# EFFECTS OF FISHERIES ON KILLER WHALES

## SUMMARY OF PRELIMINARY ANALYSIS

The National Marine Fisheries Service (NMFS) has conducted a preliminary analysis of the effects of Chinook fisheries on Southern Resident killer whales in anticipation of the consultation on the Puget Sound Chinook Harvest Management Plan. The preliminary analysis explores the relationship between Chinook abundance and the wellbeing of the Southern Resident killer whale population, and the effects of fisheries on that relationship. For purposes of our analysis, we considered all salmon fisheries that cause mortality of Chinook salmon that would otherwise have been available to Southern Resident killer whales within their known range (Figure 1). This includes fisheries that occur in Southeast Alaska, the inland waters of Washington State and British Columbia ('inland waters') and coastal waters off British Columbia, Washington, Oregon and California ('coastal waters'). We did not include fisheries that occur in terminal areas where the Chinook are migrating to their spawning grounds and have exited the range of the killer whales. This analysis informs our evaluation of harvest management actions as well as our larger responsibilities for recovering the whales.

**Figure 1. Geographic Range (light shading) of Southern Resident killer whales (Wiles 2004).**


Southern Resident killer whales are listed as endangered under the U.S. Endangered Species Act. The population has 88 members, and a variable productivity rate. Several factors identified in the final recovery plan for Southern Residents may be limiting recovery (NMFS 2008). These are quantity and quality of prey, toxic chemicals that accumulate in top predators, and disturbance from sound and vessels. Oil spills are also a risk factor. It is likely that multiple threats are acting together. For example, disturbance from vessels may make it harder for the whales to locate and capture prey, which may cause them to expend more energy to catch less food. Although it is not clear which threat or threats are most significant to the survival and recovery of Southern Residents, all of the threats identified are important to address.

In anticipation of the consultation on the Chinook Harvest Management Plan, we analyzed the effect of salmon fisheries on Chinook abundance and the whales in two steps. We first estimated the reduction in prey available to the whales caused by the fisheries. Although the anticipated consultation before us is only for Puget Sound Chinook fisheries, we also considered other U.S. fisheries, as well as Canadian fisheries, because reductions in Chinook prey from Puget Sound fisheries would be in addition to reductions in prey from those other fisheries. In the second step, we considered information that would help put these reductions in context (that is, information that would indicate whether the whales are food-limited such that even small reductions in availability of their preferred prey would be harmful). This contextual information included evidence of Southern Resident's preference for Chinook salmon as prey, estimates of the ratio of Chinook prey available to the whales' Chinook needs, observational reports about poor body condition of individual whales, and studies of correlations between Chinook abundance and different measures of the health of the whale population. Our analysis relies on what we have preliminarily concluded to be the best scientific data available.

Southern Resident's Preference for Chinook: In inland waters from May to September, Southern Residents' diet consists of a high percentage of Chinook, with an overall average of 82% Chinook across the timeframe and monthly proportions as high as >90% Chinook (i.e., July: 96% and August: 91%, see Table 2 of Hanson et al. 2010). Hanson et al. (2010) find that the whales are likely consuming Chinook salmon stocks at least roughly proportional to their local abundance, as inferred by Chinook run-timing pattern and the stocks represented in killer whale prey for a specific area of inland waters, the San Juan Islands. Ongoing studies also confirm a shift to chum salmon in fall (Hanson unpubl. data).

These data on the predominance of Chinook in the whales' diet are consistent with previous studies of Southern and Northern Resident diet composition (i.e., Ford and Ellis 2006). Resident killer whales may favor Chinook salmon because Chinook have the highest lipid content (Stansby 1976, Winship and Trites 2003), largest size, and highest caloric value per kg of any salmonid species (Osborne 1999, Ford and Ellis 2006). The preference for Chinook salmon may also relate to the whales' ability to detect or catch large fish (Au et al. 2010), or may be a constraint of their culturally inherited foraging strategies (Ford et al. 2010).

Although less is known about diet preferences of Southern Residents off the Pacific coast, the available information indicates that salmon, and Chinook in particular, are also important when Southern Residents occur in coastal waters. To date, there are direct observations of two predation events (where the prey was identified to species and stock from genetic analysis of prey remains) when the whales were in coastal waters. Both were identified as Columbia River spring Chinook stocks (Hanson et al. unpubl. data). Chemical analyses also support the importance of salmon in the year round diet of Southern Residents (Krahn et al. 2002, 2007). Southern Residents' preference for Chinook in inland waters, even when other species are more abundant, combined with information to date about prey selection in coastal waters, makes it reasonable to expect that Southern Residents prefer Chinook salmon when available in coastal waters.

The Whales' Chinook Energy Needs: We used the following scientific information to estimate the whales' energy needs from Chinook: (1) The Southern Resident population's age/sex structure and abundance (The Center for Whale Research catalogue available at http://www.whaleresearch.com/orca_ID_pods.html), (2) Their metabolic requirements (Noren 2011), (3) Estimated time spent in inland and coastal areas of their range (Hanson and Emmons, unpubl. data), and (4) How much of their metabolic needs would ideally be met by Chinook of a certain size, based on data regarding the percent Chinook in their diet (Hanson et al. 2010 and unpubl. data), their preference for large Chinook (Ford and Ellis 2006; Hanson et al. unpubl. data), and a statistical model of their selection of large Chinook fit to collected data (Ward et al. unpubl. data; Hanson et al. unpubl. data).

Chinook Food Energy Available and the Reduction from Chinook Fisheries: We used a Fishery Regulation Assessment Model (FRAM; PFMC, MEW 2008) to estimate Chinook abundance[1]. Using FRAM predicted abundance, NMFS estimated Chinook food energy available to the whales with a five-step process (La Voy unpubl. data): (1) Developed methods to assign Chinook by stock, age and time period to a regional location (inland waters or coastal waters) within the whales' range, (2) Identified average Chinook lengths by stock, age and time period with Von Bertallanfy growth functions (as described in PFMC, MEW 2008), (3) Applied the above referenced size-selective model to depict selectivity of the whales' predation for larger fish and removed Chinook that did not meet this selectivity function, (4) Applied a Chinook length-to-kilocalorie model to estimate kilocalories of Chinook from the identified stock/age specific lengths (O'Neill et al. unpubl. data), and (5) Multiplied the number of Chinook from FRAM, modified by the size-selective model, by kilocalories derived in step three above to arrive at an estimate of Chinook food energy available to Southern Residents.

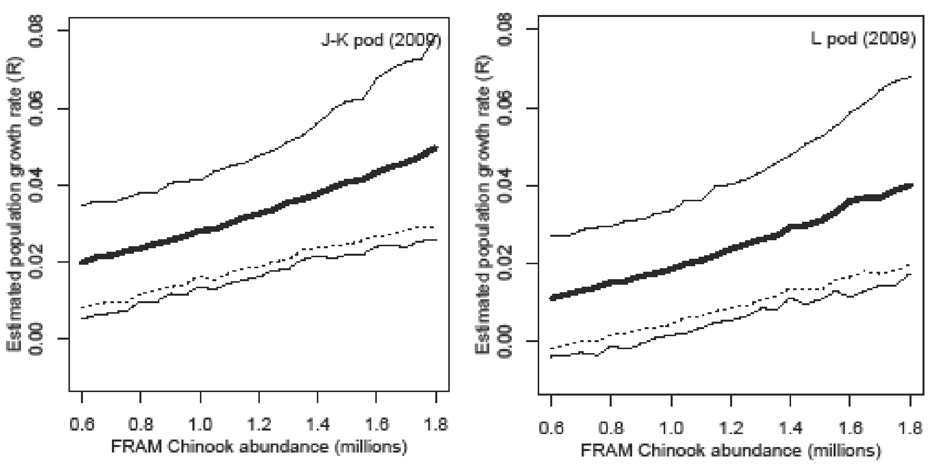
We conducted these five steps with and without Chinook mortalities caused by salmon fishing, using our knowledge of existing and proposed fisheries regimes for Canadian and U.S. fisheries to represent mortality levels that would occur with salmon fisheries. We evaluated a range of potential available Chinook and harvest conditions based on a retrospective analysis that considered annual variability of Chinook available from 1994 through 2008.

Other information suggesting that whales may be malnourished or suggesting a connection between Chinook abundance and killer whale population health: Observational information from the Center for Whale Research suggests that the Southern Resident population may be nutritionally stressed and that malnutrition may have contributed to recent killer whale deaths. The Center has observed very poor condition in 13 members of the Southern Resident population from the mid-1990's to present, and all but two of those whales subsequently died (Durban et al. 2009; Table 1). None of the whales that died were subsequently recovered, and therefore definitive cause of death could not be identified. Durban et al. document body condition with

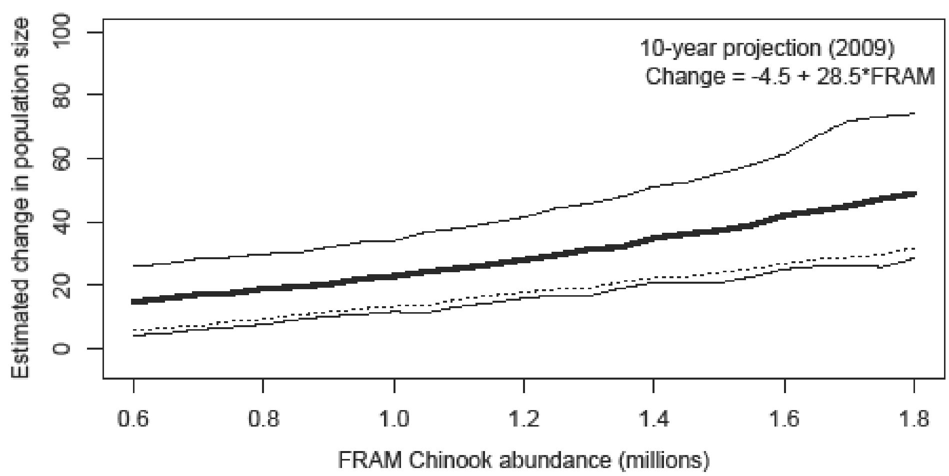
[1] For this analysis, Chinook abundance for each model time period was estimated after natural mortality and before terminal fisheries (where killer whales do not occur). Using abundance at this stage excluded Chinook alive at the start of a time period that either died from natural mortality, including from killer whale predation, or were caught in pre-terminal fisheries during that time period. These estimates represent abundance at the end of a time period, instead of at the beginning and therefore may underestimate overall abundance available to Southern Residents. This stage of the model was used even though it excluded some fish available during a portion of each time period, because the purpose of the analysis is to evaluate the effects of fishing. The effects of fishing within a time period are only shown using abundances after fishing rather than before.

boat-based visual observation and photographs. This technique is not able to detect fine scale differences in condition, because from the dorsal field of view a detectable change is only visible when a whale’s condition has become very poor.

In addition to these observations, recent demographic modeling demonstrates strong correlations between Chinook abundance and resident killer whale survival and birth rates (Ford et al. 2005, 2010; Ward et al. 2009). In the most recent modeling efforts, the NMFS Northwest Fisheries Science Center found that both the Southern Resident population growth rate and subsequent change in population size are positively correlated with abundance of Chinook in inland waters (Ward unpublished data). When Chinook abundance is relatively high (i.e., 1.8 million) predicted growth rate and change in population size are twice as high as when Chinook abundance is relatively low (i.e., 0.6 million) (Figure 1).




(a)




(b)

**Figure 1. (a) Estimated population growth rate for J/K (left) and L pods (right) based on the 2009 age/sex structure and FRAM Chinook abundance. The bold line represents the mean maximum likelihood estimate, and solid light lines represent 95% 2-sided confidence intervals. The light dashed line represents the lower 1-sided 95% confidence interval. In panel (b), we project the**

**population forward 10 years, and quantify the change in population size from the 2009 level. Again, the maximum likelihood estimate (bold line), 2-sided 95% intervals (light solid line) and 1-sided 95% interval (dashed line) are presented (from Ward unpublished data).**

Considering this information and based on the most conservative, risk averse, scenarios in our analysis, there are times and places where Chinook prey available to Southern Resident killer whales is likely insufficient to meet their metabolic needs. There also are Chinook fisheries that cause a measurable reduction in prey available (Table 1) at times when the amount of prey available compared to the whales' needs is already low (Table 2).

The preliminary analysis described here was limited to Chinook mortalities in salmon fisheries and inland waters of the whales' range because it was developed in anticipation of a consultation on the proposed Puget Sound Chinook harvest plan. Reductions in Chinook prey from Puget Sound Chinook fisheries are part of the larger reductions caused by all fisheries which, in turn, are part of larger ecosystem effects that limit Chinook abundance. Within the focused context of harvest, the reductions from Puget Sound fisheries are roughly equivalent to the estimated reductions from Southeast Alaska fisheries and fisheries prosecuted under the Pacific Coastal Salmon Plan, respectively (La Voy, unpubl. data).

This analysis, taken together with the whales' small population size and other threats to the population, raises concerns about the adverse effects of fisheries on the Southern Resident killer whale population.

**Table 1. Estimated percent reduction in Chinook food energy available to the whales in inland waters when(a) all fisheries are open, (b) only U.S. fisheries are open, and (c) only Puget Sound fisheries are open.**

**(a)**

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct-Apr** | -1.9% | -1.8% | -1.6% | -1.0% | -1.8% | -1.1% | -1.1% | -1.3% | -0.8% | -0.7% | -0.8% | -1.1% | -0.8% | -1.0% | -0.7% |
| **May-Jun** | -7.7% | -6.8% | -6.7% | -6.1% | -6.6% | -7.2% | -5.5% | -5.9% | -5.3% | -5.9% | -5.5% | -8.0% | -4.3% | -6.3% | -4.0% |
| **Jul-Sep** | -17.7% | -15.7% | -16.9% | -15.5% | -14.9% | -15.9% | -16.4% | -16.5% | -17.1% | -17.0% | -15.9% | -20.5% | -14.3% | -19.2% | -15.3% |

**(b)**

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct-Apr** | -0.1% | -0.1% | -0.1% | -0.2% | -0.2% | -0.2% | -0.1% | -0.3% | -0.2% | -0.2% | -0.3% | -0.4% | -0.3% | -0.5% | -0.4% |
| **May-Jun** | -2.1% | -1.4% | -1.1% | -1.5% | -1.6% | -2.6% | -1.4% | -1.3% | -0.7% | -1.8% | -2.0% | -2.2% | -1.7% | -2.4% | -1.4% |
| **Jul-Sep** | -5.3% | -4.2% | -4.8% | -4.3% | -4.8% | -6.3% | -5.0% | -5.2% | -5.1% | -6.2% | -6.9% | -7.5% | -6.4% | -9.2% | -6.3% |

**(c)**

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct-Apr** | 0.0% | -0.1% | -0.1% | -0.1% | -0.2% | -0.1% | 0.0% | -0.1% | -0.1% | -0.1% | -0.2% | -0.2% | -0.1% | -0.3% | -0.3% |
| **May-Jun** | -0.1% | -0.1% | -0.1% | -0.1% | -0.2% | -0.1% | -0.1% | -0.2% | -0.1% | -0.1% | -0.2% | -0.2% | -0.1% | -0.3% | -0.3% |
| **Jul-Sep** | -0.8% | -0.8% | -1.9% | -0.7% | -1.4% | -0.6% | -1.5% | -2.3% | -1.6% | -1.9% | -2.1% | -2.1% | -2.2% | -4.1% | -3.3% |

**Table 2. Estimated ratio of Chinook food energy available compared to the whales' food energy needs from Chinook in inland waters: (a) with all fisheries closed, (b) with Canadian fisheries open but with all U.S. fisheries closed, (c) with Canadian and all U.S. fisheries open, with the exception of Puget Sound fisheries, and (d) with all fisheries open.**

**(a)**

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct-Apr** | 4.8 | 4.2 | 5.8 | 5.9 | 5.2 | 4.5 | 4.4 | 5.8 | 6.4 | 7.6 | 6.2 | 6.5 | 6.9 | 4.5 | 4.7 |
| **May-Jun** | 6.7 | 5.9 | 8.2 | 8.6 | 7.5 | 6.4 | 6.2 | 8.3 | 9.5 | 11.1 | 8.7 | 9.1 | 9.9 | 6.4 | 6.8 |
| **Jul-Sep** | 5.8 | 4.1 | 5.8 | 6.1 | 7.4 | 5.0 | 5.4 | 7.0 | 8.0 | 10.1 | 6.5 | 7.3 | 7.7 | 6.4 | 5.4 |

**(b)**

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct-Apr** | 4.7 | 4.2 | 5.8 | 5.9 | 5.2 | 4.5 | 4.3 | 5.8 | 6.4 | 7.6 | 6.2 | 6.5 | 6.9 | 4.5 | 4.7 |
| **May-Jun** | 6.3 | 5.5 | 7.7 | 8.2 | 7.1 | 6.1 | 5.9 | 7.9 | 9.1 | 10.7 | 8.4 | 8.6 | 9.7 | 6.2 | 6.6 |
| **Jul-Sep** | 5.1 | 3.6 | 5.1 | 5.3 | 6.6 | 4.5 | 4.7 | 6.1 | 7.0 | 8.9 | 5.9 | 6.3 | 7.0 | 5.7 | 4.9 |

**(c)**

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct-Apr** | 4.7 | 4.2 | 5.7 | 5.9 | 5.2 | 4.4 | 4.3 | 5.8 | 6.4 | 7.6 | 6.2 | 6.4 | 6.9 | 4.5 | 4.7 |
| **May-Jun** | 6.2 | 5.5 | 7.6 | 8.1 | 7.0 | 5.9 | 5.8 | 7.8 | 9.0 | 10.5 | 8.3 | 8.4 | 9.5 | 6.0 | 6.5 |
| **Jul-Sep** | 4.8 | 3.5 | 5.0 | 5.1 | 6.4 | 4.2 | 4.6 | 6.0 | 6.8 | 8.5 | 5.6 | 6.0 | 6.7 | 5.4 | 4.8 |

**(d)**

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct-Apr | 4.7 | 4.1 | 5.7 | 5.9 | 5.2 | 4.4 | 4.3 | 5.8 | 6.4 | 7.6 | 6.2 | 6.4 | 6.9 | 4.5 | 4.7 |
| May-Jun | 6.2 | 5.5 | 7.6 | 8.1 | 7.0 | 5.9 | 5.8 | 7.8 | 9.0 | 10.5 | 8.3 | 8.4 | 9.5 | 6.0 | 6.5 |
| Jul-Sep | 4.8 | 3.5 | 4.9 | 5.1 | 6.3 | 4.2 | 4.5 | 5.8 | 6.7 | 8.4 | 5.5 | 5.8 | 6.6 | 5.2 | 4.6 |

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