THE EFFECTS OF SALMON FISHERIES ON SOUTHERN RESIDENT KILLER WHALES

FINAL REPORT OF THE INDEPENDENT SCIENCE PANEL

*** DRAFT ***

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Independent Science Panel of the
Bilateral Scientific Workshop Process to
Evaluate the Effects of Salmon Fisheries on
Southern Resident Killer Whales

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Executive Summary

Southern Resident Killer Whales (SRKW; Orcinus orca) are listed as an endangered species under both the Endangered Species Act (ESA) in the U.S. and the Species at Risk Act (SARA) in Canada. The National Marine Fisheries Service (NOAA Fisheries) and Fisheries and Oceans Canada (DFO) have developed and adopted recovery plans for SRKW as required by their respective national statutes. One of the potential threats to the recovery of SRKW may be a reduction in salmon prey available to SRKW due to salmon fisheries. This document represents the draft final report of the Independent Science Panel of the Bilateral Scientific Workshop Process to Evaluate the Effects of Salmon Fisheries on Southern Resident Killer Whales.

During 2011-2012, NOAA Fisheries and DFO commissioned a series of three scientific workshops to rigorously explore the evidence available to determine to what extent are salmon fisheries affecting recovery of SRKW by reducing the abundance of their available prey, and what are the consequences to their survival and recovery? The Independent Science Panel consists of 7 scientists from the U.S. and Canada chosen for their expertise in population dynamics, marine mammals and fisheries. The Independent Science Panel was provided with a large collection of documents prepared by agency science teams and other scientists, as well as presentations at the first two workshops. Between Workshop 1 and Workshop 2 the panel requested various forms of further information and analysis from agency staff, and received input from other stakeholders based on presentations at Workshop 1.

The underlying hypothesis presented by the two agencies is that SRKW are highly dependent on Chinook salmon, that the rate of increase of SRKW is higher in years of high abundance of Chinook, and that reductions in Chinook harvest would lead to an increase in SRKW abundance. Over the last 4 decades, the SRKW population has been increasing at an average rate of about 1% per year, far short of the 2.3% per year established as a goal for downlisting or delisting under the U.S. Endangered Species Act. The panel found that the evidence for high dependence on Chinook salmon during the summer is convincing. There is also a statistical correlation between periods of lower Chinook abundance and higher SRKW mortality rates. However the panel cautions that this correlation does not imply causation, but rather both could be caused by another environmental factor. There are also concerns about whether the index of Chinook abundance accurately reflects the Chinook stocks most important to SRKW. Currently Chinook stocks are harvested at a rate of about 20%, so there is limited potential for increasing Chinook abundance by reducing fishing pressure. The panel also found that there are concerns that forgone harvest may not result in proportionally higher Chinook abundance because (1) all Chinook foregone from harvest may not be the stocks that SRKW depend on, (2) all Chinook foregone will not be mature and available to SRKW, and (3) there are many competitors for Chinook salmon, particularly other marine mammals, and they may consume additional Chinook before they are available to SRKW. Overall the panel felt that the estimated impact of Chinook catch reductions on SRKW should be regarded as a maximum estimate and that the realized impact would likely be less.

The panel recommends that research in the near term should emphasize (1) further photogrammetric analysis of individual SRKW body condition, (2) use of contaminant data to determine if the indices of Chinook abundance used in the statistical models accurately reflect the Chinook stocks important to SRKW, (3) revision of models to allow for the simultaneous mortality due to other predators on Chinook salmon and (4) an ecosystem view of factors affecting SRKW.

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1.0 Introduction

This document represents the ***draft*** final report of the Independent Science Panel of the Bilateral Scientific Workshop Process to Evaluate the Effects of Salmon Fisheries on Southern Resident Killer Whales.

NOTE:

*This **draft** version of the final report reflects the Independent Science Panel's evaluation of the evidence presented up to and including Workshop 2, and subsequent follow-up with agency scientists on particular issues and participant responses following Workshop 2. At the time of writing (April, 2012), this report has not been subject to broader public comment (will occur May to mid-June, 2012, see below) and Workshop 3 has not yet occurred (September, 2012).*

PUBLIC COMMENT:

*Feedback and input on this draft will be accepted until **June 15, 2012***

Please send comments to orca.plan@noaa.gov.

If you require additional information about the workshop process or the process of providing comments on this draft report, please contact Larry Rutter at 360-753-4407 or email at Larry.Rutter@noaa.gov.

This section provides a brief overview of the background context, workshop process, the role of the Independent Science Panel, and an introduction to the structure of the present report.

1.1 Context

Southern Resident Killer Whales (SRKW; *Orcinus orca*) are listed as an endangered species under both the Endangered Species Act (ESA) in the U.S. and the Species at Risk Act (SARA) in Canada. The National Marine Fisheries Service (NOAA Fisheries) and Fisheries and Oceans Canada (DFO) have developed and adopted recovery plans for SRKW as required by their respective national statutes. One of the potential threats to the recovery of SRKW may be a reduction in salmon prey available to SRKW due to salmon fisheries. During 2011-2012, NOAA Fisheries and DFO commissioned a series of three scientific workshops to rigorously explore the evidence available to answer the key question:

> *To what extent are salmon fisheries affecting recovery of SRKW by reducing the abundance of their available prey, and what are the consequences to their survival and recovery?*

As part of the workshop process, the NOAA and DFO Steering Committee appointed an expert science panel ("the Panel") to provide an independent review of the evidence available and advice on future research. The scientists from the national, state and tribal fisheries agencies, members of the Panel and other participants in the workshops examined existing research as well as completely new research directed by the outcomes of the first two workshops.

1.2 Workshop Process

The detailed design of the workshop process and various outputs of this process, including workshop presentations, background literature, new materials developed for the workshops, preliminary responses from the Panel, and feedback from other participants are all available elsewhere. In this report, we wish to avoid repeating information that is readily available in other documents. Instead we have provided a brief summary below of other documents, reports and materials associated with the overall workshop process. The following materials are currently all available at http://www.nwr.noaa.gov/Marine-Mammals/Whales-Dolphins-Porpoise/Killer-Whales/ESA-Status/KW-Chnk.cfm.

1. **Process Description** – describes the overall workshop process; the role of the Panel, the Science Panel Chair, and the Science Facilitator; the flow of tasks through the entire process; and the contextual background (both scientific and regulatory) to the key question.
2. **Process Diagram** – outlines the timeline associated with the major tasks and stages of the overall workshop process.
3. **Reading List** – breaks the overall question into the original topics used by the Panel to organize their assessment, provides a contextual description of each topic, poses key questions for each topic, and provides an extensive list of relevant background literature.
4. **Background Literature** – a comprehensive library of relevant background literature compiled by the Steering Committee prior to the Workshop 1 for participants and panel members to review.
5. **Workshop Agendas** – lists all the speakers and presentations for each of the workshops.
6. **Workshop Presentations** – the final presentations delivered by each of the speakers at each of the workshops.
7. **Workshop Audio Files** – audio recordings of the entire proceedings of each workshop.
8. **Response Papers** – short papers prepared by NOAA and DFO scientists in response to requests from the Panel for additional information on particular topics. These response papers were prepared in place of presentations on these topics at Workshop 2.
9. **Additional Workshop Materials** – additional materials provided by presenters and participants, including supplementary papers or data sets, short papers on additional research not presented, and official institutional statements.
10. **NOAA and DFO Questions & Answers** – provides responses from NOAA and DFO scientists to short-term information / analysis requests that the Panel provided to the Steering Committee shortly after each workshop.

11. **Workshop 1 Proceedings** – includes questions and discussion from Workshop 1 integrated into a compilation of all of the responses (feedback, comments, recommendations, etc.) received from participants following Workshop 1.
12. **Participant Responses to Workshop 2** – written comments, feedback and additional analyses submitted by participants to the Panel in response to Workshop 2.
13. **Science Panel "Reflections" Document** – the preliminary report of the Panel following Workshop 1, including initial responses and recommendations for work to be done prior to Workshop 2. The Panel based its responses on the evidence available prior to the workshop, the presentations and discussion at the workshop, the information available immediately following the workshop, and the feedback submitted by other participants.

1.3 The Independent Science Panel

The Independent Science Panel ("the Panel") consists of seven senior scientists from five U.S. and Canadian universities and one non-university research institution. These scientists were chosen to be members of the Panel according to their relevant expertise in salmon fisheries, killer whales and predator-prey dynamics, and their ability to constructively and objectively collaborate to fulfill the purposes of the workshop process. The Panel comprises the following members:

Dr. Ray Hilborn (Chair)
School of Aquatic and Fishery Science, University of Washington, Seattle, WA

Dr. Sean Cox
School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC

Dr. Frances Gulland
Marine Mammal Center, Sausalito, CA

Dr. David Hankin
Department of Fisheries Biology, Humboldt State University, Arcata, CA

Dr. Tom Hobbs
Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO

Dr. Daniel Schindler
School of Aquatic and Fishery Science, University of Washington, Seattle, WA

Dr. Andrew Trites
Marine Mammal Research Unit, University of British Columbia, Vancouver, BC

The principal role of the Panel is to critically evaluate the scientific evidence available and the approach by which that evidence is being used to answer the central question. The Panel attended all of the workshops, questioning the presenters and participating in discussions. In their first report (Hilborn et al., 2011), delivered in November 2011, the Panel provided initial, preliminary responses based on the evidence available prior to Workshop 1, the proceedings of Workshop 1, and the comments and feedback of other participants. The Panel then revised these responses while working on this draft final report, in light of new information and analyses presented at Workshop 2 and additional input from participants. The ultimate goal of the Panel is to examine current methods of addressing the central question and provide guidance for future research to reduce critical uncertainties.

The responsibility of the Panel explicitly excludes addressing management issues or making management recommendations. The responsibility of the Panel only covers the critical examination of scientific issues. The Process Description thoroughly describes the full role of the Panel.

1.4 Report Overview

The remainder of this report consists of two major sections. Part I provides a synthesis of the responses and recommendations of the Panel across all of the broad topic areas covered in greater detail in Part II. Section 2.0 provides an integrated discussion of the most critical themes identified by the Panel and the recommendations that the Panel considered to be of the highest priority.

Part II provides an examination of each of four broad topic areas in greater depth. These topic areas represent a consolidation of the nine topics originally identified by NOAA and DFO and addressed in the Panel's preliminary report subsequent to Workshop 1. The Panel felt that considerable overlap existed among the original topics both in terms of the questions being asked and the evidence available to answer those questions, and that a consolidation of these topics would allow the Panel to address the total suite of questions in a more effective manner. Table 1-1 illustrates how those original topics were consolidated for the purposes of the Panel's final report. Appendix 1 provides a complete listing of the original questions posed to the Panel within each topic. Each of the sections in Part II serves four broad functions: 1) providing a contextual introduction to the particular topic, including relevant background information; 2) reiterating or summarizing the key questions asked of the Panel across the original topics consolidated into each section; 3) reporting the Panel's assessment and conclusions in response to those questions; and, 4) providing recommendations, where appropriate, for future research and analysis to reduce key uncertainties and improve the level of scientific understanding.

Table 1-1. Consolidation of original topics into the sections of the current report.

Report section	Section title	Topics as originally defined by the NOAA and DFO Steering Committee
3.0	Status and Growth Rates of Killer Whales	• Status of Killer Whales
4.0	Feeding Habits and Energetic Needs of Killer Whales	• Feeding Habits and of Killer Whales • Chinook Needs of Southern Resident Killer Whales • Ratio of Chinook Food Energy Available Compared to Chinook Food Energy Needed by Southern Residents with (and without) Fishing
5.0	Fisheries and Prey Availability	• Fisheries that May Affect Prey Availability • Chinook Abundance and Food Energy Available to Killer Whales • Reduction in Chinook Abundance and Food Energy from Fisheries
6.0	Projected Future Status and	• Relationship between Chinook Abundance and Killer Whale Population Dynamics

Recovery	• Change in Killer Whale Population Growth Rates Annually, Abundance over Time and Species Survival and Recovery

The views, conclusions and recommendations of the Panel reported in this document have been informed by multiple sources of evidence within the workshop process:

- literature reviewed prior to Workshop 1
- presentations and discussion at Workshop 1
- responses from NOAA and DFO scientists to short-term requests from the Panel immediately following Workshop 1
- feedback and comments submitted by participants in response to Workshop 1
- feedback from NOAA and DFO scientists on the Panel’s preliminary responses
- presentations and discussion at Workshop 2
- response papers prepared for Workshop 2
- additional information and materials provided by participants for Workshop 2
- responses from NOAA and DFO scientists to short-term requests from the Panel immediately following Workshop 2
- direct discussions with NOAA and DFO scientists to clarify methodological questions
- feedback and comments submitted by participants in response to Workshop 2

PART I: SCIENCE PANEL SYNTHESIS

2.0 SUMMARY

2.1 Approach used in 2010 Biological Opinion

The 2010 Biological Opinion, and the presentations at the first two workshops, develop a chain of logic for how Chinook salmon fisheries affect killer whales. This logic and data support can be described as follows:

1. SRKW depend upon Chinook salmon as a critical food resource. This is supported by summer diet information.
2. SRKW are on occasion in poor condition, which may indicate nutritional stress. Poor condition is supported by photogrammetry and possibly the peanut-head syndrome.
3. Individuals who have been identified as being in poor condition have a higher probability of dying than individuals who have not been so identified.
4. SRKW have shown a statistical correlation between indices of Chinook salmon abundance and fecundity, death rates and rates of population increase.
5. Reducing Chinook harvesting would increase the availability of Chinook to SRKW.
6. Models using the coefficients of the statistical models (from item 4 above) suggest that there would be larger SRKW populations on average in the future if more Chinook salmon were available because of reductions in Chinook harvesting.

The core of the analysis in the Biological Opinion is the statistical correlation between indices of Chinook abundance and rates of increase in the SRKW population. The rest of the logic provides a mechanistic explanation for why that correlation could be causative.

2.2 The Conclusions of the Panel

Status of Southern Resident Killer Whales

The SRKW population has on average been increasing slowly (about 1% per year) since the 1970s with alternating periods of increase and decline. Because of the small population size much of this fluctuation may be the result of random events, but sustained periods of increase and decline, shared between both SRKW and NRKWs suggest there is likely a common causal factor. The two issues of concern about the status of SRKW are the low population size, and the low rate of increase. Compared to NRKWs the SRKW have a smaller population size, a slower growth rate, lower birth rates and higher death rates. Historical population sizes were discussed in the 2010 Biological Opinion, and are also reviewed in section 6.4 of this report.

The panel believes that the existing delisting criterion of 2.3% growth rate is unlikely to be achieved given current circumstances or by reducing Chinook fisheries, but if current trends continue SRKW will eventually increase to a point where a reappraisal of their status would lead to downlisting or delisting. It is difficult to estimate what the potential maximum population for SRKWs may be, but NRKWs, seals and sea lions all compete with SRKW for their food supply and this may limit the potential of SRKW to continue to increase in the long-term. The Biological Opinion discusses potential carrying capacities from a minimum of 140 animals to a maximum of 400. Demographic reconstruction showed that the largest known size was likely 96 animals in 1967[1], leading to the conclusion that the population size has not varied dramatically over the last 45 years. We would expect the rate of increase to decline as the population approaches the carrying capacity. The lower growth rate of SRKW compared to NRKWs could be because the SRKW are closer to their carrying capacity.

Dependency on Chinook

Diet information from SRKW in the summer indicates a heavy reliance on Chinook salmon. As Chinook abundance declines in the fall the diet data show that chum salmon and other species become more important. There is little winter diet data, but the data that do exist also suggest the importance of Chinook. It seems somewhat illogical that SRKW would forgo feeding on other species at time of low Chinook abundance, and there is not enough data to determine if the percentage Chinook in the diet is related to between year variation in abundance of Chinook. Other fish-eating killer whales in the North Pacific show a broader range of diet. However the increase in the frequency of feeding on other species as summer ends and Chinook availability declines does suggest that SRKW would switch to other species at times and places of low Chinook abundance.

The panel found the evidence for strong reliance on Chinook in the summer convincing.

Poor Condition and Possible Nutritional stress

Some SRKWs are in poor condition (which can be caused by nutritional stress, the most common cause, or other factors) and animals in poor condition have a higher probability of dying. The strongest suggestion of poor condition is the photographic evidence from Durban et al. (2009) and the peanut-head syndrome. Durban et al. documented 13 SRKW in poor condition over the period 1994 through 2008 and all but two of these individuals subsequently died. Poor condition and nutritional stress could contribute to increased mortality or reduced fecundity of Southern Residents through a variety of mechanisms (i.e., direct starvation, increased susceptibility to trauma due to increased movements to forage, decreased resistance to infectious disease, mobilization of lipophilic toxic chemicals), as well as to decreased recruitment through changes in calving interval and calf survival. There are insufficient data to relate the incidence of poor condition to nutritional stress caused by low Chinook abundance or other causative factors. These data serve primarily to support the assertion that poor condition, which is clearly linked to mortality, and by implication to fecundity, may reflect nutritional stress.

[1] Ford, M. and K. Parsons. 2012. Estimating the historical size of the southern resident killer whale population. Presentation at workshop 2, slide 4.

The panel believes the photographic evidence is convincing that poor condition (and *possibly* nutritional stress) is an issue of concern for SRKW. However, not all members of the Panel were convinced that poor condition was *necessarily* an indicator of nutritional stress (due to low availability of prey) as compared to some other factor (disease, organ malfunction) that might lead to reduced or less successful feeding and thereby generate "poor condition". Unless a large fraction of the population experienced poor condition in a particular year, and there were ancillary information suggesting a shortage of prey in that same year, malnutrition remains only one of several possible causes of poor condition.

Statistical correlation between Chinook abundance and rates of increase in Southern Resident Killer Whales

Several analyses performed by both NOAA and DFO have shown correlations between recruitment, survival and rate of increase for SRKW. The presentations at Workshop 2 by Eric Ward and co-authors used the Parken-Kope index of salmon abundance and showed significant correlation between the Chinook abundance index and SRKW survival, and a weak indication of some impact on fecundity[2].

This analysis is the core of the evidence that changing Chinook abundance affects SRKW demographic parameters. The statistical analysis performed uses state-of-the-art methods and has been very thorough.

Nevertheless there are a number of reasons to not accept the conclusions at face value. First and foremost the evidence is simply correlative, the period of low Chinook abundance in the 1990s coincided with a period of poor survival for SRKW. While it seems unlikely this is pure chance, it is certainly possible that another factor has affected both Chinook abundance and SRKW survival, and there is no causative link. The history of population dynamics is replete with correlations that have not turned out to be causal.

A major concern is the choice of indices of Chinook abundance. The Parken-Kope index does not provide an index of the Chinook stocks that are most important to SRKW from the diet data available, and the range of statistical analysis over the years have explored a broad range of Chinook indices, many of which do not show any correlation. In his most recent analyses presented at Workshop 2 Ward et al. explored quite a few indices and again there were varying degrees of correlation, many of them weak.

Ward found little evidence for density dependent rates of increase in SRKW[3]. If Chinook abundance is limiting the rate of increase, and if the SRKW are consuming a very high proportion of available

[2] Ward, E. C. Parken, R. Kope, J. Clark, A. Velez-Espino, L. LaVoy, J. Ford 2012. Exploring sensitivity of the relationship between salmon abundance indices with killer whale demographics. Presentation at Workshop 2.

[3] E. Ward, J. Ford, A. Velez-Espino. Comparison of SRKW and NRKW population dynamics; Presentation at Workshop 2; slide 59

Chinook, then we would have expected to see stronger density dependent impacts as the abundance of SRKW has increased in the last few decades.

The panel believes the NOAA and DFO scientists have done an excellent job of their statistical analysis, but in the end believe considerable caution is warranted in interpreting the results as confirming a causative relationship between Chinook abundance and SRKW survival.

Reducing harvest would increase availability

Recent analyses presented at the workshops explored whether reductions in Chinook harvest would increase food for SRKW and thus SRKW population rates of increase. These analyses have made the simple assumption that a certain number of Chinook foregone from the harvest will result in an equivalent increase in abundance of Chinook for SRKW.

There are several reasons this assumption may not be true. First and foremost there is a range of other predators on Chinook salmon, especially NRKWs, harbor seals and sea lions that may eat some of the foregone Chinook before or at the same time that the SRKW have access to them. The actual increase in food availability to SRKW may be considerably less than the foregone harvest.

Secondly the foregone harvest would likely not consist exclusively of Chinook stocks that are important to SRKW. Most Chinook harvesting takes place on a mix of stocks, and some forgone harvest would almost certainly be fish not important or critical to SRKW.

Thirdly, it appears that the key Chinook stocks in the summer are mature fish, yet many of the Chinook fisheries harvest a mix of immature and mature fish. While the foregone immature fish would ultimately become mature if they survive, not all would survive and thus not all foregone harvest would result in mature fish.

Finally an important issue is that the harvest rates on Chinook salmon are now quite low (on the order of 20% on average) so that there is limited room for reductions in Chinook harvesting to increase the abundance of Chinook.

The panel sees many potential reasons why there wouldn't be much of an increase in available prey (e.g., other predators, functional responses), and is therefore skeptical that reduced Chinook harvesting would have a large impact on the abundance of Chinook available to SRKW.

Projections show increased abundance of Chinook leads to more rapid rebuilding of Southern Resident Killer Whales

Analysis presented by Ward at both workshops, and earlier analyses included in the Biological Opinion, suggest that reductions in Chinook harvesting would lead to increases in Chinook abundance, which would in turn have some impact on the growth rates and the future population size of SRKW. The statistical methods used were generally considered suitable, although the Panel has little confidence in specific predictions about population size more than 5 years in the future because of the uncertainties described in the next paragraph, and the stochasticity of fecundity and survival. In addition, more recent logistic regression analyses (requested by the Panel) suggest that growth rates of SRKW are also related to the abundance of other marine mammal predators, which were not included in earlier versions of the statistical models.

The panel's overall view is that the projected increases in SRKW abundance are both small, and likely overestimated because of our concerns expressed in the issue of correlation versus causation, the roles of other marine mammals in the ecosystem, and the question of what fraction of foregone harvest would result in increased food availability to SRKW.

Conclusions

The panel concludes that there is good evidence that Chinook salmon are a very important part of the diet of SRKW and that there is good evidence, collected since 1994, that some SRKW have been in poor condition and poor condition is associated with higher mortality rates. There is a statistical correlation between SRKW survival rates and some indices of Chinook salmon abundance. Based on those correlations, increases in Chinook abundance would lead to higher survival rates, and therefore higher population growth rates, of SRKW. However, the effect is not a linear one as improvements in SRKW survival diminish at Chinook abundance levels beyond the historical average. Using the statistical correlations, consistently positive SRKW growth rates can occur by avoiding extremely low Chinook abundance levels observed in the 1970-80s and late-1990s.

However, the panel cautions against overreliance on the correlation implying causation, and the fact that the level of correlation is highly dependent on the choice of Chinook abundance indicators. It is also not clear what would be the impact of reduced Chinook harvest on food availability to SRKW.

The sum of these concerns is that we believe the estimated benefits of reducing Chinook harvest in NOAA's recent analyses provide a maximum estimate of the benefits to SRKW and the realized benefits would likely be lower.

2.3 Mechanisms

Discussion of mechanistic approach

Much of the work done by NOAA and DFO and contained in the Biological Opinion relates to mechanisms that support the statistical correlation between indices of Chinook abundance and vital rates of SRKW. The basic mechanism is that SRKW are on some occasions food limited, leading to poor condition and lower survival and fecundity and that Chinook is a highly important part of their food supply. NOAA and DFO have documented that some killer whales are in poor condition, that those in poor condition have lower survival, and that Chinook are an important part of SRKW diet.

This mechanistic approach does not provide a quantitative method to evaluate the benefits of reducing Chinook harvesting. What is needed is documentation of the relationship between Chinook abundance and number of animals that are in poor condition. This could provide strong evidence that periods of low Chinook abundance lead to poorer condition, more nutritional stress and lower survival rates. At the moment we simply have the correlation based primarily on one extended period of low Chinook abundance in the mid-1990s, and the coincident mortality of an unusually high number of SRKW. If possible it would be very useful to expand the photogrammetric data collection program to provide a spring and fall measure of the condition of most of the SRKW and then relate that data directly to indices of Chinook abundance.

Importance and value of studying mechanisms

As discussed in Section 2.2 the panel has reservations about assuming that correlation implies causation. The role of mechanistic studies is to identify the causal mechanism that would then support the causation vs. correlation hypothesis. The mechanistic data developed so far certainly provide some support for causation, if only because if there was no evidence for poor condition (possibly due to nutritional stress), or if Chinook were not an important part of SRKW diet, then the support for causation would be weakened.

Limitations to mechanistic approach

The major limitation to the mechanistic approach at present, is that very little information on condition is currently available to provide scientific or management guidance. Similarly there is so little information on winter diet that the mechanistic approach must remain, at present, merely supportive of causation.

SRKW are imbedded in a complex ecosystem with diverse possible food sources and a range of competitors for that food. At Workshop 2 we had a presentation on an Ecopath with Ecosim model[4] that was the only whole ecosystem look at SRKW and their key competitors. The mechanistic approach used in the Biological Opinion essentially ignores all other ecosystem connections except Chinook salmon.

2.4 Recommendations for Future Work

Critical missing pieces

The panel has identified a range of data and analyses that would be high priority to obtain, but were not feasible during the duration of our review. We classify these into those critical to the evaluation of the link between food supply and rates of increase, and those that that provide supporting mechanistic evidence.

Items Critical to the underlying hypothesis

[4] Preikshot, D. and I. Perry. 2012. Interactions between marine mammals and chinook salmon in a Strait of Georgia ecosystem model. Presentation at Workshop 2.

Critical: Nutrition status. The evidence that some individuals are in poor condition and those individuals have high mortality rates is a strong piece of evidence for the causative hypothesis, but currently available from a very small sample size, and poor condition has not been definitively related to nutritional stress *per se*. These data have the potential to demonstrate that periods of low Chinook abundance are associated with more frequent poor condition. The panel recommends that spring and fall photogrammetric work be expanded and ideally become a routine part of monitoring for the SRKW, helping to determine when SRKW condition deteriorates, and thereby focusing efforts on the most critical season.

Critical: Continuous fishing and natural mortality. The model indices of Chinook abundance generally relied on assumptions about natural mortality rates that were assumed fixed and that natural mortality and fishing mortality were discrete events. Given that the abundance of many of the predators have changed over time it would seem reasonable to attempt to model time varying natural mortality. Additionally, much of the natural mortality and some of the fisheries are continuous processes so modifying models to account for simultaneous predation and fishing mortality might improve the reliability of the evaluation of impacts of fishing on food available to killer whales.

Critical: Contaminant fingerprinting. At Workshop1, Brad Hansen[5] showed that contaminant signatures indicate the feeding habitats of killer whales, and further contaminant work could establish the major Chinook stocks that contribute to SRKW diets. This would help identify which Chinook indices of abundance are most appropriate indicators of food supply. If the contaminant data indicated a preponderance of Chinook stocks whose indices did not correlate with changes in SRKW rates of increase, support for the underlying hypothesis would be decreased.

Critical: Revise projected SRKW abundance and growth rates. Use more realistic fishery scenarios, instead of exploring the consequences of “eliminating" fisheries independent of future Chinook abundance,

Critical: Simulation testing of the ability to detect the impact of possible changes in Chinook fisheries. An important question that should be asked is: “if particular changes were made to Chinook fisheries, could statistical analysis detect the impact on both Chinook abundance and SRKW survival?”. Recognizing that management of the ecosystem of SRKW is a long-term task, it is important to know if agencies would be able to learn from any regulatory changes they make.

Items supporting the mechanism

[5] Hansen, B., 2012. Southern Resident Killer Whale diet as determined from prey remains and fecal samples. Presentation at Workshop 1. Slide 40.

Supporting: Winter distribution and diet. If low food availability is leading to poor condition, nutritional stress and higher mortality rates, this may be happening during the winter rather than the summer. It is broadly recognized that more data on winter distribution and diet would be important to have. It is also recognized that these data are expensive and difficult to collect. .

Supporting: Marine mammal competition. Some estimates presented to the panel showed that marine mammal predation on Chinook may be very large and potentially growing. Further evaluation of the role of marine mammal predation is recommended.

Supporting: Other ecosystem factors. A major potential concern with the statistical correlation between Chinook abundance and SRKW rates of increase is the potential for other factors in the ecosystem to be affecting both Chinook and SRKW. Thus the panel would have liked to see more evaluation of ecosystem factors affecting killer whales, and recommend that future analysis explore a broad range of ecosystem factors. A first step would be to explore a range of indices of ocean productivity as alternatives to Chinook abundance.

Supporting: Fecal and blubber samples. Fecal sampling would help identify the importance of non-salmonids in the diet. At present it appears that salmonids are likely over-represented in floating feeding scraps. Fecal and blubber samples should be archived from future stranded animals. There is a wide range of potential information from such animals and archiving these data should be part of the ongoing SRKW monitoring program.

PART II: SCIENCE PANEL RESPONSES BY TOPIC AREA

3.0 STATUS AND GROWTH RATES OF KILLER WHALES

3.1 Context

Data on the abundance and demography of killer whales are highly detailed and accurate as a result of the ability to recognize individuals by photographing their dorsal fins and adjacent markings. Photo identification allows every individual in the population to be observed over time, providing exceptional reliability in estimates of population size and vital rates.

The abundance of SRKW fluctuated between 60 and 100 individuals during 1975 to 2010. Intervals of population increase alternated with periods of decline, but the duration of intervals of positive growth substantially exceeded those when growth was negative. During the last decade, the population has been increasing slowly, showing growth rates that averaged 1.1 % per year.

In contrast to the Southern Residents, Northern Resident killer whales have increased more rapidly over the same time interval, from 120 animals in 1975 to more than 260 currently. The trajectory of growth has been, for the most part, steadily positive over the last three decades. Increases in abundance were interrupted only briefly during the late 1990s and early 2000 when the population declined at a rate of one percent annually, a downturn that coincided with steeper declines in the abundance of SRKW.

The history of predominantly positive growth rates in SRKW would promote confidence about the future persistence of the population if the population were large. However, the relatively small size of the population raises concerns about its viability as a result of environmental and demographic effects exposing the population to risks of extinction. A key point, occasionally overlooked by participants in both meetings, is that the Southern Resident population is *not* declining. Concerns about its future arise entirely from the current and recent size of the population and the potential impacts of future, unforeseen events on a population that lacks the resilience created by higher abundance.

3.2 Key Questions

Understanding the current status of the Southern Resident population is a necessary starting point for any discussion of actions needed to improve its status. The panel was asked to examine current knowledge of population size, growth rates, and demography of SRKW relative to Northern Residents, to assess current trends relative to historical trends in abundance and to evaluate understanding of the current status of the population relative to recovery goals.

3.3 Responses to Key Questions

Population growth rate

The database of observations of known individuals over an extended period of time easily meets the highest standards for inference in population ecology. The analyses conducted to infer population trends were state-of-the-art in their statistical and mathematical sophistication. The panel finds little fault in the data or in their implementation in models of historic population dynamics.

Analysis of the long-term population growth rate (hereafter, λ) of the population of SRKW from data obtained during 1970-2010 revealed reasonably strong evidence that the population is increasing (Ward presentation cite here). There were large differences in λ among pods, with J and K pods showing the strongest evidence of growth. The posterior distribution of λ for the L pod revealed that values for λ <1 cannot be ruled out (Figure 3-1). The mean value of λ across J, K, and L pods was less than the recovery goal of 1.023. However, there was evidence that the long-term population growth rate of all pods may have *exceeded* recovery goals, as well as evidence that the long-term λ was less than one. The key result here is the uncertainty about the population's growth rate.

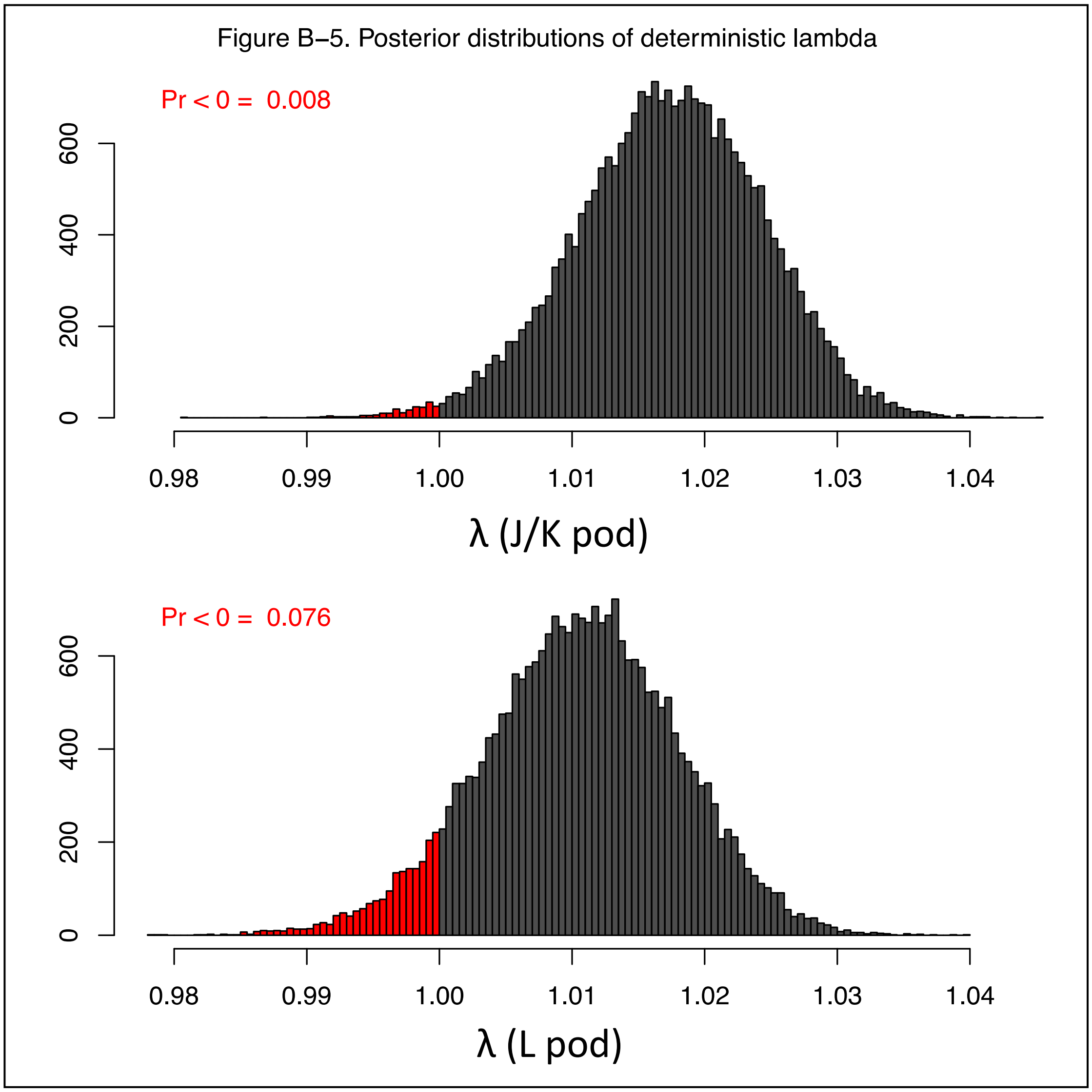

Figure 3-1. Estimates of the posterior distribution of population growth rate from Ward presentation at the second workshop[6]. "Pr < 0" is actually the probability that $\lambda < 1.0$ (the red area under the probability distribution), or the probability that the population may be experiencing a long term population decline.

The evidence that recovery goals may currently be met results in part from the assumptions required by the analysis of λ. The λ analysis only applies to time scales of decades and applies only to populations at long-term equilibrium for sex and age composition (but not for abundance). What this means is that the estimate for λ depends on a mix of sexes and ages that would be expected if the population were to grow largely unperturbed for a long period of time. So, in this analysis, there is no variation resulting from demography. The value of this approach is that it focuses on the long-term and does not respond to short term fluctuations in population composition.

[6] E. Ward, J. Ford, A. Velez-Espino. 2012. Comparison of SRKW and NRKW population dynamics; presentation at workshop 2; slide 8.

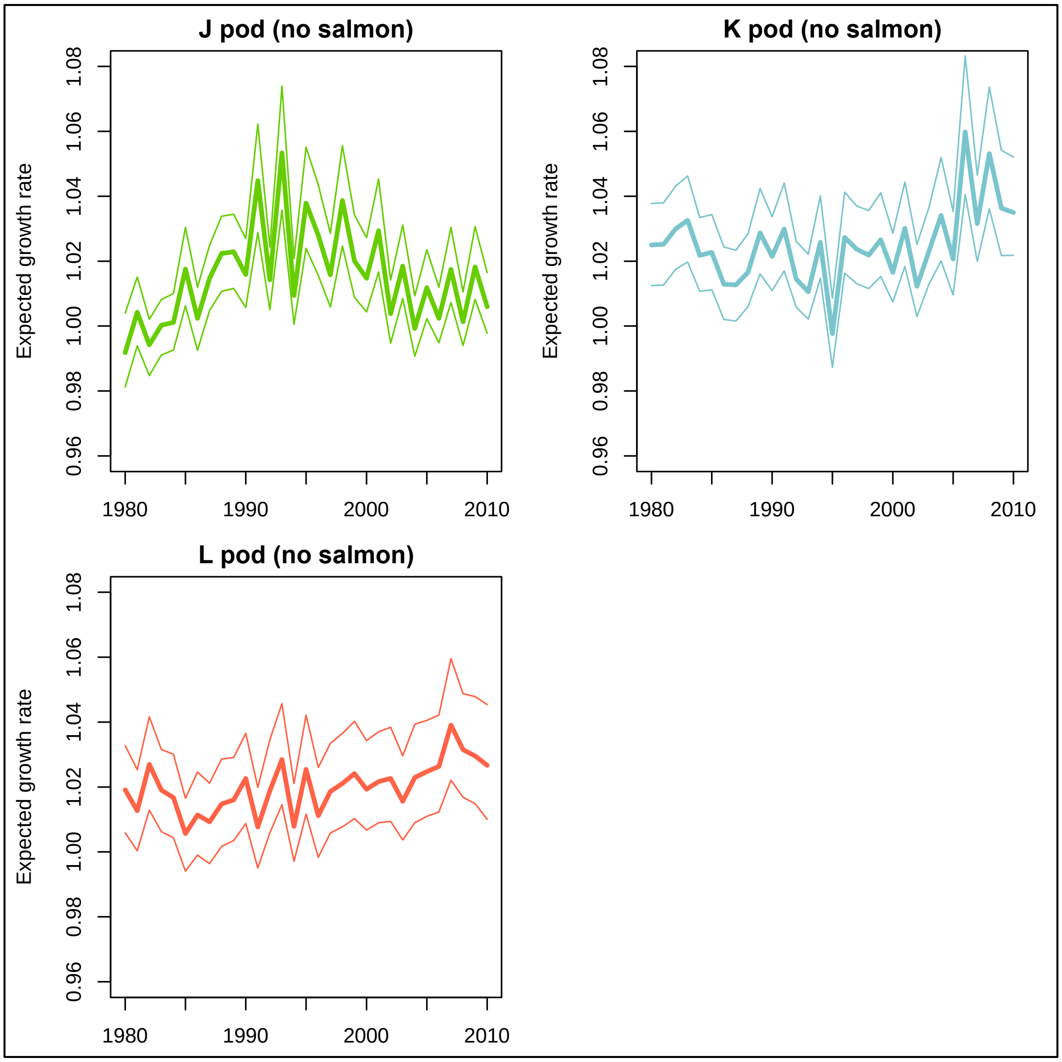

Figure 3-2. Growth rate of J, K, and L. The growth rate is the expected number of animals that survive from t to t+1 added to the expected number of births where the expectation is conditioned on the population age and sex structure. The expected survival and birth rates are determined just by the age and sex structure of the population, without any consideration of salmon abundance (hence the "no salmon" in graph titles).[7]

A focus on short-term dynamics revealed substantial annual variability in the growth rate of SRKW, some of which resulted from demography (Figure 3-2). The expected growth rates of K and L pod, growth rates that incorporated effects of differences in sex and age structure, have been increasing since the 1980s while the expected growth rates of the J pod increased to a peak in the mid-1990s, then declined. Despite this variability, the short-term analysis also showed evidence of strongly positive growth in all pods, particularly during the last decade when growth rates of L pod have accelerated.

The long-term population growth rate (λ) of Southern Residents is unambiguously lower than λ for the Northern Residents (Figure 3-3). These differences in λ result from clear differences in vital rates;

[7] E. Ward, J. Ford, A. Velez-Espino. 2012. Comparison of SRKW and NRKW population dynamics; presentation at workshop 2; slide 17.

Southern Residents have lower fecundities and survival probabilities relative to Northern Residents. Life expectancy of females showed large regional effects (37.8 SRKW vs. 44.9 NRKW). Expected number of offspring also differs markedly between regions (3.1 SRKW vs. 3.5 NRKW). Regional differences in strength of density dependence could not account for the observed differences in population growth rates. However, a skewed sex ratio in J and L pods toward reduced numbers of females (<40%) plays an important role in the regional differences in λ. The regional differences in λ observed in the current analysis are substantially larger than those found in earlier work that found virtually identical growth rates for the two populations (λ =1.0250 for SRKW, λ = 1.0256 for NRKW, Brault and Caswell 1993). Thus, it appears that regional differences in growth rates have existed over the last twenty years.

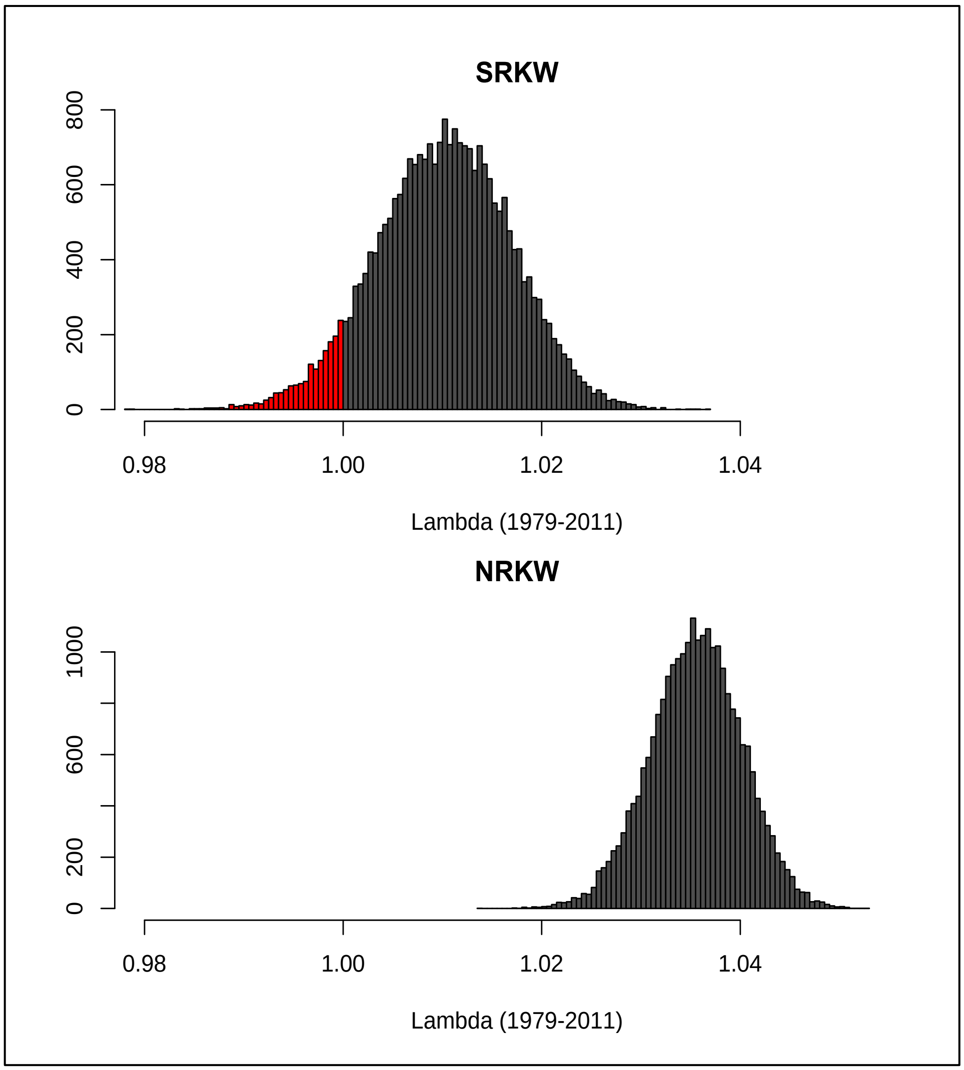

Figure 3-3. Posterior distributions of population growth rate for Southern and Northern populations of resident killer whales. The top graph represents the average λ for J, K and L pods.[8]

[8] E. Ward, J. Ford, A. Velez-Espino. 2012. Comparison of SRKW and NRKW population dynamics; presentation at workshop 2; slide 38.

Controls on population growth rate

Historic data provide insight into the factors that controlled the population dynamics of Northern and Southern RKW. An exhaustive model selection exercise showed evidence for differences in fecundity between Northern and Southern populations. The best-supported model included region and indices of salmon abundance as predictors of fecundity, but did not include a density effect. The effect of indices of salmon abundance did not depend on region--- the best model performed better than any model with an interaction term, suggesting fecundity of Southern and Northern populations responds in a similar way to the prey index. The second best model included male population density and region as predictors.

Models predicting survival from historic data were not easily interpreted. There were three way interactions among region, density dependence, and indices of salmon abundance, interactions that could not be understood biologically. Eliminating models with three way interactions failed to clearly isolate factors controlling survival. The best model showed a negative relationship between female density and survival for Northern Resident killer whales and an inexplicable positive (although weak) relationship between female density and survival of SRKW. The next best model contained a similar response to salmon for Northern and Southern residents and female-based density dependence for both. However, the effect of density dependence varied by region. Effects of female density on survival were far weaker in the southern population relative to the northern population.

The results of analysis of historic data complicate the interpretation of the mechanism presumed to be responsible for the correlation between salmon abundance and killer whale vital rates. The textbook mechanism for bottom-up limitation of predators by prey is that reductions in prey abundance retard the per-capita rate of consumption of prey by predators via their functional response. Reductions in per-capita rate of prey capture, in turn, cause reductions in survival and/or fecundity, thereby reducing population growth via the numerical response. This chain of logic implies that there are *two* ways that the growth of populations of predators can be accelerated: by increasing the supply of prey or by reducing the number of predators exploiting the prey. In both cases, per-capita rate of prey consumption should go up leading to enhanced fecundity and/or survival. If the classic mechanism prevails, then we should see support in predictive models of vital rates for effects of prey availability, i.e. the salmon indices, *and* the effect of predator density.

However, the effects of density for SRKW were difficult to interpret using the classical line of logic. It is not immediately clear why increases in male density should be more strongly associated with fecundity than increases in female or total density. The weak, positive relationship between SRKW females and survival is contrary to a mechanistic interpretation of functional response influencing the numerical response. The fact that density dependence was stronger in the northern population than in the southern population[9] suggests that the northern population should experience stronger bottom-up limitations as the population grows, a prediction that is contrary to observations. All of these difficulties of interpretation cast doubt on a simple, causal interpretation of the positive correlation between salmon abundance and killer whale vital rates. The absence of a clear signal from density lends support to the non-causal

[9] E. Ward, J. Ford, A. Velez-Espino. 2012. Comparison of SRKW and NRKW population dynamics; presentation at workshop 2; slide 59.

interpretation that salmon abundance is correlated with an unmeasured limiting factor that is not influenced by population density of killer whales.

Population size and demography

Evidence for a positive growth rate in populations of SRKW suggests that the population should be increasing, but trends in abundance show little change in population size, particularly during the last decade. This raises the question, why has the population remained small despite a positive growth rate?

The answer to this question appears to come from demography. A skewed sex ratio at birth favors males in the Southern Resident population and the K and L pods are 60% male. These changes in the proportion of females in the population cause the population to grow more slowly than would be expected if the sex ratio of pods were 50/50 male/females. In contrast, the proportion of females in the Northern Resident population has been increasing recently and in some pods exceeds 60% female. Differences in sex ratios between the Southern and Northern populations partially explain the differences in their rates of increase and in their abundance.

The primary cause for concern about the viability of the Southern Resident population is its small size. This concern motivated the panel to ask what is known about the historic size of the population. Demographic reconstruction showed that the largest known size was likely 96 animals in 1967[10], leading to the conclusion that the population size has not varied dramatically over the last 45 years. Genetic analyses[11] allow crude estimates of population sizes in the more distant past. These suggest that the current population may be orders of magnitude smaller than the ancestral population, but it is unclear if the “ancestral population” (10,000 – 40,000 years ago) consisted of SRKW or of all killer whales in the Pacific.

Synthesis

Understanding the current state of the population of SRKW and the forces that have shaped the current state provides insight into the need to take action to alter the future trajectory of the population. There were two results from the analysis of current status that are particularly compelling. First, analysis of the long-term population growth rate emphasized the importance of properly estimating uncertainty. Although the estimate of the mean λ was strongly positive, the possibility of growth rates less than 1 cannot be ruled out, nor can we reject the idea that long-term growth rates have exceeded recovery goals. Second, the absence of a clear negative feedback from population size to vital rates complicates the mechanistic interpretation of a positive correlation between vital rates and food supply. Classical theory in community ecology predicts that reductions in the number of predators or increases in the number of prey should produce similar responses at the population level. This finding raises doubts about the cause and effect relationship between salmon abundance and killer whale vital rates.

[10] Ford, M. and K. Parsons. 2012. Estimating the historical size of the southern resident killer whale population. Presentation at workshop 2, slide 4.

[11] Ibid. Slides 6-13.

3.4 Recommended Information and Analyses

No further analyses are recommended.

4.0 Feeding Habits and Energetic Needs of Killer Whales

4.1 Context

The apparent specialized diet of SRKW on Chinook salmon means that it is biologically plausible for reduced Chinook salmon abundance to cause nutritional stress and impede recovery of SRKW. NOAA, DFO and NGOs have undertaken considerable research to assess the mechanistic link between Chinook salmon abundance and the demographic dynamics of SRKW. Their research has sought to determine whale distribution, diet composition, metabolic requirements, and indicators of nutritional stress—and whether salmon abundance is low enough to cause such stress in SRKW.

Distribution: J, K, and L pods typically feed in the inland waters of Washington State and British Columbia (Strait of Georgia, Strait of Juan de Fuca, and Puget Sound) from late spring to fall (Bigg 1982, Ford et al. 2000, Krahn et al. 2002). They are known to visit coastal sites off Washington and Vancouver Island (Ford et al. 2000), and are known to travel as far north as Southeast Alaska (Frederic Sound), and as far south as central California. Winter and early spring movements and distribution are largely unknown but limited photo-identification data suggest they spend substantial time in coastal waters off the coasts of WA, OR and northern CA.

Diet (Species & Size Selectivity): Limited dietary information for SRKW suggests that they have a strong preference for large Chinook salmon from late spring to fall, and a secondary preference for chum salmon in autumn (Hanson et al. 2005, Ford and Ellis 2006). Other salmonids (coho, steelhead, sockeye, and pink) and other non-salmonids (herring and rockfish) do not appear to be consumed in significant numbers. Winter diets remain poorly described but are believed to be more diverse than in summer and consist of smaller Chinook salmon and greater numbers of non-salmonids (ling cod, dover sole, and halibut) than observed during the summer and fall. SRKW also have strong preferences for larger-bodied organisms, particularly in Chinook salmon, which tend to be more energetically dense prey. Selectivity by Southern Residents on different stocks of Chinook salmon is poorly known, an important uncertainty both in terms of understanding which Chinook stocks they rely on, and in terms of energy intake, because the energy density of Chinook varies among stocks.

Daily Prey Energy Requirements: The amount of Chinook salmon required by SRKW was estimated by NOAA using a bioenergetics model (Noren 2011) for three time periods (Oct-April, May-June and July-Sept) based on the composition of Chinook in the diet, daily prey energy requirements and time spent in inland waters. DFO also estimated the number of Chinook needed by Resident killer whales using the Noren bioenergetics model (Ford et al. 2010).

Nutritional Stress: Photographs of thin whales and observations of the “peanut-head syndrome” (loss of the nuchal fat pad behind the skull) in SRKW suggest that some individuals in some seasons are significantly emaciated. Such weight loss can arise from a variety of causes that range from infectious disease to chronic degenerative processes, but the most common cause in wildlife is poor nutrition. Body condition of marine mammals can range widely among individuals within a population, but little is known about the factors that influence body condition of wild whales. One study indicated that weight loss behind the skull ("peanut head") of gray whales (*Eschrichtius robustus*) is associated with lactation in adult females (Bradford et al. 2012), while another study concluded that body condition varies with the duration of the previous feeding season (Perryman et al. 2002). Thus an association has been made between nutritional status and body shape in baleen whales.

The presence of emaciated whales in the SRKW population that have subsequently disappeared indicates that some individuals in poor condition may have experienced nutritional stress, although it remains unclear whether it is a seasonal and frequently occurring phenomenon in SRKW. It also remains unclear exactly what caused the poor condition of these animals, and what the background rates of this syndrome are. Poor condition and nutritional stress could contribute to increased mortality or reduced fecundity of Southern Residents through a variety of mechanisms (i.e., direct starvation, increased susceptibility to trauma due to increased movements to forage, decreased resistance to infectious disease, mobilization of lipophilic toxic chemicals). Poor condition and nutritional stress could also decrease recruitment through changes in calving interval and calf survival. Indicators of nutritional stress in individual whales include behavioral, morphological, hormonal and reproductive changes that can be assessed with a variety of methods. However, prey sharing (documented to occur 76% of the time; Ford and Ellis 2006) complicates understanding of the effects of prey limitation on some individuals of the Southern Resident population, especially adult females that do more sharing.

4.2 Key Questions

Diet composition, foraging distributions and metabolic requirements of SRKW are not well described because the data are difficult to obtain. Considerable effort has been expended towards determining diet composition and selectivity, particularly on Chinook salmon. The panel was asked whether the approaches and methods used to estimate diet composition and selectivity were scientifically reasonable and whether these techniques could be improved. The panel was also asked to assess the conclusion that SRKW eat mostly Chinook salmon during the summer and fall in the Salish Sea.

In terms of the prey requirements of Southern Residents, the panel was asked to assess whether the bioenergetics modeling approach used to estimate energy needs was a scientifically defensible approach and whether there were additional refinements that could be made to improve these estimates of predatory demand on Chinook salmon in the Salish Sea. The panel was also asked to evaluate whether ratios of energy needed by Southern Residents to the energy available from Chinook salmon in the Salish Sea were a reasonable and defensible way to assess the adequacy of Chinook stocks for sustaining and rebuilding SRKW.

Last, the panel addressed whether behavioral, hormonal, or estimates of body condition were useful metrics for assessing nutritional stress in SRKW in relation to seasonal and inter-annual variation in prey availability.

4.3 Responses to Key Questions

Diets of Southern Resident Killer Whales

Diets of SRKW have been determined from scales and tissue recovered from salmonid prey that are broken up near the surface for sharing among individuals, from the stomach contents of dead whales, and from the prey DNA in fecal samples. These methods are solid and are state of the art. However, sampling is concentrated in the summer through autumn months, with little or no coverage in the winter months. The winter ecology of Southern Residents is unknown, and there is little or no information about diet composition and selectivity.

The majority of dietary data show that Resident killer whales have a preference for salmon, particularly large Chinook which appear to account for >80% of the diet from May-September. The general conclusion that SRKW consume primarily large Chinook salmon (ages 4 and 5 y) is reasonable and supported by the available information. However, it is conceivable that smaller Chinook may not be shared as readily and could be swallowed whole without much handling. Furthermore, some groundfish could be swallowed at depth without being brought to the surface, and would not be detected by scale and tissue sampling. Fecal DNA testing may overcome this potential sampling bias (although digestion may obscure the passage of DNA from some prey species).

The small numbers of samples obtained during the winter suggest a greater reliance on chum salmon and on demersal species in this season. The paucity of winter diet data limits the ability to assess the degree to which SRKW rely on chum salmon, smaller Chinook salmon, or other fish species during this potentially challenging time period.

Biopsy samples from some individuals in a small sample of years give indirect information on diet. Limited data on nitrogen stable isotope ratios in skin samples suggest that L pod may have changed its dietary trophic level of over the last decade. The isotope ratios also suggest that the diet trophic level of K pod varies seasonally. Fingerprints of lipophilic contaminants in blubber biopsies also provide insight into diets. Ratios of these contaminants found in the blubber of K and L pod match with similar ratios of prey species in California, suggesting that fish from California form a significant component of their diets (Krahn et al. 2007, 2009).

Though logistically challenging, future work on diet habits of SRKW should expand seasonally and include winter surveys. Further refinement of the currently employed methodologies and sampling designs are likely to show a more complex and diverse diet related to age, sex, pod and time of year than presently recognized. However, further diet studies are unlikely to change the fundamental finding to date that Chinook are the most important component of the SRKW diet. Instead, they should provide data needed to determine whether SRKW can adapt their foraging during times when Chinook are rare to consume alternate prey at rates that do not compromise their fitness.

Dietary analysis that determines the frequency with which species of prey occur in stomachs or fecal samples requires ~70 samples by season to accurately describe diet (Trites and Joy 2005). A sampling design should be implemented with a coordinated effort to collect the necessary numbers of samples. Additional insights into diets of SRKW can be obtained from killer whale blubber and skin samples through analysis of contaminant ratios, stable isotopes and fatty acids. Direct observations of predation by SRKW relative to potential prey sources can also contribute useful information about diets and preferences.

Energy needs of Southern Resident Killer Whales

The modeling approach used to estimate the food requirements of SRKW is reasonable and consistent with the models that have been developed for other species of marine mammals. The estimated energy requirements seem reasonable, though they reflect the uncertainty caused by combining multiple assumptions and parameter estimates.. They have been derived using the best available data, and can only be refined by incorporating better parameter estimates for such variables as body mass at age, activity, reproductive state (lactation), seasonal changes in body condition, and basal metabolic rates. Such model refinements would improve confidence in the estimates. Nevertheless, the numbers of fish that NOAA and DFO estimate that SRKW require are within reasonable limits.

In addition to refining model parameter estimates, seasonal variability in energy requirements still needs to be addressed. Photogrammetry data could be used to address seasonal changes in body condition, and its possible relationship with seasonal changes in metabolism due to differences in dive behavior and daily activity budgets. A mismatch in seasonal prey availability with seasonal energy requirements can have significant physiological effects on fecundity and susceptibility to disease. Photogrammetry data could also be used to investigate body condition changes in years of high versus low Chinook abundance. A systematic use of photogrammetry to evaluate seasonal and annual changes in individual whale body condition can provide key data to assess the nutritional status of SRKW relative to population recovery. However, this use of photogrammetry assumes that changes in condition can be causally linked to changes in individual reproductive success and survival.

Ratios of energy needs to energy available

The ratios of energy needed by SRKW to the energy available to them from Chinook are not particularly useful for understanding whether fisheries for Chinook salmon affect the population dynamics of SRKW. This is because there is no objective means to evaluate the biological significance of the ratios on the status of the Southern Residents. The forage ratios therefore do not provide much insight into prey limitation in SRKW. To do this requires a functional response that describes whale fitness or vital rates as a function of the supply-to-demand ratios. Without such a functional response there is no way to interpret the ratio (unless it is < 1 and clearly indicative of a prey deficiency).

Additionally, the comparison between the SRKW and other apex predators in other ecosystems is not well justified and, again, difficult or impossible to interpret. There are several reasons for this, the most important of which is that the predator demand component of the ratio should include the demands on Chinook salmon (or any prey) by the entire community of predators that feed on them. It is possible that killer whales consume a larger component of the Puget Sound Chinook stocks because there are fewer other important apex predators compared to other ecosystems.

This exercise in calculating ratios does not appear to provide any meaningful information about either the ecosystem or the biology of SRKW. Continuing to undertake this analysis is not warranted. Such analyses might provide some insights into the ecology of the Salish Sea ecosystem if directly comparable models were generated for the Salish Sea and other ecosystems (i.e. same assumptions, taxonomic resolution etc.). The ratios presented at Workshop 1 in September 2011 were derived from many disparate models with very different assumptions.

Nutritional stress

The available information on body condition of individual SRKW summarized in Durban et al. (2009) documented 13 members of the Southern Resident population in poor condition as detected by boat-based photographs obtained from May-September over the period 1994 through 2008. All but two of those individuals subsequently died. None of the individuals that died were recovered and examined, so definitive date and cause of death are unknown. However the implication from these data is that some SRKW have been nutritionally limited at certain times of year.

The data available on fecal hormone levels are not clearly indicative of nutritional stress in the SRKW population. The fecal thyroid hormone data presented in Workshop 1 showed seasonal patterns consistent across years in batched feces. Such a pattern is hard to interpret as the number of individuals and their age and sex samples were not presented. Although nutritional status can influence fecal thyroid hormone levels, other factors such as age, activity, day length, reproductive status and contaminant exposure will also affect these fecal hormone levels (Oki and Atkinson 2004, Ciloglu et al. 2005, Ross et al. 2007). It is thus not clear whether the seasonal decrease reported in fecal thyroid hormone levels indicates nutritional stress or a seasonal endocrine shift for other reasons.

Cortisol levels are indicative of activation of a stress response, which is a common physiological pathway that results from any stressor in addition to nutrition such as sound, boat traffic, or conspecific aggression. Thus, use of fecal cortisol as an indicator of nutritional stress is limited in an environment with considerable human activity.

Changes in social behavior may also result from changes in nutritional status. For example, group sizes of killer whales might change in response to changes in the availability of prey (Lusseau et al. 2004). However, mechanisms to explain such behavioral changes are unclear.

4.4 Recommended Information and Analyses

Diet analysis

A shortage of samples during winter is the biggest gap in diet studies of SRKW. Increased effort is needed to obtain winter samples (Nov-May). One approach is to satellite track tagged individuals to determine where fecal and tissue and scale samples can be collected

A second limitation of current understanding of killer whale diets is that tissues and scales recovered in the water column after food sharing are biased towards salmonids. More fecal sampling is needed to detect non-salmonids.

Third, fecal and blubber samples should be archived from future stranded animals in addition to stomach contents. These samples can be used for dietary analysis to compare results with those obtained from stomach content analysis. The full thickness of the blubber should be archived for future dietary analyses using fatty acids.

Last, using contaminant fingerprinting techniques hold substantial promise for improving estimates of SRKW diets based on the similarity between their contaminant fingerprints and the fingerprints of their available prey. More effort could be directly expended in these approaches.

Energetic needs

Satellite tagging of whales in late summer is needed to identify winter foraging areas and calculate activity budgets to better estimate the prey requirements of SRKW. In addition, increased analysis of foraging behaviors is needed to detect changes in activity budgets (proportion of time spent foraging, socializing, resting, travelling), movement patterns (frequency and duration of excursions outside of regular feeding areas), dispersion (spreading out if prey density is low), foraging success (lower catch per unit effort when prey availability low), and prey switching (increased predation on alternative prey if Chinook density low). However, the challenge will remain with interpreting changes in behavioral patterns as indications of nutritional (or other) stresses.

Nutritional status

Research designed to monitor nutritional status of SRKW should focus on: biopsy sampling to detect seasonal changes in blubber lipid levels; photogrammetry methods used by Durban et al. (2009) and Fearnback et al. (2011) to evaluate different width-length ratios; and longitudinal sampling to investigate seasonal changes in body condition in individuals, and at risk age and sex classes. Further, analysis of individual calving intervals, and of group sizes and association strengths could be assessed as measures of relative feeding conditions and payoffs to the predators.

5.0 FISHERIES AND PREY AVAILABILITY

5.1 Context

Historic vs. current abundances and marine distribution of Chinook: the "big picture"

At Workshop 1, Myers[12] presented "back of the envelope" calculations (based on cannery records and various assumptions regarding relationships between numbers of fish processed and cannery records) of historic (1890-1920) abundances of Chinook salmon in the mainland US, coastal British Columbia and the Fraser River. These estimates suggest that historic abundances were dominated by fish from the Columbia River (4.6 million), California's Central Valley (1.1 million), and Coastal BC stocks (Skeena + "Outlying Area" = 1.2 million), with the Fraser River (0.55 million) and Puget Sound (0.69 million) making substantial contributions as well. Historic fisheries were most heavily directed toward spring-run (usually stream-type juvenile life history) Chinook salmon due to their high fat content and excellent condition at river entry compared to later-returning fall-run Chinook (usually ocean-type juvenile life history), which enter freshwater at a more advanced state of maturity with lower fat content.

Contemporary abundances of Chinook salmon in the Pacific Northwest and California have been greatly reduced from these historic abundances and many Evolutionarily Significant Units (ESUs) of Chinook salmon are listed as threatened or endangered under the US Endangered Species Act. (One wonders if recovery of some of these Chinook salmon populations is limited by killer whales and increasing stocks of harbor seals and sea lions.) As noted by Myers, declines in spring-run fish have been dramatic in many river systems, in part because the historic spawning grounds of these fish are today often above impassable dams. Declines in abundance of spring-run fish have been particularly evident in California's Central Valley, in the Columbia River (Interior spring Chinook) and in Puget Sound. Coastal British Columbia populations from the Skeena and "Outlying Areas" also seem to have experienced alarming declines in abundance.

Associated with the declines in abundance have also been shifts in age structure of many populations toward younger age and smaller adults. Such shifts have ranged from fairly modest (e.g., Willamette River spring-run) to quite striking (e.g., California's Central Valley). In many of today's Chinook populations, age 5 adults are rare and age 6 fish are virtually non-existent, though historical records from the same populations indicate that age 5 fish were common and age 6 regularly present.

Recoveries of coded-wire tagged hatchery Chinook salmon in ocean fisheries have provided strong evidence that marine distributions vary substantially according to stock of origin. For example, Chinook salmon stocks south of Oregon's Cape Blanco (with the exception of Elk River) are "south-

[12] Myers, J. 2011. Frame of Reference: Understanding the distribution of historical Chinook salmon populations. Presentation at Workshop 1.

migrating" fish that are captured almost entirely from central Oregon through central California (Nicholas and Hankin 1989). Northern Oregon Coastal stocks, and most late-maturing Columbia River fall Chinook stocks are "far north-migrating" and are captured in fisheries in "outside coastal waters" off Washington, British Columbia and Alaska. Chinook stocks from Puget Sound and the Fraser River system seem to have north-migrating migration patterns, although more restricted than the far-north-migrating stocks, with ocean fishery catches made primarily from Vancouver Island through the Queen Charlottes and in Puget Sound. Finally, stream-type spring-run Chinook from the Interior Columbia system (and also the Fraser River) appear to have a non-coastal ocean distribution[13]. Marine fishery impacts on Columbia River spring Chinook are therefore very minor.

Recent trends in abundance and fisheries

At Workshop 1, Kope and Parken[14] summarized trends in abundance and fishery catches of Chinook salmon for various aggregates for the period 1979 to the present. The period begins with the first years of fisheries regulated under the 1976 US Fisheries Conservation & Management Act which established the Pacific Fisheries Management Council, and also is a period of time during which fisheries managers have relied very heavily on recoveries of coded-wire tagged hatchery fish to serve as indicators of exploitation history for many natural-origin Chinook salmon stocks. Comparing averages for 2001-2010 with those for 1979-1988 and considering stocks of likely importance to the SRKW, Kope noted that: (1) Fraser Early Chinook total abundance (terminal run + fishery impacts) has increased by about 36%, and terminal run size has increased by more than 100%; (2) West Coast Vancouver Island aggregate total abundance has decreased by 35%, but terminal run sizes have increased by about 19%; (3) Fraser Late Chinook total abundance has decreased by about 51%, but terminal run size has increased by about 38%; and (4) Puget Sound total abundance has decreased by about 38%, but terminal run size has not changed. Coast-wide, Kope noted an approximate 16% decrease in total Chinook abundance, but a concurrent 37% increase in ocean escapement to terminal areas. These shifts toward larger terminal run sizes reflect changes in management policies that have responded to: (a) unacceptably high ocean fishery exploitation rates on certain Chinook stocks; (b) legal requirements for catch sharing of certain stocks between ocean fisheries and terminal net fisheries (Native American and First Nations fishing rights); and (c) weak stock management policies designed to improve conservation status of listed populations of Chinook.

Also at Workshop 1, Long (WDFW)[15] provided a very detailed view of changes in marine fisheries catches that have taken place in the immediate vicinity of the summer feeding area of the SRKW, i.e. in the Strait of Juan de Fuca and around the San Juan Islands. Reductions in average ocean fishery catches in these areas have been dramatic, as a comparison between averages for 1975-1993 and 2005-2009 indicates: (a) from 23,621 to 3,177 salmon for Tribal troll, (b) from 52,737 to 4,728 in

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[13] Myers, J. 2011. Frame of Reference: Understanding the distribution of historical Chinook salmon populations. Presentation at workshop 1; slide 14

[14] Kope, R. and C. Parken. Recent Trends in Abundance of Chinook salmon stocks from British Columbia, Washington, Oregon, and California. Presentation at workshop 1

[15] Long, J. 2011. Southern U.S. Fisheries Affecting Chinook Salmon. Presentation at workshop 1

Areas 5&6 recreational fishery; from 14,138 to 3,677 in the San Juan Island recreational fishery; and bycatch of Chinook in Puget Sound pink and sockeye net fisheries declined from 40,960 to 2,664. Much of the recent (1994-2008) Puget Sound recreational catch of Chinook salmon has been dominated by Puget Sound hatchery fish, and recent dramatic reductions in ocean fishery impacts have apparently been primarily in response to listing of Puget Sound Chinook stocks as Threatened in 1999 (relisted in 2011).

Van Will and Adicks (Workshop 1)[16] summarized recent changes in abundance and fisheries for other salmon species that are present in diets of SRKW, though at less high prevalence (chum salmon) or very low prevalence (coho salmon, sockeye salmon, steelhead trout). Aggregate escapement of "inside southern chum" (a British Columbia group which moves between Vancouver Island and the mainland of B.C.) has averaged about 3.5 million (catch + escapement), with an apparent increasing trend from 1965 through 1999. Puget Sound fall chum enter the eastern Strait of Juan De Fuca and Puget Sound during September through December and are the most abundant run type (average run size of 1-2 million). Abundance of these fish has generally increased over the period 1968 through 2009.

At Workshop 1, LaVoy[17] presented a FRAM-based analysis of possible increases in kilocalories of Chinook salmon that might be generated from various levels of fishery closures, and at Workshop 2 Hagen-Breaux (WDFW)[18] presented a simplified assessment of the probable effects of fishery closures on total abundance (numbers) of mature age 4 and 5 Chinook salmon from "inland stocks" (Puget Sound + Fraser early run, Fraser late run, Lower Georgia Strait stocks). If all Chinook fisheries (Puget Sound, all US + Canadian) were closed, average increases in Chinook abundance were about 20% for all inland stocks combined, with increases to Fraser stocks of about 15%, but with only about 3.5% increase in Puget Sound Chinook.

Geographic distribution of Southern Resident Killer Whales

Barre[19] gave an overview of the NOAA Recovery Program for the SRKW at Workshop 1 and indicated that the range of this population extended from the Queen Charlotte Islands in British Columbia to central California, with the San Juan Islands in Puget Sound being a May-September "hot spot". Designated Critical Habitat (under the ESA) for the SRKW was defined as the US side of the Strait of Juan de Fuca, Puget Sound, and regions around the San Juan Islands to the Canadian border, and similar Critical Habitat has been defined in Canada under SARA. Ford presented evidence at Workshop 2[20] that the winter distribution of SRKW (L pod) may range as far north as

[16] Val Will, P. and K. Adicks. 2012. Trends in other known SRKW prey species. Presentation at Workshop 1.

[17] LaVoy, L. 2011. Chinook abundance and food energy available to Southern Residents. Which fisheries affect prey availability and to what extent? Presentation at Workshop 1.

[18] Hagen-breaux, A. 2012. Effects of West-Coast Fisheries on the Abundance of Mature Age Four and Five Chinook in the Salish Sea. Presentation at workshop 2.

[19] Barre, L. 2011. Southern resident killer whales recovery program. Presentation at Workshop 1.

[20] Ford, J. 2012. Assessment of Potential Food Limitation in Resident Killer Whales: How, When and Where. Presentation at workshop 2.

Pt. Ellis, Alaska, about 275 km north of the Queen Charlottes. Audience discussions following Bernard's presentation at Workshop 2[21] suggested that SRKW feed in California waters during winter months, but there were no detailed presentations of winter location observation data from California or Oregon waters.

5.2 General Comments

There is no question that contemporary abundance of Chinook salmon in the Pacific Northwest is small compared to historic abundance, with greatest reductions in abundance for spring-run Chinook from the Columbia River system. According to Kope, however, changes in coastwide abundance of Chinook populations over the past 30 years, the period of time over which status of SRKW has been closely monitored, has been relatively modest: an approximate 16% decline in total abundance, but with a corresponding substantial 37% increase in terminal abundance (returns to freshwater) due to increased restrictions on marine fishery harvests.

There seems no question that during the summer period, when the SRKW clearly spend almost all of their time in the areas that have been designated as Critical Habitat, the SRKW population must be foraging primarily on maturing Chinook salmon that are entering the Strait of Juan de Fuca or Georgia Strait on their return to freshwater streams, primarily those spawning in streams that enter Puget Sound and the Fraser River. Therefore, during the summer period it seems fairly clear that a rather limited set of Chinook populations and only the maturing fish from those populations would be directly exposed to predation by the SRKW, and only fisheries that impacted these stocks could affect prey availability during the summer period. If the summer period were the critical foraging period for SRKW, these observations would strongly argue for exploration of a possible link between SRKW performance attributes (net reproductive rates, survival rates) and terminal run size (i.e., mature fish only) of a very limited number of relatively well-identified Chinook salmon populations. Given the relatively small size and young age of most Puget Sound Chinook, particularly of hatchery origin, and the apparent inclination of SRKW to prefer larger age 4 and 5 Chinook, stocks of Fraser River Chinook would *a priori* appear to be the most vulnerable to SRKW predation and the most important stocks during the summer months.

The extent to which SRKW depend on Chinook salmon during the winter period seems poorly identified as is the geographic and temporal distribution of the SRKW during the winter period. It does seem reasonably clear that the SRKW are more often found in coastal areas (e.g., Washington coast) than in the designated critical habitat during the winter months. If the winter period is the critical period with respect to energetic needs, with the possibility of poor condition leading to increased death rates or decreased fecundity, and SRKW are indeed critically reliant on Chinook salmon during this period, then an argument could be made that other Chinook salmon populations might be available to SRKW during the winter. This would be despite the fact that these would typically be immature and smaller fish that might not be highly sought after based on selectivity

[21] Bernard, D. R. 2012. Mortality Rates and Birth Rates of SRKWs and CTC Abundance Indices for Fraser Stocks of Chinook Salmon. Workshop 2 presentation.

data presented at Workshop 1. Many Chinook populations would not be available even during this winter period, however, including immature fish from the northern Oregon coast and many far-north-migrating Columbia River stocks that are probably generally beyond the northern range of the SRKW until they return as mature fish on spawning runs. Chinook from the southern Oregon coast and California would be available only to the unknown extent that winter feeding activities are focused on Oregon and California waters.

5.3 Key Questions and Responses

1) Do any parts of these data need further clarification?

In the Panel's report following Workshop 1, substantial attention was devoted to: (a) discrepancies between estimates of Chinook salmon abundance generated using the FRAM model and the CTC-generated abundance indices for stock aggregates, (b) inconsistencies in statistical inferences concerning the effects of Chinook salmon abundance on SRKW "fecundity" (net reproductive rates) and survival rates based on the two alternative abundance indicators, and (c) concerns relating to whether Chinook salmon available to killer whales were generally mature/maturing as compared to immature fish. We also expressed concern about how selectivity functions had been developed and used to account for the apparent preference of killer whales for larger and older Chinook. Finally, we devoted considerable attention to some concerns about the FRAM model structure, in particular with respect to how natural mortality (and predation on Chinook salmon by SRKW and NRKW) was treated. We suggested that a 'competing risks of death' framework might provide a more informative setting within which to model the effects of fisheries on potential consumption of Chinook salmon by killer whales (and also other marine mammals).

Chinook salmon abundance indices

Following Workshop 1, there was substantial response to our concerns regarding the FRAM and CTC indicators of Chinook salmon abundance. Workshop 2 provided a major improvement in our ability to assess the reliability of abundance indices and their representation of Chinook available to SRKW. Several presentations were made that deliberately attempted to clarify the key assumptions and limitations of 3 abundance indices: FRAM, CTC, and a new Kope-Parken index. Specifically, Ward and co-authors[22] presented revised logistic regression analyses relating the Kope -Parken run reconstruction-based measures of terminal run size and total ocean abundance metrics to SRKW "fecundity" and survival rates; Hagen-Breaux presented a simplified application of FRAM (as noted above); and LaVoy[23] presented a useful overview and contrast of the FRAM, CTC, and Kope &Parken procedures. With respect to availability of Chinook salmon stocks to SRKW in their summer range,

[22] Ward, E. C. Parken, R. Kope, J. Clark, A. Velez-Espino, L. LaVoy, J. Ford 2012. Exploring sensitivity of the relationship between salmon abundance indices with killer whale demographics. Presentation at Workshop 2.

[23] LaVoy, L. 2012. Comparison of methods for Chinook abundances using CWT Run Reconstruction, PSC Chinook Model, and FRAM. Presentation at Workshop 2.

the Kope-Parken metrics of terminal abundances seem more transparently appropriate than the original FRAM-based metrics. It is unclear how these metrics might relate to prey availability during the winter months as extensive information would be needed on both the coastal marine distribution of various Chinook stocks during winter months and on the coastal marine distribution of SRKW, both of which appear very poorly understood. Based on LaVoy's presentation, it was not clear that the CTC-based abundance indexes of stock aggregates available for specific fisheries in specific geographic areas would be an appropriate metric for evaluation of the availability of Chinook to SRKW. Viewed from that perspective, the "inland" FRAM-based abundance measures seem more appropriate than the CTC-based aggregate-stock indices. We recognize, however, that Ward's presentations in Workshop 2 suggested that effects of Chinook abundance on "fecundity" and survival rates were relatively consistent between CTC abundance indices (WVI, NBC) and the Kope-Parken terminal abundances whereas they were not between FRAM and the Kope-Parken metrics.

We also note that aggregates of terminal run sizes and/or total ocean abundance for stocks reasonably considered to be available to SRKW may still be problematic measures of availability due to age-composition issues as they relate to size-selective foraging by SRKW (see Selectivity below)

Mature vs. immature Chinook salmon

The use of the Kope-Parken terminal run size estimates as a metric in Ward's logistic regression analyses, and in some of his subsequent predictions of changes in SRKW population growth rates due to elimination of fisheries[24], reflects a positive response to our conjecture that, at least during the summer period, SRKW must be intercepting and primarily consuming maturing/mature Chinook salmon en route to their freshwater spawning grounds. As noted above, however, it is conceivable, even perhaps likely, that abundance of Chinook salmon during winter months is more critical to successful reproduction and survival of SRKW. If so, then Ward's use of Kope - Parken's estimates of both terminal run size and terminal abundance + fishery catches seems a worthy approach to address this key uncertainty.

Size selectivity

The concerns expressed by the Panel regarding the "data" used to fit age/size selection curves did not receive much attention at Workshop 2. There is no dispute from the Panel that SRKW appear to prefer larger and older Chinook, but that is quite a different issue from accurately describing this tendency via selectivity functions that might in turn be applied to size- or age-structured abundance estimates for different Chinook salmon stocks. If the "real" selectivity functions are similar to those presented at Workshop 1, then, for all practical purposes, SRKW will consume only age 4 and older fish. In many early-maturing Chinook salmon stocks (e.g., Puget Sound hatchery stocks), age 3 is often the dominant age at maturity. Therefore, maturation schedule of individual

[24] Ward, E. 2012. Quantifying fishing impacts on past and future killer whale growth rates. Presentation at workshop 2.

stocks would appear critical with respect to whether or not abundance of particular salmon stocks could theoretically be related to SRKW dynamics or not. Size-selective foraging by SRKW could mean that very abundant, early maturing stocks passing through Puget Sound en route to their spawning grounds could be unimportant compared to much lower abundance stocks with later mean age at maturity and larger mature size. (Note: Ken Warheit, WDFW, has tentatively agreed to give a presentation relating to this topic at Workshop 3.) Although size-selective foraging issues were not as prominent in Workshop 2 as they were in Workshop 1, they remain highly relevant in the Panel's judgment. In particular, the Panel feels that it is important to better define the degree to which SRKW consume age 3 Chinook. Comparisons of age composition in SRKW feces or surface-collected samples - while SRKW are in their summer habitat - should be compared with mature age composition of stocks passing directly through the Puget Sound Critical Habitat. (Note: Steve Latham. Pacific Salmon Commission, in his post-Workshop 2 comments, correctly observed that comparison of age composition of Chinook in SRKW samples with test fishery age composition is not appropriate due to size selectivity in the test fisheries themselves.)

Competing risks of death framework

In our report following Workshop 1 (Hilborn et al. 2011), the Panel indicated that a 'competing risks of death' framework might have considerable heuristic value for developing a better conceptual understanding of the joint dynamics of Chinook salmon predators (fishermen, SRKW, NRKW, harbor seals, sea lions) and their prey. Among other things, we showed that, under an assumption that killer whales consume an approximately constant number of Chinook salmon, the force of mortality associated with killer whales (and possibly also the forces of mortality for other pinniped predators) likely increases dramatically as abundance of Chinook salmon decreases. In contrast, according to modern abundance-based management of Chinook fisheries, the expectation of death from fishing (exploitation rate) associated with fishing should be roughly constant at all levels of Chinook salmon abundance, though with small "jumps" at 0.5 and 1.0 levels of abundance indexes. These very basic observations suggest that "natural mortality" (predation from all non-human sources + all other natural causes of death) is quite unlikely to be independent of Chinook salmon abundance, as current models (like FRAM) assume. Furthermore, the probable effects of eliminating fishing as a cause of death, expressed as an increase in survival rate of Chinook salmon, must also surely change, perhaps dramatically, as Chinook salmon abundance changes. Given the potential rates of consumption of Chinook salmon by the SRKW generated by Ford during his Workshop 1 presentation[25] (67,000 – 81,000 Chinook during the months of July and August, with range of from 342,000 – 410,000 Chinook per year assuming 70% of diet is Chinook), and conjecturing similar consumption of Chinook salmon by the NRKW, it is easy to imagine that the force of mortality associated with killer whales at low Chinook salmon abundance may be quite large, especially if Chinook abundance is measured by those populations that are actually available to SRKW and of appropriate size/age (selectivity).

[25] Ford, J.K.B., Brianna Wright, & Graeme Ellis. Preliminary estimates of Chinook salmon consumption rates by Resident killer whales. Presentation at workshop 1, Slides 13 and 14.

At Workshop 2, Preikshot and Perry[26] presented Ecopath with Ecosim (EwE) modeling results that appear closely related to the competing risks of death framework that we recommended, although they apparently reflect analyses originally carried out for another purpose within context of a Strait of Georgia EwE modeling exercise. First, they correctly noted that the force of fishing increased through the early 1980s, when it was perhaps 9-10 times the magnitude of the force of natural mortality on Chinook, whereas during the period 2000-present, the force of fishing had become very much less than the force of natural mortality, which had approximately doubled (slide 10 in their presentation). These changes presumably reflect the dramatic post-FCMA reductions in fishing and the corresponding rapid increase in pinniped abundance in this area. Preikshot and Perry also suggested (slide 13) that simulated Chinook salmon mortality (force of mortality) in Georgia Strait associated with pinnipeds was well below that of killer whales for the period 1960-1985, whereas during the period 1990-2010 it was roughly comparable to that associated with killer whales. Although we cannot judge the analytic merits of their results based only on what was presented, the pattern of increasing natural mortality for Chinook salmon does seem plausible. However, it is important to note that mortality rates in EwE are sensitive to the predator-prey interaction assumptions. Nevertheless, the EwE results suggest that developing a competing risks of death model for Chinook could provide important insights into possible temporal patterns of Chinook salmon mortality, as well as what role fishing has played in those patterns.

2) Are the methods employed to predict salmon abundance by stock in specific times/places scientifically valid?

As LaVoy pointed out in Workshop 2[27], only the FRAM model makes any attempt to model the seasonal abundance of Chinook salmon in specific times/places. The CTC model and the Kope-Parken run reconstruction estimates of total abundance are probably best thought of as projected pre-season abundances, prior to the beginning of the annual fishery cycle.

Our understanding is that the FRAM seasonal abundances for various stocks are based on CWT recovery data from the late 70s when ocean fisheries were much less restricted than current fisheries so that it was reasonable to conclude that the ocean catch distribution of CWTs from a given stock probably provided a reasonable picture of a stock's geographic distribution through time. Contemporary fisheries, which have extensive time/area closures, would not provide useful information on ocean distribution patterns based on CWT recoveries. Whether or not the "historic" (late 70s) ocean distribution patterns for various stocks can be reasonably assumed to apply to contemporary management is an open question that has in part motivated on-going fishery-independent GSI-based surveys of salmon off Oregon and California (e.g., Goldenberg and Fitzpatrick, 2011).

[26] Preikshot, D. and I. Perry. 2012. Interactions between marine mammals and chinook salmon in a Strait of Georgia ecosystem model. Presentation at Workshop 2.

[27] LaVoy, L. 2012. Comparison of methods for Chinook abundances using CWT Run Reconstruction, PSC Chinook Model, and FRAM. Presentation at Workshop 2.

For many stocks, existing CWT recovery data does provide a moderately good basis from which to judge whether or not certain stocks would likely be found within the SRKW winter "range". Among other things, these data suggest, for example, that the far-northern-migrating Chinook stocks (including those from the Northern Oregon Coast, NOC) would likely not be present in substantial numbers within the range of the SRKW during the winter months and they would very clearly not be available during the summer months as they would have no reason to enter the Strait of Juan de Fuca or Puget Sound en route to their spawning streams as maturing fish. We note that NOC north-migrating Chinook were included as part of the "fall" and "north" groupings in Ward's Workshop 2 logistic regression[28]. (See also comments from ADFG in reference to Workshop 2 presentations[29].)

3) Are there improvements to the methods you would suggest?

Stocks such as NOC (and also many Columbia River Chinook stocks), which have far-north-migrating ocean distributions, are probably not available to SRKW during winter months. Or, if they are available, generally the smaller and younger fish would be present. Therefore, their total abundances should be subtracted from those of north-migrating and fall groupings used by Ward and the logistic regression analyses should be run again to determine if previous patterns still emerge. Those stocks that would seem most likely to be "available" to SRKW during the winter are those from Puget Sound and ocean-type Fraser River stocks, especially the Harrison stock. During summer months, the primary available stocks would seem to be maturing fish from Puget Sound and Fraser River stocks (all types). Bernard[30] attempted to select a set of "biologically meaningful" stocks that might be available to SRKW before engaging in statistical analyses. This approach, at a conceptual level, seems preferable to the extensive "exploratory" and/or "data-mining" analyses presented by Ward at both Workshops 1 and 2. The objection that one might raise to Bernard's actual analyses, however, is that they appeared to have focused exclusively on the summer foraging period. As noted previously, it is quite possible that winter availability of Chinook is even more important for SRKW survival and reproduction. If so, a broader set of stocks should be considered than in Bernard's presentation. The possibility that SRKW may spend considerable time off California during winter would obviously be of great importance in selection of appropriate stock groupings.

4) Are the methods employed to predict the reduction in salmon abundance by stock in specific times/places scientifically valid?

If terminal run size is used as an explanatory variable in a logistic regression model, then it is inappropriate to just "scale it up" by 20% in an attempt to account for elimination of fishery

[28] Ward, E. C. Parken, R. Kope, J. Clark, A. Velez-Espino, L. LaVoy, J. Ford 2012. Exploring sensitivity of the relationship between salmon abundance indices with killer whale demographics. Presentation at Workshop 2. Slide 15.

[29] Carlile, J., D. Bernard, J. Clark. 2012. Alaska Department of Fish and Game Comments Relative to Presentations at Southern Resident Killer Whale Workshop Two. On NOAA Fisheries website.

[30] Bernard, D. R. 2012. Mortality Rates and Birth Rates of SRKWs and CTC Abundance Indices for Fraser Stocks of Chinook Salmon. Workshop 2 presentation.

impacts. This device will exaggerate, perhaps significantly, the expected increase in terminal run size (mature fish only - the units with which the logistic regression parameter was estimated) that would be expected in the absence of fishing because the scaling up is based on ocean catches that include immature as well as maturing fish. Consultations with LaVoy, Kope, and Parken could provide a more realistic value for such generic "scaling up" of terminal run sizes based on current fishery impacts. Alternatively, if the total abundance metric is used as the explanatory variable, then perhaps a 20% scaling up would be more appropriate.

5.4 Recommended Information and Analyses

- Further discussion of all available information on winter distribution of Chinook salmon stocks, including CWTs recovered in AK fisheries above the range of SRKW, possible incidental catches in midwater trawls, etc..

- Further discussion of existing information on winter distribution of SRKW, with particular focus on frequency of observations off Oregon and northern California. It seems likely that marine mammal observers in at least Newport, OR and Monterey, CA, may take relevant photos, even during the winter months.

- Update fecundity/survival logistic regression analyses by including (i) some measure of pinniped abundance (weighted according to conjectured average daily intake for harbor seals vs sea lions), (ii) NRKW abundance, and (iii) an improved aggregate of Chinook stocks "most likely to be available to SRKW during the summer and/or winter months". If possible, chum salmon should also be included subject to the same thoughtful consideration of the particular stocks that may be available and thus important.

- To evaluate the sensitivity of SRKW responses in the current suite of models, update projected SRKW abundance and growth rates using a wider range of fishery scenarios. Instead of exploring the consequences of "eliminating" fisheries independent of future Chinook abundance, it would be valuable to also explore the effects of reducing fisheries only during those projection years in which simulated Chinook abundance falls below some critical level (say, <50% of average terminal run sizes of appropriate stocks over past 20 years). Results from such simulations could be compared to comparable results for the "absolutely no fishing" scenario. These sensitivity analyses have already been conducted since workshop 2, and would be worth presenting at workshop 3.

- Explore the implications of the competing risks of death framework (Quinn and Deriso 1998) for capturing the interactions among competing predators, in the context of potential expected benefits to SRKW due to reduction / elimination of fishing at different relative abundances of Chinook salmon. This exercise would not require modification of a complicated model like FRAM, but could instead be done at a very simple, heuristic level.

The intent would be to calculate the change in survival rate of Chinook salmon due to reduction/elimination of fishing at different levels of abundance of Chinook salmon.

6.0 PROJECTED FUTURE STATUS AND RECOVERY

6.1 Context

The preceding sections of this report highlight the reasonably strong evidence that SRKW population growth has been clearly positive over the past several decades and that recent growth rates are near or at recovery goals for some SRKW pods (Section 3.0, Status and Growth Rates). However, the SRKW population is also relatively small ($N < 100$) and potentially subject to interacting stochastic effects that make future population status and recovery difficult to predict (Lacy 2000). Regardless of these difficulties, fishery decisions still need to be made, and these decisions could have important biological and social implications. It is therefore critical that the scientific approach to population viability modeling is subject to as much scrutiny as possible by challenging the data, assumptions, and methods used in their development.

We separate this section into two somewhat separate issues of: (1) projected future status based on population viability models; and (2) assessment of recovery to non-threatened status based on a broader suite of information. Our review of projected future status issue is structured around two particular Key Questions that were asked of the Panel. Key Question 1 focused on the past by asking that we examine the methods used to establish historical relationships between salmon abundance and killer whale survival and birth rates. Other sections of this report review SRKW population growth rates, the biological justification for linking salmon to SRKW nutritional status, and fishery effects on salmon available to SRKW. Therefore, we looked specifically at how this historical information has been used (or not) to estimate population model parameters for salmon effects on SRKW dynamics. Key Question 2 focused on the future by asking that we review the basis for projecting this model forward to assess future status and recovery of SRKW under alternative salmon abundance scenarios. Projecting modeled SRKW abundance forward in time, although technically simple, involves a separate suite of assumptions and is, therefore, far more uncertain than fitting those models to past abundance data.

6.2 Development of Population Model to Forecast Future Status

Projections of future status of SRKW requires a quantitative population dynamics model for which parameters have been reliably estimated from historical data, along with scenarios for how these parameters might change in the future.

Key Question 1. Are the methods employed to evaluate the relationship between salmon abundance and SRKW (and/or NRKW) fecundity, survival and population growth scientifically reasonable? Do you have any additional analyses or specific suggestions to improve the methods?

The methods for evaluating relationships between salmon abundance and vital rates of SRKW are scientifically reasonable given the problem at hand and limitations of the available data. Nonetheless, the demographic modeling and estimation techniques involve a typical set of issues among which we address potential risks around the observational study design and choices of independent variables.

Observational study design: Although there is considerable individual-level evidence showing that Chinook salmon are important prey for SRKW, there is limited mechanistic understanding and empirical evidence clearly linking specific Chinook salmon populations to SRKW population growth rates. Such information can only be obtained via controlled experiments in which most confounding factors are held constant. Obviously, SRKW growth and salmon abundance data are observations of uncontrolled events obtained from an unknown sampling design. Such observational study designs pose a high risk of incorrectly assigning causes to correlations, result in relatively weak inferences, and are typically considered more useful for hypothesis generation (Schwarz 1998).

Choice of independent variables: The model fitting methods presented in the workshop focused on explaining variation in survival and fecundity of SRKW's with covariates based on various aggregated indices of abundance of Chinook salmon. There are other factors that could have been examined, including changes in other prey (e.g., chum salmon), contaminants, boat/whale-watching traffic, increasing food competition with other marine mammals, and incidental mortality[31]. Over the course of the two workshops, participants presented and commented on how many of these alternative potential factors could also cause changes in SRKW growth rates. In follow-up analyses requested by the Panel after Workshop 2, some of these alternatives (e.g., marine mammals), also appear to correlate with SRKW survival.

The above issues are relatively common in ecological modeling for a wide range of applications, including population viability and fisheries assessment. From the information provided, the Panel concluded that the approaches are reasonable, but could possibly be evaluated more critically given the importance of the decisions for which the models will be used. In particular, we feel that the above issues warrant more critical evaluation of the model than what is provided in model selection criteria like AIC. Other approaches such as cross-validation, model stability tests, and retrospective/prospective analyses can help determine whether the "best" models are robust to subsets of the original data. Posterior predictive checks could be used to assure that the models provide adequate fit to the original data.

6.3 Projection of Future Status

Key Question 2. Are the methods employed to evaluate the viability of the SRKW under alternative assumptions about future salmon abundance scientifically reasonable? Do you have any specific suggestions to improve the methods?

Projections of future SRKW population status were performed using stochastic individual-based models, which are commonly used for population viability analyses (PVA; Lacy 2000). A critical issue in assessing individual-based PVA models is to determine whether the distribution of future population size adequately reflects the stochastic processes likely to influence growth/decline of small populations. For populations the size of SRKW ($N < 100$), the three most important stochastic processes to represent in the PVA model include: breeding success as reflected by calving probability, stage-specific survival rates, and the sex ratio at birth. Although these processes are modeled independently, they could potentially operate synergistically to have either positive or negative consequences for SRKW growth. For example, a temporarily low birth rate could, by chance, combine with an altered sex ratio at birth to depress short-

[31] Note that Ward et al. (2009) did look at several of these effects on fecundity and found little correlation.

term growth rates, as well as to disrupt the breeding structure and age-distribution for a considerable time into the future. As noted above with Key Question 1, the methods employ a reasonably standard approach to PVA. However, the Panel has some concerns that the uncertainty regarding future abundance has been under-represented in the PVA models, in particular involving processes of calving probability, stage-specific survival, and sex ratio at birth.

Calving probability: The fecundity $f_{a',t}$ and survival rates $s_{a,t}$ are derived via logistic regression, e.g, $\left(logit\left(f_{a',t}\right) = \mathbf{X_t}\beta^{\mathbf{F}}\right)$, so the total process variance in the forecasting model is embedded within future salmon abundance, the parameter uncertainty for $\beta^{\mathbf{F}}$, and the binomial variation in total births. It is therefore difficult to show this total process error explicitly in a single parameter like σ^2_{proc} , which cannot be estimated directly. The Panel feels that some of this process uncertainty is under-represented. For example, Figure 6-1 is taken from the Ward et al. (2009; J. App Ecol) paper estimating effects of prey on SRKW and NRKW fecundity. Fecundity may or may not still be modeled this way, but it helps to illustrate a couple of our concerns about process errors in the forecasting model. Figure 6-1 shows the posterior distribution of predicted SRKW births (i.e., $\sum f_{a',t}$), which depend via a logistic model on the WCVI abundance index and female age. If births are measured exactly (which they are apparently not), then this figure shows that process error in births is under-estimated because the (+/-) 2 std error intervals do not include about half of actual births and some fall seriously outside the range. Predictions for lower observed birth values prior to mid-1990s also seem biased high. Logistic regression coefficients for small sample size (n<500) are typically biased high, but this seems like more than what is expected. In any case, the variability shown in the plot represents the combination of the above-mentioned factors, which seem, in total, to under-estimate the actual process variation in the data. Because there is no observation error assumed here, this variation should be encompassed by the posterior predictive distribution indicated by the dotted lines. Figures like Figure 6-1 should be provided for all estimated relationships to help lend support (or not) to model projections.

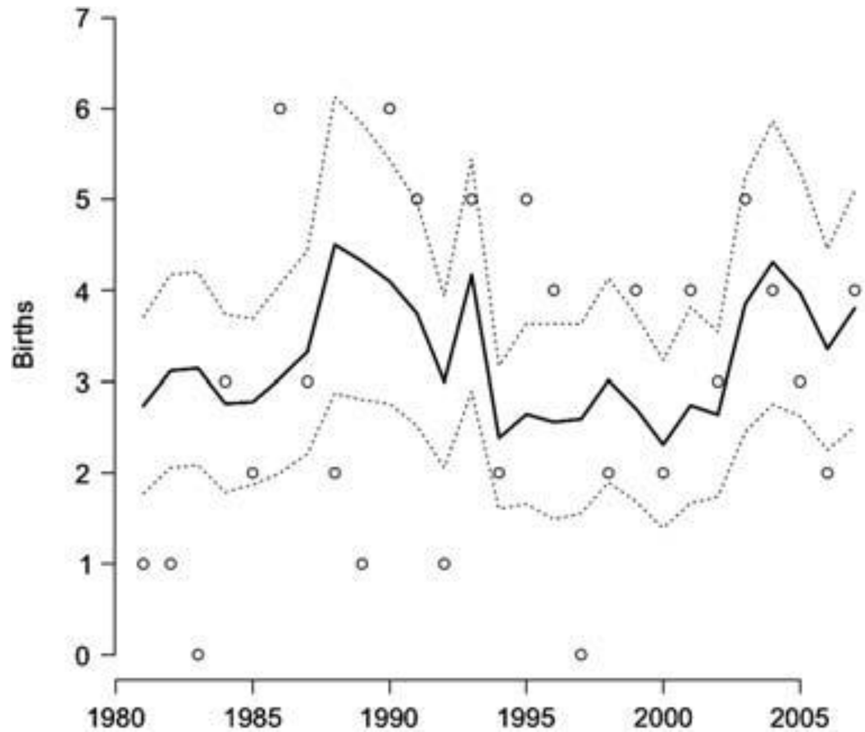

Figure 6-1. Posterior distribution of predicted SRKW births. Source: Ward et al. (2009)

Stage-specific survival: In the PVA models, Chinook salmon abundance is assumed to affect SRKW annual stage-specific survival rates via a similar logistic regression model as described above. As noted in several sections of this report, there could be a range of factors that also correlate with SRKW survival, which means that ignoring the dynamics of these processes also under-estimates process uncertainty in future survival.

Sex ratio at birth: In the projection models, sex ratio at birth is assumed constant at either historical 45 female:55 male or expected 50 female:50 male. Treating either one as constant in the future under-represents this component of process uncertainty since it is likely that the ratio will continue to fluctuate. In fact, the small number of SRKW births alone will likely ensure that the variability in sex ratio will continue to be high due to small sample effects on the binomial variance. Sorting out whether the observed sex ratio is the result of small sample effects or is possibly a trend would be helpful for interpreting existing relationships as well as future projections.

Under-representing uncertainty in population projections is unfortunately easy to do because of our limited understanding of the causes of variability in population processes. However, for PVA modeling of SRKW, the Panel feels that the current approach could be improved, but probably not in a substantial way. Adopting a fully Bayesian hierarchical approach would allow for propagation of several types of uncertainty, including the possibility that the sex ratio follows a trend, is related to abundance, or depends on population structure.

6.4 Assessing Recovery

Assessing potential recovery of SRKW is somewhat arbitrary: there are several choices for recovery criteria; several metrics which might indicate performance related to those criteria; different probabilities of meeting the various criteria; and many alternative scenarios (fishing and ecological) for which these metrics might be generated.

Growth rate criteria: The weakness of the growth rate metric of SRKW population recovery is evident in the population viability analyses. Based on NOAA's 50-year projections, the cumulative probability of downlisting (i.e., when 2.3% growth occurs over 14 years) is never greater than 0.6 even when the total population reaches > 250 animals (187% cumulative growth). Based on existing classifications of killer whale abundance, such an increase goes from Rare-Uncommon to Common. (Forney and Wade 2007). These projections are also probably optimistic (e.g., no density-dependence, 20% increase in Chinook, true causative relation, no other changes in mortality/fecundity), which suggests that the choice of 2.3% growth rate as a downlisting criterion should be re-assessed.

If the 2.3% growth rate is retained as a recovery criterion, then perhaps the probability of achieving this rate should be decided. For instance, based on analyses presented at Workshop 2, the posterior distribution of λ, which includes data spanning >28 years, offers some evidence that this recovery goal has been met (Figure 3-3). There are, of course, caveats to this conclusion, notable among them that the sex and age structure of the population did not match the long-term expectation, as well as the complementary evidence that the population is actually declining (i.e., $\lambda < 1.0$). The strength of the analyses presented to the Panel is in computing its posterior distribution of λ and in so doing, revealing the uncertainties that accompany estimates of the population growth rate. Both long- and short-term analyses showed a substantial weight of evidence in the right tail of the probability distribution of growth rates where $\lambda > 1.023$, indicating that historic rates exceeding recovery criteria cannot be ruled out. These uncertainties will not go away, which means that, at some point in the future, decision-makers will need to choose a probability of achieving the downlisting objective anyway.

Abundance-based criteria: Abundance-based metrics may be more reliable in this case mainly because abundance is directly measureable and there are at least 3 independent measures or indicators of historical SRKW population size (Section 3.0, Status and Growth Rates). The difficulty, of course, is choosing an abundance threshold for downlisting the population. Although historical SRKW population size remains uncertain, the historical reconstruction (96-117 whales)[32] and comparisons to other killer whale populations suggests the population may have always been Rare-Uncommon.

Projection scenarios: The scenarios chosen to establish recovery potential and metrics have a strong influence on perceptions about the efficacy of alternative recovery strategies. Fishing scenarios, for instance, assumed constant mean Chinook abundance coupled with a de-trended, auto-correlated random walk. An auto-correlated random walk is a reasonable choice for modeling population dynamics as a 'black box" in which future Chinook abundance retains some memory of recent past abundances. In fact, auto-correlation in Chinook abundance indices was demonstrated in Bernard's Workshop 2 presentation

[32] Ford, M. and K. Parsons. 2012. Estimating the historical size of the southern resident killer whale population. Presentation at workshop 2, slide 4.

(cited earlier). However, as noted in the presentation, some of the apparent auto-correlation is an artifact of the method used to compute the indices so the projections should be adjusted appropriately.

Although the historical Chinook abundance indices are easily explained by an auto-correlated random-walk structure, the future abundance of Chinook is not guaranteed to follow a similar process, especially if the future scenario proposes to alter the management regime. Section 5.0 (Fisheries and Prey Availability) describes the uncertainties involved in projected salmon abundance.

Future scenarios also cannot incorporate effects of other marine mammals, chum, etc. without a model (or models) to project those future abundances, even if some of those factors are also correlated to SRKW fecundity or survival. Adding these components would rapidly expand the range of uncertainty in future prey available to SRKW.

Key Question 3. Based on your expert opinion, what level of confidence would you assign to the conclusion that predicted changes in Chinook salmon abundance caused by fisheries affect the population growth rate of the SRKW?

Confidence - LOW to MEDIUM. The Panel recognizes the considerable progress that has been made in understanding how salmon abundance affects killer whale population dynamics. The analyses performed to date on the relationship between salmon abundance and killer whale fecundity and survival have likely extracted as much information as can be gained from the historical data. The results certainly lend credibility to the hypothesis that SRKW growth rates and abundance are related to salmon abundance, but they also raised many questions about specific mechanisms, the chance of spurious correlations, alternative hypotheses, data gaps, and expected changes in Chinook availability. In the absence of controlled experiments, we will continue to rely on observational data, and therefore will remain unable to clearly distinguish among these alternatives in the future.

Key Question 4. Based on your expert opinion, are there additional analyses that could be conducted on the SRKW population or other resident killer whale populations to better understand the relationship between salmon abundance and killer whale population viability?

The Panel suggests that simulation analyses be performed to determine whether any magnitude of realistic increase in salmon fisheries would have a detectable effect on future killer whale growth rates. Although the population viability analyses show potential improvements in SRKW growth rates (i.e., differences in medians), the presence of considerable process uncertainty in salmon abundance, as well as killer whale vital rates, implies that anything but dramatic impacts will be undetectable. For instance, Figure 6-2 (lower left panel) suggests that Chinook abundance would need to increase 25-40% to achieve SRKW population growth rates near 2.3% per year. There have only been 3-5 years out of the past 32 years in which Chinook abundance has been near those levels. Furthermore, the non-linear relationship between SRKW growth rate and Chinook abundance shows a diminishing return as Chinook abundance increases beyond the historical average levels.

Although there are many ways that simulation analyses could be performed, the Panel suggests beginning with the most optimistic approach; that is, assuming that variation in SRKW vital rates depends only on salmon abundance, the relationship is causal, and that future analysts know the exact model structure. Based on these assumptions, one would then run an estimation procedure similar to NOAA's existing one (i.e., Bayesian logistic regression) to re-estimate model parameters and expected impacts of Chinook on growth rates. Results from such experiments will help clarify two things: (1) the best possible future scenario for our ability to learn more about these relationships; and (2) the lowest magnitude of uncertainty that decision-makers will be faced with when they confront this issue in the future.

Key Question 5. Based on your expert opinion, what level of confidence would you assign to the conclusion that predicted changes in Chinook salmon abundance caused by fisheries increases the risk of extinction of the SRKW population?

Confidence - VERY LOW. Analyses presented at Workshop 2 suggest that Chinook escapement to terminal areas has actually increased in recent years, while growth rate analyses show that SRKW growth rates are currently positive and most likely increasing. Furthermore, based on the PVA models, it would take salmon abundance levels consistently less than half of what they are today to cause extended periods of SRKW decline (Figure 6-2). Thus, a detectable effect of Chinook abundance on SRKW extinction is quite unlikely unless Chinook populations were to suffer a massive collapse.

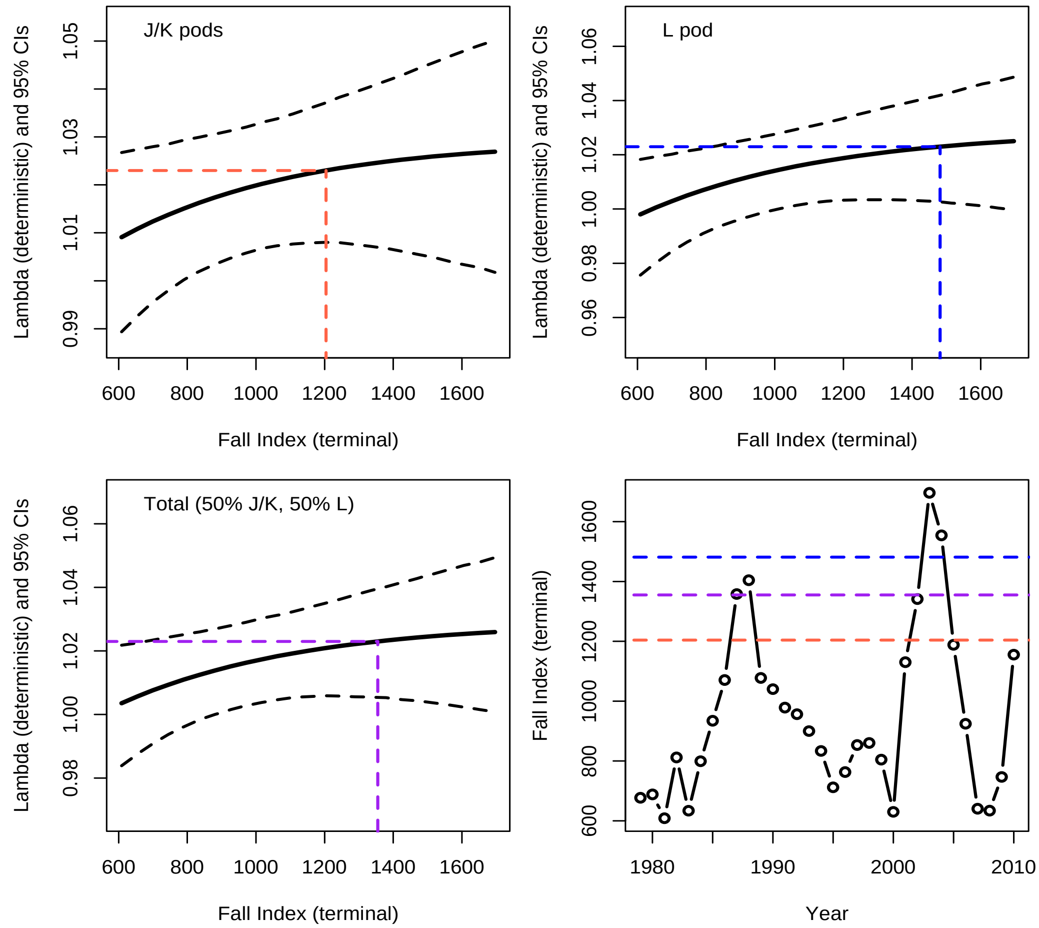

Figure 6-2. Deterministic lambdas as a function of Fall Index (terminal). Source: Ward (2012)[33]

6.5 Recommended Information and Analyses

The simulation analyses we suggested above could also be used within a formal decision analysis to examine trade-offs between Chinook salmon fisheries and SRKW growth rates. Statistical decision theory is well-suited to dealing with these problems, and the Bayesian estimation procedures already developed for this workshop provides much of the necessary analytical framework. Ultimately, decisions to change fisheries, or to proceed with the status quo, will be based on scientific assessments of biological impact along with value judgments about those impacts. Combining these in a formal decision-analytic approach will at least ensure that key uncertainties are taken into account in making those decisions.

[33] Ward, E. 2012. Quantifying fishing impacts on past and future killer whale growth rates. Presentation at workshop 2. Slide 19.

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APPENDIX 1: ORIGINAL QUESTIONS FROM THE NOAA AND DFO STEERING COMMITTEE

Original questions from the NOAA and DFO Steering Committee, as presented in the Reading List document:

1. What Do We Know about Their Feeding Habits?

Review the Available Information on Distribution, Diet, Food Energy Value of Prey, Daily Prey Energy Requirements of Southern Resident Killer Whales

1) Are the methods used to estimate the SRKW diet (including species, Chinook salmon stocks, and Chinook salmon age/size) scientifically reasonable given the available information? Do you have any suggestions to improve the methods?
2) Are the methods employed to estimate the daily prey energy requirements of the SRKW scientifically reasonable given the available information? Do you have any suggestions to improve the methods?
3) Based on your expert opinion, what level of confidence would you assign to the conclusion that, during the May-Sept time period in the Salish Sea, the SRKW have a diet consisting largely of Chinook salmon?
4) Based on your expert opinion, what level of confidence would you assign to the estimate of the distribution of age 3, 4 and 5 Chinook in the SRKW diet (May-Sept, Salish Sea)?
5) Based on your expert opinion, what level of confidence would you assign to the conclusion that the SRKW's coastal diet largely consists of salmon? Of Chinook salmon?
6) Do you have specific suggestions to address key assumptions and uncertainties?

2. What Do We Know About Their Status?

Review the Available Information1 on Census and Population Structure, the Species Status and Recovery Criteria, Historical Abundance and Carrying Capacity of Southern Residents as well as Information about Northern Residents

1) What ecosystem considerations and/or trends might be relevant, including environmental carrying capacity questions?
2) Based on your expert opinion, what can we learn from evaluating the similarities and differences between Northern and Southern Resident?

3. What Do We Know About the Relationship Between Chinook Abundance and Killer Whale Population Dymanics?

Review the Available Information1 **on Demographic Modeling, the Role of Nutrition in Individual Growth and Condition, and Available and Emerging Methods to Investigate Body Condition**

1) Are the methods employed to evaluate the relationship between salmon abundance and SRKW (and/or NRKW) fecundity, survival and population growth scientifically reasonable? Do you have any specific suggestions to improve the methods?
2) Based on your expert opinion, are there additional analyses that could be conducted on the SRKW population or other resident killer whale populations to better understand the relationship between salmon abundance and killer whale survival, fecundity, and population growth?

3) Are the methods employed to evaluate the potential for nutritional stress in the SRKW population scientifically reasonable?
4) Based on your expert opinion, what level of confidence would you assign to the conclusion that the SRKW exhibit signs of nutritional stress? Of cumulative effects that include lower than optimal nutrition?
5) Are the methods employed to evaluate the viability of the SRKW under alternative assumptions about future salmon abundance scientifically reasonable? Do you have any specific suggestions to improve the methods?
6) Based on your expert opinion, are there additional analyses that could be conducted on the SRKW population or other resident killer whale populations to better understand the relationship between salmon abundance and killer whale population viability?

4. Identify Fisheries That May Affect Prey Availability

Review the Available Information on Fisheries That May Affect Prey Availability

1) Do any parts of these data need further clarification?

5. Chinook Needs of Southern Resident Killer Whales

Review the NMFS and DFO's Analyses of the Population's Chinook Needs. Based on this Information

1) Based on your expert opinion, what level of confidence would you assign to the conclusion that the SRKW prey energy requirements are within the range of Chinook kilocalories or numbers of Chinook estimated by NMFS and DFO?
2) Do you have specific suggestions to address key assumptions and uncertainties in the analysis?

6. Chinook Abundance and Food Energy Available to Killer Whales

Review the Analysis Conducted to Date

1) Are the methods employed to predict salmon abundance by stock in specific times/places scientifically valid?
2) Are there improvements to the methods you would suggest?

7. Reduction in Chinook Abundance and Food Energy from Fisheries

Review the Analytical Approach from the Opinion and NMFS Report on Fishery Profiles

1) Are the methods employed to predict the reduction in salmon abundance by stock in specific times/places scientifically valid?
2) Are there improvements to the methods you would suggest?

8. Ratio of Chinook Food Energy Available Compared to Chinook Food Energy Needed by Southern Residents with (and without) Fishing

Review the Analysis Conducted to Date

1) Are the methods employed to estimate the prey ratios under alternative fishing scenarios scientifically reasonable?
2) Do you have specific suggestions to address key assumptions and uncertainties?
3) How sensitive is the ratio analysis to its component parts? (e.g., selectivity function, whale population size and structure, percent of Chinook in diet, food energy value of prey, etc.)
4) In your expert opinion, do forage ratios provide meaningful information about potential prey limitation in the SRKW?
5) How can we improve comparisons to ratios for other marine predators and systems?
6) What more can we learn from the ratios? For example, is it possible to estimate what the ratio should be in a given time and area to support survival and recovery of the whales?

9. Change in Population Growth Rates Annually, Abundance Over Time and Species Survival and Recovery

Review the Analysis Conducted to Date

1) Based on your expert opinion, what level of confidence would you assign to the conclusion that predicted changes in Chinook salmon abundance caused by fisheries affect the population growth rate of the SRKW?
2) Based on your expert opinion, what level of confidence would you assign to the conclusion that predicted changes in Chinook salmon abundance caused by fisheries affect the population growth rate of the SRKW?
3) Based on your expert opinion, what level of confidence would you assign to the conclusion that predicted changes in Chinook salmon abundance caused by fisheries increases the risk of extinction of the SRKW population?