Agenda Item H.1
Situation Summary
September 2011

PROGRESS REPORTS ON COLUMBIA RIVER TULE AND SACRAMENTO WINTER RUN CHINOOK MANAGEMENT ISSUES

Columbia River Tules

The States of Oregon and Washington recovery plans adopted in 2010 for Lower Columbia River (LCR) Chinook included specific measures calling for the evaluation of abundance-based management for tule Chinook. The National Marine Fisheries Service (NMFS) also identified the need to develop options for incorporating abundance-driven management principles into LCR tule Chinook management in a 2010 letter to the Council summarizing consultation standards and guidance regarding the potential effects of the 2010 season on listed salmonid species. This guidance letter described a set of tasks designed to accelerate the recovery process by completing actions with immediate benefit to tule populations. NMFS guidance indicated that total exploitation rate (ER) limits on tule Chinook will be contingent on satisfactory progress in completing the set of tasks.

At their June 2010 meeting, the Council convened an Ad Hoc tule Chinook Work Group (TCW) to explore abundance-based approaches for LCR tule Chinook. Initial assessments by the TCW showed that an abundance-based approach was potentially practical and effective. In April, the TCW initiated steps to develop potential alternatives and complete a draft analysis for further consideration. Agenda Item H.1.b, TCW Report provides a summary of issues and findings to date by the TCW.

At this time, the Council and advisory bodies should consider the alternatives presented in the report and provide guidance on narrowing the alternatives to a very few for final analysis. Considerations should include trade-offs between risk reduction and harvest benefits with regard to frequency and duration of low, moderate, and high abundance periods, and therefore allowable ERs. Particularly important will be realization of reduced risks to various natural tule populations, availability and allocation of impacts during low abundance periods, and ER limits during moderate (most of the time) abundance periods. The models and technical analyses used to develop and analyze the alternatives will be considered in the Salmon Methodology Review process in October and November 2011, and is not the focus of this Agenda Item.

Sacramento Winter Run

On April 30, 2010, NMFS completed a biological opinion of fishery impacts on Sacramento River winter-run Chinook (winter-run), which concluded that the ocean salmon fishery, as managed under the Pacific Coast Salmon Fishery Management Plan, was likely to jeopardize the continued existence of winter-run. This determination was based on the recent declines in winter-run spawning returns and the lack of a quantitative management process to assess impacts to winter-run Chinook. As part of the biological opinion, NMFS issued a Reasonable and Prudent Alternative (RPA) requiring a new framework for managing impacts on winter-run, which includes the development of new models and analyses that will evaluate and quantify impacts of various fishery management options on winter-run. Clearly defined and measureable status thresholds and management objectives are to be established and supported by new analytical tools for use by the Council and NMFS by March 2012.

A progress report on the development of such a management approach will be presented, but again, the models and technical analyses will be considered in the Salmon Methodology Review process in October and November 2011, and is not the focus of this Agenda Item.

Council Action:

1. **Receive information and provide guidance for selection and analysis of alternatives for abundance based management approaches for Columbia River natural tule fall Chinook.**
2. **Receive information and provide guidance on potential management approaches for Sacramento River Winter Chinook.**

Reference Materials:

1. Agenda Item H.1.b, TCW Report: Exploration of Abundance-Based Management Approaches for Lower Columbia River Tule Chinook.

Agenda Order:

a. Agenda Item Overview — Chuck Tracy
b. Columbia River Tule Chinook Report — Ray Beamsdorfer
c. Sacramento Winter Run Chinook Report — Mark Helvey
d. Reports and Comments of Advisory Bodies and Management Entities
e. Public Comment
f. **Council Action**: Guidance on the Abundance Based Methodology for Tule Chinook and Progress of Sacramento Winter Run Biological Opinion Revisions

PFMC
08/23/11

PROGRESS REPORT ON THE SACRAMENTO WINTER RUN BIOLOGICAL OPINION REASONABLE AND PRUDENT ALTERNATIVE AND DEVELOPMENT OF A NEW MANAGEMENT FRAMEWORK

At the March 2011 Pacific Fisheries Management Council (PFMC) meeting, NOAA Fisheries (NMFS) submitted an overview of the NMFS ocean fishery management guidance for Sacramento River winter-run Chinook (winter-run). The overview explained that, as a result of the April 2010 jeopardy biological opinion of ocean salmon fishery impacts on winter-run, a new framework for managing impacts on winter-run must be implemented by March 2012, as stipulated by the opinion's Reasonable and Prudent Alternative (RPA). The jeopardy determination was based on the recent substantial declines in winter-run spawning returns, and the lack of sufficient analytical information and tools to establish specific harvest impact level objectives or an explicit management process to specifically avoid or reduce impacts to winter-run when this stock is declining and/or facing increased extinction risks (NMFS 2010).

Since March, the NMFS Southwest Fisheries Science Center Salmon Assessment Team (SAT) has been engaged in efforts to develop the analytical tools required to (1) perform annual assessments of winter-run, (2) forecast the effects of fisheries on winter-run, and (3) evaluate alternative fishery exploitation scenarios to aid in the construction of a new winter-run management framework.

With regard to performing annual assessments of winter-run, the SAT has further developed and updated cohort reconstructions, analyzing the effects of ocean fisheries on brood years 1998-2007. Results of the cohort reconstructions indicate that approximately 70% of winter-run impacts come from the recreational fishery, and almost all impacts occur south of Point Arena. Additionally, the age-3 impact rate closely approximates the total ocean fishery exploitation rate owing to high age-3 maturation rates, which are typically in excess of 90% (NMFS 2010, O'Farrell et.al 2011). Given the results of this assessment, the measurable objective in the new winter-run management framework will be the age-3 ocean fishery impact rate and any winter-run management measures will apply to ocean salmon fisheries south of Point Arena. The cohort analysis used to support the 2010 Biological Opinion was reviewed by the Center for Independent Experts, and an updated cohort analysis will be reviewed the SSC-salmon subcommittee at the 2011 Methodology Review.

Implementation of winter-run annual management measures in the PFMC arena requires development of a winter-run "harvest model". The harvest model will be used to determine the expected impact rate as a function of fishery management measures. It will allow ocean salmon fishery management measures to be designed on an annual basis such that the impact rate specified by the control rule is met. The harvest model will share many of the same characteristics of existing harvest models (e.g., the KOHM and SHM). It will allow managers the ability to modify fishing opportunity and minimum size limits in order to achieve age-3 impact rate objectives. It is important to note that the harvest model will produce a pre-season prediction of the impact rate. It is possible, and in fact will be required, that a post-season estimate of the rate will be made following the fishery, once the data are available to do so (2 years after the fishing season has ended), in order to monitor the performance of the harvest model and management framework. The harvest model will be presented to the SSC-salmon subcommittee at the 2011 Methodology Review.

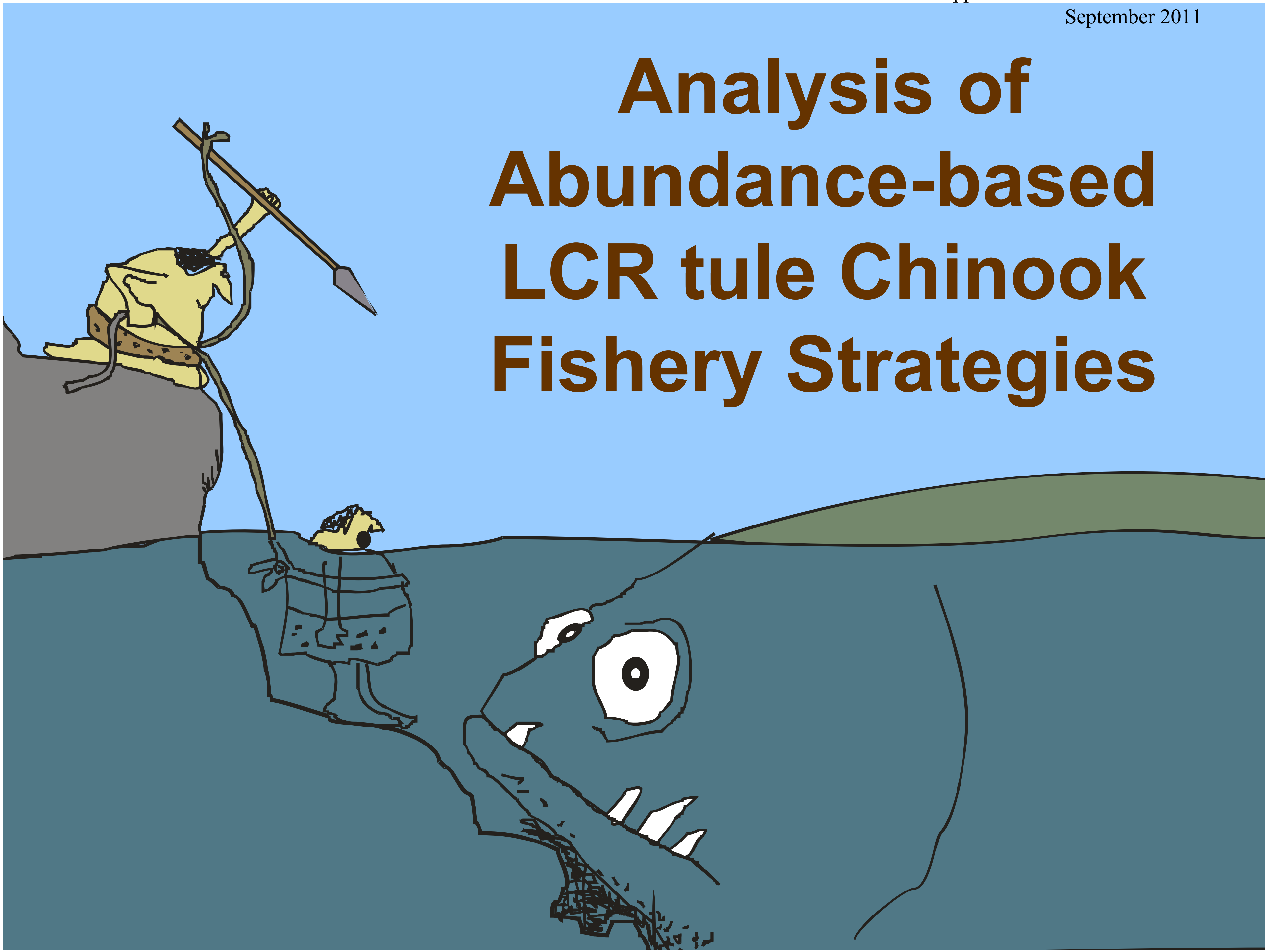
The development of the management framework is ongoing, and implementation is expected to be completed before the March, 2012 PFMC meeting. The foundation of this entire process is the development of a "Management Strategy Evaluation" (MSE). At the core of the MSE is a full life-cycle winter-run population model that includes natural population dynamics, observation of the population, and fishery impacts. Without going into great detail, the model is being developed with sufficient structure to account for key aspects of population dynamics (e.g., density dependence, stochastic recruitment and survival), errors in estimates of population abundance, and variability in fishery impact rates. The purpose of the MSE approach is to simulate winter-run population dynamics under a variety of prospective management "control rules" and to assess the performance of these control rules relative to established population criteria or benchmarks. In this MSE, a control rule specifies the level of winter-run age-3 impact rate that fishery managers may allow for in a given year. For example, a control rule which allows a fixed annual fishing impact rate can be simulated and compared to other rules, such as a control rule that increases the allowable impact rate as the population increases. The goal of this simulation work is to develop a fisheries management framework (control rule) for winter-run based on the relative performance of alternative control rules.

Until results of the MSE have been analyzed and finalized, NMFS is unable to discuss details about any specific possible outcomes. However, at this time NMFS can offer some general comments in preparation for the implementation of a new management framework. As mentioned previously, the control rule will result in annual specification of an allowable age-3 impact rate. The determination of that rate will likely have dependence on recently observed winter-run spawner abundance, since these estimates are expected to be readily available on an annual basis.

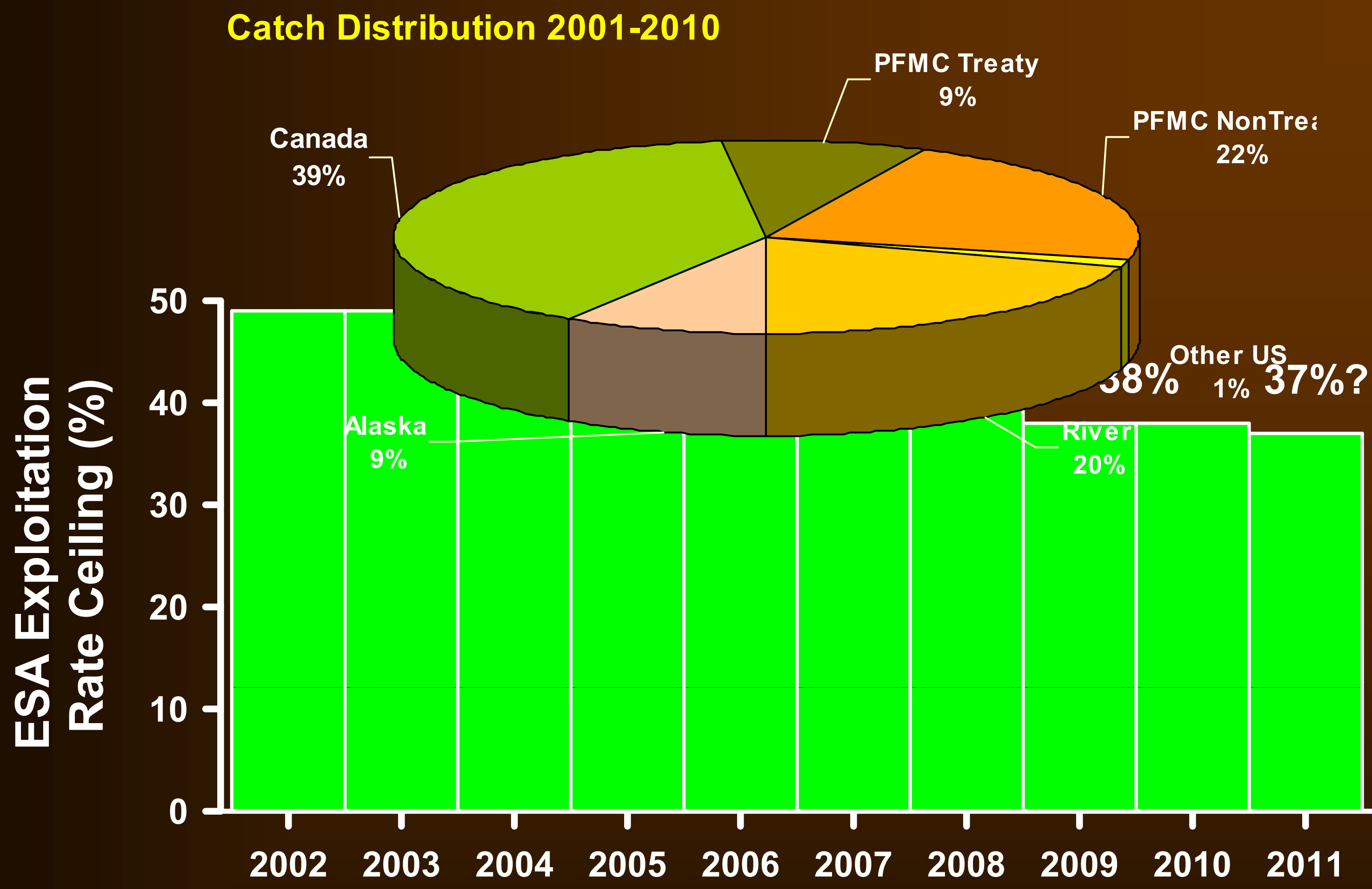
After the MSE has been completed, all documents related to this process of evaluating fishing management scenarios and implementing the management framework, including development of the winter-run population model and the MSE simulation results, will be made available to the public.

NMFS. 2010. Biological Opinion on the Authorization of Ocean Salmon Fisheries Pursuant to the Pacific Coast Salmon Fishery Management Plan and Additional Protective Measures as it affects Sacramento River Winter Chinook Salmon. National Marine Fisheries Service, Southwest Region. April 30, 2010.

O'Farrell, M.R., Mohr, M.S., Grover, A.M., and W.H. Satterthwaite. 2011. Sacramento River winter Chinook population and fishery assessment. *In preparation.*

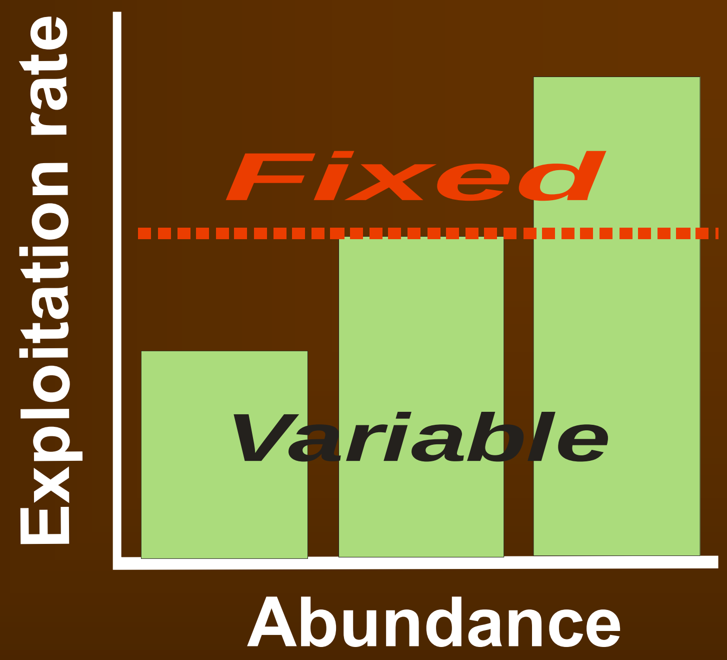

Analysis of
Abundance-based
LCR tule Chinook
Fishery Strategies

LCR Tule Chinook




Tule Chinook Work Group*
• ABM Examples
• Abundance Forecasts
• Fishery Implications
• LCN Risk Analysis
• ABM Alternatives
*Ad Hoc

ABM Examples

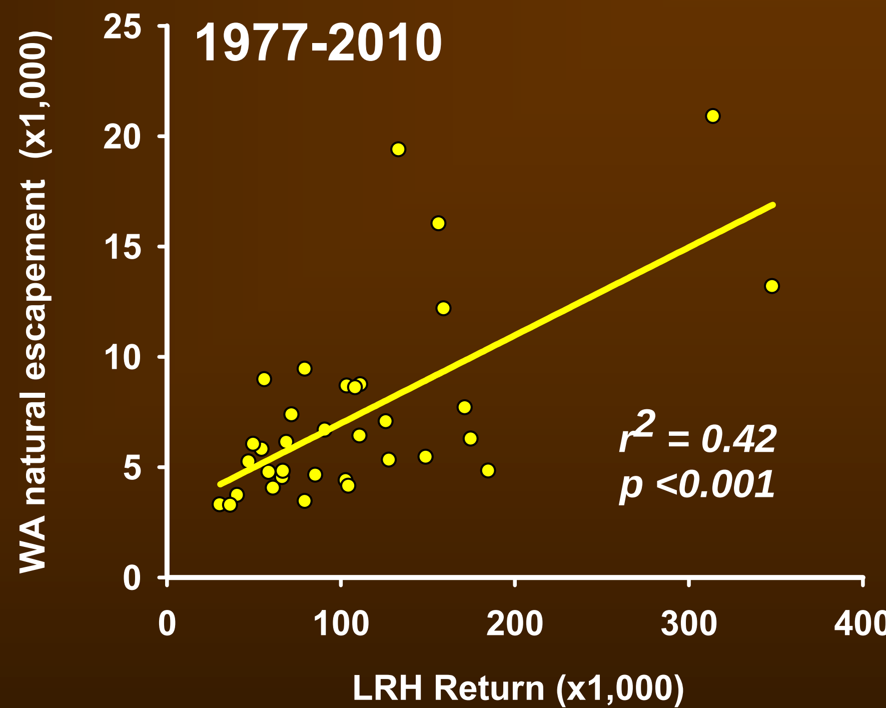


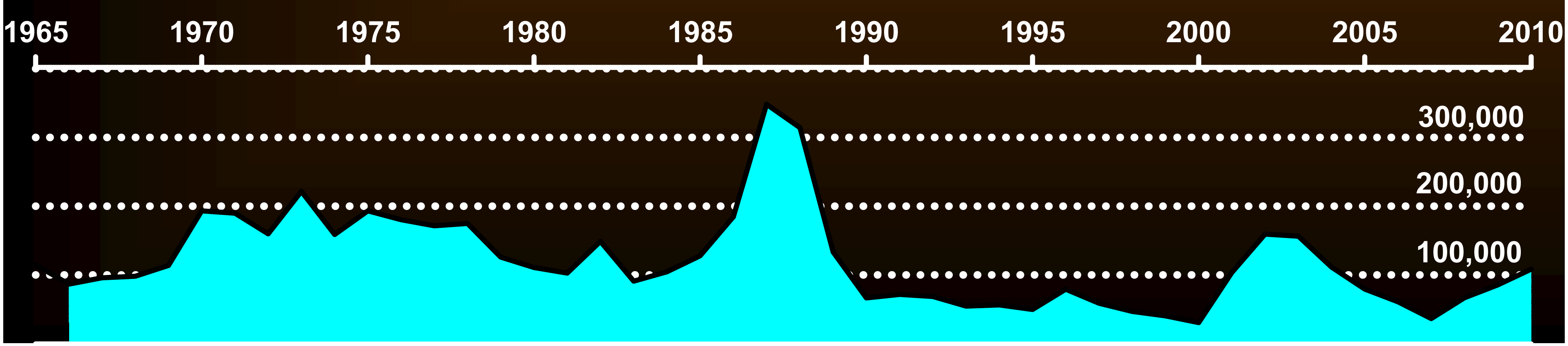
- Puget Sound coho
- Klamath & Sacramento Fall Chinook
- OCN & CR coho
- CR Upriver bright Fall Chinook

Forecasts - CR Hatchery Tules

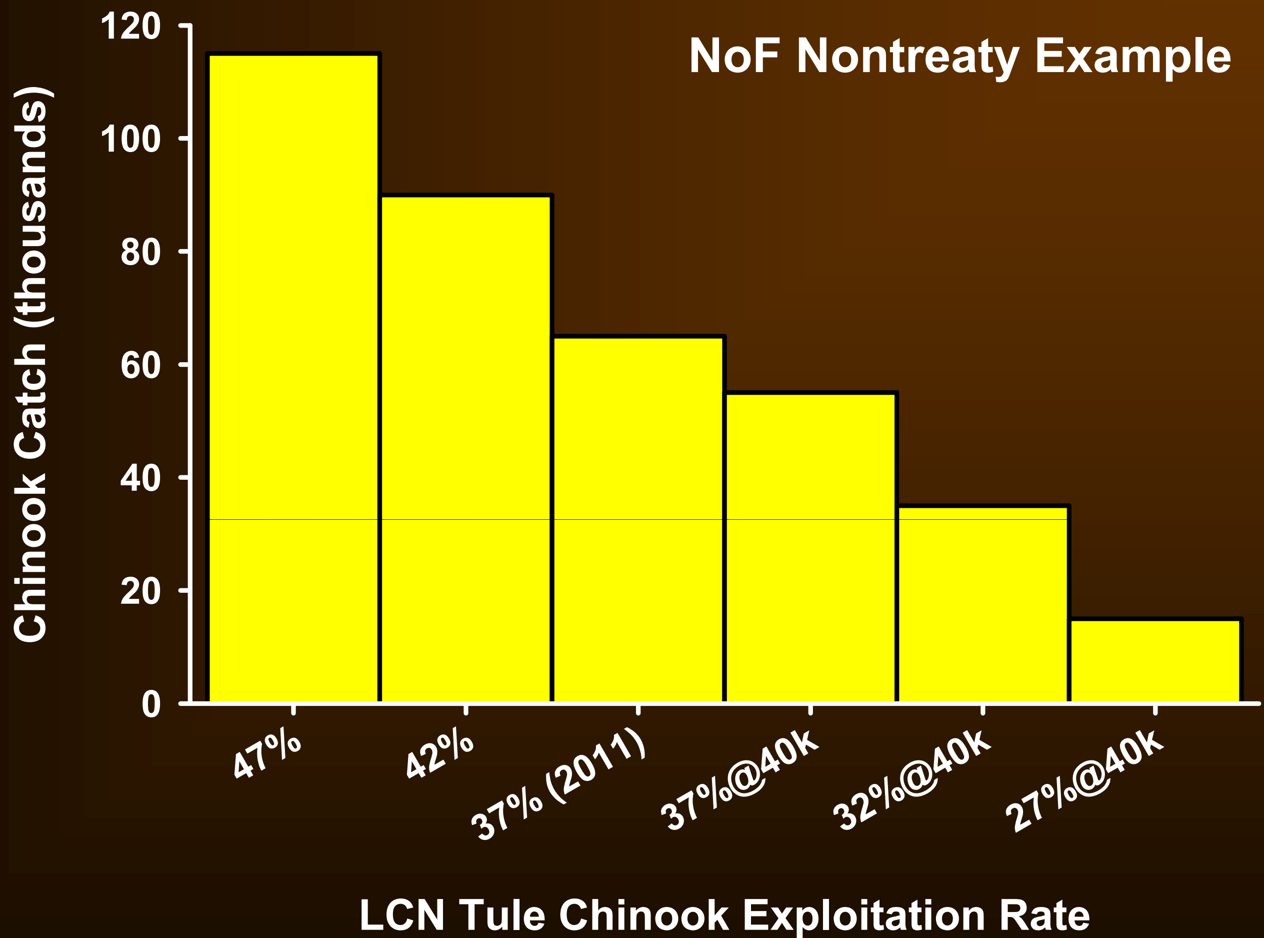
Current releases
22 mil / yr

1991-2010 CR run
Avg. 70,000
(27,000 – 156,000)



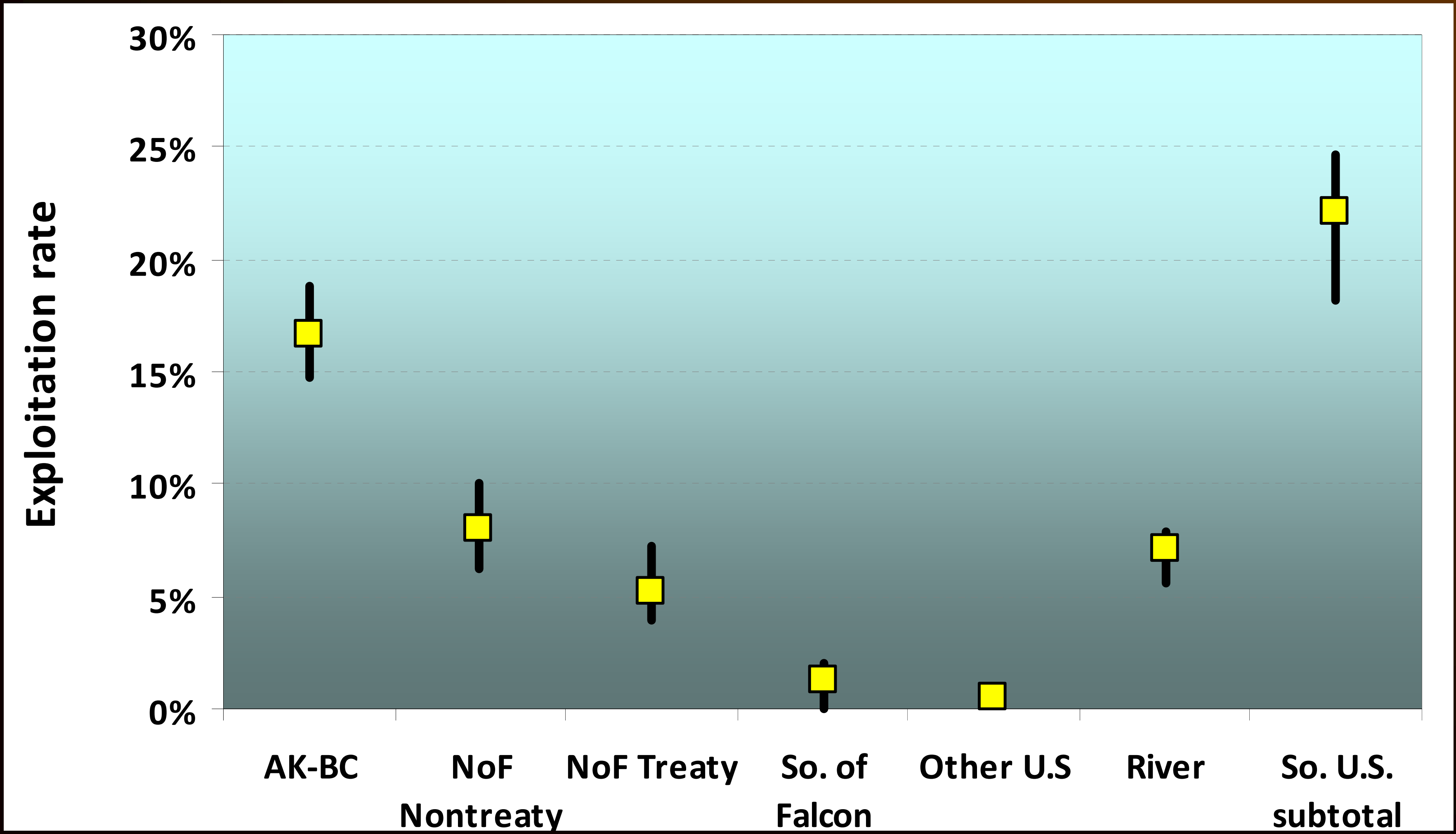


Fishery Implications

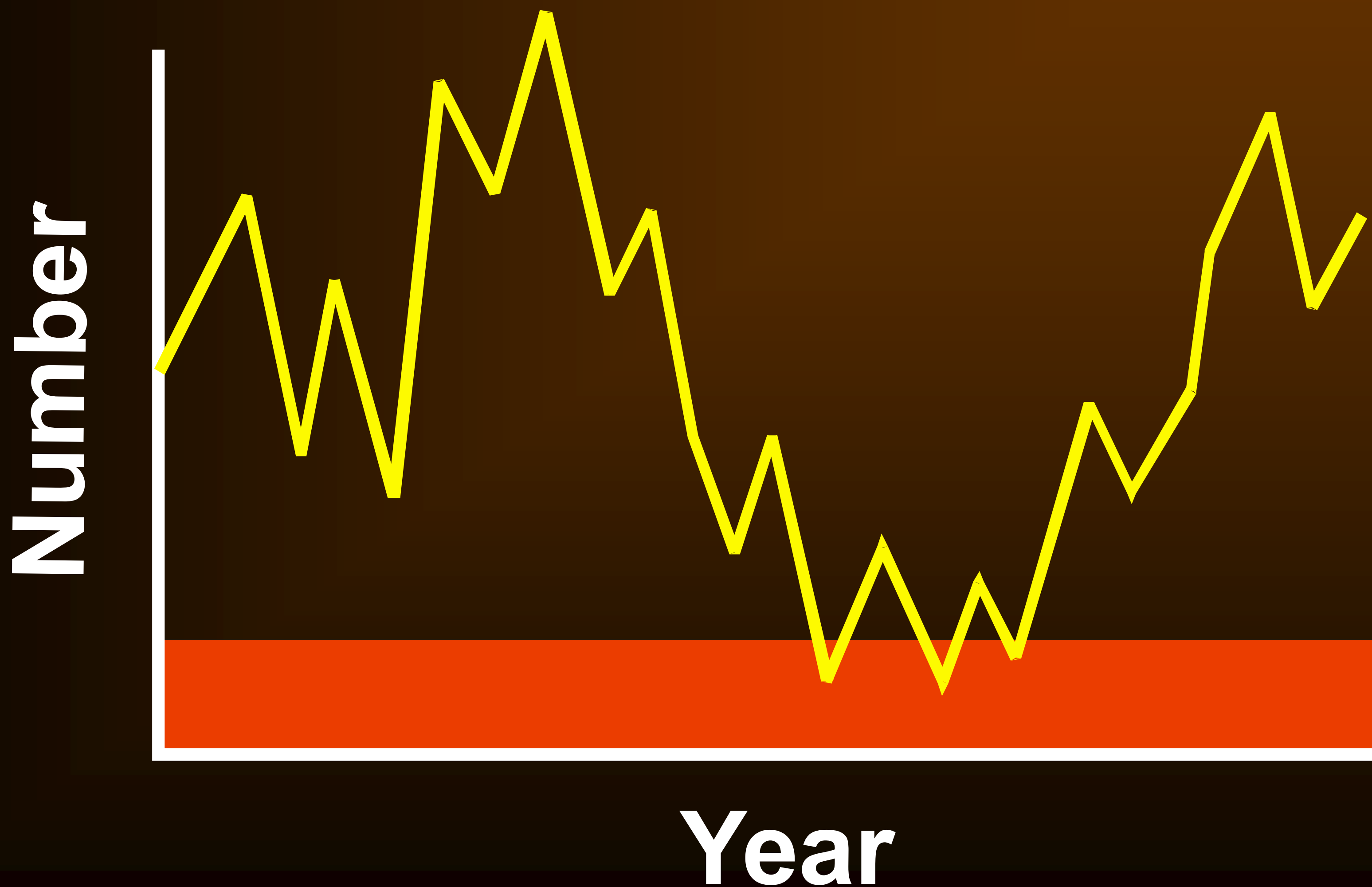


** 2011 w/ LRH at preseason 133,000 or low abundance of 40,000*

Recent LCN Exploitation Rates



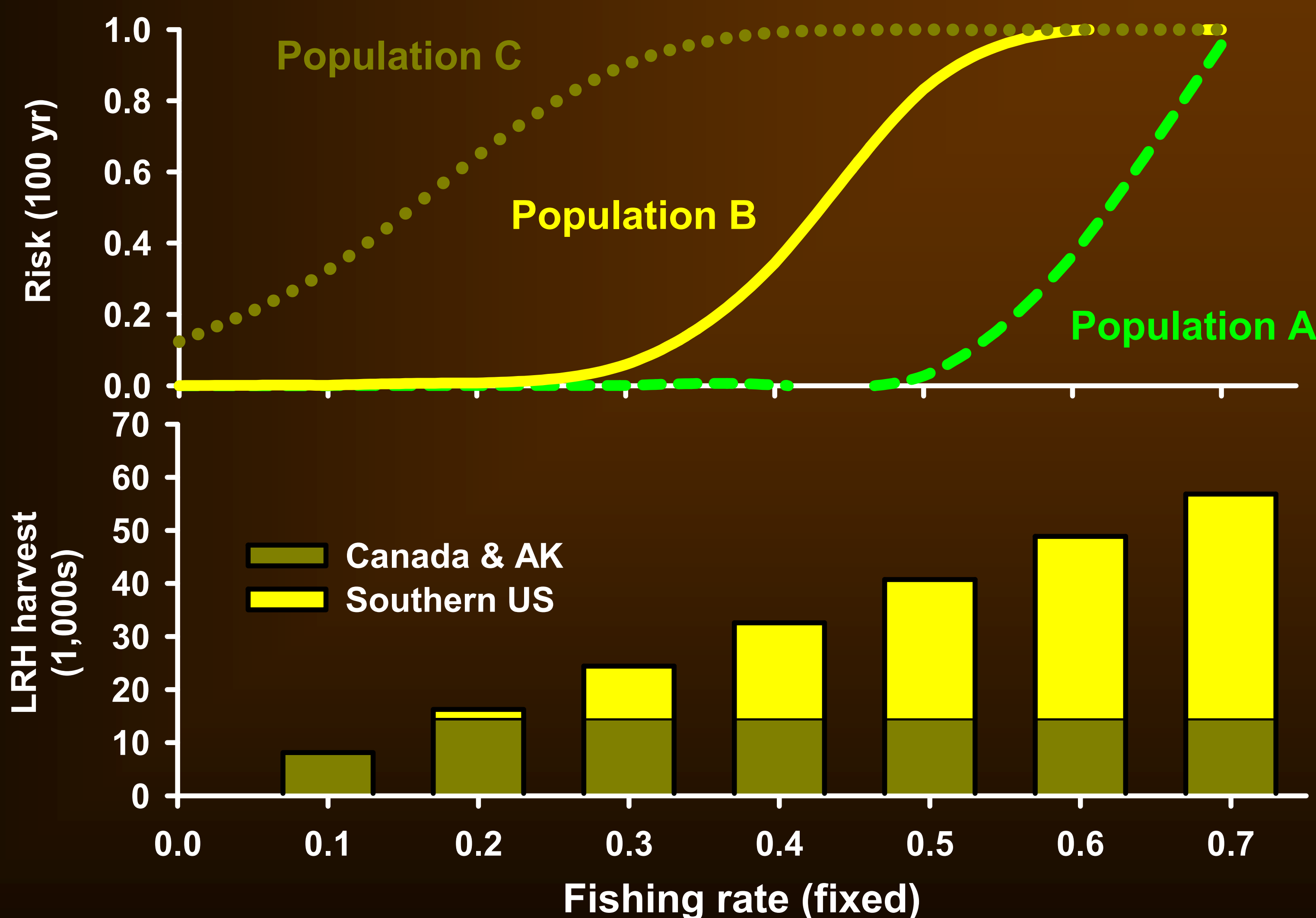
LCN Risk Analysis



Population Viability Analysis Model

Index Populations

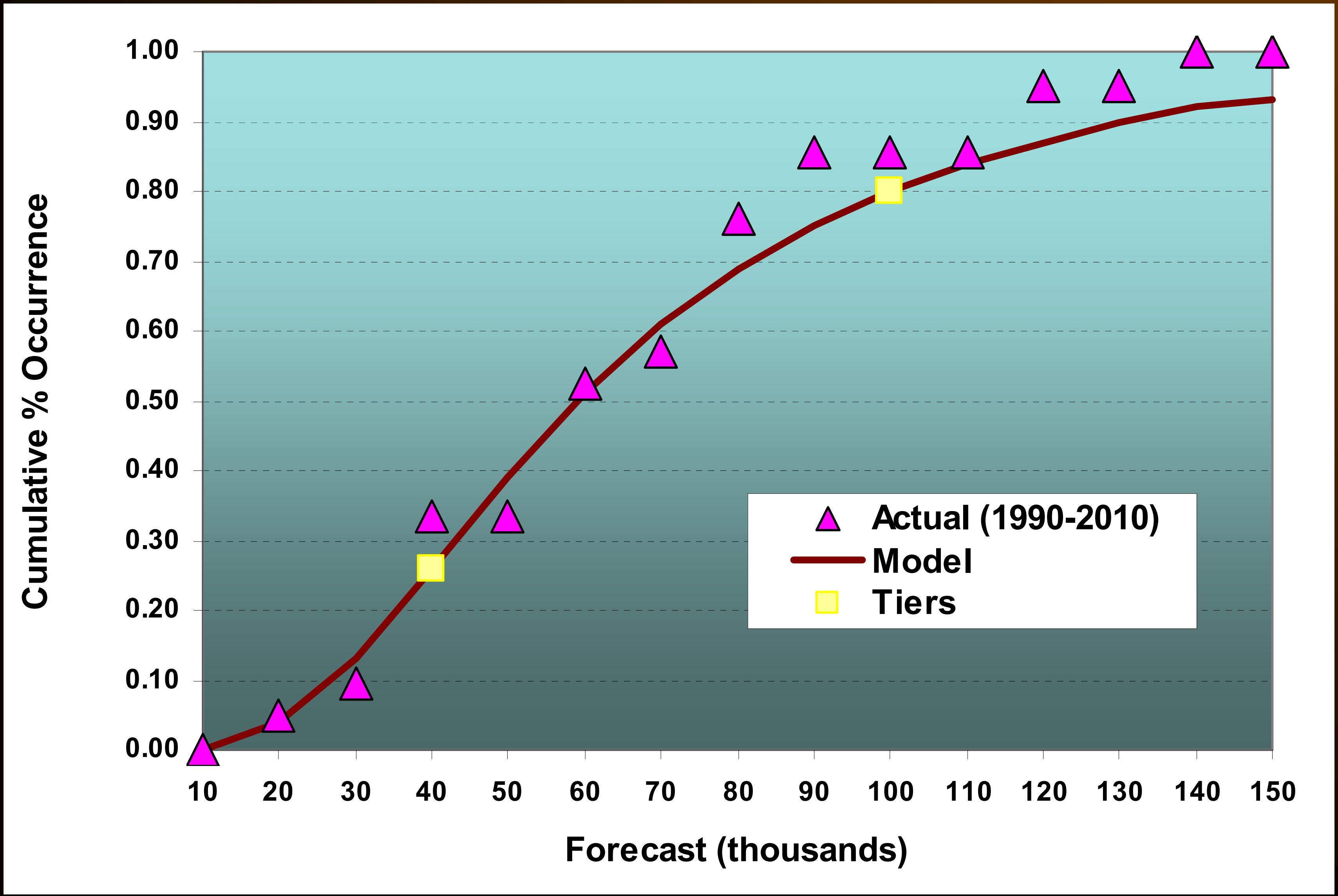
Effect of Population "Condition"



Scenario Example

	F37	V37±5
<40,000	22%	
40,000-100,000	55%	
>100,00	23%	
LCN Risk	0.210	0.163
Δ	--	-5%
LCR Harvest	30,130	31,540
Δ	--	+5%

Tier Frequencies



Scenario Categories

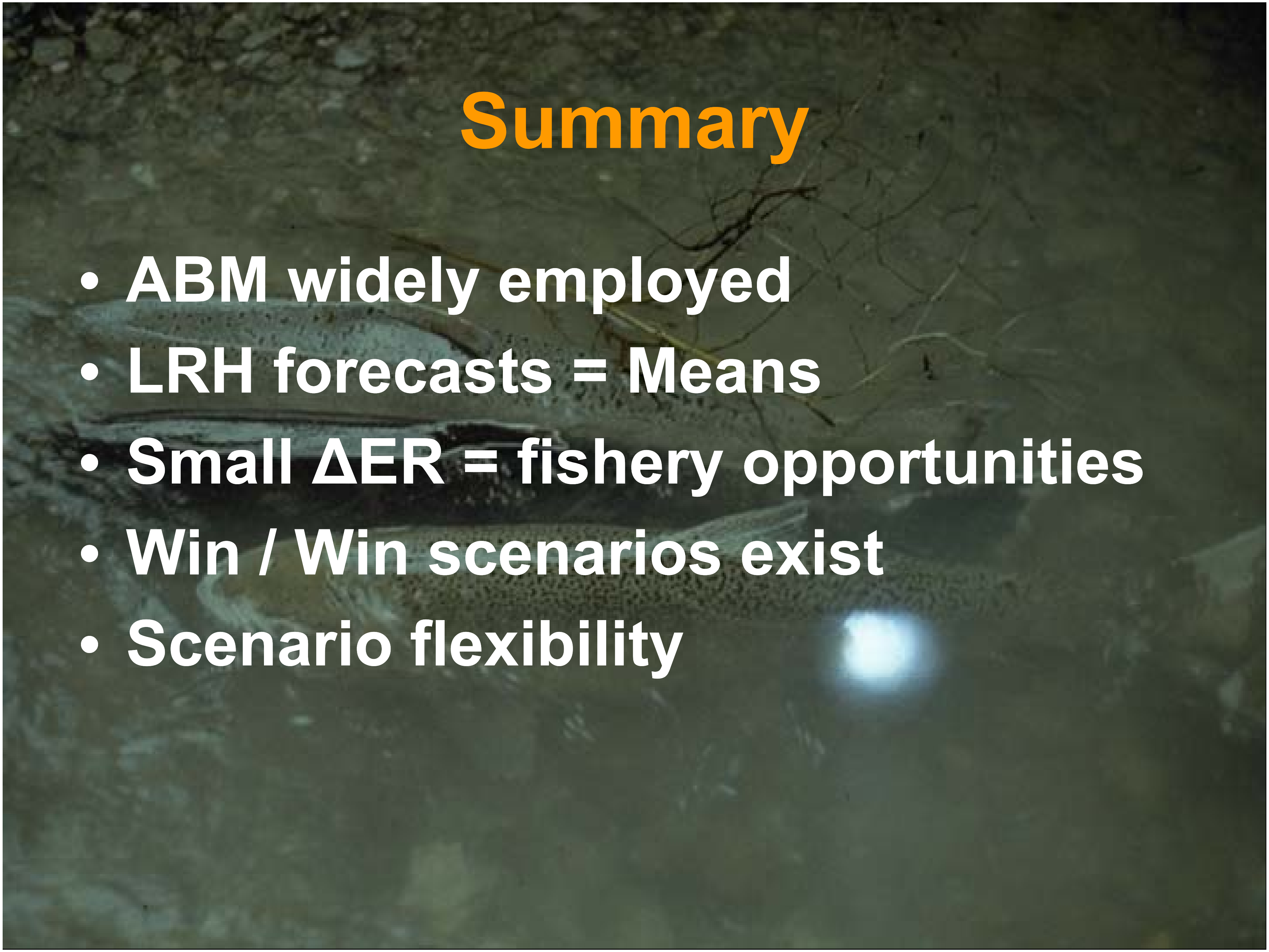
	Risk	Fishing
Win/Win	↓	↑
Risk Reduction	↓	↓
Fishery Opportunity	↑	↑
Equivalent	--	--

** Substantive difference = ± 3.5% risk*
± 3.0% harvest

Scenario Examples

#	Scenario	Tiers (thousands) 1	2	3	4	Frequency	Change in Risk	Harvest	Category
54	F37	<40	40-100	100+	--	22/55/23	0.0%	0.0%	--
67	V37±3	<40	40-100	100+	--	22/55/23	-3.4%	2.8%	Equiv
55	V39±5	<40	40-100	100+	--	22/55/23	1.0%	10.1%	Fishery ↑
66b	V35/41	<100	100+	--	--	77/23	-4.3%	1.7%	Risk ↓
68d	V30/35/38/40	<30	30-40	40-80	>80	11/11/42/35	-3.8%	4.6%	Win/Win

** Substantive difference = ± 3.5% risk*
± 3.0% harvest



Summary

- ABM widely employed
- LRH forecasts = Means
- Small ΔER = fishery opportunities
- Win / Win scenarios exist
- Scenario flexibility

3 Questions

- How much additional fishery opportunity is desirable in large run years?
- How much of a reduction in the low run years can be supported?
- How often can the fishery withstand reduced rates in the lower tier?

Agenda Item H.1.b
TCW Report
September 2011

DRAFT

EXPLORATION OF ABUNDANCE-BASED MANAGEMENT APPROACHES FOR LOWER COLUMBIA RIVER TULE CHINOOK

AD HOC TULE CHINOOK WORK GROUP (TCW)

PACIFIC FISHERY MANAGEMENT COUNCIL

AUGUST 2011

Executive Summary

This report explores the potential utility of abundance-based management alternatives for Lower Columbia River tule Fall Chinook. This stock is currently managed with fixed annual impact rate limits intended to avoid jeopardy of long-term persistence of the natural stock component. Fishery limits have been substantially reduced from historical levels and the need for further reductions has been contemplated in Endangered Species Act (ESA) consultations by the National Marine Fisheries Service (NMFS). These limits are a significant constraint in fisheries administered by the Pacific Fishery Management Council (Council) and by the states of Washington and Oregon in the Columbia River. Abundance-based management is a variable rate alternative to the current fixed rate strategy that potentially reduces conservation risks in years of low returns and increases fishery flexibility in years of high returns.

This report summarizes investigations of the feasibility and effectiveness of abundance-based management of lower Columbia River tule Fall Chinook by the Ad Hoc tule Chinook Work Group (TCW) convened by the Council at their June 2010 meeting. Four fundamental questions were evaluated:

1. What is abundance-based management and where has it been used?
2. Can Columbia River tule Fall Chinook abundance be predicted with sufficient accuracy and precision to feasibly implement an abundance-based strategy?
3. What are the effects of different fishing rates for Columbia River tule Fall Chinook on Council fisheries and in-river?
4. Can alternatives be implemented with negligible effects on escapement and viability of natural tule Chinook populations?

Abundance-Based Management Alternatives

Abundance-based fishery management strategies are currently employed in a variety of salmon fisheries throughout the Pacific Northwest. These strategies employ a variety of estimators or indicators related to natural fish abundance including abundance forecasts, brood year spawner numbers, marine survival, and ocean conditions related to marine survival. Indicators might be based on wild or hatchery fish at an aggregate or indicator population level. Fishery management strategies also involve different combinations of exploitation rates and thresholds at which different rates might be applied. Different rates and thresholds might be selected depending on the desired balance of conservation risks and fishery objectives.

Most management approaches are based on a preseason abundance forecast where allowable exploitation rates are either a stepped function based on abundance status bins or a continuous function designed to target a specific escapement value (spawners, dam count, etc.). These are essentially a one dimensional matrix; examples include Puget Sound coho and Sacramento River fall Chinook, respectively. Oregon Coast Natural coho exploitation rates are based on a two dimensional matrix using parental spawner abundance and estimated marine survival. Parental spawner abundance is further stratified into sub-aggregate populations so harvest in any year is based on status of the weakest population.

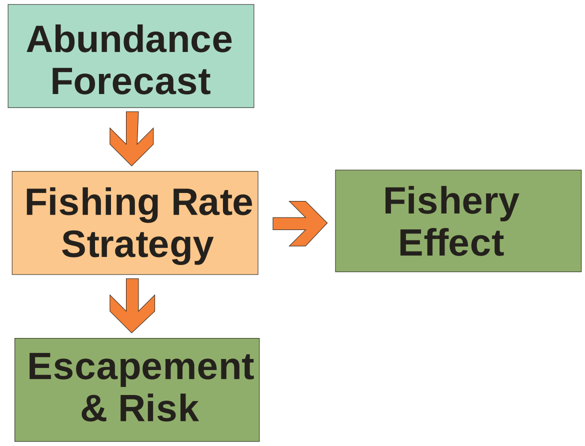


Figure 1. Conceptual depiction of an abundance-based management analysis.

Forecasting Abundance

Tule Fall Chinook from the lower Columbia River are forecast using sibling models from run reconstruction of the Lower River Hatchery (LRH) stock management unit. Although this is considered a hatchery stock unit, the accounting of the LRH run does include a small, but not easily quantifiable, proportion of naturally produced tule Fall Chinook from the lower Columbia River tributaries (LCN tules). LCN tule numbers cannot be accurately predicted at this time in aggregate or by population due to a lack of reliable age composition data for many natural populations.

Forecasts of the aggregate run of LRH Fall Chinook have been relatively accurate but imprecise. Error averaged just -2% for predicted number of total adults over the period from 1980 through 2009 but annual predictions have ranged from -66% to 85% of the actual return with a standard deviation of 37%. Errors were highly autocorrelated among years.

While LCN tule numbers cannot be predicted directly, aggregate forecasts based primarily on hatchery returns would appear to be a suitable proxy due to common effects of marine conditions to which both hatchery and wild fish are subject. The aggregate LRH return was at least partially correlated with LRN numbers considered in aggregate and in many or most natural populations throughout the historical data set and in the recent 10-year period. Correlations were similar for a brood year survival rate index, and the total LRH return.

Evaluations of the effects of incorporating indicators of ocean environmental conditions into the forecast models suggested that it might be feasible to improve forecast accuracy of aggregate tule abundance. However, any proposed improvements in forecast techniques will need to be tested with pre- and post- season comparisons. In the interim, considerations of abundance-based fishing strategies for tule Fall Chinook will necessarily rely on current forecast methods.

Fishing Rates, Contributions & Effects

Tule Fall Chinook are harvested in ocean fisheries from Alaska to Oregon and in the Columbia River. They are a major contributor to ocean fisheries north of Cape Falcon, Oregon managed by the Council. Prior to 1990, cumulative total exploitation rates (ER) regularly reached or exceeded 0.65. Following ESA listing, fishery impact ceilings were established by NMFS at 0.49 in 2002-2006, 0.42 in 2007, 0.38 in 2009-2010, and 0.37 in 2011.

Fishery limits on tule Fall Chinook are one of several potential constraints on mixed stock fisheries managed by the Council and Columbia River Compact. In some years, these limits can significantly constrain access to harvest of other fish stocks in these fisheries.

Analyses of 2009-2011 fisheries were conducted using the Fishery Regulation Assessment Model (FRAM) to identify example changes in fishery-specific ERs that would have resulted from a low status estimate for LCN tule Chinook under implementation of an abundance-based management system. Exploitation rates in Council fisheries can approach 0.15 depending on overall Columbia River stock abundances and extent of fishing South of Cape Falcon (primarily Oregon troll) that can add 0.01-0.03. Exploitation rates in the mainstem Columbia net and sport fisheries have averaged about 8%. Approximately two thirds of the ER in Council fisheries is in the nontreaty troll and sport fisheries (Treaty troll averages about 0.05 in these runs). In these examples, impacts on LCN tules in the southern U.S. would have to be reduced by nearly 50% in order to remain under an ER ceiling of 0.28 and by 23% to remain under a ceiling of 0.33, assuming current average conditions in northern fisheries.

Natural Population Risk Analysis

Abundance-based fishing strategies were evaluated for their effects on fisheries and on escapement and risk for LRN tule fall Chinook. Wild population risks were estimated with stochastic stock-recruitment modeling in a Population Viability Analysis framework like that employed in salmon ESA status assessments and recovery plans. Similar modeling approaches have previously been utilized by the Council in conservation risk analyses for other stocks including Klamath River fall Chinook.

Based on a review of abundance-based approaches for other fisheries and an assessment of information available for lower Columbia River tule Fall Chinook, the TCW initially identified a series of alternative strategies for further evaluation. Alternatives included a variety of fixed exploitation rate strategies ranging from 0 to 0.53 that were used for comparison with variable rate alternatives. Variable rate strategies used a one dimensional matrix based on abundance of LRH tules, with bins representing approximately 20% of the lowest preseason forecasts (< 40,000), 20% of the highest abundance forecasts (> 100,000) and the remaining 60% in the middle bin. A variety of ERs were assigned to these bins and assessed for changes to population risk and overall LRH harvest availability.

Changes in risks and LRH harvest levels were compared relative to a fixed 0.37ER limit, which represents the 2011 ESA consultation standard. Fishing rate scenarios were categorized based on whether risk and harvest levels were substantively greater or lower than corresponding values at the 0.37 exploitation rate. Substantive differences were based on changes to risk and harvest benefits approximating a one percentage point change in the fixed ER limit. Corresponding values were ±3.5% change in 100-year risk, ±0.25% change in 20-year risk, and ±3.0% change in average 100-year harvest. These numbers were used to classify fishing rate scenarios into one of four categories:

- The Win/Win group involved both a substantive reduction in risk to the natural population and a substantive improvement in fishing opportunity for tule Fall Chinook. This group would represent the ideal abundance-based strategy.
- The Risk Reduction group involves a substantive decrease in wild population risk with little or no fishery benefit.
- The Fishery Opportunity group involves a substantive increase in harvest opportunity.
- The Equivalent group provides similar wild population risk and tule Fall Chinook harvest level as the fixed 37% exploitation rate strategy.

No fishery scenarios were contemplated that increase natural population risks and reduce fishery opportunities.

Results indicate that a variety of variable exploitation rate strategies based on forecasts of aggregate tule Fall Chinook abundance can increase fishery management flexibility while also effectively controlling wild population risks. However, increased flexibility associated with higher exploitation rates in years of higher abundance must be compensated by reduced exploitation rates in years of lower abundance. This tradeoff would potentially increase variability in harvest of mixed stocks.

Model sensitivity analyses indicate that this conclusion is relatively robust to uncertainties in model inputs and functions related to the lack of specific data on wild population status and dynamics. Some examples of Win/Win scenarios and the current fixed 37% ER limit are presented below:

Table ES-1 Effects of variable rate fishing strategies based on abundance tiers. (Scenarios are sorted by the change in 100 year risk.)

ER	Abundance Tier	Population risk		LRH	Change in risk		Δ Harvest
Scenario	Frequency	100 yr	20 yr	Harvest	100 yr	20 yr	100 yr
F37	22/55/23	0.210	0.016	30,130	0%	0.0%	0%
V28/38/50	22/55/23	0.158	0.007	34,470	-5%	-0.9%	14%
V25/40/45	22/55/23	0.136	0.006	33,250	-7%	-1.0%	10%
V28/37/50	22/55/23	0.142	0.007	34,080	-7%	-0.9%	13%
V40-15	22/55/23	0.120	0.006	31,480	-9%	-1.0%	4%
V25/37/50	22/55/23	0.111	0.005	33,860	-10%	-1.1%	12%
V35±10	22/55/23	0.072	0.003	31,320	-14%	-1.3%	4%

Contents

INTRODUCTION

This report explores the potential utility of an abundance-based management alternative for Lower Columbia River (LCR) tule Fall Chinook in fisheries managed by the Pacific Fishery Management Council (Council). Lower Columbia Chinook salmon were listed as threatened under the U.S. Endangered Species Act Fisheries in 1999. This stock is currently managed with fixed annual impact rate limits intended to avoid jeopardy of long-term persistence of the wild stock. Fishery limits have been substantially reduced from historical levels and the need for further reductions has been contemplated in ESA consultations by the National Marine Fisheries Service (NMFS). These limits are a significant constraint in fisheries managed by the Council.

Tule Chinook are harvested in fisheries from Oregon to Alaska. While no single fishery harvests a large number of this stock, the combined impact of all fisheries can be significant. Because much of the tule fishery impact currently occurs in Canada and Alaska outside the Council's direct management authority, reduced impact limits have seriously constrained Columbia River fisheries and have the potential to constrain Oregon and Washington ocean fisheries in some years.

Abundance-based management is a variable rate alternative to the current fixed rate strategy. An abundance-based strategy might offer two potential benefits. It reduces conservation risks in years of low returns and increases fishery flexibility in years of high returns. When abundance is low, decreased impact rates reduce the risk of low spawning escapements that can damage the long term viability of weak wild populations. When annual abundance is high, increased impact rates increase access to harvestable surpluses of stronger stocks and hatchery components of the run. Effective use of this strategy could potentially increase average harvest of both tule Chinook and other salmon with no additional long-term risk to wild tule Chinook. The benefit of increased harvest on large runs is effectively bought with the cost of reduced harvest in the small run years.

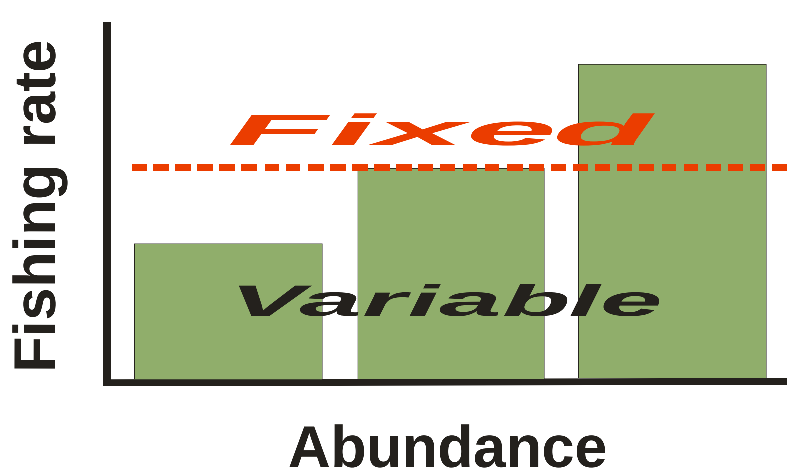


Figure 2. Illustration of a variable exploitation rate fishing strategy based on abundance.

The potential application of abundance-based management of Lower Columbia Natural (LCN) tule Fall Chinook is also complicated by selection and interpretation of appropriate indices by which to measure fishery impacts and effects on wild population risks. Impacts on wild fish were historically indexed based on Cowlitz Hatchery tags to represent the Coweeman wild population.[1] However, Coweeman tules are one of the stronger extant populations[2] and a more effective conservation strategy will involve protection of both weak and strong tule populations.

ESA Recovery Plans adopted in 2010 for lower Columbia River salmon include specific measures calling for the evaluation of abundance-based management for tule Chinook. NMFS also identified the need to develop options for incorporating abundance-driven management principles into LCN tule Chinook management in a 2010 letter to the Council summarizing consultation standards and guidance regarding the potential effects of the 2010 season on listed salmonid species. This guidance letter described a set of tasks designed to accelerate the recovery process by completing actions with immediate benefit to tule populations. NMFS advised indicated that total exploitation rate limits on Lower Columbia River tule Chinook will be contingent on satisfactory progress in completing tasks.

At their June 2010 meeting, the Council convened an Ad Hoc tule Chinook Work Group (TCW) to explore abundance-based approaches for LCN tule Chinook. The work group included members from NMFS, Washington and Oregon Departments of Fish and Wildlife (WDFW and ODFW), Columbia River treaty Tribes, and the Makah tribe, and is facilitated by Council staff. The TCW met on September 30, 2010 to identify a process, tasks, schedule and assignments. A draft work plan and schedule was developed from initial TCW discussions. The draft work plan also described a schedule for integrating this review with the Council's annual salmon methodology review process that produces recommendations in November of each year. Initial assessments by the TCW showed that an abundance-based approach was potentially practical and effective. In April the TCW initiated steps to complete a draft technical analysis for further consideration. This report is the product of that analysis.

This analysis addresses four fundamental questions regarding the feasibility and effectiveness of an abundance-based fishery strategy for LCR tule Fall Chinook:

1. What is abundance-based management and where has it been used?
2. Can Columbia River tule Fall Chinook abundance be predicted with sufficient accuracy and precision to feasibly implement an abundance-based strategy?
3. What are the effects of different fishing rates for Columbia River tule Fall Chinook on Council fisheries?
4. Can alternatives be implemented with negligible effects on escapement and viability of wild tule Chinook populations?

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[1] *Fishery impacts are currently indexed using coded-wire tags (CWT's) from all lower Columbia River hatchery tule Chinook. This provides better representation in ocean fisheries than the previous use of Cowlitz Hatchery tags alone.*

[2] *In the case of LCN tules, strong is a relative term. All populations have been found to be at significant risk of extinction. However, risks for the Coweeman population are more moderate than for most other populations.*

STOCK DESCRIPTION

LCR tule Fall Chinook are part of a lower Columbia River Evolutionarily Significant Unit (ESU) that was initially listed in 1999 as threatened under the U.S. Endangered Species Act. The listing was reaffirmed in 2005. This ESU includes all naturally spawned populations of spring, fall (tule) and late fall (bright) Chinook salmon from the Columbia River and its tributaries from its mouth at the Pacific Ocean upstream to a transitional point between Washington and Oregon east of the Hood River and the White Salmon River. Celilo Falls, which historically presented a migration barrier to Chinook salmon under certain flow conditions, is the eastern boundary of the ESU (Myers et al. 2006).

Fall Chinook historically spawned in large tributaries of the lower Columbia River from the mouth of the Columbia River to the Klickitat River. Columbia tule Fall Chinook typically enter freshwater from August to September and spawn from late September to November, with peak spawning activity in late September to mid-October. A total of 21 historical populations of tule Fall Chinook were identified by NMFS (Myers et al. 2006). All were estimated to be at high or very high risk of extinction at the time of listing (Figure 3) in recovery plans prepared by Washington and Oregon, and adopted by NMFS. Risks were determined by a combination of qualitative assessments relative to viable salmonid population characteristics (abundance, productivity, spatial structure, and diversity) and quantitative assessments using population viability analysis involving stochastic population models.

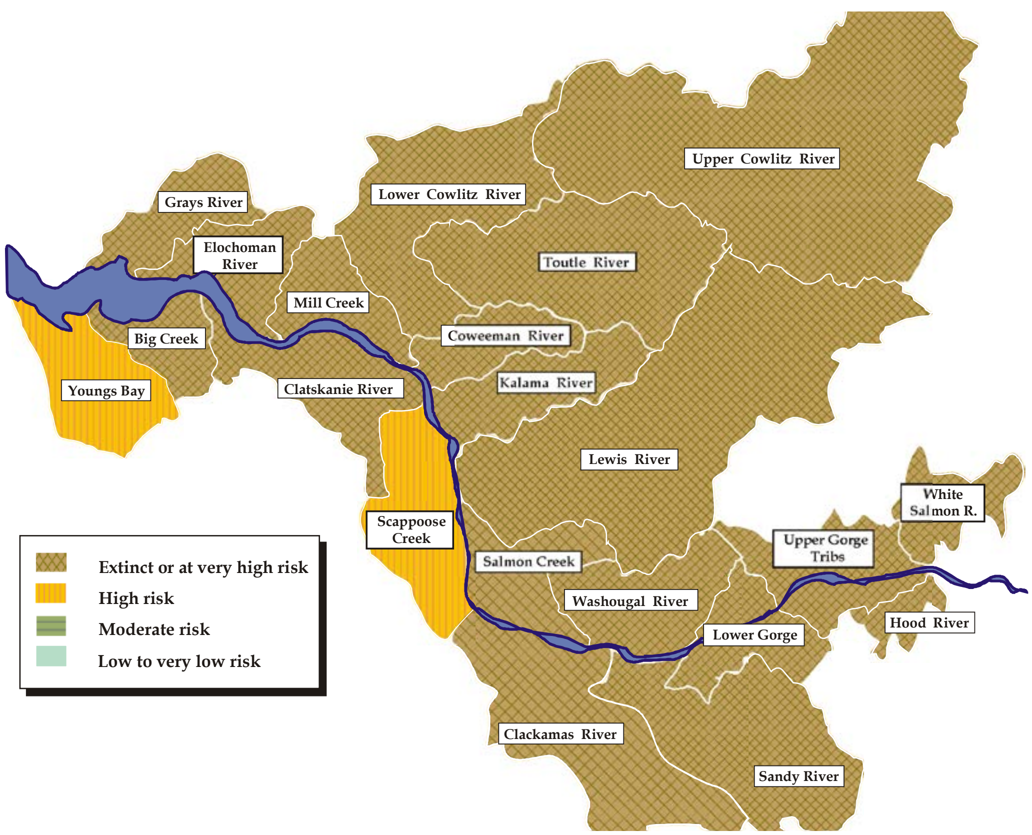

Figure 3. Current status of historical demographically-independent lower Columbia fall (tule) Chinook populations (LCFRB 2010). Risk thresholds are >60% (very high), 26-60% (high), 6-25% (medium), 1-5% (low) and <1% (very low) within 100 years.

Columbia River tule Fall Chinook have been distinguished into two stocks for fishery management purposes. The Lower River "Hatchery" stock (LRH) includes all fish returning to hatchery and natural production areas in the lower 145 miles of the Columbia River downstream from Bonneville Dam. The naturally-produced component (LCN) of the LRH stock includes both wild fish and naturally-produced offspring from hatchery-origin fish spawning in the wild. The Bonneville Pool Hatchery stock (BPH) includes tules returning to hatchery and natural production areas upstream from Bonneville Dam.

Total numbers of wild tule Chinook returning to lower Columbia River streams have declined in the last century from over 100,000 (LCFRB 2010, ODFW 2010) to less than 10,000 per year (Table 1). As wild numbers declined, hatcheries were established to produce fish for fisheries in an effort to mitigate the decline. Hatchery production of LRH tules averaged approximately 60 million juveniles per year from 1978 through 1991 but has since been reduced to an annual average of about 22 million (Figure 5). An additional 6.5 million BPH tules are produced in Spring Creek Hatchery upstream from Bonneville Dam. Over 90% of the current tule run to the lower Columbia River is comprised of hatchery-origin fish. Hatchery-origin fish also appear to contribute 40% to 80% of the total number of naturally-spawning fish in Washington lower Columbia streams since 1977. Hatchery fractions vary considerably from stream to stream (Table 1).

Returns to the Columbia River of LRH Chinook has averaged 110,000 and varied between 30,000 and 348,000 between 1977 and 2010. Average annual survival (estimated from hatchery releases) declined from about 0.7% per year prior to 1977 to just 0.3% per year since (Table 1, Figure 5). This change coincided with the shift in ocean environmental regime in the mid 1970s. Average survival improved somewhat since the mid-1990s, in part due to the termination of several of the less-successful hatchery programs in the basin following reductions in federal Mitchell Act funding.

Variable marine survival has resulted in variable and unpredictable tule run size over the last 30 years. Very low numbers corresponded to a severe El Niño event in the early 1980s and mid to late 1990s. High returns were produced by apparently favorable survival conditions in years immediately following El Niños. From 1977-2010, approximately runs of 40,000 fish or less occurred 6% of the time and runs of 140,000 or greater occurred 24% of the (Figure 4).

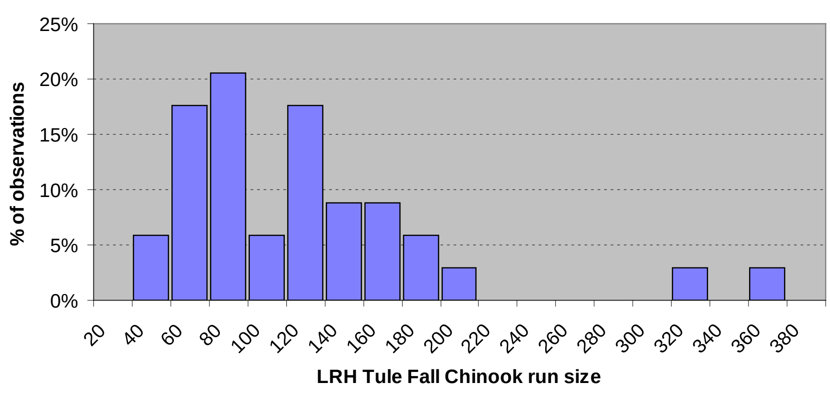

Figure 4. Frequency distribution of LRH tule Fall Chinook run size, 1977-2010.

Table 1. LRH Tule Chinook data including hatchery releases, total run size to the Columbia River and population-specific estimates, naturally-produced fractions , and wild numbers (WDFW unpublished data).

Run year	hatchery releases (millions)	LRH run (1,000's)	LRH wild fraction	LRH run yr survival	Grays			Mill/Abernathy/Germany			Elochoman/Skamokawa			Coweeman			Cowlitz			Kalama			Lewis			Washougal			Natural escapement		
					# total	% wild	# wild	# total	% wild	# wild	# total	% wild	# wild	# total	% wild	# wild	# total	% wild	# wild	# total	% wild	# wild	# total	% wild	# wild	# total	% wild	# wild	Total number	% wild	Wild number
1977	39.3	171.5	4.5%	0.74%	1,009	0.46	464				568	0.42	239	337	1.00	337	5837	0.26	1518	6,549	0.50	3275	1,086	1.00	1,086	1,652	0.46	760	17,038	0.45	7678
1978	66.0	174.9	3.6%	0.83%	1,806	0.46	831				1,846	0.42	775	243	1.00	243	3192	0.26	830	3,711	0.50	1856	1,448	1.00	1,448	593	0.46	273	12,839	0.49	6255
1979	72.2	126.1	5.6%	0.51%	344	0.46	158				1,478	0.42	621	344	1.00	344	8253	0.26	2146	2,731	0.50	1366	1,304	1.00	1,304	2,388	0.46	1,098	16,842	0.42	7037
1980	83.4	111.0	5.8%	0.34%	125	0.46	58	516	0.49	253	64	0.42	27	180	1.00	180	1793	0.26	466	5,850	0.50	2925	899	1.00	899	3,437	0.46	1,581	12,864	0.50	6388
1981	50.4	103.0	4.2%	0.21%	208	0.46	96	1,367	0.48	656	138	0.42	58	116	1.00	116	3213	0.26	835	1,917	0.50	959	799	1.00	799	1,841	0.46	847	9,599	0.45	4366
1982	51.4	149.0	3.6%	0.22%	272	0.46	125	2,750	0.50	1,375	340	0.42	143	149	1.00	149	2100	0.26	546	4,595	0.50	2298	646	1.00	646	330	0.46	152	11,182	0.49	5433
1983	56.9	91.1	7.3%	0.12%	825	0.46	380	3,725	0.51	1,900	1,016	0.42	427	122	1.00	122	2463	0.26	640	2,722	0.50	1361	598	1.00	598	2,677	0.46	1,231	14,148	0.47	6659
1984	34.4	104.6	3.9%	0.17%	252	0.46	116	614	0.52	319	294	0.42	123	683	1.00	683	1737	0.26	452	3,043	0.50	1522	340	1.00	340	1,217	0.46	560	8,180	0.50	4115
1985	52.7	128.0	4.1%	0.24%	532	0.46	245	1,815	0.53	962	464	0.42	195	491	1.00	491	3200	0.26	832	1,259	0.50	630	1,029	1.00	1,029	1,983	0.46	912	10,773	0.49	5295
1986	52.2	184.9	2.6%	0.37%	370	0.46	170	980	0.49	480	918	0.42	386	396	1.00	396	2474	0.26	643	2,601	0.50	1301	696	1.00	696	1,589	0.46	731	10,024	0.48	4803
1987	64.2	348.2	3.8%	0.89%	555	0.46	255	6,168	0.59	3,639	2,458	0.42	1032	386	1.00	386	4260	0.26	1108	9,651	0.50	4826	256	1.00	256	3,625	0.46	1,668	27,359	0.48	13169
1988	61.5	314.2	6.6%	0.87%	680	0.46	313	3,133	0.69	2,162	1,370	0.42	575	1,890	1.00	1,890	5327	0.26	1385	24,549	0.50	12275	744	1.00	744	3,328	0.46	1,531	41,021	0.51	20874
1989	51.1	133.4	14.5%	0.30%	516	0.46	237	2,792	0.69	1,926	122	0.42	51	2,549	1.00	2,549	4917	0.26	1278	20,495	0.50	10248	972	1.00	972	4,578	0.46	2,106	36,941	0.52	19368
1990	53.6	66.6	6.8%	0.12%	166	0.46	76	650	0.63	410	174	0.42	73	812	1.00	812	1833	0.26	477	2,157	0.50	1079	563	1.00	563	2,205	0.46	1,014	8,560	0.53	4503
1991	52.2	71.9	10.2%	0.12%	127	0.47	60	2,017	0.85	1,714	196	0.09	18	340	1.00	340	935	0.26	243	5,152	0.54	2782	470	1.00	470	3,673	0.47	1,726	12,910	0.57	7353
1992	42.7	68.9	8.9%	0.12%	109	0.76	83	839	0.47	394	190	1.00	190	1,247	1.00	1,247	1022	0.26	266	3,683	0.48	1768	335	1.00	335	2,399	0.76	1,823	9,824	0.62	6106
1993	37.3	54.8	10.6%	0.10%	27	0.52	14	885	0.71	628	288	0.78	225	890	1.00	890	1330	0.06	80	1,961	0.89	1745	164	1.00	164	3,924	0.52	2,040	9,469	0.61	5787
1994	38.8	56.3	15.9%	0.11%	30	0.7	21	3,854	0.40	1,542	706	0.98	692	1,695	1.00	1,695	1225	0.19	233	2,014	0.71	1430	610	1.00	610	3,888	0.70	2,722	14,022	0.64	8944
1995	47.9	49.9	12.1%	0.11%	9	0.39	4	1,395	0.51	711	156	0.50	78	1,368	1.00	1,368	1370	0.13	178	3,012	0.69	2074	409	1.00	409	3,063	0.39	1,195	10,782	0.56	6017
1996	33.7	79.5	11.9%	0.20%	280	0.17	48	593	0.54	320	533	0.66	352	2,305	1.00	2,305	1325	0.58	769	10,630	0.44	4728	403	1.00	403	2,921	0.17	497	18,990	0.50	9421
1997	25.9	58.8	8.1%	0.15%	15	0.12	2	603	0.23	139	1,875	0.11	206	689	1.00	689	2007	0.72	1445	3,539	0.40	1402	305	1.00	305	4,669	0.12	560	13,702	0.35	4748
1998	16.8	47.2	11.1%	0.11%	96	0.24	23	368	0.60	221	228	0.25	57	491	1.00	491	1665	0.37	616	4,294	0.69	2973	127	1.00	127	2,971	0.24	713	10,240	0.51	5221
1999	22.2	40.7	9.1%	0.10%	195	0.68	133	575	0.69	397	718	0.25	180	299	1.00	299	969	0.16	155	2,577	0.03	81	331	1.00	331	3,129	0.68	2,128	8,793	0.42	3703
2000	20.9	30.6	10.7%	0.11%	169	0.7	118	416	0.58	241	196	0.62	122	290	1.00	290	2165	0.10	217	1,284	0.21	266	515	1.00	515	2,155	0.70	1,509	7,190	0.46	3277
2001	24.1	103.6	8.4%	0.53%	261	0.43	112	4,024	0.39	1,569	2,354	0.82	1930	802	0.73	585	3647	0.44	1605	3,553	0.18	654	750	0.70	525	3,901	0.43	1,677	19,292	0.45	8659
2002	24.5	159.4	7.6%	0.84%	107	0.47	50	3,343	0.05	167	7,581	0.00	0	877	0.97	851	9671	0.76	7350	18,627	0.01	106	1,032	0.77	795	6,050	0.47	2,844	47,288	0.26	12162
2003	23.3	156.5	10.2%	0.74%	398	0.39	155	3,810	0.56	2,134	6,820	0.65	4433	1,106	0.89	984	7001	0.88	6161	24,684	0.00	74	738	0.98	723	3,444	0.39	1,343	48,001	0.33	16007
2004	23.4	111.4	7.8%	0.51%	766	0.25	192	6,804	0.02	136	4,796	0.01	48	1,503	0.91	1,368	4621	0.70	3235	6,434	0.11	686	1,388	0.29	403	10,597	0.25	2,649	36,909	0.24	8716
2005	17.7	79.5	4.3%	0.34%	147	0.41	60	2,083	0.13	271	2,204	0.05	110	853	0.60	512	2968	0.17	505	9,053	0.03	264	607	1.00	607	2,678	0.41	1,098	20,593	0.17	3427
2006	22.4	61.3	6.6%	0.25%	302	1.00	302	636	0.62	394	317	1.00	317	561	1.00	561	2,051	0.47	964	10,386	0.01	140	1,300	0.82	1,068	1,936	0.14	279	17,489	0.23	4025
2007	18.3	36.7	8.9%	0.16%	63	1.00	63	335	0.48	161	165	1.00	165	234	1.00	234	1,401	0.53	743	3,296	0.06	208	492	0.73	359	1,528	0.87	1,325	7,514	0.43	3257
2008	25	66.9	7.2%	0.34%	40	0.68	27	750	0.49	368	841	0.10	84	404	0.52	210	1,259	0.90	1136	3,734	0.04	149	567	0.87	495	2,491	0.93	2,324	10,086	0.48	4794
2009		85.6	5.4%	0.44%	312	0.43	133	604	0.93	563	2,246	0.18	412	780	0.63	494	2,602	0.45	1165	7,548	0.10	736	299	1.00	299	2,741	0.30	814	17,132	0.27	4616
2010		108.5	7.9%	0.56%	19	1.00	19	3,030	0.57	1,712	913	0.16	150	421	0.44	186	2,489	0.52	1305	5,576	0.29	1625	2,198	0.86	1,883	5,212	0.33	1,704	19,858	0.43	8584
g 1977-20	40.8	109.8	7.6%	0.35%	327	0.51	151	1,983	0.51	899	1,311	0.44	426	760	0.93	715	3,009	0.36	1,221	6,555	0.38	2,053	718	0.94	653	3,083	0.46	1,336	17,572	0.45	7,375
g 2000-20	22.2	90.9	7.7%	0.44%	235	0.61	112	2,349	0.44	701	2,585	0.42	706	712	0.79	570	3,625	0.54	2,217	8,561	0.09	446	899	0.82	697	3,885	0.47	1,597	22,850	0.34	7,048

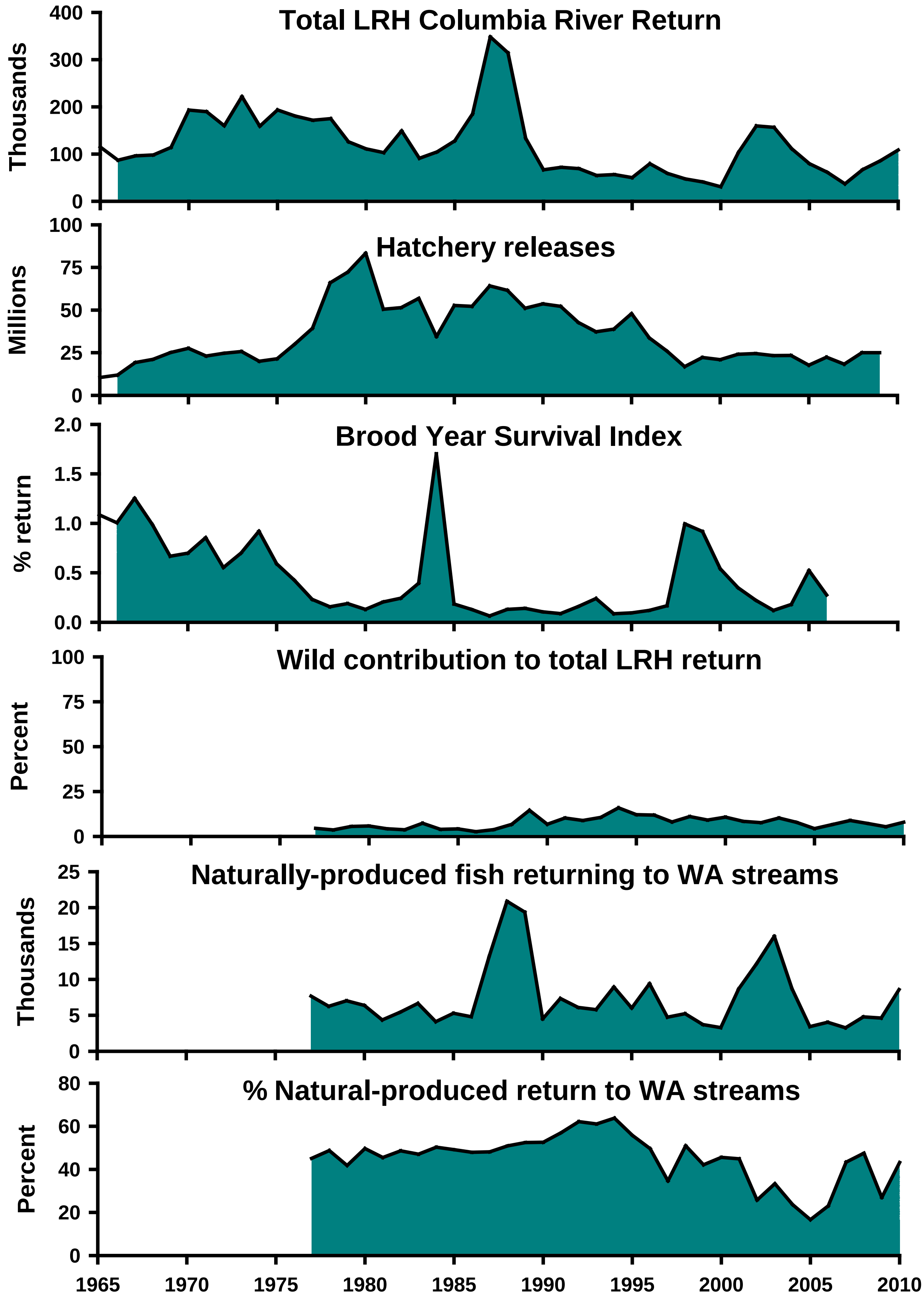

Figure 5. Historical trends in lower Columbia tule Fall Chinook numbers.

ABUNDANCE-BASED MANAGEMENT EXAMPLES

Abundance-based fishery management strategies are currently employed in a variety of salmon fisheries throughout the Pacific Northwest. These strategies employ a variety of estimators or indicators related to natural fish abundance including abundance forecasts, brood year spawner numbers, marine survival, and ocean conditions related to marine survival. Indicators might be based on wild or hatchery fish at an aggregate or indicator population level. These examples can help identify a range of indicators that might be considered for application to LCN tule Fall Chinook.

Fishery management strategies also involve different combinations of exploitation rates and thresholds at which different rates might be applied. Related considerations include both conservation and fishery objectives. Many different combinations of rates and thresholds might be contemplated. Single year alternatives might be based on annual run size expectations. Multi-year alternatives might also include extra conditions on adoption of higher or lower rates (for instance, limits if coming off successive low run years.) Different rates and thresholds might be selected depending on the desired balance of conservation risks and fishery objectives.

This section reviews examples of abundance-based strategies employed in other fisheries throughout the region.

Pacific Salmon Commission

Aggregate Abundance Based Management (AABM): For Chinook fishery management under the PST, an abundance based approach is used in three regional fisheries: southeast Alaska troll, net and sport; northern British Columbia troll and sport, and WCVI troll and sport. The abundance measurement used to set allowable landed catches in these fishery groups is a aggregate stock abundance index of stocks that contribute to each of these fisheries. The abundance index (AI) is calculated from the PSC Chinook Model and is the ratio of the modeled catch in each fishery under 1979-82 base period exploitation rates and current year abundances divided by the catch under base period exploitation rates and base period abundances. There are several different AI tiers per fishery where the fishery harvest rate steps up to a higher level (Table 2). The AIs that contain these incremental harvest rate increases are associated with a total allowable landed catch per fishery in Table 1 of the PST. There are additional provisions in the treaty that reduce AI catch levels when selected stock and stock aggregates are below conservation objectives recognized by the Pacific Salmon Commission.

Table 2. Pacific Salmon Treaty AABM stepped harvest regime (from Appendix B to Annex IV, Chapter 3, updated January 27, 2009).

Relationships between AIs, Catches and HRIs[15]

Southeast Alaska All Gear	North BC Troll & QCI Sport	WCVI Troll & Outside Sport
Proportionality Constant (PC) = 12.38	Proportionality Constant (PC) = 11.83	Proportionality Constant (PC) = 13.10
Harvest Rate Index (HRI) = EXP(LN(Troll Catch / AI) - PC) Troll Catch = (Total Catch - 17,000) * 0.8 = EXP(PC + LN(HRI * AI))	Harvest Rate Index = EXP(LN(Troll Catch / AI) - PC) Troll Catch = Total Catch * 0.8 = EXP(PC + LN(HRI * AI))	Harvest Rate Index = EXP(LN(Troll Catch / AI) - PC) Troll Catch = Total Catch * 0.8 = EXP(PC + LN(HRI * AI))
Total Catch = 17,000 + Troll Catch / 0.8	Total Catch = Troll Catch / 0.8	Total Catch = Troll Catch / 0.80
Reduction in catch from 1999 Agreement: 15%	Reduction in catch from 1999 Agreement: 0%	Reduction in catch from 1999 Agreement: 30%
For AIs less than 1.005	For AIs less than 1.205	For AIs less than 0.5
Total Catch = 17,000 + 110,500 * AI	Total Catch = 130,000 * AI	Total Catch = 128,347 * AI
Troll Catch = (110,500 * AI) * 0.8	Troll Catch = (130,000 * AI) * 0.8	Troll Catch = (128,347 * AI) * 0.8
HRI = 0.371	HRI = 0.757	HRI = 0.21
For AIs between 1.005 and 1.2	For AIs between 1.205 and 1.5	For AIs between 0.5 and 1.0
Total Catch = -114,750 + 242,250 * AI	Total Catch = -20,000 + 146,667 * AI	Total Catch = 149,739 * AI
Troll Catch = (-131,750 + 242,250 * AI) * 0.8	Troll Catch = (-20,000 + 146,667 * AI) * 0.8	Troll Catch = (149,739 * AI) * 0.8
HRI increasing from 0.371 to 0.445	HRI increasing from 0.757 to 0.777	HRI = 0.245
For AIs between 1.205 and 1.5	For AIs greater than 1.5	For AIs greater than 1.0
Total Catch = 17,000 + 151,721 * AI	Total Catch = 145,892 * AI	Total Catch = 171,130 * AI
Troll Catch = (151,721 * AI) * 0.8	Troll Catch = (145,892 * AI) * 0.8	Troll Catch = (171,130 * AI) * 0.8
HRI = 0.51	HRI = 0.85	HRI = 0.28
For AIs greater than 1.5		
Total Catch = 17,000 + 164,364 * AI		
Troll Catch = (164,364 * AI) * 0.8		
HRI = 0.5525		

[15] If alternative harvest rate metrics are adopted in any of the AABM fisheries this will necessitate a recalculation of the proportionality constants in the affected fisheries and will in turn lead to an adjustment of the associated HRI values in this appendix. However, the formulas to estimate total catch in this appendix and the catches in Table 1 will remain unaffected.

Table 3. Catches specified for AABM fisheries at levels of the Chinook abundance index (January 27, 2009 update).

Values for catch at levels of abundance between those stated may be linearly interpolated between adjacent values.

Abundance index	SEAK	NBC	WCVI
0.25	44,600	32,500	32,100
0.30	50,200	39,000	38,500
0.35	55,700	45,500	44,900
0.40	61,200	52,000	51,300
0.45	66,700	58,500	57,800
0.495	71,700	64,400	63,500
0.50	72,300	65,000	74,900
0.55	77,800	71,500	82,400
0.60	83,300	78,000	89,800
0.65	88,800	84,500	97,300
0.70	94,400	91,000	104,800
0.75	99,900	97,500	112,300
0.80	105,400	104,000	119,800
0.85	110,900	110,500	127,300
0.90	116,500	117,000	134,800
0.95	122,000	123,500	142,300
1.00	127,500	130,000	149,700
1.005	128,700	130,700	172,000
1.05	139,600	136,500	179,700
1.10	151,700	143,000	188,200
1.15	163,800	149,500	196,800
1.20	176,000	156,000	205,400
1.205	199,800	156,700	206,200
1.25	206,700	163,300	213,900

Puget Sound Coho

Puget Sound coho stocks are managed under the PST using a stepped harvest rate control rule (Figure 6) (Southern Coho Management Plan Chapter 5, Annex IV, Article XV, PST 2009). Under this control rule, exploitation rate ceilings are determined on the basis of abundance, where abundance is divided into three zones defined by two breakpoints defined as

$A = \frac{MSST}{1-F_{low}}$, breakpoint between critical and low abundance,

$B = \frac{S_{MSY}}{1-MFMT}$, breakpoint between low and normal abundance.

The exploitation rate ceiling has a maximum value of maximum fishing mortality threshold (MFMT; F_{MSY}) when N > B, is reduced to a low exploitation rate (F_{low}) when A < N < B, and further reduced to a critical exploitation rate ($F_{critical}$) to allow for *de minimis* impacts not to exceed 0.20 when N < A. For all Puget Sound coho stocks, the critical/low spawning escapement breakpoint and low exploitation rate are used to define minimum stock size threshold (MSST).

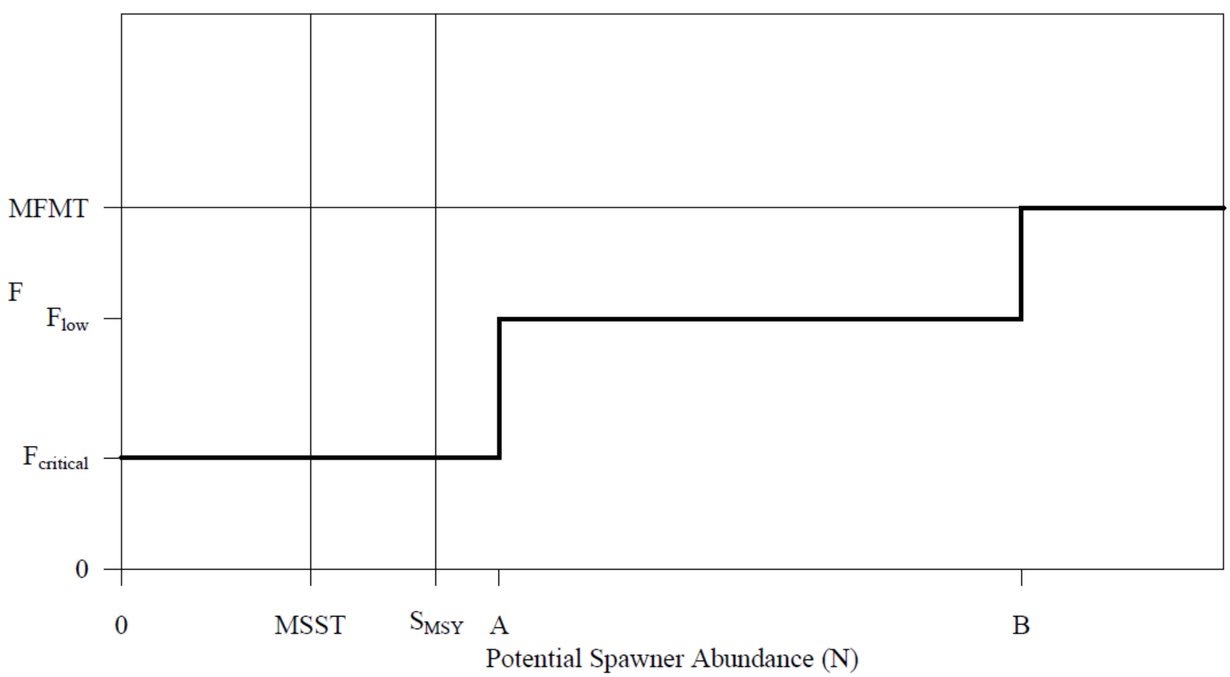

Figure 6. Control rule for Puget Sound coho. Abundance is pre-fishery ocean abundance in spawner equivalent units, and F is the exploitation rate.

Klamath & Sacramento Fall Chinook

Klamath River fall Chinook (KRFC) and Sacramento River fall Chinook (SRFC) have a control rule defined in terms of the reference points F_{ABC} ($0.95 * F_{MSY}$ and $0.9 * F_{MSY}$ for KRFC and SRFC, respectively), MSST, S_{MSY} (MSY spawning escapement), and two levels of *de minimis* exploitation rates, F = 0.10 and F = 0.25. The allowable exploitation rate, F, in a given year, depends on the pre-fishery ocean abundance in spawner equivalent units, N, as shown in Figure 7, with the abundance breakpoints defined as

$$A = \mathrm{MSST} / 2$$
$$B = (\mathrm{MSST} + S_{MSY}) / 2$$
$$C = S_{MSY} / (1 - 0.25)$$
$$D = S_{MSY} / (1 - F_{ABC}) .$$

For N between 0 and A, F increases linearly from 0 at N = 0, to 0.10 at N = A. For N between A and MSST, F is equal to 0.10. For N between MSST and B, F increases linearly from 0.10 at N = MSST, to 0.25 at N = B. For N between B and C, F is equal to 0.25. For N between C and D, F is the value that results in S_{MSY} spawners. For N greater than D, F is equal to F_{ABC}. The control rule may thus be summarized as follows.

$$F = \begin{cases} 0.10 \times (N / A), \\ 0.10, \\ 0.10 + (0.15 \times ((N - \mathrm{MSST}) / (B - \mathrm{MSST}))), \\ 0.25, \\ (N - S_{MSY}) / N, \\ F_{ABC}, \end{cases}$$

$$\begin{array}{ll} \text{if} & 0 \leq N \leq A; \\ \text{if} & A < N \leq \mathrm{MSST}; \\ \text{if} & \mathrm{MSST} < N \leq B; \\ \text{if} & B < N \leq C; \\ \text{if} & C < N \leq D; \\ \text{if} & D < N. \end{array}$$

The control rule describes maximum allowable exploitation rates at any given level of abundance. The Council may recommend lower exploitation rates as needed to address uncertainties or other year specific circumstances.

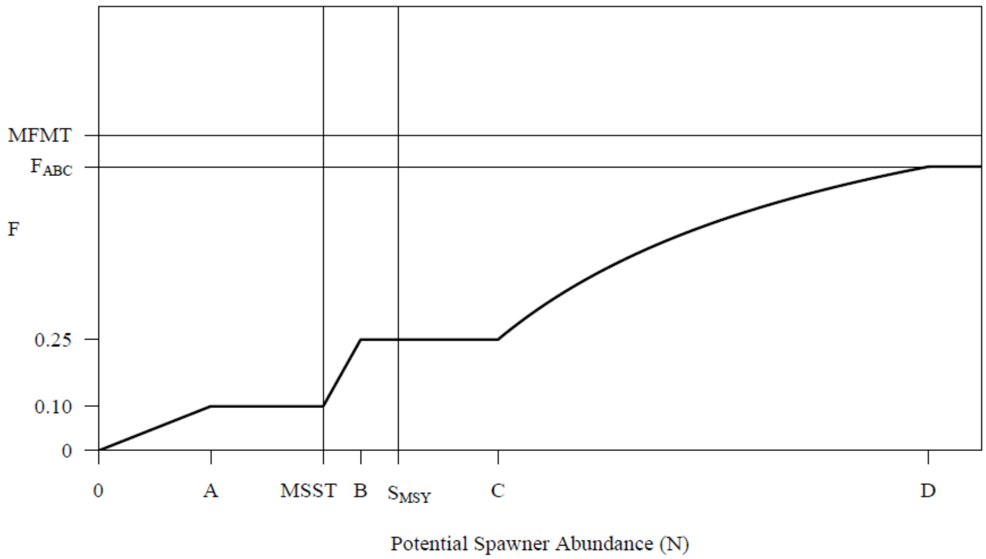

Figure 7. Control rule for SRFC and KRFC. Abundance is pre-fishery ocean abundance in spawner equivalent units, and F is the exploitation rate.

Oregon Coast Natural and Columbia River coho

An abundance-based exploitation strategy was adopted by the Council in 1997 for management of fisheries for Oregon Coast natural (OCN) and Columbia River natural (LCN) coho. The maximum allowable exploitation rates for OCN vary in response to changes in observed brood year-specific parental spawner abundance and marine survival conditions.

Table 4. Harvest management matrix identifying allowable fishery impacts and ranges of resulting recruitment based on parental spawner abundance and marine survival (OCN work group revisions to original Council matrix).

	Marine Survival Index (based on return of jacks per hatchery smolt)			
Parental Spawner Status*	**Extremely Low (<0.0008)**	**Low (0.0008-0.0014)**	**Medium (>0.0014-0.0040)**	**High (>0.0040)**
High (>75% of full seeding)	≤8%	≤15%	≤30%	≤45%
Medium (>50% to ≤75% of full seeding)	≤8%	≤15%	≤20%	≤38%
Low (>19% to ≤50% of full seeding)	≤8%	≤15%	≤15%	≤25%
Very Low (>4 fish/mile to ≤19% of full seeding)	≤8%	≤11%	≤11%	≤11%
Critical (≤4 fish/mile)	0-8%	0-8%	0-8%	0-8%

Sub-aggregate and Basin-specific Spawner Criteria Data

			Critical		Spawner Status Intervals		
Sub-aggregate	**Miles of Available Spawning Habitat**	**100% of Full Seeding**	**4 fish/mile**	**12% of full seeding**	**19% of full seeding**	**50% of full seeding**	**75% of full seeding**
Northern	899	21,700	3,596	NA	4,123	10,850	16,275
North-Central	1,163	55,000	4,652	NA	10,450	27,500	41,250
South-Central	1,685	50,000	6,740	NA	9,500	25,000	37,500
Southern	450	5,400	NA	648	1,026	2,700	4,050
Total	*4,197*	*132,000*		*15,636*	*25,099*	*66,050*	*99,075*

* Parental spawner abundance status for the OCN aggregate assumes the status of the weakest sub-aggregate.

** Critical parental status is defined as ≤4 fish per mi for the Northern, North-Central, and South-Central sub-aggregates; because of high quality spawning habitat in the Rogue River basin, critical status for the Rogue River (Southern sub-aggregate) is defined as 12% of full seeding of high quality habitat.

Columbia River Upriver Bright Fall Chinook

The parties to U.S. v Oregon are currently operating under the 2008-2017 Management Agreement. This agreement provides specific fishery management constraints for upriver spring, summer, and Fall Chinook, coho, sockeye and steelhead. Fall season fisheries in the Columbia River Basin below the confluence of the Snake River are managed according to the abundance based harvest rate schedule shown in Table 5. In this table, Upriver Bright (URB) stock Chinook harvest rates are used as a surrogate for Snake River wild Fall Chinook harvest rates. Upriver Bright Fall Chinook escapement goals include 7,000 adult Fall Chinook (4,000 females) to Spring Creek Hatchery and a 60,000 adult Fall Chinook (natural and hatchery) management goal above McNary Dam. Total harvest rates in combined Treaty Indian and non-Indian Columbia River fisheries increase with increased run size based on forecasted returns to the Columbia River.

Table 5. Columbia River Fall Management Period Chinook Harvest Rate Schedule for upriver bright Fall Chinook included the listed Snake River wild component.[1]

Expected URB River Mouth Run Size	Expected River Mouth Snake River Natural Origin Run Size [1]	Treaty Total Harvest Rate	Non-Treaty Harvest Rate	Total Harvest Rate	Expected Escapement of Snake R. Natural Origin Past Fisheries
<60,000	<1,000	20%	1.50%	21.50%	784
60,000	1,000	23%	4%	27.00%	730
120,000	2,000	23%	8.25%	31.25%	1,375
>200,000	5,000	25%	8.25%	33.25%	3,338
	6,000	27%	11%	38.00%	3,720
	8,000	30%	15%	45.00%	4,400

[1] If the Snake River natural fall Chinook forecast is less than level corresponding to an aggregate URB run size, the allowable mortality rate will be based on the Snake River natural fall Chinook run size.

FORCASTING TULE ABUNDANCE

The feasibility and effectiveness of an abundance-based fishing strategy depends in part on whether abundance can be predicted with reasonable accuracy and precision. Annual tule run size is currently predicted for fishery management purposes using sibling models for the LRH stock aggregate that consists primarily of lower river hatchery fish. Effective conservation-based management objectives would ideally be based on population-specific forecasts of wild fish. However, forecasts of aggregate or population-specific wild run components are not available for LCN tule Chinook at this time. Preliminary examinations by NMFS suggested that, absent better age composition data for the wild populations, it will be difficult to obtain forecasts of wild abundance that are meaningful to managers attempting to set harvest limits based on adult run size (Scheurell 2009) using currently available information. Therefore, this assessment also examined correlations between hatchery and wild population run sizes in order to evaluate whether the aggregate LRH forecast might serve as an effective indicator of wild population run strength.

This section reviews: 1) current methods of forecasting Columbia River LRH tule Fall Chinook abundance from LRH stock accounting, 2) forecast accuracy and precision of LRH, 3) correlations between hatchery and wild run size, and 4) the potential for forecast improvements.

Current Forecast Methods

Current forecast methods were summarized along with aggregate and population-specific information on run size and escapement, wild and hatchery composition, and age-composition. Correlations between age cohorts utilized in the sibling-based forecasts were reported.

Wild Fall Chinook numbers cannot practically be predicted due to a lack of reliable age composition data for many wild populations. Data is available for some of the larger populations (e.g. Coweeman and the Cowlitz). However, sample sizes are quite limited for the smaller, less productive populations due to the simple fact that escapement numbers are currently very low.

Sizes of the LRH Chinook run to the Columbia River mouth are currently predicted each year based on sibling relationships. Thus, the number of age 2 fish predicts the number of age 3 fish in the following year, 3's predict 4's, and 4's predict 5's. Figure 8 illustrates these relationships for the historical dataset back to the 1961 brood year. Forecasts of Age 2 numbers are typically based on a recent year average. Run composition typically averages 6% age 2, 37% age 3, 48% age 4, 8% age 5, and <1% age 6 (Table 6). Forecasts of LRH include both hatchery and natural fish. However, the hatchery component comprises the large majority of this run.

Relationships between age cohorts are not stable over time. For instance, Figure 8 shows a change in observed ratios coinciding with the ocean regime shift in the mid-1970s. Patterns also appear to be temporally autocorrelated at a smaller scale (although we did not attempt to quantify this effect). To accommodate these effects, annual forecasts are based on yearly decisions regarding which data periods appear to be most appropriate based on ad hoc judgments by a committee of stock assessment experts involved with the Columbia River fishery.

Current practice estimates numbers of fish recruited to ocean fisheries by back-calculating from the Columbia River forecasts based on approximate ocean harvest rates representative of recent return years.

Table 6. Historical run size of Columbia River tule Fall Chinook by age.

run	return						brood	Return						Age composition (by brood year)				
year	Age 2	Age 3	Age 4	Age 5	Age 6	total	year	Age 2	Age 3	Age 4	Age 5	Age 6	total	Age 2	Age 3	Age 4	Age 5	Age 6
1959							1959				0.8							
1960							1960			41.8	3.0							
1961							1961		42.4	85.7	7.7							
1962							1962	1.6	13.6	24.9	4.5		44.6	0.036	0.305	0.558	0.101	0.000
1963							1963	12.7	50.6	68.0	15.0		146.3	0.087	0.346	0.465	0.103	0.000
1964	1.6	42.4	41.8	0.8	0.0	86.6	1964	3.7	18.0	41.8	6.6		70.1	0.053	0.257	0.596	0.094	0.000
1965	12.7	13.6	85.7	3.0	0.0	115.0	1965	5.7	35.0	58.5	13.7		112.9	0.050	0.310	0.518	0.121	0.000
1966	3.7	50.6	24.9	7.7	0.0	86.9	1966	6.3	34.3	72.8	5.7		119.1	0.053	0.288	0.611	0.048	0.000
1967	5.7	18.0	68.0	4.5	0.0	96.2	1967	14.5	90.2	123.7	12.1		240.5	0.060	0.375	0.514	0.050	0.000
1968	6.3	35.0	41.8	15.0	0.0	98.1	1968	16.4	51.6	101.1	38.5		207.6	0.079	0.249	0.487	0.185	0.000
1969	14.5	34.3	58.5	6.6	0.0	113.9	1969	8.7	38.4	106.5	13.8		167.4	0.052	0.229	0.636	0.082	0.000
1970	16.4	90.2	72.8	13.7	0.0	193.1	1970	8.3	70.1	93.6	20.2		192.2	0.043	0.365	0.487	0.105	0.000
1971	8.7	51.6	123.7	5.7	0.0	189.7	1971	6.7	46.8	123.5	20.5		197.5	0.034	0.237	0.625	0.104	0.000
1972	8.3	38.4	101.1	12.1	0.0	159.9	1972	4.6	39.8	74.4	17.6		136.4	0.034	0.292	0.545	0.129	0.000
1973	6.7	70.1	106.5	38.5	0.0	221.8	1973	9.8	76.1	85.9	8.0		179.8	0.055	0.423	0.478	0.044	0.000
1974	4.6	46.8	93.6	13.8	0.0	158.8	1974	9.6	61.6	102.2	10.4	0.1	183.9	0.052	0.335	0.556	0.057	0.001
1975	9.8	39.8	123.5	20.2	0.0	193.3	1975	6.4	56.3	57.4	6.5	0.0	126.6	0.051	0.445	0.453	0.051	0.000
1976	9.6	76.1	74.4	20.5	0.0	180.6	1976	8.4	50.9	63.1	5.1	0.0	127.5	0.066	0.399	0.495	0.040	0.000
1977	6.4	61.6	85.9	17.6	0.0	171.5	1977	7.4	35.9	43.1	4.8	0.1	91.2	0.081	0.394	0.472	0.053	0.001
1978	8.4	56.3	102.2	8.0	0.0	174.9	1978	5.4	46.6	48.4	2.5	0.1	103.1	0.053	0.452	0.470	0.025	0.001
1979	7.4	50.9	57.4	10.4	0.0	126.1	1979	8.2	86.2	40.6	1.6	0.0	136.6	0.060	0.632	0.297	0.012	0.000
1980	5.4	35.9	63.1	6.5	0.1	111.0	1980	9.5	44.9	47.9	6.3	0.2	108.8	0.088	0.413	0.440	0.058	0.001
1981	8.2	46.6	43.1	5.1	0.0	103.0	1981	3.0	49.3	42.7	8.5	0.1	103.6	0.029	0.476	0.412	0.082	0.001
1982	9.5	86.2	48.4	4.8	0.0	149.0	1982	5.7	62.0	49.3	7.9	0.1	125.0	0.045	0.496	0.395	0.064	0.001
1983	3.0	44.9	40.6	2.5	0.1	91.1	1983	17.0	96.8	98.7	11.7	0.1	224.4	0.076	0.432	0.440	0.052	0.000
1984	5.7	49.3	47.9	1.6	0.1	104.6	1984	30.1	237.3	270.8	48.1	1.8	588.2	0.051	0.404	0.460	0.082	0.003
1985	17.0	62.0	42.7	6.3	0.0	128.0	1985	4.1	27.3	57.3	8.6	0.1	97.4	0.042	0.281	0.588	0.088	0.001
1986	30.1	96.8	49.3	8.5	0.2	184.9	1986	4.3	25.5	33.5	3.5	0.0	66.8	0.064	0.381	0.502	0.053	0.001
1987	4.1	237.3	98.7	7.9	0.1	348.2	1987	2.5	16.0	19.7	2.6	0.0	40.8	0.061	0.392	0.482	0.064	0.000
1988	4.3	27.3	270.8	11.7	0.1	314.2	1988	6.6	39.4	30.4	3.8	0.0	80.2	0.083	0.491	0.379	0.047	0.000
1989	2.5	25.5	57.3	48.1	0.1	133.4	1989	9.2	29.6	28.0	4.8	0.0	71.6	0.129	0.413	0.391	0.067	0.001
1990	6.6	16.0	33.5	8.6	1.8	66.6	1990	6.3	20.5	24.3	5.2	0.1	56.4	0.112	0.364	0.432	0.091	0.001
1991	9.2	39.4	19.7	3.5	0.1	71.9	1991	2.4	24.5	17.0	1.9	0.0	45.8	0.053	0.533	0.371	0.042	0.000
1992	6.3	29.6	30.4	2.6	0.0	68.9	1992	2.7	24.1	36.3	4.9	0.1	68.2	0.040	0.354	0.532	0.072	0.002
1993	2.4	20.5	28.0	3.8	0.0	54.8	1993	3.5	37.2	39.6	9.1	0.1	89.5	0.039	0.416	0.442	0.101	0.001
1994	2.7	24.5	24.3	4.8	0.0	56.3	1994	4.0	12.9	14.9	1.4	0.0	33.1	0.120	0.389	0.449	0.041	0.000
1995	3.5	24.1	17.0	5.2	0.0	49.9	1995	1.4	21.2	20.7	2.3	0.0	45.6	0.031	0.464	0.454	0.050	0.001
1996	4.0	37.2	36.3	1.9	0.1	79.5	1996	2.0	17.8	18.3	2.3	0.0	40.4	0.049	0.440	0.453	0.057	0.000
1997	1.4	12.9	39.6	4.9	0.0	58.8	1997	0.8	6.4	31.5	4.6	0.1	43.4	0.018	0.148	0.726	0.106	0.002
1998	2.0	21.2	14.9	9.1	0.1	47.2	1998	3.6	60.5	86.2	16.8	0.6	167.7	0.022	0.361	0.514	0.100	0.004
1999	0.8	17.8	20.7	1.4	0.1	40.7	1999	9.3	65.6	107.0	21.5	0.5	203.9	0.046	0.322	0.525	0.106	0.002
2000	3.6	6.4	18.3	2.3	0.0	30.6	2000	2.9	31.1	63.1	16.0	0.4	113.5	0.026	0.274	0.556	0.141	0.003
2001	9.3	60.5	31.5	2.3	0.0	103.6	2001	1.5	23.8	45.5	13.2	0.2	84.3	0.017	0.283	0.540	0.157	0.003
2002	2.9	65.6	86.2	4.6	0.0	159.4	2002	2.3	16.3	32.1	3.8	0.1	54.7	0.042	0.298	0.587	0.070	0.002
2003	1.5	31.1	107.0	16.8	0.1	156.5	2003	1.2	12.6	12.5	1.7	0.0	28.0	0.044	0.449	0.445	0.062	0.000
2004	2.3	23.8	63.1	21.5	0.6	111.4	2004	2.9	16.2	20.8	2.1	0.0	42.0	0.070	0.384	0.496	0.051	0.000
2005	1.2	16.3	45.5	16.0	0.5	79.5	2005	4.0	38.9	44.9	4.8		92.7	0.043	0.420	0.485	0.052	0.000
2006	2.9	12.6	32.1	13.2	0.4	61.3	2006	5.3	29.7	26.5								
2007	4.0	16.2	12.5	3.8	0.2	36.7	2007	8.9	71.6									
2008	5.3	38.9	20.8	1.7	0.1	66.9	2008	5.5										
2009	8.9	29.7	44.9	2.1	0.0	85.6	2009											
2010	5.5	71.6	26.5	4.8	0.0	108.5	2010											
Mean	6.5	44.8	59.1	9.3	0.1	119.8		6.5	44.8	59.1	9.3	0.2	120.4	0.055	0.373	0.495	0.076	0.001
Min	0.8	6.4	12.5	0.8	0.0	30.6		0.8	6.4	12.5	0.8	0.0	28.0	0.017	0.148	0.297	0.012	0.000
Max	30.1	237.3	270.8	48.1	1.8	348.2		30.1	237.3	270.8	48.1	1.8	588.2	0.129	0.632	0.726	0.185	0.004

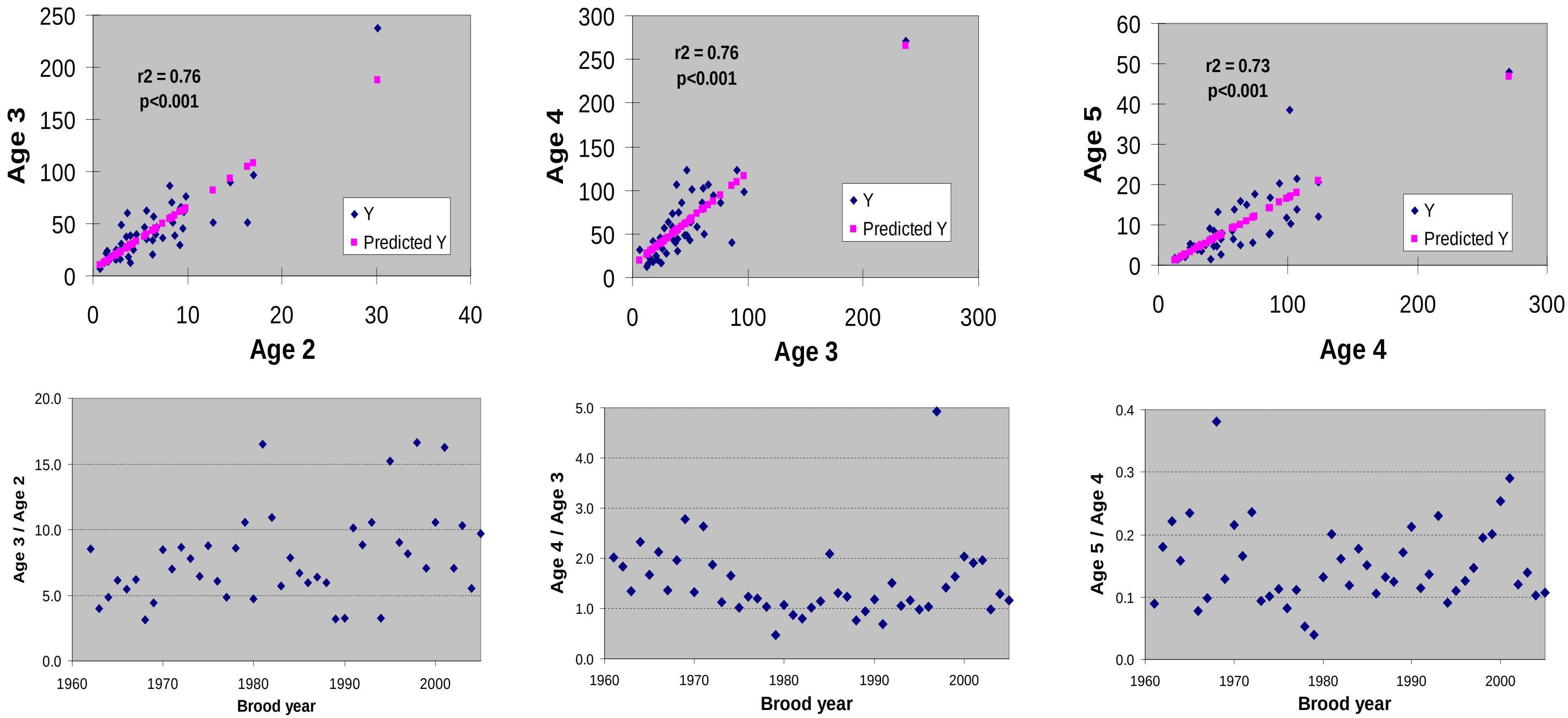

Figure 8. **Relationships between age groups by brood year of Columbia River tule Fall Chinook at return (numbers in thousands).**

Forecast Accuracy & Precision

Forecast accuracy and precision was estimated by a retrospective comparison of pre and post-season estimates of predicted and actual run size numbers for the aggregate LRH return. Numbers were based on Columbia River mouth returns of adults. Forecast error was estimated as [(predicted-actual)/actual] expressed as a percentage. Thus, negative numbers reflect under-predictions and positive number represent over-predictions. Accuracy was described based on the average of errors. Precision was described as the standard deviation of errors.

On average, forecasts of LRH Chinook have been relatively accurate over the period from 1980 through 2009 (Table 7). Error averaged just -2% for predicted number of total adults. However, errors were highly auto-correlated among years with a consistent pattern of under prediction from 1994 through 2006 (Figure 9). Forecasts were relatively accurate on average for age 3 (1% average error) and age 4 (-3% average error) (Table 7). Age 5 fish were more consistently under-predicted (-16% average error) although this age group typically comprises less than 10% of the run.

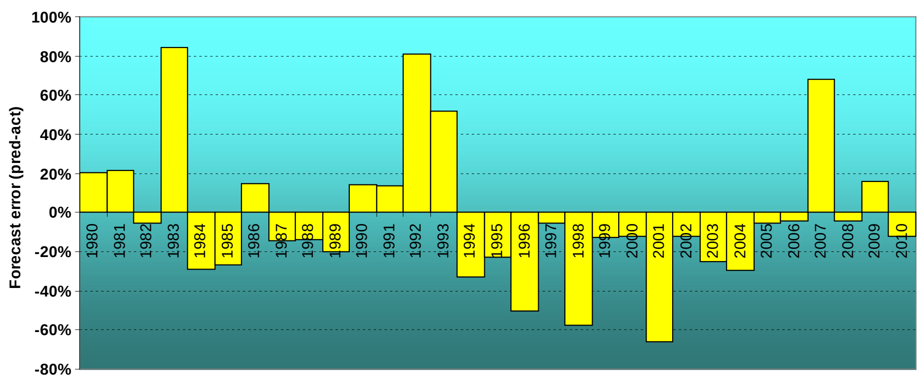

Figure 9. Past errors in forecasts of total annual adult returns of LRH tule Chinook to the Columbia River mouth, 1980-2009.

Annual predictions ranged from -66% to 85% of the actual return with a standard deviation of 37% over the period of record. The distribution of errors is slightly skewed to negative values although three quarters of values are within ±30% of the actual number.

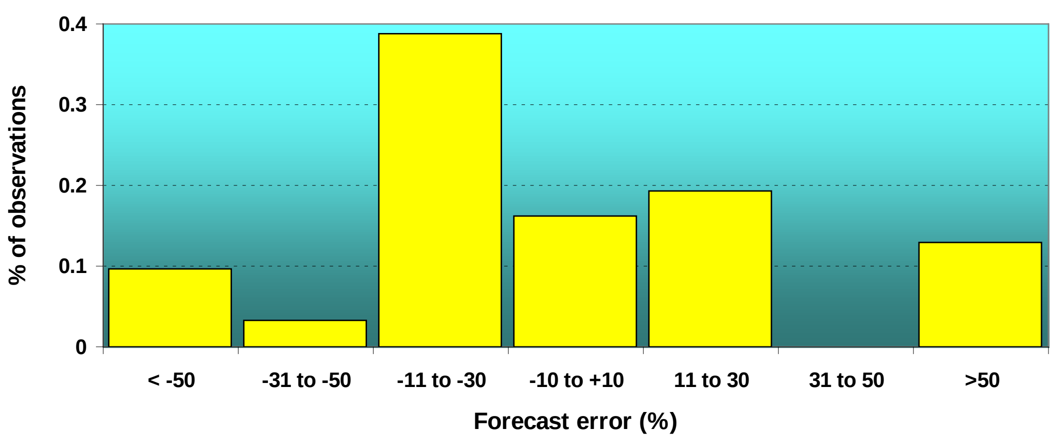

Figure 10. Frequency distribution of forecast errors.

Table 7. Forecast error based predicted and actual returns (thousands) of LRH Chinook to the Columbia River mouth, 1980-2009.

	Total Adults			Age 3			Age 4			Age 5		
Year	**Predicted**	**Actual**	**Error**	**Predicted**	**Actual**	**Error**	**Predicted**	**Actual**	**Error**	**Predicted**	**Actual**	**Error**
1980	127.3	105.6	21%									
1981	115.0	94.9	21%									
1982	132.2	139.5	-5%									
1983	162.5	88.1	85%									
1984	70.4	98.9	-29%	25.0	49.3	-49%	41.7	47.9	-13%	3.7	1.6	132%
1985	81.5	111.0	-27%	37.7	62.0	-39%	38.7	42.7	-9%	5.1	6.3	-19%
1986	177.6	154.8	15%	108.0	96.8	12%	65.4	49.3	33%	4.2	8.5	-51%
1987	294.9	344.1	-14%	189.0	237.3	-20%	100.9	98.7	2%	5.0	7.9	-37%
1988	267.7	309.9	-14%	36.5	27.3	33%	219.1	270.8	-19%	12.1	11.7	3%
1989	104.9	130.9	-20%	32.5	25.5	28%	40.6	57.3	-29%	31.8	48.1	-34%
1990	68.5	60.0	14%	22.4	16.0	40%	39.1	33.5	17%	7.0	8.6	-19%
1991	71.4	62.7	14%	52.1	39.4	32%	15.8	19.7	-20%	3.5	3.5	-1%
1992	113.2	62.6	81%	65.1	29.6	120%	47.2	30.4	55%	0.9	2.6	-65%
1993	79.3	52.3	51%	45.5	20.5	122%	30.7	28.0	10%	3.1	3.8	-18%
1994	36.1	53.6	-33%	14.1	24.5	-42%	19.1	24.3	-22%	2.9	4.8	-39%
1995	35.8	46.4	-23%	16.8	24.1	-30%	17.7	17.0	4%	1.3	5.2	-75%
1996	37.7	75.5	-50%	22.0	37.2	-41%	15.3	36.3	-58%	0.4	1.9	-79%
1997	54.2	57.4	-6%	25.3	12.9	96%	26.2	39.6	-34%	2.7	4.9	-45%
1998	19.2	45.3	-58%	7.6	21.2	-64%	8.0	14.9	-46%	3.6	9.1	-60%
1999	34.8	39.9	-13%	12.3	17.8	-31%	20.8	20.7	0%	1.7	1.4	25%
2000	23.7	27.0	-12%	5.5	6.4	-14%	16.2	18.3	-12%	2.0	2.3	-12%
2001	32.2	94.3	-66%	23.5	60.5	-61%	6.7	31.5	-79%	2.0	2.3	-13%
2002	137.6	156.4	-12%	60.6	65.6	-8%	72.7	86.2	-16%	4.3	4.6	-7%
2003	115.9	155.0	-25%	21.8	31.1	-30%	80.1	107.0	-25%	14.0	16.8	-17%
2004	77.1	109.1	-29%	13.3	23.8	-44%	45.8	63.1	-27%	18.0	21.5	-16%
2005	74.1	78.3	-5%	19.2	16.3	18%	44.6	45.5	-2%	10.3	16.0	-35%
2006	55.8	58.3	-4%	12.4	12.6	-1%	34.8	32.1	8%	8.6	13.2	-35%
2007	54.9	32.7	68%	19.4	16.2	20%	29.2	12.5	134%	6.3	3.8	64%
2008	59.0	61.6	-4%	26.6	38.9	-32%	30.9	20.8	48%	1.5	1.7	-13%
2009	88.8	76.7	16%	36.8	29.7	24%	48.7	44.9	8%	3.3	2.1	55%
2010	90.6	103.0	-12%	43.7	71.6	-39%	38.2	26.5	44%	8.7	4.8	80%
2011	133.5			38.7			90.6			4.3		
Mean	*94.6*	*99.5*	*-3%*	***36.9***	41.3	***0%***	***45.9***	48.9	***-2%***	***6.2***	8.1	***-12%***
SD	*63.8*	*70.9*	*36%*	***36.7***	45.1	***51%***	***42.2***	51.4	***41%***	***6.8***	9.7	***46%***

Hatchery-Wild Correlations

Methods

Correlations were examined among historical data on total LRH returns, hatchery releases, a hatchery survival index, and naturally-produced fish returning to Washington streams. LRH return data to the Columbia River mouth were available for 1964-2010 from WDFW. Hatchery release data for LRH tule fall Chinook released downstream from Bonneville Dam from 1964-2008 were compiled from the Pacific Marine Fisheries Commission (PSMFC) Regional Mark Information System database. An annual survival rate index was estimated as the quotient of total brood year LRH return across all ages and total hatchery release. For comparison with run year returns, a run year survival index was also calculated by averaging brood-year survival rates among ages weighted in proportion to the age composition in each year. Both these indices would of course be inflated by a small amount in proportion to the number of wild fish included the LRH return (since wild juveniles are not included in the denominator).

Results

The aggregate LRH return was at least partially correlated with wild numbers considered in aggregate and in many or most wild populations throughout the historical data set and in the recent 10-year period. Table 8 and Table 9 show the correlation coefficients and significance levels among pair-wise comparisons of LRH and wild run size numbers. The strongest relationships were observed between the LRH and wild total returns (Figure 11). Population-specific correlations to the LRH return varied as did correlations among the individual wild populations.

Correlations were similar for the survival rate index and the total LRH return. Stronger correlations were expected to the survival rate index which controlled for effects of variable hatchery release numbers over time. Forecasts based strictly on hatchery numbers may be confounded by effects of changes in hatchery release levels. Indices based on survival rather than numbers should avoid this effect. However, this was not apparent. The survival index did appear to be related to hatchery release numbers. Survival rates increased concurrent with reduction in hatchery release numbers in the late 1990s in response to reductions in Federal Mitchell Act funding. Effects of ocean conditions, ecological factors and release numbers were not distinguished but at least some of this improvement likely resulted from the reduction in the less successful hatchery programs measured in terms of lower juvenile to adult survival success.

These results suggest that further analyses of an abundance-based approach to tule harvest rate management are appropriate. While wild numbers cannot be predicted directly at this time, aggregate forecasts based primarily on hatchery returns appear to be a suitable proxy due to common effects of marine conditions to which both hatchery and wild fish are subject.

Table 8. Correlation matrix (r values) of LRH run size to the Columbia River and wild run size numbers to Washington streams, 1977-2010 run years .

	LRH run	LRH surv.	Wild total	Grays	Mill/Ab/Ger	Elochoman	Coweeman	Cowlitz	Kalama	Lewis	Washougal
LRH run size	1.00	--	--	--	--	--	--	--	--	--	--
LRH survival	0.80***	1.00	--	--	--	--	--	--	--	--	--
Wild total	0.65***	0.59***	1.00	--	--	--	--	--	--	--	--
Grays	0.47***	0.51***	0.18	1.00	--	--	--	--	--	--	--
Mill/Ab/Ger	0.67***	0.49***	0.66***	0.47***	1.00	--	--	--	--	--	--
Elochoman	0.27*	0.42**	0.41**	0.14	0.46***	1.00	--	--	--	--	--
Coweeman	0.08	0.00	0.63***	0.12	0.12	0.07	1.00	--	--	--	--
Cowlitz	0.28**	0.61***	0.47***	0.02	0.08	0.49***	0.12	1.00	--	--	--
Kalama	0.55***	0.27*	0.75***	0.21	0.48***	0.08	0.60***	0.12	1.00	--	--
Lewis	0.24*	0.43**	0.18	0.44***	0.21	0.05	0.15	0.18	0.07	1.00	--
Washougal	0.03	0.10	0.35**	0.31	0.15	0.01	0.27*	0.31**	0.03	0.13	1.00

**** p-value<0.01*
*** p-value<0.10*
** p-value<0.20*

Table 9. Correlation matrix (r values) of LRH run size to the Columbia River and wild run size numbers to Washington streams, 2000-2010 run years .

	LRH run	LRH surv.	Wild total	Grays	Mill/Ab/Ger	Elochoman	Coweeman	Cowlitz	Kalama	Lewis	Washougal
LRH run size	1.00	--	--	--	--	--	--	--	--	--	--
LRH survival	0.99***	1.00	--	--	--	--	--	--	--	--	--
Wild total	0.92***	0.90**	1.00	--	--	--	--	--	--	--	--
Grays	0.06	0.14	0.01	1.00	--	--	--	--	--	--	--
Mill/Ab/Ger	0.50*	0.49*	0.63**	0.05	1.00	--	--	--	--	--	--
Elochoman	0.50*	0.44*	0.70**	0.20	0.79***	1.00	--	--	--	--	--
Coweeman	0.64**	0.57**	0.62**	0.46*	0.03	0.34	1.00	--	--	--	--
Cowlitz	0.88***	0.87***	0.89***	0.00	0.24	0.45*	0.66**	1.00	--	--	--
Kalama	0.11	0.15	0.03	0.24	0.39	0.18	0.16	0.25	1.00	--	--
Lewis	0.25	0.26	0.23	0.10	0.46*	0.03	0.23	0.05	0.58**	1.00	--
Washougal	0.44*	0.48*	0.42*	0.47*	0.14	0.16	0.35	0.52*	0.06	0.07	1.00

**** p-value<0.01*
*** p-value<0.10*
** p-value<0.20*

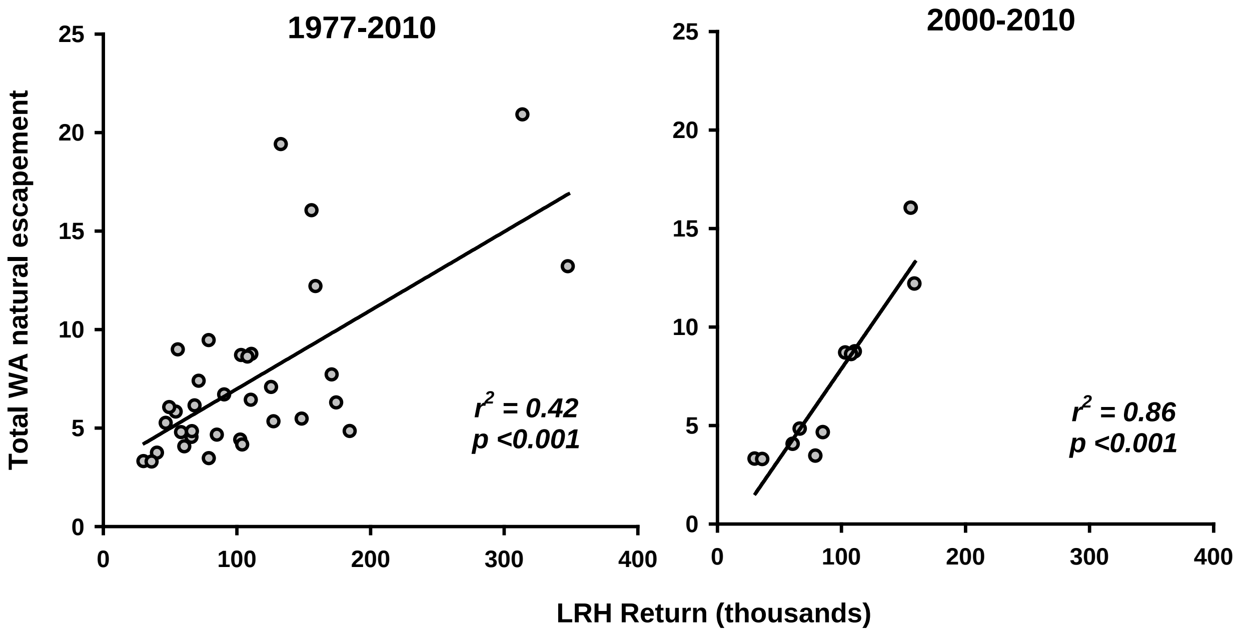

Figure 11. Correlations between the aggregate LRH lower river hatchery return of tule Fall Chinook to the Columbia River and total escapement of natural-origin tules to Washington streams downstream from Bonneville Dam.

Discussion

In should be noted that the reported significance levels assume independence among data points but annual run sizes and survival are not independent of adjacent years. This is not important for the purpose of this analysis, to find a pattern in the data without inferring the underlying biological process. The abundance of a given age class at a given time is used to compute both LRH run and LRH survival. Thus, observational error (not biological variation) of abundance can induce a false correlation between the two variables. P-values of 0.1 and 0.2 are a relatively low standard for "significance," especially since the data are not independent. For the 55 correlations examined above, we should expect about three spurious correlations if we applied the usual 0.05 significance level. However, results are clearly indicative of a significant partial correlation between hatchery and natural tule Fall Chinook numbers.

Potential for Forecast Improvements

Forecasts can be improved in a number of ways. Recommendations for improvements include:

1) Forecasts based on wild fish returns, rather than hatchery fish returns, should be developed. Ideally these forecasts would be population-specific with mixed stock management decisions based on consideration for an aggregate of the weaker stocks. Development of such forecasts entails implementing, or continuing to implement, monitoring of wild fish.

2) In order to make forecasts more accurate, environmental variables that account for variability in returns should be identified and included in forecast models.

3) Alternative forecasting methods should be explored.

The remainder of this section describes an initial exploratory effort addressing the second and third recommendations above.

Methods

The potential for improvement in forecast accuracy was evaluated by an examining the effects of incorporating indicators of ocean environmental conditions into the forecast models. However, the accuracy of traditional forecasting methods such as multiple regression can be compromised by high co-linearity among independent variables – metrics of marine conditions are known to be highly correlated with one another. Therefore an autoregressive neural network approach was explored to test the feasibility for improving tule forecasts by incorporating various metrics related to marine conditions.

A neural network is a machine learning method, with origins in the field of artificial intelligence. Neural networks are widely applied in engineering and economic contexts (e.g. missile guidance systems, stock market prediction) but are seldom used in ecological science. Nonetheless, neural networks have properties that make them inherently and demonstrably superior to more traditional methods such as generalized linear models. In particular, neural networks are well suited to problems where multiple interacting factors nonlinearly influence some phenomenon of interest. This is precisely the nature of the LRH forecast problem, with the exception that both LRH abundance and the marine conditions used to predict LRH abundance are time-series. For this reason, a neural network was applied with internal structure that accommodates the time-series nature of these data was evaluated. This kind of neural network is known as a NARX network (nonlinear autoregressive network with exogenous inputs), and has the form

$$y_t = f(y_{t-1}, y_{t-2}, \ldots y_{t-4}, x1_{t-1}, x1_{t-2}, \ldots x1_{t-4}, x2_{t-1}, x2_{t-2}, \ldots x3_{t-4}, \ldots xn)$$

where the function f includes complex interactions among the n different predictor variables, x.

Variables compared to the LRH aggregate run size included the number of jacks in the previous two runs, the Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation (NPGO), Ocean Nino Index (ONI), and multivariate ENSO Index (MEI). Ocean data were as reported by Scheurell (2009) and Rupp et al. (2010). Analyses were limited to data that are available in the pre-season time frame when forecasts are made. (Some ocean data considered in other analyses were only available post-season.)

Fitting a neural network is unlike traditional methods because the predictions of a complex network are capable of exactly matching observations. Thus, the essence of fitting a neural network is to prevent the network from becoming overfit (i.e. the model not only fits the signal, but also fits the noise. This results in false confidence in the model's prediction of new observations). Overfitting is prevented by withholding data from the model fitting process and using it to evaluate model performance. The original data set includes 40 observations (1962-2001). Since lag-4 autoregressive framework was used, there are 36 observations that can be predicted. These 36 observations were pseudorandomly broken into three groups: i) 26 observations were used to fit the model, ii) five observations were used to determine when the model begins to become overfit, and iii) five observations were used as an independent test of model predictions. The partitioning of the 36 observations into these three groups is pseudorandom because I repeated the process of dividing data and fitting the model was repeated several times. Estimation stopped when the model effectively predicted the data withheld for testing (group iii).

Model performance was assessed based on a statistic called Ordinary Cross-Validation (OCV) that describes the predictive ability of the model (Rupp et al. 2010). The process will: (1) leave out a single point, (2) fit the model, (3) obtain a prediction of the point that was left out, (4) subtract the empirically observed value from the prediction, and (5) square this difference. These steps are repeated until every point has been sequentially left out. Summing all the values obtained on the 5th step yields the numerator in the equation below. The denominator is simply the variance of the entire data set.

$$\text{OCV} = 1 - \frac{\sum_{i=1}(\hat{y}_i - y_i)^2}{\sum_{i=1}(\bar{y} - y_i)^2}$$

The approach applied simultaneously leaves out 12 points rather than sequentially leaving out all the points. A statistic that is similar to OCV was calculated

$$1 - \frac{\sum_{i=1}^{i=6}(\hat{y}_i - y_i)^2 / 6}{\sum_{k=1}^{l=36}(\bar{y} - y_k)^2 / 36}$$

Where j=5 are the five points used as independent tests (red dots, Figure 12). Using averages in the numerator and denominator rather than the sum, as in OCV, rescales the statistic to a single observation.

Results

Results of the nonlinear autoregressive network model are displayed in Figure 12. The model appeared to reasonably predict aggregate LRH abundance. Model results provided a rescaled goodness of fit value of 0.86. This compares favorably with OCV scores of approximately 0.6 – 0.7 estimated by Rupp et al. (2010) for coho forecast models. However, LRH model results should be interpreted cautiously because the year of extremely high abundance (Time = 18) contributes to the denominator of the equation but does not contribute to the numerator. This would not be true of the OCV value. Furthermore, as with any neural network, concern that this model is over fit is legitimate.

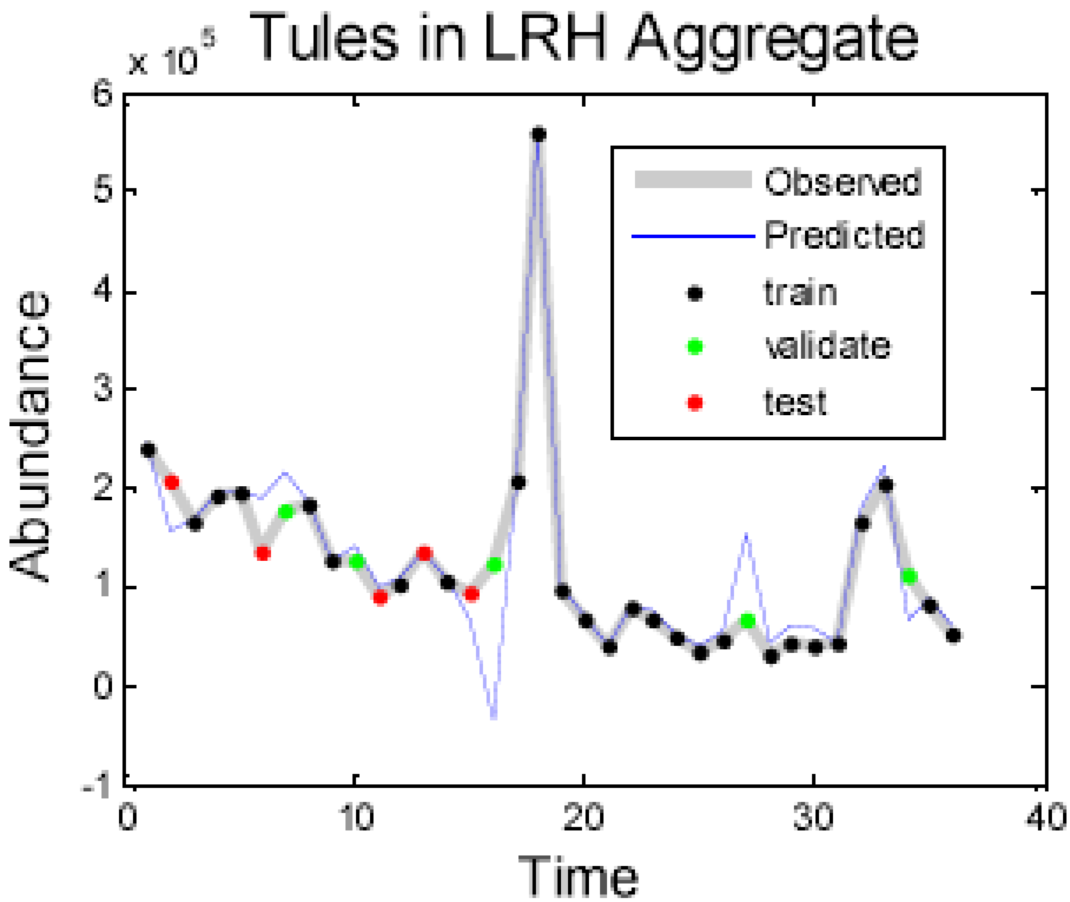

Figure 12. Results of an autoregressive neural network fit to LRH aggregate Tule Chinook abundance. The x-axis is years, beginning with 1966. All points are empirical observations. The black points were pseudo-randomly chosen to train/fit the model. Training/fitting stopped when the difference between predictions and the green points began to increase (i.e. the model showed evidence of overfitting). The red points were never used during model development and can therefore be used as an independent test of model performance.

Discussion

While wild numbers cannot be forecast directly, their partial correlation with LRH abundance makes the aggregate forecasts a suitable index for implementation of an abundance-based management approach.

Analyses of alternative forecast methods suggest that it might be feasible to improve forecast accuracy of LRH abundance by incorporation of some combination of marine indicator variables. However, any proposed improvements in forecast techniques will need to be tested with pre- and post-season comparisons of alternative forecast methods. In the interim, the TCW recommends that considerations of abundance-based fishing strategies for LCN tule Fall Chinook continue to be based on current forecast methods.

Analyses also highlight the need for improvements in data on natural population status and trends, including numbers, age composition, hatchery fractions, and productivity. Both Oregon and Washington have initiated significant efforts to augment existing monitoring of wildnatural populations with additional sampling. It is likely that additional data will at some point improve our ability to more directly forecast natural abundance at a population scale.

FISHING RATES, CONTRIBUTIONS & EFFECTS

While fishery impact limits on LCN tule Fall Chinook obviously affect harvest of this stock, they can also constrain access to harvest of other Chinook stocks in mixed stock fisheries occurring in the ocean and Columbia River. Thus, conservation benefits of lower impact rates limits on natural stocks can come at the cost of significant harvest reductions of other stocks. Impact reductions and costs in foregone harvest do not fall on all fisheries evenly or in proportion to their share of the harvest impact due to the particulars of regulatory authorities and management agreements governing fisheries that impact LCN tule Fall Chinook.

This section: 1) summarizes recent harvest patterns of Columbia River tule Fall Chinook, 2) describes management of LCN tule Fall Chinook including fishery effects, and 3) evaluates potential the impact of different ceiling exploitation rates on ocean and Columbia River fisheries.

Harvest patterns

Recent harvest patterns were summarized based on total and fishery-specific annual impact rates to establish a baseline point of reference. All rates are expressed in terms of adult equivalents, the same metric used for fishery impact assessment for ESA. Observed rates were taken from post-season runs of FRAM using actual landings by fishery and post season estimates of FRAM stock abundances. Observed and target rates were compared for each year to identify fishery implementation uncertainty.

LCN tule Fall Chinook are harvested in ocean fisheries from Alaska Oregon and in the Columbia River and the cumulative exploitation rate in combined fisheries is significant. Prior to 1990, total exploitation rates regularly reached 0.65 and rates exceeding 0.80 were seen in some years (Figure 13, Table 10). Rates were substantially reduced around the mid-1990s with reductions in Council and Canadian ocean fisheries during a period of low runs for many stocks. However, exploitation increased again by 2000 as fisheries recovered. Fishery impact limits were established by NMFS beginning in 2002. Limits were reduced from 0.49 in 2002-2006, to 0.42 in 2007, 0.38 in 2009-2010, and 0.37 in 2011.

The majority of the ocean harvest of LCN tule Fall Chinook currently occurs in fisheries off Alaska and Canada which are governed by the Pacific Salmon Treaty (PST) (Figure 13). Canadian fisheries, primarily off the west Coast of Vancouver Island (WCVI), accounted for about 39% of the total fishery exploitation rate on LCN tules from 2001-2010. In 2010, impact included approximately 0.14 in Canada and SE Alaska ocean, 0.14 in Council fisheries, and 0.06 in Columbia River fisheries.

Tule Fall Chinook typically comprise only a limited portion of the harvest in mixed stock fisheries. LRH tules typically comprise only about 1% of the total Chinook harvest in southeast Alaska and northern British Columbia fisheries, increasing to about 10-15% in the WCVI fishery (CTC 2011). These fisheries harvest a broad mixture of stocks originating in Alaska, Canada, Oregon and Washington. In the Council fisheries north of Cape Falcon, Oregon, LRH tules typically comprise about 20-30% of the harvest (CTC 2009).

In the Columbia River, LRH tule Fall Chinook typically comprise only about 20% on average of the annual Chinook harvest in sport and commercial fisheries downstream from Bonneville Dam. The majority of the Columbia River harvest is of other Fall Chinook stocks including Upriver Brights destined for natural spawning areas upstream from Bonneville Dam, hatchery-produced bright stocks destined for mid-Columbia facilities, and Bonneville Pool Hatchery tules produced at Spring Creek Hatchery. Tules are more important in some Columbia River fisheries than others. For instance, tules typically comprise a higher percentage of the harvest in the Buoy 10 sport fishery at the mouth of the Columbia than in other sport and commercial fisheries upstream.

Since fishery impact limits were established, ERs have averaged 0.02 less than the established limits although annual rates may have been more or less than the limits due to variability in run sizes relative to forecasts and variability in observed versus expected catches (Table 10, Figure 14). Actual rates have been 0.01 to 0.08 less than the ceiling for the last three years.

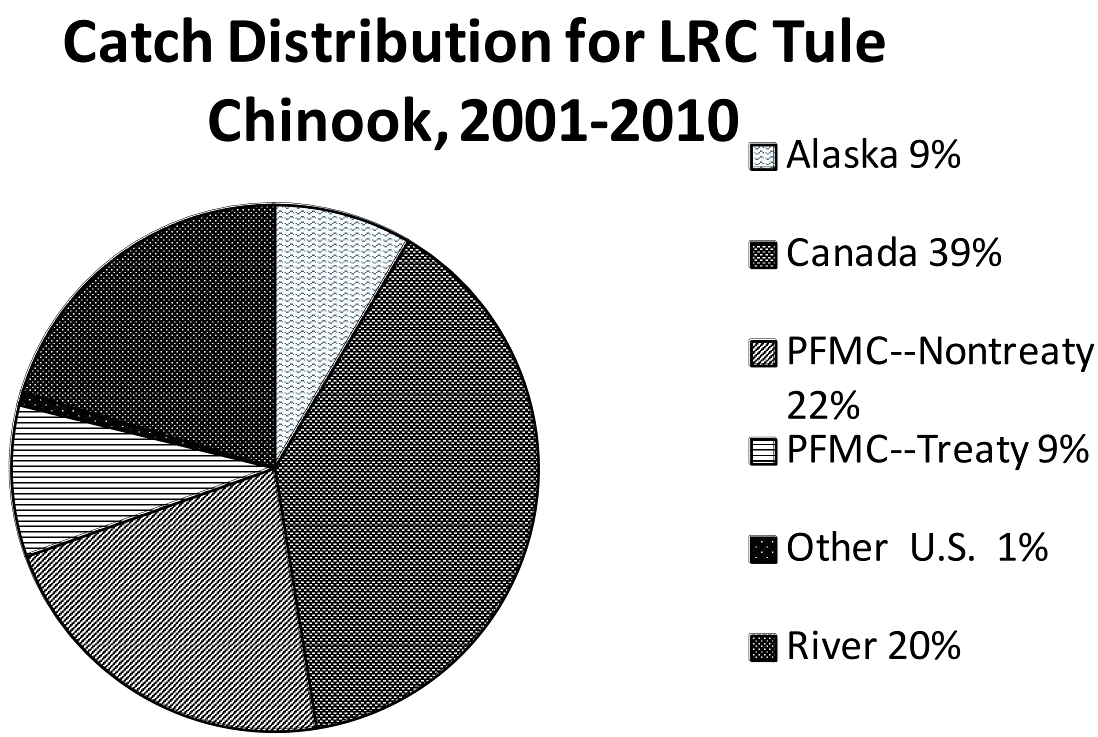

Figure 13. Catch distribution for lower Columbia natural-origin tule Fall Chinook, 2001-2010.

Table 10. Exploitation rates (% in adult equivalents) by fishery for lower Columbia natural-origin tule Fall Chinook from FRAM post-season model runs.

Year	Alaska	Canada	Council--Nontreaty	Council--Treaty	Other So. U.S. Marine	River	Total ER	ESA ER Ceiling
1983	4%	37%	16%	2%	2%	7%	68%	--
1984	4%	40%	4%	1%	3%	17%	68%	--
1985	4%	30%	11%	2%	3%	10%	60%	--
1986	3%	30%	11%	1%	4%	29%	78%	--
1987	4%	28%	12%	2%	3%	29%	78%	--
1988	2%	29%	14%	4%	3%	30%	81%	--
1989	3%	22%	17%	5%	3%	16%	66%	--
1990	3%	31%	18%	6%	3%	5%	65%	--
1991	3%	30%	9%	4%	3%	12%	61%	--
1992	3%	37%	15%	4%	3%	7%	68%	--
1993	3%	32%	12%	5%	3%	9%	64%	--
1994	4%	34%	0%	1%	1%	3%	44%	--
1995	4%	22%	3%	2%	1%	6%	38%	--
1996	4%	5%	3%	3%	1%	9%	24%	--
1997	5%	14%	5%	3%	2%	11%	39%	--
1998	4%	11%	4%	3%	0%	11%	33%	--
1999	4%	11%	6%	5%	0%	15%	41%	--
2000	5%	18%	7%	2%	0%	10%	42%	--
2001	3%	14%	7%	3%	0%	8%	35%	--
2002	4%	17%	12%	3%	0%	7%	42%	49%
2003	3%	20%	16%	3%	0%	4%	47%	49%
2004	4%	21%	10%	5%	0%	6%	46%	49%
2005	4%	17%	9%	6%	0%	12%	49%	49%
2006	4%	17%	9%	6%	0%	16%	53%	49%
2007	5%	19%	9%	6%	0%	9%	48%	42%
2008	3%	14%	5%	3%	0%	7%	33%	41%
2009 a/	3%	15%	5%	2%	1%	11%	37%	38%
2010 a/	3%	11%	11%	3%	0%	6%	35%	38%

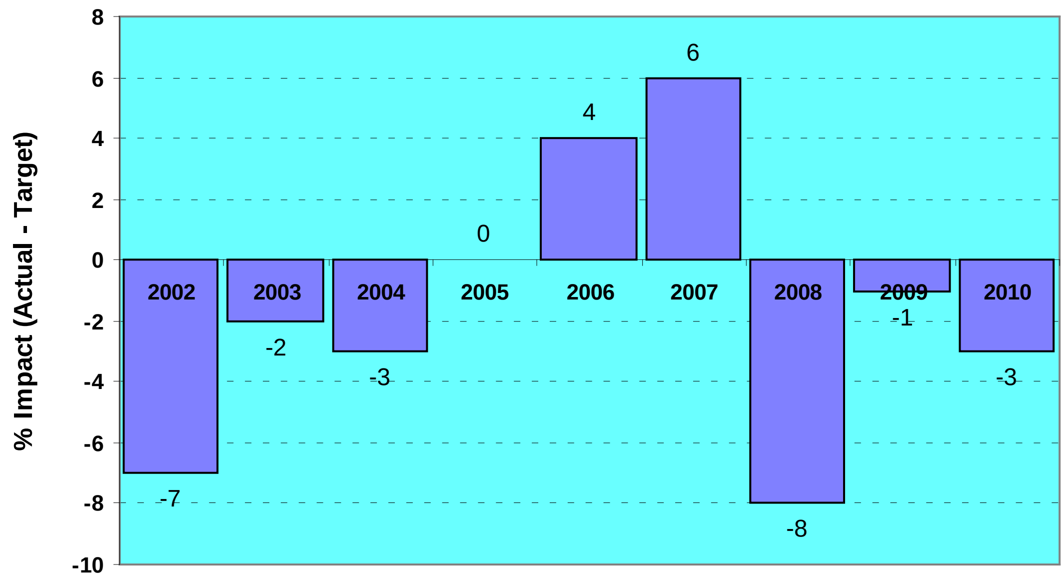

Figure 14. Differences between actual and target fishery impact ceilings for Lower Columbia tule Fall Chinook.

Fishery Management

Management of LCN tule Fall Chinook in freshwater and ocean fisheries was described to provide a context for consideration of future changes associated with implementation of potential abundance-based management strategies. These descriptions establish how different LCN tule Fall Chinook abundance and fishing rates generally affects ocean and Columbia River fisheries.

In Council ocean fisheries from the U.S. Canada Border to Cape Falcon, Chinook harvest is managed to:

1. Comply with ESA consultation standards for LCN tule Fall Chinook, Lower Columbia River wild bright Fall Chinook, and Snake River wild Fall Chinook;
2. Meet treaty Indian sharing obligations and the allocation provisions in the Salmon Fishery Management Plan (FMP);
3. Meet provisions of the Pacific Salmon Treaty; and
4. To the extent possible, provide for viable ocean and in-river fisheries while meeting natural stock escapement objectives and hatchery broodstock needs (PFMC 2011).

Exploitation rate limits for ESA-listed coho stocks can also constrain fisheries and limit access to otherwise harvestable Chinook. Which of these constraints limits the fisheries in any given year depends on mixture of stock-specific abundances and the resulting stock composition available to each fishery. In 2010, the primary constraint for North of Falcon ocean fisheries was the LRN tule Chinook ESA consultation standard of no more than a 0.38 exploitation rate in all combined marine and freshwater fisheries. Exploitation rates are estimated for a composite of Washougal, Kalama, Cowlitz, and Big Creek hatchery tules as a surrogate for natural tules. Other ESA consultation standards include a spawning escapement of 5,700 for Lower Columbia

River wild bright Fall Chinook in the North Fork Lewis River, at least a 30% reduction in the total ocean age-3 and age-4 adult equivalent (AEQ) exploitation rate of Snake River Fall Chinook from the 1988-1993 average, and McNary Dam escapement targets.

Fisheries in southeast Alaska and troll and sport fisheries in northern Canadian and WCVI have been managed since 1999 under a PST framework regulating Chinook harvest under aggregate abundance-based management (AABM) regimes. These fishery management regimes establish a catch ceiling derived from estimates of total aggregate abundance of all stocks contributing to the AABM fisheries and indexed to a series of stepped target harvest rates. For fisheries not driven by AABM regimes, management is individual stock based (ISBM) with provisions in the treaty limiting the aggregate impact on any depressed stock across all ISBM fisheries. The 1999 agreement established conservation obligations to reduce harvest rates on depressed Chinook stocks by 36.5% for Canadian fisheries and 40% for U.S. fisheries, relative to levels observed during 1979-1982. In May, 2008 the Pacific Salmon Commission recommended to the Governments of Canada and the United States a new bilateral agreement for the conservation and harvest sharing of Pacific salmon. The new fishing regimes are in force from the beginning of 2009 through the end of 2018 and are contained in Chapters 1, 2, 3, 5, and 6 of Annex IV of the Treaty. The 2008 Agreement, contained two key provisions pertaining to the AABM fisheries; a shift towards management for total morality rather than landed catch and reductions from the levels in the 1999 Agreement of 15% in southeast Alaska and 30% in WCVI fisheries. Impacts to all stocks in the AABM fisheries are reduced; hence, LCN tules have lower ERs in the northern fisheries, especially in WCVI.

Columbia River treaty Indian and non-Indian fisheries are managed under a 10-year agreement adopted in 2008 between *U.S. versus Oregon* parties. This agreement limits non-Indian fisheries in the lower 145 miles of Columbia River downstream from Bonneville Dam in order to provide adequate numbers of salmon to treaty Indian fishing areas upstream from Bonneville Dam. Combined Columbia River fisheries are typically constrained by consultation standards for LCN tule and Snake River wild Chinook. Fall fisheries below the confluence of the Snake River are managed according to an abundance-based harvest rate schedule that allocates harvest rates for Upriver Bright Fall Chinook between treaty Indian and non-Indian fisheries within the ceiling established by NMFS for total allowable harvest rates. Fisheries in the lower Columbia River downstream from Bonneville Dam are shaped within the constraints of this agreement to optimize harvest and opportunity while also meeting other objectives and constraints including the portion of the LCN tule harvest rate ceiling identified via the Council regulatory process for Columbia River fisheries. Current limits on LCN tule impacts are being met by a combination of fishery reductions and area restrictions. The recent year strategy has been to limit the Buoy 10 sport fishery and to move other fisheries targeting upriver fall Chinook to areas above the Lewis River. In 2010, ERs on LCN tule Chinook in combined sport and commercial fisheries were limited to just 0.08. Further restrictions might require mark-selective regulations in specific fisheries (such as the Columbia River Buoy 10 sport fishery) or shorter retention fisheries.

Impact Ceiling Effects on Fisheries

For perspective on the effect to preseason fisheries shaping of a “low” status under an abundance based management system for LCN tule Chinook, the 2009-2011 preseason estimates of total ER for LCN tule Chinook were modeled in FRAM. A "low" status abundance forecast was defined as returns to the Columbia River of 40,000 LRH adult age 3-5 Chinook. All fishery catches/inputs and stock abundances (including mark rates) were unchanged from the preseason runs except that the LRH abundances were lowered to achieve a terminal run of about 40,000 adults.

Table 3 contains exploitation rates by fishery group for 2009-2011 preseason model runs and corresponding estimates with a "low" abundance for LRH stock using the FRAM and in-river harvest model system currently employed during Council preseason management. LCN tule Chinook exploitation rates in Alaska and Canada fisheries ranged between 0.15-0.19 and averaged 0.17 in both the preseason and low LRH abundance examples. Exploitation rates in Council fisheries ranged between 0.12-0.15 and averaged 0.14 in the preseason runs and 0.17 in the low abundance runs (modeled with same catch quotas). The exploitation rate in the river fisheries ranged from 0.06-0.08. Exploitation in the treaty Indian troll fishery was slightly lower than the river fishery impacts. Council managed fisheries south of Cape Falcon were severely restricted in 2009 and 2010 but approached a more normal season structure in 2011 when the exploitation rate was estimated to be about 0.02. In general, the fishing seasons in the southern U.S. were constrained by LCN tule Chinook in river and ocean fisheries north of Cape Falcon and by Sacramento-Central Valley Chinook in fisheries south of Cape Falcon. Stocks contributing to northern fisheries were generally abundant which provided for higher aggregated abundances and fishing levels in the AABM fisheries. In these examples, impacts on LCN tule Chinook in the southern U.S. would have to be reduced by nearly 50% in order to remain under an ER ceiling of 0.28 and by 23% to remain under a ceiling of 0.33, assuming current conditions in northern fisheries.

Table 11. Projected exploitation rates for LCN tule Chinook from FRAM and in-river harvest models.

	2009		2010		2011		2009-11 Average	
Fishery	**LRH at 88.8K**	**LRH at 40K a/**	**LRH at 90.6K**	**LRH at 40K a/**	**LRH at 133.5K**	**LRH at 40K a/**	**Preseason**	**LRH at 40K a/**
AK-BC	0.164	0.164	0.147	0.148	0.188	0.189	0.166	0.167
Council Total	**0.149**	**0.188**	**0.163**	**0.180**	**0.121**	**0.143**	**0.144**	**0.170**
No. of Falcon	0.149	0.188	0.146	0.163	0.101	0.123	0.132	0.158
(treaty troll only)	0.072	0.088	0.045	0.051	0.039	0.046	0.052	0.062
So. of Falcon	0.000	0.000	0.017	0.017	0.020	0.020	0.012	0.012
Other So. U.S. marine	0.006	0.005	0.005	0.003	0.005	0.005	0.005	0.004
River @ preseason HR	0.078	0.074	0.079	0.079	0.056	0.054	0.071	0.069
So. U.S subtotal	0.233	0.267	0.247	0.262	0.182	0.202	0.221	0.244
LCN Tule Total ER	**0.397**	**0.431**	**0.394**	**0.410**	**0.370**	**0.391**	**0.387**	**0.411**

% Reduction in So. U.S.	**2009**		**2010**		**2011**		**2009-11 Average**	
to achieve total ER of:	**Preseason**	**LRH at 40K**	**Preseason**	**LRH at 40K**	**Preseason**	**LRH at 40K**	**Preseason**	**LRH at 40K**
0.20	85%	87%	79%	80%	93%	95%	85%	86%
0.22	76%	79%	70%	73%	82%	85%	76%	78%
0.27	55%	60%	50%	53%	55%	60%	53%	58%
0.32	33%	42%	30%	34%	27%	35%	30%	37%
0.37	12%	23%	10%	15%	0%	10%	8%	17%

a/ Modeled with same preseason quotas in Council fisheries North of Cape Falcon.

Table 12. Range and average ER for LCN tule Chinook for 2009-11 FRAM preseason runs with preseason abundances and LRH abundance at 40,000.

	2009-11 Preseason			2009-11 Low Abundance		
Fishery	High	Low	Average	High	Low	Average
AK-BC	18.8%	14.7%	16.6%	18.9%	14.8%	16.7%
NoF Nontreaty	10.1%	6.2%	8.0%	11.2%	7.7%	9.6%
NoF Treaty	7.2%	3.9%	5.2%	8.8%	4.6%	6.2%
So. of Falcon	2.0%	0.0%	1.2%	2.0%	0.0%	1.2%
Other U.S	0.6%	0.5%	0.5%	0.5%	0.3%	0.4%
River	7.9%	5.6%	7.1%	7.9%	5.4%	6.9%
So. U.S. subtotal	24.7%	18.2%	22.1%	26.7%	20.2%	24.4%

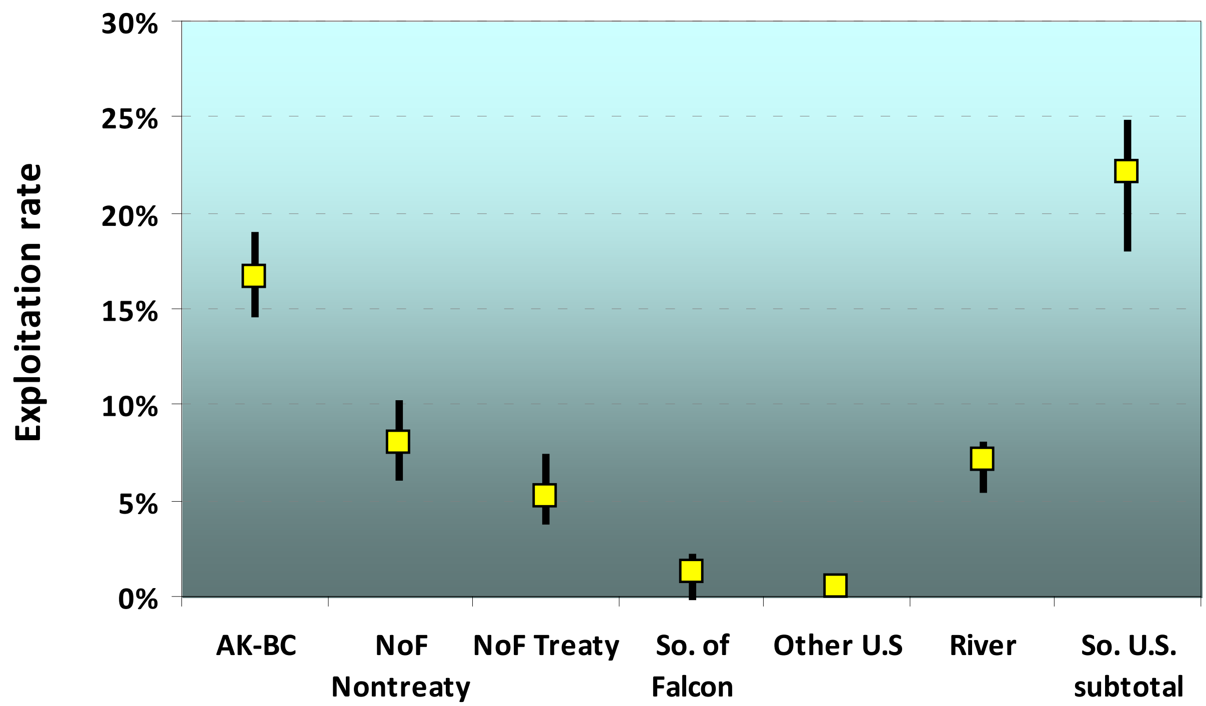

Figure 15. Range and average LCN tule ER for 2009-11 Preseason FRAM.

Effect on 2011 Chinook Harvest Example

Landed catch in Council fisheries north of Cape Falcon and in the Columbia River were estimated from FRAM using the 2011 preseason model run as a base for stock abundances and catch levels in Alaska, Canada and Council waters south of Cape Falcon. LCN tule exploitation rates modeled were 0.42 and 0.47, representing a high status level of +0.05 and +0.10 from the 0.37 ceiling in 2011. The low status exploitation rate modeled was -0.05 and -0.10 from the 0.37 base and the LRH river return was reduced to 40,000 fish to represent the abundance under a low status tier. Landed catch in fisheries north of Cape Falcon and harvest rates on LRH Chinook in the lower Columbia River were uniformly increased or decreased by the same level for modeling simplicity. The in-river harvest rate model was used to estimate the harvest rate on other fall Chinook stocks when river fisheries are shaped to achieve the target LRH harvest rate in the different scenarios. Of course for annual management, fishing levels and the seasons in ocean and river fisheries vary according to the abundances and circumstances that arise each year. The fishing levels in non-treaty and treaty ocean fisheries and between ocean and the river sharing are not a uniform multiplier of the previous year's rates. However, this simplistic approach does provide a way of comparing the effects of different ceiling exploitation rates on total landed catch of all stocks in ocean and river fisheries.

Table 13 contains landed catch estimates under high (0.42 and 0.47) and low (0.32 and 0.27) status exploitation rates for LCN tule Chinook. Under high status, total allowable catch (TAC) in the Council fisheries would increase by 38% under an LCN tule ceiling ER of 0.42 and by 75% for a ceiling of 0.47. In the river, catch of Chinook for "bright" stocks (Lower River Wild, Select Area Bright and Upriver Bright units) and tule stocks (LRH and BPH) would increase by a lower amount that reflects the varying change in stock specific harvest rates associated with the different river fisheries. Under low status of 40,000 LRH Chinook, the ocean TAC would decrease for the 0.37 ceiling as well as at the 0.32 and 0.27 levels. The TAC would be reduced by 15% for a 0.37 ceiling exploitation rate on LCN tule Chinook, 46% for 0.32 ceiling, and 76% for a 0.27 ceiling. Catch reductions in the river are not nearly as dramatic although fishing seasons and opportunity are significantly restricted, especially at the 0.27 ceiling.

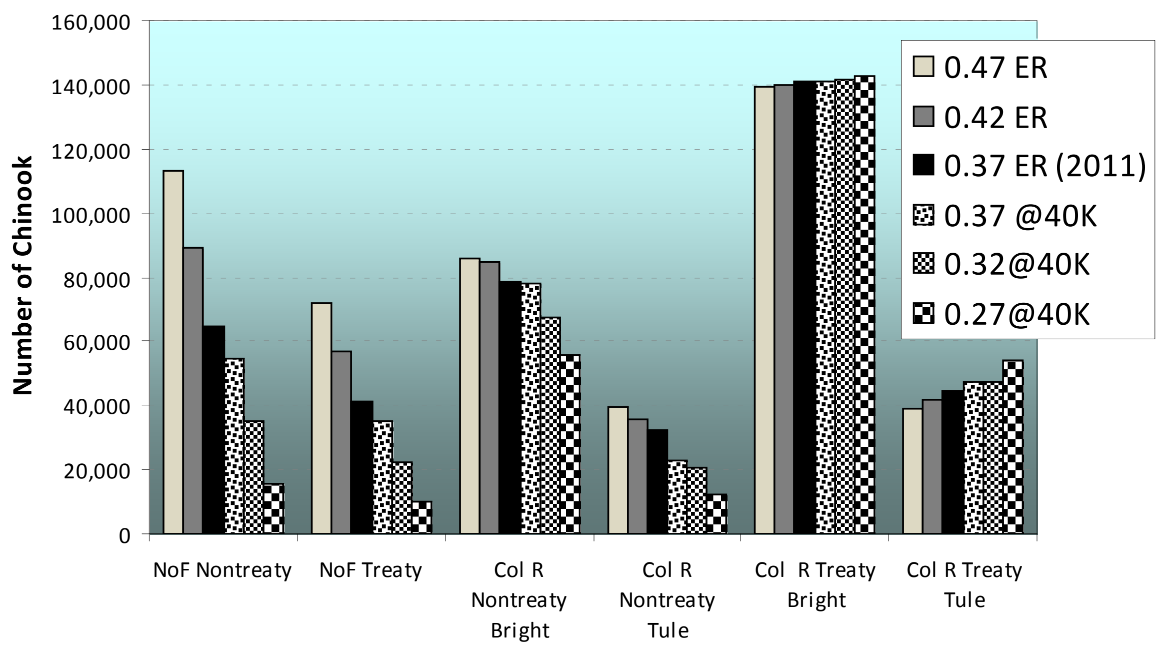

Figure 16. Landed Catch of Chinook in North of Falcon and River Fisheries under variable ERs for LCN Tule Chinook (2011 with LRH abundance at preseason of 133,500 or low abundance of 40,000).

Table 13. Landed catch of Chinook in Council waters North of Cape Falcon and in the Columbia River under different ceiling exploitation rates (ER) for LCR tule Chinook.

LCN Tule Total ER	0.37	LCN Tule Total ER	0.42	LCN Tule Total ER	0.47
2011 Preseason		@1.38X for 42%		@1.75X for 47%	
Council NoF TAC All Stocks		Council NoF TAC All Stocks		Council NoF TAC All Stocks	
Nontreaty	64,600	Nontreaty	89,100	Nontreaty	113,000
Treaty	41,000	Treaty	56,600	Treaty	71,800
Columbia River		Columbia River		Columbia River	
Nontreaty		Nontreaty		Nontreaty	
Bright	78,600	Bright	84,900	Bright	86,000
Tule	32,100	Tule	35,900	Tule	39,700
Treaty		Treaty		Treaty	
Bright	141,000	Bright	140,000	Bright	139,500
Tule	44,400	Tule	41,700	Tule	39,000
LCN ER		LCN ER		LCN ER	
NoF ocean	0.101	NoF ocean	0.137	NoF ocean	0.173
Columbia Ri	0.056	Columbia Ri	0.074	Columbia Ri	0.090

LCN Tule Total ER	0.37	LCN Tule Total ER	0.32	LCN Tule Total ER	0.27
@0.85X for 37% w LRH 40K		@0.54X for 32% w LRH 40K		@0.24X for 27% w LRH40K	
Council NoF TAC All Stocks		Council NoF TAC All Stocks		Council NoF TAC All Stocks	
Nontreaty	54,900	Nontreaty	34,900	Nontreaty	15,500
Treaty	34,900	Treaty	22,100	Treaty	9,800
Columbia River		Columbia River		Columbia River	
Nontreaty		Nontreaty		Nontreaty	
Bright	78,000	Bright	67,500	Bright	55,800
Tule	22,700	Tule	20,500	Tule	12,200
Treaty		Treaty		Treaty	
Bright	140,800	Bright	141,800	Bright	142,700
Tule	44,400	Tule	47,600	Tule	53,900
LCN ER		LCN ER		LCN ER	
NoF ocean	0.108	NoF ocean	0.070	NoF ocean	0.032
Columbia Ri	0.047	Columbia Ri	0.031	Columbia Ri	0.015

Note: @N.NNX represent the all-stocks harvest increase over 2011 preseason expectations.

In these examples, the allowable catch in the Council fisheries fall within the very broad range of annual management during 1991-2010 (Table 14). In most years, actual landed catch was less than 90% of the TAC for the non-Indian and treaty Indian fisheries. The magnitude of the TAC did not correlate very well with whether the TAC was achieved or not. A low TAC did not necessarily mean the TAC was achieved nor did a large TAC necessarily mean that there was significant number of fish remaining on the quotas at the end of the season. The 2011 example shows that both high and low status tiers may provide TACs that have been used in the past. The tiers need to be evaluated in terms of the ability of the fisheries to take advantage of the high status ceiling exploitation rates and the restrictions required in the fisheries at the low status in addition to the potential conservation benefits that may accrue to LCN tule Chinook. Also, because the annual abundances are highly correlated between years, consecutive years of low status could occur creating several years of very restrictive fisheries.

Table 14. Landed catch and total allowable catch (TAC) in Council waters North of Cape Falcon, Oregon.

	May-Sep Landed Chinook Catch				Allowable Catch (TAC)		Actual % of TAC	
Year	NT Troll	Sport	Total	Treaty Troll	Nontreaty	Treaty	Nontreaty	Treaty
1991	29,800	13,700	43,400	21,900	80,000	33,000	54%	66%
1992	45,900	18,700	64,700	23,100	80,000	33,000	81%	70%
1993	30,500	13,900	44,300	25,000	60,000	33,000	74%	76%
1994	0	0	0	4,600	0	16,400	--	28%
1995	0	600	600	9,800	0	12,000	--	82%
1996	0	400	200	12,300	0	11,000	--	112%
1997	6,500	4,200	10,600	14,200	23,000	15,000	46%	95%
1998	6,000	2,300	8,200	14,700	10,000	15,000	82%	98%
1999	18,600	10,800	29,400	27,500	50,000	30,000	59%	92%
2000	13,000	9,200	22,200	7,600	25,000	25,000	89%	30%
2001	26,500	25,600	52,000	28,800	60,000	37,000	87%	78%
2002	81,600	60,600	142,100	39,800	142,883	60,000	99%	66%
2003	69,800	36,500	106,200	35,200	124,000	60,000	86%	59%
2004	47,000	27,100	74,100	49,700	89,000	49,000	83%	101%
2005	45,200	40,000	85,100	42,000	86,500	48,000	98%	88%
2006	27,300	11,200	38,300	30,500	65,000	42,200	59%	72%
2007	15,800	9,500	25,200	22,900	32,500	35,000	78%	65%
2008	14,100	15,500	29,500	20,900	40,000	37,500	74%	56%
2009	13,100	13,300	26,300	12,400	41,000	39,000	64%	32%
2010	56,200	38,700	94,900	33,400	102,350	55,000	93%	61%
2011	--	--	--	--	64,600	41,000	--	--

NATURAL POPULATION RISK ANALYSIS

Background

Current fishery limitations for ESA-listed salmon species, including LRN tule Fall Chinook, are intended to avoid jeopardizing the continued existence of the species. NMFS' approach to making determinations regarding the effects of harvest actions involves analysis of effects of a proposed action on abundance, productivity, or distribution of the species (NMFS 2009). Determinations are ultimately based on whether the proposed action, taken together with any cumulative effects and added to the environmental baseline, can be expected, directly or indirectly, to reduce appreciably the likelihood of both survival and recovery of the affected species.

Biological risk assessments for listed salmon species have widely taken the form of a Population Viability Analysis (PVA). PVAs use quantitative methods to predict the likely future status of a population or collection of populations of conservation concern (Morris and Doak 2002; Beissinger and McCullough 2002). Salmon are believed to go extinct when population abundance and resilience are reduced to low levels where numbers "bottom out" under periods of low survival associated with variable environmental conditions. Current salmon recovery plans for listed Columbia River salmon define status in terms of risk which is estimated as the probability that a population will be above some minimum size over a prescribed period of time. Salmon PVA's typically utilize stochastic stock-recruitment models to estimate species survival and recovery likelihoods from population abundance, productivity and spatial structure, and population variability. PVA models have been developed and applied by NMFS, ODFW and WDFW to status assessments and recovery plan analyses for Columbia River tule Fall Chinook (LCFRB 2010; ODFW 2010).

The traditional approach to fishery effects analysis involved simple comparison of escapement numbers relative to goals. Fishery risk analyses consider the combined effects of fishing, fishery uncertainty, and variable production and survival on escapement levels that may threaten the long term persistence or viability of a population or group of populations. PVA models are particularly well-suited for fishery risk assessments because effects of exploitation rates on demographic risk can be directly quantified. This approach can also effectively evaluate fishing effects on populations of different productivity including weak populations that are most at risk of falling to critical low levels where they are no longer capable of sustaining themselves.

This assessment adapted and applied the PVA framework from the lower Columbia salmon recovery plans to evaluate risks associated with alternative fishing strategies for lower Columbia River tule Fall Chinook. Adaptation of an existing model will ensure that results are consistent with salmon conservation needs driving current salmon management and associated consultations. Similar modeling approaches have previously been utilized by the Council in conservation risk analyses for other stocks including Klamath River fall Chinook.

Model Description

Viability risks associated with different implementation strategies were estimated using the PopCycle model. PopCycle is a simple stochastic stock-recruitment model developed for the analysis of population viability of Washington lower Columbia salmon and steelhead populations addressed by the Recovery Plan (LCFRB 2010). This analytical framework is consistent with the approach used in Oregon's CATAS and NOAA's SLAM models. Each of these models are stochastic life cycle models built around the salmon stock-recruitment function and both models can be expected to produce relatively similar results if parameterized with equivalent inputs. Models differ in the detail by which stages of the salmon life cycle are represented. Both the PopCycle model employed by Washington and the SLAM model employed by NMFS have been utilized to evaluate effects of fixed exploitation rates, including evaluating scenarios incorporating potential impacts of habitat and hatchery recovery actions. Additional analysis using multiple models may be contemplated in the future depending on resource availability.

The model used in the analyses described in this report estimates annual run size, harvest and spawner numbers over a prescribed number of years (Figure 17). The model estimates average and frequencies of values over a prescribed number of iterations (typically 1,000). Model populations include the aggregate Lower Columbia River tule stock which consists primarily of hatchery (LRH) fish but also includes a small proportion of naturally-produced fish. The model simultaneously simulates a wild tule population. This wild population can be parameterized to represent a specific population (e.g. Coweeman) or a generic population representative of low, medium, or high viability. However, the simulated wild population number is not included in the aggregate stock numbers. The aggregate number is thus effectively defined in terms of hatchery fish alone (LRH) consistent with current information which indicates that even a significant portion of the natural production is driven by stray hatchery fish spawning in the wild. The total wild/natural aggregate (LCN) consisting of multiple populations was not simulated by the model because individual wild populations behave differently due to difference in size and productivity, and because we lack population-specific information. The model thus simulates representative wild populations subjected to the same and fishery conditions as the aggregate LRH stock.

Number of LRH adults recruiting to ocean fisheries is estimated based on hatchery releases and juvenile to adult survival rates. Number of wild adults in the representative wild population is estimated from recruitment generated by a stock-recruitment function from the brood year number of spawners for that population. This analysis models three representative wild population types describing a productivity and abundance range believed to be representative of the current status of most LRN populations. Recruits of LRH and of the wild population are estimated as an ocean adult cohort. Annual numbers of fish from this cohort are apportioned among years based on an input age schedule. The annual run is subjected to fishing with the surviving wild population spawning to seed the next wild generation and the hatchery adults dead-ending into the hatchery. The model does not simulate straying of hatchery fish into the wild population. Wild population parameters are thus assumed to represent an equilibrium contribution of hatchery fish and any changes in hatchery contributions due to changes in fishery strategy are not captured. While it is computationally simple to simulate hatchery strays, assumptions regarding their effects on population productivity over time would be highly subjective.

Random annual variability is introduced into the model at the juvenile-to-adult survival stage for the LRH population and in the stock-recruitment relationship for the representative wild population. Variances are proportional to survival or productivity, log-normally distributed, annually autocorrelated, and partially correlated in between hatchery and wild fish. Log-normal distributions provide for the occasional very high survival or productivity years that we see periodically. Autocorrelation means that poor survival or production years are generally more likely to be followed by poor years, and good years by good years.

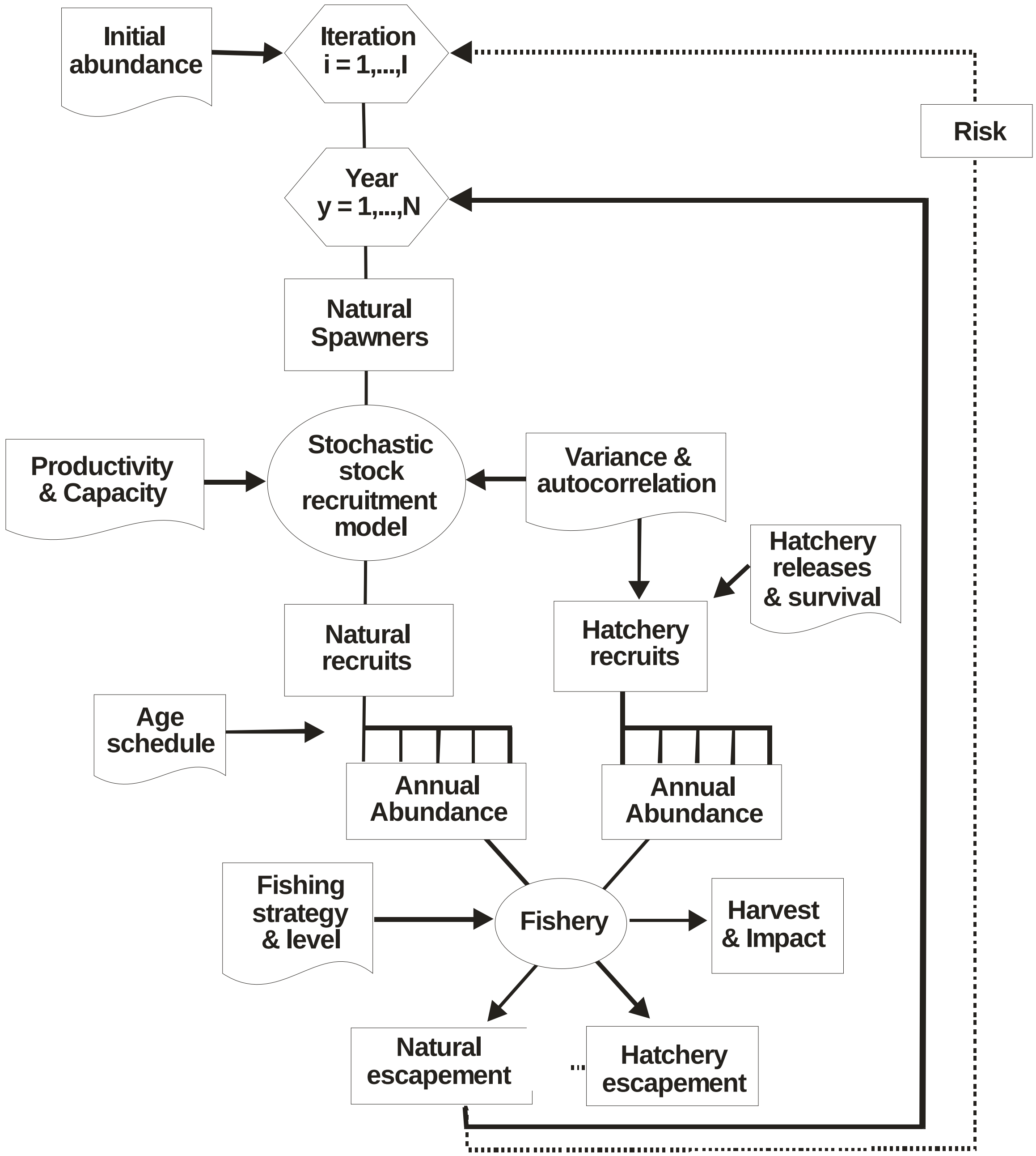

Figure 17. Conceptual depiction of model algorithm.

The model includes optional inputs to apply fishing rates in each year to calculate harvest and fishery effects on population dynamics. Either fixed or abundance-based rates may be utilized. Abundance-based rates are applied according to forecast abundance tiers (e.g. <40,000, 40,000 to 100,000, > 100,000). Input parameters allow for forecast errors which introduce uncertainty and variability into model estimates, notably including errors in predicting which fishing rate tier should be operated in. Inputs also allow for normal differences in target and actual fishing rates which result from a variety of factors mostly related to lack of predictability in stock composition, fishery catch rates, etc.

Viability risk was defined in this analysis as the probability of average abundance of a generation of salmon falling below a critical abundance threshold over the course of a simulation. A quasi-extinction risk threshold (QET) was defined as a population size where functional extinction occurs due to the effects of small population processes (McElhany et al. 2006). The model assumes that extinction occurs if the average annual population size over a moving generational average falls below this threshold at any point in a modeled trajectory. Extinction risk is thus estimated as the proportion of all iterations where the moving generational average spawner number falls below the threshold at any point in each simulation period.

The model is built in Microsoft Excel using Visual Basic. A simple interface page facilitates model use and review of results.

Model Parameters

Table 15. Model input variables and parameters used for fishery risk analysis.

Variable or parameter	Notation	Value
Initial spawner abundance	$S_{y-6},\ldots,S_{y-1}$	Equilibrium abundance @ avg. fishing rate
Stock-recruitment		
Function	Option 2	Beverton-Holt
Productivity	p	Pop A = 3.0; Pop B = 2.0; Pop C = 1.5
Equilibrium abundance	N_{eq}	Pop A = 2,000; Pop B = 1,000; Pop C = 300
Maximum spawner constraint	lim S_y	(10) (N_{eq})
Maximum recruit constraint	lim R_y	(10) (N_{eq})
Production trend	PT	0%
Recruitment failure threshold	RFT	50
Critical risk threshold	CRT	50 (avg. per generation)
Recruitment stochasticity		
Variance	σ^2	0.5
Autocorrelation	$\emptyset$	0.5
Age schedule	$m_2,\ldots,m_7$	Age 2 = 0.055; Age 3 = 0.373; Age 4 = 0.495; Age 5 = 0.076
Hatchery fish		
Annual releases	HR	22,000,000
Smolt-to-adult-survival (to ocean)	SAR	0.0031 (0.0020 geomean to Col. River @ a 30% ocean ER)
Wild population correlation	r_w	0.5
Run size forecast error (CV)	E_f	0.75
Fishery implementation error (CV)	E_i	0.10

Wild Populations

Rather than modeling specific wild populations, this assessment identified three general categories of populations and modeled representative abundance and productivity parameters for each category. Categories generally correspond to moderate, low, and very low levels of population viability identified in lower Columbia River salmon recovery plans.

This approach was taken because population-specific data was generally inadequate for confident estimation of model parameters. However, general information was adequate to identify a reasonably representative range of parameters for LCR population based on values reported in Washington and Oregon recovery plans.

Table 16. Representative population parameters.

Category	Abundance	Productivity	Viability response	Examples
A	2,000	3.0	Moderate	Coweeman[a], Washougal[a], Cowlitz,
B	1,000	2.0	Low	EF Lewis[a], Mill/Abernathy/Germany[a], Elochoman/Skamokawa[a], Kalama, Toutle[a]
C	300	1.5	Very low	Clatskanie[ab], Scappoose[ab], Hood[ab], Grays, Sandy, Clackamas

[a] *"Primary" populations targeted for restoration to high or very high levels of viability in lower Columbia River salmon recovery plans.*
[b] *Denotes high degree of uncertainty in current population status.*

Example populations were identified for each population category based on viability estimates and parameters reported in salmon recovery plans and analyses by Washington, Oregon, and NMFS. The binning of populations represented above is based on information from those efforts, not the specific conclusions. The best available data includes a mixture of population-specific parameter estimates based on reconstructions of spawning ground survey information and inference from habitat amounts and conditions.

While the range of population categories are reasonably representative of the status of most LRN tule Fall Chinook, different analyses and assumptions might result in specific populations being classified in different categories (

Table 17). These differences reflect both different approaches and assumptions utilized in the available analyses, and uncertainty in population parameters due to data limitations. NMFS described groups of populations in three categories based on SLAM modeling results and assumptions regarding current production. The NMFS analysis was limited to “primary” populations identified in recovery plans for improvement to high or very high levels of viability. The SLAM model did not explicitly model adult-to-adult stock-recruitment equation parameters – rather, a functional relationship was implicit in life stage-specific parameters and functions used in that mode. The Washington Recovery Plan analysis did report adult to adult stock-recruitment parameters but included only Washington populations. The Oregon Recovery Plan analysis also utilized an adult-to-adult stock recruitment analysis but did not report parameters comparable to the Washington plan. However, all three modeling efforts reported model-derived abundance levels under roughly approximate conditions.

Table 17. Population parameters for lower Columbia River natural tule fall Chinook populations based on analyses and population viability modeling conducted by Washington, Oregon, and NMFS for the purposes of salmon Recovery Plans. Populations are sorted by maximum modeled abundance reported for any of the plans.

		WA plan parameters[a]		Modeled abundance		
Population	**State**	N_{eq}	**R/S**	**WA[b]**	**OR[c]**	**NMFS[d]**
Lower Cowlitz	WA	8,200	3.0	4,260	--	--
Washougal	WA	1,100	1.9	310	--	1,700
Lewis	WA	800	1.7	100	--	1,700
Coweeman	WA	1,700	3.2	920	--	1,400
Mill/Abernathy/Germany	WA	1,000	2.2	360	--	700
Clackamas	OR	--	--	--	558	--
Hood	OR	--	--	--	33	400
Elochoman/Skamakowa	WA	1,300	1.9	390	--	200
Toutle	WA	2,400	1.6	380	--	--
Youngs Bay	OR	--	--	--	379	--
Scappoose	OR	--	--	--	356	100
Kalama	WA	1,000	2.0	280	--	--
Big Creek	OR	--	--	--	216	--
Sandy	OR	--	--	--	144	--
Clatskanie	OR	--	--	--	6	100
Grays/Chinook	WA	300	1.9	<50	--	
L. Gorge	WA/OR	500	--	<50	--	--
U. Gorge	WA/OR	500	--	<50	--	--
White Salmon	WA	--	--	<50	--	--
Upper Cowlitz	WA	--	--	--	--	--
Salmon	WA	--	--	--	--	--

a *Beverton-Holt stock-recruitment parameters from the Washington Recovery Plan (LCFRB 2010) under habitat conditions and hatchery impacts in the listing period baseline (late 1990s). Values reflect pre-harvest equilibrium inferred from habitat conditions with the Ecosystem Diagnosis and Treatment model with productivity reduced by the Hatchery Scientific Review Group hatchery impact.*

b *Modeled population abundance using the Washington recovery plan model at a fixed exploitation rate of 0.37 (unpublished data).*

c *Modeled abundance for Oregon populations from the Oregon Recovery Plan (ODFW 2010) represent the average of 100-year forward projections that assume environmental conditions effecting survival are similar to those from 1974 to 2004; as such is not comparable to observed wild spawner counts in more recent times when the natural survival rates have been lower and fishery impacts generally less than in the early 2000s.*

d *Modeled abundance in NMFS' SLAM model at an ER of approximately 0.37 under current habitat and hatchery conditions, assuming hatchery fish depress natural survival (NMFS Scenario 2).*

Categorization of example populations reflects current conditions including habitat quantity and quality, and hatchery influences. The category of any given population can change in the future as habitat, hatchery, or hydropower-related actions improve productivity and numbers. Thus, populations that may currently be relatively unresponsive to exploitation rate changes may become more responsive and benefit from harvest limitations at some point in time.

It should also be noted that there are additional populations of extremely low viability that currently appear to be consistently below replacement levels – limitations on these populations are predominately driven by factors other than fisheries and were not modeled. Examples include Big Creek, Youngs Bay tributaries, Salmon Creek, White Salmon River, Lower Gorge, and Upper Gorge populations.

Hatchery Populations

LRH abundance was estimate based on annual hatchery releases of lower Columbia River programs which have averaged 22 million juveniles per year from 1998 through 2008. This production level reflects program changes in the mid-1990s to reduce production and selectively eliminate programs with lower success rates. This production level does not reflect any future changes that may be implemented based on conservation and recovery plans for wild populations.

Average annual survival of hatchery fish to the Columbia River mouth was estimated from brood year run reconstructions at 0.0028 for the 1987-2006 brood years. This was less similar to the long term (1962-2006 run year) average of 0.0045 (Figure 5). Average survival to ocean recruitment was estimated from Columbia River mouth run size estimates expanded for average ocean exploitation rates [0.0028/(1-0.35) =0.0043]. These survival estimates are slight overestimates of actual hatchery fish survival because they are based on total Lower Columbia River tule returns, which include a small percentage of wild fish. However, this approach is consistent with the definition of the LRH population in the model and produces a total LCR tule return similar in number to the actual number. (This is critical for application of the fishery rules where the tiers are based on total adult run size.)

Age Composition

Age composition of both LRH and the wild population was based on 1962-2005 brood year data for adults only (Figure 18). Average percentages were similar based brood year (age 2 = 5.5, age 3 = 37.3%, age 4 = 49.5%, age 5 = 7.6%) and run year (age 2 = 6.0%, age 3 = 37.2%, age 4 = 48.5%, age 5 = 8.2%) analyses over the long time frame of this data.

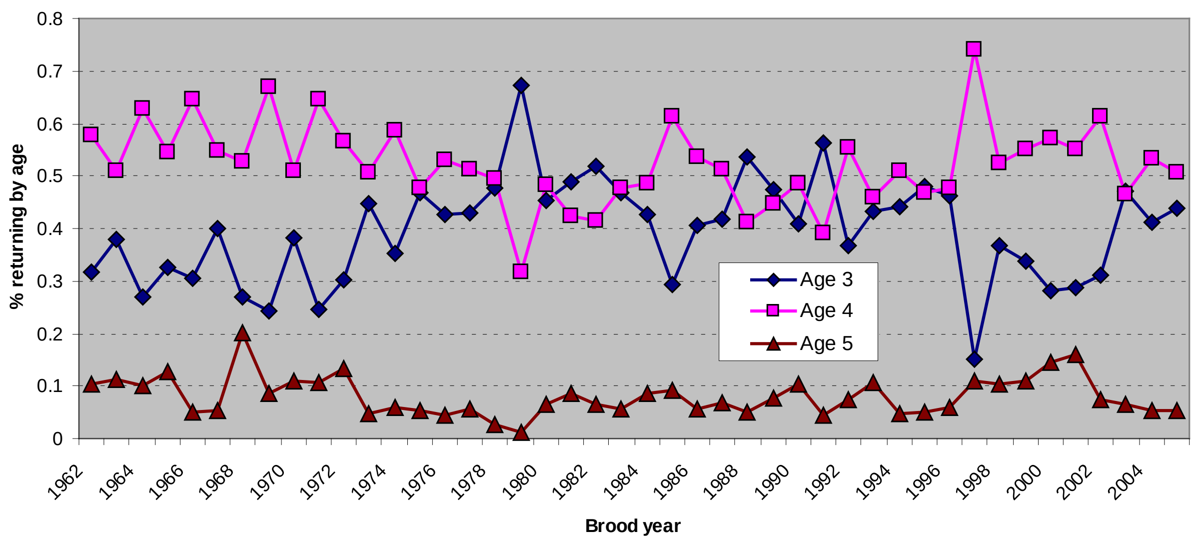

Figure 18. Age composition of adult LRH return to the Columbia River by brood year, 1964-2010.

Variation in Survival & Recruitment

Annual variability in natural production of the wild population is incorporated in the stock-recruitment relationship. The same relative variance was applied to annual survival of hatchery fish under the assumption of common effects of ocean conditions on wild and hatchery fish in the same cohort. The variance in recruits per spawner was parameterized with a variance of 0.5. This parameter produced an average hatchery survival rate to the Columbia River in the model equivalent to the recent 20-year average (0.00276) and CV (0.97). Note that this is less than the 0.9 value used in population viability analyses for all wild LCR fall Chinook population in the Washington Recovery Plan (LCFRB 2010) based on recommendations by NMFS' Technical Recovery Team (TRT) following review of all available population data.

Variance was assumed to be auto-correlated with a coefficient of 0.50. This value was used in the Washington Recovery Plan PVA as recommended by the TRT. The autocorrelation coefficient was independently estimated at 0.50 for the hatchery survival rate index from the long term dataset.

Finally, wild and hatchery population variability was assumed to be only partially correlated from year to year based on correlation analyses summarized in Table 8, Table 9, and Figure 11. A correlation coefficient of 0.5 was applied to all wild populations.

Forecast & Fishery Errors

Forecast and fishery errors were based on data reported earlier in this report. Forecast error was estimated to have a CV of 0.75. Fishery implementation error was estimated to have a CV of 0.1.

Conservation risks

Wild population risks were based on a QET of 50 estimated as a moving average of years in one generation of the species in question (4 years for Chinook) as per (McElhany et al. 2006). Estimates of absolute risk are extremely sensitive to the selection of this parameter which is why model-derived risks are most useful for relative comparisons among risk factors. While there is an extensive amount of literature on the relationships among extinction risk, persistence time, population abundance, and level of variation in demographic parameters, there are no simple generic abundance levels that can be identified as viable (McElhany et al. 2000). Because empirical data on actual extinction and conservation risk levels is lacking, this QET value was based on theoretical numbers identified in the literature based on genetic risks. Effective population sizes between 50 and 500 have been identified as levels which theoretically minimize risks of inbreeding depression and losses of genetic diversity, respectively (Franklin 1980, Soule 1980, Thompson 1991, Allendorf et al. 1997). Effective population size assumes balanced sex ratios and random mating. Relatively low QET values are supported by recent observations of salmon rebounds from very low numbers (e.g. Oregon lower Columbia River coho: ODFW 2005 and Washington lower Columbia winter steelhead: D. Rawding, WDFW, unpublished) and apparently-sustainable small population sizes of salmon in other regions (e.g. King Salmon River Chinook population in Alaska: McPherson et al. 2003).

Simulations

A series of model simulations were conducted to:

1. Evaluate the effects of exploitation rate on risk for wild populations in each abundance/productivity category.
2. Describe short versus long term risks associated with exploitation rates.
3. Explore the effect of abundance tier selection on population risks.
4. Identify the risk reduction and fishery opportunity benefits of a variety of fixed and abundance-based fishery scenarios.
5. Evaluate the sensitivity of model results to key input parameters.

Population sensitivity to exploitation rates was evaluated based on simulations of A, B, and C population types to a series of fixed annual ERs ranging from 0.0 to 0.70.

Effects of the simulation duration on risk were used to identify an appropriate time period for analysis of fishery effects. Recovery plan risk assessments involving all threat categories (fisheries, habitat, hydropower, hatcheries, ecological factors, etc.) were typically based on 100-year simulations. However, fishery plans addressed by this analysis are intended primarily for use in an interim period until the longer term benefits of other recovery measures begin to be realized. Thus, 100-year simulations would overestimate the risk when other improvements are not considered. Conversely, very short term simulations may not accurately describe risks related to harvest because they do not allow for the compounding effects high harvest rates on unproductive populations over time, particularly under a series of temporally auto-correlated poor ocean survival years. Therefore, evaluations of abundance-based fishery scenarios considered both 100-year and 20-year simulations.

Abundance tiers refer to run size forecast trigger points identifying the appropriate fishing rate for use in any particular year. For instance, the TCW identified a 3-tier variable rate strategy involving the LRH aggregate stock operating approximately 25% of time in the high tier, 25% of time in the low tier, and 50% of the time in the middle tier. This is a “balanced” tier structure with equal frequencies in the lower and higher tiers. The model was used to identify corresponding forecast levels that provide the desired tier frequency. Effects of other tier frequencies were also evaluated for a three-tier scenario. Five-tier examples were also considered.

Based on a review of abundance-based approaches for other fisheries and an assessment of information available for lower Columbia River tule Fall Chinook, the TCW initially identified a series of alternative scenarios for further evaluation. Alternatives included a variety of fixed ER strategies ranging from 0.0 to 0.53. Variable rate strategies were evaluated for different base fishing rates. Alternatives also included a variety of more specific combination of higher or lower variable fishing rates.

Risks were compared among scenarios based on the Population B category. In a 100-year simulation, the B populations provide the most sensitive index of fishery effect on risk. The B populations also represent populations which are a primary concern of the recovery strategies.

Changes in risks and LRH harvest levels were compared relative to a fixed 0.37 ER, which represents the 2011 ESA consultation standard. Fishing rate scenarios were categorized based on whether risk and harvest levels were substantially greater or lower than corresponding values at the 0.37 ER. For the purposes of this analysis, changes in risks and harvest levels were classified as substantial when they exceeded the difference observed for a ±0.01 change in fixed harvest rate from 0.37 values. Corresponding values were ±3.5% change in 100-year risk, ±0.25% change in 20-year risk, and ±3.0% change in average 100-year harvest.

These numbers were used to classify fishing rate scenarios into one of four categories:

The Win/Win group involved both a substantial reduction in risk to the natural population and an improvement in fishing opportunity for tule Fall Chinook. This group would represent the ideal abundance-based strategy.

The Risk Reduction group involves only a substantial decrease in wild population risk with little or no fishery benefit. This group includes scenarios that greatly reduce fishing opportunity.

The Fishery Opportunity group involves only a substantial increase in harvest opportunity relative to the fixed 0.37 ER standard with either no substantial risk reduction or increased risk. This group includes some scenarios that increase natural population risks.

The Equivalent group provides the same or similar wild population risk and tule Fall Chinook harvest level as the fixed 0.37 ER strategy. Equivalent scenarios include those where some change might occur but the magnitude falls short of the above definition of substantial.

No fishery scenarios were contemplated that increase natural population risks and reduce fishery opportunities.

Results

Population Sensitivity to Exploitation Rates

The sensitivity of long-term risks to fishery impacts varies with population status. Long-term population risks can be substantially reduced by reducing fishery impacts only for populations with significant intrinsic capacity or productivity (e.g. category B populations). Smaller less productive populations are less affected and cannot be brought to high levels of viability over the long term even at very low fishing rates (e.g. category C populations).

Incremental benefits of fishery reductions progressively decrease at lower and lower fishing rates. Fishing rates below which population viability is largely independent of the effects of fishing are sometimes referred to as *de minimis* fishing rates. Definition of an appropriate *de minimis* rate depends of the specification of an acceptable risk level. Rates may vary among populations in relation to differences in abundance and productivity.

Average abundance of a natural population increases in direct proportion to the decrease in fishing rate over the 100-year period of the simulation. Improvements are greatest in the most productive populations and least in relatively unproductive populations. While risk of falling below a critical small-population threshold may be relatively insensitive to fishing at low impact rates, abundance is consistently sensitive to fishing at all impact levels. Thus, while reductions to very low fishing rates do not substantially affect risk, they do translate into ever larger numbers of spawners.

Of course, harvest of LRH Chinook increases in direct proportion to increasing ER. However, under an assumption of a fixed northern (Alaska and Canada) exploitation rate of 0.18, the southern US share of the harvest depends on the total ER.

Table 18. Modeled effects of different exploitation rates on short term (20-year) and long term (100-year) risks falling below critical wild population abundance thresholds, median wild abundance by population, average total harvest of hatchery and wild tule fall Chinook.

Outcome	Population category	Exploitation rate							
		0	10	20	30	40	50	60	70
Risk (20 yr)	A	0.000	0.000	0.000	0.000	0.000	0.002	0.025	0.231
	B	0.000	0.000	0.000	0.004	0.024	0.134	0.431	0.891
	C	0.020	0.049	0.134	0.291	0.533	0.850	0.982	1.000
Risk (100 yr)	A	0.000	0.000	0.000	0.000	0.001	0.027	0.365	0.957
	B	0.000	0.001	0.007	0.059	0.344	0.832	0.997	1.000
	C	0.123	0.324	0.644	0.901	0.992	1.000	1.000	1.000
Wild number (100 year)	A	2,200	1,880	1,560	1,240	920	600	240	<50
	B	1,120	920	700	500	280	60	<50	<50
	C	340	230	120	<50	<50	<50	<50	<50
Total LRH Harvest	--	0	8,140	16,260	24,430	32,580	40,720	48,870	56,820
US Harvest		0	0	1,598	9,768	17,918	26,058	34,208	42,158

(US harvest south of Canada assumes first exploitation of 18% comes from north)

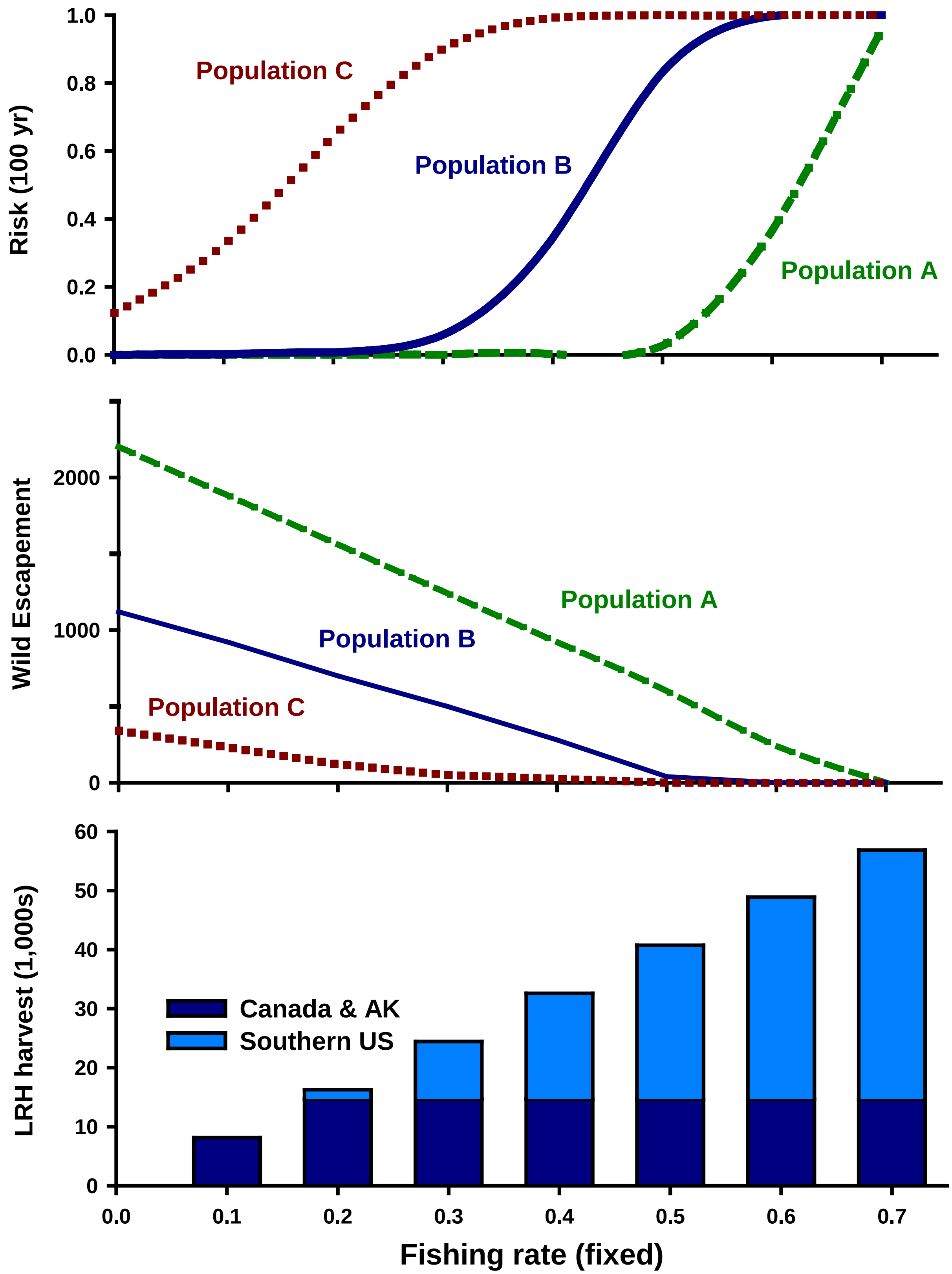

Figure 19. Modeled effects of different exploitation rates on long-term risk of falling below critical wild population abundance thresholds, median wild abundance by population, and average total harvest of hatchery and wild tule fall Chinook.

Short-term vs. long-term risk

Fishery risks to natural populations generally increase with simulation duration as compounding effects of low run sizes and chance occurrences of poor ocean survival years have a chance to accrue. Even relatively high fishing rates are extremely unlikely to drive numbers to low levels within a couple of fish generations starting at recent average numbers.[3] Absolute values of risk estimates vary considerably but relative values of risk are generally similar in short term versus long term calculations. Sensitivity varies with population category.

Shorter simulation periods have the effect of shifting population risk profiles to the right. As a result, population sensitivity to variable fishing rates around a mean rate depends greatly on the duration of the simulation. For instance, Population B is most sensitive to fishing rates around 40% in a 100-year simulation. In a 20-year simulation, the effects to the B populations are smaller – not as measurable, but still meaningful/relevant. In contrast, Population C is relatively insensitive to ERs around 0.40 in a 100-year simulation but highly sensitive to the same rates in a 20-year simulation.

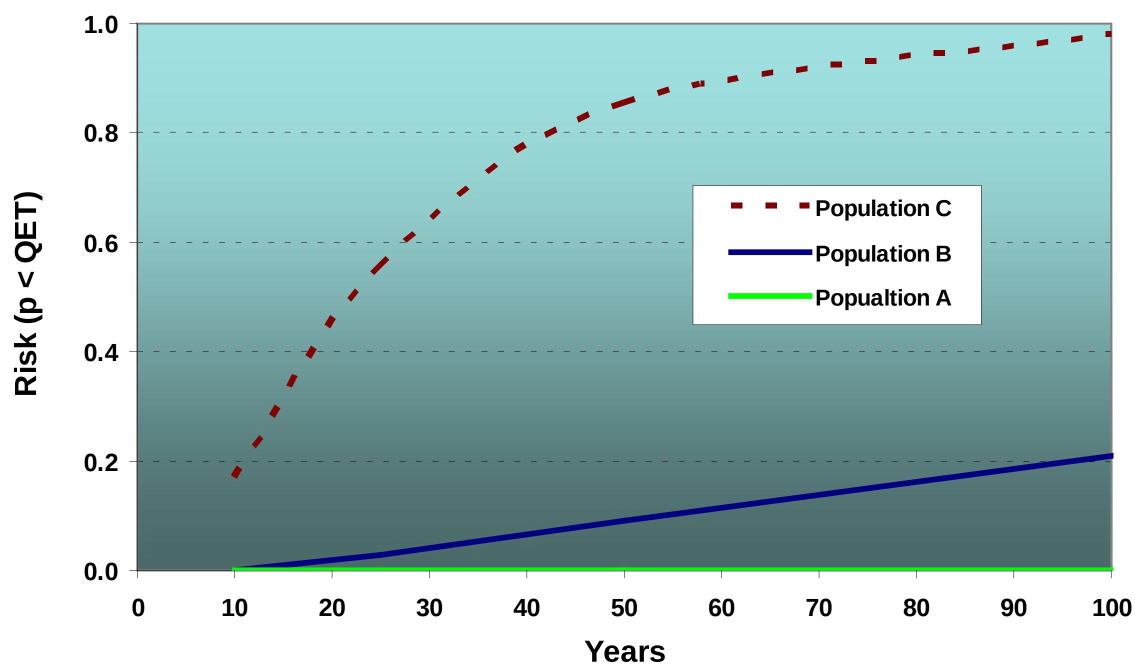

Figure 20. Effect of simulation years on natural population risk under a fixed 37% fishing rate scenario.

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[3] Short-term risks are influenced by initial population values. Lower initial population abundances will increase near-term risks.

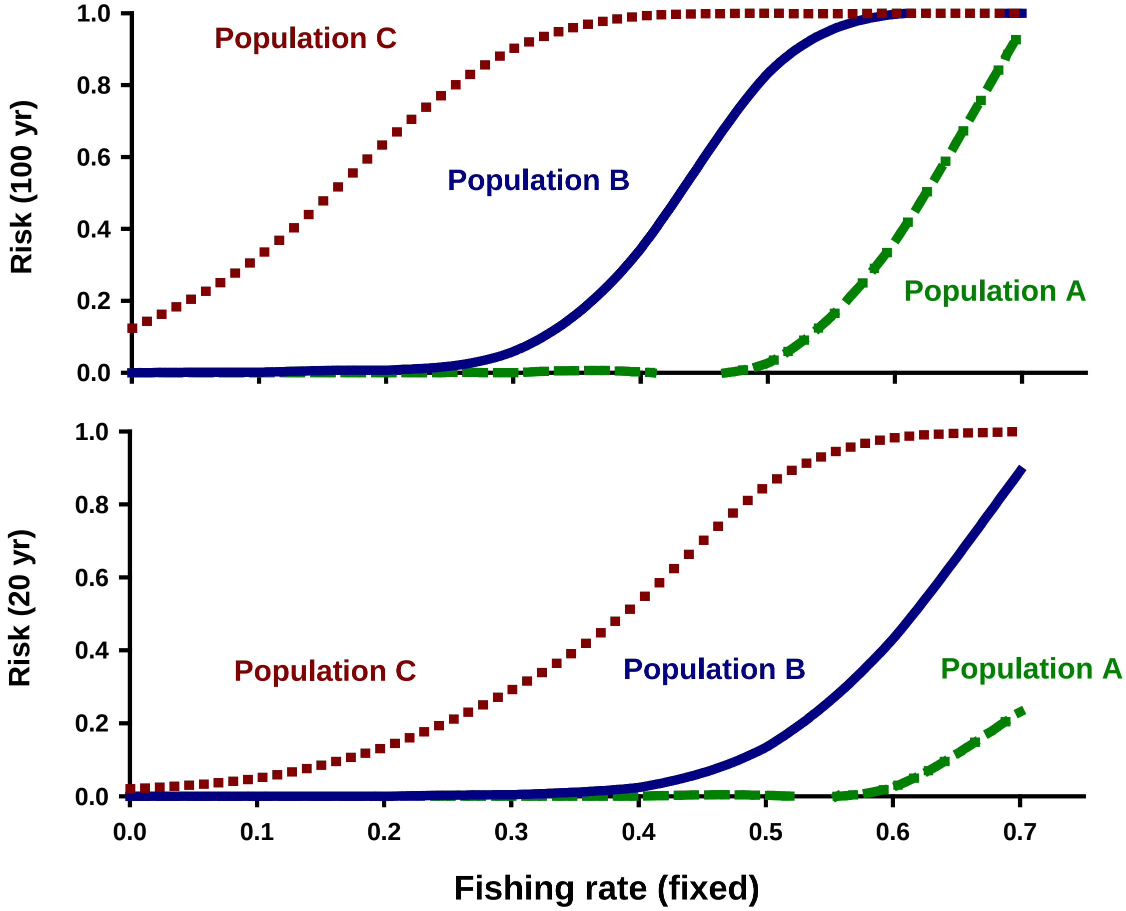

Figure 21. Modeled effects risks of different exploitation rates on long-term (100 year) and short-term (25 year) risk of falling below critical wild population abundance thresholds.

Effect of Fixed Harvest Rates

Average LRH harvest increases in direct proportion to increasing harvest rate (Figure 22). Risk increases in a curvilinear relationship to increasing harvest rate (Figure 23).

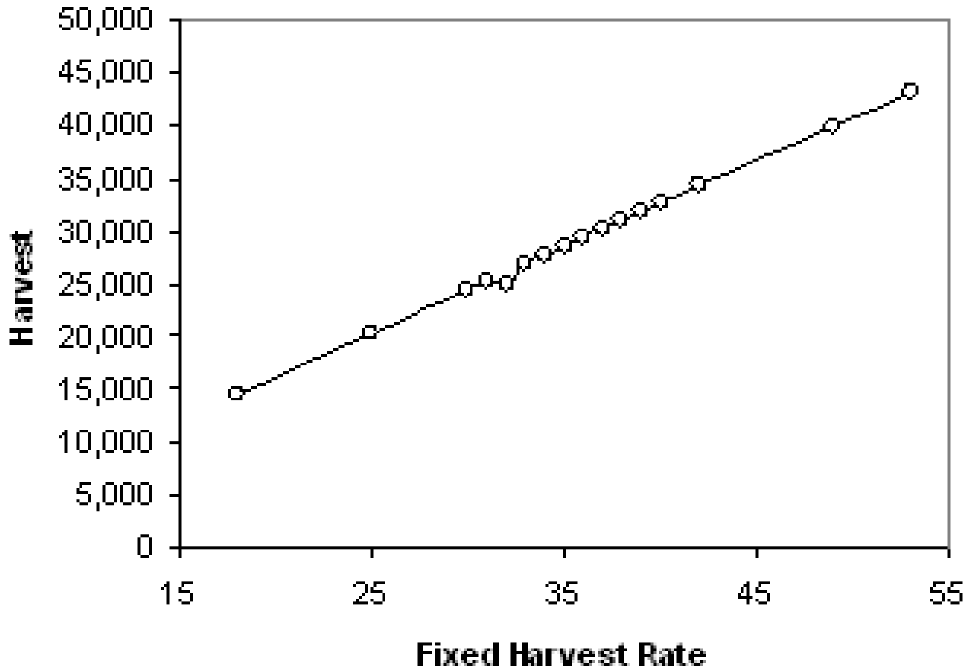

Figure 22. Simulated change in 100-year average harvest in response to fixed exploitation rate scenarios.

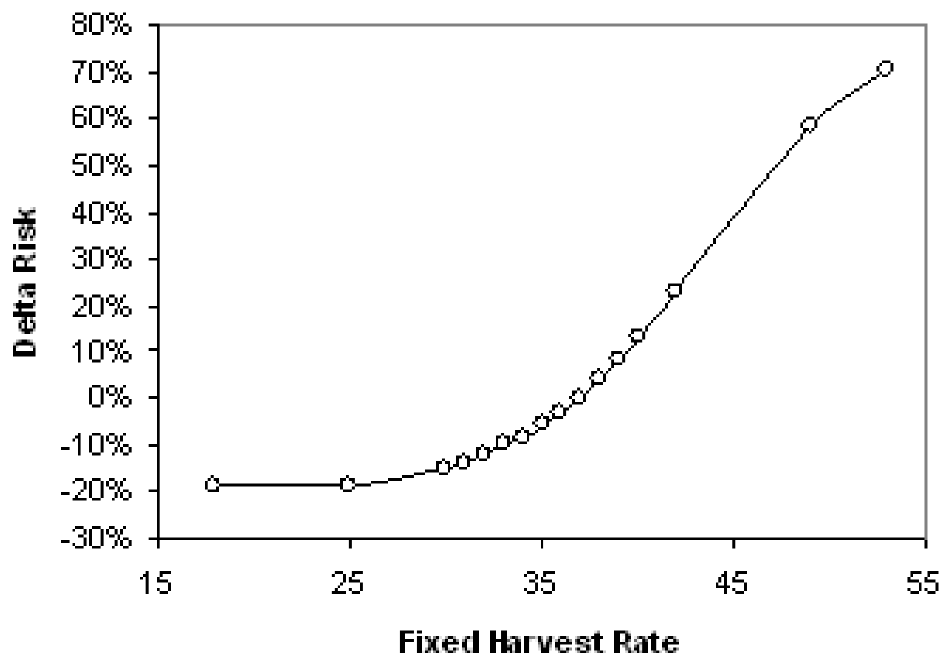

Figure 23. Simulated change in 100-year risk for category B populations in response to fixed exploitation rate scenarios.

Effect of Tier Selection

Frequencies of occurrence of predicted values projected by the model are depicted in Figure 24 and Table 19. Modeled frequencies closely correspond with frequencies observed during the last 20 years. Tier frequencies are of course affected by the ocean exploitation rate because forecasts are to the Columbia River mouth.

Figure 24 is helpful for identifying forecast tier levels consistent with a desired frequency of occurrence in model simulations. For instance, forecasts of less than 40,000 are modeled to occur approximately 22% of the time at an ocean exploitation rate of 0.30. Forecasts greater than 100,000 are modeled to occur approximately 23% of the time.

Wild population risks can be affected by the tier selection of forecast triggers which determines the frequency with which a tier-specific rate is applied. Risks do not vary with tier frequencies for fixed rate scenarios because the same rate is applied no mater what tier we are in. For abundance-based scenarios, risks generally increase as fewer years occur in tiers with lower fishing rates and more years occur with higher fishing rates. In general, the lower the forecast numbers used to define the tiers, the greater the wild population risk. However, tier values and abundance-based rates can be mixed and matched to provide a net benefit relative to any given fixed rate strategy.

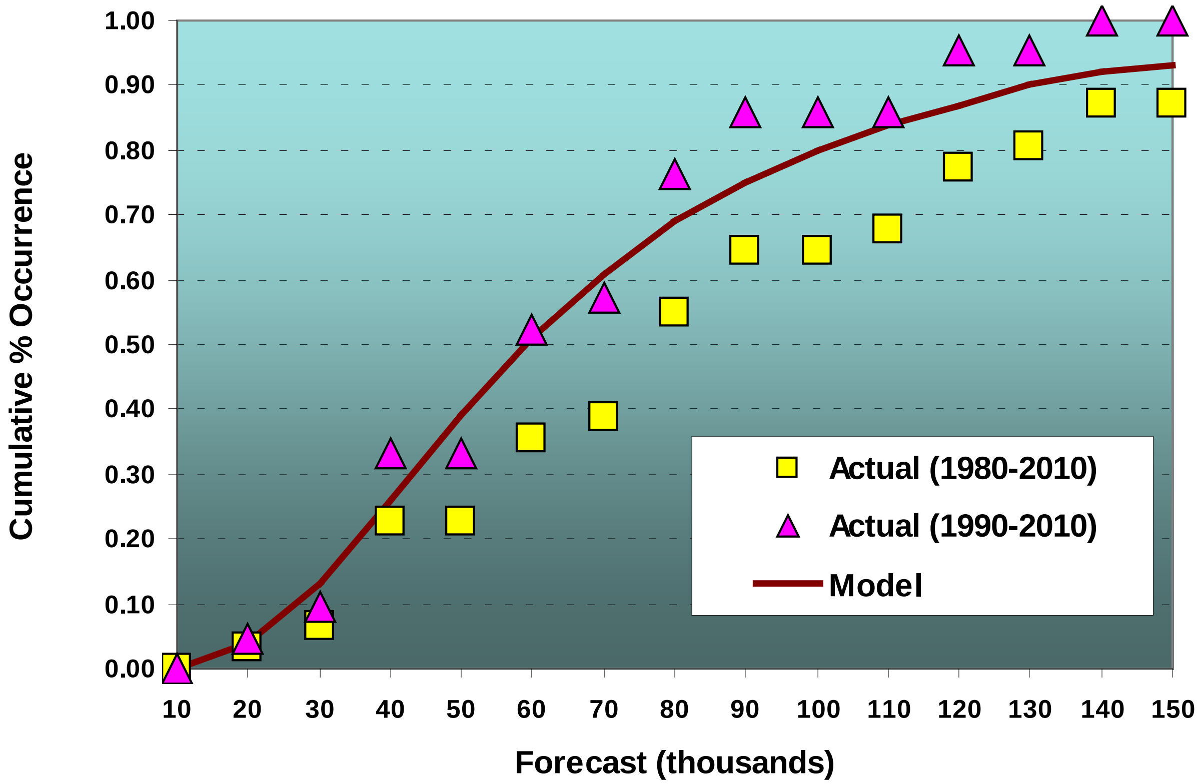

Figure 24. Cumulative frequency of occurrence of LRH run size to the Columbia River mouth based on model simulations.

Table 19. Observed and model frequencies of preseason forecasts and actual run sizes for LRH tule Chinook.

	1980-2010		1990-2010		Model simulation[a]	
Tier	Predicted	Actual	Predicted	Actual	ER = 49%	ER = 37%
<40,000	0.22	0.10	0.33	0.14	0.26	0.22
40,000-100,000	0.42	0.55	0.52	0.67	0.54	0.55
>100,000	0.36	0.35	0.14	0.19	0.20	0.23

[a] *Assuming ocean exploitation rates of 35% when 49% total and 30% when 37% total. The 49% example approximates the recent period. The 37% example is a reference for simulations of scenarios under current conditions.*

Tier frequencies in the future will depend on average and variability in LRH run size which in turn is affected by hatchery production, ocean survival patterns, and ocean exploitation rates. If parameters change significantly in the future, then the tier break points would change as well. The risk assessment thus presumes some base level of hatchery production – e.g., 22 million smolts. Ocean survival patterns are assumed to be similar to those occurring over the last 20 years which represented an extended period of lower-than-average productivity for LRH Chinook. The relative benefits of different fishing alternatives could be affected by any future changes in conditions which affect tier frequencies.

Table 20. Effects of different tier frequencies on risks and harvest levels associated with fixed and abundance-based fishery scenarios (Population B, 100-year simulation).

Scenario	Frequency	Risk	Harvest	Δ Risk	Δ Harvest	Category
F37	22/55/23	0.210	30,130	0%	0%	Equivalent
V37±5	22/55/23	0.163	31,540	-5%	5%	Win/Win
V37±10	22/55/23	0.117	32,950	-9%	9%	Win/Win
V37-5	22/55/23	0.147	29,770	-6%	-1%	Risk reduction
V37-10	22/55/23	0.100	29,400	-11%	-2%	Risk reduction
F37	46/31/23	0.210	30,130	0%	0%	Equivalent
V37±5	46/31/23	0.135	30,890	-8%	3%	Win/Win
V37±10	46/31/23	0.065	31,650	-15%	5%	Win/Win
V37-5	46/31/23	0.121	29,120	-9%	-3%	Risk reduction
V37-10	46/31/23	0.056	28,100	-15%	-7%	Risk reduction
F37	22/34/44	0.210	30,130	0%	0%	Equivalent
V37±5	22/34/44	0.175	32,479	-4%	8%	Win/Win
V37±10	22/34/44	0.163	34,810	-5%	16%	Win/Win
V37-5	22/34/44	0.147	29,770	-6%	-1%	Risk reduction
V37-10	22/34/44	0.100	29,400	-11%	-2%	Risk reduction

[a] *tiers: <40,000; 40,000-100,000; >100,000*

[b] *tiers: <60,000; 60,000-100,000; >100,000*

[c] *tiers: <40,000; 40,000-70,000; >70,000*

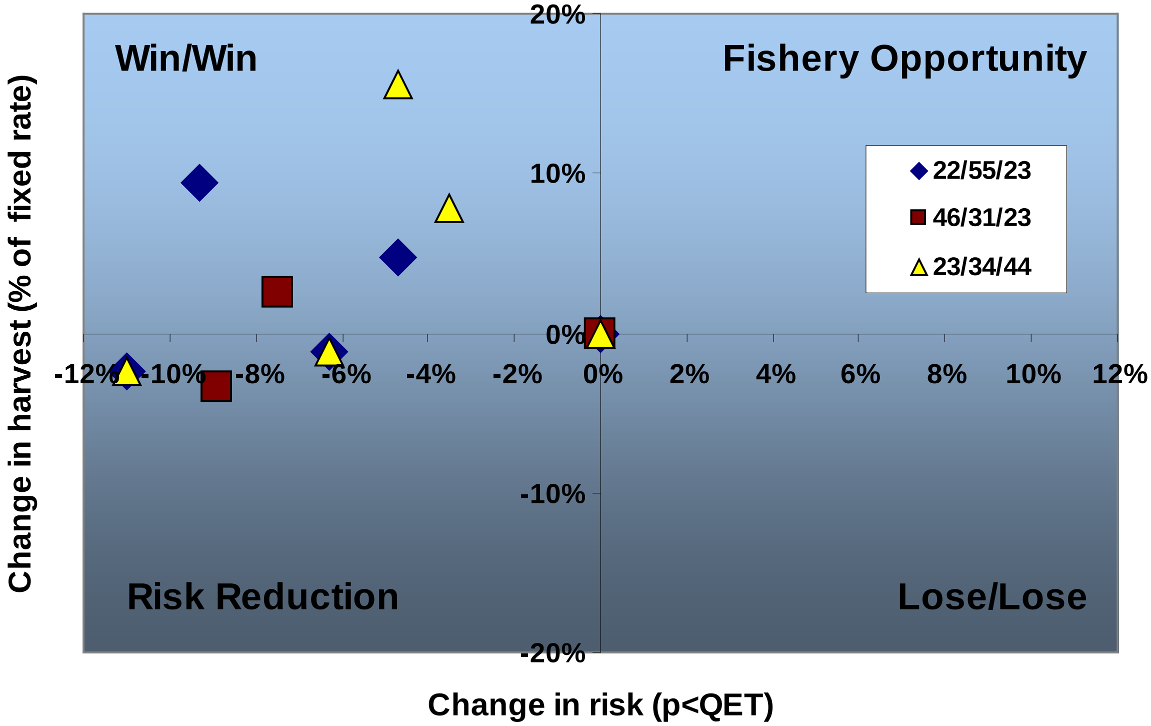

Figure 25. Example plot of the relative changes in natural population risk and LRH tule Chinook harvest level associated with different tier frequencies and fishery scenarios (Population B, 100-year simulations from Table 20).

Scenario Analysis

A variety of abundance-based approaches effectively reduce risks to wild B populations while also increasing average LRH harvest relative to a benchmark fixed rate of 0.37 used for comparison purposes. Risks are generally most sensitive to reductions in fishing rates in the lower tier and relatively less sensitive to increased fishing rates in higher tiers where the frequency of occurrence is similar in the lower and upper tiers. Risks are reduced by lower ERs in poor ocean survival years which are most to result in low wild spawning escapements. Risks are relatively unaffected by higher ERs in years of good survival. Harvest benefits in years are higher abundance exceed harvest reductions in years of lower abundance. It should be noted however that lower ERs may be borne disproportionately by specific fisheries. The fishery implications of lower ERs are substantially more complex than the simple harvest numbers reflect.

Scenario results are summarized in Table 21 and Table 22. For the purposes of this analysis, risks and harvest levels within the range observed for a ±1% change in fixed harvest rate were classified as equivalent to the fixed 0.37 values (shaded blue). Corresponding values were ±3.5% change in 100-year risk, ±0.25% change in 20-year risk, and ±3.0% change in average 100-year harvest. Lower risks and higher harvests (both desirable conditions) were shaded green. Higher risks and lower harvests (both undesirable conditions) were shaded yellow.

Table 21. Effects of variable rate fishing strategies based on three abundance tiers. Simulations are sorted by the 100-year Population B risk.

		Tier			Tier	Pop B risk		LRH	Change in risk		Δ Harvest	
	Scenario	Lower	Middle	Upper	Frequency	100 yr	20 yr	Harvest	100 yr	20 yr	100 yr	Category
1	F0	0.00	0.00	0.00	9/47/44	0.000	0.000	0	-21%	-1.6%	-100%	Risk reduction
2	F18	0.18	0.18	0.18	15/53/32	0.005	0.000	14,660	-21%	-1.6%	-51%	Risk reduction
3	F25	0.25	0.25	0.25	19/54/27	0.022	0.002	20,360	-19%	-1.4%	-32%	Risk reduction
4	V36-15	0.21	0.36	0.36	22/55/23	0.044	0.002	28,220	-17%	-1.4%	-6%	Risk reduction
5	F30	0.30	0.30	0.30	22/55/23	0.059	0.004	24,430	-15%	-1.2%	-19%	Risk reduction
6	V37-15	0.22	0.37	0.37	22/55/23	0.060	0.003	29,040	-15%	-1.3%	-4%	Risk reduction
7	V36±15	0.21	0.36	0.51	22/55/23	0.066	0.003	33,540	-14%	-1.3%	11%	Win/Win
8	V20/37/53	0.20	0.37	0.53	22/55/23	0.068	0.003	34,560	-14%	-1.3%	15%	Win/Win
9	F31	0.31	0.31	0.31	22/55/23	0.071	0.005	25,250	-14%	-1.1%	-16%	Risk reduction
10	V35±10	0.25	0.35	0.45	22/55/23	0.072	0.003	31,320	-14%	-1.3%	4%	Win/Win
11	V38-15	0.23	0.38	0.38	22/55/23	0.080	0.004	29,850	-13%	-1.2%	-1%	Risk reduction
12	V36-10	0.26	0.36	0.36	22/55/23	0.080	0.005	28,590	-13%	-1.1%	-5%	Risk reduction
13	V20/38/53	0.20	0.38	0.53	22/55/23	0.087	0.003	34,950	-12%	-1.3%	16%	Win/Win
14	F32	0.32	0.32	0.32	22/55/23	0.089	0.007	26,060	-12%	-0.9%	-14%	Risk reduction
15	V37±15	0.22	0.37	0.52	22/55/23	0.090	0.003	34,350	-12%	-1.3%	14%	Win/Win
16	V36±10	0.26	0.36	0.46	22/55/23	0.099	0.005	32,130	-11%	-1.1%	7%	Win/Win
17	V25/36/50	0.25	0.36	0.50	22/55/23	0.100	0.005	33,480	-11%	-1.1%	11%	Win/Win
18	V39-15	0.24	0.39	0.39	22/55/23	0.100	0.005	30,670	-11%	-1.1%	2%	Risk reduction
19	V37-10	0.27	0.37	0.37	22/55/23	0.100	0.005	29,400	-11%	-1.1%	-2%	Risk reduction
20	V25/37/50	0.25	0.37	0.50	22/55/23	0.111	0.005	33,860	-10%	-1.1%	12%	Win/Win
21	F33	0.33	0.33	0.33	22/55/23	0.114	0.008	26880	-10%	-0.8%	-11%	Risk reduction
22	V35±5	0.30	0.35	0.40	22/55/23	0.115	0.007	29,910	-10%	-0.9%	-1%	Risk reduction
23	V25/38/50	0.25	0.38	0.50	22/55/23	0.124	0.005	34,250	-9%	-1.1%	14%	Win/Win
24	V36-5	0.31	0.36	0.36	22/55/23	0.123	0.007	28,950	-9%	-0.9%	-4%	Risk reduction
25	V40-15	0.25	0.40	0.40	22/55/23	0.120	0.006	31,480	-9%	-1.0%	4%	Win/Win
26	V38-10	0.28	0.38	0.38	22/55/23	0.119	0.007	30,220	-9%	-0.9%	0%	Risk reduction
27	V37±10	0.27	0.37	0.47	22/55/23	0.117	0.005	32,950	-9%	-1.1%	9%	Win/Win
28	V38±15	0.23	0.38	0.53	22/55/23	0.116	0.005	35,170	-9%	-1.1%	17%	Win/Win
29	F34	0.34	0.34	0.34	22/55/23	0.129	0.011	27690	-8%	-0.5%	-8%	Risk reduction
30	V36±5	0.31	0.36	0.41	22/55/23	0.132	0.007	30,730	-8%	-0.9%	2%	Risk reduction
31	V25/40/45	0.25	0.40	0.45	22/55/23	0.136	0.006	33,250	-7%	-1.0%	10%	Win/Win
32	V28/37/50	0.28	0.37	0.50	22/55/23	0.142	0.007	34,080	-7%	-0.9%	13%	Win/Win
33	V39±15	0.24	0.39	0.54	22/55/23	0.144	0.007	35,980	-7%	-0.9%	19%	Win/Win
34	V38±10	0.28	0.38	0.48	22/55/23	0.147	0.007	33,760	-6%	-0.9%	12%	Win/Win

35	V39-10	0.29	0.39	0.39	22/55/23	0.147	0.008	31,030	-6%	-0.8%	3%	Risk reduction
36	V37-5	0.32	0.37	37	22/55/23	0.147	0.010	29,770	-6%	-0.6%	-1%	Risk reduction
37	F35	0.35	0.35	0.35	22/55/23	0.154	0.012	28,500	-6%	-0.4%	-5%	Risk reduction
38	V28/37/53	0.28	0.37	0.53	22/55/23	0.156	0.007	35,150	-5%	-0.9%	17%	Win/Win
39	V28/38/50	0.28	0.38	0.50	22/55/23	0.158	0.007	34,470	-5%	-0.9%	14%	Win/Win
40	V37±5	0.32	0.37	0.42	22/55/23	0.163	0.011	31,540	-5%	-0.5%	5%	Win/Win
41	V30/37/50	0.30	0.37	0.50	22/55/23	0.165	0.009	34,230	-5%	-0.7%	14%	Win/Win
42	V28/38/53	0.28	0.38	0.53	22/55/23	0.166	0.008	35,530	-4%	-0.8%	18%	Win/Win
43	V38-5	0.33	0.38	0.38	22/55/23	0.173	0.014	30,580	-4%	-0.2%	1%	Risk reduction
44	V30/37/53	0.30	0.37	0.53	22/55/23	0.174	0.011	35,290	-4%	-0.5%	17%	Win/Win
45	V39±10	0.29	0.39	0.49	22/55/23	0.175	0.011	34,580	-4%	-0.5%	15%	Win/Win
46	V30/38/50	0.30	0.38	0.50	22/55/23	0.176	0.012	34,620	-3%	-0.4%	15%	Fishery opportunity
47	V40-10	0.30	0.40	0.40	22/55/23	0.176	0.012	31,850	-3%	-0.4%	6%	Fishery opportunity
48	F36	0.36	0.36	0.36	22/55/23	0.179	0.014	29,320	-3%	-0.2%	-3%	Risk reduction
49	V40±15	0.25	0.40	0.55	22/55/23	0.180	0.007	36,800	-3%	-0.9%	22%	Fishery opportunity
50	V30/38/53	0.30	0.38	0.53	22/55/23	0.181	0.012	35,680	-3%	-0.4%	18%	Fishery opportunity
51	V38±5	0.33	0.38	0.43	22/55/23	0.183	0.014	32,360	-3%	-0.2%	7%	Fishery opportunity
52	V39-5	0.34	0.39	0.39	22/55/23	0.201	0.014	31,400	-1%	-0.2%	4%	Fishery opportunity
53	V40±10	0.30	0.40	0.50	22/55/23	0.204	0.012	35,390	-1%	-0.4%	17%	Fishery opportunity
54	F37	0.37	0.37	0.37	22/55/23	0.210	0.016	30,130	0%	0.0%	0%	Equivalent
55	V39±5	0.34	0.39	0.44	22/55/23	0.220	0.014	33,170	1%	-0.2%	10%	Fishery opportunity
56	V40-5	0.35	0.40	0.40	22/55/23	0.239	0.016	32,210	3%	0.0%	7%	Fishery opportunity
57	F38	0.38	0.38	0.38	22/55/23	0.248	0.019	30,950	4%	0.3%	3%	Fishery opportunity
58	V40±5	0.35	0.40	0.45	22/55/23	0.266	0.016	33,980	6%	0.0%	13%	Fishery opportunity
59	F39	0.39	0.39	0.39	22/55/23	0.294	0.019	31,760	8%	0.3%	5%	Fishery opportunity
60	F40	0.40	0.40	0.40	22/55/23	0.344	0.024	32,580	13%	0.8%	8%	Fishery opportunity
61	F42	0.42	0.42	0.42	22/55/23	0.438	0.034	34,210	23%	1.8%	14%	Fishery opportunity
62	F49	0.49	0.49	0.49	26/54/20	0.792	0.116	39,910	58%	10.0%	32%	Fishery opportunity
63	F53	0.53	0.53	0.53	28/54/18	0.912	0.200	43,160	70%	18.4%	43%	Fishery opportunity

Table 22. Effects of variable rate fishing strategies based on five abundance tiers. Simulations are sorted by the 100-year Population B risk.

		Tier					Tier	Pop B risk		LRH	Change in risk		Δ Harvest	
	Scenario	**1**	**2**	**3**	**4**	**5**	**Frequency**	**100 yr**	**20 yr**	**Harvest**	**100 yr**	**20 yr**	**100 yr**	**Category**
65	V25/30/35/40/45	0.25	0.30	0.35	0.40	0.45	10/25/30/25/10	0.076	0.004	31,090	-13%	-1.2%	3%	Risk reduction
54	F37	0.37	0.37	0.37	0.37	0.37	10/25/30/25/10	0.210	0.016	30,130	0%	0.0%	0%	Equivalent
64	V30/35/40/45/50	0.30	0.35	0.40	0.45	0.50	10/25/30/25/10	0.210	0.013	35,160	0%	-0.3%	17%	Fishery opportunity

Tiers: <29,000; 29,000-50,000; 51,000-80,000; 81,000-137,000; >137,000

Scenario results may be highlighted with several examples. All of the following examples represent a significant reduction in risk and increase in average harvest relative to the fixed 0.37 ER scenario.

Simple abundance-based centered on current ER

These scenarios decrease ER by a fixed increment (0.05, 0.10, and 0.15) from the base rate in years when Columbia River run forecasts are less than 40,000 which occur about 22% of the time over the last 20 years. ER is increased by the same increment in years of forecasts over 100,000 which occur about 23% of the time. About 55% of the time, the base rate of 0.37 applies. Each of these simple scenarios would substantially reduce risk to the wild populations and increase harvest opportunity for LRH relative to a fixed 0.37 strategy. The greater the steps, the greater the effects.

		Pop B risk		LRH	Change in risk		Δ Harvest	
	Scenario	100 yr	20 yr	Harvest	100 yr	20 yr	100 yr	Category
54	F37	0.210	0.016	30,130	0%	0.0%	0%	Equivalent
40	V37±5	0.163	0.011	31,540	-5%	-0.5%	5%	Win/Win
27	V37±10	0.117	0.005	32,950	-9%	-1.1%	9%	Win/Win
15	V37±15	0.090	0.003	34,350	-12%	-1.3%	14%	Win/Win

Simple abundance-based with reduced ER

Abundance-based strategies may also be centered around different exploitation rates. This example employs a 0.35 ER at forecasts between 40,000 and 100,000, and ERs of 0.25 or 0.45 at lower or higher forecasts. This example also substantially reduces risk and increases harvest relative to the fixed 0.37 ER scenario.

		Pop B risk		LRH	Change in risk		Δ Harvest	
	Scenario	100 yr	20 yr	Harvest	100 yr	20 yr	100 yr	Category
54	F37	0.210	0.016	30,130	0%	0.0%	0%	Equivalent
10	V35±10	0.072	0.003	31,320	-14%	-1.3%	4%	Win/Win

V25/37/50

This is a symmetrical scenario centered on the current ER with bottom and top ends reflecting other fishery constraints. The bottom end (0.25) provides for very limited southern fisheries while recognizing current ERs of northern (Canada & Alaska) fisheries. The top end represents the limit of what is likely to be achievable in light of constraints on other stocks such as Snake River Wild fall Chinook.. This example also represents a significant reduction in risk and increase in average harvest relative to the fixed 0.37 ER scenario.

		Pop B risk		LRH	Change in risk		Δ Harvest	
	Scenario	100 yr	20 yr	Harvest	100 yr	20 yr	100 yr	Category
54	F37	0.210	0.016	30,130	0%	0.0%	0%	Equivalent
20	V25/37/50	0.111	0.005	33,860	-10%	-1.1%	12%	Win/Win

V40-15 (V25/40/40)

This is an example of an unbalanced scenario that increases the base ER in the middle and upper tiers from 0.37 to 0.40 with an offsetting reduction in ER in the lower tier from 0.37 to

0.25. The corresponding increase in risk relative to the fixed 0.37 scenario is offset by a large reduction in ER in the lower tier. This example illustrates the required cost in low years to achieve a modest increase in most years. There is no risk of higher ERs in the upper tier if the forecast is off. This example also represents a significant reduction in risk and increase in average harvest relative to the fixed 0.37 ER scenario.

		Pop B risk		LRH	Change in risk		Δ Harvest	
	Scenario	100 yr	20 yr	Harvest	100 yr	20 yr	100 yr	Category
54	F37	0.210	0.016	30,130	0%	0.0%	0%	Equivalent
25	V40-15	0.120	0.006	31,480	-9%	-1.0%	4%	Win/Win

<u>V25/40/45</u>

This scenario is similar to V40-15 above with slightly more risk/benefit from high forecast years when the ER in the upper tier is increased from 0.40 to 0.45. This scenario produces comparable risks and harvest to V25/37/50 which illustrates that a variety of scenarios can be configured to produce similar effects depending with different frequencies of operating at any given ER level.

		Pop B risk		LRH	Change in risk		Δ Harvest	
	Scenario	100 yr	20 yr	Harvest	100 yr	20 yr	100 yr	Category
54	F37	0.210	0.016	30,130	0%	0.0%	0%	Equivalent
31	V25/40/45	0.136	0.006	33,250	-7%	-1.0%	10%	Win/Win
32	V25/37/50	0.142	0.007	34,080	-7%	-0.9%	13%	Win/Win

<u>V28/38/50</u>

This scenario steps down the ER to 0.28 at forecasts under 40,000, increases the base ER from 0.37 to 0.38 in the middle tier, and goes to a substantially higher ER of 0.50 in the upper tier. This scenario produces similar benefits to V25/37/50 shown above. It illustrates that substantial flexibility can be gained in the middle and upper tiers if substantially reductions are implemented in the lower tier.

		Pop B risk		LRH	Change in risk		Δ Harvest	
	Scenario	100 yr	20 yr	Harvest	100 yr	20 yr	100 yr	Category
54	F37	0.210	0.016	30,130	0%	0.0%	0%	Equivalent
39	V28/38/50	0.158	0.007	34,470	-5%	-0.9%	14%	Win/Win
32	V25/37/50	0.142	0.007	34,080	-7%	-0.9%	13%	Win/Win

Sensitivity Analysis

Effects on wild population risk of fishery "errors" in abundance-based management scenarios are illustrated in Figure 26. Fishery "error" in these simulations refers to the difference between target and actual exploitation rates. Over the last 10 years, the fishery error rate has averaged a CV of about 0.10. The sensitivity analysis shows that risks are relatively insensitive to error rates in that range at recent exploitation rates around 0.40. However, higher error rates increase risks under all scenarios as some run years, including low run abundance years that drive the risk calculation, may be subjected to substantially higher exploitation rates.

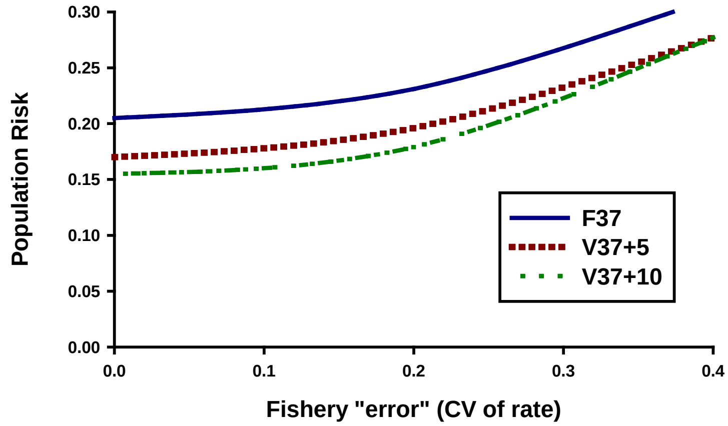

Figure 26. Effect of fishery "error" on 100-year risk for a category B population under several exploitation rate scenarios. Effects do not include the potential impacts of habitat/hatchery actions aimed at increasing natural production.

Effects on wild population risk of forecast errors in abundance-based management scenarios are illustrated in Figure 27. Of course, forecast error has no effect on risk in a fixed rate scenario where the same exploitation rate occurs in every run size tier. Risk increases with increased forecast error rates for abundance-based strategies as higher exploitation rates are implemented for lower runs than would otherwise occur if run forecasts were more accurate. However, risk is not extremely sensitive to forecast error rates up to the current LRH level (CV=0.75).

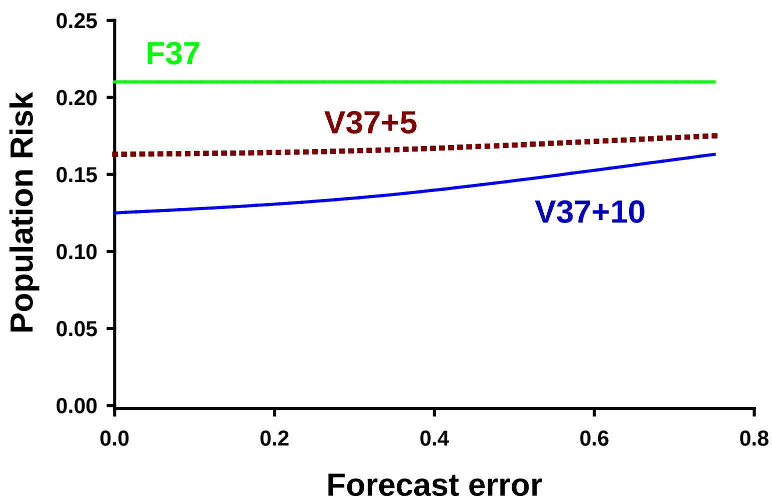

Figure 27. Effect of forecast error on 100-year risk for a category B population under several exploitation rate scenarios.

Discussion

Simulations of the effects of different fishing rate scenario suggest that wild population risks of low escapements can be reduced by an abundance-based approach, which reduces exploitation rates in years of low run forecasts. The general result of the model is that lower ERs provide benefits when run sizes are low, which offsets the cost of higher ERs when runs size is up. At the same time, fishery opportunities may be improved by higher exploitation rates in years of larger returns. A variety of scenarios were identified that provide both risk reduction and fishery opportunity benefits.

Both risk reduction and harvest benefits are relatively modest in the majority of abundance-based scenarios examined. However, the stochastic population model provided a systematic means of identifying scenarios that provide equivalent or lower risks to wild populations in comparison to the simple fixed rate approach currently employed.

While several abundance-based approaches appear to provide conservation and fishery benefits based on average numbers, this analysis did not attempt to evaluate the implications of different scenarios. Different scenarios consisting of different combinations and frequencies of fishing rates may produce very similar risk and average harvest numbers but have very different implications to specific fisheries. For instance, a V37±10 scenario reduces risk and increases average harvest relative to a V37±-5 scenario but certain fisheries might not be fishing at all 22% of the time under the V37±10 scenario. Fishery stability will also be a critical consideration in identifying appropriate or acceptable scenarios. A desirable fishing strategy will seek to balance risk reduction, harvest benefits, and the frequency of being able to fish. Different fishing rates identified earlier in this report for specific fisheries provide a basis for application of some logical expectations regarding the implications of different fishing rate alternatives.

Expectations about tier frequency change depending on whether conditions remain similar to the preceding 20-year period or return to conditions more representative of the longer term. The model was parameterized to represent the last 20 years which represent a prolonged period of low productivity and survival. The model estimates that forecasts under 40,000 LRH will occur approximately 22% of the time under similar conditions in the future. These projects also assume continuing production of about 22 million LRH hatchery juveniles per year which is less than historical levels. However, the expectation changes depending on whether we look at the last 10, 20, or 30 yrs. The fact is we really have no way to know what the relative frequency of bad, medium and good years will be over the next several years. Because run sizes are highly variable as well as temporally autocorrelated, we could also easily see a sequence of low or high runs simply due to chance within any short term period.

Scenario comparisons focused primarily on category B populations, which the risk modeling predicts will benefit the most from fishery limitations over the long term. The modeling indicates that previous reductions in ERs from very high levels observed in the late 1980s and early 1990s have substantially reduced the fishing-related risks to the more productive Category A populations. Modeling also showed that the long-term viability of the relative small and unproductive Category C populations will depend on improvements in the full spectrum of factors that are limiting including habitat and hatchery influences.

It is important to underscore that the risk estimates provided in this analysis should not be used or interpreted as absolute values, but rather as relative changes in risk depending on the population type and fishing strategy. Absolute estimates of risk depend on the combined effect of a suite of model inputs and functions. The details of the model are based on the best available science but in many cases information is limiting and the model structure is necessarily limited in turn. For instance, population-specific data is lacking for most lower Columbia River Chinook populations. Simulations assume that current conditions persist without consideration of improvements related to other recovery actions or degradation due to climate change. Effects of hatchery fish on spawner abundance or changes in hatchery contributions on population productivity are not modeled. Absolute estimates of risk also depend on definition of a standard for defining risk. In this case, risk is defined as the probability of the average number of wild spawners falling below a critical threshold of 50 fish for one generation (four years) within a prescribed period. However, selection of both the critical threshold and the simulation duration are somewhat subjective.

It should also be emphasized that the model runs included in this analysis do not include any potential contributions from the proposed habitat and hatchery improvements, and that the absolute value of the risk indices used to contrast harvest alternatives would be a function of those improvements. Absolute risk would be a function of assumptions regarding how much and how fast the response will be to implementing habitat actions (and in many cases local hatchery actions) designed to achieve the habitat targets. That, along with uncertainty in current model parameters, is the reason for focusing on relative reductions in risk instead of absolute risks values in the comparisons.

Application of these risk models are relatively robust to comparisons of the relative changes in risk (Morris and Doak 2002; Ralls et al. 2002). Comparisons of the effects of different fishing strategies on example populations of varying status are an example of a relative analysis. In this case, all the assumptions, inputs, and functions driving estimates of the absolute value of risks are common to all strategies. Thus, relative differences in risk estimated by the model reflect only the effects of the strategies being evaluated.

CONCLUSIONS & RECOMMENDATIONS

1. Fishery models indicate that an abundance-based exploitation rate schedule can provide benefits to wild populations and the fisheries.
    - An abundance-based approach reduces ERs at low run sizes and increases ERs at high run sizes.
    - Wild populations benefit from reduced risk of low spawning escapements in years following poor ocean survival.
    - Fisheries benefit from increased ERs and greater harvest in years of larger returns.
    - Fishery benefits come at a cost of reduced opportunity in low run years.
2. Several things need to be considered for an abundance-based approach
    - The run sizes that are used to put into the three tiers are important. The run sizes should accurately reflect what the future conditions will be. This needs to incorporate both the abundances in each tier and the frequency in each tier.
    - Other fishery constraints need to be considered in weighing the feasibility and benefits of implementing some abundance-based scenarios. For instance, other stock limitations will constrain opportunities for increased exploitation rates on LRH tule Chinook. Similarly, low run sizes result in other constraints on ERs, such as risk of reaching hatchery brood stock goals.
3. Different fishery sectors are likely to share the benefits and burdens of the variable exploitation rate strategy unevenly.
    - The fishers will have to feel comfortable with the expectation of being in the lowest and highest tiers about 20% of the time for each, and recognize the likelihood of consecutive years in those tiers.
4. There are numerous scenarios that should be considered when choosing an abundance-based matrix. Scenarios should meet the following criteria:
    - Wild population risks should be less than the risk associated with a fixed 0.37 ER.
    - On average, there should be a benefit to the fisheries – fisheries/harvest should be increased over the fixed 0.37 ER
    - There are low end ERs that could essentially eliminate fisheries off of Washington and Oregon and should not be considered in the analysis.

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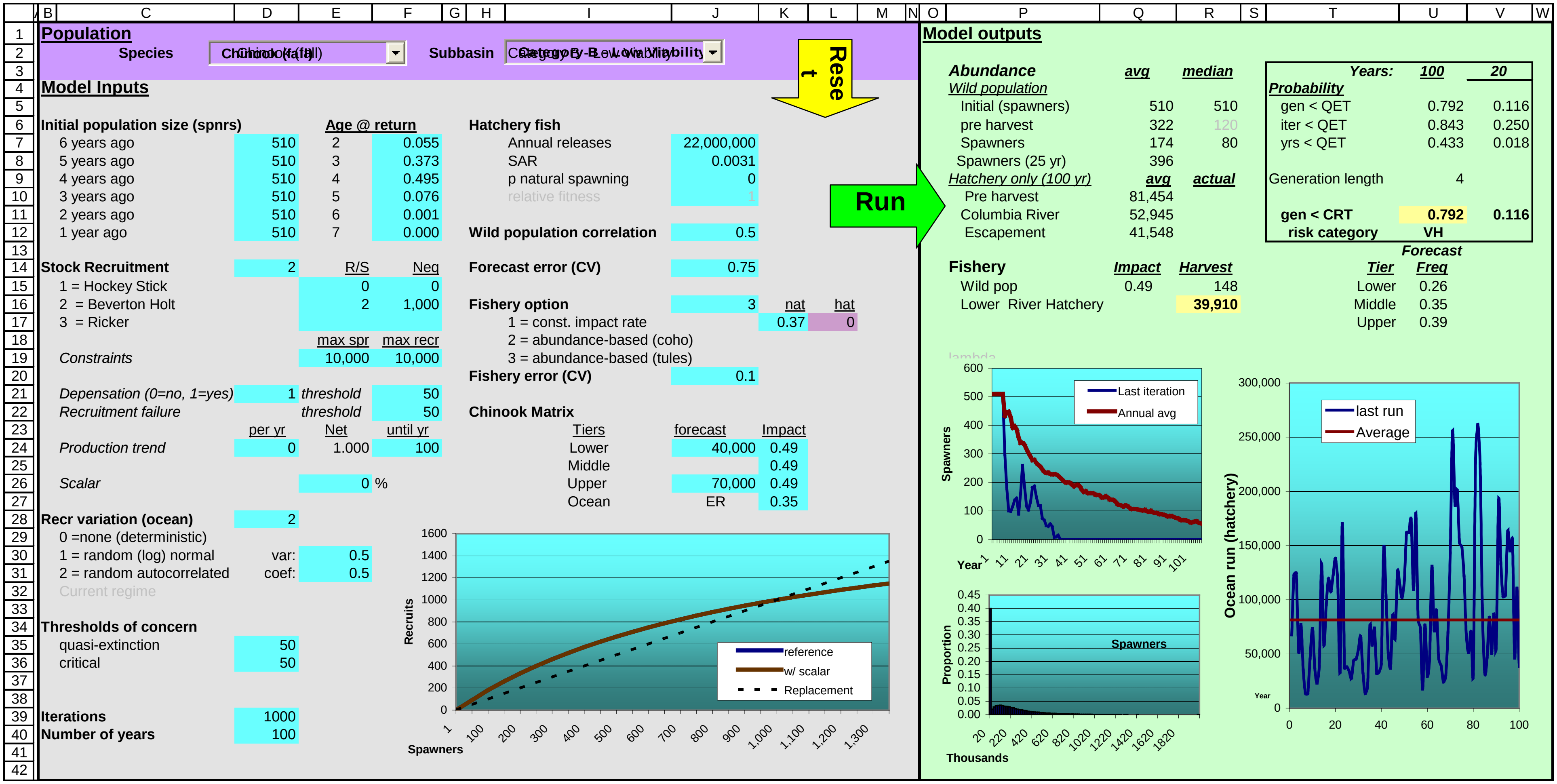
APPENDIX A – POPULATION VIABILITY ANALYSIS DOCUMENTATION

Interface Page



Formulae

Stock-Recruitment Function

The model stock recruitment function was based on the Beverton-Holt functional forms.

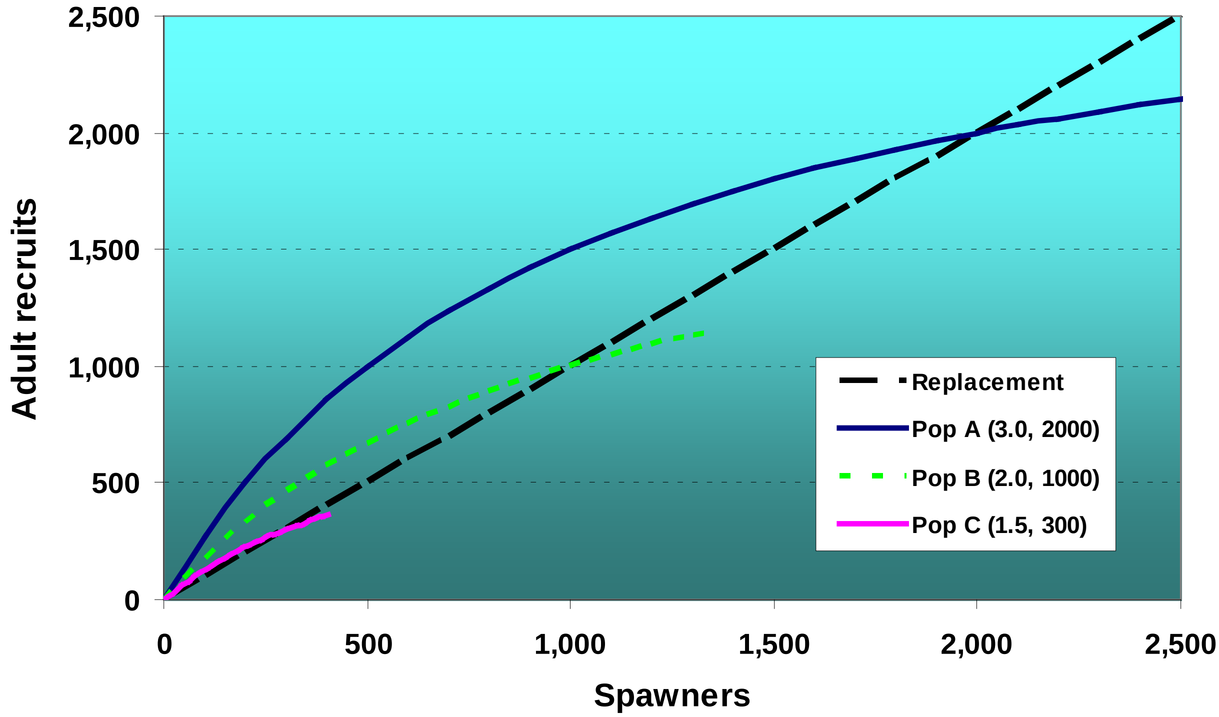


Figure 28. Examples of Beverton-Holt stock-recruitment curves.

The Beverton-Holt form of the relationship is:

$$R_y = \{a\, S_y / [1 + (S_y\, (a -1)/ N_{eq})]\}\, e^{\varepsilon}$$

where

R_y = recruits,
S_y = spawners,
a = productivity parameter (maximum recruits per spawner at low abundance),
N_{eq} = parameter for equilibrium abundance,
e = exponent, and
ε = normally-distributed error term ~ $N(0, \sigma^2)$.

Stock-Recruitment Variance

The stochastic simulation model incorporated variability about the stock-recruitment function to describe annual variation in fish numbers and productivity due to the effects of variable freshwater and marine survival patterns (as well as measurement error in stock assessments). This variance is modeled as a lognormal distribution (e^{ε}) where ε is normally distributed with a mean of 0 and a variance of σ_z^2 .

The model allows for simulation of autocorrelation in stock-recruitment variance as follows:

$$Z_t = \emptyset\, Z_{t-1} + \varepsilon_{t}, \qquad \varepsilon_{t} \sim N(0, \sigma_e^2)$$

where

Z_t = autocorrelation residual,

Ø = lag autoregression coefficient,

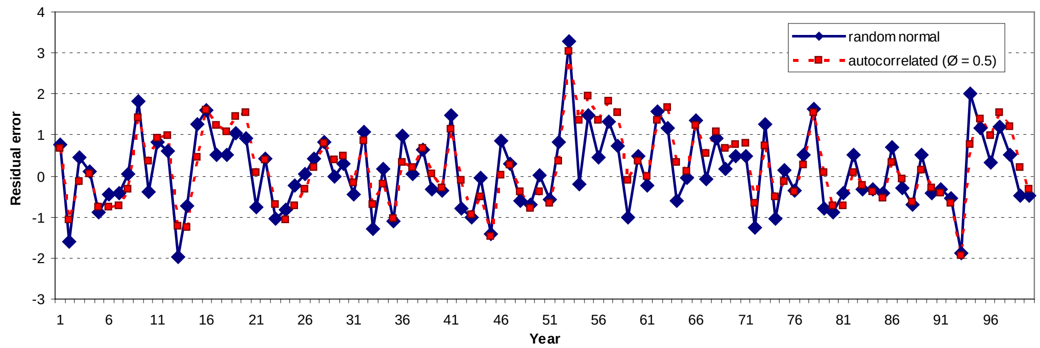
ε_t = autocorrelation error, and

σ_e^2 = autocorrelation error variance.

The autocorrelation error variance (σ_e^2) is related to the stock-recruitment error variance (σ_z^2) with the lag autoregression coefficient:

$$\sigma_e^2 = \sigma_z^2 (1 - Ø^2)$$

Model simulations using the autocorrelated residual options were seeded in the first year with a randomly generated value from N(0, σ_z^2).



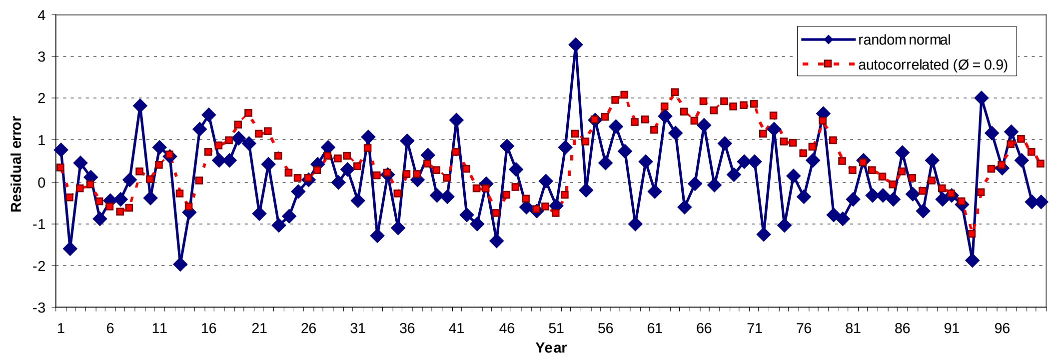


Figure 29. Examples of autocorrelation effect on randomly generated error patterns (σ_z^2 = 1).

Depensation & Recruitment Failure Thresholds

The model provides options to limit recruitment at low spawner numbers consistent with depensatory effects of stock substructure and small population processes. Options include 1) progressively reducing productivity at spawner numbers below a specified recruitment depensation threshold (RDT) and/or 2) setting recruitment to zero at spawner numbers below a specified recruitment failure threshold (RFT):

$$R' = R * (1 - Exp((Log(1 - 0.95) / (RDT - 1)) * S)) \text{ when } S > RFT$$

$$R' = 0 \text{ when } S < RFT$$

where

R' = Number of adult recruits after depensation applied,

R = Number of adult recruits estimated from stock-recruitment function,

S = spawners, and

RDT = Recruitment depensation threshold (spawner number).

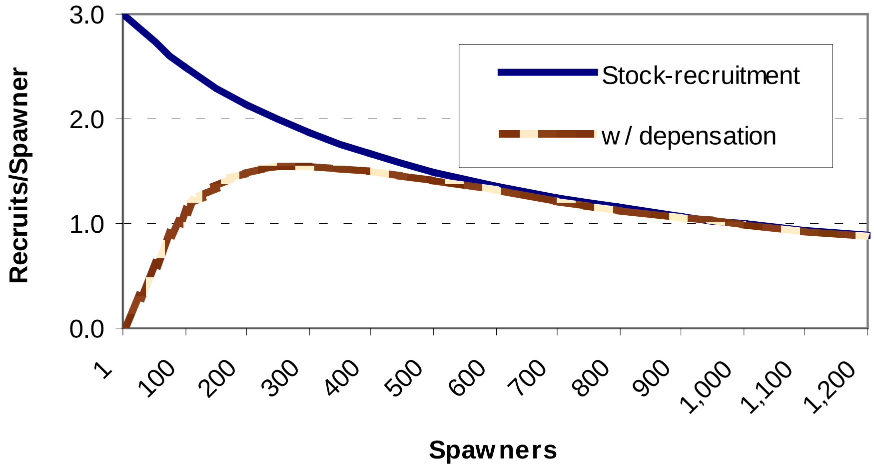


Figure 30. Example of depensation function effect on recruits per spawner at low spawner numbers based on a Beverton-Holt function (a = 3.0, Neq =1,000, γ =500).

Generic sensitivity analyses of production and abundance effects were based on a recruitment failure threshold of 50 (equal to the QET) and a recruitment depensation threshold equal to the CRT. Thus, spawning escapements of fewer than 50 spawners are assumed to produce no recruits and the depensation function reduces productivity of spawning escapements of under the CRT value in any one year. Population-specific analyses were similarly based on a RFT of 50 and a recruitment depensation threshold equal to the CRT.

Production Trend

The model includes an optional input to allow average productivity to be annually incremented upward or downward so that effects of trends in habitat conditions might be considered:

$$R'' = R' (1 + t)^y$$

where

R' = Number of adult recruits after depensation applied, and

t = proportional annual change in productivity.

McElhany et al. (2006) assumed a median annual decline of ln(y) = 0.995 to future simulations based on a precautionary expectation of declining snow packs, survival indices, and climate change. Generic sensitivity and population-specific analyses included in this analysis did not assume a trend but additional sensitivity analyses were conducted to evaluate the effect of a range of declining trends on projected risks.

Annual Abundance

Numbers of naturally-produced fish ($N_{.y}$) destined to return to freshwater in each year are estimated from a progressive series of recruitment cohorts based on a specified age composition:

$$N_{.y} = \Sigma N_{xy}$$

$$N_{xy} = R^*_{y-x} m_x$$

where

N_{xy} = Number of mature naturally-produced adults of age x destined to return to freshwater in year y, and

m_x = Proportion of adult cohort produced by brood year spawners that returns to freshwater in year x

Hatchery Fish

The model includes option inputs for modeling co-occurring natural and hatchery populations. Number of hatchery-produced fish ($H_{.y}$) destined to return to freshwater in each year is estimated based on input juvenile release numbers (J), release-to-adult survival rates (SAR), and age composition (m_x):

$$H_{.y} = \Sigma H_{xy}$$

$$H_{xy} = (J)(SAR)(e^{\varepsilon})(m_x)$$

where

H_{xy} = Number of mature hatchery-produced adults of age x destined to return to freshwater in year y

Note that the model incorporates random normal variation in hatchery survival rates among release cohorts using a scalar based on natural productivity derived from the stock-recruitment variance. Thus, hatchery and natural numbers varied in tandem. The corresponding assumption would be that variation in hatchery and wild production was highly correlated due to common effects of freshwater and marine factors.

Run Forecasts

```
Forecast3(y) = NAd2H(i, y - 1) * (m3 / (m2 + 0.0000000001)) * (1 - LRHOcnER)
Forecast4(y) = NAd3H(i, y - 1) * (m4 / (m3 + 0.0000000001)) * (1 - LRHOcnER)
Forecast5(y) = NAd4H(i, y - 1) * (m5 / (m4 + 0.0000000001)) * (1 - LRHOcnER)
Forecast6(y) = NAd5H(i, y - 1) * (m6 / (m5 + 0.0000000001)) * (1 - LRHOcnER)
Forecast7(y) = NAd6H(i, y - 1) * (m7 / (m6 + 0.0000000001)) * (1 - LRHOcnER)

Forecast(y) = Forecast3(y) + Forecast4(y) + Forecast5(y) + Forecast6(y) + Forecast7(y)
'adults only
ForeVar(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd()) * (ForeErr * Forecast(y))
Forecast(y) = Forecast(y) + ForeVar(y)
```

Where

ForecastX(y) = age-specific forecast to Columbia River

mX = average proportion of brood year return by age X

Fisheries & Harvest

Annual numbers are subject to optional fishing rates. This option is useful for adjusting future projections for changes in fisheries and evaluating the effects of alternative fishing strategies and levels. Fishery impact is defined in the model in terms of the adult equivalent number of fish that die as a result of direct and indirect fishery effects:

$$IN_y = N_{.y} fN_y \text{ and } IH_y = H_{.y} fH_y$$

where

IN_y = fishery impact in number of naturally-produced fish,

fN_y = fishery impact mortality rate on naturally produced fish including harvested catch and catch-release mortality where applicable,

IH_y = Fishery impact in number of hatchery-produced fish, and

fH_y = fishery impact mortality rate including harvested catch and other mortality where applicable.

Spawning Escapement

Estimates of natural spawning escapement (S_y) include naturally-produced fish that survive fisheries plus a proportion of the hatchery escapement that spawns naturally decremented by the relative spawning success of a hatchery fish:

$$S_y = SN_y$$

$$SN_y = (N_{.y} - IN_y)$$

where

SN_y = Naturally-produced spawners in year y.

Model Processing Code

```
Option Explicit
'Dimension variables
   Public i    'iteration count
   Public y    'year count
   'Input variables
   Public Spp  'species
   Public Subbasin
   Public Nyr
   Public iter
   Public NSpn6ago
   Public NSpn5ago
   Public NSpn4ago
   Public NSpn3ago
   Public NSpn2ago
   Public NSpn1ago
   Public SRopt
   Public HSrps
   Public HSneq
   Public BHrps
   Public BHneq
   Public Rrps
   Public Rneq
   Public limitS 'large spawner number where recruitment no longer declines with increasing spawners
   Public limitR 'max recruitment allowed
   Public Depopt
   Public depthres
   Public RFT
   Public FWtrend
   Public FWyrs
   Public FWcond
   Public Ropt
   Public RMSE
   Public Rlag
   Public m3
   Public m4
   Public m5
   Public m2
```

```
Public m6
Public m7

Public Quasi
Public Genetic
Public Recov
Public Rgoal
Public Fopt
Public FrateNin
Public FrateN(110)
Public tgFrateN(110)
Public FrateHin
Public FrateH
Public Fcv
Public Fvar(110)
Public HatRel
Public HatSAR
Public Hatp

Public PopCor
Public ForeErr

Public Gen  'Weighted mean generation time by species for calc of moving avg

Public ISpp(150)
   Public ISubbas(150)
   Public ICRT(150)
   Public ISRtype(150)
   Public INeq(150)
   Public IRpS(150)
   Public IVar(150)
   Public Ilag(150)
   Public Iage2(150)
   Public Iage3(150)
   Public Iage4(150)
   Public Iage5(150)
   Public Iage6(150)
   Public Iage7(150)
   Public IER(150)

'State variables
Public NSpn(1000, 110) 'total spawners
Public NSpn2(1000, 110)
Public NSpn3(1000, 110)
Public NSpn4(1000, 110)
Public NSpn5(1000, 110)
Public NSpn6(1000, 110)
Public NSpn7(1000, 110)

Public NSpnN(1000, 110) 'natural origin spawners
Public NSpn2N(1000, 110)
Public NSpn3N(1000, 110)
Public NSpn4N(1000, 110)
Public NSpn5N(1000, 110)
Public NSpn6N(1000, 110)
```

```
Public NSpn7N(1000, 110)

Public NSpnH(1000, 110) 'hatchery origin spawners
Public NSpn2H(1000, 110)
Public NSpn3H(1000, 110)
Public NSpn4H(1000, 110)
Public NSpn5H(1000, 110)
Public NSpn6H(1000, 110)
Public NSpn7H(1000, 110)

Public Nocn(1000, 110)      'total
Public NocnN(1000, 110)     'natural origin ocean recruits
Public NocnH(1000, 110)     'ocean recruits hatchery

Public NEsc(1000, 110) 'total escaping fishery
Public NEsc2(1000, 110)
Public NEsc3(1000, 110)
Public NEsc4(1000, 110)
Public NEsc5(1000, 110)
Public NEsc6(1000, 110)
Public NEsc7(1000, 110)

Public NEscN(1000, 110) 'natural escaping fishery
Public NEsc2N(1000, 110)
Public NEsc3N(1000, 110)
Public NEsc4N(1000, 110)
Public NEsc5N(1000, 110)
Public NEsc6N(1000, 110)
Public NEsc7N(1000, 110)

Public NEscH(1000, 110) 'hatchery escaping fishery
Public NEsc2H(1000, 110)
Public NEsc3H(1000, 110)
Public NEsc4H(1000, 110)
Public NEsc5H(1000, 110)
Public NEsc6H(1000, 110)
Public NEsc7H(1000, 110)

Public NAd(1000, 110) 'total adults returning to freshwater
Public NAd2(1000, 110)
Public NAd3(1000, 110)
Public NAd4(1000, 110)
Public NAd5(1000, 110)
Public NAd6(1000, 110)
Public NAd7(1000, 110)

Public NAdN(1000, 110) 'natural adults returning to freshwater
Public NAd2N(1000, 110)
Public NAd3N(1000, 110)
Public NAd4N(1000, 110)
Public NAd5N(1000, 110)
Public NAd6N(1000, 110)
Public NAd7N(1000, 110)

Public NAdH(1000, 110) 'hatchery adults returning to freshwater
```

```
Public NAd2H(1000, 110)
Public NAd3H(1000, 110)
Public NAd4H(1000, 110)
Public NAd5H(1000, 110)
Public NAd6H(1000, 110)
Public NAd7H(1000, 110)

Public NHarN(1000, 110) 'natural adults harvested
Public NHar2N(1000, 110)
Public NHar3N(1000, 110)
Public NHar4N(1000, 110)
Public NHar5N(1000, 110)
Public NHar6N(1000, 110)
Public NHar7N(1000, 110)

Public NHarH(1000, 110) 'hatchery adults harvested
Public NHar2H(1000, 110)
Public NHar3H(1000, 110)
Public NHar4H(1000, 110)
Public NHar5H(1000, 110)
Public NHar6H(1000, 110)
Public NHar7H(1000, 110)

Public NHar(1000, 110) 'total adults harvested
Public NHar2(1000, 110)
Public NHar3(1000, 110)
Public NHar4(1000, 110)
Public NHar5(1000, 110)
Public NHar6(1000, 110)
Public NHar7(1000, 110)

'working variables
Public SRvar(1000, 110)
Public SRvarH(1000, 110)
Public HSvRate(1000, 110)
Public Z1(110)
Public Z2(110)
Public eSRvar
Public eSRvarLast
Public alphax       'revised stock-recruit alpha for fw production trend
Public Nsp

Public NRec5ago       'natural recruits 5 years ago
Public NRec4ago
Public NRec3ago
Public NRec2ago
Public NRec1ago

Public HRec5ago       'hatchery recruits 5 years ago
Public HRec4ago
Public HRec3ago
Public HRec2ago
Public HRec1ago
Public r
Public n
```

```
Public x
Public j    'counter for freq distr
Public jj
Public k    'counter
Public CountE(105)
Public CountR(105)
Public CounttgF(105)
Public CountF(105)
Public CntExtinct
   Public CntExtinctST 'short term
Public CntGenetic
   Public CntGeneticST 'gen < CRT short term
Public flagEx(1000)
      Public flagExST(1000)
Public MovGenAvg(1000, 110)
Public CntQETiter
Public CntQETiterST 'short term
   Public flagQET(1000)
   Public flagQETST(1000) ' short term
Public flagGR(1000)
   Public flagGRST(1000)
Public CntQETyr
   Public CntQETyrST
Public ENSpn
Public ENSpn10
Public ENocnN
Public ENocnH
Public ENAdH
Public ENEscH
Public EFrate
Public GNSpn(1000)
Public GNSpnE
Public NspnAvg(110)
'    Public cntFloor1
'    Public minNSpn1
 '   Public maxNSpn1
 '   Public ssNSpn1
'Coho matrix inputs
Public FIR(5, 5)
Public Neq
Public seedN(110)
Public MSIN(110)
Public seed(110)
Public MSI(110)
Public CntErr(30)
Public CntCell(5, 5)

Public LRHLT   'lower theshold forecast level for use in Chinook abundance-based modeling
Public LRHUT   'upper threshold
Public LRHLTER 'impact rate to apply to forecasts below lower threshold
Public LRHMTER 'impact rate to apply to forecasts below lower threshold
Public LRHUTER 'impact rate to apply to forecasts below lower threshold
Public LRHOcnER 'ocean impact used to back CR forecast out to preharvest recruits
Public Forecast(110) 'tule forecast used to drive fishing rate (derived)
Public Forecast2(110)
```

```
   Public Forecast3(110)
   Public Forecast4(110)
   Public Forecast5(110)
   Public Forecast6(110)
   Public Forecast7(110)
   Public ForeVar(110)
   Public CntTierA
   Public CntTierB
   Public CntTierC

Public Sub RunModel()
   Load UserForm1
   UserForm1.Show vbModeless

'Initialize inputs
   'Nyr = 100
   Nyr = Cells(40, 4)
   x = Rnd(-1234567)  ' initializes random number seed so that the same sequence of random numbers are
generated for any simulation
   eSRvarLast = 0

   'read from model sheet
   Spp = Cells(2, 4)
   Subbasin = Cells(3, 4)
   NSpn6ago = Cells(7, 4)
   NSpn5ago = Cells(8, 4)
   NSpn4ago = Cells(9, 4)
   NSpn3ago = Cells(10, 4)
   NSpn2ago = Cells(11, 4)
   NSpn1ago = Cells(12, 4)

   SRopt = Cells(14, 4)
   HSrps = Cells(15, 5)
   HSneq = Cells(15, 6)
   BHrps = Cells(16, 5)
   BHneq = Cells(16, 6)
   Rrps = Cells(17, 5)
   Rneq = Cells(17, 6)
   limitS = Cells(19, 5)
   limitR = Cells(19, 6)

   Depopt = Cells(21, 4)
   depthres = Cells(21, 6)

   RFT = Cells(22, 6)
   FWtrend = Cells(24, 4)
   FWyrs = Cells(24, 6)

   Ropt = Cells(28, 4)
   RMSE = Cells(30, 5)
   Rlag = Cells(31, 5)

   m2 = Cells(7, 6)
   m3 = Cells(8, 6)
   m4 = Cells(9, 6)
```

```
m5 = Cells(10, 6)
m6 = Cells(11, 6)
m7 = Cells(12, 6)

iter = Cells(39, 4)
Quasi = Cells(35, 4)
Genetic = Cells(36, 4)
Recov = Cells(26, 5)
Fopt = Cells(16, 10)
FrateNin = Cells(17, 11)
FrateHin = Cells(17, 12)

Fcv = Cells(20, 10)

HatRel = Cells(7, 10)
HatSAR = Cells(8, 10)
Hatp = Cells(9, 10)

PopCor = Cells(12, 10)
ForeErr = Cells(14, 10)

'MSI(1) = Cells(45, 10)
'MSI(2) = Cells(45, 10)
'MSI(3) = Cells(45, 10)

'coho matrix inputs
FIR(1, 1) = Cells(47, 10)
FIR(1, 2) = Cells(47, 11)
FIR(1, 3) = Cells(47, 12)
FIR(1, 4) = Cells(47, 13)

FIR(2, 1) = Cells(48, 10)
FIR(2, 2) = Cells(48, 11)
FIR(2, 3) = Cells(48, 12)
FIR(2, 4) = Cells(48, 13)

FIR(3, 1) = Cells(49, 10)
FIR(3, 2) = Cells(49, 11)
FIR(3, 3) = Cells(49, 12)
FIR(3, 4) = Cells(49, 13)

FIR(4, 1) = Cells(50, 10)
FIR(4, 2) = Cells(50, 11)
FIR(4, 3) = Cells(50, 12)
FIR(4, 4) = Cells(50, 13)

FIR(5, 1) = Cells(51, 10)
FIR(5, 2) = Cells(51, 11)
FIR(5, 3) = Cells(51, 12)
FIR(5, 4) = Cells(51, 13)

LRHLT = Cells(24, 10)
LRHUT = Cells(26, 10)
LRHLTER = Cells(24, 11)
LRHMTER = Cells(25, 11)
```

```
   LRHUTER = Cells(26, 11)
   LRHOcnER = Cells(27, 11)

   'If Spp = 1 Then  'coho
   '    Gen = 3
   'ElseIf Spp = 2 Then  'steelhead
   '    Gen = 7
   'ElseIf Spp = 3 Then  'spring chinook
   '    Gen = 6
   'ElseIf Spp = 4 Then 'fall chinook
   '    Gen = 5
   'ElseIf Spp = 5 Then 'chum
   '    Gen = 5
   'Else 'default
   '    Gen = 5
   'End If
   Gen = Round(2 * m2 + 3 * m3 + 4 * m4 + 5 * m5 + 6 * m6 + 7 * m7)

'Initialize summary statistics
   CntExtinct = 0
   CntExtinctST = 0
   CntGenetic = 0
   CntGeneticST = 0
   CntQETiter = 0
   CntQETiterST = 0
   CntQETyr = 0
   CntQETyrST = 0
   For j = 1 To 30
      CntErr(j) = 0
   Next j
   CntTierA = 0
   CntTierB = 0
   CntTierC = 0
   ENSpn = 0
   ENAdH = 0
   ENSpn10 = 0
   ENEscH = 0
   ENocnN = 0
   ENocnH = 0
   EFrate = 0
   '    minNSpn1 = 1000000
   '    maxNSpn1 = 0
   '    ssNSpn1 = 0
   For j = 1 To 100
      CountE(j) = 0
      CountR(j) = 0
      CounttgF(j) = 0
      CountF(j) = 0
   Next j
   For j = 1 To 5
      For k = 1 To 4
         CntCell(j, k) = 0
      Next k
   Next j
   If SRopt = 1 Then
```

```
        jj = HSneq * ((1 + FWtrend) ^ (FWyrs)) * (1 + (Recov / 100))
    ElseIf SRopt = 2 Then
        jj = BHneq * ((1 + FWtrend) ^ (FWyrs)) * (1 + (Recov / 100))
    ElseIf SRopt = 3 Then
        jj = Rneq * ((1 + FWtrend) ^ (FWyrs)) * (1 + (Recov / 100))
    End If
    jj = Int(jj * 2 / 100)
    For y = 1 To Nyr + 6
        NspnAvg(y) = 0
        tgFrateN(y) = 0
        FrateN(y) = 0
        seedN(y) = 0
        MSIN(y) = 0
        seed(y) = 0
        MSI(y) = 0
        Fvar(y) = 0
        'MovGenAvg(y) = 0
    Next y
    For i = 1 To iter
        GNSpn(i) = 1
        flagQET(i) = 0
        flagQETST(i) = 0
        flagEx(i) = 0
        flagExST(i) = 0
        flagGR(i) = 0
        flagGRST(i) = 0
    Next i
    GNSpnE = 0

'Iterations
For i = 1 To iter
    'reset annual values to 0 from previous iteration
    For y = 1 To Nyr + 6
        MovGenAvg(i, y) = 0
    Next y

    For y = 1 To Nyr + 6
      'Estimate recruits (for bookkeeping purposes recruits assumed to be 1 year old)
        If y > 1 Then Nsp = NSpn(i, y - 1)

        'Call GetSRvar
        'Hatchery recruits - estimate annual variation based on variance input
            Z1(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
            If Ropt = 0 Then
                SRvarH(i, y) = 0
            ElseIf Ropt = 1 Then
                SRvarH(i, y) = Z1(y) * Sqr(RMSE)
            ElseIf Ropt = 2 Then
                If y = 1 Then
                    SRvarH(i, y) = Z1(y) * Sqr(RMSE * (1 - (Rlag ^ 2)))
                Else
                    SRvarH(i, y) = (Rlag * eSRvarLast) + Z1(y) * Sqr(RMSE * (1 - (Rlag ^ 2)))
                End If
            End If
        'Natural recruits - estimate annual variation based on variance input
```

```
        Z2(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
        Z2(y) = (PopCor * Z1(y)) + (Sqr(1 - (PopCor ^ 2)) * Z2(y))  'Adjustment for partial correlation
        If Ropt = 0 Then
           SRvar(i, y) = 0
        ElseIf Ropt = 1 Then
           SRvar(i, y) = Z2(y) * Sqr(RMSE)
        ElseIf Ropt = 2 Then
        '    SRvar(i, y) = Z2(y) * Sqr(RMSE)
           If y = 1 Then
              SRvar(i, y) = Z2(y) * Sqr(RMSE * (1 - (Rlag ^ 2)))
           Else
              SRvar(i, y) = (Rlag * eSRvarLast) + Z2(y) * Sqr(RMSE * (1 - (Rlag ^ 2)))
           End If
        End If

        eSRvarLast = SRvarH(i, y) ' for autocorrelated reference
        'eSRvarLast = SRvar(i, y) ' for autocorrelated reference

     'Stock-recruitment calculation
     If SRopt = 1 Then 'hockey stick
        If Nsp * HSrps > HSneq Then NocnN(i, y) = HSneq * Exp(SRvar(i, y)) Else NocnN(i, y) = Nsp * HSrps *
Exp(SRvar(i, y))
        'If Nsp * HSrps > HSneq Then NocnN(i, y) = HSneq Else NocnN(i, y) = Nsp * HSrps
        Neq = HSneq
     ElseIf SRopt = 2 Then 'Beverton Holt
        NocnN(i, y) = Nsp * (BHrps / (1 + (((BHrps - 1) / BHneq) * Nsp))) * Exp(SRvar(i, y))
        Neq = BHneq
     ElseIf SRopt = 3 Then 'Ricker
        If Nsp > limitS Then Nsp = limitS 'bound spawner number to avoid weird descending limb effects
        NocnN(i, y) = Nsp * Exp((Rrps * (1 - (Nsp / Rneq))) + SRvar(i, y))
        'NocnN(i, y) = (Nsp * Exp(-(beta * Nsp) + SRvar(i, y)))
        Neq = Rneq
     End If

     If y > 6 Then
        If y < 7 + FWyrs Then FWcond = ((1 + FWtrend) ^ (y - 6)) Else FWcond = ((1 + FWtrend) ^ (FWyrs))
        NocnN(i, y) = NocnN(i, y) * FWcond * (1 + (Recov / 100)) 'adjust for freshwater production trend * recovery
increment
     End If

     If NocnN(i, y) > limitR Then NocnN(i, y) = limitR  'guards against unrealistic recruitment that exceeds observed
range
     If Depopt = 1 Then NocnN(i, y) = NocnN(i, y) * (1 - Exp((Log(1 - 0.95) / (depthres - 1)) * Nsp)) ' apply as
appropriate
     If Nsp < RFT Then NocnN(i, y) = 0  'assume critical depensation when spawners below recruitment failure
threshold

   'Hatchery recruits
     'NocnH(i, y) = HatRel * HatSAR * (1 + SRvarH(i, y - 1))
     NocnH(i, y) = HatRel * HatSAR * Exp(SRvarH(i, y - 1))
     If NocnH(i, y) < 0.2 * HatRel * HatSAR Then NocnH(i, y) = 0.2 * HatRel * HatSAR ' limits for unrealistic
randomly-generated values
     If NocnH(i, y) > 8 * HatRel * HatSAR Then NocnH(i, y) = 6 * HatRel * HatSAR
     HSvRate(i, y) = NocnH(i, y) / (HatRel + 0.0000000001)
```

```
    'total recruits
      Nocn(i, y) = NocnN(i, y) + NocnH(i, y)

    'annual number of adult escapement
      If y > 1 Then
        NAd2N(i, y) = NocnN(i, y - 1) * m2
        NAd2H(i, y) = NocnH(i, y - 1) * m2
      End If
      If y > 2 Then
        NAd3N(i, y) = NocnN(i, y - 2) * m3
        NAd3H(i, y) = NocnH(i, y - 2) * m3
      End If
      If y > 3 Then
        NAd4N(i, y) = NocnN(i, y - 3) * m4
        NAd4H(i, y) = NocnH(i, y - 3) * m4
      End If
      If y > 4 Then
        NAd5N(i, y) = NocnN(i, y - 4) * m5
        NAd5H(i, y) = NocnH(i, y - 4) * m5
      End If
      If y > 5 Then
        NAd6N(i, y) = NocnN(i, y - 5) * m6
        NAd6H(i, y) = NocnH(i, y - 5) * m6
      End If
      If y > 6 Then
        NAd7N(i, y) = NocnN(i, y - 6) * m7
        NAd7H(i, y) = NocnH(i, y - 6) * m7
      End If

      NAd2(i, y) = NAd2N(i, y) + NAd2H(i, y)
      NAd3(i, y) = NAd3N(i, y) + NAd3H(i, y)
      NAd4(i, y) = NAd4N(i, y) + NAd4H(i, y)
      NAd5(i, y) = NAd5N(i, y) + NAd5H(i, y)
      NAd6(i, y) = NAd6N(i, y) + NAd6H(i, y)
      NAd7(i, y) = NAd7N(i, y) + NAd7H(i, y)

      NAdN(i, y) = NAd2N(i, y) + NAd3N(i, y) + NAd4N(i, y) + NAd5N(i, y) + NAd6N(i, y) + NAd7N(i, y)
      'NAdH(i, y) = NAd2H(i, y) + NAd3H(i, y) + NAd4H(i, y) + NAd5H(i, y) + NAd6H(i, y) + NAd7H(i, y)
      NAdH(i, y) = NAd3H(i, y) + NAd4H(i, y) + NAd5H(i, y) + NAd6H(i, y) + NAd7H(i, y) 'jacks not counted in hatchery
adults
      NAd(i, y) = NAd2(i, y) + NAd3(i, y) + NAd4(i, y) + NAd5(i, y) + NAd6(i, y) + NAd7(i, y)

    'Fishing rates (rates don't matter before year 6 because spawners overwritten by historic observed)
      If y > 6 Then
        FrateN(y) = 0
        FrateH = 0
        If Fopt = 1 Then
          tgFrateN(y) = FrateNin
'          FrateH = FrateHin
        End If
        If Fopt = 2 Then
          FrateH = FrateHin
          If NSpn(i, y - 3) > 0.75 * Neq Then
            seedN(y) = 1
          ElseIf NSpn(i, y - 3) > 0.5 * Neq Then
```

```
            seedN(y) = 2
        ElseIf NSpn(i, y - 3) > 0.2 * Neq Then
            seedN(y) = 3
        ElseIf NSpn(i, y - 3) > 0.1 * Neq Then
            seedN(y) = 4
        ElseIf NSpn(i, y - 3) <= 0.1 * Neq Then
            seedN(y) = 5
        Else
            seedN(y) = 0
        End If

        If SRvar(i, y) > 1.3 * RMSE Then
            MSIN(y) = 4
        ElseIf SRvar(i, y) > 0 * RMSE Then
            MSIN(y) = 3
        ElseIf SRvar(i, y) > -0.7 * RMSE Then
            MSIN(y) = 2
        ElseIf SRvar(i, y) <= -0.7 * RMSE Then
            MSIN(y) = 1
        Else
            MSIN(y) = 0
        End If

        tgFrateN(y) = FIR(seedN(y), MSIN(y))
    End If
    If Fopt = 3 Then
        'Forecast includes an an adjustment for avg ocean harvest because matrix is indexed by Col R returns
        'Forecast based on hathery fish only
        'Forecast2(y) = (NAd2H(i, y - 1) + NAd2H(i, y - 2) + NAd2H(i, y - 3) + NAd2H(i, y - 4) + NAd2H(i, y - 5) +
NAd2H(i, y - 6)) / 6
        'Forecast2(y) = (NAd3H(i, y - 1)) * (0.055 / 0.373)
        Forecast3(y) = NAd2H(i, y - 1) * (m3 / (m2 + 0.0000000001)) * (1 - LRHOcnER)
        Forecast4(y) = NAd3H(i, y - 1) * (m4 / (m3 + 0.0000000001)) * (1 - LRHOcnER)
        Forecast5(y) = NAd4H(i, y - 1) * (m5 / (m4 + 0.0000000001)) * (1 - LRHOcnER)
        Forecast6(y) = NAd5H(i, y - 1) * (m6 / (m5 + 0.0000000001)) * (1 - LRHOcnER)
        Forecast7(y) = NAd6H(i, y - 1) * (m7 / (m6 + 0.0000000001)) * (1 - LRHOcnER)

        'Forecast(y) = Forecast2(y) + Forecast3(y) + Forecast4(y) + Forecast5(y) + Forecast6(y) + Forecast7(y)
        Forecast(y) = Forecast3(y) + Forecast4(y) + Forecast5(y) + Forecast6(y) + Forecast7(y) 'adults only
        ForeVar(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd()) * (ForeErr * Forecast(y))
        If ForeVar(y) > 0.8 * Forecast(y) Then ForeVar(y) = 0.8 * Forecast(y)
        If ForeVar(y) < 0.2 * Forecast(y) Then ForeVar(y) = 0.2 * Forecast(y)
        Forecast(y) = Forecast(y) + ForeVar(y)

        If Forecast(y) < LRHLT Then
            tgFrateN(y) = LRHLTER
            CntTierA = CntTierA + 1
        ElseIf Forecast(y) > LRHUT Then
            tgFrateN(y) = LRHUTER
            CntTierC = CntTierC + 1
        Else
            tgFrateN(y) = LRHMTER
            CntTierB = CntTierB + 1
        End If
    End If
```

```
      Fvar(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd()) * (Fcv * tgFrateN(y))
      FrateN(y) = tgFrateN(y) + Fvar(y)
      'If FrateN(y) > 3 * tgFrateN(y) Then FrateN(y) = 3 * tgFrateN(y)
      'If FrateN(y) < tgFrateN(y) / 3 Then FrateN(y) = tgFrateN(y) / 3
      If FrateN(y) > 0.8 Then FrateN(y) = 0.8
      If FrateN(y) < 0 Then FrateN(y) = 0
      FrateH = FrateN(y)
    End If

'Number escaping fishery
    NEsc2N(i, y) = NAd2N(i, y) * (1 - FrateN(y))
    'NEsc2N(i, y) = NAd2N(i, y) ' no harvest of jacks
    NEsc3N(i, y) = NAd3N(i, y) * (1 - FrateN(y))
    NEsc4N(i, y) = NAd4N(i, y) * (1 - FrateN(y))
    NEsc5N(i, y) = NAd5N(i, y) * (1 - FrateN(y))
    NEsc6N(i, y) = NAd6N(i, y) * (1 - FrateN(y))
    NEsc7N(i, y) = NAd7N(i, y) * (1 - FrateN(y))
    NEscN(i, y) = NEsc2N(i, y) + NEsc3N(i, y) + NEsc4N(i, y) + NEsc5N(i, y) + NEsc6N(i, y) + NEsc7N(i, y)

    'NEsc2H(i, y) = NAd2H(i, y) * (1 - FrateH)
    NEsc2H(i, y) = 0 ' only counting hatchery adults from this point forward
    NEsc3H(i, y) = NAd3H(i, y) * (1 - FrateH)
    NEsc4H(i, y) = NAd4H(i, y) * (1 - FrateH)
    NEsc5H(i, y) = NAd5H(i, y) * (1 - FrateH)
    NEsc6H(i, y) = NAd6H(i, y) * (1 - FrateH)
    NEsc7H(i, y) = NAd7H(i, y) * (1 - FrateH)
    NEscH(i, y) = NEsc2H(i, y) + NEsc3H(i, y) + NEsc4H(i, y) + NEsc5H(i, y) + NEsc6H(i, y) + NEsc7H(i, y)

    NEsc2(i, y) = NEsc2N(i, y) + NEsc2H(i, y)
    NEsc3(i, y) = NEsc3N(i, y) + NEsc3H(i, y)
    NEsc4(i, y) = NEsc4N(i, y) + NEsc4H(i, y)
    NEsc5(i, y) = NEsc5N(i, y) + NEsc5H(i, y)
    NEsc6(i, y) = NEsc6N(i, y) + NEsc6H(i, y)
    NEsc7(i, y) = NEsc7N(i, y) + NEsc7H(i, y)
    NEsc(i, y) = NEsc2(i, y) + NEsc3(i, y) + NEsc4(i, y) + NEsc5(i, y) + NEsc6(i, y) + NEsc7(i, y)

'Number impacted by the fishery farvest
'NHar2N(i, y) = NAd2N(i, y) * FrateN(y)
    NHar2N(i, y) = 0  'not counting harvest of jacks
    NHar3N(i, y) = NAd3N(i, y) * FrateN(y)
    NHar4N(i, y) = NAd4N(i, y) * FrateN(y)
    NHar5N(i, y) = NAd5N(i, y) * FrateN(y)
    NHar6N(i, y) = NAd6N(i, y) * FrateN(y)
    NHar7N(i, y) = NAd7N(i, y) * FrateN(y)
    NHarN(i, y) = NHar2N(i, y) + NHar3N(i, y) + NHar4N(i, y) + NHar5N(i, y) + NHar6N(i, y) + NHar7N(i, y)

    'NHar2H(i, y) = NAd2H(i, y) * FrateH
    NHar2H(i, y) = 0   'not counting harvest of jacks
    NHar3H(i, y) = NAd3H(i, y) * FrateH
    NHar4H(i, y) = NAd4H(i, y) * FrateH
    NHar5H(i, y) = NAd5H(i, y) * FrateH
    NHar6H(i, y) = NAd6H(i, y) * FrateH
    NHar7H(i, y) = NAd7H(i, y) * FrateH
    NHarH(i, y) = NHar2H(i, y) + NHar3H(i, y) + NHar4H(i, y) + NHar5H(i, y) + NHar6H(i, y) + NHar7H(i, y)
```

```
  NHar2(i, y) = NHar2N(i, y) + NHar2H(i, y)
  NHar3(i, y) = NHar3N(i, y) + NHar3H(i, y)
  NHar4(i, y) = NHar4N(i, y) + NHar4H(i, y)
  NHar5(i, y) = NHar5N(i, y) + NHar5H(i, y)
  NHar6(i, y) = NHar6N(i, y) + NHar6H(i, y)
  NHar7(i, y) = NHar7N(i, y) + NHar7H(i, y)
  NHar(i, y) = NHar2(i, y) + NHar3(i, y) + NHar4(i, y) + NHar5(i, y) + NHar6(i, y) + NHar7(i, y)

'Natural Escapement to spawners
 If y = 1 Then
     NSpn(i, y) = NSpn6ago
  ElseIf y = 2 Then
     NSpn(i, y) = NSpn5ago
  ElseIf y = 3 Then
     NSpn(i, y) = NSpn4ago
  ElseIf y = 4 Then
     NSpn(i, y) = NSpn3ago
  ElseIf y = 5 Then
     NSpn(i, y) = NSpn2ago
  ElseIf y = 6 Then
     NSpn(i, y) = NSpn1ago
  Else
     NSpn2N(i, y) = NEsc2N(i, y)
     NSpn3N(i, y) = NEsc3N(i, y)
     NSpn4N(i, y) = NEsc4N(i, y)
     NSpn5N(i, y) = NEsc5N(i, y)
     NSpn6N(i, y) = NEsc6N(i, y)
     NSpn7N(i, y) = NEsc7N(i, y)
     NSpnN(i, y) = NSpn2N(i, y) + NSpn3N(i, y) + NSpn4N(i, y) + NSpn5N(i, y) + NSpn6N(i, y) + NSpn7N(i, y)

     NSpn2H(i, y) = NEsc2H(i, y) * Hatp
     NSpn3H(i, y) = NEsc3H(i, y) * Hatp
     NSpn4H(i, y) = NEsc4H(i, y) * Hatp
     NSpn5H(i, y) = NEsc5H(i, y) * Hatp
     NSpn6H(i, y) = NEsc6H(i, y) * Hatp
     NSpn7H(i, y) = NEsc7H(i, y) * Hatp
     NSpnH(i, y) = NSpn2H(i, y) + NSpn3H(i, y) + NSpn4H(i, y) + NSpn5H(i, y) + NSpn6H(i, y) + NSpn7H(i, y)

     NSpn2(i, y) = NSpn2N(i, y) + NSpn2H(i, y)
     NSpn3(i, y) = NSpn3N(i, y) + NSpn3H(i, y)
     NSpn4(i, y) = NSpn4N(i, y) + NSpn4H(i, y)
     NSpn5(i, y) = NSpn5N(i, y) + NSpn5H(i, y)
     NSpn6(i, y) = NSpn6N(i, y) + NSpn6H(i, y)
     NSpn7(i, y) = NSpn7N(i, y) + NSpn7H(i, y)
     NSpn(i, y) = NSpn2(i, y) + NSpn3(i, y) + NSpn4(i, y) + NSpn5(i, y) + NSpn6(i, y) + NSpn7(i, y)
     If NSpn(i, y) < 0 Then NSpn(i, y) = 0

  seed(y) = NSpn(i, y) / (Neq + 0.0000000001)

  End If
'update iteration totals
  NspnAvg(y) = NspnAvg(y) + NSpn(i, y)
  'spawner frequencies
  If y > 6 Then
```

```
If NSpn(i, y) <= Quasi Then
   CntQETyr = CntQETyr + 1
   flagQET(i) = 1
   If y < 32 Then
      CntQETyrST = CntQETyrST + 1
      flagQETST(i) = 1 'count interations in 1st 25 yrs where i yr < QET
   End If
End If
ENocnN = ENocnN + NocnN(i, y)
ENocnH = ENocnH + NocnH(i, y)
ENAdH = ENAdH + NAdH(i, y)
ENSpn = ENSpn + NSpn(i, y)
ENEscH = ENEscH + NEscH(i, y)
If y < 17 Then ENSpn10 = ENSpn10 + NSpn(i, y)
EFrate = EFrate + FrateN(y)
'          GNSpn(i) = GNSpn(i) * (NSpn(i, y) + 1)
j = (Int(NSpn(i, y) / jj) + 1)
   If j > 100 Then j = 100
   If j < 1 Then j = 1
   CountE(j) = CountE(j) + 1
j = (Int(NocnN(i, y) / jj) + 1)
   If j > 100 Then j = 100
   If j < 1 Then j = 1
   CountR(j) = CountR(j) + 1

j = (Int(100 * tgFrateN(y) / 5) + 1)
   If j > 20 Then j = 20
   If j < 1 Then j = 1
   CounttgF(j) = CounttgF(j) + 1

j = (Int(100 * FrateN(y) / 5) + 1)
   If j > 20 Then j = 20
   If j < 1 Then j = 1
   CountF(j) = CountF(j) + 1

For k = 0 To Gen - 1
   MovGenAvg(i, y) = MovGenAvg(i, y) + (NSpn(i, y - k) / (Gen + 0.0000000001))
Next k
If MovGenAvg(i, y) < Quasi Then flagEx(i) = 1
If MovGenAvg(i, y) < Genetic Then flagGR(i) = 1
If y < 27 Then
   If MovGenAvg(i, y) < Quasi Then flagExST(i) = 1
   If MovGenAvg(i, y) < Genetic Then flagGRST(i) = 1
End If
If SRvar(i, y) > 1.4 * RMSE Then
   CntErr(1) = CntErr(1) + 1
ElseIf SRvar(i, y) > 1.3 * RMSE Then
   CntErr(2) = CntErr(2) + 1
ElseIf SRvar(i, y) > 1.2 * RMSE Then
   CntErr(3) = CntErr(3) + 1
ElseIf SRvar(i, y) > 1.1 * RMSE Then
   CntErr(4) = CntErr(4) + 1
ElseIf SRvar(i, y) > 1# * RMSE Then
   CntErr(5) = CntErr(5) + 1
ElseIf SRvar(i, y) > 0.9 * RMSE Then
```

```
        CntErr(6) = CntErr(6) + 1
      ElseIf SRvar(i, y) > 0.8 * RMSE Then
        CntErr(7) = CntErr(7) + 1
      ElseIf SRvar(i, y) > 0.7 * RMSE Then
        CntErr(8) = CntErr(8) + 1
      ElseIf SRvar(i, y) > 0.6 * RMSE Then
        CntErr(9) = CntErr(9) + 1
      ElseIf SRvar(i, y) > 0.5 * RMSE Then
        CntErr(10) = CntErr(10) + 1
      ElseIf SRvar(i, y) > 0.4 * RMSE Then
        CntErr(11) = CntErr(11) + 1
      ElseIf SRvar(i, y) > 0.3 * RMSE Then
        CntErr(12) = CntErr(12) + 1
      ElseIf SRvar(i, y) > 0.2 * RMSE Then
        CntErr(13) = CntErr(13) + 1
      ElseIf SRvar(i, y) > 0.1 * RMSE Then
        CntErr(14) = CntErr(14) + 1
      ElseIf SRvar(i, y) > 0 * RMSE Then
        CntErr(15) = CntErr(15) + 1
      ElseIf SRvar(i, y) > -0.1 * RMSE Then
        CntErr(16) = CntErr(16) + 1
      ElseIf SRvar(i, y) > -0.2 * RMSE Then
        CntErr(17) = CntErr(17) + 1
      ElseIf SRvar(i, y) > -0.3 * RMSE Then
        CntErr(18) = CntErr(18) + 1
      ElseIf SRvar(i, y) > -0.4 * RMSE Then
        CntErr(19) = CntErr(19) + 1
      ElseIf SRvar(i, y) > -0.5 * RMSE Then
        CntErr(20) = CntErr(20) + 1
      ElseIf SRvar(i, y) > -0.6 * RMSE Then
        CntErr(21) = CntErr(21) + 1
      ElseIf SRvar(i, y) > -0.7 * RMSE Then
        CntErr(22) = CntErr(22) + 1
      ElseIf SRvar(i, y) > -0.8 * RMSE Then
        CntErr(23) = CntErr(23) + 1
      ElseIf SRvar(i, y) > -0.9 * RMSE Then
        CntErr(24) = CntErr(24) + 1
      ElseIf SRvar(i, y) > -1 * RMSE Then
        CntErr(25) = CntErr(25) + 1
      ElseIf SRvar(i, y) > -1.1 * RMSE Then
        CntErr(26) = CntErr(26) + 1
      Else
        CntErr(27) = CntErr(27) + 1
      End If

      'Sheet9.Cells(y, 14) = seedN(y)
      'Sheet9.Cells(y, 15) = MSIN(y)

      CntCell(seedN(y), MSIN(y)) = CntCell(seedN(y), MSIN(y)) + 1
    End If
  Next y
  GNSpnE = GNSpnE + (GNSpn(i) ^ (1 / Nyr))
  If flagQET(i) = 1 Then CntQETiter = CntQETiter + 1
    If flagQETST(i) = 1 Then CntQETiterST = CntQETiterST + 1
  If flagEx(i) = 1 Then CntExtinct = CntExtinct + 1
```

```
      If flagExST(i) = 1 Then CntExtinctST = CntExtinctST + 1
   If flagGR(i) = 1 Then CntGenetic = CntGenetic + 1
      If flagGRST(i) = 1 Then CntGeneticST = CntGeneticST + 1
Next i
Call RunModelOutputs
Unload UserForm1
End Sub

'Public Sub GetSRvar()

'End Sub

Public Sub RunModelOutputs()
'Output summary statistics
   Sheet3.Cells(6, 17) = ENocnN / ((iter * Nyr) + 0.0000000001)
   Sheet3.Cells(7, 17) = ENSpn / ((iter * Nyr) + 0.0000000001)
   Sheet3.Cells(8, 17) = ENSpn10 / ((iter * 10) + 0.0000000001)  'short term (10 yr)spawners
   Sheet3.Cells(10, 17) = ENAdH / ((iter * Nyr) + 0.0000000001)
   Sheet3.Cells(11, 17) = (ENAdH / ((iter * Nyr) + 0.0000000001)) * (1 - LRHOcnER)
   'Sheet3.Cells(10, 17) = ENocnH / ((iter * 100) + 0.0000000001)
   'Sheet3.Cells(11, 17) = (ENocnH / ((iter * 100) + 0.0000000001)) * (1 - LRHOcnER)
   Sheet3.Cells(12, 17) = ENEscH / ((iter * Nyr) + 0.0000000001)
   Sheet3.Cells(15, 17) = EFrate / ((iter * Nyr) + 0.0000000001)
   'Sheet3.Cells(6, 18) = GNSpnE / (iter + 0.0000000001)
   Sheet3.Cells(5, 21) = CntExtinct / (iter + 0.0000000001)
      Sheet3.Cells(5, 22) = CntExtinctST / (iter + 0.0000000001)
   'Sheet3.Cells(5, 21) = CntExtinct
   Sheet3.Cells(6, 21) = CntQETiter / (iter + 0.0000000001) 'prob of gen<QET (100 Yr)
      Sheet3.Cells(6, 22) = CntQETiterST / (iter + 0.0000000001) 'prob of gen<QET (short term)
   Sheet3.Cells(7, 21) = CntQETyr / ((iter * Nyr) + 0.0000000001)
      Sheet3.Cells(7, 22) = CntQETyrST / ((iter * Nyr) + 0.0000000001)
   Sheet3.Cells(9, 21) = Gen
   Sheet3.Cells(11, 21) = CntGenetic / (iter + 0.0000000001)
      Sheet3.Cells(11, 22) = CntGeneticST / (iter + 0.0000000001)
   Sheet3.Cells(15, 21) = CntTierA / ((iter * Nyr) + 0.0000000001) 'tule forecast tiers
   Sheet3.Cells(16, 21) = CntTierB / ((iter * Nyr) + 0.0000000001)
   Sheet3.Cells(17, 21) = CntTierC / ((iter * Nyr) + 0.0000000001)
```

SALMON ADVISORY SUBPANEL REPORT ON PROGRESS REPORTS ON COLUMBIA RIVER TULE CHINOOK AND SACRAMENTO WINTER RUN CHINOOK MANAGEMENT ISSUES

Tule Chinook

The Salmon Advisory Subpanel (SAS) received a presentation on the exploration of abundance-based management approaches for lower Columbia River tule Chinook from Ray Beamesderfer. The presentation summarized the report from the Tule Chinook Workgroup (TCW). The SAS agreed with the five summary points for abundance based management approaches:

1. Abundance based management approaches are widely employed in salmon management;
2. Lower River Hatchery (LRH) tule forecasts provide a mechanism to develop an abundance based approach for natural tule management;
3. Small changes in exploitation rates can result in substantial changes fisheries opportunities;
4. Scenarios that reduce risks to natural populations and provide fishery benefits do exist;
5. There is flexibility in developing abundance based scenarios to achieve desired results.

The SAS discussion focused on four areas:

1. Identifying additional scenarios to model;
2. Identifying thresholds to provide criteria against which scenarios could be evaluated;
3. Highlighting issues that could affect implementation of an abundance based approach;
4. Developing recommendations for moving the process towards completion at the November 2011 Council meeting.

After discussions with state representatives, the SAS recommends consideration of a 30,000 preseason LRH forecast as a threshold below which non-Indian fisheries north of Cape Falcon and in-river fisheries may need to be restricted to incidental impacts only to ensure achieving hatchery escapement goals. The SAS further identified an exploitation rate of 0.30 as the minimum rate necessary to accommodate expected impact from northern fisheries, consideration of treaty Indian troll fishery, Puget Sound fisheries, south of Cape Falcon fisheries, and Chinook non-retention fisheries in non-Indian north of Cape Falcon and in-river fisheries.

In order to assess the effects of these thresholds, the SAS requested Mr. Beamesderfer model several additional scenarios that included different allowable exploitation rates, abundance forecast bins, and number of tiers. After some iterations, the SAS recommends the Council consider an alternative that would use the following four tiers:

Abundance Forecast	Exploitation Rate Limit
0-30,000	0.30
30,000-40,000	0.35
40,000-80,000	0.38
>80,000	0.40

This should provide a risk reduction of 3.8% and a harvest benefit of 4.6%, which would be a Win/Win scenario based on the criteria used in the TCW report.

The SAS recommends the TCW work products be reviewed during the 2011 salmon methodology review process to ensure its recommendations are based on reliable science.

The SAS also requests NMFS conduct a review of any adopted abundance based management approach for tule Chinook after three years of implementation.

Winter Run Chinook

After discussions with pertinent members of the NMFS Salmon Assessment Team, the SAS was encouraged by the prospect of having a quantitative harvest model for winter run Chinook. The SAS requests relevant members of the SAS and Salmon Technical Team have an opportunity to meet and preview the model prior to the 2012 preseason planning process, including looking at some hind-casting scenarios to see how the model could have affected prior seasons. The SAS also recommends the model and cohort reconstruction be reviewed during the 2011 salmon methodology review process.

PFMC
09/17/11

Agenda Item H.1.d
Supplemental SSC Report
September 2011

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON PROGRESS REPORT ON COLUMBIA RIVER TULE AND SACRAMENTO RIVER WINTER CHINOOK MANAGEMENT ISSUES

Mr. Chuck Tracy and Dr. Robert Kope attended the Scientific and Statistical Committee (SSC) meeting and answered questions about the draft report entitled Exploration of Abundance-based Management Approaches for Lower Columbia River Tule Chinook. The SSC did not identify any concerns at this time. A more thorough review will be conducted at the Salmon Methodology Review meeting and reported to the Council at the November, 2011 meeting.

Dr. Michael O'Farrell also attended the SSC meeting and answered questions about Agenda Item H.1.b, entitled Progress Report on the Sacramento Winter Run Biological Opinion Reasonable and Prudent Alternative and Development of a New Management Framework.

There will be two documents (a cohort analysis and a harvest model) available for the Salmon Methodology Review meeting, in addition to those identified by the Council in April. In addition, new data from genetic stock identification (GSI) studies are available that provide fine-scale winter-run catch distributions. The SSC encourages the use of these data in development of harvest rules designed to reduce winter-run impacts.

PFMC
09/16/11

Agenda Item H.2
Situation Summary
September 2011

2011 SALMON METHODOLOGY REVIEW

Each year, the Scientific and Statistical Committee (SSC) and Salmon technical Team (STT) complete a methodology review to help assure new or significantly modified methodologies employed to estimate impacts of the Council's salmon management use the best available science. This review is preparatory to the Council's adoption, at the November meeting, of all proposed changes to be implemented in the coming season, or, in certain limited cases, providing directions for handling any unresolved methodology problems prior to the formulation of salmon management options the following March. Because there is insufficient time to review new or modified methods at the March meeting, the Council may reject their use if they have not been approved the preceding November.

The Methodology Review is also used as a forum to review updated stock conservation objective proposals, which allows the Council to approve updates at the November meeting and allows adequate time for planning fisheries in the subsequent year. The Salmon Fishery Management Plan (FMP) allows conservation objectives to be updated without a formal FMP amendment, provided a comprehensive technical review of the best scientific information available provides conclusive evidence that, in the view of the STT, SSC, and the Council, justifies a modification.

At its April 2011 meeting, the Council adopted the following priority candidate items that the SSC and STT may consider for the 2011 Salmon Methodology Review. *Source entities to deliver detailed reports for SSC review are included with each candidate item*.

- Examination of the potential bias in Coho and Chinook Fishery Regulation Assessment Model (FRAM) of fishery-related mortality introduced by mark-selective fisheries - *Model Evaluation Workgroup*
- A multi-year review and evaluation of preseason and postseason mark-selective fisheries both north and south of Cape Falcon -*Salmon Technical Team*
- Risk analysis of fall fisheries relative to future fisheries and returns of Klamath River and Sacramento River fall Chinook stocks -*Salmon Technical Team*
- Incorporation of age-structured run reconstruction information into the Sacramento Harvest Model -*Salmon Technical Team*
- Revisions to Amendment 13 matrix control rules for Oregon coastal natural coho stocks-*Oregon Department of Fish and Wildlife*
- Abundance-based management framework for Lower Columbia River tule fall Chinook-*Tule Chinook Workgroup*
- Forecast methodology for Lower Columbia River tule fall Chinook-*Tule Chinook Workgroup*

These subjects and the responsible agencies were identified in a reminder email dated July 13, 2011, which requested agencies prepare to speak to the status of the subjects in terms of completeness and priority. The last two items on the list will be addressed in Agenda Item H.1, along with similar topics for Sacramento River winter Chinook.

Other review topics or conservation objective updates may be considered for review at this meeting, provided responsible agencies or individuals are prepared to justify their inclusion. All materials for review are to be received at the Council office at least two weeks prior to the review meeting of the SSC Salmon Subcommittee and STT, which is scheduled for October 4-5, 2011.

Council Action:

1. **Determine if topics identified for review will be ready for the joint SSC Salmon Subcommittee - STT meeting in October.**
2. **Set priorities for review of methodologies and/or conservation objective update proposals**.

Reference Materials:

None.

Agenda Order:

a. Agenda Item Overview — Chuck Tracy
b. Reports and Comments of Advisory Bodies and Management Entities
c. Public Comment
d. **Council Action**: Adopt Final Review Priorities

PFMC
08/16/11

Agenda Item H.2.b
Supplemental MEW Report
September 2011

MODEL EVALUATION WORKGROUP REPORT ON 2011 SALMON METHODOLOGY REVIEW

At the April meeting, the Council identified the Model Evaluation Workgroup (MEW) as the lead entity on one of seven priority candidate topics for the 2011 Salmon Methodology Review. That priority topic was stated as: "Examination of the potential bias in Coho and Chinook Fishery Regulation Assessment Model (FRAM) of fishery-related mortality introduced by mark-selective fisheries." A MEW report has been prepared, for the Salmon Methodology Review, that analyzes coho FRAM and the bias in exploitation rates on unmarked fish using the 2009 and 2010 preseason model runs as a base. The report contains estimates of the bias and a proposed correction. The bias correction methodology will be further tested by incorporation into coho FRAM.

Another priority candidate item was a multi-year review and evaluation of preseason and postseason mark-selective fisheries both north and south of Cape Falcon. The MEW has discussed a preliminary Salmon Technical Team (STT) report on this topic and endorses fuller review at the Methodology Meeting.

In addition to the priority candidate items identified by the Council in April, the MEW has been reviewing the upgraded FRAM Visual Studio program. There are not changes in methodology or model computations, but a conversion to a more flexible program language platform. The conversion of FRAM to Visual Studio has been tested by MEW and the new version is expected to be available for 2012 preseason assessment. A progress report on the review and debugging of the FRAM Visual Studio version will be available for potential consideration at the October Methodology Review Meeting.

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09/14/11

Agenda Item H.2.b
Supplemental SSC Report
September 2011

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON 2011 SALMON METHODOLOGY REVIEW

The Scientific and Statistical Committee (SSC) met with Mr. Chuck Tracy and Dr. Robert Kope, of the Salmon Technical Team (STT) to identify which of the following topics prioritized by the Council at the April meeting would be available for the 2011 Salmon Methodology Review:

1. Examination of the potential bias in Coho and Chinook Fishery Regulation Assessment Model (FRAM) of fishery-related mortality introduced by mark-selective fisheries (Model Evaluation Workgroup)
2. A multi-year review and evaluation of preseason and postseason mark-selective coho fisheries both north and south of Cape Falcon (Salmon Technical Team)
3. Risk analysis of fall fisheries relative to future fisheries and returns of Klamath River and Sacramento River fall Chinook stocks (Salmon Technical Team)
4. Incorporation of age-structured run reconstruction information into the Sacramento Harvest Model (Salmon Technical Team)
5. Revisions to Amendment 13 matrix control rules for Oregon coastal natural coho stocks (Oregon Department of Fish and Wildlife)
6. Abundance-based management framework for Lower Columbia River tule fall Chinook (Tule Chinook Workgroup)
7. Forecast methodology for Lower Columbia River tule fall Chinook (Tule Chinook Workgroup)

Reports on the above topics will be available for the methodology review, except for topics 3, 4, and 5.

Three additional review topics were identified for review: a) updated cohort analysis for Sacramento winter-run Chinook (NMFS Southwest Fisheries Science Center); b) Sacramento winter-run Chinook harvest model (NMFS Southwest Fisheries Science Center); and c) progress report and documentation for a new, re-coded version of FRAM (Model Evaluation Workgroup).

The SSC will review reports on these topics for the November meeting. The SSC Salmon Subcommittee and STT will hold a joint meeting on October 4 and 5 in Portland to review these issues. The SSC requires proper documentation and ample review time to make efficient use of the SSC Salmon Subcommittee's time. Materials for review should be submitted at least two weeks prior to the scheduled review. Agencies should be responsible for ensuring that materials submitted to the SSC are technically sound, comprehensive, clearly documented, and identified by author.

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09/16/11

SALMON TECHICAL TEAM REPORT ON 2011 SALMON METHODOLOGY REVIEW

At the April meeting, the Council identified a list of seven priorities for review at the Scientific and Statistical Committee (SSC)/Salmon Technical Team (STT) Methodology Review scheduled for October. The STT was identified as lead on three of these topics: 1) Multi-year review of coho mark selective fisheries, 2) Risk analysis of fall fisheries for future fisheries of Klamath River fall Chinook, and 3) Sacramento fall Chinook, and incorporation of age-structured run reconstruction information into the Sacramento Harvest Model.

The STT has completed a preliminary analysis of preseason forecasts and post-season assessments of mark selective fisheries for coho salmon from 2000 through 2010. This analysis has been discussed with the Model Evaluation Workgroup and will be available for the 2011 Methodology Review.

With regard to a risk assessment of fall fisheries, the STT addressed this topic at the October 2009 Methodology Review. The report titled "Assessment of fall ocean Chinook salmon fisheries south of Cape Falcon, Oregon" was presented to the SSC Salmon Subcommittee and was distributed to the Council in the November 2009 briefing book. The conclusions and recommendations contained within that report remain relevant as no new information has become available since the assessment.

The STT has not developed an age-structured assessment of Sacramento River fall Chinook, as the data do not currently exist to perform such an assessment. Sufficient data to perform such an assessment may be available in the future, if Central Valley coded-wire tag recovery and river run scale aging programs continue.

PFMC
09/15/11

Salmon Methodology Review

The Tribes strongly encourage the STT to complete a multi-year review and evaluation of preseason and postseason mark-selective fisheries both north and south of Cape Falcon to go forward to the SSC for review in October. The Tribes have been requesting a multi-year review of the ocean mark-selective fisheries for coho for the past 6 years.

The Tribes believe that ocean fisheries responsible for the largest source of impacts on coho under PFMC jurisdiction should be monitored more closely. Past reports from WDFW for the North of Falcon fisheries have not provided enough information to evaluate the precision of the sampling methodology. The reported actual mark rates when compared to pre-season projections show a consistent bias for all years. All management areas are overestimating hatchery contributions and therefore, underestimating impacts on natural stocks. The 2010 WDFW mark selective report was an improvement from past years reports. However, ODFW did not report on mark selective fisheries that occurred in waters South of Cape Falcon.

We believe the Council must establish a better reporting system for all mark selective fishing in council waters. Reporting post-season assessments of mark selective fisheries should occur in the annual Review of Fisheries document. For mark selective fisheries targeting chinook, the Columbia River tribes require post season estimates of stock specific impacts on upriver summer and fall stocks in order to assess compliance with the *U.S. v. Oregon* Management Agreement.

The exchange of these reports between the STT, SSC, NOAA Fisheries and the Tribes is extremely important, and the tribes feel that a multi-year review and evaluation of these reports is needed to see the trends in the fisheries. This data exchange is required if mark selective fisheries are to continue in the ocean.

The Tribes support implementing the bias correction methods for the 2012 salmon pre-season planning process.