worldwide [Hoelzel et al. 2002a]) could be explained by incomplete lineage sorting following a worldwide expansion. The mtDNA data do not clearly identify different lineages corresponding to ecotypes, and therefore suggest that the ecological specializations (e.g., fish eating versus marine mammal eating) may have developed several times (Hoelzel et al. 2002a, Hoelzel 2004).

- The nuclear genetic divergences are consistent with evolutionarily recent (hundreds to low thousands of years) divergence between resident and transient ecotypes in the eastern North Pacific (Hoelzel et al. 2002a, 2004). These groups may therefore be relatively short-lived compared to the age of the *Orcinus* genus (estimated at 5 million years [Waples and Clapham 2004]). One hypothesis is that the ecotypes originated in the Pleistocene as glaciers retreated and new foraging niches became available (Hoelzel et al. 2002a, Barrett-Lennard and Heise 2004, Hoelzel 2004).

- Foraging specializations and other behavioral characteristics such as distinct vocalizations may be learned and therefore are not good indicators of species status (Barrett-Lennard and Heise 2004).

- Morphological differences similar in scale to those provisionally observed among the killer whale ecotypes occur within species of other animals, such as wolves and other canids, and therefore are not compelling indicators of species-level difference (Waples and Clapham 2004).

- The morphological differences so far observed among the Antarctic or eastern North Pacific ecotypes have not yet been sufficiently quantified to serve as a basis for a taxonomic decision at the species level (Waples and Clapham 2004).

3.1.2. Arguments for Multiple Species

- For residents and transients in the North Pacific, there is congruence among patterns of genetic variation, acoustics, color pattern, and foraging specialization (Krahn et al. 2002).

- There is no direct evidence of interbreeding or even interaction between the resident and transient whales in the eastern North Pacific. The genetic data are subject to multiple interpretations and are consistent with a fairly high degree of contemporary reproductive isolation between the resident and transient ecotypes (see subsection 2.2 above).

- Diagnostic differences in mtDNA exist between the resident and transient ecotypes in both the Antarctic and Pacific Northwest, despite the variation within them (Section 2 of Krahn et al. 2002).

- All available genetic and observational data show no evidence of any female migration or gene flow among killer whale ecotypes, either in the eastern North Pacific or the Antarctic (Waples and Clapham 2004).

- For the Antarctic killer whales, the data on differences in morphology (body size, size and orientation of postocular patch), genetics, and ecological specialization suggest existence of two or possibly three species in the region, with types B and C representing forms not found elsewhere in the world (Pitman and Ensor 2003, LeDuc and Pitman 2004).

Overall, in the opinion of the participants in the Cetacean Taxonomy Workshop who favored the concept of multiple species, the data suggest existence of at least four new species: residents and transients in the North Pacific and Types B and C in the Antarctic.

3.1.3. Conclusions of the BRT on Species

After discussion of information relating to these arguments in the North Pacific, the BRT reached consensus that—although multiple species may exist and may be confirmed in the future—the present data are not adequate to support designation of any new species. In particular, the BRT concluded that, provisionally, North Pacific transients and residents should be considered to belong to a single species.

3.2. Subspecies

The BRT next considered the question of whether Southern Residents and transients belong to different subspecies.

3.2.1. Evidence for Subspecies Status

As noted above (subsection 2.3.1), the majority of participants in the Cetacean Taxonomy Workshop agreed that North Pacific residents and transients probably belong to different subspecies. A number of differences between residents and transients have been suggested to support subspecific separation.

- Residents and transients differ on average in external morphology, including dorsal-fin size and shape, saddle-patch shape, and pigmentation (Krahn et al. 2002, Waples and Clapham 2004).

- Differences between the two ecotypes have been found in skull features (Fung and Barrett-Lennard 2004), although the sample size is still small and uncontrolled for age and sex (Reeves et al. 2004, Waples and Clapham 2004).
- Residents and transients are sympatric in the summer range, but no intermingling or interbreeding has ever been observed, suggesting that the two groups meet the operational definition of species (let alone subspecies) under the biological species concept (Mayr 1963).
- The two groups have markedly different feeding specializations and social organization (Barrett-Lennard and Heise 2004); also see subsection 2.1, as well as relevant sections of Krahn et al. (2002) and Wiles (2004).
- The two ecotypes exhibit markedly different acoustic dialects and acoustic practices that may relate to differences in feeding ecology (J. K. Ford 2004).
- The two forms are genetically divergent at both mtDNA and nuclear DNA markers. The level of divergence between the residents and transients is higher than the average level of divergence within populations of either group (subsection 2.2).
- Residents and transients fall into two different global mtDNA clades (the R and T clades in Figure 2 [LeDuc and Taylor 2004]). One theory is that the two clades arose in different ocean basins, with movement of R-clade whales from the Atlantic to the Pacific following the last glacial period.

3.2.2. Conclusions of the 2004 BRT on Subspecies

The 2004 BRT agreed that if the Southern Residents belonged to a subspecies separate from that of the transients, the subspecies would include the Southern Residents and the Northern Residents, as well as the resident killer whales of Southeast Alaska, Prince William Sound, Kodiak Island, the Bering Sea, and Russia. In short, the subspecies would include all of the resident, fish-eating killer whales of the North Pacific. The rationale for this decision was that all of these groups are apparently fish-eating specialists, occupy relatively similar habitats, and appear to be genetically more closely related to each other than to sympatric transient populations.

The 2004 BRT also considered whether the offshore form would be included in a subspecies with the residents (if such a subspecies were agreed to exist). A number of differences exist between North Pacific residents and offshores, including distribution, diet (as indicated by analyses of stable isotopes, fatty acids and contaminants, and differential tooth wear in whales with sharks in stomach contents), mtDNA haplotypes, nuclear DNA, external morphology (saddle patch and degree of sexual dimorphism, although data have not yet been well quantified), group size, and acoustic dialects (Krahn et al. 2002, J. K. Ford 2004).

The possible inclusion of killer whales of the eastern Tropical Pacific with residents in a potential subspecies was discussed. Differential characteristics of these whales include small group size (up to 20, but mostly 3–8), indistinct saddles, multiple haplotypes within sampled groups, vocal patterns that do not match those of the North Pacific, and prey that includes large baleen whales (Mesnick and Escorza-Treviño 2004, Waples and Clapham 2004).

It was noted that other fish-eating whales of the R-clade (e.g., herring eaters in Norway) occur in regions remote from the North Pacific (i.e., the North Atlantic, Australasian region, and Antarctic [Hoelzel et al. 2002a, Hoelzel 2004]). However, it was decided that inclusion of these in a potential subspecies would only be considered if the adjacent eastern Tropical Pacific whales were included, as subspecies designations in taxonomy are traditionally geographically coherent (Winston 1999).

The BRT concluded that there was the potential for considerable uncertainty regarding the taxonomic status of eastern North Pacific killer whales. In order to characterize that uncertainty, the BRT used the 10-point likelihood voting method described by Krahn et al. (2002). Briefly, for each taxonomic question, each BRT member distributed 10 likelihood votes among the possible alternatives in proportion to the relative likelihood the member assigned to each alternative. The following questions were put to likelihood votes (overall likelihood scores in parentheses):

1. Do North Pacific residents and transients belong to a separate subspecies? (84 yes, 16 no)
2. If the North Pacific residents belong to a separate subspecies, does the subspecies include:
   a. North Pacific offshores? (42 yes, 58 no)
   b. Eastern Tropical Pacific killer whales? (29 yes, 71 no)

After considering the arguments for existence of subspecies, the conclusions of the Cetacean Taxonomy Workshop, and the results of the likelihood votes, the BRT decided that the taxon to use for determining a DPS under the ESA should be the North Pacific residents, an unnamed subspecies of *O. orca*.

4. Determination of DPS

4.1. Taxonomic Uncertainty

Uncertainty about the taxonomic status of killer whales was a problem for the DPS determinations in the 2002 status review. In particular, the 2002 BRT noted that there was increasing evidence to suggest that the currently recognized species *Orcinus orca* should be split into more than one species or subspecies, but authorities on killer whale taxonomy generally viewed that evidence as insufficient (see subsection 2.3). Getting the taxonomy right is an important part of the status review process, because the significance criterion of a DPS is made with reference to the taxon to which it belongs (USFWS and NMFS 1996).

The 2002 BRT emphasized the uncertainty surrounding killer whale taxonomy, but also found that no clear taxonomic alternatives had been proposed and widely accepted, particularly for the eastern North Pacific. Lacking the information necessary to revise the taxonomy, the BRT explored whether or not the Southern Residents would be considered a DPS under several plausible taxonomic scenarios. The scenarios ranged from the currently recognized global species to a taxon containing only North Pacific residents. The 2002 BRT considered the Southern Residents likely (48% of likelihood votes) to be a DPS only if the North Pacific residents were themselves considered to be the taxon of reference (species or subspecies) (see Table 8 in subsection 3.4.2 of Krahn et al. 2002).

4.2. Additional Information Available to the 2004 BRT

In part due to the uncertainty highlighted by the 2002 status review, the Southwest and Northwest Fisheries Science Centers sponsored the Cetacean Taxonomy Workshop in 2004 (Perrin and Reeves 2004). The results of that workshop vis-a-vis killer whale taxonomy are summarized in subsection 2.3. In addition to addressing taxonomic questions, another goal of the workshop was to review and summarize “existing information on the characteristics, ecology, and behavior of killer whales worldwide and attempt to resolve biological relationships within the genus *Orcinus* at all levels from species to local breeding populations” (Waples and Clapham 2004). The workshop did not address the particular question of whether or not the Southern Residents are a DPS, but it provided a useful forum for experts in killer whale biology to discuss and summarize information relevant to this question.

The 2004 BRT benefited from considerable new information on killer whale taxonomy (summarized in subsection 2.3), allowing the team to focus on a much more limited range of scenarios compared to the 2002 BRT. In particular, the 2004 BRT concluded that it was likely that North Pacific residents were a subspecies distinct from both transients and offshores. The unnamed North Pacific resident subspecies was considered to include killer whales from throughout the Pacific Rim, ranging from Puget Sound to the Russian Far East (Figure 1). The BRT focused most of its efforts on determining if the Southern Residents were a DPS of this unnamed North Pacific resident subspecies. In addition, the BRT considered the question of whether the Southern Residents were a DPS of a hypothetical subspecies that included both North Pacific resident and offshore killer whales, a taxonomic hypothesis that received some minority support from the BRT (subsection 2.3).

4.3. Data Relevant to Determining ESA Discreteness and Significance

Joint NOAA/USFWS policy defines a population to be a DPS if it is both discrete and significant relative to the taxon to which it belongs (USFWS and NMFS 1996). Under the policy, a population may be considered discrete if is satisfies either one of the following conditions:

- It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation.
- It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of Section 4(a)(1)(D) of the ESA.

Data relevant to the distinctiveness question include the physical, ecological, behavioral, and genetic data that are summarized in Krahn et al. (2002) and updated in section 2 above.

If a population segment is considered discrete, NMFS must then consider whether the discrete segment is "significant" to the taxon to which it belongs. Criteria that can be used to determine whether the discrete population segment is significant include:

- persistence of the discrete segment in an ecological setting unusual or unique for the taxon,
- evidence that loss of the discrete segment would result in a significant gap in the range of the taxon,
- evidence that the discrete segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historical range, or
- evidence that the discrete segment differs markedly from other populations of the species in its genetic characteristics.

A discrete population segment needs to satisfy only one of these criteria to be considered significant. The policy also allows for consideration of other factors if they are appropriate to the biology or ecology of the species. Data relevant to the significance question include the morphological, ecological, behavioral, and genetic data summarized in Krahn et al. (2002) and updated in section 2 above.

4.4. Evaluation of ESA Discreteness

The BRT unanimously concluded that the Southern Residents are discrete from other North Pacific resident killer whale populations. In particular, all available data, including behavior, demography, and core and summer ranges (subsection 2.1), as well as genetics (subsection 2.2), indicated that the Southern Residents are an independent population that is distinct from other populations.

4.5. Evaluation of ESA Significance

The BRT discussed at length the significance of the Southern Residents with respect to the North Pacific resident taxon. In particular, the BRT focused on the following four factors:

- the ecological setting of the Southern Residents, including diet and habitat, and how it differs from that of other North Pacific resident populations,
- information related to the range of the Southern Residents and other North Pacific resident populations, and whether loss of the Southern Residents would result in a significant gap in the range of the unnamed North Pacific resident subspecies (taxon),
- genetic information, including both molecular and morphological differences among North Pacific resident populations, and
- behavioral and cultural diversity within the North Pacific resident and what role the Southern Residents play in maintaining this diversity.

During these discussions, most BRT members expressed some uncertainty regarding whether or not the Southern Residents met the significance criterion as it is defined in the DPS policy. To quantify this uncertainty, the BRT employed the same 10-point voting system it used for making the taxonomic determinations (subsection 3.2).

The BRT concluded by a 2-to-1 margin of likelihood points that the Southern Residents are significant with respect to the North Pacific resident taxon, and therefore should be considered a DPS. The BRT also concluded by a 3-to-2 margin of likelihood points that the Southern Residents would be a DPS of a taxon consisting of both North Pacific residents and offshores. The arguments favoring significance under both taxonomic scenarios were as follows.

4.5.1. Ecological Setting

The Southern Residents appear to occupy an ecological setting distinct from the other North Pacific resident populations (see subsections 2.3 and 2.4 in Krahn et al. 2002 and updates in subsection 2.4 above). In particular, the Southern Residents are the only North Pacific resident population to spend a substantial amount of time in the California Current ecosystem, an ocean habitat that differs considerably from the Alaskan Gyre occupied by the Alaska Residents and (to a lesser extent) by Northern Residents. There is some evidence of differences in prey utilization (see subsection 2.1.3 above), with Southern and Northern Residents favoring Chinook salmon and certain Alaska resident populations also eating groundfish such as halibut and turbot. Southern Residents and Western Alaska Residents (west of 170ºW) also differ in their stable isotope signatures (Herman unpubl. data), which suggests that they are consuming different prey. There are reasons to believe that the Southern Residents may have historically utilized the large salmon runs to the Columbia and perhaps Sacramento Rivers as a major source of prey, consistent with an ecological specialization for Chinook salmon.

4.5.2. Range

The BRT discussed data related to both the Southern Residents' year round and summer core ranges (see subsection 2.4.1 in Krahn et al. 2002 and updates in subsection 2.4.1 above), and concluded that loss of the Southern Residents would result in a significant gap in the range of the North Pacific resident taxon. In particular, the Southern Residents are the only North Pacific resident population to be sighted in the coastal areas off of California, Oregon, and Washington, and are the only population to regularly inhabit Puget Sound. Based on experience from other cetaceans, the BRT found little reason to believe that these areas would be repopulated by other North Pacific resident populations in the foreseeable future should the Southern Resident population become extinct (see subsection 3.2.1 in Krahn et al. 2002).

4.5.3. Genetic Differentiation

The Southern Residents differ markedly from other North Pacific resident populations at both nuclear and mitochondrial genes (subsection 2.2 above). The Southern Residents also differ from other North Pacific resident populations in the frequency of certain saddle-patch variants, a trait believed to have a genetic basis (see subsection 2.2 in Krahn et al. 2002).

4.5.4. Behavioral and Cultural Diversity

The BRT noted that culture (knowledge passed through learning from one generation to the next) is likely to play an important role in the viability of killer whale populations (see subsection 2.1.6 in Krahn et al. 2002). Although the importance of culture has not been directly quantified in killer whales, it has been demonstrated to affect the survival of other highly social mammalian species such as elephants (McComb et al. 2001) and humans (Lahdenpera et al. 2004). It is a reasonable hypothesis, therefore, that the cultural knowledge that may be possessed by the Southern Resident killer whales could be important for the survival of the North Pacific resident taxon as a whole. For example, the Southern Residents may possess unique knowledge of the timing and location of salmon runs in the southern part of the North Pacific residents' range. The BRT also noted that there was some evidence that cultural traditions, such as greeting behavior, beach rubbing, and utilization of prey from longlines, differed among the resident populations.

4.6. Conclusions for DPS Determination

The 2004 BRT concluded that the Southern Residents are likely to be a DPS of the unnamed North Pacific resident subspecies (taxon). Although the BRT believed that the weight of evidence supported recognizing the Southern Residents as a DPS, nearly all BRT members put some likelihood points into the "not a DPS" category as well. The primary reason for this uncertainty was that much of the data bearing on the significance question is preliminary and unpublished, particularly recent data on the ecology and behavior of the offshores and the western Alaska populations. Some BRT members also expressed some uncertainty about how to evaluate behavioral and cultural traits with respect to the significance criterion.

Despite some uncertainty, the 2004 BRT was considerably more confident than the 2002 BRT that the Southern Residents should be considered a DPS. For example, the 2002 BRT was almost evenly split on the question of whether or not the Southern Residents are a DPS of the North Pacific resident taxon and gave only minor support to the idea that Southern Residents would be a DPS of a taxon consisting of North Pacific residents and offshores (Table 8 of Krahn et al. 2002). In contrast, the 2004 BRT was fairly confident that the Southern Residents should be considered a DPS under both of these scenarios. The 2004 BRT discussed this increase in support for the Southern Residents as a DPS and attributed it primarily to the amount of new information that has been collected over the last couple of years. For example, knowledge about worldwide patterns of genetic variation in killer whales has increased dramatically over the last couple of years, and has demonstrated that sharing of a similar mtDNA haplotype does not necessarily indicate a close evolutionary relationship between two populations (subsection 2.2 above). This is important, because the offshores and Southern Residents are characterized by very similar mtDNA haplotypes, a factor that influenced the conclusions of the 2002 BRT. In addition, the 2004 BRT was aware of recently collected information about the social structure, morphology, behavior, and diet of offshore killer whales that was unavailable at the time of the 2002 status review, and this information tends to suggest that the offshores are more distinct from resident killer whales than was appreciated by the 2002 BRT (subsection 2.1). Finally, knowledge about ecological and behavioral diversity within killer whales has increased as a result of ongoing studies in British Columbia, Alaska, and the Russian Far East (subsection 2.1). The BRT generally concluded that this new information tended to suggest substantial ecological differentiation between the Southern Residents and other populations.

5. Assessment of Extinction Risk

5.1. Population Viability Analysis

The 2002 BRT developed a PVA that modeled combinations of a variety of parameters to estimate the probability that the Southern Resident killer whale population would go extinct over a specific timeframe (Krahn et al. 2002). The 2002 model and analysis have been updated for this report and new results are presented. The updated results incorporate data on the Southern Resident population collected through 2003.

Although excellent information is available on age-specific survival and fecundity of the Southern Resident killer whale population, there are other parameters needed for the model that are less well understood. Necessary model parameters (e.g., carrying capacity and the probability of occurrence of a catastrophic mortality event) are unknown, so a variety of scenarios were analyzed in order to understand the implications of these parameters on the probability that the population would go extinct. Carrying capacities ranging from 100 to 400 animals were chosen to bracket the range of likely values: 100 whales represents the approximate size of the largest population that has been observed for Southern Residents and 400 whales represents a reasonable maximum value. Additionally, Krahn et al. (2002) showed that using a carrying capacity higher than 400 gave results identical to using the value of 400. The frequency of large mortality events or catastrophes was set at 0 (no catastrophes), 0.01 (one catastrophe on average every 100 years), or 0.02 (two catastrophes on average every 100 years). Potential sources of catastrophic mortalities include major oil spills or disease epidemics.

The only substantial change from the 2002 PVA (Krahn et al. 2002) was the use of updated information on survival and fecundity, using the results of subsection 2.4.2 above. Three different scenarios of assumed survival rates were examined. The model-averaged estimates of fecundity were used, and were assumed to continue cycling through the same 29-year pattern indefinitely. The three survival scenarios used are described in detail below.

One addition to the 2002 PVA (Krahn et al. 2002) was examination of both the probability of extinction (defined as <1 male or female) and the probability of "quasi-extinction" (defined as $\leq$10 males or females). The BRT strongly believed that a population that included less than 10 males or females was highly unlikely to persist, and so this would provide a conservative threshold below which populations would not be expected to persist over the long-term, even though literal extinction might still take decades or more because individual killer whales can live for a long time. Therefore, for all three survival scenarios the probability that the current population would decline to this quasi-extinction threshold was also calculated. The following describes the results of all of these PVA scenarios. Note that the probabilities given in Tables 6–11 are not given as percentages.

5.1.1. PVA Results

Scenario A, all 29 years of data, modeled to extinction

Scenario A involved using the best fitting model for survival and the entire 29-year sequence of estimates. This was the additive group effect model with a temporal trend S(7t c) (subsection 2.4.2 above). In other words, the temporal trend model had constant survival periods of length 5, 7, 7, 7, and 3 years, but the survival rates were scaled differently for each age and sex class. In this scenario, the full 29 years of survival estimates were assumed to be the best predictor of future survival rates over the next 100–300 years. This scenario gave the highest average survival rate and can therefore be considered the most optimistic of the three survival scenarios considered.

As expected, carrying capacity had a strong influence on the estimated risk of extinction of Southern Resident killer whales (Table 6). Most sets of parameters resulted in a probability of extinction of less than 1% in 100 years if the carrying capacity was between 200 and 400 animals, and a probability of extinction of from less than 0.1% to 3% in 100 years if the carrying capacity was 100 animals. When the model results were examined for 200 and 300 years, the pattern remained—a large carrying capacity resulted in a substantially lower probability of extinction at 200 and 300 years than a small carrying capacity.

The probability of a catastrophic mortality event and the severity of that event also had a major impact on the probability that the modeled population would go extinct. Under the assumption that there were no catastrophic mortality events (Scenario A1), simulations with a carrying capacity of 200–400 animals had nearly identical results—the risk of extinction was less than 0.1% at 100 years, approximately 0.6% after 200 years, and approximately 2% after 300 years. When carrying capacity was reduced to 100, the risk of extinction remained at less than 0.1% at 100 years, but rose to 2% in 200 years and 12% after 300 years

When a 1% probability of a mortality event with a magnitude that reduced survival by 10% was included (Scenario A2), there was still little chance of extinction after 100 years at any carrying capacity. However, with carrying capacity at 200 or more, the chance of extinction was approximately 1% after 200 years and 3–4% after 300 years. At a carrying capacity of 100, the chance of extinction rose to 3% after 200 years and 17% after 300 years. At the highest catastrophe rates and magnitudes, the risk of extinction rose to 17% after 200 years and 42% after 300 years (Scenario A4).

Scenario A(Q), all 29 years of data, modeled to a quasi-extinction threshold

These calculations used the same survival and fecundity as in Scenario A described above, but estimated the probability the population will fall below the quasi-extinction threshold. Again, carrying capacity had a strong influence on the estimated risk of meeting the threshold (Table 7)—all scenarios had substantially higher risks at 100 years when the carrying capacity was set at 100 animals than when the carrying capacity was higher. For the most optimistic of these scenarios (Scenario A(Q)1), a carrying capacity of 100 animals resulted in a probability of meeting the quasi-extinction threshold of 2% at 100 years, 12% at 200 years, and 31% at 300 years. When catastrophic mortality events were included (Scenarios A(Q)2–4), the probability

Table 6. Survival Scenario A, using all 29 years of data and S(G+7c) best survival model, 7-year groups, modeled to extinction.[a]

	Catastrophe		**Probability of extinction (years)**		
K	**Probability**	**Magnitude**[b]	**100**	**200**	**300**
Scenario A1					
400	0.000	1.000	<0.001	0.006	0.019
300	0.000	1.000	<0.001	0.005	0.018
200	0.000	1.000	<0.001	0.007	0.020
175	0.000	1.000	<0.001	0.007	0.024
150	0.000	1.000	<0.001	0.006	0.031
125	0.000	1.000	<0.001	0.009	0.047
100	0.000	1.000	<0.001	0.021	0.121
Scenario A2					
400	0.010	0.900	0.001	0.012	0.034
300	0.010	0.900	<0.001	0.013	0.037
200	0.010	0.900	<0.001	0.012	0.038
175	0.010	0.900	0.001	0.013	0.044
150	0.010	0.900	0.001	0.014	0.046
125	0.010	0.900	<0.001	0.015	0.075
100	0.010	0.900	0.001	0.030	0.165
Scenario A3					
400	0.010	0.800	0.005	0.037	0.081
300	0.010	0.800	0.005	0.034	0.081
200	0.010	0.800	0.006	0.037	0.088
175	0.010	0.800	0.006	0.034	0.091
150	0.010	0.800	0.005	0.039	0.108
125	0.010	0.800	0.007	0.042	0.139
100	0.010	0.800	0.008	0.072	0.244
Scenario A4					
400	0.020	0.800	0.024	0.104	0.210
300	0.020	0.800	0.024	0.107	0.211
200	0.020	0.800	0.024	0.111	0.230
175	0.020	0.800	0.024	0.113	0.232
150	0.020	0.800	0.026	0.115	0.250
125	0.020	0.800	0.025	0.128	0.304
100	0.020	0.800	0.028	0.166	0.424

[a] Extinction defined as <1 male or female.

[b] The magnitude shows the fraction of the population remaining following the catastrophe; the SE of the magnitude is 0.020.

Table 7. Survival Scenario A(Q), using all 29 years of data and S(G+7c) best survival model, 7-year groups, modeled to a quasi-extinction threshold.[a]

	Catastrophe		Probability of quasi-extinction (years)		
K	**Probability**	**Magnitude[b]**	**100**	**200**	**300**
Scenario A(Q)1					
400	0.000	1.000	0.010	0.024	0.036
300	0.000	1.000	0.009	0.022	0.035
200	0.000	1.000	0.010	0.024	0.044
175	0.000	1.000	0.010	0.024	0.052
150	0.000	1.000	0.010	0.027	0.077
125	0.000	1.000	0.009	0.044	0.138
100	0.000	1.000	0.019	0.123	0.311
Scenario A(Q)2					
400	0.010	0.900	0.016	0.042	0.063
300	0.010	0.900	0.017	0.043	0.065
200	0.010	0.900	0.017	0.043	0.074
175	0.010	0.900	0.018	0.045	0.087
150	0.010	0.900	0.020	0.051	0.121
125	0.010	0.900	0.017	0.072	0.198
100	0.010	0.900	0.037	0.175	0.392
Scenario A(Q)3					
400	0.010	0.800	0.043	0.092	0.130
300	0.010	0.800	0.039	0.088	0.129
200	0.010	0.800	0.042	0.091	0.147
175	0.010	0.800	0.039	0.094	0.161
150	0.010	0.800	0.045	0.105	0.208
125	0.010	0.800	0.042	0.132	0.288
100	0.010	0.800	0.065	0.252	0.492
Scenario A(Q)4					
400	0.020	0.800	0.105	0.212	0.298
300	0.020	0.800	0.101	0.217	0.303
200	0.020	0.800	0.105	0.226	0.337
175	0.020	0.800	0.105	0.227	0.347
150	0.020	0.800	0.107	0.242	0.398
125	0.020	0.800	0.107	0.291	0.494
100	0.020	0.800	0.146	0.427	0.677

[a] Quasi-extinction threshold defined as ≤10 males or females.

[b] The magnitude shows the fraction of the population remaining following the catastrophe; the SE of the magnitude is 0.020.

of meeting the threshold increased from approximately 2% in 100 years (K ≥ 125, 1% probability and 0.90 magnitude of a catastrophe) to as high as 43% after 200 years and 68% after 300 years with the highest catastrophe rate and magnitude (Scenario A(Q)4).

Scenario B, 14 years of data, modeled to extinction

Scenario B (Table 8) involved using the best fitting model with a shorter time sequence, the S(4t c) temporal model and using only the survival estimates over the last four time periods, a total of 14 years. The last time period of 2 years was assumed to be the beginning of an eventual 4-year period, so it was extended to 4 years. Therefore, this scenario had two 4-year periods with relatively high survival and two 4-year periods with relatively low survival. However, the average survival for the 14 years was lower than the overall average survival used in Scenario A, so this scenario was more pessimistic. This scenario was used to investigate the assumption that survival will continue to cycle for about equal periods of relatively low and high survival—but at the overall lower average level seen the last 14 years—instead of assuming that the overall average survival seen over 29 years would prevail. Thus this scenario carried an assumption that the environment has gotten worse for this population than it was in the initial period the population was monitored.

Scenario B was the “average” scenario that was expected to give results between the most (A) and least (C) optimistic scenarios. This scenario’s most optimistic forecast (for all values of K, no catastrophes; Scenario B1) resulted in a risk of extinction in 100 years of about 0.3% (Table 8). For the worst case, the 300-year extinction risk was 66% (K = 100 and the highest probability and magnitude of a catastrophe; Scenario B4).

Scenario B(Q), 14 years of data, modeled to a quasi-extinction threshold

Scenario B(Q) **(**Table 9) used the same survival rates found in Scenario B. Assuming the quasi-extinction Scenario B(Q), the most optimistic 100-year forecast (for all K values, no catastrophes; Scenario B(Q)1) had a risk of meeting the quasi-extinction threshold of 6–8%. The highest risk, 85% in 300 years, resulted from Scenario B(Q)4 with a carrying capacity of 100 and two catastrophes every 100 years that each reduced the population by 20%.

Scenario C, last 10 years of data, modeled to extinction

Scenario C (Table 10) used the same survival model as Scenario B, S(4t c), but only used the last 10 years of survival data. The last 10 years had two 4-year periods of relatively low survival, with just the last 2-year period having relatively higher survival. This scenario, the most pessimistic, was designed to investigate the assumption that the survival rates for the population observed most recently were most representative of the population’s dynamics and would continue into the future. The most optimistic forecast of extinction risk for Scenario C (K = 400, no catastrophes; Scenario C1) had a risk of extinction of 5–6% in the next 100 years. The highest extinction risk, 94% in 300 years, resulted from a modeled population with a carrying capacity of 100, two catastrophes of magnitude 0.8 every 100 years (Scenario C4).

Table 8. Survival Scenario B, using the last 14 years of data and survival model S(4t c), assuming four 4-year periods, modeled to extinction.[a]

	Catastrophe		Probability of extinction (years)		
K	**Probability**	**Magnitude[b]**	**100**	**200**	**300**
Scenario B1					
400	0.000	1.000	0.002	0.054	0.144
300	0.000	1.000	0.003	0.059	0.145
200	0.000	1.000	0.003	0.052	0.138
175	0.000	1.000	0.003	0.057	0.149
150	0.000	1.000	0.002	0.055	0.157
125	0.000	1.000	0.003	0.064	0.202
100	0.000	1.000	0.003	0.086	0.303
Scenario B2					
400	0.010	0.900	0.004	0.083	0.195
300	0.010	0.900	0.004	0.082	0.200
200	0.010	0.900	0.005	0.085	0.199
175	0.010	0.900	0.006	0.087	0.210
150	0.010	0.900	0.004	0.084	0.211
125	0.010	0.900	0.005	0.094	0.258
100	0.010	0.900	0.006	0.126	0.370
Scenario B3					
400	0.010	0.800	0.015	0.144	0.289
300	0.010	0.800	0.014	0.144	0.288
200	0.010	0.800	0.017	0.147	0.298
175	0.010	0.800	0.013	0.150	0.312
150	0.010	0.800	0.016	0.147	0.318
125	0.010	0.800	0.015	0.151	0.353
100	0.010	0.800	0.017	0.191	0.481
Scenario B4					
400	0.020	0.800	0.048	0.275	0.483
300	0.020	0.800	0.046	0.274	0.490
200	0.020	0.800	0.045	0.272	0.486
175	0.020	0.800	0.046	0.277	0.502
150	0.020	0.800	0.044	0.277	0.516
125	0.020	0.800	0.043	0.292	0.562
100	0.020	0.800	0.052	0.343	0.656

[a] Extinction defined as <1 male or female.

[b] The magnitude shows the fraction of the population remaining following the catastrophe; the SE of the magnitude is 0.020.

Table 9. Survival Scenario B(Q), using the last 14 years of data and survival model S(4t c), assuming four 4-year periods, modeled to a quasi-extinction threshold.[a]

	Catastrophe		**Probability of quasi-extinction (years)**		
K	**Probability**	**Magnitude[b]**	**100**	**200**	**300**
Scenario B(Q)1					
400	0.000	1.000	0.061	0.152	0.214
300	0.000	1.000	0.064	0.153	0.214
200	0.000	1.000	0.056	0.142	0.214
175	0.000	1.000	0.061	0.157	0.241
150	0.000	1.000	0.060	0.160	0.274
125	0.000	1.000	0.064	0.199	0.363
100	0.000	1.000	0.082	0.305	0.548
Scenario B(Q)2					
400	0.010	0.900	0.089	0.205	0.281
300	0.010	0.900	0.092	0.209	0.293
200	0.010	0.900	0.091	0.208	0.300
175	0.010	0.900	0.092	0.214	0.314
150	0.010	0.900	0.084	0.215	0.343
125	0.010	0.900	0.093	0.252	0.439
100	0.010	0.900	0.122	0.381	0.618
Scenario B(Q)3					
400	0.010	0.800	0.140	0.296	0.389
300	0.010	0.800	0.138	0.296	0.392
200	0.010	0.800	0.145	0.302	0.414
175	0.010	0.800	0.150	0.316	0.444
150	0.010	0.800	0.139	0.314	0.467
125	0.010	0.800	0.141	0.350	0.550
100	0.010	0.800	0.181	0.488	0.720
Scenario B(Q)4					
400	0.020	0.800	0.251	0.481	0.605
300	0.020	0.800	0.250	0.483	0.609
200	0.020	0.800	0.245	0.478	0.617
175	0.020	0.800	0.255	0.490	0.644
150	0.020	0.800	0.245	0.498	0.676
125	0.020	0.800	0.250	0.542	0.739
100	0.020	0.800	0.298	0.654	0.853

[a] Quasi-extinction threshold defined as ≤10 males or females.

[b] The magnitude shows the fraction of the population remaining following the catastrophe; the SE of the magnitude is 0.020.

Table 10. Survival Scenario C, using last 10 years of survival estimates from model S(4t c), assuming two 4-year periods and one 2-year period, modeled to extinction.[a]

	Catastrophe		Probability of extinction (years)		
K	**Probability**	**Magnitude[b]**	**100**	**200**	**300**
Scenario C1					
400	0.000	1.000	0.056	0.453	0.682
300	0.000	1.000	0.051	0.454	0.677
200	0.000	1.000	0.055	0.451	0.681
175	0.000	1.000	0.056	0.460	0.680
150	0.000	1.000	0.053	0.450	0.681
125	0.000	1.000	0.056	0.454	0.703
100	0.000	1.000	0.052	0.475	0.752
Scenario C2					
400	0.010	0.900	0.074	0.534	0.757
300	0.010	0.900	0.070	0.535	0.760
200	0.010	0.900	0.069	0.534	0.750
175	0.010	0.900	0.075	0.533	0.756
150	0.010	0.900	0.071	0.537	0.763
125	0.010	0.900	0.069	0.530	0.767
100	0.010	0.900	0.072	0.546	0.813
Scenario C3					
400	0.010	0.800	0.107	0.620	0.816
300	0.010	0.800	0.105	0.607	0.812
200	0.010	0.800	0.108	0.617	0.817
175	0.010	0.800	0.110	0.613	0.823
150	0.010	0.800	0.104	0.607	0.816
125	0.010	0.800	0.105	0.610	0.832
100	0.010	0.800	0.106	0.636	0.870
Scenario C4					
400	0.020	0.800	0.186	0.735	0.904
300	0.020	0.800	0.176	0.741	0.906
200	0.020	0.800	0.182	0.742	0.904
175	0.020	0.800	0.184	0.748	0.911
150	0.020	0.800	0.179	0.742	0.911
125	0.020	0.800	0.182	0.742	0.914
100	0.020	0.800	0.187	0.765	0.942

[a] Extinction defined as <1 male or female.

[b] The magnitude shows the fraction of the population remaining following the catastrophe; the SE of the magnitude is 0.020.

Scenario C(Q), last 10 years of data, modeled to a quasi-extinction threshold

Scenario C(Q) (Table 11) used the same survival assumption as Scenario C, but examined the probability the population would fall below the quasi-extinction threshold. The most optimistic scenario involved no catastrophes over 100 years; the estimated probability of meeting the threshold in that case was approximately 40% at all carrying capacities (Scenario C(Q)1). The highest risk, 98% in 300 years, resulted from a modeled population with a carrying capacity of 100 and two catastrophes every 100 years that each reduced the population by 20% (Scenario C(Q)4).

5.1.2. Discussion and Conclusions

The PVAs were conducted using available demographic information for Southern Resident killer whales. Under the assumption that population growth rates in the future will more accurately be predicted by the full (29-year) time series of data (most optimistic model), the extinction model predicted a risk of <0.1–3% in 100 years and 2–42% in 300 years (Scenarios A1–A4). If a quasi-extinction threshold was used instead of actual extinction, the predicted probability of meeting the threshold ranged 1–15% in 100 years and 4–68% in 300 years, with the higher values associated with higher probability and magnitude of catastrophic mortality events (Scenarios A(Q)1–A(Q)4).

When it was assumed that the population survival for last 10 years would best predict the future (most pessimistic model), the analysis predicted a probability of extinction of 6–19% in 100 years and 68–94% in 300 years (Scenarios C1–C4). If a quasi-extinction threshold was used in lieu of actual demographic extinction, the predicted probability of meeting the threshold ranged from 40–67% in 100 years to 76–98% in 300 years (Scenarios C(Q)1–C(Q)4).

The estimated risk of extinction was, therefore, very sensitive to the assumption regarding survival rates in the future. If the assumption was made that the last 29 years are a good indicator of future population trends, then the estimated probability of extinction was much lower than if a more pessimistic assumption was made that the last 10 years are a good indicator of the future. Under the pessimistic assumption, uncertainties with respect to the level of carrying capacity, as well as the rate and magnitude of catastrophes, had relatively little effect on the extinction probability (i.e., it was high regardless). In contrast, under the more optimistic prediction using the 29-year series of survival rates, the risk of extinction was strongly influenced by the assumption made about carrying capacity and was to a lesser extent influenced by the level and magnitude of catastrophes.

5.1.3. Comparison of Parameters Used in the 2002 and 2004 PVA Models

There were many similarities and only a few differences between the PVAs developed by the 2002 BRT (Krahn et al. 2002) and the current BRT. The same basic killer whale population parameters, such as life span and the youngest female to give birth, were used in both models and were based on information reported in Olesiuk et al. (1990). Demographic and environmental variances were modeled identically in both PVAs. In addition, both models incorporated an Allee effect in the same manner and gradually incorporated density-dependent changes in survival and fecundity when the modeled killer whale populations were above an

Table 11. Survival Scenario C(Q), using last 10 years of survival estimates from model S(4t c), assuming two 4-year periods and one 2-year period, modeled to a quasi-extinction threshold.[a]

	Catastrophe		Probability of quasi-extinction (years)		
K	**Probability**	**Magnitude[b]**	**100**	**200**	**300**
Scenario C(Q)1					
400	0.000	1.000	0.394	0.667	0.761
300	0.000	1.000	0.396	0.667	0.761
200	0.000	1.000	0.394	0.671	0.770
175	0.000	1.000	0.394	0.670	0.769
150	0.000	1.000	0.388	0.670	0.778
125	0.000	1.000	0.395	0.680	0.810
100	0.000	1.000	0.399	0.736	0.877
Scenario C(Q)2					
400	0.010	0.900	0.465	0.745	0.831
300	0.010	0.900	0.460	0.743	0.833
200	0.010	0.900	0.455	0.740	0.828
175	0.010	0.900	0.467	0.741	0.836
150	0.010	0.900	0.462	0.750	0.846
125	0.010	0.900	0.454	0.747	0.865
100	0.010	0.900	0.472	0.796	0.916
Scenario C(Q)3					
400	0.010	0.800	0.535	0.799	0.880
300	0.010	0.800	0.525	0.794	0.875
200	0.010	0.800	0.537	0.806	0.879
175	0.010	0.800	0.534	0.808	0.886
150	0.010	0.800	0.528	0.801	0.890
125	0.010	0.800	0.527	0.809	0.912
100	0.010	0.800	0.542	0.856	0.952
Scenario C(Q)4					
400	0.020	0.800	0.653	0.888	0.947
300	0.020	0.800	0.652	0.890	0.948
200	0.020	0.800	0.661	0.889	0.946
175	0.020	0.800	0.665	0.897	0.953
150	0.020	0.800	0.655	0.891	0.954
125	0.020	0.800	0.652	0.898	0.959
100	0.020	0.800	0.665	0.927	0.983

[a] Quasi-extinction threshold defined as $\leq$10 males or females.

[b] The magnitude shows the fraction of the population remaining following the catastrophe; the SE of the magnitude is 0.020.

assumed carrying capacity. In both models, the same range of carrying capacity values were used to reflect the range of possible population carrying capacities. Finally, both modeling efforts examined what increase in the risk of extinction could occur if 0, 1, and 2 catastrophes over 100 years, on average, affected the survival rates of individuals.

There were two major differences between the 2002 PVA (Krahn et al. 2002) and the current PVA. First the current modeling effort updated the 2002 population parameters by adding an additional 3 years to the information on survival and fecundity rates. Thus survival and fecundity rates from 1974 to 2000 have been updated and the 2004 PVAs included an analysis of survival and fecundity rates from 1974 to 2003.

Some members of the BRT believed strongly that the 2004 PVA should reflect the probability of the population reaching some very low number of animals, but one that is above the level identified as "extinction" (defined as <1 male or female). This level, called the "quasi-extinction" threshold, was set as the number of animals at which the BRT was reasonably certain that the population would be "doomed" to extinction. The BRT believed that if there were ≤10 males or 10 females, the population would likely not persist longer than the lifespan of those animals. PVA scenarios were then examined that incorporated both extinction and the quasi-extinction threshold.

5.2. Application of IUCN Criteria

Although the IUCN (International Union for the Conservation of Nature and Natural Resources or "the World Conservation Union") criteria were originally created to measure the global risk to all species, there was such widespread need for measures of risk on smaller scales that the IUCN created guidelines for regional applications of their criteria. The guidelines (IUCN 2001) suggest using the criteria unmodified if the group under consideration meets the following definition for subpopulations:

> Geographically or otherwise distinct groups in the (global) population between which there is little demographic or genetic exchange (typically one successful migrant individual or gamete per year or less [IUCN 2001]); a subpopulation may or may not be restricted to a region.

Assuming a generation time of 20 years and using the estimated genetic differentiation between Southern and Northern Resident populations ($F_{ST} = 0.144$) (Barrett-Lennard 2000) and using Wright's formula of $Fst = 1/(4Nm + 1)$, the number of migrants/generation is 1.49 or 0.074/year. Thus by the IUCN criteria, the Southern Residents qualify as a subpopulation.

The IUCN "Redlist" criteria classify species into four different risk categories—critically endangered, endangered, vulnerable, and least concern—using five criteria:

A. magnitude of population reduction,
B. geographic range,
C. abundance and trends in abundance,
D. abundance alone (population size numbers fewer than 50 mature individuals), and
E. quantitative estimate of the probability of extinction.

Qualification for a risk category depends on meeting any one of these criteria. For killer whales, historical range and abundance are so poorly known that data-driven assessments cannot be made. The Redlist guidelines base classification on the highest risk category for which the "species" can qualify. In this case, Southern Residents would qualify as "critically endangered" under criterion D. The IUCN defines mature individuals as "the number of individuals known, estimated or inferred to be capable of reproduction." There are currently no more than 41 mature individuals in the Southern Resident population, thus this population is below the threshold for "critically endangered" using criterion D.

It is worth noting that, although the listing would be based on criterion D above, Southern Residents may qualify as either "critically endangered" or "endangered" under criterion C1.

> To meet the C1 criterion at the 'critically endangered' level: Population size estimated to number fewer than 250 mature individuals and an estimated continuing decline of at least 25% within 3 years or one generation, whichever is longer (up to a maximum of 100 years in the future).

The removals of the Southern Residents for oceanaria in the late 1960s and early 1970s, coupled with recent declines, may make the reduction in mature individuals more that 25% in the last generation.

> To meet the C1 criterion at the 'endangered' level: Population size estimated to number fewer than 2,500 mature individuals and an estimated continuing decline of at least 20% within 5 years or two generations, whichever is longer (up to a maximum of 100 years in the future).

5.3. Extinction Risk—Summary of BRT Concerns

The Southern Resident killer whale population is a relatively small, substantially reproductively isolated population in the eastern North Pacific Ocean. Although its historical population size is unknown, the development of photo-identification techniques in the 1970s has led to comprehensive documentation of population size, survivorship, and reproductive success of individuals. To assess risk, the BRT evaluated population size, population trends, age structure, social structure, diversity, recent fecundity, and survivorship, as well as external risk factors such as habitat degradation or potential catastrophic events. Due to the long life span of this species, the BRT believed that it is important to consider the risk of extinction using a relatively long time frame (e.g., hundreds of years). Populations of long-lived animals can have considerable demographic inertia; thus a nonviable population has the potential to persist for many decades simply due to the long life spans of its existing members.

5.3.1. Population Size

In comparison to most other marine mammal stocks, the Southern Resident killer whale population is extremely small (Angliss and Lodge 2002, Carretta et al. 2002). Although the historical population size is unknown, the current population is only slightly higher than its level in the early 1970s after being reduced by about one-third by collections for oceanaria. The Southern Resident population has been able to persist at a relatively low level over the past 30 years, but the relatively long life span of this species may be masking its future viability.

Resident killer whales of the North Pacific have a highly structured social organization with matrilineal groups as the basic structural element. The Southern Residents killer whale community consists of three generally separate pods (J, K, and L), each containing several matrilineal groups. Because individual killer whales are most often in proximity to their pod, any event that reduces survival (e.g., disease outbreak, oil spill) could adversely impact the entire pod. Thus the combination of small population size and their occurrence in socially cohesive groups puts the Southern Residents at risk for a significant population decrease resulting from catastrophic events.

A well-recognized factor that may have an adverse impact on an already small population is the Allee effect of inbreeding depression. Inbreeding depression is more likely to be manifested as the population size decreases. The IUCN suggests that if the number of reproductive animals is fewer than 50, the potential for impacts associated with inbreeding depression increases substantially. Given that the population of Southern Resident killer whales currently has a small number of reproductive females (28, ages 11–41) and an even smaller number of reproductive males (9, ages 15 and older) it could be approaching the level at which the effects of inbreeding depression may start to be a factor impacting the population's ability to maintain itself or increase.

A too-small population could also experience a breakdown of social structure. Although certain cultural and behavioral aspects of the Southern Resident killer whale community have been described, the mechanisms by which they contribute to the viability of the population are not yet well understood. However, the situation of the killer whale population may be analogous to those of the few other large mammal populations in which females live far beyond their reproductive span (e.g., elephants, higher primates, and other toothed cetaceans such as pilot whales) (McComb et al. 2001, Lahdenpera et al. 2004). The loss of only a few key individuals—primarily the older, post-reproductive females in this matriarchal society—could result in a significant loss of inclusive fitness conveyed by "aunting" behavior (i.e., assistance in care of the young of other females in the pod). In addition, cultural knowledge (e.g., about how to cope with environmental changes occurring on decadal scales) could be lost, leading to reduced survival or fecundity of some or all age classes. This factor may have contributed to the decline observed in the AB Pod in Alaska (Matkin et al. 2003).

5.3.2. Population Trends

Over the past 30 years the population size has fluctuated, with two increasing and two decreasing periods. Following the removal of approximately a third of the population for displays in oceanaria in the late 1960s and early 1970s, the Southern Resident population increased, demonstrating its ability to recover following a significant "mortality event" (i.e., removing subadults from the population). From 1980 to 1984, the population declined by 11%, but the decline was followed by a steady increase from 74 to 97 animals (31% increase) between 1985 and 1996. Then, another sharp decline (20%) followed between 1997 and 2001, but the factors responsible for this recent decline are not clear. Although the population has increased since 2001 and is at a level that is slightly higher today than it was 30 years ago, it is unknown whether this trend will continue. These trends are in contrast to the population of Northern Resident killer whales which increased steadily until the late 1990s before undergoing a 7%

decline. The apparent inability of Southern Resident killer whales to recover to preharvest (presumably higher) levels is of concern.

5.3.3. Sex and Age Class Structure

Although the breeding system in killer whales is not fully understood, previous research on Northern Resident killer whales has indicated that breeding occurs only between pods (Barrett-Lennard 2000). In addition, the observed sexual dimorphism of the resident whales suggests some selection pressure is being exerted, either through female choice or male-male competition.

The sex and age class structure of the Southern Residents differs from that of other killer whale populations. The proportion of adult males, particularly in J and K Pods, appears to be lower than found for other resident killer whale populations in the eastern North Pacific Ocean (Wade unpubl. data). In the early 1990s there were five adult males total in J and K Pods. By 1997 the last male in K Pod had died and by 2000, when a J Pod male died, there was only one adult male (J1) remaining in these two pods. It is only within the last 2 years that a male in K Pod appears to be attaining sexual maturity. Consequently, the pool of males available to breed with females in L Pod appears to be extremely limited. Furthermore, L Pod has a greater proportion of post-reproductive females (9 compared to 2 and 3 in J and K Pods, respectively).

The lack of reproductive males or post-reproductive females can have substantial consequences to the population. If loss of the sexually mature males from J and K Pod were to occur, the reproductive output of L Pod could potentially be suspended, perhaps for as few as 2 years or as many as 7 years, until other J Pod or K Pod males become physically and socially mature. The likelihood of these two males dying in the near future is relatively high, because J1 is the oldest male (50+ years) in the Southern Resident population and K21, at age 18, is nearing the age (20–25 years) when a substantial portion of the male population has died. Additionally, because post-reproductive whales have a higher mortality rate than other age classes, deaths of members of this class may result in a faster decline in L Pod than in the other pods.

5.3.4. Fecundity

In addition to a large proportion of post-reproductive females, L Pod also currently has a smaller proportion of reproductive-age females compared to J and K Pods (17% versus 26% and 27%, respectively). Although several females in L Pod have recently reached reproductive age, none have produced viable calves. Furthermore, in a comparison of females that have given birth to their first calf since 1972, 7 of the 16 females in L Pod had an average inter-calf interval greater than 6 years compared to only 3 of 13 females in J and K Pods combined. In the past 5 years, L Pod has had the lowest birth rate of viable calves (4 for the 9 reproductive age females ≥15 years old). Although the average fecundity of the Southern Residents has not declined (see subsection 2.4.2), these anomalies found for L Pod may affect the population’s future ability to grow.

5.3.5. Survivorship

Although mortality patterns through time are similar among the three Southern Resident pods, L Pod has had a lower survival rate (Figure 6) than the other two pods, particularly during the most recent decline. When compared to J and K Pods, L Pod has lost about a third more of its adult whales and, perhaps more significantly, has also lost about a third more subadults and calves. This loss of subadults may impact this pod's future reproductive potential. Because the factors associated with mortality in L Pod are unclear—particularly for subadults and young adults—the uncertainty about the viability of L Pod has increased substantially.

5.3.6. Conclusions

Taken together, the population dynamics of the Southern Residents describe a population that is at risk for extinction, due either to incremental small-scale impacts over time (e.g., reduced fecundity or subadult survivorship) or to a major catastrophe (e.g., disease outbreak or oil spill). Additionally, the small size of this killer whale population makes it potentially vulnerable to both Allee effects (e.g., inbreeding depression) and loss of post-reproductive females that could cause a major decline. Although this population has demonstrated the ability to recover from lower levels in the past, the factors responsible for the recent decline are unclear, may still exist, and may continue to persist, precluding a substantial population increase. Furthermore, the small number of breeding males, as well as possible reduced fecundity and subadult survivorship in L Pod, may limit the population's potential for rapid growth in the future.

6. Conclusions of the Status Review

Although multiple species of killer whales may exist and may be confirmed in the future, the 2004 BRT concluded that present data do not adequately support designation of any new species. In particular, the BRT concluded that North Pacific transients and residents should be considered to belong to a single species.

The 2004 BRT agreed (by a 5-to-1 margin) that Southern Residents belong to a subspecies separate from that of the transients. That subspecies would include the Southern Residents and the Northern Residents, as well as the resident killer whales of Southeast Alaska, Prince William Sound, Kodiak Island, the Bering Sea, and Russia (but not the offshores). Thus the taxon to use for determining a DPS under the ESA would be resident killer whales in the North Pacific, an unnamed subspecies of *O. orca*.

The 2004 BRT unanimously concluded that the Southern Residents are discrete from other North Pacific resident killer whale populations. In particular, all available data—including behavior, demography, and core and summer ranges, as well as genetics—indicated that the Southern Residents are an independent population that is discrete with respect to other populations.

The BRT concluded (by a 2-to-1 margin) that the Southern Residents are significant with respect to the unnamed North Pacific resident subspecies (taxon) and therefore should be considered a DPS. The BRT also concluded (by a 3-to-2 margin) that the Southern Residents would be a DPS of a taxon consisting of both North Pacific residents and offshores. Arguments favoring significance under both taxonomic scenarios were as follows:

- The Southern Residents appear to occupy an ecological setting, the California Current ecosystem, distinct from the other North Pacific resident populations. There is also some evidence of differences in prey utilization.
- The loss of the Southern Residents would result in a significant gap in the range of the North Pacific resident taxon, because the Southern Residents are the only North Pacific resident population to be sighted in the coastal areas off of California, Oregon, and Washington and are the only population to regularly inhabit Puget Sound.
- The Southern Residents differ markedly from other North Pacific resident populations at both nuclear and mitochondrial genes, as well as in the frequency of certain saddle-patch variants.
- Culture (knowledge passed through learning from one generation to the next) is likely to play an important role in the viability of killer whale populations. For example, the Southern Residents may possess unique knowledge of the timing and location of salmon runs in the southern part of the North Pacific residents' range. There was some evidence that cultural traditions (e.g., greeting behavior, beach rubbing, and utilization of prey from long-lines) differed among the resident populations.

The 2004 BRT considered whether certain factors that currently pose a risk for Southern Residents might continue in the future. Concern remains about whether reduced quantity or quality of prey are adversely affecting the Southern Resident population. In addition, concentrations of OC contaminants are not declining appreciably and those of many newly emerging contaminants (e.g., PBDE flame retardants) are increasing, thus Southern Residents are likely at risk for chronic effects, similar to those demonstrated for other marine mammal species (e.g., immunotoxicity in harbor seals). Other serious risk factors that may impact Southern Residents are oil spills, as well as noise and disturbance from vessel traffic.

A PVA was conducted to synthesize the potential biological consequences of a small population size, a slowly increasing or a declining population trend, and potential risk factors. Using the most optimistic model (29-year data set), the model predicted that the probability that Southern Residents would become extinct was from less than 0.1% to 3% in 100 years and 2–42% in 300 years. If a quasi-extinction threshold was used instead of actual extinction, the predicted probability of meeting the threshold ranged 1–15% in 100 years and 4–68% in 300 years. For both scenarios, the higher percentages in each range were associated with higher probability and magnitude of catastrophic mortality events (e.g., oil spills), as well as with a smaller carrying capacity (i.e., K = 100). When the most pessimistic model was used (the last 10 years), the analysis predicted a probability of extinction of 6–19% in 100 years and 68–94% in 300 years. If a quasi-extinction threshold was used in lieu of actual demographic extinction, the predicted probability of meeting the threshold ranged from 40–67% in 100 years to 76–98% in 300 years.

Overall, the 2004 BRT was concerned about the viability of the Southern Resident population of killer whales. The population dynamics describe a population that is at risk for extinction, due either to incremental small-scale impacts over time (e.g., reduced fecundity or subadult survivorship) or to a major catastrophe (e.g., disease outbreak or oil spill). Additionally, the small size of this killer whale population makes it potentially vulnerable to Allee effects (e.g., inbreeding depression). Furthermore, the small number of breeding males, as well as possible reduced fecundity and subadult survivorship in L Pod, may limit the population's potential for rapid growth in the future. Although the Southern Resident population has demonstrated the ability to recover from lower abundance levels in the past, the factors responsible for the recent decline are unclear, may still exist and may continue to persist, precluding the likelihood of a substantial population increase.

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