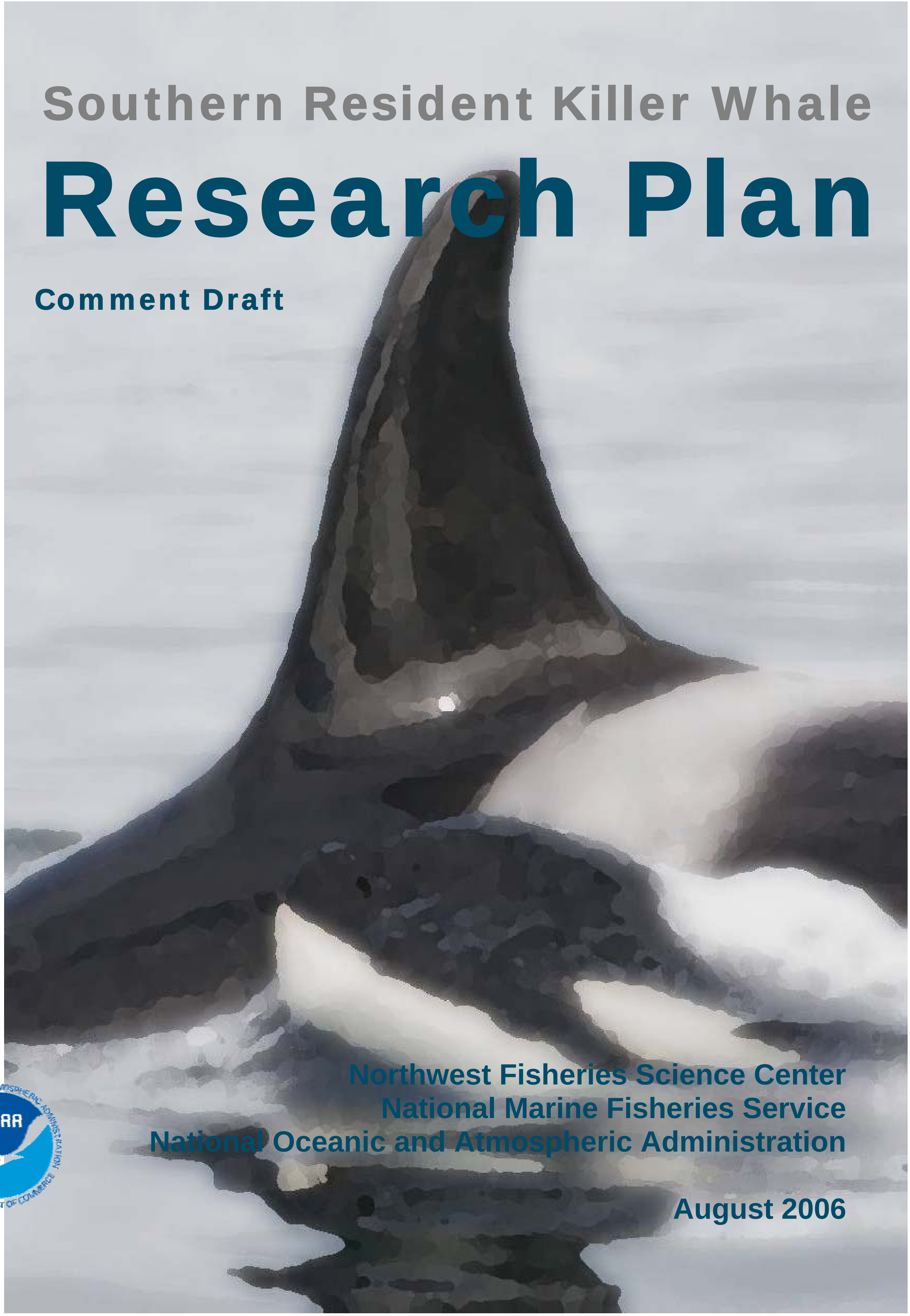
Southern Resident Killer Whale

Research Plan

Comment Draft



Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration

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Introduction

From late spring through fall, the greater Puget Sound waters host a population of killer whales (*Orcinus orca*) known as the Southern Residents. These killer whales are an important top predator in the marine ecosystem, contribute to its biodiversity and bring socioeconomic benefits to the region. Their presence in a heavily populated urban area and their cultural importance has generated substantial public interest in their well being.

Studies of killer whales in the inland waters of British Columbia and Washington began in the early 1970's with the pioneering work of Michael Bigg (Bigg et al. 1987), and the whales' status and biology has been extensively reviewed (Baird 2001; Ford et al. 2000; Krahn et al. 2002; Krahn et al. 2004; Olesiuk et al. 1990; Wiles 2004). Annual counts and observations of the Southern Residents were initiated in 1976 by the Center for Whale Research and form the basis of our knowledge of the current status of this population. Since 1973, the size of the population has fluctuated between 71 and 99 animals (Figure 1). The population was subject to a live capture fishery in the 1960's and early 1970's, and a total of 34 animals were removed from the population by the end of the fishery in 1973 (Olesiuk et al. 1990). After a period of erratic population growth through the mid 1990's, the population declined sharply in the late 1990's from 99 to 79 animals. This sharp decline, combined with concerns about environmental threats to the population, led to endangered listings under Canada's Species at Risk Act in 2001, by Washington State in 2004, and under the U.S. Endangered Species Act (ESA) in 2006.

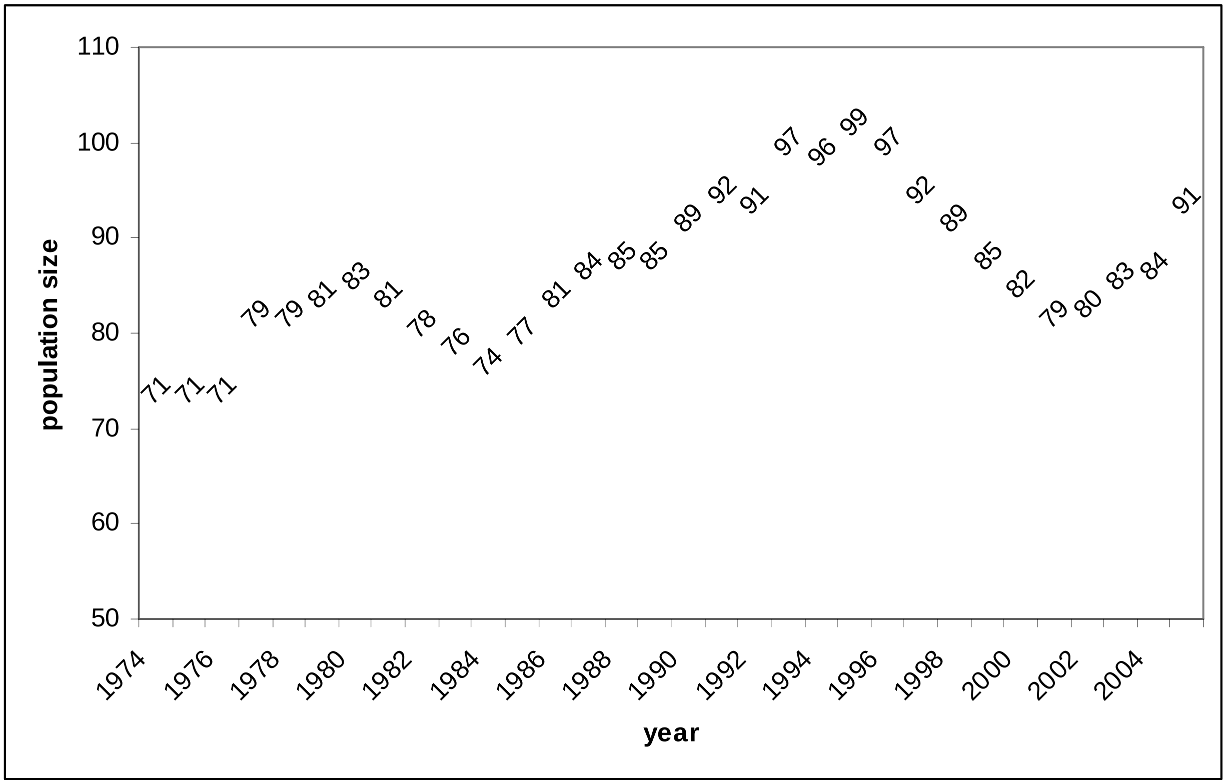

Figure 1 -- Abundance of Southern Resident whales, 1974-2005 (data from Center for Whale Research).

The Southern Resident Killer Whales are only one of several marine species in the Puget Sound and California Current ecosystems that have declined sharply. For example, 26 West Coast Evolutionarily Significant Units (ESUs) of salmon and steelhead have been listed as threatened or endangered under the ESA (http://www.nwr.noaa.gov/), and 40 marine and terrestrial species in the Puget Sound area are currently listed on federal or state endangered species lists. The Puget Sound Action Team (http://www.psat.wa.gov/) in their 2004 "State of the Sound" report documented widespread problems facing the Puget Sound ecosystem, including nearshore and estuary habitat loss, widespread contamination of sediments, and significant declines of key species such herring, rockfish, and salmon. The human population of Washington State is projected to grow from 6,375,000 in 2006 to over 9,000,000 in 2030 (Figure 2), creating the potential for additional stress on the Puget Sound ecosystem. As highly visible, long-lived top predators, the Southern Resident killer whales are particularly vulnerable to ecosystem disturbance, and their status as "sentinel" species provides a window into the ecological state of Puget Sound.

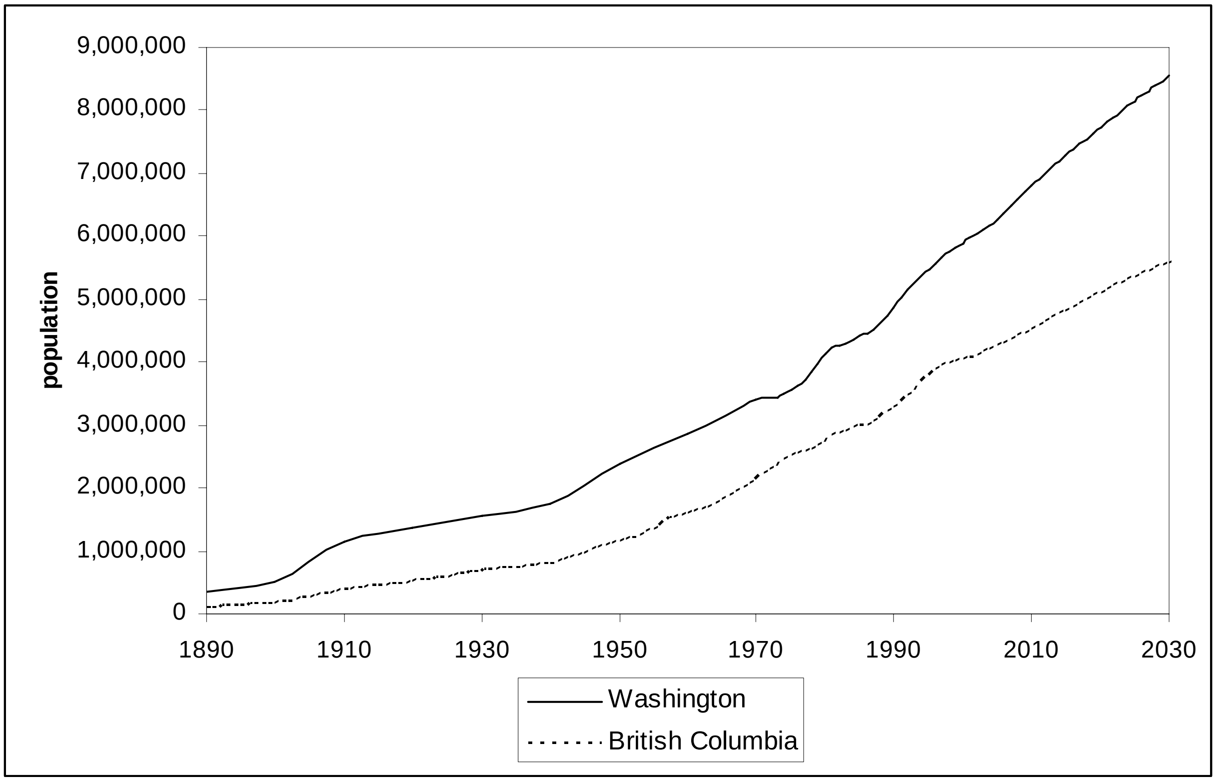

Figure 2 -- Historical and projected human population size in Washington State and British Columbia. Source: Washington State OFM (http://www.ofm.wa.gov/pop/decseries/default.asp), BC Stats (http://www.bcstats.gov.bc.ca/DATA/pop/popstart.asp).

Many of the questions identified in this plan involve complex ecological interactions and will only be answered incrementally over a period of many years. In developing conservation plans for the Southern Resident killer whales, it is therefore important to use information as it becomes available, rather than waiting for definitive answers to every question. The questions we identify in this plan will also not be addressed by any single agency or organization. Coordination among researchers working on Eastern North Pacific killer whales and their ecosystems is therefore essential, both for maximizing the rate at which our understanding of the whales improves and for minimizing research-associated impacts to the whales. The Northwest Fisheries Science Center (NWFSC) is therefore closely coordinating our own research efforts with those of other agencies and organizations.

Starting in 2003, the NWFSC received funding to conduct research to aid the conservation and recovery of the Southern Resident killer whale population. Between 2003 and 2006, the NWFSC, Washington Department of Fish and Wildlife (WDFW) and the Canadian Department of Fisheries and Oceans (CDFO) jointly sponsored a series of workshops and symposia to help determine priorities for research on the Southern Residents. The workshops were attended by numerous experts on killer whale biology and ecology, and identified many specific research questions that need to be answered to conserve the Southern Resident population. This plan is a distillation of the most important research questions identified by these workshops. Research topics are divided into two main categories: studies of the biology and ecology of the Southern Residents, and studies to quantify the threats facing the Southern Residents.

Biological and Ecological Questions

These questions involve improving our understanding of those aspects of the biology and ecology of the Southern Resident killer whales that are most important for their effective conservation. They fall into three broad categories: evolution and taxonomy, demographics, and habitat and distribution. Studies of killer whale prey and diet are also largely biological and ecological in nature, but are treated under the Threats section.

Evolution and taxonomy

When did the Southern Resident population originate, and what are the rates of gene flow (mating) between the Southern Residents and other North Pacific killer whale populations?

What was the historical size of the Southern Resident killer whale population?

Why these questions are important

Knowing the time of origin of the Southern Residents and ongoing rates of gene flow between the Southern Residents and other killer whale populations is important for two reasons. First, both time of origin and rates of gene flow are important factors for addressing the discreteness and evolutionary significance of the population. To be eligible for listing under the U.S. Endangered Species Act, a population must be meet the Act's definition of a species, which is defined to be "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." Uncertainty about whether the Southern Residents meet the criteria necessary to be considered a 'distinct population segment' played a large role in past and ongoing litigation related to the listing of the Southern Residents (see summary in Krahn et al. 2004), so obtaining more information about the degree to which the Southern Residents are genetically distinct is important.

In addition to helping to inform the legal question of whether or not the Southern Residents are "distinct", understanding how genetically interconnected they are to other populations is critical for evaluating the long-term viability of the population and for setting recovery goals. In particular, a population of 80-100 animals that does not interbreed with other populations is usually considered to be too small to be genetically viable in the long-term (Lande 1995). On the other hand, even quite low rates of interbreeding with other populations (a few inter-populational mating events per generation) can greatly reduce the genetic problems associated with small population size. Confirming whether or not the

Southern Residents regularly interbreed with other populations therefore is important for determining how large the population needs to be in order to be viable in the long-term.

In addition to knowing the long-term rates of gene flow between the Southern Residents and other killer whale populations, it is also important to obtain a reasonable estimate of the Southern Resident population's historical size. The population has only been observed for the last thirty years, and its size prior to large-scale European settlement on the North American west coast is not known. Estimating the population's historical size is therefore important for understanding how large the population needs to be in order to be considered viable.

Current knowledge and recent progress

Killer whales are the most widely distributed marine mammal, and are currently considered to consist of a single cosmopolitan species (Heyning and Dahlheim 1988). There is, however, behavioral, morphological, acoustic and genetic evidence from Antarctic and North Pacific populations that suggests there might be more than one species of killer whale. At a recent workshop on killer whale taxonomy (Reeves et al. 2004), diverse opinions were evident regarding the global killer whale taxonomy. The majority of the scientists attending, however, concluded that the North Pacific resident and transient whales are likely to be separate species or subspecies. The NMFS's Biological Review Team (BRT) concluded that the resident and transient ecotypes in the North Pacific are distinct subspecies, a finding that was important to the proposed ESA listing of Southern Residents (Krahn et al. 2004).

The most comprehensive study to date of patterns of genetic variation among killer whales worldwide is that of Hoelzel et al. (2002). They found relatively low total levels of genetic diversity at both mitochondrial DNA (mtDNA) and nuclear microsatellite loci, although the sample sizes were low in some regions and for some ecotypes. They also found little geographic structure in the patterns of mtDNA variation – in other words geography is a poor predictor of population or individual mtDNA type. This lack of geographic pattern, combined with overall low levels of diversity, led them to hypothesize that killer whales have recently expanded greatly in worldwide population size. The patterns of variation also generally suggest that the various killer whale ecotypes (resident, transient, etc) have evolved relatively recently – within the last several hundred thousand years.

Since 2003, the NWFSC has funded several additional killer whale genetic studies. The most significant of these was an expansion of Hoelzel et al.'s work to include a larger number of samples and more microsatellite loci. This work provided important information to both the 2004 taxonomy workshop and the 2004 status review (Hoelzel 2004). More recently, we have funded a collaboration between Drs. Hoelzel and Jody Hey to employ analytical methods developed by Dr. Hey (Hey and Nielsen 2004) to directly estimate divergence times, rates of gene flow, and historical population sizes among killer whale populations. This work found evidence for interbreeding between the Southern Resident population and other North Pacific killer whale populations and was reported at a NWFSC symposium in 2006. The models employed also generally suggested that all of the killer whale populations sampled used to be much larger than they are now, but this result is likely to be an artifact of the two-population assumption used by the model. This assumption is being relaxed in current work, and we expect more reliable estimates of historical population size as a result of this ongoing work. The NWFSC also provided funding for efforts to develop new genetic markers for killer whales and for a study to examine genetic variation in historical samples of North Pacific killer whales (Morin et al. in press). The latter study involved analysis of 30 samples originating from the mid-1800's to the 1980's, and found patterns of genetic variation consistent with the differences observed among contemporary populations.

Future priorities and level of effort

Future priorities include formally revising the taxonomy of killer whales, and in particular confirming the 2004 BRT's conclusion that Eastern North Pacific resident killer whales are a sub-species. In addition, depending on the final results of the Hoelzel/Hey project, there may be a need to continue to refine the estimates of gene flow among populations using additional types of genetic markers (e.g, nuclear single nucleotide polymorphisms). However, the immediate issue of whether the Southern Residents qualify as a "species" under the ESA was resolved by the 2004 BRT. We therefore anticipate investing only modest levels of effort in this topic in the future.

Demographic questions

What are the basic demographic parameters – population size, age and pod specific fecundity and mortality rates – of the Southern Residents and the closely related Northern Residents?

How and why do demographic parameters differ between the Northern and Southern Residents?

How does social structure influence demographic parameters?

Why these questions are important

Understanding the basic demographics of a population is essential for predicting its future status and for understanding why a population is increasing or decreasing in size. Basic demographic parameters include the number of individuals of each age and sex, and life-stage specific fecundity and mortality rates. Understanding the demographics of the both the Southern Residents and the Northern Residents is essential for understanding the differences in population trends between these closely related populations, as well as differences among the Southern Resident pods. Understanding why different subgroups have different patterns of mortality or fecundity provides is an essential first step for understanding what environmental factors most influence the population as a whole.

Understanding the population's social structure, such as determining if there are constraints on who will mate with whom, is also important for predicting future population growth and evaluating extinction risk. For example, a paucity of breeding age males, combined with the possibility that females may mate only with males outside of their pod, is a potential risk factor for the Southern Resident population (Krahn et al. 2004). The impacts of reduced population size on social structure are also not well understood. Although certain cultural and behavioral aspects of the Southern Resident community have been described, the mechanisms by which they contribute to the viability of the population are not known. In addition, long-term cultural knowledge (e.g., how to respond to environmental changes occurring on decadal scales) could be lost with the death of older individuals, leading to reduced survival or fecundity within the pod.

Current knowledge and recent progress

The Southern and Northern Resident populations have been observed and counted annually since 1973 (Ford et al. 2000), and these data have been used to calculate fundamental demographic parameters including life-stage specific birth and death rates (Krahn et al. 2002; Krahn et al. 2004; Olesiuk et al. 1990). This information has been essential for evaluating the viability of the populations, and for comparative studies aimed at understanding the differences and similarities between the populations. Critical information gained from these studies include: the observation that the Northern population has a higher overall rate of population growth than the Southern population (Baird 2001; Olesiuk et al. 1990; Wiles 2004), that mortality rates between the two populations are nonetheless highly correlated (Ford et al. 2005), that mortality rates are cyclical and these cycles are highly correlated across ages, sexes and pods (Krahn et al. 2004), and that mortality rates differ significantly among sexes, ages, and pods (Krahn et al. 2004; Olesiuk et al. 1990).

The annual surveys have also provided a wealth of information on killer whale social structure, including our current understanding of the transient and resident ecotypes (Ford et al. 1998) and the strong matrilineal nature of the resident's social structure (Ford et al. 2000). These data have also been essential for understanding changes in behavior over time (e.g., Riesch et al. 2006), and for relating social structure to behavioral patterns such as differences in vocalization among groups (Ford 1991).

One important piece of information the annual surveys do not provide is information on mating patterns within the population. Although maternal relationships are accurately inferred by observation (Ford et al. 2000), paternal relationships can only be determined through genetic analysis of mothers, offspring, and potential fathers. To date, an insufficient number of Southern Residents have been genetically sampled and analyzed to evaluate patterns of breeding within the population. Hypotheses about patterns of mating within the Southern Residents have therefore been generated from data obtained from the more completely sampled Northern Resident population (Barrett-Lennard 2000). These analyses show that in the Northern Resident community most matings occur between pods. Whether or not this is true for the Southern Residents is not known.

In 2004, NWFSC staff initiated a project to collect prey samples following killer whale kills (see prey section below). An unanticipated benefit of this project was the collection of samples of killer whales feces, from which we have successfully extracted whale DNA from cells of sloughed tissue that is found in the fecal material. In addition, in 2006 NWFSC staff initiated a biopsy sampling program for Southern Resident killer whales. These new samples, combined with the existing collections held by NMFS, the Canadian Department of

Fisheries and Oceans, and academic researchers (primarily Rus Hoelzel, University of Durham), may be used to evaluate patterns of paternity within the Southern Residents.

Future priorities and level of effort

Obtaining annual census data for the Southern Resident population provides essential information for evaluating the status of the population and provides important data for nearly all other research on the population. Continued support of these efforts therefore remains a very high priority. Analysis of these data is also critical for testing hypothesis about factors influencing the population, and therefore we anticipate continuing to put a relatively high level of effort into data analysis and population modeling. Finally, gaining a more complete understanding of patterns of mating within the population remains a high priority, and is becoming increasing possible as more genetic samples are collected. We therefore anticipate continuing to put resources into both genetic sample collection and analysis.

Distribution and Habitat

What habitats are important for Southern Resident killer whales, particularly in outer coastal waters?

Why this question is important

Protecting habitat quality and function is critical for conservation and for defining "critical habitat" under the ESA. In order to know what to protect, however, it is first necessary to know the temporal and spatial distribution of the whales such that the key features of these habitats can be identified for conservation. Thirty years of observation in the inland marine waters of Washington and British Columbia have provided a good understanding of the Southern Resident's spatial and temporal distribution in this area (see the June 2006 NMFS proposed critical habitat notice). Relatively little is known, however, about the whales' distribution or habitat requirements in coastal areas. It is therefore particularly important to gain a better understanding of the whales' spatial and temporal distribution in coastal areas, particularly during winter months when K and L pods are rarely seen in inland waters.

Current understanding and recent progress

Adult salmon are concentrated in time as they return to spawn in their natal rivers primarily in the spring, summer, and fall. They are also concentrated in space as they make their way through the inland waters to these rivers and streams. The whales appear to take advantage of this temporal and spatial aggregation as the whales departure to coastal waters coincidences with the cessation of these salmon runs in the late fall and early winter. Despite expanded efforts to locate the winter areas, confirmed coastal observations of Southern Residents number only 37 over a 38-year period. Most of these observations were relatively close to the coast, and there is little or no information concerning how far offshore the Southern Residents may travel. Recent observations in Monterey Bay, California, and the Queen Charlotte Islands, British Columbia, suggest that their current range may extend further south and north than previously documented. Sightings of the pods returning to Georgia Strait through Johnstone Strait also suggest that the Queen Charlotte region may be a common part of their range.

Moored passive acoustic monitors that stay in place for several months, a coastal sighting network, and winter research cruises using both observational and acoustic monitoring are some of the methods the NWFSC funded to increase our understanding of the whales' coastal distribution. NWFSC-sponsored studies from 2003 – 2006 contributed 32% (12/37) of the total confirmed coastal observations of Southern Residents in the last 38 years. We are therefore making significant progress in understanding the whales' winter distribution. Despite the low total number of sightings, multiple sightings have occurred in a few locations, suggesting some patterns of habitat use. For example, L Pod has been reported off Tofino, BC, on five occasions off Westport, Washington, on four occasions, and near the mouth of the Columbia River on four occasions. Current work is focusing on examining correlations between these sightings and spatial/temporal patterns of salmon distribution.

In the Puget Sound area, the primary use by the whales of channels adjacent to the San Juan and Gulf Islands may be associated with runs of adult salmonids returning to their natal rivers. How the whales locate and capture prey within these habitats is not well understood. Most diving activity occurs in the upper 30 m of the water column (Baird et al. 2005), where most salmon are distributed (e.g., Candy and Quinn 1999; Stasko et al. 1976). Chinook salmon, an important prey item for resident killer whales in the Pacific Northwest, tend to be found in deeper water (25–80 m average depth) (e.g, Candy and Quinn 1999). By recording Southern Resident killer whale behavior at depth, we will better understand three-dimensional habitat use and foraging behavior. For example, recent analyses of time-depth recorder data show that whales make dives deeper than 30m and that males and females have different diving patterns (Baird et al. 2005). In addition, the NWFSC has funded work to examine detailed pod-specific summer spatial distributions (Hauser 2006).

Future priorities and level of effort

Coastal habitat use was consistently identified by participants in the research workshops as a high priority information gap. Although recent studies have provided important information, our knowledge of coastal distribution and habitat use remains limited. We also do not have a good understanding of how ocean-climate processes affect the whales, either directly or through their prey. We therefore anticipate continuing to invest significantly in this area in the form of continued acoustic monitoring, research cruises and sighting networks. We also anticipate continuing to improve our understanding of detailed summer habitat use, particularly as it relates to potential prey acquisition.

Threats

These questions involve research on specific threats that have been identified as having a high potential to impact the Southern Resident population. These include prey availability and quality, underwater noise, vessel traffic, and chemical contaminants. Research on these factors involves primarily quantifying how they influence the Southern Resident population, determining whether the impact is a significant limiting factor for the population, and developing the data necessary to determine how changes in these activities would affect the whales.

Prey and diet questions

What are the important prey species for Southern Resident population?

Is prey availability or quality a significant factor limiting the population growth rate of the Southern Resident population?

Why these questions are important

Killer whales are a large bodied top predator and as such require a substantial amount of food – up to 200,000 kcal/day for adult males (see Krahn et al. 2002 for a review of available studies). Their ecological function as a predator and the strong cyclical correlations of mortality rates across sexes, ages and populations (Krahn et al. 2004; Olesiuk et al. 1990) strongly suggest that environmental factors, such as prey availability, play an important role in killer whale population dynamics. Understanding how prey availability and quality affect the Southern Resident population is therefore critical to determining how to best conserve the population.

Current knowledge and recent progress

Ford et al. (1998) summarized dietary information of the Southern and Northern Residents based on examination of stomach contents from stranded individuals and sampling of scales and fish parts after predation events. Although sample sizes were small, particularly for the Southern Residents, the available information indicated that salmon, especially Chinook salmon, were an important prey item. A more recent study by Ford and Ellis (2006) showed similar patterns to the previous data but the sample size was still relatively small for Southern Residents. In 2004, NWFSC staff initiated additional predation event studies to increase the sample size for Southern Residents. The results from these studies are consistent with Ford et al's (1998) and Ford and Ellis (2006) conclusions that Chinook salmon (summer) and chum salmon (fall) are the most important part of the whale's diet in the Haro Strait/San Juans and Puget Sound areas.

A critical information gap regarding the Southern (and Northern) Resident's diet is a lack of information on what they eat when they are not in inland waters. Every winter, K and L pods in particular (and often J pod) leave the greater Puget Sound area for the outer coast. We have very limited knowledge about their distribution in coastal areas (see Habitat, above), and essentially no information about what prey they are consuming while in coastal areas. In 2004 and 2006, NWFSC staff conducted winter cruises on the outer coast to observe the whales. These cruises provided valuable information on distribution, but limited encounter durations and winter weather conditions precluded any opportunity to obtain prey samples.

A potentially useful method for obtaining indirect information about prey involves chemical analysis of tissue samples obtained from the whales themselves. In a literal sense, the whales are what they eat, and unique chemical signatures of particular types of prey can be detected by analysis of whale tissue. For example, fatty acid signature analysis of blubber (Iverson et al. 2004) and stable isotope enrichments of ^{13}C and ^{15}N in the epidermis (Kelly 2000) are indirect chemical methods that have been used to assess the dietary preferences and trophic position of marine mammals. In addition, patterns of organochlorine contaminants (OCs) have been shown to differ among cetacean stocks, presumably as a result of differences in the OC composition of their respective prey (Krahn et al. 1999; Muir et al. 1996). Studies of the ratios of particular contaminants measured in the small number of biopsies of Southern Residents, compared to those in potential prey species, were in agreement with earlier studies that salmon is a major prey group (Krahn et al. 2002). All these techniques have been combined (Herman et al. 2005; Krahn et al. in press; Krahn et al. 2005) to qualitatively examine the dietary specializations of eastern North Pacific killer whale populations.

In addition to determining what the whales eat, it is also important to determine if prey abundance affects the Southern Resident's population dynamics. Approaches to this problem include determining the population's total food requirements and comparing this to availability of prey, and by developing models that statistically link whale population dynamics with prey abundance. For example, using the average energy requirements calculated by Kriete (1995), Richard Osborne estimated that the Southern Resident population would need to consume ~800,000 salmon annually if salmon were their sole prey item (Osborne 1999), and Ford et al. (2005) recently found that mortality rates in both the Southern and Northern Resident populations are correlated with a broad index of Chinook salmon ocean abundance. The latter observation suggests the possibility that Chinook salmon abundance may be a limiting factor for the Southern Residents, or both species may be responding in common to periodic shifts in ocean conditions.

Finally, the quality of the fish is important in determining the nutritional value of the prey. Over the past several years, the NWFSC and WDFW have conducted a study of Pacific salmon to measure the proximate composition (amount of protein, lipid and carbohydrate) and to estimate the caloric content as an indicator of species- and regionally-specific variation in nutritional quality of prey to killer whales. Overall, the total caloric content per kg of fish was higher for Chinook and sockeye salmon than the other salmon species sampled, due to their higher fat content. Moreover, because of their greater size, the total Kcal per fish was highest for Chinook salmon. Regional differences in caloric content among Chinook populations were also observed. Puget Sound Chinook had lower caloric content (total Kcals per fish) than summer/fall run Chinook salmon from all other regions sampled (from central California to northern British Columbia). Assuming that the fish sampled were representative of the sizes of fish available for killer whale consumption, whales feeding on Chinook salmon in Puget Sound would need to eat 1.5 to 1.8 times as many Chinook salmon as animals feeding outside Puget Sound to obtain the same caloric content.

Future priorities and level of effort

Improving our understanding of the Southern Resident's diet and how prey abundance and quality affects the population's viability remains a very high priority. In particular, gaining a better understanding of the linkage between salmon abundance and the Southern Resident's population dynamics is essential for determining the degree to which changes in salmon fisheries or salmon population status can be expected to affect the status of the whale population. Particular high priority efforts in this regard include continuing to study the whale's diet, especially when they are in outer coastal waters; confirming and extending Ford et al.'s (2005) results that suggest a direct linkage between salmon abundance and whale mortality; continuing studies of prey quality including contaminant levels in known and potential prey; continuing studies to determine which specific populations of salmon prey are most important for the Southern Residents; and additional studies of killer whale metabolism including better information on age and sex specific prey requirements. Given the importance of this topic, we expect to continue to invest a high level of effort on these problems.

Noise and vessels

How does noise or vessel traffic affect the behavior of the whales?

What effect does noise or vessel traffic have on the population's demographic characteristics (birth rate and death rate)?

Why these questions are important

During the summer months, the Southern Resident population spends much of its time in an relatively noisy underwater environment and in the presence of a relatively large number vessels. In particular, commercial and recreational whale-watching vessels accompany the whales from morning to dusk throughout the late spring, summer, and fall. In addition to recreational and whale watching vessels, the whales' summer habitat includes busy shipping channels and several naval operation areas. The whales use echolocation to find prey and vocalizations appear to play an important role in social cohesion and possibly communication, so underwater noise has the potential to have an impact on the population. Understanding how vessels and underwater noise affect the whales' behavior, foraging, and population dynamics is therefore clearly important.

Current understanding and recent progress

Noise -- Anthropogenic underwater noise originates from a variety of sources: commercial vessel traffic, including large freighters, tugs, barges, and fishing and whale-watching boats; recreational boats; and industrial activities such as dredging, drilling, marine construction, seismic testing of the sea bottom, and sonar from military and other vessels (Gordon and Moscrop 1996; NRC 2003). Many of these activities are prevalent in coastal and inland areas, coinciding with habitats used by this killer whale population.

Loud sounds may impair foraging and other behaviors and may also alter the movements of prey, which would affect foraging efficiency (Bain and Dahlheim 1994; Erbe 2002; Gordon and Moscrop 1996; Williams et al. 2002a; Williams et al. 2002b). 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) or inducing behavioral responses that result in fatal or debilitating actions (Gordon and Moscrop 1996; Jepson et al. 2003). Threshold levels at which underwater noise becomes harmful to killer whales are poorly understood. A model of how vessel noise levels affect killer whales' audio detection capabilities predicted that sounds of fast boats are audible to killer whales at distances of up to 16 km, mask their calls up to 14 km away, elicit behavioral responses within 200 m, and cause temporary hearing impairment after 30–50 minutes of exposure within 450 m (Erbe 2002). The characteristics of killer whale echolocation clicks have been characterized, along with some information on the intensity and frequency range of the echos (Au et al. 2004). Additional information along these lines will be useful for developing more accurate models of how changes in ocean noise impact the whales' foraging ability.

In the last three years, the NWFSC has funded studies to characterize the ambient sound field of the whales' summer range in the Haro Strait area, study the noise levels produced by specific classes of boats, determine the sound propagation characteristics of Haro Strait, and quantify the temporal trends in sound levels in recent years in Haro Strait. Projects funded in 2006 include a study to better characterize the echolocation reflections from specific killer whale prey items, including Chinook salmon, as well as a study to correlate the whales' behavior with changes in sound intensity in their immediate environment.

Vessels -- The average number of boats near the whales has increased from about 5 in 1990 to 26 by 1996 (Baird 2001; Erbe 2002; Marine Mammal Monitoring Project 2002; Osborne et al. 1999). The presence of numerous vessels may cause changes in behavior or physical and social stress to the whales. There is evidence that other dolphin and whale species demonstrate horizontal or vertical avoidance behavior in response to vessel traffic (Jelinski et al. 2002; Lusseau 2003; Ng and Leung 2003; Nowacek et al. 2001). They may also display agonistic behaviors, such as slapping flukes or pectoral fins on the surface of the water (Williams et al. 2002b). In a recent study, Foote et al. (2004) found an increase in the duration of Southern Resident vocalizations associated with the increase in whale-watching vessel traffic, but the potential effects of unrecorded confounding factors make it difficult to establish firm cause and effect relationships. Although cetaceans (whales and dolphins) are known to respond to boat traffic with stereotyped, short-term avoidance tactics, determining a link between short-term responses and a long-term effect such as decreased reproductive success is difficult.

Differences in the distribution of the three Southern Resident pods may mean that members of J, K, and L pods experience differing levels of acoustical, behavioral, and energetic impacts from vessels. Specifically, J pod has the most exposure to whale-watching and private vessels because it spends the most time in Puget Sound (Osborne 1999). L Pod likely has the least because of the extended time it spends outside Puget Sound. Because of these differences, comparing behavior and responses of the three pods is important. Comparison with the Northern Resident killer whales, whose range overlaps somewhat with the Southern Residents, is also useful because they are subjected to lower boat densities during the summer months.

In the last three years, the NWFSC has funded three studies to assess individual and social behavioral responses to vessels in the whales' summer range in the Haro Strait area. In addition, another small study was conducted to assess behavioral responses of Northern Resident killer whales to vessels for comparative purposes. Results from these projects show that both Southern and Northern Resident killer whales demonstrate some behavioral responses to vessel presence.

Future priorities and level of effort

Thus far, studies on noise and vessel effects have shown that there is a potential for vessels to disturb whales. Although killer whales demonstrate minor behavioral reactions in the presence of vessels, more information is needed to assess whether these generally subtle behavioral changes have the potential to cause a cumulative impact. Future work also includes additional data analyses and research on how the mode of vessel operation and the distance between vessels and whales affects the whales' behavior. In addition, studies investigating how vessel noise impacts the foraging ability of Southern Resident killer whales are also warranted. These studies are needed to provide information that will inform future management actions to mitigate vessel disturbance to whales.

Contaminants

What are the patterns of contaminant levels within the Southern Residents, and between the Southern Residents and other Eastern North Pacific killer whale populations?

Is there a relationship between exposure to contaminants in Southern Resident whales and their survivorship or reproductive success?

Why these questions are important

Chemical contaminants accumulate up through the food chain to relatively high concentrations in top-level predators such as killer whales. Accumulation of contaminants has been linked in marine mammal species to various deleterious biological and physiological impacts, including reproductive impairment, immune suppression and pathological lesions. With better information on contaminants and their levels in the environment and prey, NMFS will be better able to work with federal, state and local water quality agencies to reduce harmful chemicals in the whales' habitat.

Current understanding and recent progress

Exposure to high levels of toxic contaminants such as persistent organic pollutants (POPs) is one of the potential factors that may be contributing to the low population growth rate of Southern Residents. These contaminants include several toxic classes of pesticides (e.g., DDTs and chlordanes) and industrial chemicals (e.g., PCBs) that are frequently found in the marine environment worldwide. In addition, new chemical contaminants such as polybrominated diphenyl ethers (PBDEs), endocrine disrupters (e.g., synthetic estrogens, steroids) and new pesticides (Richardson 2003; Schnoor 2003) have been introduced into the environment in increasing levels. In particular, PBDEs, which are used as flame retardants in many common consumer goods, have increased dramatically in Puget Sound small cetaceans in the last 10 years (NWFSC unpubl. data).

The level of chemical contamination of some Eastern North Pacific killer whales has been previously assessed (Jarman et al. 1996; Rayne et al. 2004; Ross et al. 2000; Ylitalo et al. 2001). However, fewer than a dozen Southern Residents have been sampled for contaminants and most of these samples were collected over a decade ago. The small sample of Southern Residents included in these studies indicated that the Southern Residents had higher levels of contaminants than other fish eating killer whales, and were at levels that have been shown to be biologically harmful in other species (Jarman et al. 1996; Rayne et al. 2004; Ross et al. 2000; Ylitalo et al. 2001). Therefore, updating our information on contaminants in the Southern Residents by determining levels of both “legacy” and “emerging” POPs is a high priority. In 2006, the NWFSC initiated a biopsy sampling program for Southern Resident killer whales in order to gain a better understanding of contaminant levels and patterns in the population.

Wide ranges of contaminant levels have been measured in killer whales and the levels appear to be influenced by diet, as well as by various biological factors (e.g., reproductive status, sex, age, order of birth). In female whales, contaminant burdens increase up to sexual maturity and then decrease during the reproductive years as a result of contaminant transfer to the calves during gestation and lactation. First-born calves have higher levels of contaminants transferred from their mothers than do later offspring (Ylitalo et al. 2001). In males, contaminants continue to accumulate throughout their lives, and as a consequence, there are significantly higher concentrations of toxic contaminants in adult males compared to reproducing females. First-born males may be at the most risk due to these combined effects. By comparing the contaminant levels with the results of the paternity study some information can be obtained on the relationship between the numbers of calves sired, an indicator of reproductive fitness, and contaminant levels.

Chemical contaminants originate from a variety of sources, and the sources and contribution of each are often poorly known. Many prey species in Puget Sound have elevated levels of contaminants. However the contaminants could also originate from non-point sources from the North Pacific, especially for salmon that spend extended periods in the ocean. To understand the exposure pathway of Southern Residents to toxic chemicals, detailed chemical analyses of potential prey need to be conducted. We also lack detailed data on whole body analyses of potential prey, which is crucial to identifying contaminant sources and modeling contaminant uptake. In 2003, NWFSC initiated a collaborative study with the Washington Department of Fish and Wildlife to collect and analyze whole body samples of potential prey species to measure contaminant levels. The preliminary analyses show that contaminant levels in salmon species differ between regions. In particular, concentrations of toxics were higher in coho and Chinook populations that have more coastal distributions than those measured in salmon species (e.g., chum, pink, sockeye) with more oceanic distributions. This project has enabled us to begin addressing contaminant loads in putative killer whale prey, but critical data needs remain

Future priorities and level of effort

Environmental contaminants are clearly a potential problem for the Southern Residents, and may be at least part of the explanation for the lower rate of population growth compared to the less contaminated Northern Residents. However, relatively few Southern Residents have been sampled for contaminants, especially in the last ten years. We therefore view increasing the sample size of Southern Residents analyzed for contaminants as a very high priority and anticipate continuing to put a relatively high level of effort into contaminant research.

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