NATIONAL MARINE FISHERIES SERVICE REPORT

National Marine Fisheries Service (NMFS) West Coast Regions and the Fisheries Science Centers will briefly report on recent developments relevant to salmon fisheries and issues of interest to the Pacific Fishery Management Council (Council).

Council Action:

Council Discussion and Guidance.

Reference Materials:

None.

Agenda Order:

a. Agenda Item Overview	Mike Burner
b. Regulatory Activities	Bob Turner
c. Fisheries Science Center Activities	Steve Lindsay
d. Reports and Comments of Advisory Bodies and Management Entities	
e. Public Comment	
f. Council Discussion and Guidance	

PFMC
10/08/13

Selected Recent Publications by SWFSC Relevant to Salmon Fisheries Management
Submitted by Steve Lindley, Fisheries Ecology Division, SWFSC, NMFS.

Satterthwaite, W. H., M. S. Mohr, M. R. O'Farrell, E. C. Anderson, M. A. Banks, S. J. Bates, M. R. Bellinger, L. A. Borgerson, E. D. Crandall, J. C. Garza, B. J. Kormos, P. W. Lawson, and M. L. Palmer-Zwahlen. In press. Use of genetic stock identification data for comparison of the ocean spatial distribution, size-at-age, and fishery exposure of Klamath River versus California Coastal Chinook salmon. Transactions of the American Fisheries Society. DOI:10.1080/00028487.2013.837096

We used GSI to perform a novel evaluation of the suitability of a tagged indicator stock for an untagged stock of conservation concern, testing a critical assumption that is widely applied but rarely tested. California Coastal Chinook (untagged, threatened stock) and Klamath River Chinook (tagged, indicator stock) may be more similar in their exposure to the fishery early in the year than late in the year, when California Coastal Chinook may have higher interactions with fisheries around Fort Bragg and Klamath Chinook may have higher interactions with fisheries around Eureka. Our techniques allow for uncertainty estimate incorporating both sampling and genetic assignment error.

Winship, A.J., O'Farrell, M.R., and Mohr, M.S. 2013. Management strategy evaluation applied to the conservation of an endangered population subject to incidental take. Biological Conservation 158:155-166.

We evaluated the population viability and fishery implications of several alternative fishery control rules for Sacramento River winter Chinook. The management strategy evaluation simulated winter Chinook population dynamics as well as monitoring, assessment, and control rule implementation processes while accounting for attendant uncertainties. The results from this paper provided quantitative scientific advice in support of the process of adopting a new winter Chinook control rule.

In review:

Winship, A.J., O'Farrell, M.R., Satterthwaite, W.H., Wells, B.K., and Mohr, M.S. In review. Expected future performance of abundance forecast models with application to Sacramento River fall Chinook.

We conducted a rigorous evaluation of a wide range of alternative Sacramento Index forecast models, including models incorporating environmental variables. Results suggest there is scope for modestly improving Sacramento Index forecasts relative to the status quo method. This analysis provides the basis for the recommendation to the Council to adopt a new forecast method: a jack model with lag-1 autoregressive errors. And, more broadly, the paper implements a rigorous forecast evaluation procedure to provide realistic expectations for future performance.

Agenda Item C.1.b
Supplemental NMFS Report 2
November 2013

BILLING CODE 3510-22-P

DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

RIN 0648-XC958

AGENCY: National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), Commerce.

ACTION: Notice of Availability of a Management Strategy Evaluation for Sacramento River winter Chinook salmon; Request for Comments

SUMMARY: The Pacific Fishery Management Council (Council) has requested that the National Marine Fisheries Service (NMFS) take into consideration alternative harvest control rules for Sacramento River winter-run Chinook (winter-run), a salmon species listed as endangered under the Endangered Species Act (ESA) and impacted by ocean salmon fisheries that the Council and NMFS manage. The Council is concerned that the existing control rule may be unnecessarily restrictive in years of low winter-run abundance, particularly when the three year average escapement drops below 500 fish. The current control rule allows for zero fishery impacts at this level of abundance rather than the *de minimis* impacts that are allowed under fishery control rules that limit impacts on other ESA listed species. The Council has expressed interest in exploring alternatives that would provide some limited harvest opportunity on other Chinook stocks when winter-run abundance is low, without significantly increasing the risk to winter-run. To help facilitate consideration of such alternatives, NMFS is requesting public comment on alternative harvest control rules analyzed in a Management Strategy Evaluation (MSE) for Sacramento River winter Chinook salmon. These alternative harvest control rules

include the current control rule implemented by NMFS on May 1, 2012 as part of the ESA consultation standard on the ocean salmon fishery and additional control rules designed to be more responsive to the status of the listed species.

DATES: Information and comments on the alternative control rules described in this notice must be received at the appropriate address or fax number (see ADDRESSES), no later than 5:00pm, on [insert date]. We encourage the public's involvement in selecting and providing rationale for a preferred control rule that may be taken into consideration during the annual salmon management process.

ADDRESSES: You may submit comments on this document, identified by NOAA-NMFS-2013-0154, by any of the following methods:

- Electronic Submissions: Submit all electronic public comments via the Federal e-Rulemaking Portal: http://www.regulations.gov. To submit comments via the e-Rulemaking Portal, first enter NOAA-NMFS-2013-0154 in the keyword search. Locate the document you wish to comment on from the resulting list and click on the "Comment Now!" icon on the right of that line.
- Mail: Submit written comments to Heidi Taylor, NMFS, 501 W. Ocean Blvd., Suite 4200, Long Beach, CA 90802. Include the identifier "NOAA-NMFS-2013-0154" in the comments.
- Fax: 562-980-4047; Attn: Heidi Taylor.

Instructions: Comments must be submitted by one of the above methods to ensure that the comments are received, documented, and considered by NMFS. Comments sent by any other method, to any other address or individual, or received after the end of the comment period, may not be considered. All comments received are a part of the public record and will generally be posted for public viewing on http://www.regulations.gov without change. All personal identifying information (e.g., name, address, etc.) submitted voluntarily by the sender will be publicly accessible. Do not submit confidential business information, or otherwise sensitive or protected information. NMFS will accept anonymous comments (enter "N/A" in the required fields if you wish to remain anonymous). Attachments to electronic comments will be accepted in Microsoft Word or Excel, WordPerfect, or Adobe PDF file formats only.

FOR FURTHER INFORMATION CONTACT: Heidi Taylor, NMFS WCR, 562-980-4039.

SUPPLEMENTARY INFORMATION:

Background

Sacramento River winter-run Chinook salmon were first listed as threatened under the Endangered Species Act in 1989 (54 FR 32085) and their status was changed to endangered in 1994 (59 FR 440). Under section 7 of the Endangered Species Act NMFS consulted with itself on the effects of the federally-managed ocean salmon fishery on the winter-run stock and in April 2010, completed a biological opinion (Biological Opinion on the(Authorization of Ocean Salmon Fisheries Pursuant to the Pacific Coast Salmon Fishery Management Plan (Salmon FMP) and Additional Protective Measures as it affects the Sacramento River Winter Chinook Salmon (winter-run) Evolutionary Significant Unit (ESU) (NMFS 2010)) (2010 BiOp). In the 2010 BiOp, NMFS found that given the current management structure of the fishery and the measures in place to protect winter-run, it was expected that adult spawning returns of winter-run cohorts would be reduced 10-25 percent as a result of impacts associated with incidental harvest in the ocean salmon fishery. These impacts occur primarily as a result of removal of age-3 winter-run, almost exclusively south of Point Arena, when fishing activity is permitted in those areas in conjunction with the seasonal and size restrictions associated with the proposed action (NMFS 2010). The results from the O’Farrell et al. (2012a) cohort reconstruction indicate that the majority of these impacts were associated with the recreational fishery in this area. The analysis also indicates that the ocean fishery spawner reduction rate[1] has averaged 20 percent in years when ocean fisheries occur (O'Farrell et al. 2012a), regardless of the spawning abundance of winter-run.

Over the last decade, this winter-run population (and consequently the entire ESU) has had years of positive growth (cohort replacement rates greater than 1.0) while sustaining ocean fishery impacts. The population increased to as many as 17,000 spawners in 2006. Therefore, NMFS concluded that the anticipated impacts of the fishery, based on past performance of both the fishery and the winter-run population, were not expected to reduce the likelihood of survival and recovery of the species during periods when the winter-run population is stable or increasing. To a large degree, the consultation standards and management measures described in the 2010 BiOp, which were designed to protect winter-run specifically, as well as address other stocks of Chinook salmon, have served to reduce fishery impacts on the winter-run Chinook salmon population to a level that is consistent with an expectation of survival and recovery for the species.

However, NMFS identified that the proposed action analyzed in the 2010 BiOp did not include measures that would avoid or constrain the fishery's impacts on winter-run during periods of decline or increased extinction risk. Without any explicit means to further constrain impacts after consideration of winter-run abundance in the fishery management process, the potential exists for total spawner reduction rates associated with the ocean salmon fishery to approach, or exceed, 25 percent during periods of time when risks of extinction are significantly increased. Therefore, NMFS concluded that the proposed operation of the fishery without consideration for additional protective measures that would be implemented when winter-run are

[1] The spawner reduction rate is defined as the reduction in a cohort's "potential adult spawning escapement owing to ocean fisheries, relative to its escapement potential in the absence of ocean fishing" (O'Farrell et al. 2012).

at low abundance was not sufficient to ensure that the fishery was not likely to appreciably reduce the likelihood of survival and recovery of winter-run.

Reasonable and Prudent Alternative (RPA)

The Endangered Species Act requires that, where NMFS concludes through consultation that a proposed action is likely to jeopardize the continued existence of a listed species, NMFS identify one or more RPAs to such action. By regulation, an RPA is defined as "alternative actions identified during formal consultation that can be implemented in a manner consistent with the intended purpose of the action, that can be implemented consistent with the scope of the Federal agency's legal authority and jurisdiction, that is economically and technologically feasible, and that the Director [NMFS] believes would avoid the likelihood of jeopardizing the continued existence of listed species or resulting in the destruction or adverse modification of critical habitat" (50 CFR 402.02).

NMFS' approach when developing the RPA in the 2010 BiOp was to address the foundation of the jeopardy conclusion, which is the lack of explicit controls in the ocean salmon fishery management process to constrain and reduce impacts when the abundance of winter-run is depressed and the extinction risk is increased. Specifically, the purpose of the RPA was to establish a long-term management framework that accounts each year for the abundance of winter-run and specifies a level of fishery impact that is responsive to that abundance and consistent with the requirement to avoid jeopardy. However, abundance at the time of the 2010 BiOp, the information and analyses required to establish specific management objectives or acceptable impact targets given various conditions, and the tools needed to incorporate those criteria into the fishery management process were not available. Additional analytical effort was required before this framework could be developed and implemented. Therefore, the RPA required NMFS to develop a winter-run management framework that 1) meets the objective of the RPA, 2) is practical given the ocean salmon fishery management process as described in the Salmon FMP, and 3) that the framework be available for consideration in time for implementation as the consultation standard for the ocean salmon fishery for winter-run for the 2012 fishing season.

For the interim between issuance of the 2010 BiOp and implementation of the new framework, NMFS determined that the winter-run population had been in significant decline since 2006, and concluded that conservative management measures should be taken and fishery impacts reduced pending completion of the new management framework. The 2010 BiOp provided options to the Council and NMFS to either increase size limits or reduce fishing effort (seasonal closures) in the recreational fishery in 2010 and 2011 to produce a qualitative constraint and reduction in winter-run impacts (see NMFS 2010 for explanation of interim RPA rationale).

Management Strategy Evaluation (MSE)

In order to develop the management framework required by the 2010 RPA, the NMFS Southwest Fisheries Science Center Salmon Assessment Team (the Team) engaged in an effort to develop the analytical tools required to evaluate various fishery exploitation control rule alternatives in a formal Management Strategy Evaluation process. The term "Management Strategy Evaluation" is being used to represent all aspects of the analytical work developed to support the decision-making process and implementation of a new fisheries management framework. The purpose of the MSE was to simulate winter-run population dynamics as well as monitoring, assessment, and implementation of the fishery management system under a variety of prospective fishery management control rules. The control rules specify the allowable level of incidental take of winter-run (age-3 impact rate) for ocean fisheries in a given year. For example, a control rule which allows a fixed annual fishing impact rate could be simulated and compared to other control rules that specify reduced allowable impact rates when population abundance is low. The goal of this simulation work was to evaluate the relative performance of various control rules in terms of conservation and fishery criteria.

In order to perform the simulations, the Team developed a model for winter-run such that the prescribed fishing impact rate under a control rule could be directly input as a source of mortality (with its attendant uncertainty). This mortality affected spawning abundance, leading directly to the generation of the next cohort, and on throughout the population simulation (Winship et al. 2012). The MSE evaluated three control rules with constant age-3 fishery impact rate target scenarios representing: no impact (0 percent), estimated historical fishery impact rate (25 percent), and current era fishery impact rate (20 percent). The MSE also considered other variations of control rules with decreasing age-3 fishery impact rates at decreasing population abundance levels (Winship et al. 2012). These are described in the paragraph titled "Public Comment and Availability of the winter-run Management Strategy Evaluation" below. The performance of alternative control rules were compared in terms of established population performance criteria and the implications for ocean fisheries. A paper consistent with the Winship et al. (2012) report describing the winter-run MSE was subsequently published (Winship et al. 2013).

Public Comment and Availability of the winter-run Management Strategy Evaluation

NMFS seeks input from the public on the control rules analyzed in the MSE as described in Winship et al. 2012 ("the MSE document"), particularly on whether commenters prefer one of those control rules over the others, and the reasons for such preference. The comment period will conclude at 5:00pm on XX XX, 2014 [90 days]. NMFS will consider all comments received by the end of the comment period as we move forward to consider potential changes to the management approach. The MSE document (Winship et al. 2012) is available at the following website http://www.pcouncil.org/wp-content/uploads/SRWC_MSE_2012_02_28.pdf and by mail upon request. NMFS is specifically interested in comments and information regarding a preferred control rule analyzed in the MSE for ocean salmon fisheries south of Point Arena that is responsive to the abundance of the species. The control rules are described in Winship et al. 2012 as "management strategies" and are as follows: management strategy 1 allowed for a zero age-3 impact rate, management strategy 2 used a historical impact rate of 25 percent, management strategy 3 used the current era impact rate of 20 percent, and management strategies 4 through 6 required a reduction in impact rates at certain abundance thresholds. The control rule included in the current RPA (referred to as "management strategy SWR" in the Winship et al. 2012 addendum found here, beginning on page 57: http://www.pcouncil.org/wp-content/uploads/SRWC_MSE_2012_02_28.pdf) was also analyzed with results presented in Winship et al. 2012 (addendum); we welcome comments on this control rule as well.

References

Lindley, S.T., R.S. Schick, E. Mora, P.B. Adams, J.J. Anderson, S. Greene, C. Hanson, B.P. May, D.R. McEwan, R.B. MacFarlane, C. Swanson, and J.G. Williams. 2007. Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin Basin. San Francisco Estuary and Watershed Science 5(1), Article 4: 26 pages. Available at: http://repositories.cdlib.org/jmie/sfews/vol5/iss1/art4.

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. Available at: http://www.pcouncil.org/wp-content/uploads/Final_Harvest_BiOp_April2010.pdf.

NMFS. 2012. Final Implementation of the 2010 Reasonable and Prudent Alternative Sacramento River winter-run Chinook Management Framework for the Pacific Coast Salmon Fishery Management Plan. National Marine Fisheries Service, Southwest Region. April 30, 2102. Available at: http://www.pcouncil.org/wp-content/uploads/30APR2012_Sacramento_Winter_run_RPA_Implementation.pdf

O'Farrell, M.R., M.S. Mohr, A.M. Grover, and W.H. Satterthwaite. 2012a. Sacramento River winter Chinook cohort reconstruction: analysis of ocean fishery impacts. U.S. Dept. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-491, 68p. Available at: http://docs.lib.noaa.gov/noaa_documents/NMFS/SWFSC/TM_NMFS_SWFSC/NOAA-TM-NMFS-SWFSC-491.pdf.

O'Farrell, M.R., S.D. Allen, and M.S. Mohr. 2012b. The winter-run harvest model (WRHM). U.S. Dept. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-489, 17p. Available at: http://docs.lib.noaa.gov/noaa_documents/NMFS/SWFSC/TM_NMFS_SWFSC/NOAA-TM-NMFS-SWFSC-489.pdf.

Winship, A.J., M.R. O'Farrell, and M.S. Mohr. 2012. Management strategy evaluation for Sacramento River winter Chinook salmon. Report available at: http://www.pcouncil.org/wp-content/uploads/SRWC_MSE_2012_02_28.pdf.

Winship, A.J., M.R. O'Farrell, and M.S. Mohr. 2013. Management strategy evaluation applied to the conservation of an endangered population subject to incidental take. Biological Conservation 158:155-166.

Agenda Item C.2
Situation Summary
November 2013

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. The Methodology Review is also used as a forum to review updated stock conservation objective proposals. This review is preparatory to the Council's adoption, at the November meeting, of all anticipated methodology and conservation objective changes to be implemented in the coming season, or in certain limited cases, of providing directions for handling any unresolved methodology problems prior to the formulation of salmon management alternatives in 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.

This year's methodology review meeting of the SSC Salmon Subcommittee, the STT, and the Model Evaluation Workgroup occurred on October 1-2, 2013 at the onset of the Federal government furlough. Accordingly, no employees of Federal agencies were in attendance, which restricted the group's ability to fully review the proposals. Therefore, the modified objective of the meeting was to conduct an initial review of the analyses, discuss alternative ways of completing this year's compromised review, and to prioritize items for the November Council meeting.

There will be insufficient time at the November Council meeting to conduct a thorough review of all of this year's topics. Methodology topics were prioritized for full SSC review in November based on two main criteria; 1) the technical merits of the analysis and the documentation, and 2) the proposed methodology's potential to directly improve the 2014 preseason process.

Based on these criteria, the following topics are recommended for full SSC review and potential Council adoption in November:

- Technical revision to the Oregon Coastal Natural (OCN) coho work group harvest matrix. (Agenda Item C.2.a, Attachment 1).
- Lower Columbia natural (LCN) coho matrix control rules (Agenda Item C.2.a, Attachments 2).
- Incorporating Recent Empirical Information on Sublegal Encounters Into Fishery Regulation Assessment Model (FRAM) Modeling (Agenda Item C.3.a, Attachment 3).
- Correction to FRAM Algorithms for Modeling Size Limit Changes (Agenda Item C.3.a, Attachment 4).
- Evaluate alternative forecast methodologies for the Sacramento fall Chinook index. (Agenda Item C.2.a, Attachment 5).

The following topics were not recommended for full SSC review in November, and Council guidance is requested on a revised schedule for their future review:

- Conservation objectives, annual catch limits, and status determination criteria for Willapa Bay coho (Agenda Item C.2.a, Attachment 6).

- Conservation objectives for southern Oregon coastal Chinook (Agenda Item C.2.a, Attachments 7).
- Standardized method to calculate Chinook age 2 FRAM stock recruit scalars (Agenda Item C.3.a, Attachment 8).
- Progress Report: new Chinook FRAM base period.

Council Action:

1. **Approve new and modified methodologies and conservation objectives as appropriate.**
2. **Provide guidance, as needed, for any unresolved methodology issues.**

Reference Materials:

1. Agenda Item C.2.a, Attachment 1: 2013 Technical Revision to the OCN Coho Work Group Harvest Matrix.
2. Agenda Item C.2.a, Attachment 2: Harvest Strategy Risk Assessment for Lower Columbia Natural Coho.
3. Agenda Item C.2.a, Attachment 3: Incorporating Recent Empirical Information on Sublegal Encounters into FRAM Modeling.
4. Agenda Item C.2.a, Attachment 4: Correction to FRAM Algorithms for Modeling Size Limit Changes.
5. Agenda Item C.2.a, Attachment 5: Expected future performance of abundance forecast 1models with application to Sacramento River fall Chinook salmon.
6. Agenda Item C.2.a, Attachment 6: Status Determination Criteria for Willapa Bay Natural Coho.
7. Agenda Item C.2.a, Attachment 7: Conservation Objective for Southern Oregon coastal Chinook.
8. Agenda Item C.2.a, Attachment 8: Standardized Method to Calculate Chinook Age 2 FRAM Stock Recruit Scalars, Based Upon the Age 3 Forecast.
9. Agenda Item C.2.b, Supplemental SSC Report.

Agenda Order:

a. Agenda Item Overview — Mike Burner
b. Reports and Comments of Advisory Bodies and Management Entities
c. Public Comment
d. **Council Action**: Adopt Final Methodology Changes and Conservation Objectives

PFMC
10/10/13

2013 Technical Revision to the OCN Coho Work Group Harvest Matrix

Erik Suring

Mark Lewis

Corvallis Research Laboratory
Oregon Department of Fish and Wildlife

September 2013

Table of Contents

Abstract

Amendment 13 (A13) to the Pacific Fishery Management Council's (PFMC) Pacific Coast Salmon Fishery Management Plan sets Oregon Coastal Natural (OCN) coho salmon harvest impact rates through a two dimensional matrix with parental status and a marine survival index as the axes. When A13 was developed available data on wild coho salmon marine survival was limited and the Oregon Production Index Hatchery (OPIH) jack/smolt ratio, as a predictor of OPIH adult marine survival, was used as a proxy. Recognizing these limits the authors stipulated that the "methods of estimating the technical parameters" could be changed as a technical revision without plan amendment. The Oregon Department of Fish and Wildlife (ODFW) as part of the Oregon Plan for Salmon and Watersheds has conducted monitoring on OCN abundance, survival, and habitat since 1998. These data show that OPIH abundance and survival are not correlated with OCN abundance and survival. In 2012 ODFW proposed technical revisions to the A13 matrix. The PFMC approved the technical revisions, including using the wild coho salmon jack/smolt ratio from the Mill Creek (Yaquina) Life Cycle Monitoring site as a new predictor of wild adult marine survival. The approval was provisional for a single year pending further analysis to address recommendations and reduce risks from reliance on a single site for the A13 marine survival prediction. To address these concerns we propose using an ensemble forecast from seven generalized additive models (GAMs) incorporating additional biologic and oceanographic indicators to predict marine survival. To address the potential for a catastrophic failure of the single site Mill Creek jack ratio indicator we demonstrate that the OCN abundance predictor GAMs could be modified for use as a fallback marine survival predictor. In a retrospective analysis from 1999 to 2012 the proposed predictor would have provided greater differentiation in impact rates between the top three recruitment years, middle eight recruitment years, and bottom three recruitment years than the OPIH predictor. Allowable impact rates would have been 28%, 22%, and 10% for the high, middle, and low abundance years under the current proposal versus 15%, 13%, and 12% for the OPIH predictor. Performance also improved relative to the 2012 revision and the 2013 proposed predictor is more robust to a change in any single indicator. It appropriately limits impact rates when survival is expected to be low but allows harvest opportunity when it is expected to be high.

Introduction

Oregon's coastal coho salmon (*Oncorhynchus kisutch*) populations are an important ecological and cultural component of the coastal landscape and have historically contributed to significant recreational and commercial fisheries. The abundance of Oregon coastal coho salmon in the late 1800's to early 1900's was likely in the range of one to two million fish (ODFW 2007). By the 1990's the runs had declined to less than 100,000 fish a year (PFMC 2012). Oregon Coastal Natural (OCN) coho salmon are currently managed as an aggregate of stocks from the Necanicum River in the north to the Sixes River in the south. These stocks compose all of the Oregon Coast Coho Evolutionarily Significant Unit (ESU), as defined by the National Marine Fisheries Service (NMFS). This ESU is listed as "threatened" under the Federal Endangered Species Act (NMFS 2011).

Harvest impacts to OCN coho salmon are managed by the Pacific Fishery Management Council (PFMC) in ocean areas beyond three miles from the coast. Within Oregon estuary and freshwater areas and in the ocean within three miles of the coast, harvest management is the responsibility of the State of Oregon. Oregon has committed to manage OCN coho salmon harvest based on Amendment 13 (A13) in the 2007 Coho Conservation Plan (ODFW 2007) and in terminal areas in the Fisheries Management and Evaluation Plan (ODFW 2009). In 1997 the council adopted A13 (PFMC 1999) to the Pacific Coast Salmon Plan. A13 utilizes a matrix of OCN parental spawner status and a marine survival index to establish allowable fishery impact rates. In 2000 the OCN Work Group (Sharr et al. 2000) reviewed A13 and expanded the matrix from a 3 x 3 to a 4 x 5 matrix to address management at very low marine survival and parental abundance. The OCN Work Group matrix was adopted by PFMC and has been used as technical guidance on implementation of A13 since 2001. As an Endangered Species Act listed species, management of OCN coho salmon is conducted in consultation with the NMFS. A13 stated a goal for harvest management of OCN coho salmon:

> *"Thus, the primary goal of the amendment is to assure that fishery related impacts will not act as a significant impediment to the recovery of depressed OCN coho and to more uniformly rebuild each component population subgroup to a higher level."*

In developing A13 the authors acknowledged the limits of the available data on OCN coho salmon and the uncertainties in the proposed management regime, and in response to these concerns A13 included a Monitoring and Evaluation section (2.2.3). This included *"…a comprehensive evaluation mechanism on a pre-determined schedule."* with the first review to occur in 2000. The 2000 OCN Work Group report is the result of that review. The comprehensive monitoring program called for in Section 2.2.3 of A13 included: juvenile surveys, spawner surveys, habitat surveys, comprehensive monitoring sites, and fishery impact monitoring. The authors anticipated that the results of improved monitoring and periodic reviews might result in changes to the matrix. Specifically, on page 7 of A13 they state:

> *"To incorporate the best science, the methods of estimating the technical parameters used in this proposal may change without plan amendment, if approved by the Council following a technical review and recommendation for change by the Scientific and Statistical Committee."*

The majority of coho salmon in Oregon return to spawn at three years old, with a variable proportion of precocious males returning at two years old after only four to six months in the ocean (Sandercock 1991). The early marine life-stage may be a survival bottleneck for coho salmon (Logerwell et al. 2003; Beamish et al. 2004). Jack coho salmon return to freshwater spawning areas after experiencing this potential survival bottleneck. Therefore, high jack return rates indicate favorable early ocean conditions for adults of that brood cycle, and thus jack returns can be a predictor of adult marine survival (Briscoe et al. 2005). Currently, A13y relies on this relationship, using the Oregon Production Index Hatchery (OPIH) jack/smolt ratio to predict OCN marine survival. At the time of A13 development, data on wild adult coho salmon marine survival were unavailable and OPIH data were used as a proxy. The relationship between OPIH jack/smolt ratios and OPIH adult returns was strong (PFMC 1999), but subsequent data from multiple monitoring projects focused on wild coho salmon show that OPIH abundance and survival are not correlated to OCN abundance and survival. With these additional data we no longer need OPIH as a proxy and can use OCN data directly for OCN harvest management.

From 1998 to present the Oregon Department of Fish and Wildlife (ODFW) has conducted an integrated monitoring program (Firman and Jacobs 2001) as part of the implementation of the Oregon Plan for Salmon and Watersheds (OPSW). The OPSW monitoring program addresses the first four monitoring components called for by A13. The program consists of three geographically extensive monitoring projects based on a spatially balanced random site selection, and one project that intensively monitors specific sub-basins. The three geographically extensive projects are based on the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program sample design. These projects incorporate a Generalized Random Tessellation Stratified (GRTS) sampling design to establish a shared set of random, spatially balanced sample points (Firman and Jacobs 2001; Stevens 2002). These projects provide the juvenile, adult spawner, and habitat surveys called for in A13. The fourth project is the Life Cycle Monitoring (LCM) project, which determines adult and juvenile coho salmon abundance and survival at specific sub-basins, providing the comprehensive monitoring sites called for in A13. . Analysis has also been done linking OCN abundance with several oceanographic indicators over a long time series (Rupp et al. 2012b).

During 2010-11 ODFW staff conducted a review of A13 and the thirteen years of OPSW monitoring data on OCN coho salmon. The results of that review showed the LCM data could provide an improvement to the method of estimating the marine survival index parameter. Suring and Lewis (2012) proposed using the LCM Mill Creek jack/smolt ratio to predict OCN marine survival. This proposal was provisionally accepted for the 2013 return year because of concerns centering on reliance on data from only a single site. We have reviewed the 2012 predictor and found no immediate concerns or changes to the marine survival relationship, but to address these concerns we propose a new predictor incorporating representative, coast wide, spawning survey data and several oceanographic indicators (Rupp et al. 2012b) using generalized additive models (GAMs). The proposed predictor further increases forecast skill and is more robust to changes in any individual indicator. In the case of a catastrophic failure of the Mill Creek LCM site we also demonstrate a fallback predictor that has better performance than the current fallback, the OPIH jack/smolt ratio.

Methods

OPSW Life Cycle Monitoring Data

A LCM site consists of a paired adult and out-migrant trap. Data presented here were collected from 1998-2012 from six sites in the Oregon Coast Coho ESU (Figure 1). Data from the East Fork Trask LCM site were not used in this analysis because it has not been operational for the entire study period. Spawner abundance at LCM sites was either a direct count from traps at complete barriers or estimated by mark-recapture methodology (Ricker 1975). Fish that entered traps were identified to species and sex and distinguished as wild or hatchery-produced based on presence or absence of an adipose fin clip. Coho salmon < 45 cm fork length were categorized as jacks and scales were taken from fish between 45 and 55 cm fork length for age assignment. Downstream juvenile salmonid out-migrants were captured with rotary screw traps or motorized incline plane traps. Fish were enumerated by species and age or size class, with coho salmon identified as fry (age 0) or smolts (age 1+). Trap capture efficiency was evaluated daily and weekly out-migrant estimates were summed for season totals. Additional details on adult and juvenile estimation methods and site specific details are found in Suring et al. (2012).

The LCM smolt to adult marine survival rate was derived by dividing the adjusted female spawner abundance in year t by half of the smolt production, assuming a 1:1 smolt sex ratio, in year $t-1$. Spawner abundance was adjusted for harvest impacts by dividing abundance by one minus the impact rate. The OCN marine survival index was calculated by averaging the marine survival rate from all sites.

Trap design at most LCM sites does not capture jack coho salmon, but the LCM adult trap on Mill Creek (Yaquina) captures all upstream migrating fish, including jack coho salmon, as the head gate controlling flow into the trap below the Mill Creek reservoir dam creates a velocity barrier. Live fish placed above the trap represent the entire spawning population. A motorized inclined plane trap was used immediately below the fish ladder and spillway of the dam to estimate juvenile out-migrant populations each spring (Suring et al. 2012). The jack/smolt ratio was calculated by dividing the jack spawner abundance in the fall of year $t-1$ by half the smolt production, assuming a 1:1 smolt sex ratio, out-migrating in the spring of year $t-1$.

OPSW Random Spawning Survey Monitoring Data

Utilizing Geographic Information System software, an integrated frame of stream reaches and potential sampling sites (GRTS points) for OCN coho salmon was established in 1998. The GRTS points were established at a density of approximately two points per mile of stream, with each point attributed to one or more of the three OPSW monitoring projects (juvenile, adult spawner, and habitat) that might sample there. Each point is randomly assigned a use order and attributed to one of 40 rotating panels. The rotating panel design is based on the three year life span of coho salmon and intended for a 27 year study duration. The 40 panels are assigned to 4 groups: 1 panel contains sites that are sampled every year; 3 panels have sites that are sampled every third year; 9 panels have sites that are sampled every ninth year; and 27 panels have sites that are sampled only once (Firman and Jacobs 2001, and Stevens 2002).

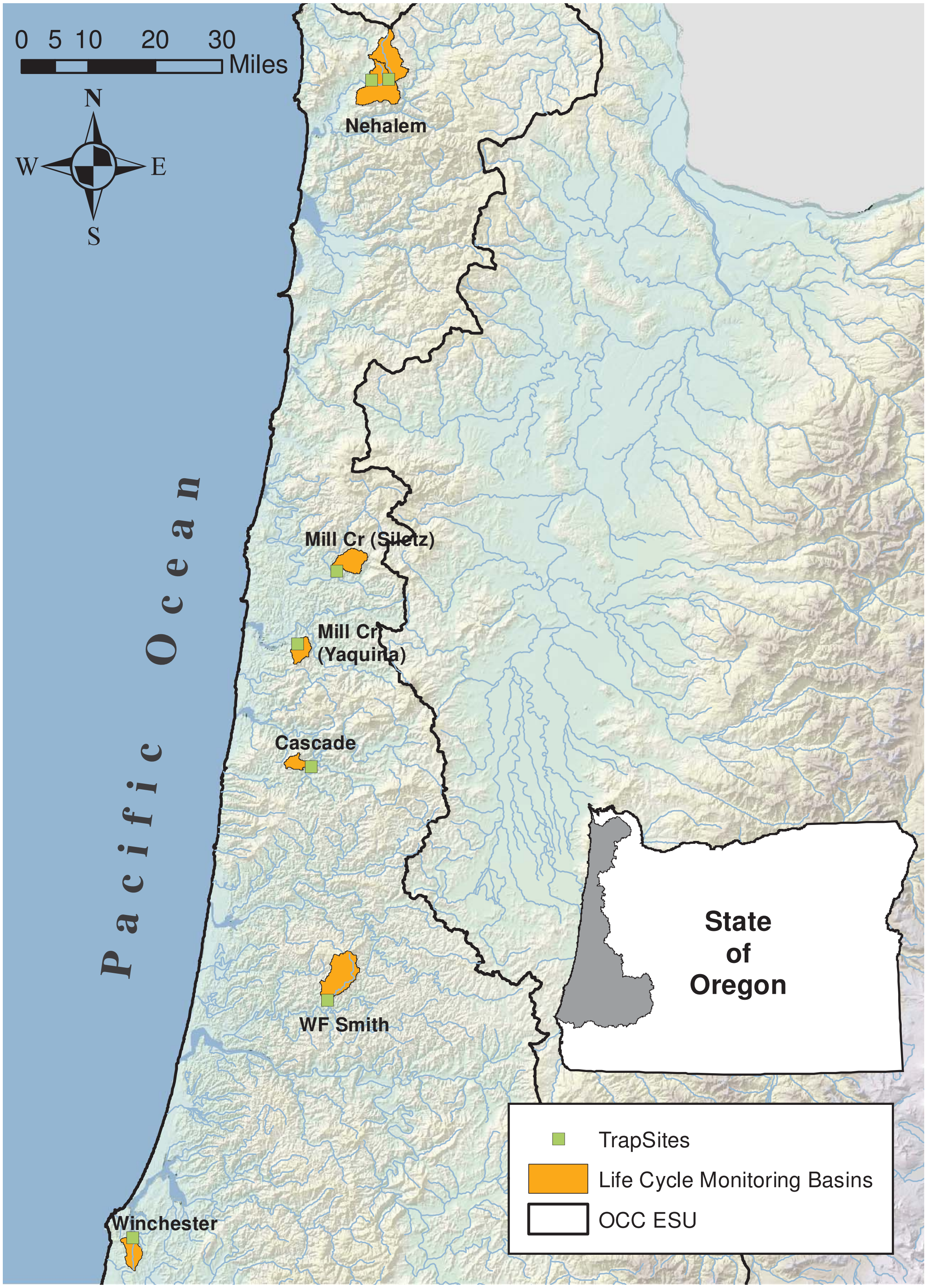


Figure 1. Oregon Department of Fish and Wildlife Life Cycle Monitoring Basins where both coho salmon adult returns and juvenile out-migrants are estimated.

Since 1998, the rotating panel design and GRTS points in potential coho salmon spawning habitat have been used annually to select Oregon coastal coho salmon spawning ground surveys. Equal numbers of sites are selected by use order, from each of the four panels for that year. The goal is 30 sites or 30% of the spawning habitat for the spatial scale being sampled. Currently, coho salmon spawning surveys are selected at the spatial scale of individual coho salmon populations as defined by NMFS (Lawson et al. 2007). Following is a brief description of the field methods and analysis of the spawning ground survey data as it applies to this proposal. A more complete description of the methods and history of changes to the sampling frame and effort are provided in Jacobs et.al (2002) and Lewis et.al (2009). Field methods are described in annual field sampling procedures manuals available on the project web page: http://oregonstate.edu/dept/ODFW/spawn/reports.htm.

Coho salmon spawning ground surveys are conducted weekly from October through January, or longer as needed. The goal is to obtain at least one valid survey (in which flow and visibility allow for counts of live fish, dead fish, and redds) before coho salmon start spawning and two consecutive valid surveys with no live coho salmon observed to end each site for the season. Although the goal is to conduct a weekly survey, current protocols allow for up to 11 days between valid survey visits, based on an average survey life of just over 11 days for coho salmon (Perrin and Irvine 1990). Surveys are conducted by walking up-stream and recording the number of live and dead fish (by species), redds observed, and categorical information on weather, stream flow, and visibility. Surveyors record species, gender, Mid Eye to Posterior Scale (MEPS) length, and any fin clips, marks, or tags for all coho salmon carcasses. A scale sample is collected from every tenth coho salmon carcass, and both a scale sample and snout are collected from every Ad Clip carcass to recover the coded wire tag, if present. Finally, the tail is cut off of every sampled carcass to preclude repeat sampling on subsequent survey visits. Coho salmon jacks are defined as a male fish measuring 430 mm MEPS or less, determined by measurement for carcasses and visually for live fish.

The jack salmon metric, based on coast wide random spawning survey data, developed for this proposal is the average jack peak count per mile, adjusted for sampling weights. Jack peak count is the maximum number of coho salmon jacks (live and dead combined) observed on any single survey day for the spawning season. This value is calculated for each randomly selected (GRTS) spawning survey each year. The peak count is then standardized for different survey lengths by dividing the peak count for each survey by the survey length (Equation 1). Sampling weight is the total miles of spawning habitat divided by the total number of GRTS sites selected for the year, for the spatial scale sampled (Equation 2).

Equation 1. $H_i = P_i / m_i$

where

H_i = Peak count per mile in survey i, and
P_i = peak count of live and dead coho salmon jacks in survey i, and
m_i = miles surveyed in survey i.

Equation 2. $W_j = M_j / n_j$

where

W_j = Sample weight for spatial scale j, and
M_j = Miles of spawning habitat in spatial scale j, and
n_j = Total number of GRTS sites selected in spatial scale j.

This site total includes target sites and non-target sites (determined to not actually be spawning habitat). The weight is adjusted for non-response target sites, which are sites that are coho salmon spawning habitat, but could not be successfully surveyed due to issues such as; denied access, unsafe conditions, or the timing and number of surveys did not meet criteria for inclusion in population estimates. Target response sites are those that are coho salmon spawning habitat and were successfully survey for the year. The adjusted weight is calculated as:

Equation 3. $W_j' = W_j * (r_j + s_j)/r_j$

where

W_j' = Adjusted sample weight for spatial scale j, and
r = Target response sites in spatial scale j, and
s_j = Target non-response sites in spatial scale j.

Because the sampling goal is 30 sites or 30% of the spawning habitat for the spatial scale being sampled, and sampling has been conducted at different spatial scales in different years, GRTS surveys for different areas have different sampling weights. To account for this difference in sampling weights we calculated a weighted average coho salmon jack peak count instead of a simple average. The weighted average peak count is calculated as:

Equation 4. $G = \Sigma (H_{ij} * W_{ij}') / \Sigma (W_{ij}')$

Where,

G = Average jack peak count per mile, adjusted for sampling weights, and
H_{iJ} = Peak count per mile in survey i in spatial scale j, and
W_{ij}' = Adjusted sample weight for survey i in spatial scale j.

To ensure the data used in calculating jack peak counts encompassed the entire spawning season, only surveys that met the criteria for inclusion in annual population estimates were used. The method for determining whether a site was successfully surveyed for the year involves three steps. First, the critical period is determined for each stratum. Critical period is defined as the time period in which 90% of the live coho salmon were seen in a stratum for the year. Second, the number of days between valid surveys is calculated for each site for the year. Finally, the “gaps” between survey dates are evaluated to determine if they meet the criteria for minimizing the chance of missing coho salmon in the live counts. The standard criteria used are: no gap of 16 or more days, and no more than one gap between 12 and 15 days during the critical period.

Generalized Additive Models

Generalized additive models were used to incorporate additional data into the marine survival predictor using the methods of Rupp et al. (2012b). To minimize the occurrence of spurious correlations when related to the short time series of OCN marine survival we used only the oceanographic indicators that were identified by Rupp et al. (2012b) as correlated with OCN recruitment over a long time series in addition to the Mill Creek jack/smolt ratio and GRTS jack peak counts (Table 1). The maximum number of knots in the spline was limited to three, restricting the resultant model complexity and reducing over-fitting of the data.

GAMs were fit in R (R Core Team 2013) using the package *mgcv* (Wood 2006) and ranked by ordinary cross-validation (OCV) score. All combinations of two (n=45) and three-variable (n=120) models were run and a subset containing the top ranked models received further review. We rejected models where any pair of variables had $r \geq 0.6$ to avoid multi-collinearity, which might otherwise complicate interpretation of individual variables' role in the prediction of marine survival. We also rejected any models if the relationship between the variable and marine survival did not match the relationship to abundance in Rupp et al. (2012b). The number of models to be used in the forecast was determined following the results of model fitting and statistical evaluation. A third set of models was run using the same GAMs as the Rupp et al. (2012b) OCN abundance predictor, set to predict marine survival rather than abundance. Forecasts were made for each model in the final subsets and an average ensemble forecast was created for each method.

Table 1. Indicators examined for use in marine survival prediction GAMs. More information on the oceanographic indicators is found in Rupp et al. (2012b).

Symbol	Indicator	Time Period
Coho salmon jack indicators		
JACKRATIO	Mill Creek (Yaquina) jack/smolt ratio	
JACKPEAK	OCN spawning ground survey peak jack count/mile	
Oceanographic indicators		
$PDO.MJJ_4$	Pacific Decadal Oscillation index	May-June-July Four year moving average
SPR	Date of spring transition between down-welling and upwelling conditions	
UWI.JAS	Upwelling wind index	July-August-September
SSH.AMJ	Sea surface height at South Beach, OR	April-May-June
SST.AMJ	Coastal sea surface temperature at Charleston, OR	April-May-June
MEI.OND	Multivariate El Nino-Southern Oscillation Index	

Retrospective Analysis

Harvest management performance of the OCN Work Group guidance on implementation of A13 (Sharr et al. 2000), the 2012 proposal, and the current proposal were compared through a retrospective analysis. The analysis used actual recent pre-season metrics for the parental spawner status and marine survival index and actual pre-harvest ocean abundance of wild adult coho salmon for the Oregon Coast Coho (OCC) ESU. The allowable total fishery impact rate was determined for each management strategy (OCN Work Group, 2012 proposal, and current proposal) for each year in the data set, 1999 through 2012. Maximum allowable harvest impact and minimum spawning escapement were calculated for each year based on the actual pre-harvest ocean abundance of wild adult coho salmon for the OCC ESU and assumed harvest impacts at the maximum allowable rate for each management strategy. Because the goal of the analysis was to compare the various management strategies performance across a consistent set of pre-season metrics, the 2002 through 2012 parental spawner status was not adjusted for the different allowable harvest impact rates that could have been implemented under each management strategy.

Post season estimates of wild adult coho salmon spawner abundance in the OCC ESU were obtained from ODFW, and are the same numbers submitted to the Oregon Production Index Technical Team meeting each February, for inclusion in the PFMC Preseason Report I. The estimated exploitation rate on OCN coho salmon was based on the post-season coho salmon run reconstruction as reported in the 2013 Preseason Report I (PFMC 2013a). The spawner abundance (spawners) and OCN exploitation rate (ER) were used to generate the actual pre-harvest ocean abundance (recruits) of wild adult coho salmon for the OCC ESU; recruits = spawners / (1 – ER). Allowable fishery impact rates under A13 and the OCN Work Group were obtained from Table V-7 in the 2013 Preseason Report I (PFMC 2013a). Pre-season predictions of the marine survival axis category from the various management strategies are available from the 1999 adult return year to present. The allowable total fishery impact rate for the 2012 proposal and current proposal are based on these marine survival predictions and the OCN Work Group parental spawner status.

Results

OPSW Monitoring Data

An index of OCN coho salmon smolt to adult marine survival can be calculated from 14 years of complementary adult return and smolt production data at six LCM sites (Table 2), providing information on wild coho salmon survival that was not available during the initial development of A13. The LCM sites are distributed latitudinaly but were not selected by a statistical design. The LCM sites in aggregate, however, are representative of ESU conditions based on spawner abundance and freshwater productivity as modeled by habitat surveys. Average spawner abundance at LCM sites, normalized to spawners/mile, correlates well with ESU wide escapement estimates (R^2=0.89, p<0.001, Figure 2). The relationship is linear over a wide range of abundance. The distribution of habitat quality as measured by the integrative metric of modeled winter parr/km productivity (Anlauf et al. 2009) is similar between LCM sites and the ESU as a whole (Figure 3).

Table 2. Coho salmon adult marine survival (adjusted for harvest), Mill Creek jack and smolt data, and coastwide jacks/mile.

Adult Return Year	LCM adult survival	LCM Mill Cr Jack Return	LCM Mill Cr Male Smolts	LCM Mill Cr Jacks/Smolt	GRTS Avg. Jack Peak (fish/mi.)
1998	6.5%	13	699	0.0186	--
1999	1.6%	19	3,342	0.0057	0.44
2000	4.0%	49	1,068	0.0459	0.53
2001	9.6%	258	2,800	0.0922	1.85
2002	9.2%	204	3,511	0.0581	1.23
2003	11.0%	245	3,415	0.0717	2.38
2004	6.0%	183	4,411	0.0415	2.01
2005	5.2%	55	4,052	0.0136	2.01
2006	3.0%	43	6,356	0.0068	1.06
2007	2.6%	25	5,085	0.0049	0.46
2008	6.6%	110	2,854	0.0385	0.85
2009	10.3%	171	2,637	0.0649	1.60
2010	8.7%	82	4,983	0.0165	1.27
2011	11.4%	170	1,675	0.1015	1.67
2012	7.2%	34	886	0.0384	0.99
2013		98	2,318	0.0422	0.63

The OPIH jack/smolt ratio remains a strong predictor of OPIH adult marine survival (R^2=0.82) as data collected since the original A13 analysis are added (1970-2012, PMFC 2013a). However, there is no relationship between OPIH jack/smolt ratio and the OCN adult marine survival index measured at the LCM sites (Figure 4). Similarly, there is no relationship between OPIH and OCN adult abundance (R^2=0.02, p=0.65). The jack/smolt ratio from the Mill Cr (Yaquina) LCM site has a strong relationship with wild adult coho salmon marine survival (Figure 5). The relationship using data through brood year 2009 with logit transformed variables is shown in Equation 5.

Equation 5. $logit(\text{adult marine survival}) = -1.024 + 0.515 * logit(\text{jack/smolt})$

This equation differs from the 2012 technical revision (Suring and Lewis 2012) by predicting marine survival adjusted for harvest impacts and incorporating the latest data through brood year 2009. As the annual impact rate has been low and consistent over the time period of the relationship (PFMC 2013b) adjusting for harvest has little impact on the relationship, but if impact rates have greater variance in the future incorporating this adjustment may improve the marine survival prediction. Adding an additional year of data does not appreciably change the relationship. The 2012 proposal (Suring and Lewis 2012), which is the accepted method for the 2013 return year, predicts a marine survival of 6.8% whereas the revised relationship predicts 6.7%. Coho salmon smolt estimates were successfully made for Mill Creek for brood year 2011 with an overall trap efficiency of 43%. The prediction for the 2012 return year was 6.4% while the observed marine survival was 7.2%.

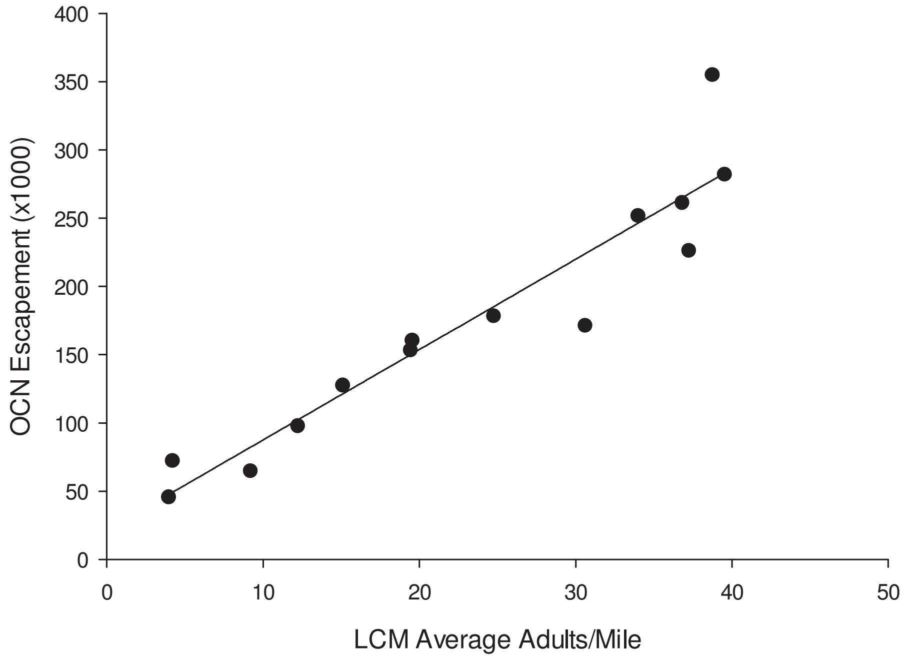


Figure 2. Relationship between average adult coho salmon returns to Life Cycle Monitoring sites (n=6) and Oregon Coastal Natural escapement (R^2=0.89, p<0.001), for return years 1999 to 2012.

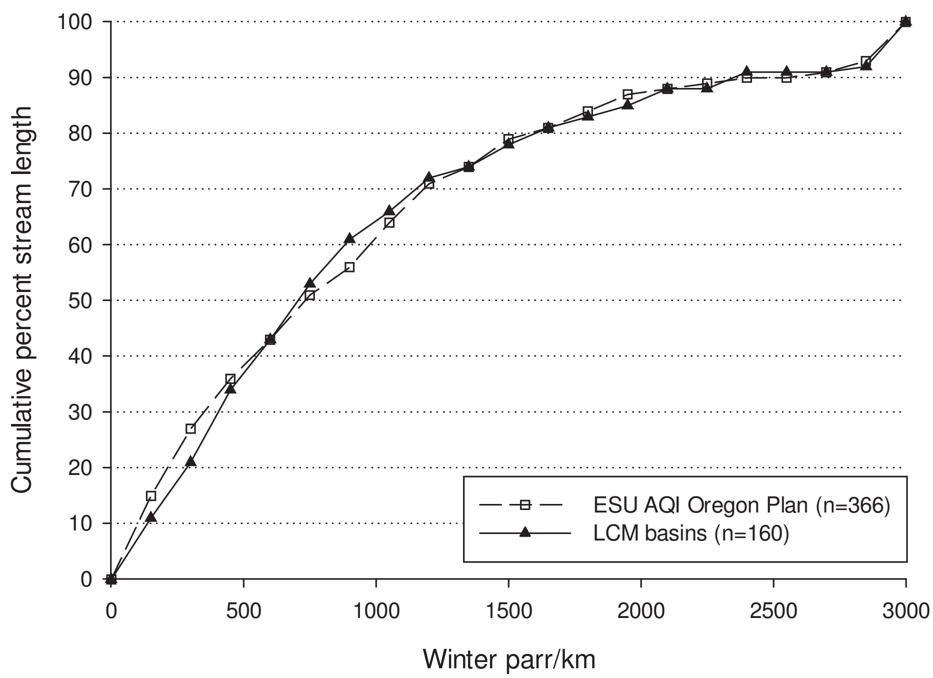


Figure 3. Cumulative distribution of modeled winter parr/km above LCM trap sites and ODFW Aquatic Inventories ESU wide probability surveys.

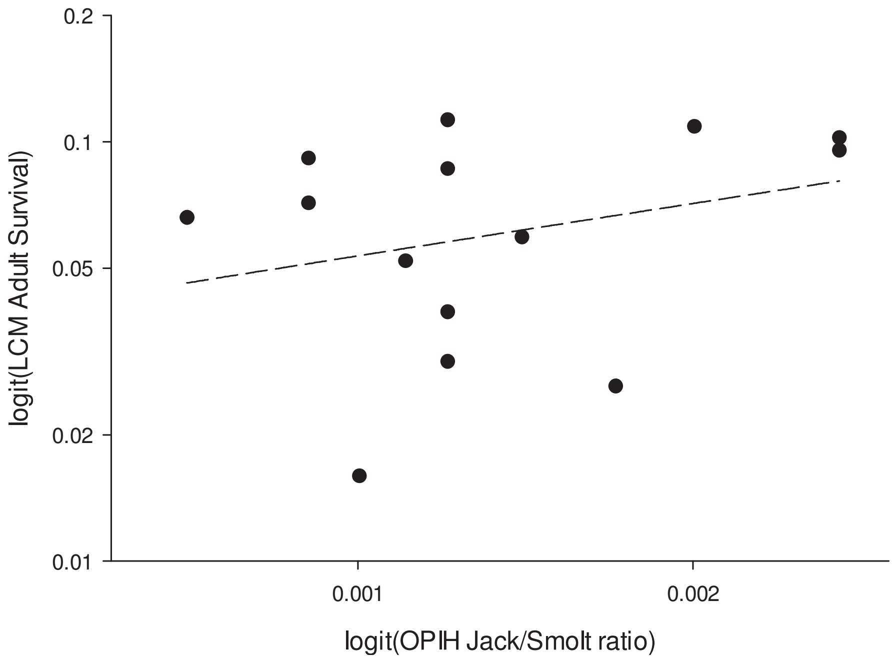


Figure 4. Relationship between the OPIH jack/smolt ratio and LCM adult marine survival (R^2=0.078, p=0.33).

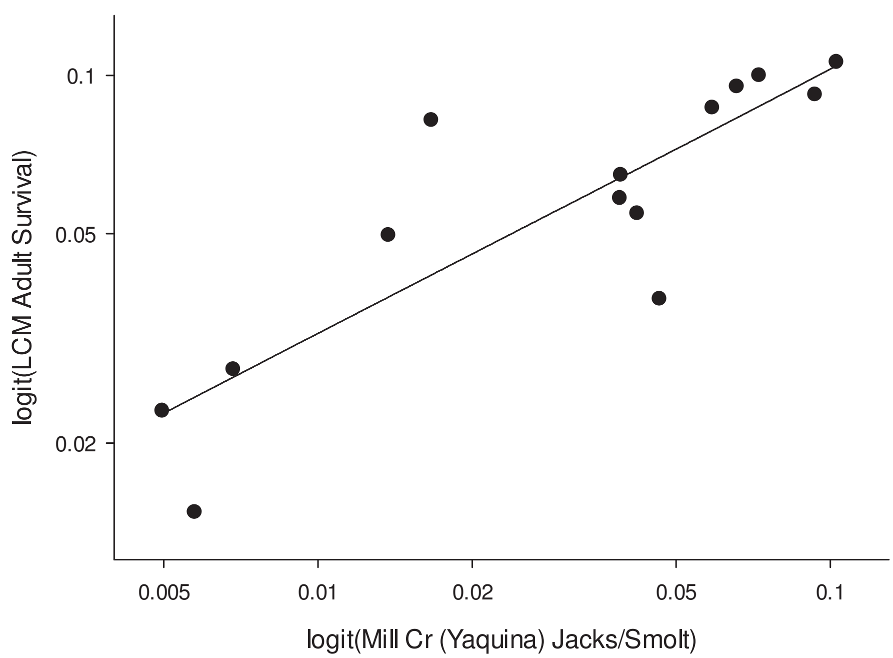


Figure 5. Relationship between the Mill Cr (Yaquina) jack/smolt ratio and LCM adult marine survival (R^2=0.74, p<0.0001).

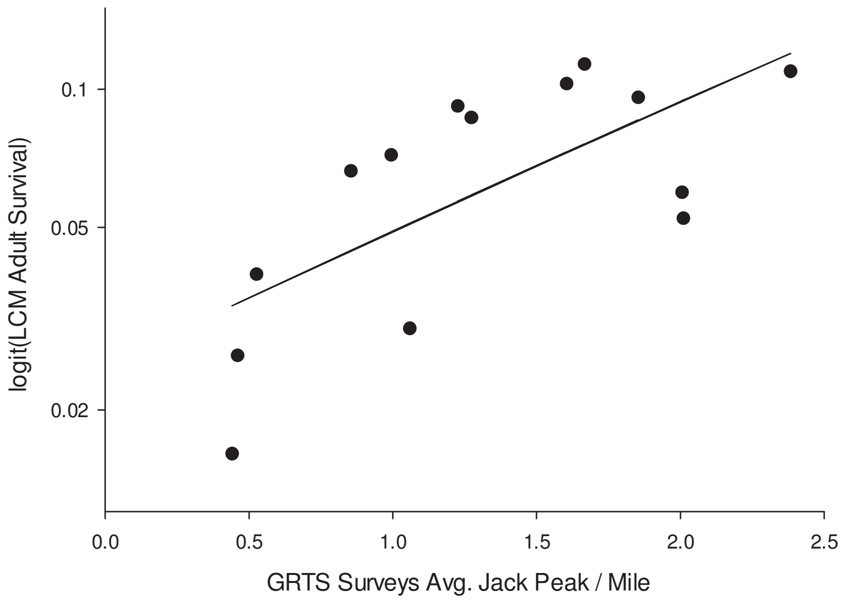


Figure 6. Relationship between the weighted average coho salmon jack peak count per mile in randomly selected spawning surveys (GRTS) and LCM adult marine survival (R^2=0.47, p<0.01).

The weighted average coho salmon jack peak count per mile was calculated from GRTS surveys for the 1998 through 2012 spawning seasons (Table 2). These jack return years correspond to adult return years 1999 through 2013. There was a fairly strong relationship (R^2 = 0.47) between the GRTS jack peak count and the corresponding adult coho salmon marine survival as measured at LCM sites (Figure 6). However, the relationship is poorer and the R^2 is substantially less than for the Mill Creek LCM jack data (Figure 5). The GRTS jack peak count was evaluated as a standalone marine survival predictor, however, because of the lower R^2 and poorer performance in the retrospective analysis in comparison to the Mill Creek jack/smolt data – it predicted the correct marine survival category in only 5 of 14 years – it was not pursued further. Two main factors likely contribute to the poorer performance for the GRTS jacks peak count metric; the annual variability in surveyor's ability to detect jacks on spawning ground surveys, and that it is a count instead of a return rate (jacks/smolt) like the Mill Creek LCM data. In spite of its poorer performance as a standalone marine survival predictor, the GRTS jack peak count metric was included as a potential variable in the GAM analysis.

Generalized Additive Models

Two and three-variable GAMs were ranked by OCV scores (Table 3). Two models were rejected because of high correlation between variables: JACKRATIO and SPR (r=0.63) and PDO.MJJ$_4$ and JACKPEAK (r=0.63). Three models were rejected because the relationship between MEI.OND and marine survival was contrary to its relationship to abundance in Rupp et al. (2012b) when paired with JACKRATIO. These aberrant models predicted that as MEI increased, i.e. that as El Nino conditions strengthened, marine survival would increase, which is opposite the hypothesized relationship (Figure 7). Using an

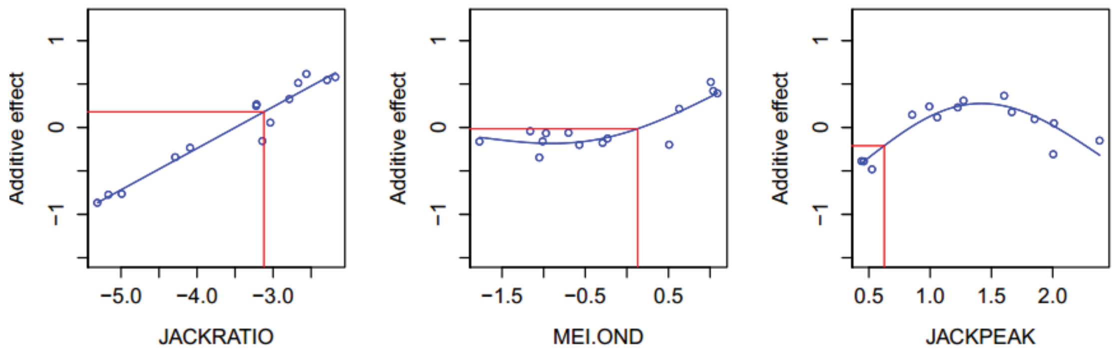


Figure 7. Partial regression plots of a three-variable GAM containing JACKRATIO and MEI.OND demonstrating a fit contrary to the hypothesized relationship.

Table 3. Performance statistics from the top ranked two and three-variable GAMs and the Abundance Predictor GAMs (Rupp et al. 2012b). Shaded models were rejected to avoid multi-collinearity or because models were contrary to hypothesized relationships.

Variable One	Variable Two	Variable Three	R^2	OCV	2013 Forecast
JACKRATIO	$PDO.MJJ_4$		0.91	0.83	8.7%
PDO.MJJ4	SPR		0.89	0.72	6.2%
JACKRATIO	MEI.OND		0.82	0.70	7.9%
JACKRATIO	JACKPEAK		0.87	0.70	5.1%
JACKRATIO	UWI.JAS		0.79	0.65	6.1%
$PDO.MJJ_4$	SSH.AMJ		0.80	0.65	7.5%
SPR	JACKPEAK		0.86	0.65	2.6%
$PDO.MJJ_4$	SST.AMJ		0.80	0.64	8.7%
Two-variable ensemble mean (unshaded models)			0.94	0.89	6.0%
JACKRATIO	$PDO.MJJ_4$	MEI.OND	0.91	0.83	9.9%
JACKRATIO	MEI.OND	JACKPEAK	0.96	0.83	6.1%
JACKRATIO	$PDO.MJJ_4$	SST.AMJ	0.93	0.82	9.1%
JACKRATIO	$PDO.MJJ_4$	UWI.JAS	0.95	0.81	8.0%
JACKRATIO	$PDO.MJJ_4$	SPR	0.95	0.80	7.3%
JACKRATIO	$PDO.MJJ_4$	SSH.AMJ	0.92	0.78	8.6%
$PDO.MJJ_4$	SPR	MEI.OND	0.94	0.78	6.0%
JACKRATIO	$PDO.MJJ_4$	JACKPEAK	0.91	0.75	8.6%
JACKRATIO	SST.AMJ	JACKPEAK	0.92	0.74	4.8%
Three-variable ensemble mean (unshaded models)			0.96	0.89	6.8%
$PDO.MJJ_4$	SPR	SPAWNERS	0.89	0.68	6.2%
$PDO.MJJ_4$	MEI.OND	UWI.JAS	0.78	0.41	8.3%
$PDO.MJJ_4$	SPR	MEI.OND	0.94	0.78	5.7%
$PDO.MJJ_4$	UWI.JAS	SST.AMJ	0.86	0.47	7.0%
$PDO.MJJ_4$	SSH.AMJ	UWI.JAS	0.86	0.42	6.1%
$PDO.MJJ_4$	UWI.SON	SST.J	0.80	0.41	8.2%
Abundance Predictor ensemble mean			0.89	0.68	6.8%

ensemble mean of the top seven two-variable models provides a result that incorporates data from five oceanographic and two fish-based indicators and fits the observed data well (Figure 8).

Adding a third variable to the models lead to only a small improvement in the performance metrics of the ensemble average (Table 3) and caused the predictor to predict the wrong category more often than the two-variable model. The top three three-variable models contain JACKRATIO and PDO.MJJ_4, much like the top two-variable model, and in these the third variable does not have a large effect on the model outcome as evidenced by the neutral slopes of the partial regression plots of the third variable (Figure 9). Considering concerns about over-fitting the data to the short marine survival time series and the limited improvement in fit when using three-variable models we do not see an advantage in using the three-variable GAM.

In case of a catastrophic failure where no Mill Creek jack/smolt ratio estimate could be made the current fallback predictor is the OPIH jack/smolt ratio. Given the poor performance of the OPIH jack/smolt predictor we evaluated alternatives. The current OCN abundance prediction model (Rupp et al. 2012b) can be modified to predict marine survival (Table 3). Retrospective performance is similar to the proposed GAM ensemble, under predicting the marine survival category in one year and over predicting in one year (Table 4) but with lower performance statistics (Table 3). It provides a fallback predictor with better performance that the OPIH jack/smolt ratio.

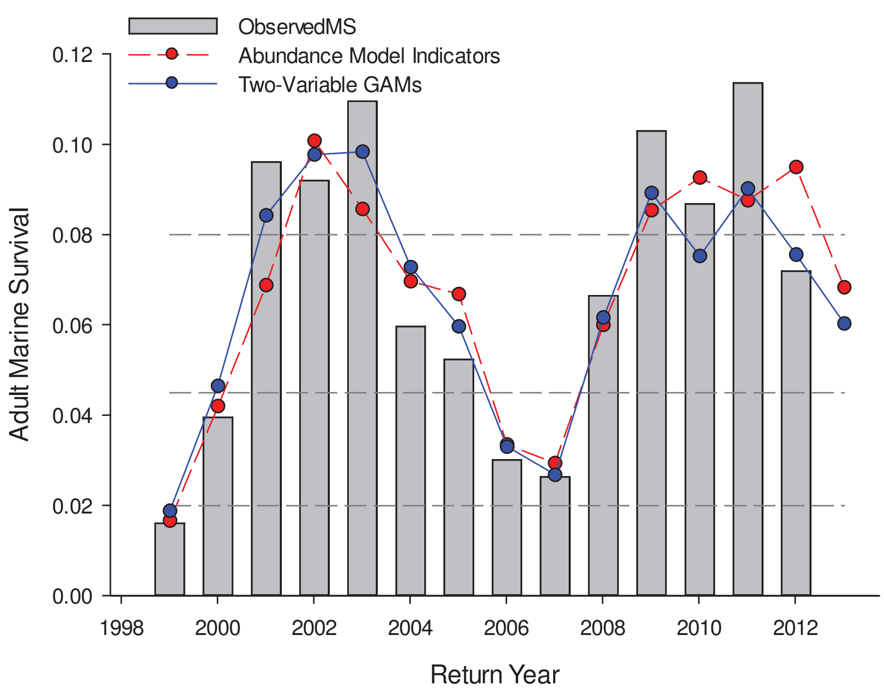


Figure 8. Time series of modeled and observed adult coho salmon marine survival. The dashed lines are the Amendment 13 harvest matrix threshold values.

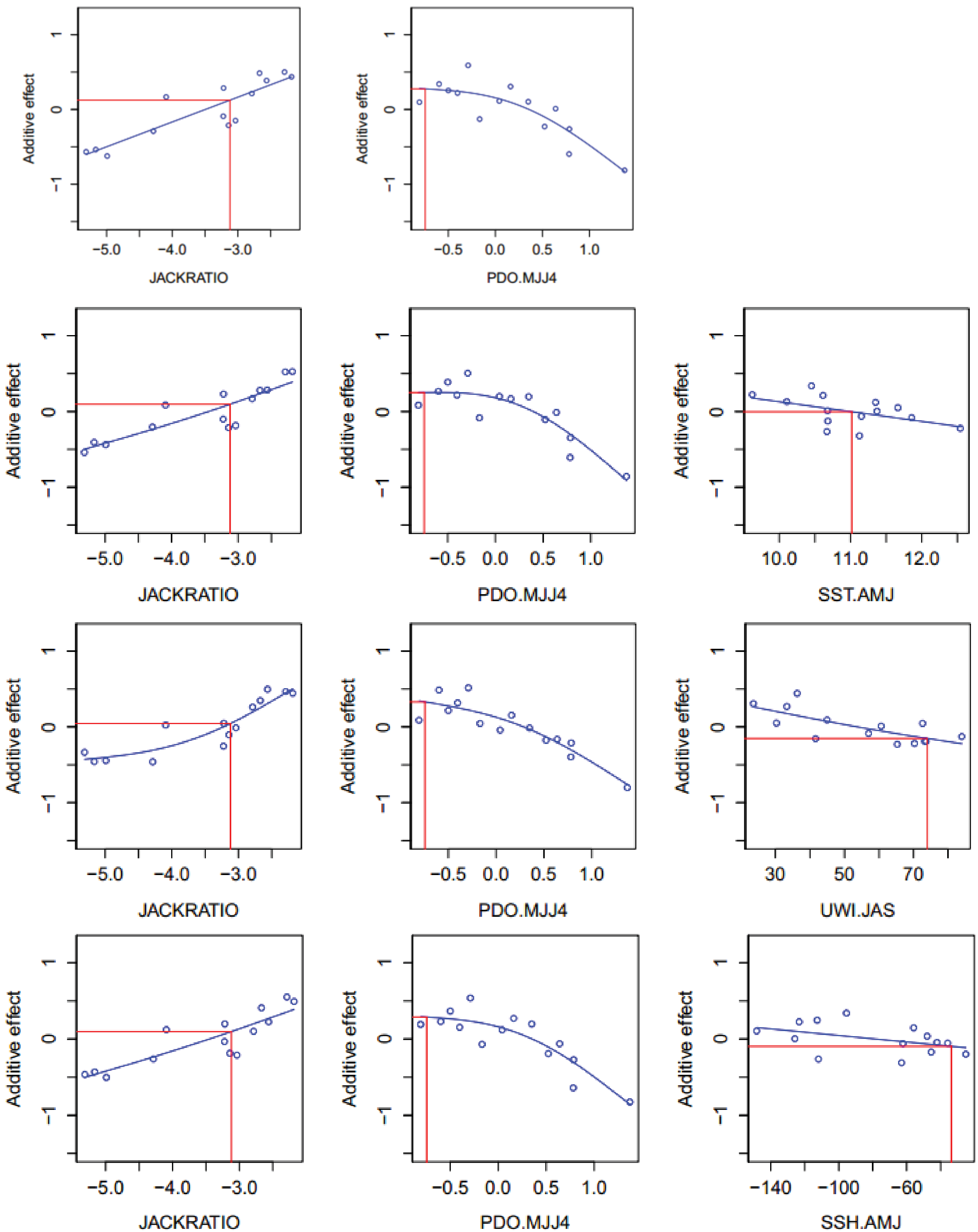


Figure 9. Partial regression plots comparing the top two-variable model with the top three three-variable models.

Retrospective Analysis

The last 14 fishery years (1999 through 2012) provided a robust dataset for a retrospective analysis, with wide ranges in OCN abundance and categories for both A13 axes. Pre-harvest ocean recruitment levels for OCN coho salmon ranged from 51,000 in 1999 to 379,000 in 2011 (Table 5). Observed marine survival from LCM sites is reported in Table 4, and ranged from 1.6% in 1999 (Extremely Low category) to 11.4% in 2011 (High category). Parental spawner categories are presented in the PFMC Pre-Season I Report (PFMC 2013a, Table V-8) and ranged from Critical to High. The number of correctly predicted A13 marine survival categories, relative to the LCM marine survival index, over the last 14 years increased dramatically from the OCN Work Group survival predictor (3 of 14 correct), to the 2012 predictor (10 of 14 correct including 2012) (Table 4). The current proposal is a further improvement, correctly predicting the marine survival category in 12 of the last 14 years (Table 4).

The allowable fishery impact rates for the period 1999 through 2012 averaged 14% under the OCN Work Group guidance, 21% under the 2012 proposal, 22% under the current proposal of a two-variable GAM and 23% under the abundance predictor GAM (Table 5). Based on post season observed marine survival categories, the allowable fishery impact rates for the period should have averaged 22% (Table 5). All of these impact rates are well below the historic levels seen prior to implementation of A13 in 1998 (Table III-2 in PFMC 2013a). In this sense, all the management scenarios were successful in achieving the goal of harvest impacts that are consistent with OCN recovery needs. In addition, the actual fishery impact rates on OCN coho salmon, reported by PFMC (PMFC 2012 Table III-5), were below the allowable rate in all years except 2012, averaging 52% and ranging from 24% to 121% of the maximum allowable rate.

One assumption inherent in the OCN harvest matrix concept is that the metrics for parental status and marine survival have a relationship with actual pre-harvest ocean recruitment levels. To evaluate this assumption, average results from the retrospective analysis were calculated for three categories: the top three recruitment years, the bottom three recruitment years, and the middle eight recruitment years (Table 5). The OCN Work Group matrix produced little differentiation between high, middle, and low recruitment years, with average allowable fishery impact rates of 15%, 13% and 12% respectively (Table 5). The 2012 proposal using wild jack/smolt ratios provides much greater differentiation of recruitment levels than the OCN work Group using OPIH jack/smolt ratios, averaging 28%, 20% and 10% fishery impact rates for the high, middle and low recruitment years (Table 5). None of these values exceed the A13 “correct” average impact rates of 32%, 22% and 10% respectively (Table 5), based on post season observed marine survival categories. Average fishery impact rates for high, middle, and low recruitment years, based on the current proposal are the same or slightly higher than those for the 2012 proposal (Table 5), but did not exceed the “correct” average rate.

Table 4. Observed and predicted marine survival and marine survival categories. Incorrect predictions are highlighted: over predicted marine survival in red, under predicted in blue.

Return Year	LCM observed adult survival	LCM observed category	OPIH predicted category	LCM Mill Cr. predicted category	Marine Survival GAM	Abundance Gam
1999	1.6%	Ex. Low	Low	Low	Ex. Low	Ex. Low
2000	4.0%	Low	Low	Medium	Medium	Low
2001	9.6%	High	Medium	High	High	Medium
2002	9.2%	High	Low	High	High	High
2003	11.0%	High	Medium	High	High	High
2004	6.0%	Medium	Medium	Medium	Medium	Medium
2005	5.2%	Medium	Low	Low	Medium	Medium
2006	3.0%	Low	Low	Low	Low	Low
2007	2.6%	Low	Medium	Low	Low	Low
2008	6.7%	Medium	Ex. Low	Medium	Medium	Medium
2009	10.3%	High	Medium	High	High	High
2010	8.7%	High	Low	Low	Medium	High
2011	11.4%	High	Low	High	High	High
2012	7.2%	Medium	Low	Medium	Medium	High
2013			*Medium*	*Medium*	*Medium*	*Medium*

Table 5. Retrospective analysis of maximum allowable OCN fishery impact rate (FIR), and resulting harvest and spawning escapement, based on post season actual marine survival category, and predicted marine survival category under four management options.

Fishery Year	Post Season Observed			Predicted Amendment 13 Marine Survival Category as Estimated by:											
				OCN Work Group (Implemented 2001)			LCM Predictor (Mill Cr.) (Implemented 2012)			Marine Survival GAM (Current Proposal)			Fallback Predictor (Abundance Predictor GAM)		
	Harvest	Spawners	FIR	Harvest	Spawners	FIR	Harvest	Spawners	FIR	Harvest	Spawners	FIR	Harvest	Spawners	FIR
1999	4,077	46,882	0.08	4,077	46,882	0.08	4,077	46,882	0.08	4,077	46,882	0.08	4,077	46,882	0.08
2000	6,161	70,856	0.08	6,161	70,856	0.08	6,161	70,856	0.08	6,161	70,856	0.08	6,161	70,856	0.08
2001	13,488	155,118	0.08	13,488	155,118	0.08	13,488	155,118	0.08	13,488	155,118	0.08	13,488	155,118	0.08
2002	67,933	203,800	0.25	40,760	230,973	0.15	67,933	203,800	0.25	67,933	203,800	0.25	67,933	203,800	0.25
2003	62,340	187,018	0.25	37,404	211,954	0.15	62,340	187,018	0.25	62,340	187,018	0.25	62,340	187,018	0.25
2004	28,079	159,113	0.15	28,079	159,113	0.15	28,079	159,113	0.15	28,079	159,113	0.15	28,079	159,113	0.15
2005	48,513	113,197	0.30	24,257	137,453	0.15	24,257	137,453	0.15	48,513	113,197	0.30	48,513	113,197	0.30
2006	20,912	118,503	0.15	20,912	118,503	0.15	20,912	118,503	0.15	20,912	118,503	0.15	20,912	118,503	0.15
2007	11,271	63,866	0.15	15,027	60,110	0.20	11,271	63,866	0.15	11,271	63,866	0.15	11,271	63,866	0.15
2008	54,950	128,216	0.30	14,653	168,513	0.08	54,950	128,216	0.30	54,950	128,216	0.30	54,950	128,216	0.30
2009	70,401	211,201	0.25	42,240	239,362	0.15	70,401	211,201	0.25	70,401	211,201	0.25	70,401	211,201	0.25
2010	74,192	222,576	0.25	44,515	252,253	0.15	44,515	252,253	0.15	44,515	252,253	0.15	74,192	222,576	0.25
2011	170,369	208,228	0.45	56,790	321,807	0.15	170,369	208,228	0.45	170,369	208,228	0.45	170,369	208,228	0.45
2012	37,121	86,616	0.30	18,561	105,176	0.15	37,121	86,616	0.30	37,121	86,616	0.30	55,682	68,055	0.45
2013						*0.30*			*0.30*			*0.30*			*0.30*
Avg.	**47,843**	**141,085**	**0.22**	**26,209**	**162,720**	**0.14**	**43,991**	**144,937**	**0.21**	**45,724**	**143,205**	**0.22**	**46,169**	**139,759**	**0.23**
Highest Three Recruitment Years (2009, 2010, 2011)															
Avg.	**104,987**	**214,002**	**0.32**	**47,848**	**271,141**	**0.15**	**95,095**	**223,894**	**0.28**	**95,095**	**223,894**	**0.28**	**104,987**	**214,002**	**0.32**
Min.		208,228			239,362			208,228			208,228			208,228	
Middle Eight Recruitment Years (2001 through 2006, 2008, 2012)															
Avg.	**41,667**	**143,948**	**0.22**	**24,764**	**160,850**	**0.13**	**38,635**	**146,980**	**0.20**	**41,667**	**143,948**	**0.22**	**43,987**	**141,628**	**0.24**
Min.		86,616			105,176			86,616			86,616			68,055	
Lowest Three Recruitment Years (1999, 2000, 2007)															
Avg.	**7,170**	**60,535**	**0.10**	**8,422**	**59,283**	**0.12**	**7,170**	**60,535**	**0.10**	**7,170**	**60,535**	**0.10**	**7,170**	**60,535**	**0.10**
Min.		46,882			46,882			46,882			46,882			46,882	

Discussion

The goal for harvest management of OCN coho salmon is to control harvest impacts such that they do not impede recovery of OCN coho salmon while also allowing for incidental harvest of OCN coho salmon during harvest of other salmon species or stocks and the directed harvest of OCN coho salmon when appropriate. Achieving this goal is dependent on forecasts that accurately represent OCN coho salmon. ODFW, as part of the OPSW, has monitored OCN coho salmon spawner abundance (Lewis et al. 2011), freshwater habitat (Anlauf et al. 2009), and an index of marine survival and jack/smolt ratios (Suring et al. 2012) from 1998 to present, providing data directly related to OCN coho salmon that were unavailable when A13 was developed. These data show that LCM sites in aggregate are representative of OCN coho salmon in regards to both adult returns and habitat quality and that the LCM marine survival index is a reasonable index of OCN adult marine survival. In the 2012 A13 revision (Suring and Lewis 2012) the LCM jack/smolt ratio explained much more of the variation in OCN adult marine survival than the OPIH jack/smolt ratio and provided a higher forecast skill. The proposal presented here continues to improve the predictor, adjusting the LCM jack/smolt ratio to account for harvest impacts and incorporating representative, ESU wide fish data and several informative oceanographic indicators. While there is no indication that the relationship between OPIH jack/smolt ratios and OPIH adult marine survival has changed since the development of A13, OPIH data, either abundance or survival, are not correlated with OCN data.

Revising the source of the A13 marine survival axis from OPIH jacks/smolt to LCM jacks/smolt (Suring and Lewis 2012) resulted in a large increase in forecast skill, as measured by Pearson's correlation coefficient *r*, from 0.30 to 0.86. Rupp et al. (2012a) conducted a management strategy evaluation (MSE) examining the effect of forecast skill on A13 performance. While Rupp et al. (2012a) did not consider a forecast skill improvement of this magnitude, their "poor" forecast skill had an $r = 0.50$ and their "good" had an r = 0.90, the increase in skill from 0.50 to 0.90 resulted in a 5% increase in long-term harvest and a reduction in the frequency of falling below the critical spawner density of 1%. This proposal offers an additional increase in forecast skill, to r = 0.97, but the forecast skill increase from the 2012 revision to the 2013 proposal is smaller than the increase obtained with the 2012 revision. The practical consequences of the forecast skill increase in the 2013 proposal are less important than the reduction in risks associated with reliance on a prediction indicator from a single LCM site.

There is currently no indication of any immediate problems with the Mill Creek jack/smolt ratio as a predictor: the 2012 prediction was in the same category as the observed marine survival and adding an additional year of data did not change the relationship. However, a concern with the 2012 A13 revision, which used only the Mill Creek jack/smolt ratio as the basis for the marine survival axis, was that it is based on a single site. If an unexpected event changes the out-migrating smolt condition such that it impacts the jack rate or early marine survival of these fish, it could disrupt the relationship between the jack/smolt ratio and the OCN marine survival index. In the springs of 2011 and 2012 smolt production was less than expected given the number of adult spawners (Suring et al. 2012), though smolt production in 2013 is near average for the monitoring period. While the absolute level of smolt production does not necessarily have an impact on the predictor, as the predictor is normalized to the number of smolts, lower smolt production may cause higher uncertainty due to low sample sizes and may be a sign that conditions have changed at the Mill Creek site. As a single site the Mill Creek jack/smolt ratio does not provide information on regional patterns in marine survival. While the Mill Creek jack ratio is correlated to average LCM survival, which is representative of OCN coho salmon, regional patterns are apparent in some years. In 2010 coho salmon abundance in the North Coast monitoring area was stronger relative to the Mid Coast monitoring area (Suring et al. 2012) whereas in 2012 the North Coast was weaker relative to the Mid Coast (Suring et al. in prep). Generally all LCM sites are correlated to each other in a single year, indicating that large scale or common processes account for most of the variation in abundance across the ESU.

The current proposal addresses these two concerns by adding a diverse set of additional information to the predictor. The proposed predictor consists of seven indicators combined in seven two-variable models with the most common indicators, PDO.MJJ4 and JACKRATIO, appearing in four and three of the models, respectively, reducing the impact of a weakening relationship with any single indicator. The components of the proposed predictor also represent a range of spatial scales. PDO.MJJ$_4$ and JACKPEAK integrate data over large scales. Indicators like SST, SSH, and JACKRATIO, are measured at single locations but encompass different areas of the ESU. Should a catastrophic failure result in a lack of data for the JACKPEAK or JACKRATIO indicators the abundance predictor GAMs (Rupp et al. 2012b) could be used to provide a fallback prediction with greater accuracy than the OPIH jack/smolt ratio formally used as a predictor.

One concern with the current proposal is the potential for spurious correlations from fitting a large number of indicators and models to a relatively short time series. We have taken several steps to avoid this problem. We only used oceanographic indictors that were shown to have a relationship with OCN abundance over a long time span and a range of abundance (Rupp et al. 2012b). The number of knots in the fitting procedure was limited and the resulting relationships were linear or quadratic. We rejected any models that did not match the hypothesized relationships between the indicators and marine survival. The proposed predictor is composed of seven different GAMs, so that if one of the models was built on spurious relationships it would not have an overwhelming effect on the ensemble. While we did evaluate a large number of models we ranked them based on the OCV score, which measures predictive power by excluding points, rather than direct fit (R^2). However, the short time series of OCN marine survival precludes some forecast skill tests such as Historic Forecast Skill (Rupp et al. 2012b). The ensemble forecast provides a good fit over a wide range of observed marine survival (1.6%-11.4%) and is based on indicators that showed relationships to OCN coho salmon over a period of 40 years.

We will continue to evaluate improvements to the marine survival predictor, testing other parameters such as copepod diversity (Peterson et al. 2012). Enumerating jacks at current or new LCM sites could give missing information on within OCN variation in marine survival. Candidates include the North Fork Nehalem, the East Fork Trask River, and Cascade Creek. Fish passage improvements will be done in the coming years at the East Fork Trask River dam that may incorporate the ability to enumerate coho salmon jacks. Developing relationships between OCN marine survival and jack/smolt ratios at other sites will be a long term project, however.

The potential for management improvement under this proposal has also been evaluated by comparing outcomes under the observed conditions of the last 14 years. Like the 2012 proposal the current proposal would have done a better job of meeting the management objectives of reducing impact rates in low recruitment years and allowing greater harvest opportunities in high recruitment years. In the lowest recruitment years the 2012 revision and the current proposal would have capped impact rates at an average of 10% versus 12% under the OCN Work Group (Table 5). In high recruitment years the OCN Work Group capped impact rates at 15%, compared to 28% for the 2012 revision and current proposal (Table 5). Overall the OCN Work Group produced very little differentiation in impact rates at different abundance levels compared to the results for the 2012 revision and current proposal. Return year 2007 had the lowest pre-harvest coho salmon abundance of the last 12 years. However, the OCN Work Group matrix mistakenly categorized the marine survival index as medium and allowed a 20% impact rate, the highest level it allowed during the last 14 years. All of the other predictor options evaluated correctly identified 2007 as a return year with low marine survival, although an allowable harvest rate of 15% would have still been set based on high parental spawner abundance. The abundance predictor GAM fallback option correctly keeps impact rate low when abundance is low but impact rates in the medium and high years are slightly higher than the 2012 revision or current proposal.

This proposed change to the implementation of A13 does not alter the current parental spawner axis, allowable fishery impact rates, or the categories of the marine survival axis (Table 6). We propose using an ensemble forecast of models based on biologic and oceanographic indicators to determine the OCN marine survival axis category. This update to the 2012 proposal, maintains the replacement of Columbia River hatchery coho salmon data with wild coho salmon data from within the OCN area in determining the OCN marine survival axis category. It addresses the concern for reliance on data from a single site, by including additional data for wild coho salmon jacks based on a spatially balanced random site selection process and a broad suite of environmental data already evaluated and approved for use in predicting OCN abundance. We expect the adoption of this technical revision will result in improved management of OCN coho salmon harvest impacts. By basing the forecast on a more comprehensive set of data, risks from variation in site specific and metric specific responses and behaviors are ameliorated. The forecast skill and robustness of the marine survival prediction is improved relative to the 2012 proposal (Suring and Lewis 2012) so that fishery impact rates will better match true pre-harvest abundance levels. While the MSE conducted by Rupp et al. (2012b) suggested that improvements will be moderate it also demonstrated that the risk of this proposal is relatively low.

Table 6. Proposed revisions to the OCN Work Group 2000 review of Amendment 13 harvest management matrix. *Changes are highlighted and italicized*.

Parent Spawner Status[1]	**Marine Survival Index** *(Wild adult coho salmon survival as predicted by the two-variable GAM ensemble forecast)*			
	Extremely Low *<2%*	**Low** *2%-4.5%*	**Medium** *>4.5%-8%*	**High** *>8%*
High Parent Spawners > 75% of full seeding	**E** ≤ 8%	**J** ≤ 15%	**O** ≤ 30%	**T** ≤ 45%
Medium Parent Spawners > 50% & ≤ 75% of full seeding	**D** ≤ 8%	**I** ≤ 15%	**N** ≤ 20%	**S** ≤ 38%
Low Parent Spawners > 19% & ≤ 50% of full seeding	**C** ≤ 8%	**H** ≤ 15%	**M** ≤ 15%	**R** ≤ 25%
Very Low Parent Spawners > 4 fish per mile & ≤ 19% of full seeding	**B** ≤ 8%	**G** ≤ 11%	**L** ≤ 11%	**Q** ≤ 11%
Critical Parent Spawners ≤ 4 fish per mile	**A** 0 – 8%	**F** 0 – 8%	**K** 0 – 8%	**P** 0 – 8%

Sub-aggregate and Basin Specific Spawner Criteria Data

Sub-aggregate	Miles of Available Spawning Habitat	100% of Full Seeding	"Critical"		Very Low, Low, Medium & High		
			4 Fish per 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
Coastwide Total	*3,747*	*126,700*	*14,988*		*24,073*	*63,350*	*95,025*

[1] Parental spawner abundance status for the OCN aggregate assumes the status of the weakest sub-aggregate.

Recommendations

Based on the results of this analysis we recommend the following technical updates to the OCN Work Group guidance on implementation of Amendment 13:

- Change the predictor for wild coho salmon adult survival to the ensemble forecast of two-variable GAMs presented in this proposal.

In the long term ODFW and partners will continue to investigate improvements to the OCN adult marine survival predictor:

- Pursue developing jack collections at other LCM sites as additions to the Mill Creek LCM data.
- Pursue analysis of other data sets as additions to the proposed models.

Acknowledgments

This proposal is in honor of Bob Buckman, retired ODFW District Biologist, who provided the vision of sustainable wild coho salmon fisheries on the Oregon Coast and the motivation to improve the status quo in salmon fisheries management. We would also like to acknowledge the contributions of Pete Lawson, NOAA Fisheries, and Chris Kern, ODFW Fisheries Management, as well as other ODFW staff for feedback on this proposal, and David Rupp for providing the R code needed to run the models in this proposal.

References

Anlauf, K.J., K.K. Jones, C.H. Stein. 2009. The status and trend of physical habitat and rearing potential in coho bearing streams in the Oregon Coastal Coho Evolutionary Significant Unit. OPSW-ODFW-2009-5. Oregon Department of Fish and Wildlife, Salem Oregon.

Beamish, R.J., C. Mahnken, and C.M. Neville. 2004. Evidence that reduced early marine growth is associated with lower marine survival of coho salmon. Transactions of the American Fisheries Society 133:26-33.

Briscoe, R.J., M.D. Adkison, A. Wertheimer, and S.G. Taylor. 2005. Biophysical factors associated with the marine survival of Auke Creek, Alaska, coho salmon. Transaction of the American Fisheries Society 134:817-878.

Firman, J.C., and S.E. Jacobs. 2001. A survey design for integrated monitoring of salmonids. In Nishida T. and C.E. Hollingworth. Proceedings of First International Symposium on GIS in Fishery Science. Saitama, Japan.

Jacobs, S., J. Firman, G. Susac, D. Stewart, and J. Weybright. 2002. Status of Oregon coastal stocks of anadromous salmonids, 2000-2001 and 2001-2002; Monitoring Program Report Number OPSW-ODFW-2002-3, Oregon Department of Fish and Wildlife, Salem, Oregon.

Lawson, P.W., E.P. Bjorkstedt, M.W. Chilcote, C.W. Huntington, J.S. Mills, K.M.S. Moore, T.E. Nickelson, G.H. Reeves, H.A. Stout, T.C. Wainwright, and L.A. Weitkamp. 2007. Identification of historical populations of Coho salmon (Oncorhynchus kisutch) in the Oregon coast evolutionarily significant unit. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-NWFSC-79.

Lewis, M., E. Brown, B. Sounhein, M. Weeber, E. Suring, and H. Truemper. 2009. Status of Oregon stocks of coho salmon, 2004 through 2008. Monitoring Program Report Number OPSW-ODFW-2009-3, Oregon Department of Fish and Wildlife, Salem, Oregon.

Lewis, M., M. Weeber, E. Brown and B. Sounhein. 2011. Status of Oregon stocks of coho salmon, 2010. Monitoring Program Report Number OPSW-ODFW-2011-3. Oregon Department of Fish and Wildlife, Salem Oregon.

Logerwell, E.A., N. Mantua, P.W. Lawson, R.C. Francis and V.N. Agonstini. 2003. Tracking environmental processes in the coastal zone for understanding and predicting Oregon coho (*Oncorhynchus kisutch*) marine survival. Fisheries Oceanography 12:6, 554-568.

National Marine Fisheries Service. 2011. Listing Endangered and Threatened Species: Threatened Status for the Oregon Coast Coho Salmon Evolutionarily Significant Unit. US Federal Register 76: 35755-35771.

Oregon Department of Fish and Wildlife (ODFW). 2007. Oregon Coast Coho Conservation Plan for the State of Oregon. Oregon Department of Fish and Wildlife, Salem Oregon.

ODFW. 2009. Fisheries Management and Evaluation Plan: Oregon Coastal Coho, Coastal Rivers Coho Sport Fishery. Oregon Department of Fish and Wildlife, Salem Oregon.

Pacific Fishery Management Council (PFMC). 1999. Final Amendment 13 to the Pacific Coast Salmon Plan. Pacific Fishery Management Council. Portland, Oregon.

PFMC. 2012. Review of 2012 Ocean Salmon Fisheries: Stock Assessment and Fishery Evaluation Document for the Pacific Coast Salmon Fishery Management Plan. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101. Portland, Oregon.

PFMC. 2013a. Preseason Report I: Stock Abundance Analysis and Environmental Assessment Part 1 for 2013 Ocean Salmon Fishery Regulations. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101. Portland, Oregon.

PFMC. 2013b. Review of 2012 Ocean Salmon Fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101. Portland, Oregon.

Perrin, C. J., and J. R. Irvine. 1990. A review of survey life estimates as they apply to the area-under-the-curve method for estimating the spawning escapement of Pacific salmon. Canadian Technical Report of Fisheries and Aquatic Sciences (1733).

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

Ricker, W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Department of the Environment Fisheries and Marine Service, Ottawa, Bulletin 191, p. 78.

Rupp, D.E, T.C. Wainwright and P.W. Lawson. 2012a. Effect of forecast skill on management of the Oregon coast coho salmon (*Oncorhynchus kisutch*) fishery. Canadian Journal of Fisheries and Aquatic Science 69: 1016–1032.

Rupp, D.E, T.C. Wainwright, P.W. Lawson, and W.T. Peterson. 2012b. Marine environment-based forecasting of coho salmon (*Oncorhynchus kisutch*) adult recruitment. Fisheries Oceanography 21:1, 1-19.

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch)*. Pages 397-443 *in* Groot C, and Margolis L. editors. Pacific salmon life histories. University of British Columbia Press, Vancouver

Sharr, S., C. Melcher, T. Nickelson, P. Lawson, R. Kope and J Coon. 2000. 2000 review of Amendment 13 to the Pacific Coast Salmon Plan. Pacific Fishery Management Council. Portland, Oregon.

Stevens, D.L. 2002. Sampling design and statistical analysis methods for integrated biological and physical monitoring of Oregon streams. OPSW-ODFW-2002-07. Oregon Department of Fish and Wildlife, Salem Oregon.

Suring, E., R.J. Constable, C.M. Lorion, B.A. Miller, D.J. Wiley. 2012. Salmonid Life Cycle Monitoring in Western Oregon streams, 2009-2011. Monitoring Program Report Number OPSW-ODFW-2012-2. Oregon Department of Fish and Wildlife, Salem Oregon.

Suring, E., P. Burns, R.J. Constable, C.M. Lorion, D.J. Wiley. In-prep. Salmonid Life Cycle Monitoring in Western Oregon streams, 2012-2014. Monitoring Program Report Number OPSW-ODFW-2014-2. Oregon Department of Fish and Wildlife, Salem Oregon.

Suring, E. and M. Lewis. 2012. 2012 Technical Revision to the OCN Coho Work Group Harvest Matrix. Oregon Department of Fish and Wildlife, Salem, Oregon.

Wood, S.N. 2006. Generalized Additive Models: An Introduction with R. Chapman and Hall/CRC.

Harvest Strategy Risk Assessment for Lower Columbia Natural Coho

J. Chris Kern, Oregon Department of Fish and Wildlife
Mara Zimmerman, Washington Department of Fish and Wildlife

September, 2013

Acknowledgments

Many individuals contributed to the development of this report. Matt Falcy, ODFW Conservation and Recovery Program gave invaluable assistance in constructing portions of the PVA model and reviewing data sets; without his assistance, certain portions of the analyses would have been impossible. Thanks to other ODFW staff, including Kevin Goodson, Mark Lewis, Erik Suring, Julie Firman, Tom Stahl, Tim Dalton, Craig Foster, Ethan Clemons, Tony Nigro, Steve Williams, John North, Jeff Whisler, and others for reviews and input throughout the process. Thanks to Kathryn Kostow, ODFW, for assistance in run reconstructions and compilation of historical information for Clackamas and Sandy River coho. From WDFW, Bryce Glaser, Cindy LeFleur, and Guy Norman provided data, document reviews, and guidance on Washington populations throughout. The PVA model used in this analysis is built on a platform developed and graciously provided by Ray Beamesderfer, who also provided valuable guidance and insight into the modeling inputs and processes.

Abstract

The current harvest control rules for ocean and mainstem Columbia River fisheries that impact lower Columbia River naturally-produced coho incorporate certain elements of a harvest proposal originally developed as a result of the listing of Oregon coho populations for protection under the State of Oregon Endangered Species Act (ESA). The proposal was developed by the Oregon Department of Fish and Wildlife (ODFW) as part of its state management plan in 2001. Following the federal listing of the entire evolutionarily significant unit (ESU) in 2005, ODFW and the Washington Department of Fish and Wildlife (WDFW) proposed the same management strategy continue to be applied.

Current harvest control rules incorporate only some of the elements of the harvest proposal endorsed by ODFW and WDFW because the National Marine Fisheries Service (NMFS) adopted a more conservative approach to fisheries management. NMFS adopted a more conservative approach because of uncertainties regarding the effects of the states' proposal on all populations in the ESU. The current rules result in more conservative exploitation rates.

This report updates and/or expands population information, expands harvest control rules to explicitly incorporate the status of additional populations compared to current methods, and constructs a modeling framework for evaluating relative risk to these populations under alternative abundance-based harvest control rules.

While a final proposed set of alternative control rules is not contained in this report, it is the intention of the states to use the background analyses and assessment model described here in developing a proposed harvest strategy or strategies for consideration by the Council at the November 2013 PMFC meeting.

List of Figures

List of Tables

Background

Naturally-produced coho populations in the lower Columbia River area have experienced substantial declines over the last few decades. Despite reductions in harvest rates, these populations continued to decline through the 1990s. The Oregon Fish and Wildlife Commission listed Oregon lower Columbia River wild coho salmon as an endangered species under the State of Oregon Endangered Species Act (ESA) in July 1999. The Oregon Department of Fish and Wildlife (ODFW) prepared a state management plan, including proposed harvest strategies, for Oregon populations in 2001. At the time, the Sandy and Clackamas populations were believed to be the only extant LCN coho populations in Oregon.

The harvest component of the 2001 ODFW plan incorporated two indicators of wild fish production: relative parental escapement and estimated marine survival. The plan developed two harvest matrices of escapement versus marine survival: one for expected exploitation rates for ocean fisheries (Table 1), and one for specifying harvest rates for mainstem Columbia River fisheries (Table 2).

ODFW does not have sole jurisdiction over exploitation rates for all fisheries that impact Oregon LCN coho. However, it was anticipated that fractional parental abundance levels for the Columbia and coastal populations would generally be relatively similar, and thus the ocean exploitation rates expressed in Table 1, which mimic those applied to Oregon Coast Natural (OCN) coho, could be expected with some degree of certainty. Past spawner escapement data for OCN and Clackamas coho populations were compared and it was determined that in most years the parental escapement matrix categories for OCN coho and Clackamas River coho matched. At the time, it appeared unlikely that Oregon LCN coho populations would fall into a lower category for spawner abundance relative to coastal populations very frequently. Table 3 shows the expected total maximum annual exploitation rates for mainstem Columbia River and ocean fisheries at various combinations of parental escapement and marine survival under the combination of the two matrices.

Table 1. 2001 ODFW harvest management matrix for Oregon LCN coho salmon showing maximum anticipated ocean fishery exploitation rates.

Parental Escapement (% of full-seeding)		Marine Survival Index (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75	< 8.0%	< 15.0%	< 30.0%	< 45.0%
Medium	0.75 to 0.50	< 8.0%	< 15.0%	< 20.0%	< 38.0%
Low	0.50 to 0.20	< 8.0%	< 15.0%	< 15.0%	< 25.0%
Very Low	0.20 to 0.10 full	< 8.0%	< 11.0%	< 11.0%	< 11.0%
Critical	< 0.10	0 – 8.0%	0 – 8.0%	0 – 8.0%	0 – 8.0%

Table 2. 2001 ODFW harvest management matrix for Oregon LCN coho salmon showing maximum allowable harvest rates for mainstem Columbia River fisheries.

Parental Escapement (% of full-seeding)		Marine Survival Index (based on return of jacks per hatchery smolt) Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75	< 4.0%	< 7.5%	< 15.0%	< 22.5%
Medium	0.75 to 0.50	< 4.0%	< 7.5%	< 11.5%	< 19.0%
Low	0.50 to 0.20	< 4.0%	< 7.5%	< 9.0%	< 12.5%
Very Low	0.20 to 0.10	< 4.0%	< 6.0%	< 8.0%	< 10.0%
Critical	< 0.10	0.0 – 4.0%	0.0 – 4.0%	0.0 – 4.0%	0.0 – 4.0%

Table 3. Expected maximum cumulative exploitation rates for Oregon LCN coho from ocean and mainstem Columbia River fisheries under the 2001 ODFW harvest matrices.

Parental Escapement (% of full-seeding)		Marine Survival Index (based on return of jacks per hatchery smolt) Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75	< 11.7%	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50	< 11.7%	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.20	< 11.7%	< 21.4%	< 22.7%	< 34.4%
Very Low	0.20 to 0.10	< 11.7%	< 16.3%	< 18.1%	< 19.9%
Critical	< 0.10	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%

LCN coho salmon from the Lower Columbia River Evolutionarily Significant Unit (ESU) were listed as threatened under the federal ESA in 2005. As a result of the federal listing, the National Marine Fisheries Service (NMFS) conducted a biological consultation on the effects of fisheries on this ESU. ODFW and the Washington Department of Fish and Wildlife (WDFW) prepared a joint biological assessment for LCN coho in 2006. In 2008, the *US v Oregon* Technical Advisory Committee (TAC) submitted a biological assessment as part of the 2008-2017 Columbia River *US v Oregon* management agreement. This document contained a biological assessment for LCN coho, which was reviewed by NMFS prior to their issuing a biological opinion on the *US v Oregon* agreement.

In the biological assessment, the states proposed that the 2001 ODFW harvest management strategy be continued for LCN coho. Due to a variety of uncertainties, NMFS has implemented only one of these schedules (Table 1), but has applied this limitation to all ocean and mainstem Columbia River fisheries that impact the ESU.

State recovery plans for Lower Columbia ESU salmon species, including LCN coho, were completed in 2010 (ODFW 2010, LCFRB 2010). The recovery plans include language related to addressing uncertainties in LCN coho population information and developing updated harvest management strategies for the ESU. This report builds extensively on the frameworks from the recovery plans and adds information and new analyses done since the publication of the recovery plans to address these needs.

ODFW and WDFW discussed the need for this update with NMFS in 2011, leading to a letter from NMFS to the agencies describing the expected products that would be needed to initiate a re-consultation on LCN coho harvest strategies.

There were four key areas to be addressed, paraphrased below:

1. Ensure that the most recent LCN coho status information is available. This includes information from surveys that ODFW has conducted since 2002 and new surveys that WDFW implemented in 2010, as well as any other relevant status data.
2. Ensure that full-seeding targets for adult spawners are the best estimates available and provide an explanation of how they relate to target abundances provided in recovery plans.
3. Incorporate additional ESU strata and populations from both states into the harvest strategy to allow for weak stock management.
4. Conduct a risk assessment for the re-consultation to demonstrate the likely effects of proposed harvest strategies.

The risk assessment component of this analysis builds upon similar past efforts and uses the same basic modeling platform as was used for a number of other abundance-based harvest evaluations. These include assessments for Willamette River spring Chinook, Klamath River fall Chinook, and lower Columbia River tule fall Chinook.

Current Harvest Management Strategies

As previously described, since the federal listing occurred, NMFS has provided annual guidance on allowable fishery impacts to LCN coho based on a partial application of the harvest strategies proposed by the states in their biological assessments.

As with Oregon coast wild (OCN) coho, allowable fishery impact rates for LCN coho are derived from a two-axis matrix that categorizes parental run strength of coho and expected marine survival of progeny by brood year. Parental run strength is characterized by the fraction of “full-seeding” of adults in the parent year. Each population is assigned a value reflecting the best available estimate of the number of spawning adults that would be needed to fully seed available habitat with progeny. Importantly, this value can be expected to change over time, particularly in cases where new habitats are opened to coho production or habitat quality improves or degrades. This aspect is particularly important in the context of planned recovery actions. The parental abundance value is a categorical measure which currently has five categories ranging from “critically low” (10%) to “high” (>75%).

Marine survival is currently characterized by the proportion of hatchery smolts from the Oregon Production Index (OPI) area that survive their first season of ocean residence and return as jacks. This measure has been shown to be highly correlated to the survival rate of OPI adult hatchery coho from the same brood year. Lacking analogous data for wild coho populations, this measure was believed to be the most reasonable available measure of trends in wild coho marine survival.

This procedure was also used for OCN coho prior to 2013. It is important to note that the marine survival for jacks is not used to directly predict adult abundance; it is a categorical measure, with four categories ranging from “extremely low” to “high”. Each of these categories was tied to an expected wild recruit-per-spawner range in the original OCN matrix.

In lieu of accurate run size forecasts for LCN coho, the matrix is used to supply a qualitative description of expected return strength that harvest decisions can be based upon. Exploitation rates are kept at low levels when low parental abundance is combined with poor marine survival, and are allowed to increase in years with higher parental abundance and/or marine survival. Until better alternatives are available, the basic approach of using parental abundance and marine survival to categorically describe expected status will be maintained.

Due to the lack of data for other populations, the current management strategy for LCN coho has been based upon status information for only the Sandy River and Clackamas River populations. Allowable exploitation rates are determined by applying the matrix to each of the two populations. The allowable exploitation rates for the two populations are averaged to determine the aggregate allowable rate. Over the period 2006-2013, there has been only one year in which the allowable exploitation rate for the two populations has differed. This exploitation rate is applied to the entire ESU. The reliance upon these two populations to index the status of the entire ESU is one of the key uncertainties that have led to limiting harvest to rates below those proposed.

While information is now available for many of the other populations, the available time series is still quite short for most. Thus, while this analysis includes new information, caution should be used in interpreting the results. As more data points become available, status and productivity estimates should be updated and risk assessments should be re-evaluated. As this will take a few years, we recommend that any proposed harvest structure be implemented for a period of no more than five years.

Selection of Populations

As previously described, a primary goal of this analysis is to incorporate new information for other populations in the ESU (beyond the Clackamas and Sandy), and to add more strata to the management strategy. The LCN coho ESU is comprised of three strata; Gorge, Cascade, and Coastal (Figure 1).

The gorge stratum includes the lower gorge and the upper gorge components. The lower gorge component includes populations in the small tributaries below Bonneville Dam and the upper gorge component includes the Wind, White Salmon, and Hood rivers. The Washington Recovery Plan (LCFRB 2010) states that natural production of coho in these tributaries is thought to be low and likely less than 50 fish annually. Natural production of LCN coho above Bonneville is negligible and other upriver natural coho have been largely extirpated in the past (Weitkamp, et. al. 1995). Presently, the historical coho salmon population in the White Salmon River is considered extinct (NMFS 2011). The White Salmon Recovery Plan (NMFS 2011) calls first for natural re-colonization of coho in the White Salmon River and recommends re-evaluation after monitoring natural escapement and production for four to five years. The Oregon Recovery Plan (ODFW 2010) identified several problematic issues affecting the interpretation and implementation of recovery actions for the Gorge stratum. First, stratum delineations among the lower Columbia River strata, especially in the Cascade and Gorge strata appeared to be fairly subjective. Several populations in the Gorge Stratum were identified in areas where historically accessible habitat did not appear adequate to support independent populations. The plan speculates that under current strata definitions, high levels of viability cannot be reached without levels of improvements that are neither feasible nor likely. The Oregon Recovery Plan recommended eliminating the Gorge stratum and considering the Hood and White Salmon populations as unique populations within the Cascade stratum, then revising de-listing criteria to specify that one of the two populations be required to meet viability criteria. Due to the uncertainties associated with the Gorge stratum, the current analysis does not propose to directly consider this stratum in harvest strategy control rules. Instead, actions that provide protection to the Coast and Cascade strata are presumed to also benefit the Gorge stratum.

Oregon has two populations in the Cascade stratum, the Clackamas and Sandy, and both will continue to be used to assess status of the Oregon portion of this stratum. Washington has eight populations in the Cascade stratum. Populations in the Lower Cowlitz, Coweeman, Toutle (S. Fork, N. Fork, and Green R.), and East Fork Lewis rivers are proposed as indicators for Washington Cascade stratum status. Although it is considered a primary population (a population targeted to achieve high viability in recovery plans), the Upper Cowlitz population was not included because it is part of a re-introduction effort through the Cowlitz Fishery and Hatchery Management Plan and is still in the experimental stages of development.

Oregon has four populations in the Coastal stratum, and the Scappoose and Clatskanie populations will be used as status indicators, because these are listed as primary populations and both have life-cycle monitoring (LCM) programs in place. The LCM program provides detailed status and productivity information and has long-term funding allocated for ongoing monitoring. The Elochoman/Skamakowa and Grays/Chinook populations are primary populations and will be used as indicators for the Washington portion of the Coastal stratum.

Table 4. Populations proposed to represent the status of LCN coho.

Population	State/Stratum	Contribution
Clatskanie	Oregon/Coast	Primary
Scappoose	Oregon/Coast	Primary
Clackamas	Oregon/Cascade	Primary
Sandy	Oregon/Cascade	Primary
Grays/Chinook	Washington/Coast	Primary
Elochoman/Skamokawa	Washington/Coast	Primary
Lower Cowlitz	Washington/Cascade	Primary
Coweeman	Washington/Cascade	Primary
South Fork /North Fork Toutle/Green	Washington/Cascade	Primary
East Fork Lewis	Washington/Cascade	Primary

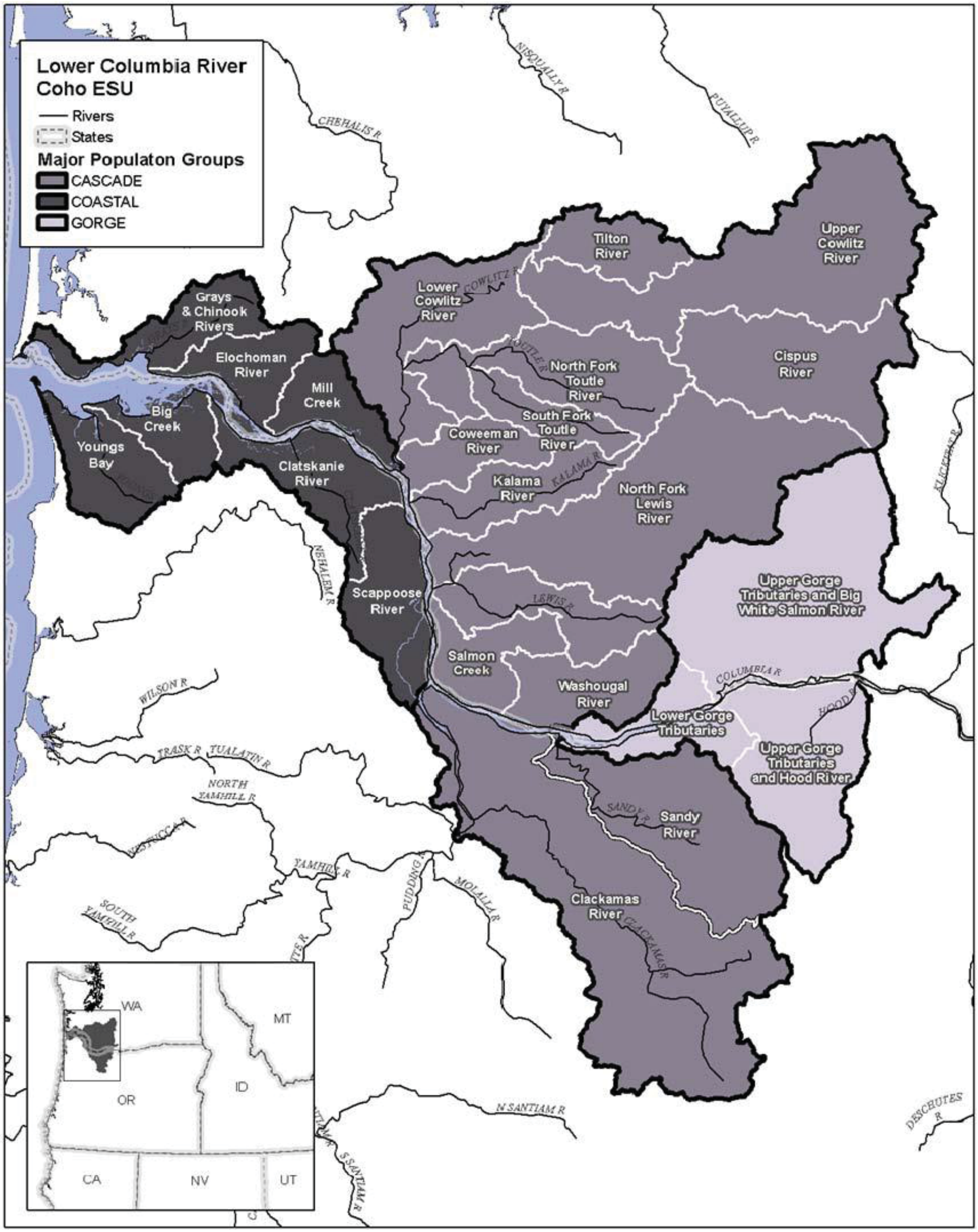


Figure 1. Lower Columbia LCN coho ESU and major population group strata.

Background Data and Run Reconstruction Methods for Oregon Populations

Clackamas

Clackamas River wild coho run reconstructions are composed largely of fish ladder counts at North Fork Dam (NFD) which are available from 1957-2012. ODFW began estimating full-basin abundance of wild and hatchery spawners with the Oregon Adult Salmonid Inventory and Sampling (OASIS) program in 2002. At the time the Oregon Recovery Plan analyses were conducted, only a few years of OASIS survey data were available for Clackamas coho, so the use of this data was limited.

Over the entire time series available for the Clackamas population (1957-2012), the estimated annual wild spawner abundance has remained stable or has slightly increased (Figure 2), though with obvious variation and periods of extended declines, particularly in the mid-1990s. In contrast, following a peak in the late 1960s, estimated wild recruitment has declined dramatically, finally stabilizing at low levels by the mid-1990s. These patterns indicate that wild recruitment has not likely been primarily driven simply by wild spawner abundance.

Full run reconstruction methodologies and summary tables are provided in Appendix A.

Sandy

Prior to 2007, total spawner abundance estimates for Sandy coho were primarily derived from fish ladder counts at Marmot Dam. Most coho habitat in the basin is upstream from the Marmot Dam site and most spawning has occurred in those areas, even following the removal of the dam in the fall of 2007. Complete dam counts of coho for 1974 through 1977 and in 1983 are not available. Rather than interpolate these missing data, as was done in the Oregon Recovery Plan, we shortened the time series for recruitment analysis to 1984-2012 – a period when complete dam counts were available for full brood returns. Basin-wide fish abundance has been estimated since 2002 by the OASIS program.

Over the time series available (1984-2012), the estimated annual wild spawner abundance has shown a clear cycle with higher abundances in the 1980s, low numbers in the 1990s, and a rebound to approximate 1980s levels since 2000 (Figure 3). As with the Clackamas population, the changes in wild spawner abundance have not been reflected in abundance of recruits. Estimated wild recruitment declined dramatically from the late 1980s through the 1990s, finally stabilizing at low levels by about 2000. Again, these patterns indicate that wild recruitment has not been primarily driven simply by wild spawner abundance.

Full run reconstruction methodologies and summary tables are provided in Appendix A.

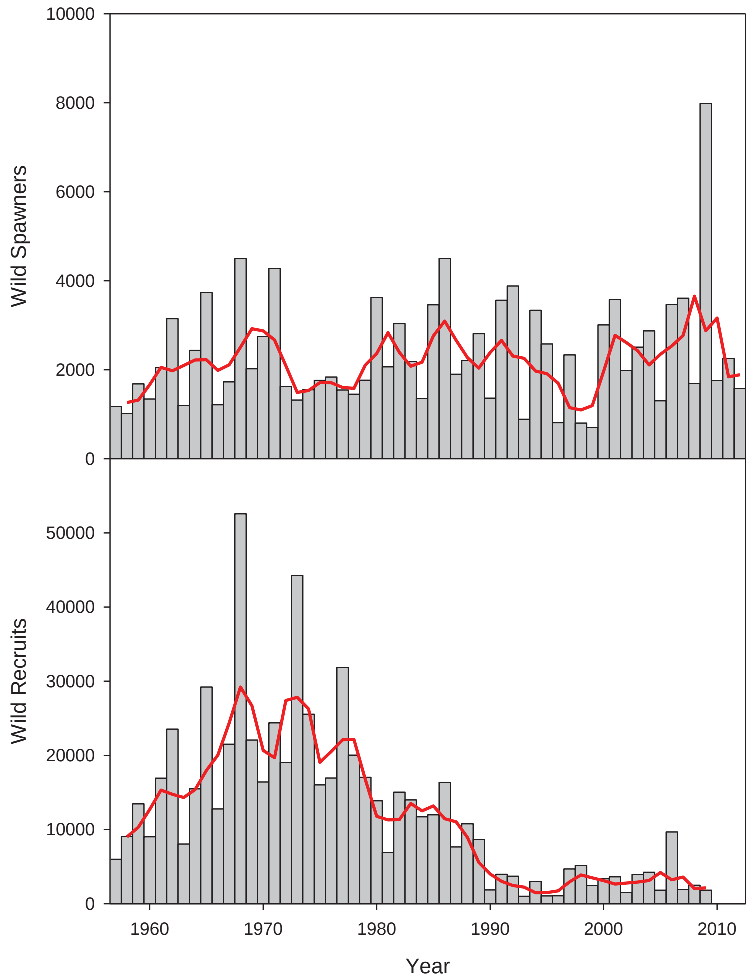


Figure 2. Clackamas wild spawner (top) and wild recruit (bottom) estimates, 1957-2009 brood years. Bold red lines represent a running three-year geometric mean.

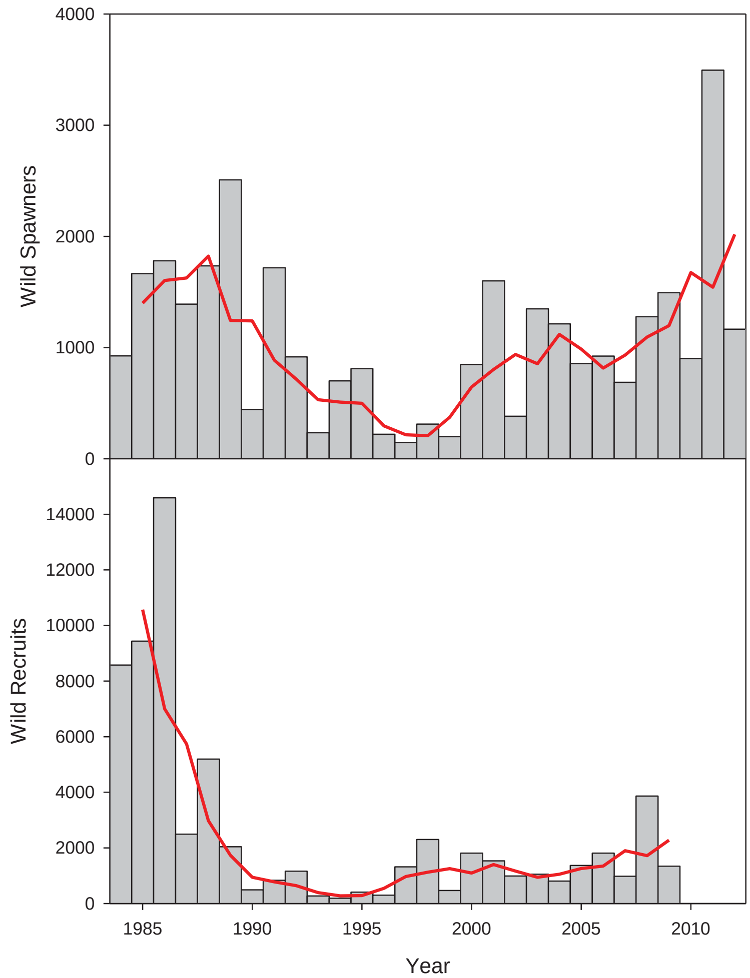


Figure 3. Sandy wild spawner (top) and wild recruit (bottom) estimates, 1984-2009 brood years. Bold red lines represent a running three-year geometric mean.

Other Oregon populations

We examined a short time series of OASIS abundance information (2002-2009 brood years) for Scappoose Creek and Clatskanie River to get a sense of how similar the assumptions of productivity and abundance in the Oregon Recovery Plan were to those generated from the limited OASIS data (Figures 4 and 5).

Full run reconstruction methodologies and summary tables are provided in Appendix A.

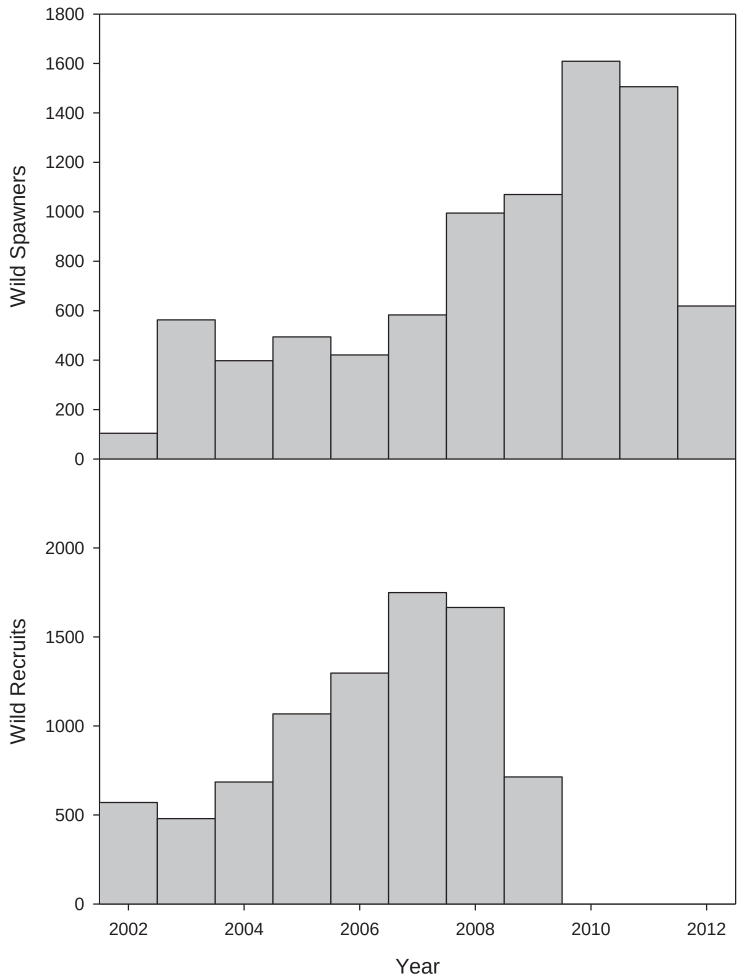


Figure 4. Clatskanie River estimated number of wild spawners (top) and wild recruits (bottom), 2002-2009 brood years.

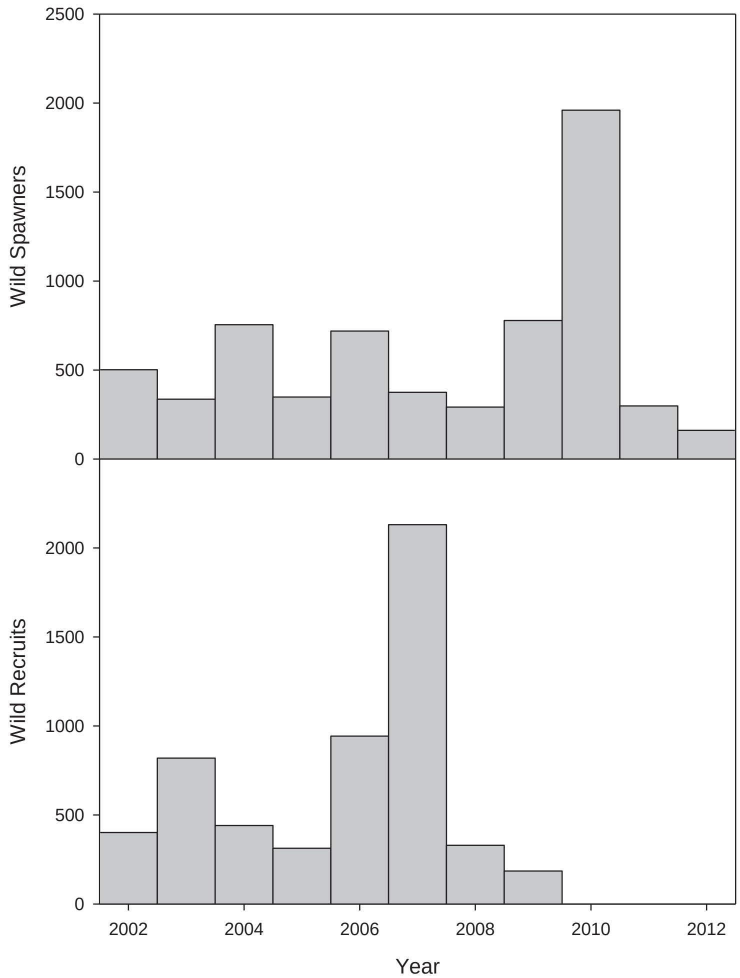


Figure 5. Scappoose Creek estimated number of wild spawners (top) and wild recruits (bottom), 2002-2009 brood years.

Fitting Spawner-Recruit Models

In order to construct the population viability analysis (PVA) model, it was necessary to calculate various parameters to describe the productivity of individual populations. For Oregon populations, these parameters were primarily derived by fitting a spawner-recruit function to observed data. For Washington populations, estimates of productivity were derived using the Ecosystem Diagnosis and Treatment (EDT) model.

Of the commonly used spawner-recruit functions, the Beverton-Holt is typically considered to be most suitable for coho salmon populations. Various parameters estimated from the Beverton-Holt function include the ratio of recruits to spawners at very low spawner abundances (α), the maximum expected number of recruits that can be produced (β), and the number of spawners that result in one-to-one replacement with recruits in an un-fished population – the equilibrium point (N_{eq}). Certain parameterizations of the Beverton-Holt function allow for the incorporation of an additional variable to represent the effects of environmental or other covariate, defined as γ.

Consistent with recovery plan analyses for both states, the Beverton-Holt recruitment function was used for the risk assessment model. This also makes it possible to incorporate estimates of intrinsic productivity and capacity estimated via the EDT process, which constitutes the only data currently available for Washington LCN coho populations.

Oregon Populations

In the current analysis, several updates to Oregon spawner-recruit data sets (Appendix A) have been made compared to those provided in the Oregon Recovery Plan (ODFW 2010), resulting in different baseline data sets than those shown in the plan.

Pre-harvest wild adult recruit estimates (R_{t-3}) are reconstructed from adult returns and fishery removals by:

$$R_{t-3} = (S_t)/(1 - F_t)$$

where S_t is the wild adult escapement in year t and F_t is the total fishery removal rate experienced by the adults prior to return.

Models for Oregon populations were fit using the non-linear regression fitting algorithm in the DataFit software program.

The function used to describe recruitment was:

$$\ln(R_{t+3}) = \ln(\alpha) + \ln(S_t) - \ln(1 + (\alpha/\beta * S_t)) + (\gamma * E_{t+n})$$

where E equals an environmental variable, or other covariate.

Recruitment model errors were assumed to be log-normally distributed (Hilborn and Walters 1992) and residuals were assumed to be autocorrelated at a one-year lag.

Implications of time series selection for Oregon populations

For the Sandy River, brood years 1984-1986 were excluded from model fitting. When incorporated into the time series these data points resulted in higher recruits per spawner at high spawner levels than at low spawner levels. This prevented the fitting algorithm from finding a numerical solution because of the lack of density dependence. The time series was therefore shortened by dropping the 1984-1986 data points, resulting in a time series of 1987-2009 brood years. Although not an ideal approach, these results were subsequently used to evaluate relative risks of various management alternatives, not to predict future conditions. Additionally, this approach resulted in a more conservative description of production than did alternatives, such as a hockey stick recruitment model, using the full time series.

For the Clackamas River, the choice of time series affects the outcomes of the risk assessment model. When examining the 1974-2009 brood year time series, the Beverton-Holt parameters from the fitted model were $\alpha = 10.07$ and $\beta = 6{,}737$. The standard deviation of residuals for this model is 0.803. This exercise was repeated with a shorter, more recent time series in an attempt to reflect recent years (1990-current) of poorer recruitment compared to earlier years (1974-1989), as shown in Figure 2. The parameters from this model were $\alpha = 1.89$ and $\beta = 4{,}834$, reflecting the poorer relative recruitment of recent years.

At first examination, using the more recent time series with lower productivity would appear to be more conservative, as it likely more accurately reflects current less productive conditions. However, in the risk assessment model, error in the fit of the Beverton-Holt model to the data is translated directly to stochasticity in the simulations. Thus, a model that has a better “fit” also has a reduced level of stochasticity in the model. The standard deviation of the residuals for the shorter time series model is 0.435, much lower than the error of the first model. As a result, measured risk in the model for the Clackamas population is actually lower with the shorter, less productive time series than it is for the full time series due to the difference in stochasticity.

When multiple populations or strata are used to index harvest strategies, the effect on one population can lead to changes in risk or other metrics for other populations. This effect appears to be relatively small in using either the 1974-2009 or 1990-2009 time series for the Clackamas. In cases where the risk to a specific population did change, the risk generally increased with the use of the longer Clackamas time series (Figure 6). This occurs because a higher productivity function for the Clackamas allows the model to simulate higher abundances, which in turn contribute to increases in stratum status, and thus somewhat increased exploitation rates when a matrix or abundance-based strategy is used.

In the end, we opted to base analyses for the Clackamas population on the 1974-2009 time series, despite indications that productivity has been reduced in the latter portion of this period. Our reasons were twofold. First, the 1974-2005 series (updated here to 2009) was the series used in the Oregon Recovery Plan published in 2010. Although our methods have modified the basic data set, this time series has been used extensively to evaluate the status of the Clackamas population. Second, we were concerned that the reduction in stochasticity associated with the more recent time series was a less appropriate measure of stochasticity in the population. We believe that, despite the higher productivity metrics associated with the longer time series, the increased stochasticity provides a more conservative assessment of population risk for the Clackamas and other populations.

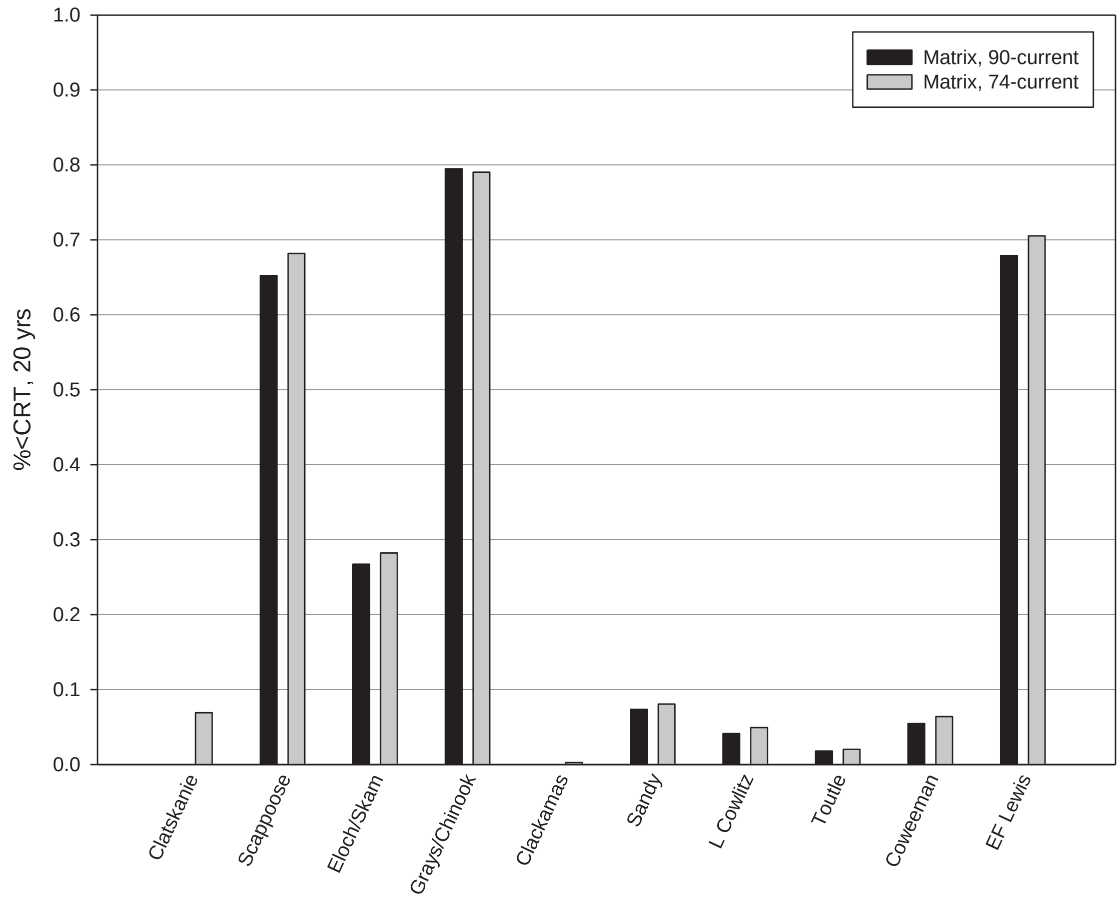


Figure 6. Differences in estimated risk of extinction (%<CRT) for all populations given 1) 1974-2009 brood Clackamas River productivity estimate, and 2) 1990-2009 brood Clackamas River productivity estimate, when using an abundance-based (matrix) harvest structure.

At the time the Oregon Recovery Plan was developed, abundance data for the Clatskanie and Scappoose populations were extremely limited. Beverton-Holt parameter values for these populations were instead inferred from other sources (ODFW 2010, Appendix C). Additional data is now available, though it is a short time series. Fitting recruitment models to the Clatskanie and Scappoose data sets is a difficult undertaking due to the small time series of available observations (eight brood years). This difficulty is consistent with expectations expressed in the Oregon Recovery Plan that “A confident assessment of these populations will only be possible after an expanded monitoring program has been in place long enough to generate at least 15 years of population specific spawner abundance data” (ODFW 2010, Chapter 4, page 60).

However, given that the available data for these two populations likely does represent low relative spawner abundance, it seemed reasonable to attempt to assess the α parameter using the current time series, at least for a qualitative comparison to the inferred values from the Oregon Recovery Plan. While the resulting α values are highly uncertain due to the short time series, we felt that it was more appropriate to use the lower α values in assessing risk, rather than the much higher values published in the Oregon Recovery Plan.

Over the period for which data are available, neither of these populations has likely demonstrated high-end spawner abundance or recruitment. Thus, calculating the β component of the productivity function is difficult because data that describe effects at higher abundances are not yet available. As a result we examined models with fixed β values for these two populations.

For each population, we fit the models with alternative two fixed β values – one from the Oregon Recovery Plan and the other from habitat-based capacity assessments. As will be discussed later (see "*Full-seeding Estimates*"), the habitat-based assessment for the Clatskanie results in a capacity estimate that is lower than is believed to be reality and new surveys are being conducted to reassess these values. Due to the uncertainty in capacity, and the fact that using the Oregon Recovery Plan β value resulted in a somewhat better model fit, we opted to keep β for the Clatskanie as it was presented in the recovery plan, while fitting both the α and γ parameters in the model. This process was duplicated for the Scappoose population.

Productivity values presented for both of these populations are highly uncertain. These uncertainties should be given due consideration in interpreting results of risk assessments in this report. These are interim measures representing the best available but obviously limited information, and they should be updated when sufficient data is available.

Washington Populations

Empirical estimates of spawner-recruit parameters are not available for Washington coho populations due to a lack of sufficient spawner abundance data. For the Washington Recovery Plan (LCFRB 2010) Beverton-Holt parameters were estimated using an EDT model. The EDT model generates these estimates based on assumed relationships between current habitat quality and the resulting coho productivity (α) and capacity (β) for each population. Beverton-Holt parameters are related to the equilibrium abundance (N_{eq}) based on the following calculation:

$N_{eq} = \beta((\alpha\text{-}1)/\alpha)$

Productivity parameters calculated by the EDT model are summarized in Table 5 and were derived from the sub-basin chapters of the Washington Recovery Plan (LCFRB 2010; Table 2 in each sub-basin chapter). However, the EDT parameters are based on current habitat conditions and do not account for differential fitness of hatchery and wild spawners or for different proportions of hatchery and wild spawners among populations. Therefore, the Beverton-Holt α parameters were adjusted for hatchery impacts using the approach used in the Washington Recovery Plan (LCFRB 2010 Table E12-6; Beamesderfer, personal communication). Parameter calculations have been updated based on the proportion of hatchery origin spawners (pHOS) from new spawner surveys conducted in 2010 and 2011.

These adjustments attempt to account for different fitness of hatchery and wild spawners by reducing the EDT-modeled α value by a hatchery impact factor. The adjusted productivity is calculated from the proportion of hatchery spawners (pHOS) and relative hatchery spawner fitness (RRS):

$\alpha(adj) = \alpha * (1\text{- }(pHOS*(1\text{-}RRS))$

Table 5. Washington population Beverton-Holt parameters used in current analysis.

Population	α (EDT)	β (EDT)	Hatchery Fitness (RRS)	pHOS	α adj)	N_{eq}
Grays/Chinook	3.80	1,511	0.5	0.90	2.09	1,113
Elochoman/Skamokawa[1]	4.33	3,157	0.5	0.65	2.93	2,429
Lower Cowlitz[2]	3.60	5,386	0.7	0.09	3.50	3,890
Coweeman	2.70	1,479	0.7	0.07	2.64	931
Toutle (NF & SF)[1,3]	2.70	5,025	0.7	0.33	2.43	3,164
East Fork Lewis	2.40	974	0.7	0.17	2.28	568

[1]Parameters are weighted values for the aggregate of n populations derived as: AggNeq=Σ(Neq1, Neq2); αaggregate = [(α1*Neq1)+(α2*Neq2)]/(AggNeq).
[2]Lower Cowlitz N_{eq} value is modified from the EDT N_{eq} value to include tributary spawning only. This adjustment allows annual comparison with spawning escapement which is estimated for the tributaries only (no mainstem). N_{eq} from the EDT analysis is 4,629. N_{eq}/mile in the Lower Cowlitz tributaries and mainstem is 9.2 (4,629/501.4, includes 80 miles main stem, 40 river miles times two river edges). N_{eq} in the tributaries is 3,890 (9.2 N_{eq}/mile * 421.4 miles).
[3]Composite Toutle coho population includes both the North Fork/Green population and South Fork Toutle population.

Final parameters for Oregon and Washington populations used in the PVA model simulations are summarized in Table 6. Estimates of residual errors σ and autocorrelation ρ needed to incorporate stochasticity in the model could only be derived for populations with a fitted Beverton-Holt model – the Clackamas, Sandy, Clatskanie, and Scappoose populations. Of these, we felt that the time series for the Clatskanie and Scappoose populations was too short and likely underestimated the level of error and autocorrelation. Values of σ and ρ for these two populations are instead based upon the average of the estimates for the Clackamas and Sandy. Values of σ and ρ for Washington populations are taken from the Washington Recovery Plan (Table E13-3, LCFRB 2010). For the γ parameter, estimates for the Oregon populations are derived from the fitted models for each population, while values for the Washington populations are derived by averaging the estimates for the Oregon populations. As with productivity functions, these estimates are uncertain, but represent what we believe is the best available information at this time.

Table 6. Summary of PVA model parameters for all populations.

Population	Method	α	β	γ[b]	σ[c]	ρ[d]
Clackamas	Data (1974-2009)	10.07	6,737	0.534	0.803	0.546
Sandy	Data (1987-2009)	2.04	4,258	0.454	0.582	0.266
Clatskanie	Data (2002-2009)/Inference	2.20	*3,356*[a]	0.346	*0.692*	*0.406*
Scappoose	Data (2002-2009)/Inference	1.22	*4,433*[a]	0.331	*0.692*	*0.406*
Grays/Chinook	EDT (with adjusted α)	2.09	1,510	*0.416*	1.000	0.300
Eloch/Skam	EDT (with adjusted α)	2.93	3,157	*0.416*	1.000	0.300
L Cowlitz	EDT (with adjusted α)	3.50	5,386	*0.416*	1.000	0.300
Coweeman	EDT (with adjusted α)	2.64	1,479	*0.416*	1.000	0.300
Toutle	EDT (with adjusted α)	2.43	5,025	*0.416*	1.000	0.300
EF Lewis	EDT (with adjusted α)	2.28	974	*0.416*	1.000	0.300

[a] Fixed value from ODFW 2010.
[b] γ = coefficient for marine survival (CRH jack). Washington populations are mean of Oregon populations.
[c] σ = standard deviation of residuals. Oregon Coast Stratum populations are mean of Oregon Cascade Stratum populations. Washington populations are from LCFRB Table E13-2 (LCFRB 2010).
[c] ρ = autocorrelation. Oregon Coast Stratum populations are mean of Oregon Cascade Stratum populations. Washington populations are from LCFRB Table E13-2 (LCFRB 2010).

Production Function Covariate

We incorporated a metric for marine survival of Columbia River hatchery coho in the current analysis. This metric is included as a recruitment covariate for fitted Beverton-Holt functions for all four Oregon populations. The metric is very similar to the marine survival value used in the OCN harvest matrix until 2013, except that it uses only Columbia River stocks instead of all OPI hatchery stocks. The parameter is derived by dividing the return of Columbia River hatchery (CRH) jacks from a given brood year by the number of hatchery smolts released from Columbia River hatcheries for the brood year. For usage in the recruitment function, these values are converted to a normalized index. A complete description of this process and its application in the model is provided in Appendix B.

There are several reasons why this parameter was chosen. First, it directly links a portion of the process for determining exploitation rate to a parameter that also affects stock productivity as modeled in the PVA. Second, it is an easily explained variable that is known to have biological significance.

Full-seeding Estimates

The number of spawners required to fully seed freshwater habitat with progeny provides a measure of the abundance that should maximize freshwater production. Spawner-recruit data for coho salmon populations often indicates that spawners in excess of some threshold level do not produce additional progeny due to density-dependent survival of offspring in the freshwater habitat. Freshwater production is one component that contributes to adult return size and can thus be linked to harvest strategies. Full-seeding spawner abundance estimates are generally more precise when calculated from a spawner-smolt function, but may also be estimated from spawner-spawner or spawner-recruit data, though this process would be expected to add uncertainty due to variability in survival rates outside the freshwater environment.

It is important to note that in this analysis, the measure of "full-seeding" is applied only to the selection of allowable exploitation rates via the harvest strategy. Full-seeding estimates derived for this purpose are not intended to represent long-term abundance targets or measures of long-term productivity. Instead, they reflect the approximate current status of adult spawners that produced offspring that are expected to return in future years. This metric is categorized and combined with a categorical metric for marine survival to provide an index of expected status which can be used to make harvest decisions.

Identifying the abundance of spawners needed to fully seed freshwater habitat requires selection of an appropriate function for which data are available. If smolt capacity of a system is known or can be modeled (through EDT or other habitat models), the number of spawners can be estimated from life-stage survival functions, such as those developed for OCN coho (Nickelson and Lawson 1998). This approach does not require observed spawner data, but assumes that the capacity is accurately estimated and that survival functions can be reasonably inferred from other sources.

Alternately, the number of spawners that produce maximum recruits can be calculated from observed data using a fitted spawner-recruit function. This method assumes that data exist in a long enough time series to satisfactorily fit the function (Bradford et al. 2000). In an alternative approach, the spawner-recruit function could be derived with shorter time series from multiple systems by combining standardized spawner-recruit data (Myers et al. 2001; Barrowman et al. 2003).

Several forms of spawner-recruit functions can be used, with Ricker, Beverton-Holt, and "hockey stick" being common for Pacific salmon populations. The asymptotic shape of the Beverton-Holt function is often appropriate for coho stocks (Barrowman et al. 2003). However, unlike the peaked Ricker function, the Beverton-Holt function predicts that an infinite number of spawners are needed to produce true full capacity of recruits, due to continually diminishing recruits-per-spawner at high spawner abundances.

A potential approach for using the Beverton-Holt function to estimate full-seeding levels would be to identify the spawner abundance at which environmental factors (freshwater for spawner-smolt and freshwater or marine for spawner-spawner) have a greater impact on recruitment than spawners (with some sort of positive error term for precaution). The hockey-stick or continuous hockey-stick function may be a reasonable approach (Barrowman and Myers 2000; Bradford et al. 2000).

Another alternative for deriving threshold seeding measures other than full-seeding is based largely on prior work done for OCN coho. The 2005 OCN Viability Assessment (ODFW 2005) established a minimum spawner abundance of four fish per mile to ensure that adults would be able to pair up and spawn. Based upon this metric, for the current analysis, one alternative for the "critically low" threshold for parental seeding would be an average of no less than four spawners per mile for each population. The 2005 OCN Viability Assessment also identified a threshold of ≥600 fish per population to meet viability criteria for genetic diversity. This abundance can be used as a proxy for minimum "viable" abundance for some populations.

Oregon Populations

One question that has arisen since the publication of the Oregon Recovery Plan is how minimum abundance threshold (MAT) targets in the plan relate to full-seeding as it is used in the harvest matrix. These are in fact two distinctly different metrics. The MAT goals are based on achievement of recovery actions across all threat categories over a 100-year period. They do not represent current capacity or full-seeding levels for these populations. Addressing harvest threats is only one of several recovery actions that are needed to achieve the MAT goals. The full-seeding metric as used in the harvest matrix simply represents the best approximation of what full-seeding of adult spawners currently is. Inherent in this representation is the realization that, as recovery actions begin to affect estimates of full-seeding, the full-seeding thresholds will need to be updated. For instance, if habitat actions are successful in increasing the amount of high-quality rearing area, full-seeding thresholds should be increased accordingly.

For the Clackamas and Sandy rivers, which both have long time series' of data, the analyses used to construct the 2001 ODFW management plan used a Ricker spawner-smolt analysis that estimated the adult abundance needed to achieve maximum smolt production as a measure of full-seeding of adult spawners. For the Clackamas, this analysis was done with spawners and smolts at North Fork Dam, and was not applicable to the entire basin.

In the revised analysis, we examined a habitat-based alternative. For the Clackamas, habitat analysis indicates a winter capacity of 545,000 coho parr. Based on assumed parr per spawner productivity rates, the number of adults required to fully seed the basins habitat would be 3,781. For the Sandy, habitat analysis indicates a capacity of 142,000 parr and that full-seeding would be achieved with 1,269 adults. Because neither the Clackamas nor Sandy values are substantially different than the 2001 ODFW Management Plan full-seeding values, we did not alter the existing full-seeding values for these populations (3,800 and 1,340, respectively). However, it is important to point out that the Clackamas and Sandy full-seeding metrics should be interpreted as full-basin measures from this point forward, rather than a measure comparable only to dam escapements, as in the past.

Similar habitat-based exercises for the Clatskanie and Scappoose populations yielded full-seeding estimates of 600 and 1,000 spawners, respectively. However, ODFW staff felt that the habitat capacity in the Clatskanie River population was higher than this, and pointed out that new habitat surveys were underway to update the Clatskanie habitat model. Due to this issue, we are not proposing to use the habitat-based measure for full-seeding for the Clatskanie at this time, but instead propose an alternative described below.

For the OCN coho harvest matrix and in current versions of the LCN coho harvest matrix, the medium parental seeding category is defined as 50% of full-seeding. If the target abundance for the medium category is set at either the 600 fish "viability" threshold derived from the OCN Viability Assessment (ODFW 2005), or 50% of an empirically-derived full-seeding value (whichever is greater), no Oregon population would have a "medium" parental abundance value that was less than the viability threshold of 600 fish.

This viability threshold abundance was doubled to create a proxy for full-seeding for the Clatskanie and the Scappoose of 1,200 fish each (Table 7). Because the habitat-derived full-seeding estimate for Scappoose (1,000) was only slightly less than this, ODFW believes the 1,200 fish value is an appropriate level for this analysis. A full-seeding threshold of 1,200 fish is double the habitat-based estimate for the Clatskanie population, but is more consistent with recent observed returns and other indications of the capacity of the system.

Table 7. Wild spawner full-seeding estimates, Oregon populations.

Population	Habitat Miles	Full-seeding	Spawners/mi at Full-seeding
Clackamas	246.0	3,800	15.4
Sandy	110.2	1,340	12.2
Clatskanie	60.1	1,200	20.0
Scappoose	75.7	1,200	15.9

Washington Populations

For Washington population's, full-seeding is represented as the equilibrium abundance (N_{eq}) for each population (Table 8). Of note, N_{eq} is likely to be an underestimate of full-seeding and should be updated once additional information becomes available. The EDT parameters are based on habitat conditions alone and assume that all spawners, regardless of origin, are able to maximize use of the available habitat. Therefore, annual spawner estimates must be adjusted to wild equivalents to be compared to EDT-based estimates of N_{eq}. The numbers of wild-equivalent spawners ($N_{WILD.EQ}$) were calculated by adjusting the total estimated spawner abundance N_T by the proportion of hatchery origin spawners (pHOS) and an assumed relative fitness of hatchery versus wild coho (RRS; Table 5):

$$N_{WILD.EQ} = (N_T*(1\text{-pHOS}))+ (N_T*\text{pHOS}*\text{RRS})$$

Proportion of hatchery spawners were based on estimates from 2010 and 2011 spawner surveys. Fitness values for hatchery spawners are the same used in the Washington Recovery Plan viability modeling (Beamesderfer, personal communication). Actual coho spawner estimates from 2010 and 2011, and in wild-equivalent spawners, are shown Table 9 and Figure 8.

Except for the Lower Cowlitz, the full-seeding values for Washington populations are identical to those used in the Washington Recovery Plan (LCFRB 2010) and will be used as interim values until a sufficient number of years of empirical data become available to conduct a spawner-smolt analysis. For the Lower Cowlitz, the full-seeding value is modified to reflect full-seeding in tributary habitats only. This adjustment was necessary to allow for annual assessment of spawning escapements relative to full-seeding, because spawning escapement is only estimated for tributaries. The full-seeding values equate to a range of 6.5 to 29.3 spawners per mile Washington LCN coho, which is lower than the 19 females/km (~63 adults/mile) estimated to fully seed freshwater habitat for 14 coho populations in coastal Washington and Puget Sound (Bradford et al. 2000).

Coho spawner and smolt data are available for five Washington lower Columbia River watersheds, although only a few years of spawner abundance are available for most populations (Table 10). When more data becomes available, spawner and smolt data will be standardized to linear miles of habitat. Equivalency adjustments will be explored for smolts to adjust for different watershed characteristics (e.g., Sharma and Hilborn 2001) and for adults to adjust for differential fitness of hatchery and wild spawners (e.g., Araki et al. 2008; Fleming and Gross

1993). The spawner-recruit analysis will utilize a hierarchical Bayesian approach that combines data from all populations into a single analysis (Myers et al. 2001; Barrowman et al. 2003) to identify the number of spawners per mile of habitat that maximizes smolt production. The number of spawners per mile estimated from populations with spawner-smolt data will be used to estimate the number of spawners needed to fully seed non-monitored watersheds. In order to get a broad representation of populations in this analysis, at least three years of concurrent spawner-smolt data are desired from each watershed. Data needed to perform this analysis are expected to be available after the 2014 outmigration year.

Table 8. Interim full-seeding spawner values for selected Washington populations.

Population	α (EDT)	β (EDT)	N_{eq} Full-seeding (EDT)
Grays/Chinook	3.80	1,511	1,113
Elochoman/Skamokawa[1]	4.33	3,157	2,429
Lower Cowlitz[2]	3.60	5,386	3,890
Coweeman	2.70	1,479	931
Toutle (NF & SF)[1]	2.70	5,025	3,164
East Fork Lewis	2.40	974	568

[1]Parameters are weighted values for the aggregate of n populations derived as: AggNeq=Σ(Neq1, Neq2); αaggregate = [(α1*Neq1)+(α2*Neq2)]/(AggNeq).
[2]Lower Cowlitz full-seeding value is modified from the EDT N_{eq} value to include tributary spawning only. This adjustment allows annual comparison with spawning escapement which is estimated for the tributaries only (no mainstem). N_{eq} from the EDT analysis is 4,629. N_{eq}/mile in the Lower Cowlitz tributaries and mainstem is 9.2 (4,629/501.4, includes 80 miles main stem, 40 river miles times two river edges). N_{eq} in the tributaries is 3,890 (9.2 N_{eq}/mile * 421.4 miles).

Table 9. Coho spawner estimates for Washington populations in 2010 and 2011 compared to interim full-seeding values.

Population	Full-seeding	2010 N_T	2010 $NWILD_{EQ}$	2011 N_T	2011 $NWILD_{EQ}$
Grays/Chinook	1,113	226	132	754	389
Elochoman/Skamokawa	2,429	798	510	518	369
Lower Cowlitz[1]	3,890	1,150	1,101	1,039	1,019
Coweeman	931	1,408	1,369	1,200	1,169
Toutle (NF & SF)	3,164	1,772	1,506	315	291
East Fork Lewis	568	430	391	456	448

[1]Lower Cowlitz full-seeding and spawner estimates are for tributary habitat only and do not include the main stem river.

Table 10. Description of Washington coho spawner-smolt data currently available for estimating spawners needed to fully seed the freshwater habitat.

Population/Watershed	Years with Spawner-Smolt Data	Spawn Years
Grays River	2	2010-2011
Abernathy Creek	5	2007-2011
Coweeman River	2	2010-2011
Cedar Creek (NF Lewis)	2	2010-2011

Matrix Parental Abundance Categories

The "high" parental abundance category threshold has been established as 75% of full-seeding for all populations and is not proposed to change. The distribution of remaining thresholds is still under development, and the effects of two alternatives are presented in this analysis. The first of these alternatives is status quo, with parental seeding categories as described in Tables 1-3.

The second alternative attempts to re-assess the "critical" parental abundance category. As previously described, the 2005 OCN Viability Assessment (ODFW 2005) assigned a critical threshold of four fish per mile of high quality spawning habitat. Our usage of it here is applied to the full range of habitat in each population, regardless of quality. At this time, information comparing the relative proportions of high quality habitat and total habitat are unavailable for most populations we examined. A density of four fish per mile in high quality habitat likely equates to a lower mean density when measured across all habitat types within a basin. This application of four fish per mile across the entirety of habitat types should be more conservative than the application of four per mile for high quality areas.

This alternative "critical" threshold was originally set at four fish per mile for all populations (Table 11). This metric ranges from 14% to 62% of full-seeding across the populations examined, resulting in uneven fractions of full-seeding to represent the "critical" category among populations. This in turn makes implementation of the matrix and risk assessment modeling difficult. Across all populations, the four fish per mile measure averaged 33% of the full-seeding value, so this alternative uses 33% of full-seeding as the critical threshold for all populations. This generates a spawner per mile threshold that ranges from 2.1 – 9.4 fish per mile (mean 5.1). The critical threshold densities shown in Table 11 for the Grays/Chinook, Lower Cowlitz, and East Fork Lewis populations, which are below four fish per mile, likely equate to higher densities in high quality habitats.

Because the alternative critical threshold ranges from 0%-33% of full-seeding, the "very low" category shown in Tables 1-3 is eliminated in this alternative (Table 12). Comparison of available escapement estimates with these category values are shown in Figures 7 and 8.

For Oregon populations, the fraction of full-seeding is simply the estimated number of wild spawners in the population divided by the full-seeding measure. For Washington populations, the number of spawners includes wild fish and hatchery spawners reduced for their relative fitness using methods previously described. Although the methods differ for each state, each remains consistent with approaches taken in the respective state recovery plans.

Table 11. Calculations of mean fraction of full-seeding to represent alternative critical thresholds.

Population	Habitat Miles	Full Seeding	Sp/mi at Full-seeding	% of Full at 4/mi	N Spawners if Critical = 33% of Full	Sp/mi if Critical = 33% of Full
Clackamas	246	3,800	15.4	0.26	1,254	5.1
Sandy	110.2	1,340	12.2	0.33	442	4.0
Clatskanie	60.1	1,200	20.0	0.20	396	6.6
Scappoose	75.7	1,200	15.9	0.25	396	5.2
Grays/Chinook	170.5	1,113	6.5	0.61	367	2.2
Eloch/Skam	100.4	2,429	24.2	0.17	802	8.0
L. Cowlitz[1]	421.4	3,890	9.2	0.43	1,284	3.0
Coweeman	60.0	931	15.5	0.26	307	5.1
Toutle (NF & SF)	107.9	3,164	29.3	0.14	1,044	9.7
East Fork Lewis	88.2	568	6.4	0.62	187	2.1
			Mean Fraction at ~4/mi	**0.33**		**5.1**

[1]Lower Cowlitz full-seeding estimates are for tributary habitat only and do not include the main stem river.

Table 12. Alternative spawner category values.

Population	Full	Parental Seeding Category: High (>75%)	Medium (>50%)	Low (>33%)	Critical (≤33%)
Clackamas	3,800	> 2,850	>1,900	>1,250	≤1,249
Sandy	1,340	> 1,010	> 670	> 440	≤ 439
Clatskanie	1,200	> 900	> 600	> 400	≤ 399
Scappoose	1,200	> 900	> 600	> 400	≤ 399
Grays/Chinook	1,113	> 830	> 560	> 370	≤ 369
Eloch/Skam	2,429	> 1,820	>1,210	> 800	≤ 799
L. Cowlitz[1]	3,890	> 2,918	>1,945	>1,280	≤1,279
Coweeman	931	> 700	> 470	> 310	≤ 309
Toutle (NF & SF)	3,164	> 2,370	>1,580	>1,040	≤1,039
East Fork Lewis	568	> 430	> 280	> 190	≤ 189

[1]Lower Cowlitz full-seeding estimates are for tributary habitat only and do not include the main stem river.

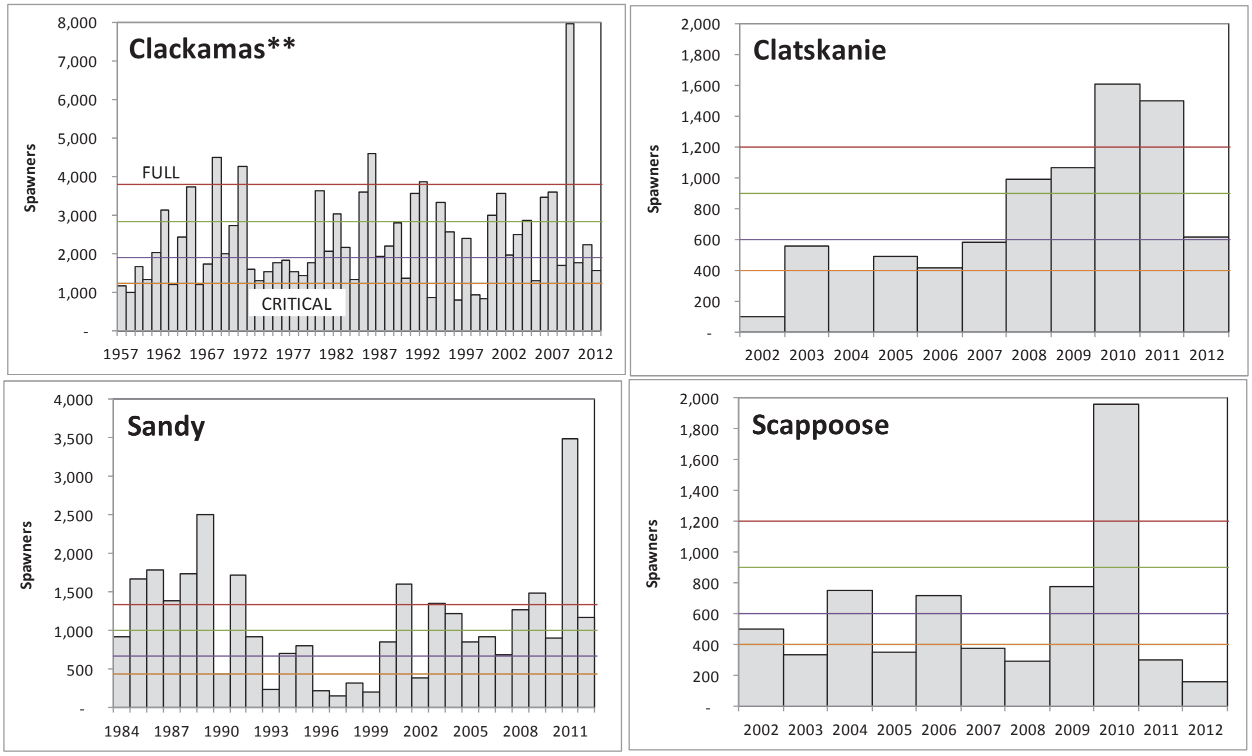


Figure 7. Wild spawning abundance estimates for Oregon populations compared to fractions of full-seeding in alternative two (Table 12). Lines in graphs are, from top to bottom, 100%, 75%, 50%, and 33% of full-seeding. Note scale change in y-axis among populations. **Values for Clackamas are based on full-seeding of 3,800 wild fish for the full basin.

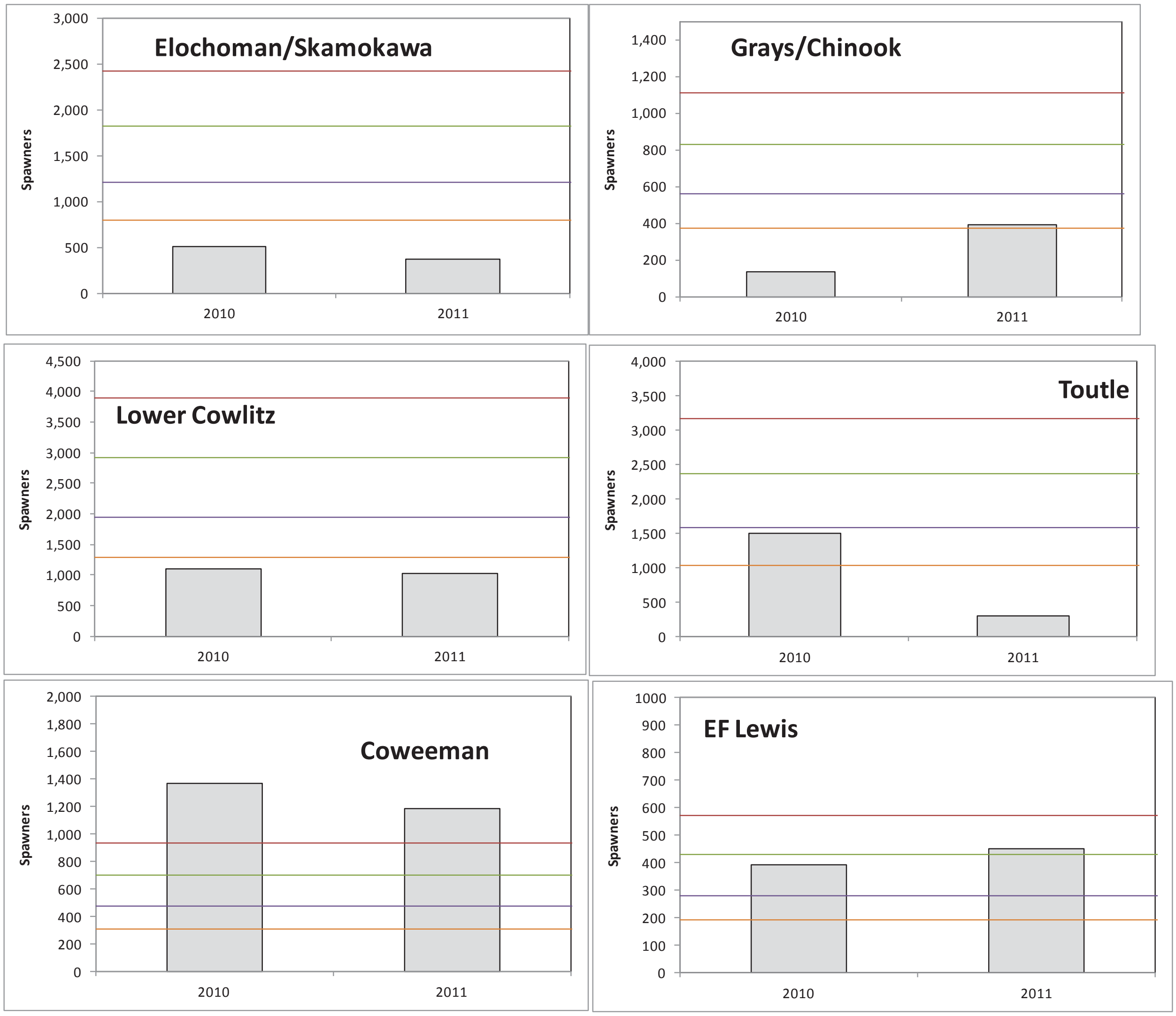


Figure 8. Wild spawning abundance estimates for Washington populations compared to fractions of full-seeding in alternative two (Table 12). Lines in graphs are, from top to bottom, 100%, 75%, 50%, and 33% of full-seeding. Note scale change in y-axis among populations.

Extinction Thresholds

There are little empirical data that can inform the selection of appropriate Critical Risk Threshold (CRT) values. It is, however, reasonable to conclude that extinction risk becomes unacceptably high at some abundance level substantially above zero. In the recovery planning process, CRT values were assigned based on species and watershed size (McElhaney et al. 2006). For coho salmon, watersheds with less than 100 km of historical spawning habitat were assigned a CRT of 100 fish, watersheds with 100 to 200 km of historical spawning habitat were assigned a CRT of 200 fish, and watersheds with more than 200 km of historical spawning habitat were assigned a CRT of 300 fish. In the PVA model, an extinction event is defined as any time a population reaches a mean wild spawner abundance of less than the CRT value for a full generation (three years). Lacking any new information on appropriate population-specific CRT values, those used in the Oregon Recovery Plan were adopted (Table 13). Population-specific CRT values for Washington populations were updated (Table 14) based on the spawning distribution model developed by WDFW to determine the sampling frame for escapement surveys (Rawding et al. 2013).

Table 13. CRT values for Oregon lower Columbia River coho salmon populations.

Population	CRT	Source
Clatskanie	200	ODFW 2010
Scappoose	200	ODFW 2010
Clackamas	300	ODFW 2010
Sandy	300	ODFW 2010

Table 14. CRT values for Washington lower Columbia River coho salmon populations.

Population	Spawning habitat (km)[1]	Watershed size[2]	CRT
Elochoman/Skamokawa	274.5	L	300
Grays/Chinook	161.5	M	200
L Cowlitz	678.1	L	300
Coweeman	96.6	S	100
Toutle (SF and NF)	173.7	M	200
EF Lewis	141.9	M	200

[1]Spawning habitat model based on precipitation, gradient, and elevation (Rawding et al. 2013).
[2]Watershed size (McElhaney et al. 2006).

Model Structure and Processes

The PVA model was constructed in VisualBasic and is operated in an Excel spreadsheet. This model is a modified version of the PopCycle model used in the Washington Recovery Plan process (LCFRB 2010) and for the PFMC lower Columbia River tule Chinook abundance-based management analyses completed in 2011. The model's primary outputs are forecast probabilities of population extinction. Extinction probability is estimated as the frequency at which simulated population abundance falls below a specified CRT, under the assumption that once the population falls below this threshold, risk of actual extinction is increased. Consistent with other salmon PVA models, an extinction event in the model is identified when simulated spawner abundance falls below the CRT threshold for a full generation. Values for model variables are set to represent current conditions for the populations and do not consider expected improvements from recovery actions beyond alternative harvest management strategies tested as part of the analysis. If productivities of populations increase this is a pessimistic assumption; if they decline this is an optimistic assumption. The model is designed to analyze relative effects of different management actions and should not be interpreted as predictive in nature.

The number of iterations to run (≤5,000) and number of years to simulate in each (100) are entered by the user. The user specifies either a fixed exploitation rate or a matrix-based rate.

Population parameters are input to the model via a data page and can be modified by the user. Three years of starting spawner abundances are supplied by the user to create the first three recruit cohorts in the model. Although values within the harvest matrix can be easily modified by the user, significant changes to the matrix, such as altering the number of categories of marine survival or parental seeding, changing the decision rules for how populations are aggregated for assessment, or altering the proportional distribution of parental seeding requires program re-coding.

The relationship between spawners and the number of recruits produced is partially randomized. The recruitment equation driving the recruit forecast from any given spawner value is deterministic, but the initial result is modified at random, proportional to the standard deviation of the residuals from the fitted spawner-recruit model (where applicable).

Recruits are calculated as:

$$R_{t+3} = (\alpha * S_t) / (1 + (\alpha/\beta * S_t)) \exp((\gamma * C_{t+2}) + \varepsilon_t)$$

where ε_t is a random number selected from a normal distribution with a mean of zero and standard deviation equal to the standard deviation of residuals σ for the population recruitment model, and C_t is the survival variable.

Residuals (v_i) were calculated from fitted models (where applicable) as:

$$v_i = \ln(A_i/P_i)$$

where A_i is the actual number of recruits and P_i is the predicted number of recruits from the fitted model. Error is expressed in the model as the standard deviation σ of v_i residuals from the fitted model. For the Clatskanie and Scappoose populations, due to the short time series of the run reconstructions for these populations the mean σ for the fitted models for the Clackamas and Sandy populations was used. For Washington populations, σ values from the Washington Recovery Plan were used (LCFRB 2010).

Annual errors in recruitment functions were assumed to be autocorrelated, i.e. that a year of below average recruitment performance was more likely to be followed by another year of below average recruitment performance and vice versa. For the Clatskanie and Scappoose populations, due to the short time series of the run reconstructions for these populations the mean autocorrelation value for the fitted models for the Clackamas and Sandy populations was used. For Washington populations, autocorrelation values from the Washington Recovery Plan were used (LCFRB 2010). The model incorporates autocorrelation via the function:

$$\varepsilon_t = \rho\varepsilon_{t-1} + \sigma\sqrt{(1-\rho^2)}Norm(0,1)$$

where σ and ρ are the standard deviation and autocorrelation of residuals from the fitted model (where applicable), respectively.

Rare combinations of very high recruitment variation combined with very high marine survival index values may result in unreasonable estimates of recruits in a few simulation years. To address this, recruitment and/or spawner ceiling values may be specified by the user if necessary.

The model allows for incorporation of depensation. Depensation and CRT are treated separately in processing simulations. The model assumes that depensation occurs at abundance levels less than CRT, representing a point where reproductive failure is likely. The model progressively reduces productivity at spawner numbers below a specified depensation threshold (RDT) using the following equation:

R'= R * (1 - exp((log(1 - 0.95) / (RDT - 1)) * S))

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.

We adopted the Oregon Recovery Plan estimate of a reproductive failure threshold (RFT) at 0.2*CRT. While the model requires abundances below CRT for one full generation to create an extinction event, a single year of spawner abundance below the level of RFT will produce zero wild recruits in the model.

Annual values for the CRH jack index are selected from a distribution created from historic data as described in Appendix B. Autocorrelation is present in the data set, and was included in the function. The distribution created is used for selecting CRH values to specify marine survival in the harvest matrix and for the marine survival covariate in the recruitment function.

Parental abundance categories in the model are selected by dividing adult escapement by the full-seeding goal for the population and comparing the result to the proportional category definitions. For Washington populations, annual comparisons to full-seeding account for the presence of hatchery spawners, discounted for their assumed relative fitness. For Oregon populations, all simulated spawners are wild-origin and these are directly compared to full-seeding thresholds.

The model simulates all populations concurrently. While complicating the computations in the model, this step was necessary because multiple populations are used to represent each stratum. In determining fishery rates, managers will examine each stratum by combining the performance of two or more populations within the stratum. The model must simulate populations concurrently so that an assessment of the aggregate can be made. In combination with simulated marine survival values, full-seeding is needed to select exploitation rates as would be done in implementation. Such an analysis would be impossible to reproduce in a single population model.

For each population, within a single iteration and during each year time step, the model uses spawner abundance and the recruitment function (with stochasticity unique to each population in each simulation year) to calculate production of wild ocean adult recruits. All populations experience the same marine survival index in each simulation year. The model removes harvest mortalities to calculate the escapement of wild adults to spawning.

For Washington populations, which are driven by EDT analysis adjusted for the effects of hatchery spawners, rather than run reconstruction data, productivity functions are adjusted for hatchery spawner presence and relative fitness, and hatchery spawners are therefore included as spawners in the recruitment calculations. This approach differs from that for Oregon populations, but is consistent with that taken in the Washington Recovery Plan. In each yearly simulation, the modeled escapement of wild spawners in Washington populations is added to a static population-specific hatchery abundance value (based on 2010 and 2011 survey results) to create an estimate of total spawners. The static value is intended to be an approximation of the relative effects of hatchery spawners. Other approaches to inclusion of hatchery spawners, such as simulated survival of a static number of hatchery-released smolts, could have been substituted. However, due to the inherent need to include substantial differential harvest of hatchery and wild fish to produce estimates of spawning escapement with that approach, and other uncertainties in the relationships between wild and hatchery fish in these areas, we settled on the more simplistic approach taken here. For Oregon populations, only wild spawners are used in recruitment calculations. The effect of spawning hatchery fish was incorporated in fitting the recruit curve, which provides a reduced intrinsic productivity that is used in the PVA.

The inclusion or exclusion of hatchery spawners in Washington populations does affect outputs from the simulation. Including hatchery spawners allows for some level of spawning in any simulation year, regardless of performance of naturally-produced fish. If this results in decreased proportions of wild spawner abundance below the CRT level, it would lead to reduced estimated risk in the model. To examine the extent of this effect on the simulations, we ran a sample fishery structure under two assumptions; include Washington hatchery spawners, and exclude Washington hatchery spawners. However, because Washington hatchery spawners are included in two protocols within the PVA, as spawners and as a component of full-seeding fractions, we examined the effects in a stepwise fashion. The first exercise attempted to isolate the effect of inclusion of Washington hatchery fish only as spawners. A 15% fixed exploitation rate model was used to do this because it eliminates the effect of full-seeding in setting exploitation rates in the model. As shown in Figure 9, this change leads to increased risk estimates for Washington populations when spawners are limited to wild fish only. Because there is no change in either scenario in how Oregon spawners are treated, risks for Oregon populations are unchanged in the fixed exploitation rate example.

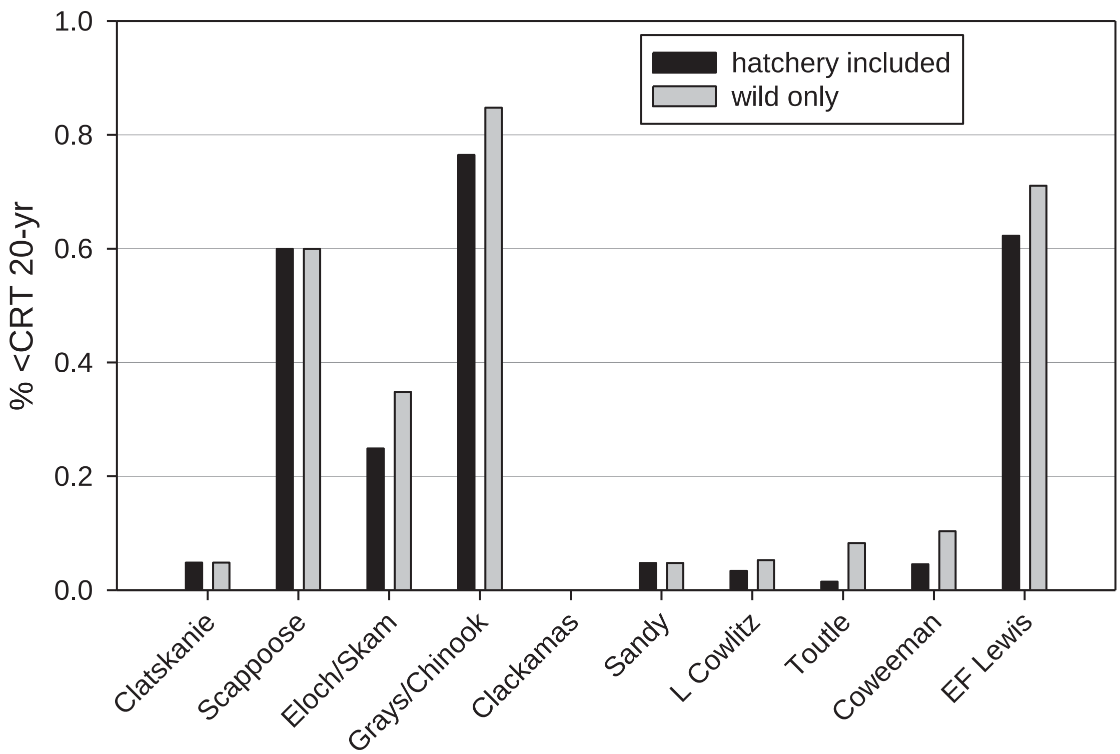


Figure 9. Example of change in modeled extinction risk with Washington hatchery spawners included and excluded in a 15% fixed exploitation rate harvest structure.

The next step was to include the effects of Washington hatchery fish as both spawners and as components of full-seeding measures in a matrix harvest approach. While this more fully assesses the complete effects of including hatchery spawners, it also confounds the independent effects of including hatchery fish as spawners and as contributors to full-seeding. Figure 10 shows the effects on risk associated with this model (based on Model 6, described subsequently in "*Example Harvest Risk Assessments*"). Because this model includes effects on exploitation rates associated with changes in population status, there were effects on Oregon populations. This is a result of changes in population status of Washington populations in each run – when Washington hatchery spawners are excluded, status of Washington populations is lower resulting in a lower average exploitation rate. This in turn reduces risk to Oregon populations because of slightly reduced harvest effects. Thus, while risk to Washington populations increases when spawners are restricted to wild fish only, risks for most Oregon populations declines, though marginally. Given the similarities between the relative changes in risk shown in Figures 9 and 10, it seems reasonable to conclude that the largest effect is related to the inclusion of hatchery spawners in producing wild recruits, and that there is a lesser effect associated with their inclusion as a component of full-seeding in matrix-based models. The inclusion of hatchery fish in matrix-models does shift the frequency of occurrence in parental categories towards higher fractions (Figure 11), which would be reflected in individual matrix-based model runs by the selection of slightly increased mean exploitation rates. However, this is likely a combination of the effects of their contribution to both recruitment and full-seeding measures.

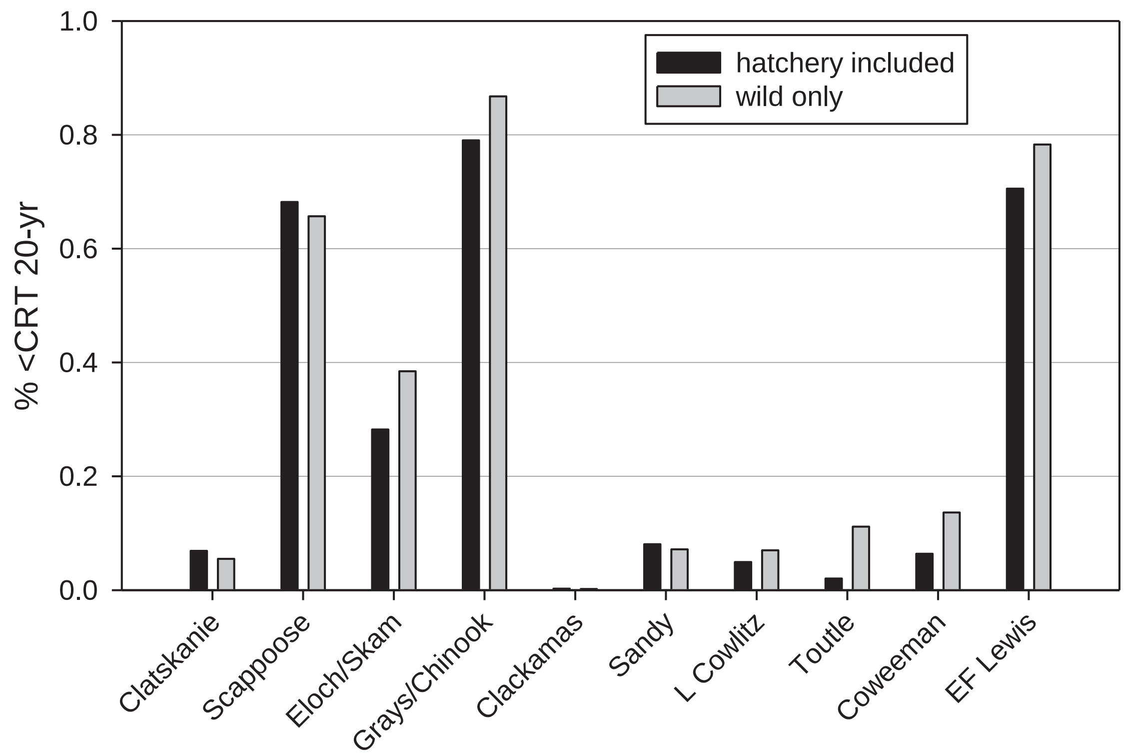


Figure 10. Example of change in modeled extinction risk with Washington hatchery spawners included and excluded in a matrix-based harvest structure.

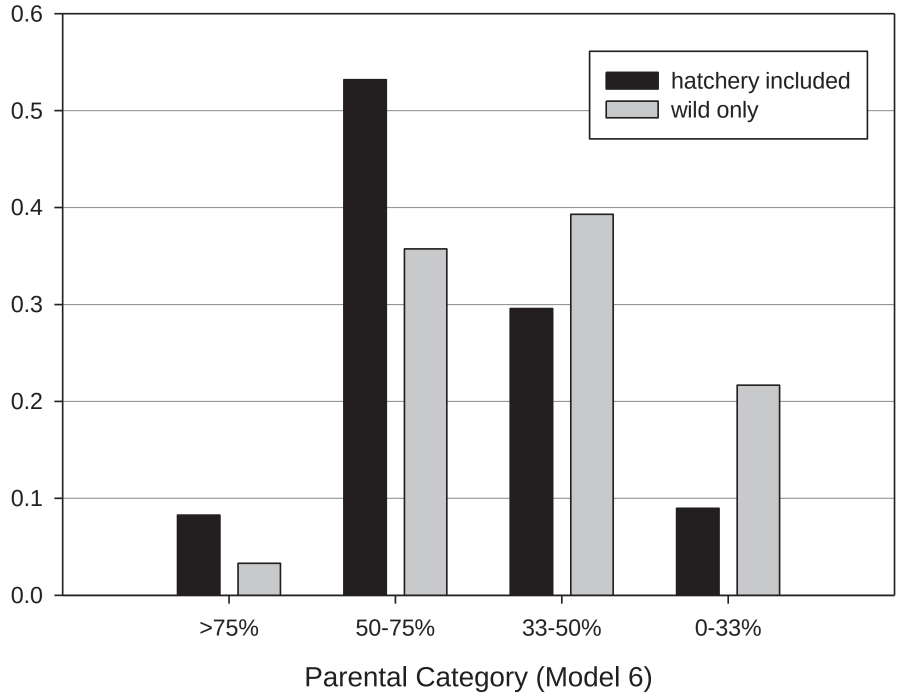


Figure 11. Frequency of occurrence in each parental seeding category with Washington hatchery spawners included and excluded. Example is based on matrix-based Model 6 ("*Example Harvest Risk Assessments*").

The number of wild spawners in each year is compared to the various thresholds, and if below the threshold, a "flag" is attached to that simulation. Populations from both states are treated identically in this regard; Washington hatchery spawners are not included in evaluation of extinction thresholds, though their simulated naturally-produced offspring are. Any simulation that results in a three-year mean wild escapement of less than CRT anywhere within the 100-year simulation is identified with an extinction flag for long term CRT risk. A separate short-term risk flag is assigned for simulations that result in escapement less than CRT for a full generation within the first 20 years of the simulation. Spawner abundances below RFT may not result in an extinction flag if they are followed by one or more years which exceed CRT, but each RFT failure event will produce zero ocean recruits.

A flag is also generated for any annual simulated abundance that exceeds the full-seeding measure for the population. This metric was created to allow for an assessment of harvest structure on population abundance. The model summarizes the number of these events that occur for each population in each model run and converts them to percentage of occurrence. The model also summarizes the frequency of occurrence in each parental abundance and marine survival cell across all iterations for each population, for each stratum (mean of all populations), and for the ESU (minimum of stratum means). Following the completion of a model run, frequencies of threshold flags, mean spawner abundances, and frequency distributions of spawners, recruits, and exploitation rates for the model run are output for review.

Fishery variance can be included to account for the effects of differences between allowed impact rates (determined pre-season) and actual impact rates; i.e. management uncertainty. Since 2006, the actual impact rate exceeded the allowed only once; by 4% in 2007. It has been less than the allowed limit in all other years (Figure 12). Overall, the average final exploitation rate has been about 89% of the allowed limit. Rather than allowing the impact rate to vary by 11%, which would imply equal probability of actually ending up above or below allowable fishing rates, simulations were conducted with fishery variance set to zero. Given that fishery rates have only exceeded expectations one out of seven years, and then only by 4%, and because errors are most often unidirectional with actual rates being less than preseason expectations, we believe this is a conservative approach. Based on past differences in rates the simulations will have a tendency to overestimate actual exploitation rates under this approach.

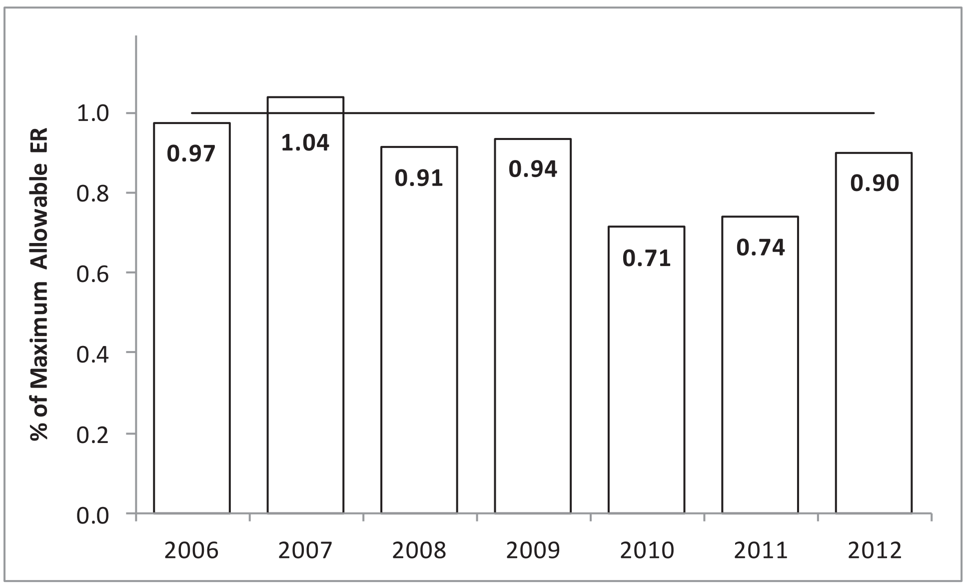


Figure 12. Ratio of post-season exploitation rate to allowable exploitation rate, 2006-2012.

Example Harvest Strategy Risk Assessments

We propose to continue the use of the parental seeding versus marine survival structure to derive allowable exploitation rates. Fraction of parental seeding for each stratum will be calculated as the simple mean of the fractions of parental seeding for the indicator populations within the stratum. However, in making this calculation, fractions for any individual population will be capped at 100%, to reduce the potential for "over-weighting" by very high escapement in any single population. The mean fraction of parental seeding for the stratum will be used to select the parental seeding category for the stratum. At this time, decisions on how many parental seeding categories and how to distribute them are still pending, thus we present two alternatives for fractional parental seeding levels; one representing status quo (Tables 1-3) and an alternative described in the section titled "*Full-seeding Estimates*" that reduces the number of categories and enlarges the span of the lowest parental seeding category.

In areas where stocks from both the Cascade and Coastal strata co-mingle, the maximum allowable exploitation rate would be the lowest rate for either stratum. This strategy is intended to ensure that fishery strategies account for weaker populations present in the fishery. In areas where a fishery impacts only a single stratum, an allowable exploitation rate based on that stratum only could be allowed. As an example, if the status of the Cascade stratum was higher than that of the Coastal stratum, mainstem Columbia River fisheries that were conducted in areas where only Cascade stratum stocks were present could be allowed a higher exploitation rate.

Substantial uncertainties regarding potential differential exploitation rates on various stocks remain. These are largely related to 1) geographic and temporal distributional differences in ocean fisheries and, 2) differential exposure to mainstem Columbia River fisheries due to migration timing differences among stocks. The analyses presented here do not attempt to account for these uncertainties. Differential impacts in ocean fisheries are assumed to be adequately quantified by the FRAM/MSM processes. Additional analyses, including a migration timing study in the mainstem lower Columbia River, are underway to attempt to address the second issue, but cannot be incorporated at this time.

A suite of potential alternative harvest strategies are presented below. These are shown to provide an assessment of relative effects and provide a basis for discussion of the PVA model being used to conduct the risk assessments. They do not constitute proposals by the states at this time, nor are they intended to reflect the entire universe of potential strategies that could be evaluated. In developing these example harvest strategies, we used a step-wise approach incorporating sequential changes. We examined several alternative strategies and present nine of them here. While these alternative strategies are examples only, it is likely that Models 1 through 6 encompass the breadth of what will eventually be proposed, in terms of exploitation rates.

Due to the multitude of potential combinations of strategies and the large number of populations to be evaluated, we present the results of harvest strategy evaluations in a few ways. Summaries of some key results are provided in tabular format. To ease visual interpretation of the results, we have created a figure that aggregates and displays only a portion of this information (Figure 13). First, because assessments for the Scappoose, Grays/Chinook, and East Fork Lewis populations demonstrate high risk under any structure, including 0% exploitation, these are excluded from the aggregate figure. Similarly, risks for the Clackamas, Toutle, and Lower Cowlitz are generally quite low under all scenarios, and these are also excluded. Figure 13 summarizes and displays the risk for the remaining two "medium" populations in each stratum (Clatskanie and Elochoman/Skamokawa for Coast; Sandy, Lower Cowlitz, and Coweeman for Cascade) by showing: the maximum population risk in each stratum and the mean population risk for the two populations in each stratum. This approach is not intended to dismiss or ignore risk assessments for any individual population, and the risk values for all are shown in tabular format. This approach is designed to simplify interpretation by demonstrating the aggregate effects on "medium" populations that appear to show the most sensitivity to changes in harvest strategy.

It is critical to reiterate that these assessments are intended to demonstrate estimates of <u>relative risk</u> among various alternative management strategies. They are not intended to estimate <u>absolute risk</u>, nor should they be interpreted in this way.

We first examined fixed exploitation rate (ER) strategies that did not incorporate the use of a matrix. A no harvest (0% ER), an 8% ER, and a 15% ER strategy were modeled. For these examples, measures of full-seeding or marine survival are irrelevant. The remaining examples all incorporate the harvest matrix strategy in varying ways. These are presented in numerical order from Model 1 through Model 6.

Model 1 was constructed to reflect the current harvest strategy. In Model 1, the Sandy and Clackamas populations are used to index the status of the ESU, as is currently the case. In each annual simulation, the parental seeding of the Sandy and Clackamas populations are compared to their full-seeding measures. For the Clackamas population, the full-seeding measure is calculated as abundance at North Fork Dam, as it is currently. The categorical fractions of full-seeding remain unchanged from Tables 1-3 in this model – the critical threshold for parental seeding remains at 10% of full-seeding. The selected CRH jack index value is used to identify the marine survival category which, as an annual value not a population-specific value, applies to all populations identically. The matrix shown in Table 1 is used to assign an exploitation rate to the Sandy and Clackamas populations independently, and if they differ, the mean of the two rates is calculated. This exploitation rate is then applied to all populations. Thus, although the harvest impact is determined based on the status of only two populations, the effect of harvest is assessed for all. No differential harvest is allowed between the Cascade and Coast stratum populations in Model 1.

Model 2 is identical to Model 1, with the exception that it uses the higher exploitation rates shown in Table 3.

Model 3 builds upon conditions evaluated in Model 2 and continues the use of the matrix shown in Table 3. In this model, allowable exploitation rate is determined separately for each stratum. Within a stratum the mean full-seeding is calculated as the simple mean of the fractional seeding across all populations, with the exception that no population is allowed to contribute a fractional seeding that exceeds 100% of its full-seeding value. The mean full-seeding value is then used in the Table 3 matrix to derive an allowable exploitation rate for the stratum. This process is done for both strata. Because mainstem Columbia River fisheries can be structured to avoid Coast stratum stocks by conducting fishing in upstream areas, when the allowable exploitation rate for the Cascade stratum exceeds the rate for the Coast stratum the exploitation rate for the Cascade stratum is applied to the Cascade stratum and the Coast stratum exploitation rate is applied to the Coast stratum. However, in simulations where the Cascades stratum rate is the lower rate, harvest on all stocks is limited to the Cascades rate. For Model 3 and the remainder of the models, full-seeding for the Clackamas population is defined as a full-basin measure, not the abundance at North Fork Dam, as it has been historically and is in Models 1 and 2.

Model 4 introduces alternative parental seeding categories described in the section titled "*Full-seeding Estimates*". In this model, allowable exploitation rate is determined by applying the matrix shown below in Table 15. This model is otherwise identical to Model 3 in how it assigns full-seeding and exploitation rates for each stratum.

Table 15. Harvest matrix used for Model 4.

Parental Escapement (% of full-seeding)		Marine Survival Index (based on return of jacks per hatchery smolt) Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75	< 11.7%	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50	< 11.7%	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.33	< 11.7%	< 21.4%	< 22.7%	< 34.4%
Critical	< 0.33	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%

Model 5 modifies the original Table 3 matrix by reducing the allowable exploitation rates in critical parental seeding and critical marine survival categories (Table 16). This model is otherwise identical to Models 3 and 4 in how it assigns full-seeding and exploitation rates for each stratum.

Table 16. Harvest matrix used for Model 5.

Parental Escapement (% of full-seeding)		Marine Survival Index (based on return of jacks per hatchery smolt) Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75	< 8%	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50	< 8%	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.20	< 8%	< 21.4%	< 22.7%	< 34.4%
Very Low	0.20 to 0.10	< 8%	< 16.3%	< 18.1%	< 19.9%
Critical	< 0.10	0.0 – 8%	0.0 – 8%	0.0 – 8%	0.0 – 8%

Model 6 (Table 17) replicates the full-seeding fractions from Model 4 (Table 15), while reducing the allowable exploitation rates in critical parental seeding and critical marine survival categories, as in Model 5. This model is otherwise identical to Models 3-5 in how it assigns full-seeding and exploitation rates for each stratum.

Table 17. Harvest matrix used for Model 6.

Parental Escapement (% of full-seeding)		Marine Survival Index (based on return of jacks per hatchery smolt) Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75	< 8%	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50	< 8%	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.33	< 8%	< 21.4%	< 22.7%	< 34.4%
Critical	< 0.33	0.0 – 8%	0.0 – 8%	0.0 – 8%	0.0 – 8%

Because the PVA model provides a multitude of descriptive and summary outputs, interpreting the results of the various model evaluations can be daunting. In an effort to simplify this process, while providing adequate information regarding high priority metrics, we have reduced the outputs presented here to a few key metrics. These are (for each population):

- risk of extinction, defined by frequency of occurrence for 20-year (Table 18) and 100-year (Table 19) simulation periods
- frequency of spawner abundance equal to or greater than 100% of full-seeding for 20-year simulation periods (Table 20 and Figure 14)
- average annual exploitation rate for 20-year simulation periods, for evaluation of fishery performance (Table 18 and Figure 13)
- frequency distributions for mean full-seeding fractions by stratum (Figures 15 and 16)
- frequency distributions for minimum mean full-seeding fractions for the ESU (Table 21)
- frequency distributions of annual exploitation rates under Models 1 and 2 (Figure 17), and
- frequency of occurrence in matrix cells for Models 3-6 (Tables 22-25).

Output values at the 20-year mark are presented for use in evaluating these strategies, since our proposal would implement a chosen strategy for five years and because over that period, it is expected that improved data collection will allow for improved evaluations and refinements. However, recognizing that longer-term metrics are also important, we have also included a summary of 100-year extinction risk values (Table 19).

"Aggregated" risk assessments, as described earlier, for each of the example harvest structures are shown in Figure 13, as are average exploitation rates. Under fixed ERs of 0% and 8%, aggregate risks for "medium" populations are lower, as expected. Relative risks for a fixed 15% ER and the current matrix approach (Model 1) are approximately equal, although the current matrix approach allows for a slightly higher mean exploitation rate, a consequence of the abundance-based approach.

Model 2, which implements the current method of assessing full-seeding, but implements higher exploitation rates, demonstrates the highest level of relative risk for the Coast stratum of all the examples shown. It results in the highest mean exploitation rate for the Coast stratum, but the allowable exploitation rate for the Cascade stratum is essentially the same in Models 2-6, as are the stratum risk values.

The relative aggregate risk values shown in Figure 13 are higher for the Coast stratum than the Cascade stratum in all models. This is reflective of the generally lower status of Coast populations, and in Figure 13, is a direct result of the effects of the Elochoman/Skamokawa population, which demonstrates a higher level of risk than does the Clatskanie, or either of the two "medium" Cascade populations.

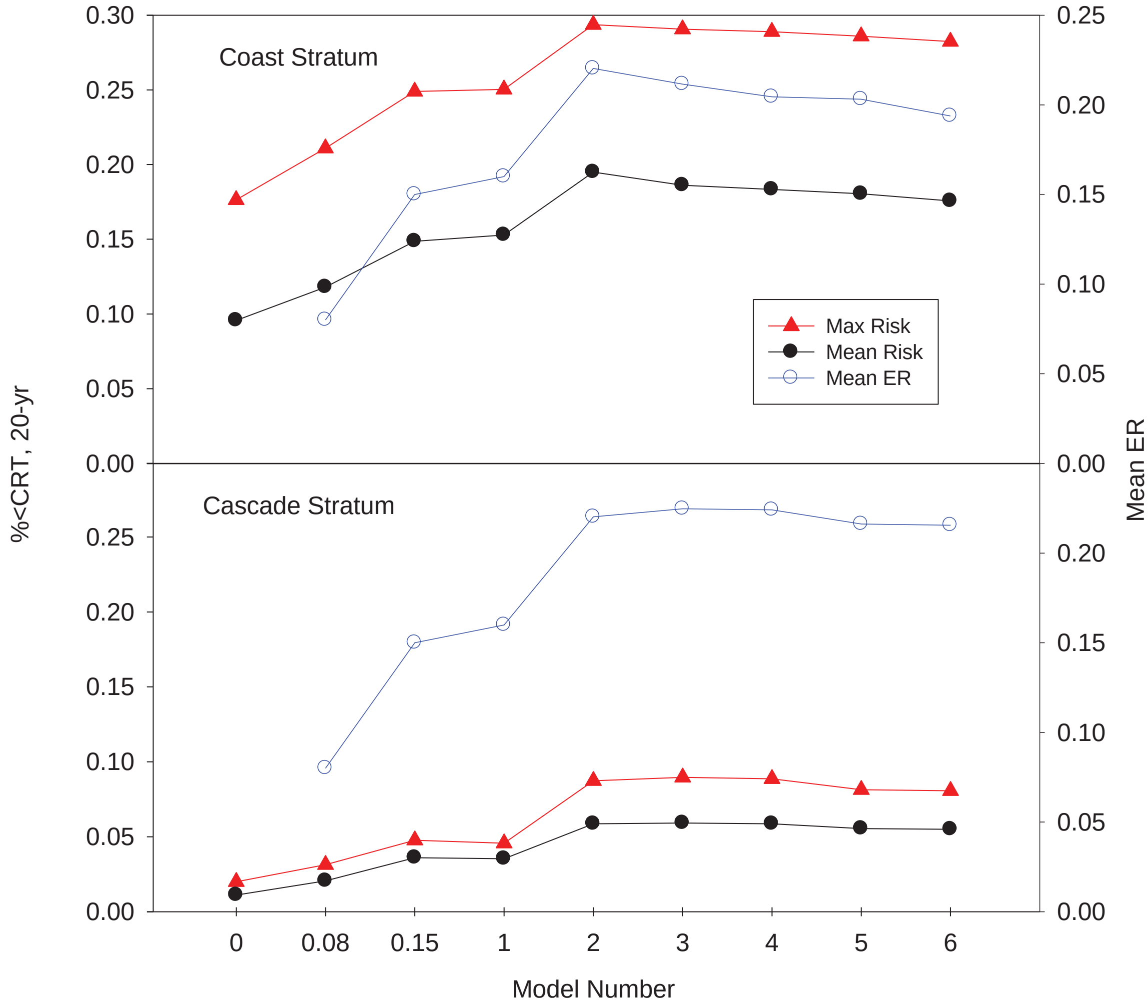


Figure 13. “Aggregate” stratum risks (%<CRT) and mean exploitation rates for 20-year simulations under example harvest structures.

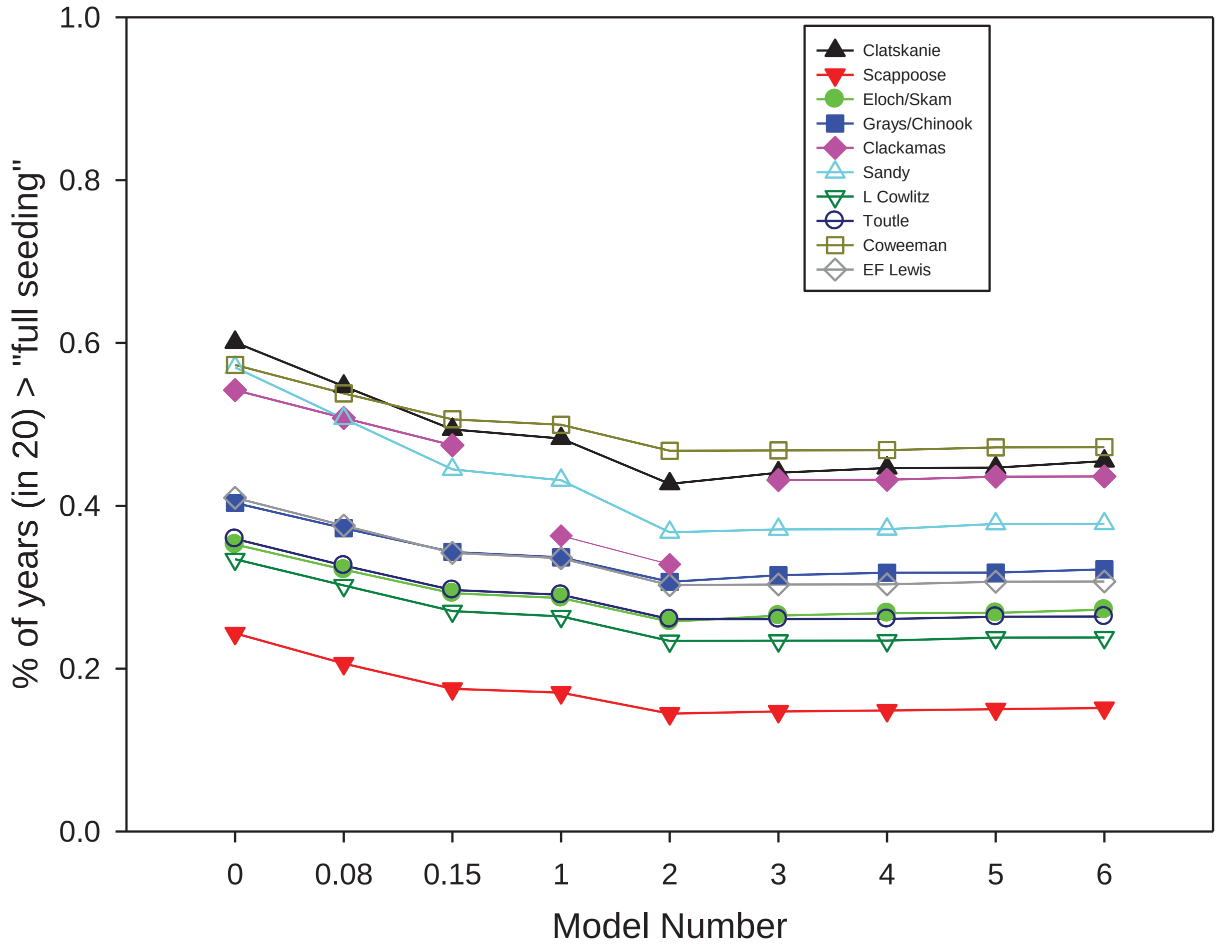


Figure 14. Frequency of annually exceeding 100% full-seeding in a 20-year time span for all populations under each example harvest structure. Shift in Clackamas for Models 1 and 2 is due to differences between current full-seeding fractions based on North Fork Dam counts and revised full-seeding fractions based on full basin counts.

Table 18. Extinction risk estimates (%<CRT) for 20-year simulations of example harvest structures.

	Coast				Cascade						Avg ER	
Model	Clatskanie	Scappoose	Eloch/Skam	Grays/Chinook	Clackamas	Sandy	L Cowlitz	Toutle	Coweeman	EF Lewis	Coast	Cascade
0%	0.015	0.373	0.176	0.683	0.000	0.007	0.014	0.006	0.020	0.467	0.00%	
8%	0.025	0.486	0.211	0.726	0.001	0.021	0.023	0.010	0.031	0.541	8.00%	
15%	0.048	0.599	0.249	0.765	0.002	0.048	0.034	0.015	0.045	0.623	15.00%	
1	0.055	0.623	0.250	0.765	0.001	0.045	0.036	0.015	0.046	0.638	16.00%	
2	0.096	0.739	0.294	0.797	0.002	0.087	0.054	0.021	0.068	0.710	22.03%	
3	0.082	0.709	0.291	0.795	0.003	0.090	0.053	0.021	0.067	0.713	21.16%	22.48%
4	0.078	0.700	0.289	0.794	0.003	0.089	0.053	0.021	0.067	0.713	20.45%	22.42%
5	0.075	0.694	0.286	0.792	0.003	0.081	0.049	0.021	0.064	0.706	20.31%	21.63%
6	0.069	0.682	0.282	0.790	0.003	0.081	0.049	0.020	0.064	0.705	19.38%	21.56%

Table 19. Extinction risk estimates (%<CRT) for 100-year simulations of example harvest structures.

	Coast				Cascade					
Model	Clatskanie	Scappoose	Eloch/Skam	Grays/Chinook	Clackamas	Sandy	L Cowlitz	Toutle	Coweeman	EF Lewis
0%	0.090	0.879	0.316	0.818	0.002	0.056	0.063	0.017	0.120	0.956
8%	0.190	0.959	0.395	0.871	0.004	0.148	0.095	0.031	0.184	0.982
15%	0.315	0.989	0.482	0.916	0.006	0.321	0.146	0.049	0.257	0.994
1	0.335	0.992	0.487	0.919	0.004	0.320	0.149	0.052	0.265	0.995
2	0.506	0.999	0.575	0.954	0.007	0.561	0.226	0.075	0.357	0.998
3	0.455	0.998	0.560	0.948	0.009	0.583	0.224	0.075	0.355	0.998
4	0.432	0.998	0.552	0.945	0.008	0.578	0.223	0.075	0.354	0.998
5	0.428	0.998	0.548	0.944	0.008	0.553	0.212	0.072	0.342	0.998
6	0.403	0.997	0.537	0.941	0.008	0.548	0.211	0.071	0.341	0.998

Table 20. Fraction of annual spawner abundances exceeding 100% full-seeding for 20-year simulations of example harvest structures.

	Coast				Cascade					
Model	Clatskanie	Scappoose	Eloch/Skam	Grays/Chinook	Clackamas	Sandy	L Cowlitz	Toutle	Coweeman	EF Lewis
0%	0.601	0.243	0.353	0.404	0.542	0.570	0.334	0.359	0.573	0.410
8%	0.547	0.206	0.322	0.372	0.508	0.507	0.302	0.327	0.538	0.376
15%	0.494	0.175	0.293	0.343	0.474	0.445	0.271	0.297	0.506	0.342
1	0.483	0.171	0.287	0.337	0.363	0.431	0.264	0.291	0.499	0.336
2	0.427	0.145	0.258	0.307	0.328	0.367	0.234	0.261	0.468	0.302
3	0.441	0.147	0.265	0.315	0.432	0.371	0.234	0.261	0.468	0.303
4	0.446	0.149	0.268	0.318	0.432	0.371	0.234	0.261	0.468	0.303
5	0.447	0.150	0.268	0.318	0.436	0.378	0.238	0.264	0.472	0.307
6	0.455	0.152	0.272	0.322	0.436	0.378	0.238	0.264	0.472	0.307

It is informative to examine the frequency of occurrence of parental seeding and exploitation rates in the various models. This can be helpful in examining the likely frequency of individual exploitation rate levels that may be experienced, as well as in assessing the status of populations or strata in relationship to their full-seeding metrics and the effects of harvest on these metrics. However, because of differences between various example harvest structures, it is difficult to create a "one size fits all" description of these outputs.

Figures 15 and 16 demonstrate the relative differences in mean full-seeding fractions for the Coast and Cascade strata occurring with each harvest structure model run. In general, as mean exploitation rate increases, the mean fraction of full-seeding within a stratum declines, as would be expected.

In any given simulation year within a model run, the mean full-seeding fraction for each stratum is calculated, and the minimum of the Coast or Cascade stratum is recorded. In Models 3-6, this value is what sets the exploitation rate. The frequencies of occurrence of this annual minimum in each parental category are shown in Table 21. Delineation of fractions of full-seeding below 50% differs for Models 4 and 6, so comparisons of lower fractions of full-seeding should be made cautiously. The delineations for fractions of seeding 50% or greater are equivalent among all models.

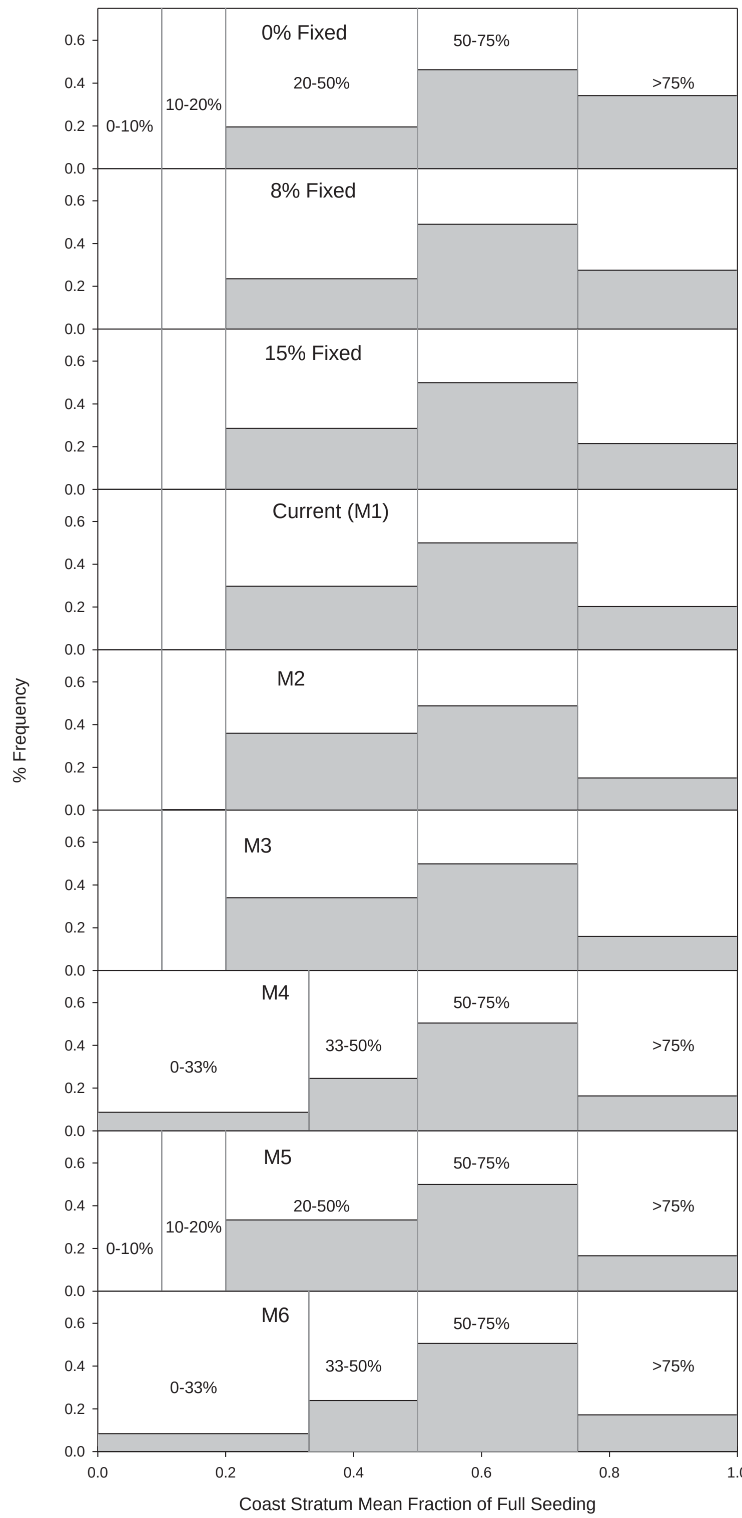


Figure 15. Frequency of occurrence of the mean fraction of full seeding for each model for the Coast stratum. Note differences in category delineations for Models 4 and 6 compared to remaining models. Vertical lines denote parental seeding category boundaries and labels are provided in each category for reference.

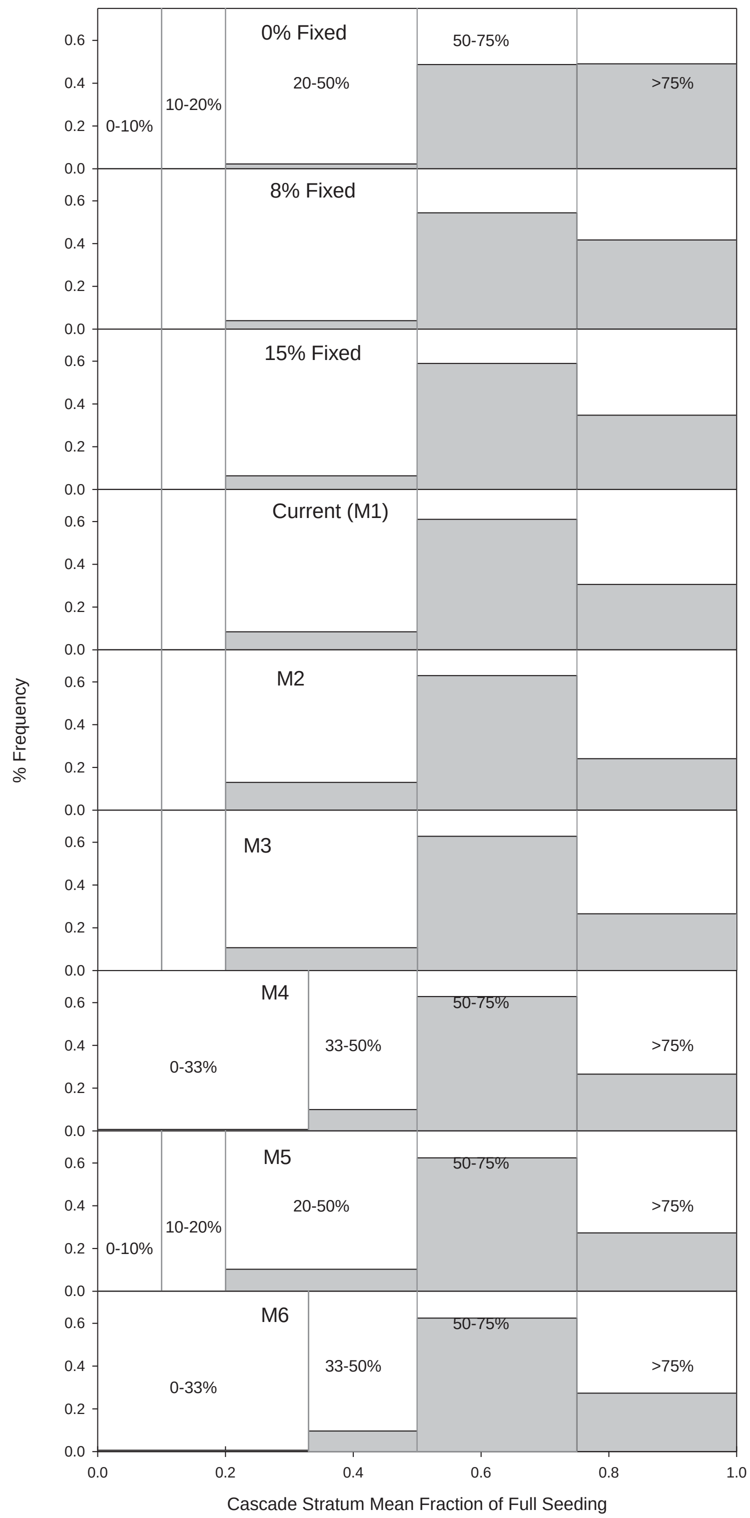


Figure 16. Frequency of occurrence of the mean fraction of full seeding for each model for the Cascade stratum. Note differences in category delineations for Models 4 and 6 compared to remaining models. Vertical lines denote parental seeding category boundaries and labels are provided in each category for reference.

Table 21. Frequency of ESU annual minimum full-seeding fractions for example harvest structures. Note different category delineations for Models 4 and 6. Fractions may not sum to 100% due to rounding.

Parental Seeding (% of Full)	Model Label						
	0%	8%	15%	M1	M2	M3	M5
>0.75	23%	17%	12%	10%	7%	8%	8%
0.5-0.75	56%	57%	55%	55%	50%	52%	52%
0.2-0.5	21%	26%	33%	35%	43%	40%	39%
0.1-0.2	0%	0%	0%	0%	0%	0%	0%
<0.1	0%	0%	0%	0%	0%	0%	0%
(alternate fractions)	M4	M6					
>0.75	8%	8%					
0.5-0.75	53%	53%					
0.33-0.5	30%	30%					
0.0-0.33	9%	9%					

Characterization of exploitation rates is simplified in fixed rate models and no detailed summaries are presented to discuss these rates. The frequencies of exploitation rate occurrences for matrix-based Models 1 and 2 are presented in a separate figure, because the method of averaging exploitation rates for Sandy and Clackamas creates a frequency distribution of rates that is very different than those for the remaining matrix-based models. Because the remaining matrix-based models (Models 3-6) base exploitation rates on assessments of the status of the ESU, frequencies of matrix cell occurrence are useful in assessing both harvest and status concurrently for these models. For these models, the frequencies of occurrence are provided in Tables 22-25 and can be compared directly to their associated harvest matrix (indicated in the table captions).

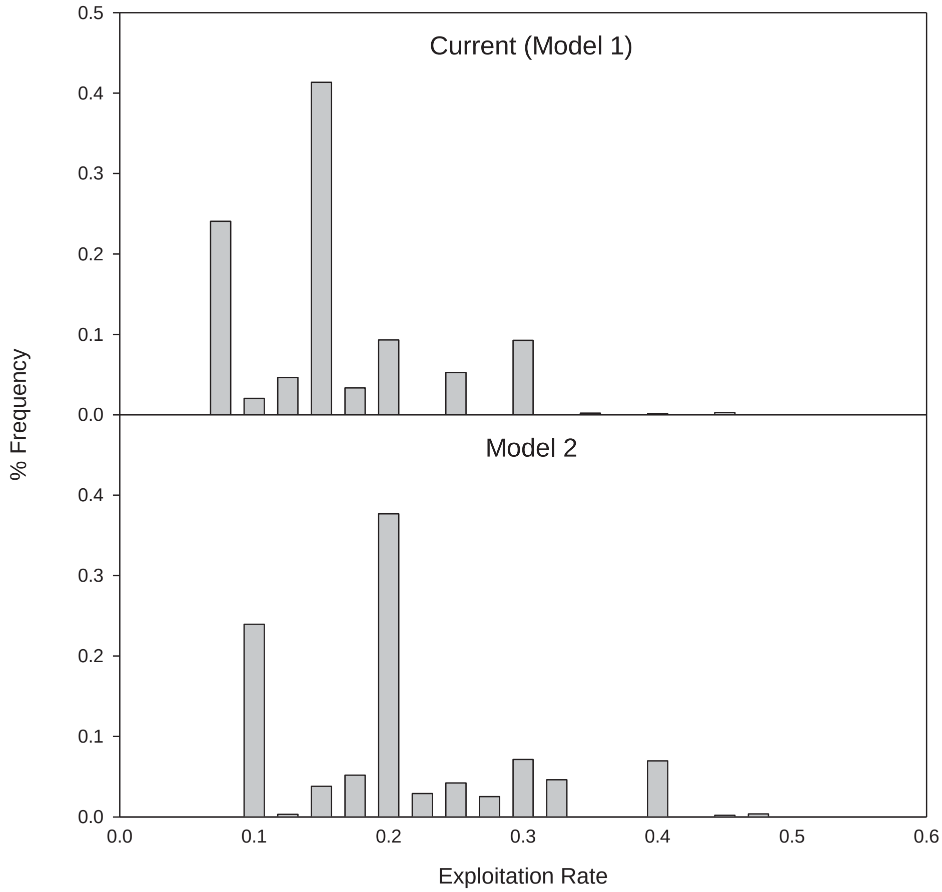


Figure 17. Frequency of exploitation rates in Models 1 and 2 (both based on Sandy/Clackamas status only). Increments of x-axis are 2.5% exploitation rate.

Table 22. Model 3, frequencies of occurrence in harvest matrix from Table 3. Exploitation rates in each cell are shown in parentheses for reference. Fractions may not sum to 100% due to rounding.

Parental Seeding	Marine Survival							
(% of Full)	Critical		Low		Medium		High	
>0.75	2%	(<0.117)	3%	(<0.214)	2%	(<0.405)	0%	(<0.574)
0.5-0.75	12%	(<0.117)	23%	(<0.214)	16%	(<0.292)	0%	(<0.498)
0.2-0.5	10%	(<0.117)	18%	(<0.214)	12%	(<0.227)	0%	(<0.344)
0.1-0.2	0%	(<0.117)	0%	(<0.163)	0%	(<0.181)	0%	(0.199)
<0.1	0%	(0.0-0.117)	0%	(0.0-0.117)	0%	(0.0-0.117)	0%	(0.0-0.117)

Table 23. Model 4, frequencies of occurrence in harvest matrix from Table 15. Exploitation rates in each cell are shown in parentheses for reference. Fractions may not sum to 100% due to rounding.

Parental Seeding (% of Full)	Marine Survival							
	Critical		Low		Medium		High	
>0.75	2%	(<0.117)	3%	(<0.214)	2%	(<0.405)	0%	(<0.574)
0.5-0.75	13%	(<0.117)	23%	(<0.214)	16%	(<0.292)	0%	(<0.498)
0.33-0.50	7%	(<0.117)	13%	(<0.214)	9%	(<0.227)	0%	(<0.344)
<0.33	2%	(0.0-0.117)	4%	(0.0-0.117)	3%	(0.0-0.117)	0%	(0.0-0.117)

Table 24. Model 5, frequencies of occurrence in harvest matrix from Table 16. Exploitation rates in each cell are shown in parentheses for reference. Fractions may not sum to 100% due to rounding.

Parental Seeding (% of Full)	Marine Survival							
	Critical		Low		Medium		High	
>0.75	2%	(<0.080)	4%	(<0.214)	2%	(<0.405)	0%	(<0.574)
0.5-0.75	12%	(<0.080)	23%	(<0.214)	16%	(<0.292)	0%	(<0.498)
0.2-0.5	9%	(<0.080)	18%	(<0.214)	12%	(<0.227)	0%	(<0.344)
0.1-0.2	0%	(<0.080)	0%	(<0.163)	0%	(<0.181)	0%	(0.199)
<0.1	0%	(0.0-0.080)	0%	(0.0-0.080)	0%	(0.0-0.080)	0%	(0.0-0.080)

Table 25. Model 6, frequencies of occurrence in harvest matrix from Table 17. Exploitation rates in each cell are shown in parentheses for reference. Fractions may not sum to 100% due to rounding.

Parental Seeding (% of Full)	Marine Survival							
	Critical		Low		Medium		High	
>0.75	2%	(<0.080)	4%	(<0.214)	3%	(<0.405)	0%	(<0.574)
0.5-0.75	13%	(<0.080)	24%	(<0.214)	16%	(<0.292)	1%	(<0.498)
0.33-0.50	7%	(<0.080)	13%	(<0.214)	9%	(<0.227)	0%	(<0.344)
<0.33	2%	(0.0-0.080)	4%	(0.0-0.080)	3%	(0.0-0.080)	0%	(0.0-0.080)

References

Araki, H., B. A. Berejikian, M. J. Ford, and M. S. Blouin. 2008. Fitness of hatchery-reared salmonids in the wild. Evolutionary Applications 2008:342-355.

Barrowman, N. J., R. A. Myers, R. Hilborn, D. G. Kehler, and C. A. Field. 2003. The variability among populations of coho salmon in the maximum reproductive rate and depensation. Ecological Applications 13:784-793.

Coleman, D. R., and A. L. Saipe. 1977. Simulating a lognormal time series with prescribed serial correlation. Management Science 23:1363-1364.

Fleming, I. A., and M. R. Gross. 1993. Breeding success of hatchery and wild coho salmon (Oncorhynchus kisutch) in competition. Ecological Applications 3:230-245.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York.

LCFRB. 2010. Washington Lower Columbia River Salmon Recovery and Fish and Wildlife Subbasin Plan. http://www.lcfrb.gen.wa.us/document_library_plans.htm.

McElhany, P., M., and 12 coauthors. 2006. Revised viability criteria for salmon and steelhead in the Willamette and lower Columbia basins. Willamette/Lower Columbia Technical Recovery Team and Oregon Department of Fish and Wildlife.

Myers, R. A., B. R. MacKenzie, K. G. Bowen, and N. J. Barrowman. 2001. What is the carrying capacity for fish in the ocean? A meta-analysis of population dynamics of North Atlantic cod. Canadian Journal of Fisheries and Aquatic Sciences 58:1464-1476.

NMFS. 2011. Proposed ESA Recovery Plan for the White Salmon River Watershed. National Marine Fisheries Service, Northwest Region. December 2011.

ODFW. 2005. Oregon Coastal Coho Assessment Part 2: Viability Criteria and Status Assessment of Oregon Coastal Coho. http://www.dfw.state.or.us/fish/CRP/coastal_coho_conservation_plan.asp.

ODFW. 2007. Appendix E: Conservation assessment and planning model (CAPM). Prepared for Oregon Department of Fish and Wildlife and National Marine Fisheries Service. http://www.nwfsc.noaa.gov/trt/wlc/trt_wlc_psr2007.cfm.

ODFW. 2010. Lower Columbia River Conservation and Recovery Plan for Oregon Populations of Salmon and Steelhead. http://www.dfw.state.or.us/fish/CRP/docs/lower-columbia/OR_LCR_Plan%20-%20Aug_6_2010_Final.pdf.

Peterman, R. M. 1981. Form of random variation in a salmon smolt-to-adult relations and its influence on production estimates. Canadian Journal of Fisheries and Aquatic Sciences 38:1113-1119.

PFMC. 1999. Final Amendment 13 to the Pacific Coast Salmon Plan. http://www.pcouncil.org/salmon/fishery-management-plan/adoptedapproved-amendments/amendment-13/.

PFMC. 2000. OCN Workgroup 2000 Review of Amendment 13 to the Pacific Coast Salmon Plan. Exhibit B.3.b, November 2000.

http://www.pcouncil.org/bb/2000/1100/B3b_OCN_WGR_Nov00BB.pdf.

Rawding, D., Buehrens, T., and B. Glaser. In draft.

Sharma, R., and R. Hilborn. 2001. Empirical relationships between watershed characteristics and coho salmon (Oncorhynchus kisutch) smolt abundance in 14 western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:1453-1463.

TRT. 2007. Willamette/Lower Columbia-Technical Recovery Team. Viability Status of Oregon Salmon and Steelhead Populations in the Willamette and Lower Columbia Basins. http://www.nwfsc.noaa.gov/trt/wlc/trt_wlc_psr2007.cfm.

Weitkamp, L.A. et al. 1995. Status review of coho salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-24. Seattle WA.

APPENDIX A: Revised Oregon Data Sets and Productivity Functions

Clackamas

We assembled ladder counts at North Fork Dam (NFD) from 1957-2012. In 1988-1990 and 2000-2002, small numbers of adults from an experimental program using naturally-produced Clackamas coho as broodstock were allowed to spawn upstream of NFD. These fish have been included as hatchery spawners in this analysis, despite their parental source.

Prior efforts to describe the proportion of wild spawners upstream and downstream of NFD had relied upon surrogate information for wild steelhead distribution. In order to estimate wild abundance downstream of NFD, we used NFD counts from 2002 through 2012 combined with ODFW estimates of total wild spawners from the OASIS program, which are available basin-wide from 2002 through 2012. We used a regression of the OASIS wild fish spawning estimate and the NFD wild fish count to estimate total basin wild fish abundance for years prior to 2002, and calculated the number of wild spawners downstream of NFD as the difference between the total wild estimate and known NFD wild fish counts.

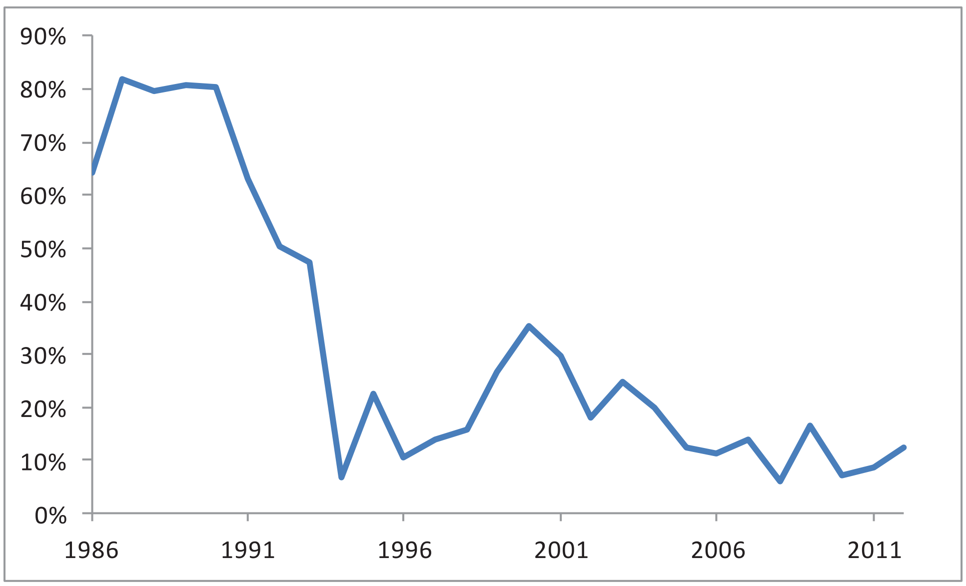
The incidence of hatchery coho upstream of NFD is believed to have been very low in most years. This conclusion is primarily based on the very low number of fin-clipped hatchery fish observed at the North Fork Dam counting facility (<2% of the run) in recent years with mass-marking of hatchery fish (ODFW 2010, Appendix C). Both hatchery and wild adults are included as spawners in this analysis, while adult recruits include only wild coho.

At the time the Oregon Recovery Plan analyses were conducted, only a few years of OASIS survey data were available for Clackamas coho. For the years that were available (2002-2006), the average proportion of hatchery spawners in the area downstream of NFD was 35%, and this value was used in the run reconstruction for the recovery plan.

The current analysis used a different approach to estimate the abundance of hatchery spawners downstream of North Fork Dam. The majority of hatchery spawners downstream of NFD are assumed to be fish produced at Eagle Creek Hatchery, the only coho facility on the Clackamas. We used annual smolt release and adult return data from Eagle Creek Hatchery from 2004–2011 to calculate smolt-to-adult return (SAR) for hatchery returns to the hatchery rack in those years. We then added the number of hatchery spawners from the OASIS surveys to the rack returns to derive a total basin hatchery adult return estimate over the same time period. These adult estimates were divided by the smolt releases to calculate SAR for total basin hatchery returns. We then used a regression of hatchery SAR versus total basin SAR over these years to back-calculate estimates of the number of hatchery fish that returned to the basin, but did not go to the hatchery rack, in previous years. At this time, the level of overlap in spawning surveys and rack returns cannot be evaluated to determine if any hatchery fish observed in surveys are subsequently captured at the hatchery rack; however, it is believed that overlap is relatively low.

Since the publication of the Oregon Recovery Plan, the fishery model that is used to estimate total exploitation rates for Columbia River coho stocks has been revised to include an estimation of harvest impacts on LCN coho, referred to as “MSM Exploitation rates” (MSM = mixed stock model). This model estimates impacts to Oregon LCN, Washington early run LCN, and Washington late run LCN from 1986 onward. Prior run reconstructions used different exploitation rate sources to estimate fishery removal. Although these are not always fully documented, it appears that OPI information was primarily used. This information is available from 1970 onward, and for the years 1986 onward is now derived from MSM (Appendix Figure

A-1). Because MSM estimates are only available for 1986 onward we did not alter exploitation rates for years prior to 1986 from those used in the Oregon Recovery Plan data sets, with one exception. We incorporated estimates of tributary sport harvest that were not accounted for in prior efforts by assuming an average 10% of wild fish present were encountered in fisheries. Of these, 100% were assumed to have been retained prior to advent of mark-selective fisheries in 2001, and 10% of non fin-clipped fish encountered in years since 2001 were assumed to have died due to post-release mortality. This addition has a relatively minor impact on the overall run reconstruction, but due to the relative changes in tributary harvest impacts resulting from mark-selective fisheries in the latter portion of the time series, we felt it was important to include. Many of the estimated exploitation rates used in prior reconstruction efforts were higher for portions of the period 1986-2008, particularly from 1986-1998. Thus, the revisions have the net effect of decreasing the reconstructed number of pre-harvest wild recruits in several years compared to prior estimates. The impact of this was significant for some years for the Clackamas population.



Appendix Figure A-1. Total estimated ocean and mainstem Columbia River fishing mortality for Oregon LCN coho populations, 1986-2012.

Over the entire time series available for the Clackamas population (1957-2012), the estimated annual wild spawner abundance has remained fairly stable, though with periods of increase and decline. In contrast, following an increase in the 1960s, estimated wild recruitment has declined dramatically, finally stabilizing at low levels by the mid-1990s (Figure 2). These patterns indicate that wild recruitment has not likely been primarily driven simply by wild spawner abundance.

Sandy

Prior to 2007, total spawner abundance estimates for Sandy coho were primarily derived from counts of fish passing Marmot Dam. Most coho habitat in the basin is upstream from the Marmot Dam site and most spawning has occurred in those areas, even following the removal of the dam in the fall of 2007.

Complete dam counts of coho for 1974 through 1977 and in 1983 are not available. Rather than interpolate these missing data, as was done in prior efforts, we shortened the time series for recruitment analysis to 1984-2008 – a period when complete dam counts were available for full brood returns. We estimated basin-wide fish abundance by using a regression of Marmot Dam counts from 2002-2007 versus OASIS spawner abundance estimates for the entire basin for the same time frame to interpolate the basin-wide wild spawner abundances in prior years from the Marmot counts.

As with the Clackamas population, the incidence of hatchery coho upstream of Marmot Dam in the majority of years was thought to be very low based on the very low number of fin-clipped hatchery fish observed at the Marmot Dam counting facility (<2% of the run) in years with mass-marking (ODFW 2010, Appendix C). From 1980 to 1986 excess hatchery fish returning to Sandy Hatchery and other lower Columbia hatchery facilities were released upstream of Marmot Dam. More than 50% of the spawning population was hatchery fish in those years. In our analysis, we accounted for hatchery spawners downstream of the Marmot Dam site using the same form of regression analysis of estimated basin and hatchery rack SARs as described for the Clackamas.

The same historic exploitation rate adjustments made to the Clackamas population were applied to the Sandy population. These revisions also resulted in changes to the Sandy data set but the differences were generally smaller than for the Clackamas. This is because returns to the Sandy River were relatively low during the period when exploitation rate changes were the largest, and also because adjustments made to the Sandy River data set to account for spawning downstream of Marmot Dam site resulted in little overall change from prior versions.

Over the time series available (1984-2012), the estimated annual wild spawner abundance has shown a clear pattern with higher abundances in the 1980s, low numbers in the 1990s, and a rebound to approximate 1980s levels since 2000 (Figure 3). As with the Clackamas population, the changes in wild spawner abundance have not necessarily been reflected in abundance of recruits. Estimated wild recruitment declined dramatically from the late 1980s through the 1990s, finally stabilizing at low levels by about 2000. These patterns seem to indicate that wild recruitment has not been primarily driven simply by wild spawner abundance.

Other Oregon populations

We examined a short time series of OASIS abundance information (2002-2009 brood years) for Scappoose Creek and Clatskanie River to get a sense of how similar the assumptions of productivity and abundance in the Oregon Recovery Plan were to those generated from the limited OASIS data. The same fishery rate information was used for these populations as was used for the Sandy and Clackamas populations.

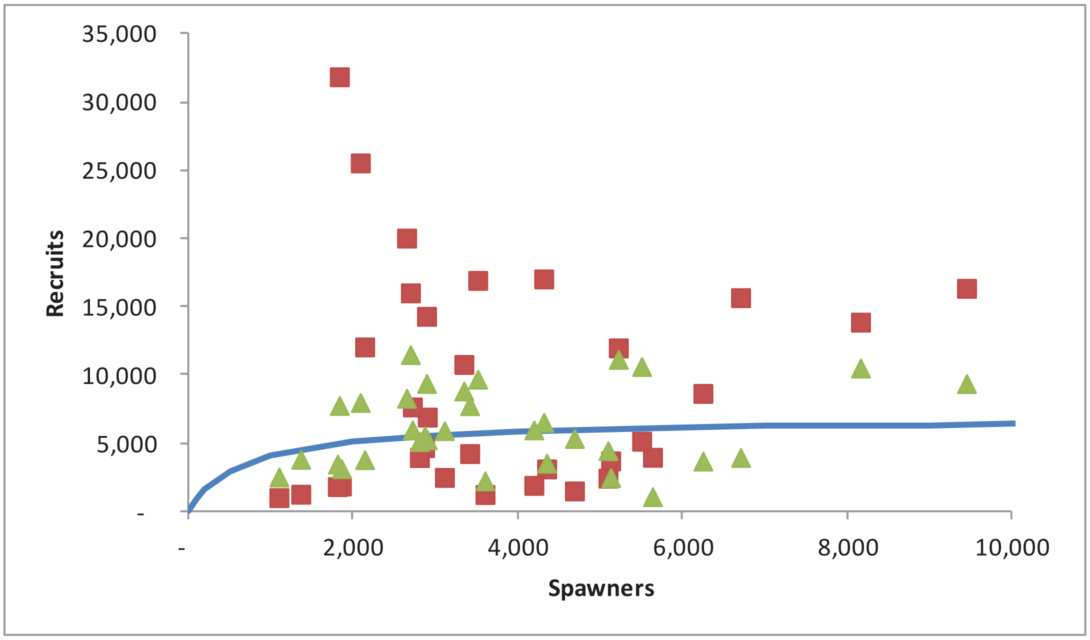
Appendix Table A-1. Clackamas run reconstruction data.

Adult Return Year	Below NFD Wild	Below NFD Hatchery	Above NFD Wild	Above NFD Hatchery	Total Spawners	Wild Recruits Post-Harvest	Fishery Rate[1]	Wild Recruits Pre-Harvest
1974	650	532	901		2,083	1,544	0.940	25,549
1975	628	931	1,133		2,692	1,450	0.909	16,024
1976	620	1,674	1,215		3,509	1,765	0.896	16,938
1977	651	286	893		1,829	3,624	0.886	31,862
1978	660	1,195	790		2,645	2,065	0.897	20,036
1979	627	2,545	1,138		4,310	3,037	0.822	17,044
1980	432	4,532	3,192		8,156	2,183	0.843	13,877
1981	596	832	1,469		2,896	1,353	0.804	6,914
1982	494	3,663	2,543		6,700	3,604	0.770	15,671
1983	584	705	1,599		2,888	4,603	0.678	14,304
1984	670	783	683		2,136	1,954	0.838	12,058
1985	435	1,612	3,169		5,216	2,203	0.816	11,989
1986	330	4,841	4,273		9,443	2,811	0.828	16,356
1987	607	761	1,347		2,715	1,361	0.822	7,660
1988	581	1,045	1,622	92	3,340	3,562	0.669	10,777
1989	518	3,312	2,293	120	6,243	3,881	0.551	8,653
1990	670	475	691	18	1,854	887	0.525	1,868
1991	439	2,069	3,123		5,631	3,336	0.160	3,971
1992	405	1,241	3,476		5,123	2,578	0.305	3,707
1993	719	208	168		1,095	813	0.196	1,011
1994	463	1,010	2,873		4,346	2,413	0.225	3,116
1995	542	1,019	2,036		3,597	941	0.241	1,240
1996	727	547	86		1,360	833	0.341	1,263
1997	559	450	1,854		2,864	3,006	0.358	4,686
1998	714	4,558	227		5,499	3,575	0.305	5,146
1999	725	4,257	108		5,090	1,981	0.188	2,439
2000	497	11,964	2,509	371	15,342	2,507	0.257	3,375
2001	438	10,895	3,137	1,144	15,613	2,874	0.209	3,631
2002	1,105	2,580	876	122	4,683	1,301	0.134	1,502
2003	390	294	2,117		2,801	3,464	0.123	3,949
2004	959	537	1,915		3,411	3,608	0.150	4,243
2005	79	504	1,222		1,805	1,694	0.068	1,818
2006	959	10,871	2,505		14,335	7,982	0.175	9,679
2007	239	582	3,369		4,190	1,757	0.080	1,910
2008	859	1,410	835		3,104	2,254	0.096	2,494
2009	2,521	2,978	5,461		10,960	1,580	0.133	1,822
2010	419	2,283	1,338		4,040			
2011	437	244	1,817		2,498			
2012	264	175	1,316		1,755			

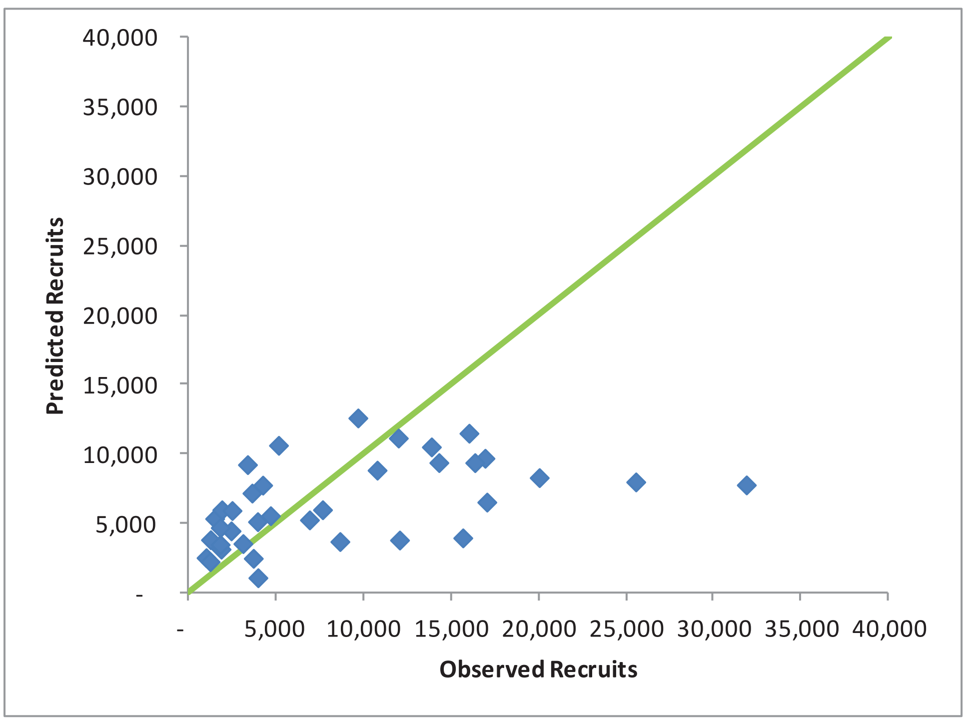
[1] Lagged at -3 years, i.e. fishery rate for calendar year 2012 is applied to post-harvest recruits in from spawner year 2009.

Appendix Table A-2. Clackamas spawner-recruit fitted model results.

		CRH Jack	Recruits		
Brood Year	Spawners	Index	Observed	Predicted	Residuals
1974	2,083	0.840	25,549	7,987	1.163
1975	2,692	1.416	16,024	11,491	0.333
1976	3,509	1.008	16,938	9,690	0.558
1977	1,829	0.851	31,862	7,771	1.411
1978	2,645	0.812	20,036	8,296	0.882
1979	4,310	0.212	17,044	6,533	0.959
1980	8,156	0.980	13,877	10,509	0.278
1981	2,896	-0.077	6,914	5,251	0.275
1982	6,700	-0.819	15,671	3,955	1.377
1983	2,888	1.010	14,304	9,377	0.422
1984	2,136	-0.563	12,058	3,798	1.155
1985	5,216	1.169	11,989	11,145	0.073
1986	9,443	0.747	16,356	9,375	0.557
1987	2,715	0.190	7,660	5,983	0.247
1988	3,340	0.849	10,777	8,833	0.199
1989	6,243	-0.937	8,653	3,690	0.852
1990	1,854	-0.852	1,868	3,140	-0.520
1991	5,631	-3.214	3,971	1,081	1.301
1992	5,123	-1.641	3,707	2,480	0.402
1993	1,095	-0.944	1,011	2,526	-0.915
1994	4,346	-0.936	3,116	3,542	-0.128
1995	3,597	-1.742	1,240	2,239	-0.591
1996	1,360	-0.313	1,263	3,820	-1.107
1997	2,864	0.031	4,686	5,552	-0.170
1998	5,499	1.068	5,146	10,622	-0.725
1999	5,090	-0.541	2,439	4,460	-0.603
2000	15,342	0.670	3,375	9,233	-1.006
2001	15,613	0.199	3,631	7,184	-0.682
2002	4,683	-0.183	1,502	5,347	-1.270
2003	2,801	-0.112	3,949	5,123	-0.260
2004	3,411	0.599	4,243	7,755	-0.603
2005	1,805	-0.649	1,818	3,475	-0.648
2006	14,335	1.257	9,679	12,594	-0.263
2007	4,190	0.054	1,910	5,979	-1.141
2008	3,104	0.125	2,494	5,925	-0.865
2009	10,960	-0.566	1,822	4,694	-0.946
				StDev	0.803
				AutoCorr	0.546



Appendix Figure A-2. Plot of observed (■) and predicted (▲) recruits from spawners, Clackamas 1974-2009 brood years.



Appendix Figure A-3. Actual versus predicted recruits, Clackamas 1974-2009 brood years.

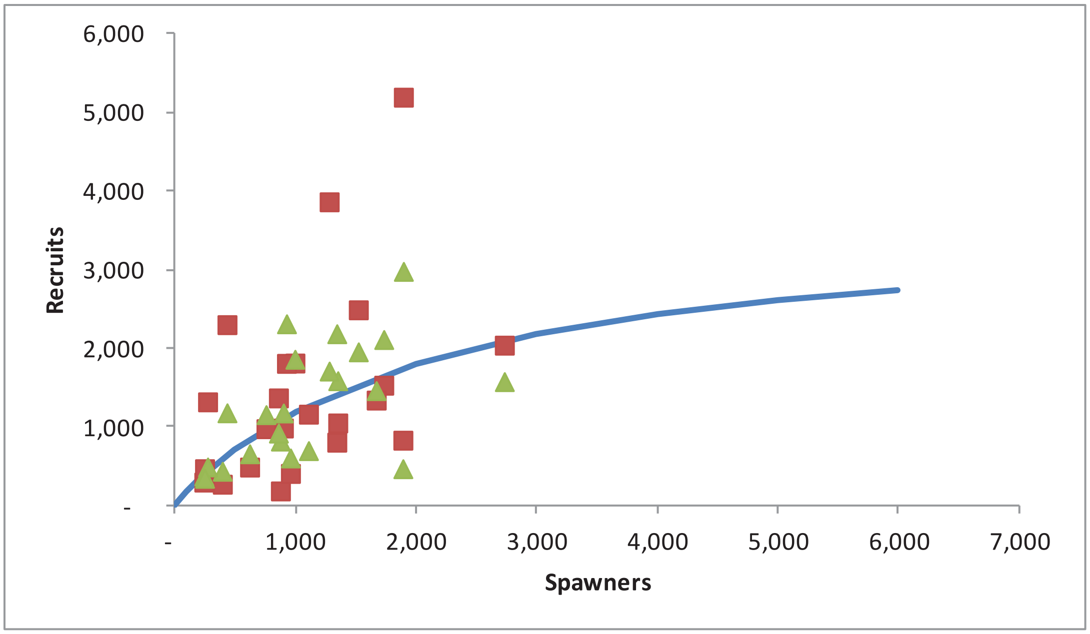
Appendix Table A-3. Sandy Run Reconstruction data.

Adult Return Year	Wild Adults Marmot D.	Wild Adults Total	Hatchery Adults Strays	Hatchery Adults Outplants	Total Spawners	Wild Recruits Post-Harvest	Fishery Rate[1]	Wild Recruits Pre-Harvest
1984	798	925	159	800	1,884	1,390	0.838	8,579
1985	1,445	1,665	140	600	2,405	1,735	0.816	9,439
1986	1,546	1,780	221	1,000	3,002	2,508	0.828	14,593
1987	1,205	1,390	128		1,519	443	0.822	2,492
1988	1,506	1,735	158		1,893	1,718	0.669	5,196
1989	2,182	2,508	222		2,730	916	0.551	2,042
1990	376	443	174		617	233	0.525	491
1991	1,491	1,718	171		1,888	700	0.160	833
1992	790	916	189		1,105	810	0.305	1,164
1993	193	233	157		391	220	0.196	273
1994	601	700	173		873	145	0.225	188
1995	697	810	146		956	311	0.241	410
1996	181	220	18		237	198	0.341	300
1997	116	145	123		268	847	0.358	1,321
1998	261	311	118		429	1,600	0.305	2,303
1999	162	198	45		243	382	0.188	470
2000	730	847	145		993	1,348	0.257	1,815
2001	1,388	1,600	130		1,730	1,213	0.209	1,533
2002	310	382	515		897	856	0.134	988
2003	1,173	1,348	0		1,348	923	0.123	1,052
2004	1,025	1,213	127		1,340	687	0.150	808
2005	717	856	0		856	1,277	0.068	1,371
2006	822	923	0		923	1,493	0.175	1,810
2007	617	687	66		753	901	0.080	980
2008	NA	1,277	0		1,277	3,494	0.096	3,866
2009	NA	1,493	174		1,667	1,165	0.133	1,343
2010	NA	901	128		1,029			
2011	NA	3,494	319		3,813			
2012	NA	1,165	33		1,198			

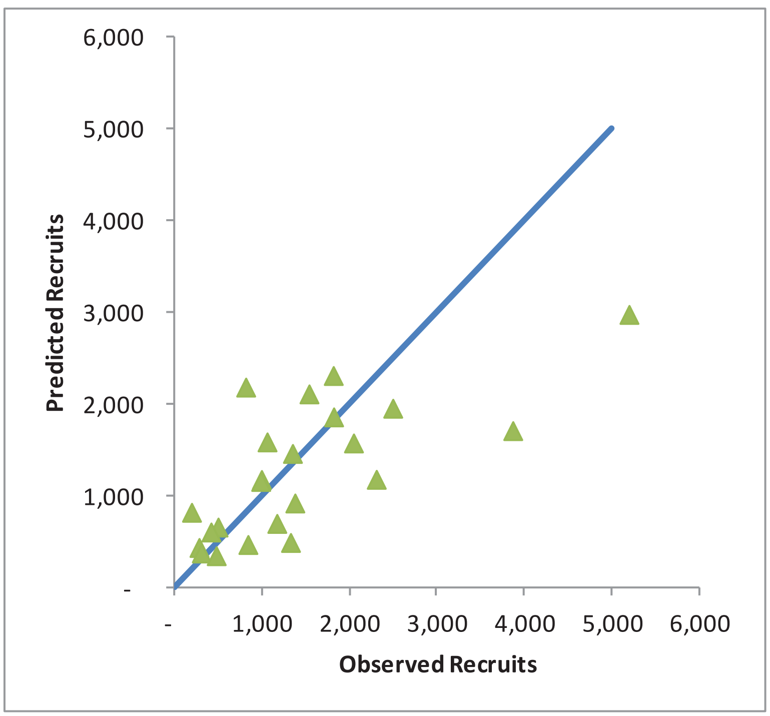
[1] Lagged at -3 years, i.e. fishery rate for calendar year 2012 is applied to post-harvest recruits in from spawner year 2009.

Appendix Table A-4. Sandy spawner-recruit fitted model results.

		CRH Jack	Recruits		
Brood Year	Spawners	Index	Observed	Predicted	Residuals
1987	1,519	0.190	2,492	1,957	0.242
1988	1,893	0.849	5,196	2,980	0.556
1989	2,730	-0.937	2,042	1,578	0.258
1990	617	-0.852	491	661	-0.296
1991	1,888	-3.214	833	470	0.572
1992	1,105	-1.641	1,164	701	0.508
1993	391	-0.944	273	438	-0.472
1994	873	-0.936	188	822	-1.477
1995	956	-1.742	410	607	-0.392
1996	237	-0.313	300	378	-0.230
1997	268	0.031	1,321	493	0.986
1998	429	1.068	2,303	1,181	0.668
1999	243	-0.541	470	348	0.301
2000	993	0.670	1,815	1,862	-0.026
2001	1,730	0.199	1,533	2,114	-0.321
2002	897	-0.183	988	1,180	-0.177
2003	1,348	-0.112	1,052	1,590	-0.413
2004	1,340	0.599	808	2,187	-0.996
2005	856	-0.649	1,371	923	0.395
2006	923	1.257	1,810	2,313	-0.245
2007	753	0.054	980	1,158	-0.168
2008	1,277	0.125	3,866	1,713	0.814
2009	1,667	-0.566	1,343	1,464	-0.086
				StDev	0.582
				AutoCorr	0.266



Appendix Figure A-4. Plot of actual (■) and predicted (▲) recruits from spawners, Sandy 1987-2009 brood years.



Appendix Figure A-5. Actual versus predicted recruits, Sandy 1987-2009 brood years.

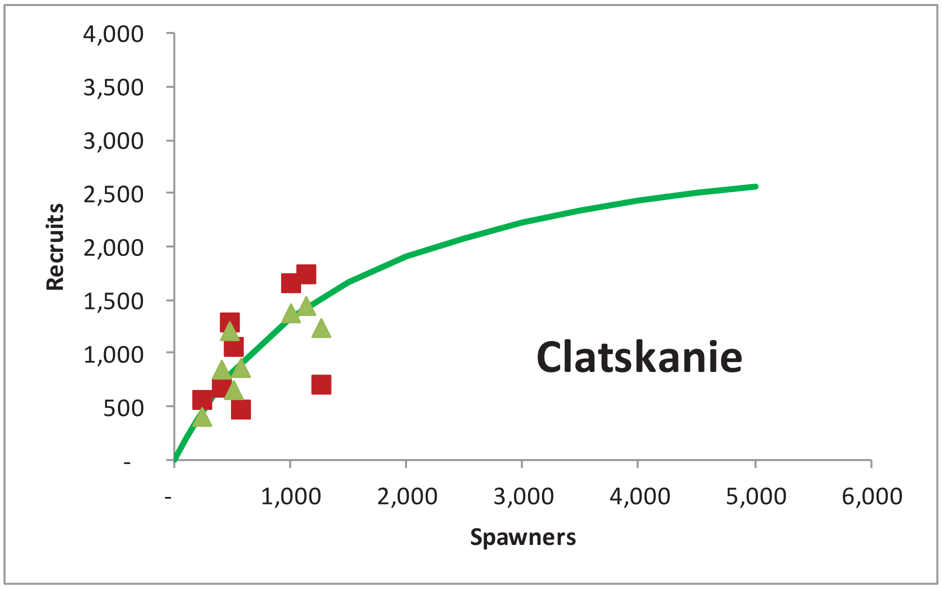
Appendix Table A-5. Clatskanie River run reconstruction data.

Adult Return Year	Adults Wild	Adults Hatchery	Total Spawners	Fishery Rate[1]	Wild Recruits Post-Harvest	Wild Recruits Pre-Harvest
2002	104	125	229	0.134	494	570
2003	563	0	563	0.123	421	480
2004	398	0	398	0.150	583	686
2005	494	7	501	0.068	995	1,068
2006	421	46	467	0.175	1,070	1,297
2007	583	543	1,126	0.080	1,609	1,749
2008	995	0	995	0.096	1,506	1,666
2009	1,070	186	1,256	0.133	619	714
2010	1,609	165	1,774			
2011	1,506	47	1,553			
2012	619	69	688			

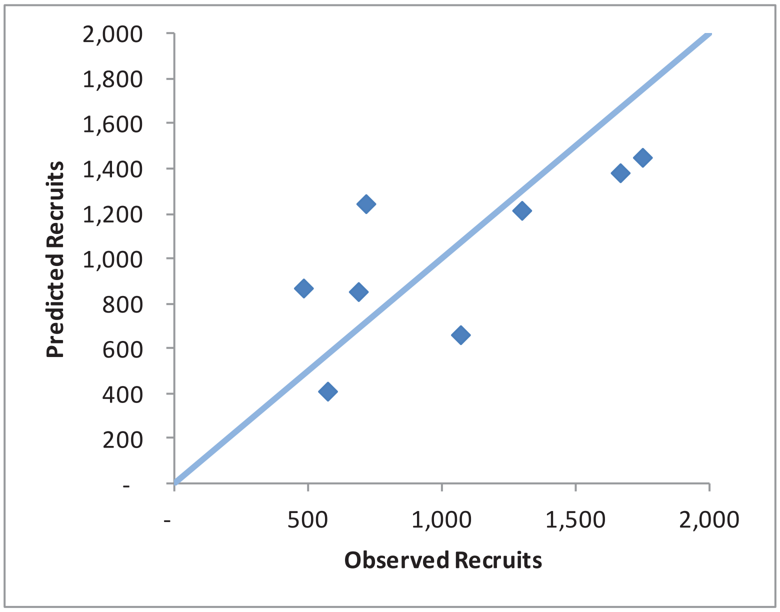
[1] Lagged at -3 years, i.e. fishery rate for calendar year 2012 is applied to post-harvest recruits in from spawner year 2009.

Appendix Table A-6. Clatskanie spawner-recruit fitted model results.

Brood Year	Spawners	CRH Jack Index	Recruits Observed	Recruits Predicted	Residuals
2002	229	-0.182	570	411	0.327
2003	563	-0.112	480	870	-0.595
2004	398	0.599	686	854	-0.220
2005	501	-0.649	1,068	663	0.477
2006	467	1.257	1,297	1,216	0.065
2007	1,126	0.054	1,749	1,452	0.186
2008	995	0.125	1,666	1,383	0.186
2009	1,256	-0.565	714	1,246	-0.557



Appendix Figure A-6. Plot of actual (■) and predicted (▲) recruits from spawners, Clatskanie 2002-2009 brood years.



Appendix Figure A-7. Actual versus predicted recruits, Clatskanie 2002-2009 brood years.

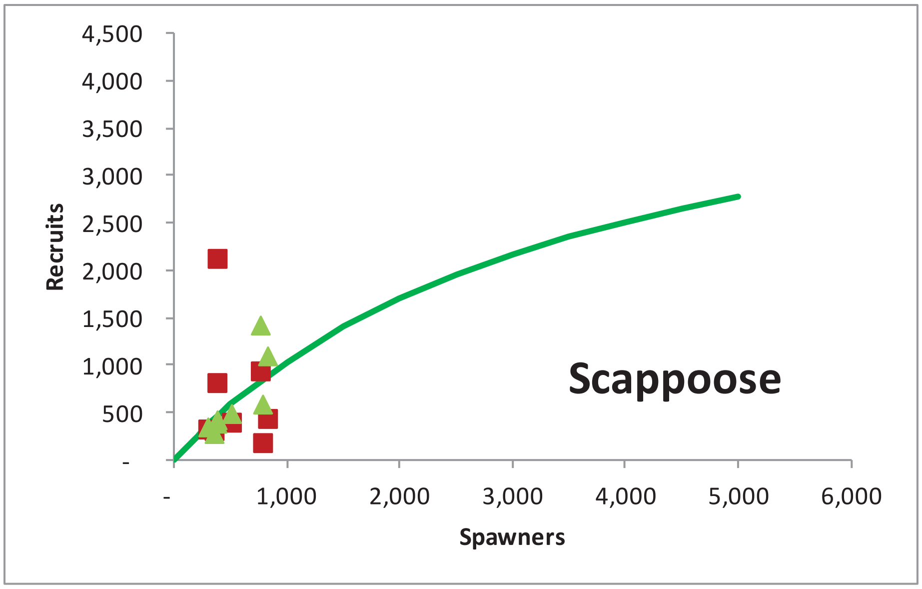
Appendix Table A-7. Scappoose Creek run reconstruction data.

Adult Return Year	Adults Wild	Hatchery	Total Spawners	Fishery Rate[1]	Wild Recruits Post-Harvest	Pre-Harvest
2002	502	0	502	0.134	348	402
2003	336	37	373	0.123	719	820
2004	755	67	822	0.150	375	441
2005	348	0	348	0.068	292	313
2006	719	39	758	0.175	778	943
2007	375	0	375	0.080	1,960	2,131
2008	292	0	292	0.096	298	330
2009	778	0	778	0.133	161	186
2010	1,960	0	1,960			
2011	298	0	298			
2012	161	49	210			

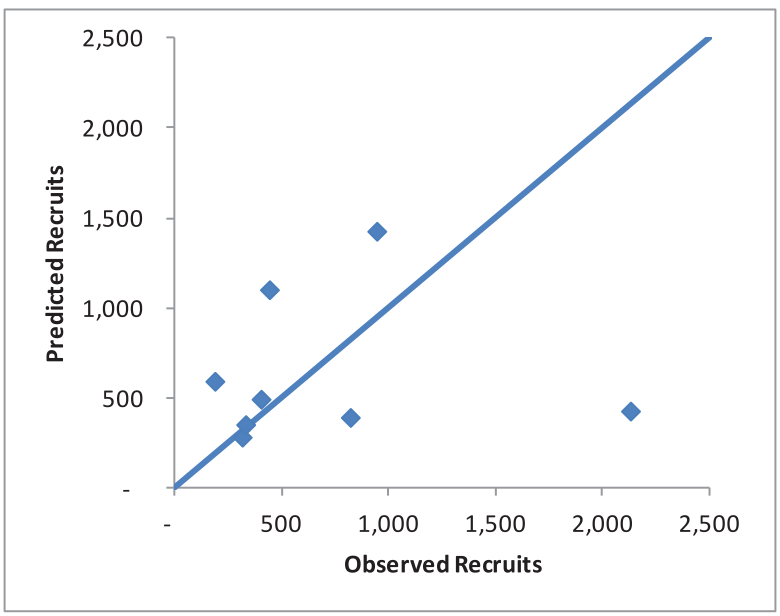
[1] Lagged at -3 years, i.e. fishery rate for calendar year 2012 is applied to post-harvest recruits in from spawner year 2009.

Appendix Table A-8. Scappoose spawner-recruit fitted model results.

Brood Year	Spawners	Jack Index	Recruits Observed	Predicted	Residuals
2002	502	-0.182	402	508	-0.235
2003	373	-0.112	820	399	0.720
2004	822	0.599	441	999	-0.818
2005	348	-0.649	313	314	0.000
2006	758	1.257	943	1,161	-0.208
2007	375	0.054	2,131	423	1.616
2008	292	0.125	330	345	-0.044
2009	778	-0.565	186	650	-1.253



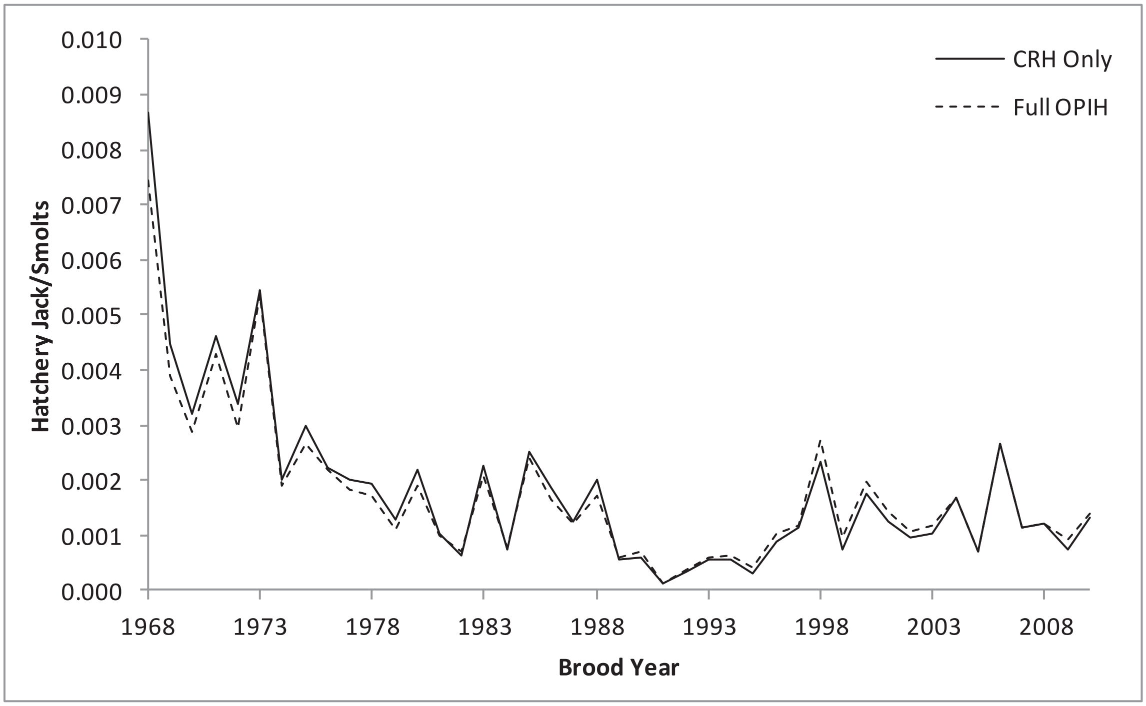
Appendix Figure A-8. Plot of actual (■) and predicted (▲) recruits from spawners, Scappoose 2002-2009 brood years.



Appendix Figure A-9. Actual versus predicted recruits, Scappoose 2002-2009 brood years.

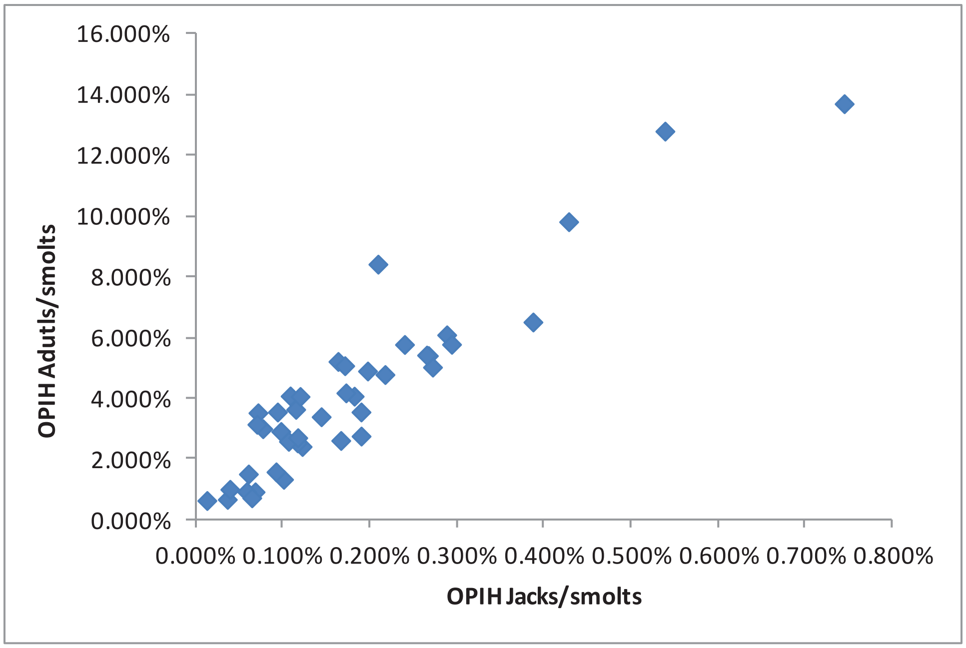
APPENDIX B: Description of the CRH jack index and implementation in the PVA

The recruitment covariate used is the OPI hatchery jack index, confined to Columbia River hatchery (CRH) stocks only. The annual values of this parameter differ only slightly (Appendix Figure A-1) from the full OPI area measure, which uses stocks from all OPI area basins. The CRH jack index is CRH jack returns divided by CRH smolts released for the same brood year. While OPI hatchery production and returns are currently almost entirely made up of Columbia River-produced fish, prior to about 1990, substantial production from areas outside the Columbia Basin, including the Oregon and California coasts was also present.

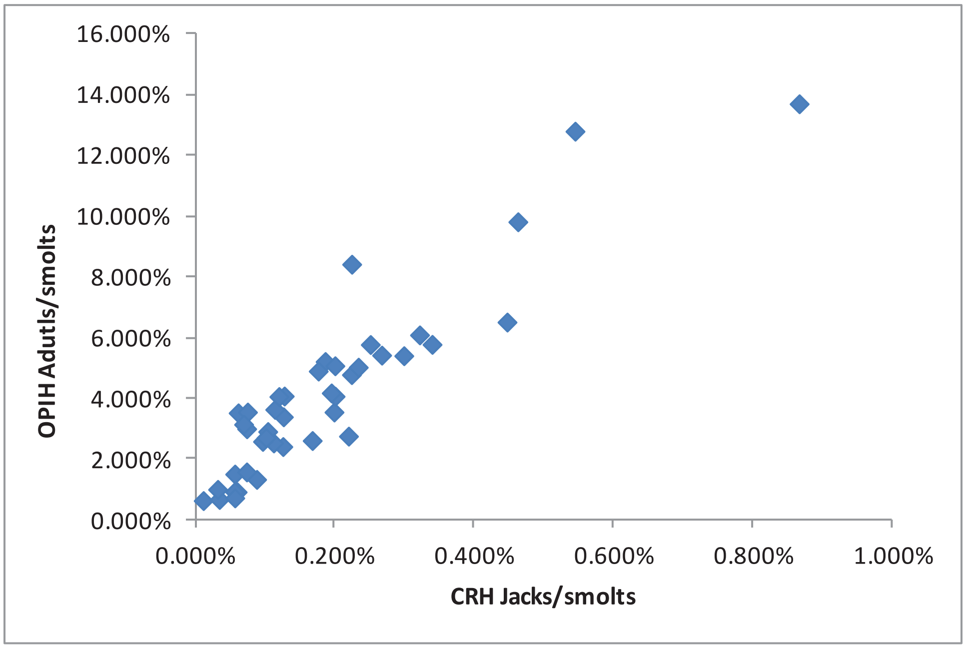


Appendix Figure B-1. Time series of CRH jack index and OPIH jack index, 1968-2010 brood years.

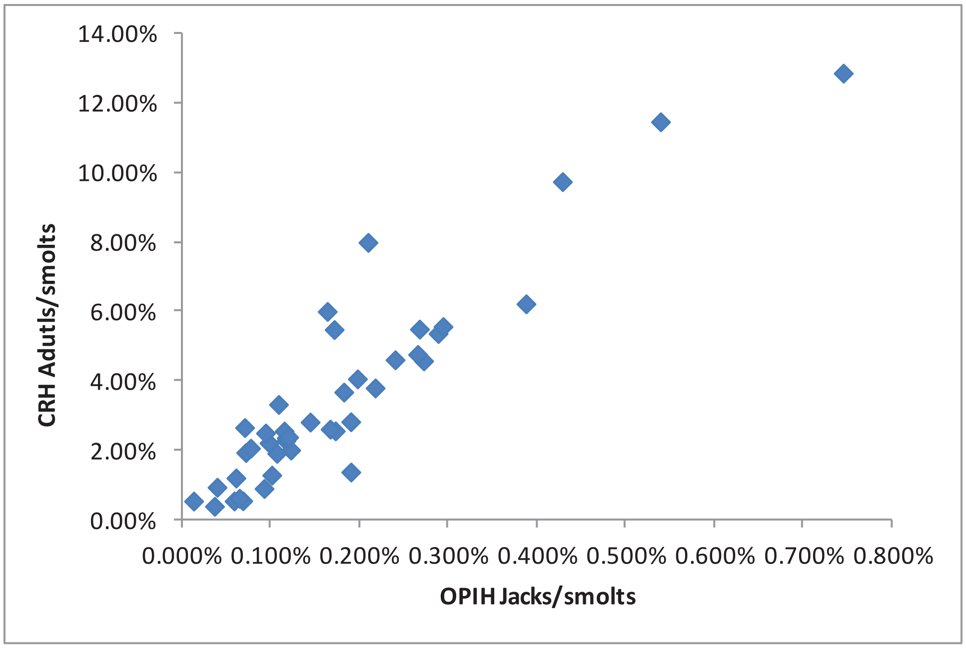
The OPIH jack index and the CRH jack index are highly correlated to both OPI area hatchery adult survival (ocean abundance of adults divided by smolts released) and Columbia River hatchery adult survival (Appendix Figures B-2 and B-3). Both jack indices are based on hatchery fish only and are primarily influenced by production from the Columbia River. At this time, similar information for wild stocks is generally not available. As full life cycle monitoring is improved and expanded across the ESU, it is hoped that a more direct measure of wild coho survival can be obtained.



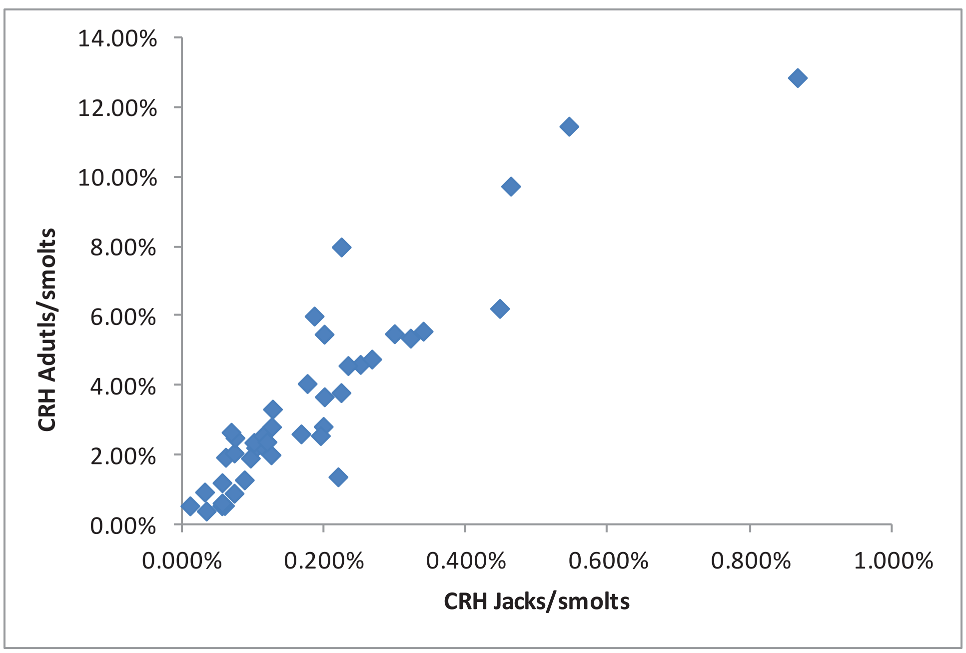
Appendix Figure B-2. Relationship between OPIH jack index and OPIH adult survival, 1968-2010 brood years.



Appendix Figure B-3. Relationship between CRH jack index and OPIH adult survival, 1968-2010 brood years.

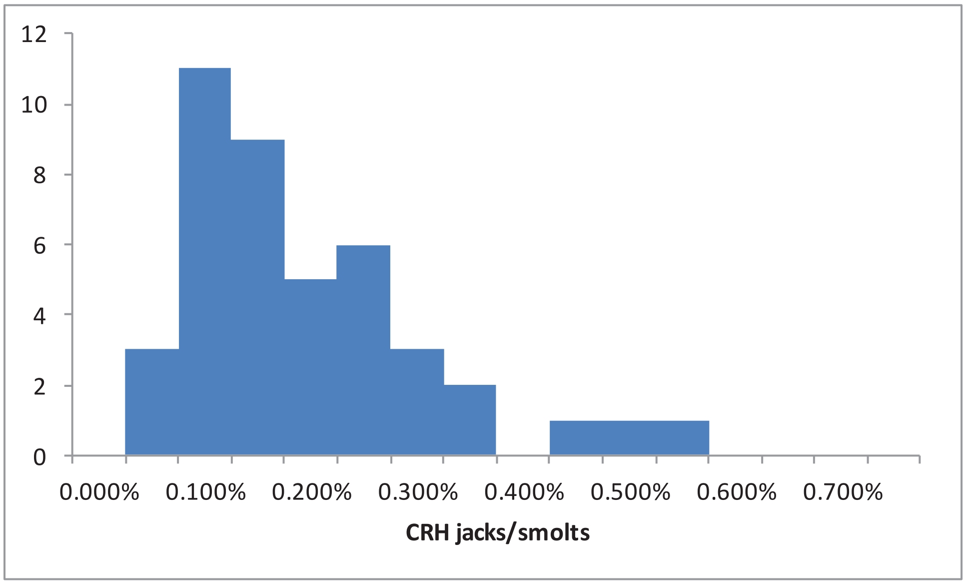


Appendix Figure B-4. Relationship between OPIH jack index and CRH adult survival, 1968-2010 brood years.



Appendix Figure B-5. Relationship between CRH jack index and CRH adult survival, 1968-2010 brood years.

The frequency distribution of the CRH jack index is not normally distributed (Appendix Figure B-6); low to medium values dominate the time series, with relatively few large values. This pattern also occurs in the OPIH jack index.



Appendix Figure B-6. Frequency distribution of CRH jack index.

Simulated values are generated within the PVA by using the procedure of Coleman and Saipe (1977), which simulates log-normal derivatives without requiring log-transformation, and allows the PVA model to select random draws that reflect the distribution of the original data.

The function used to simulate annual model values for ε_t, the simulated CRH, is:

$\varepsilon_t = e^{\rho'(ln(\varepsilon_{t-1})-\mu')+z_t\sigma'\sqrt{(1-\rho'^2)}+\mu'}$, where z_t is a standard normal deviate with a mean of zero and standard deviation of one (Coleman and Saipe 1977), and

$\mu' = ln\left(\frac{1}{\sqrt{\mu(1+\frac{\sigma^2}{\mu^2})}}\right)$; mean of log-transformed CRH values, and

$\sigma'^2 = ln\left(1+\frac{\sigma^2}{\mu^2}\right)$; standard deviation of log-transformed CRH values, and

$\rho' = \frac{ln\left(1+\frac{\rho\sigma^2}{\mu^2}\right)}{ln\left(1+\frac{\sigma^2}{\mu^2}\right)}$; autocorrelation among log-transformed annual CRH values.

The model simulates a full 100-year time series for each iteration. For use in the recruitment function, the model standardizes these values to create the recruitment covariate by subtracting the mean value from the annual values and dividing the result by the standard deviation for the series (Appendix Table B-1).

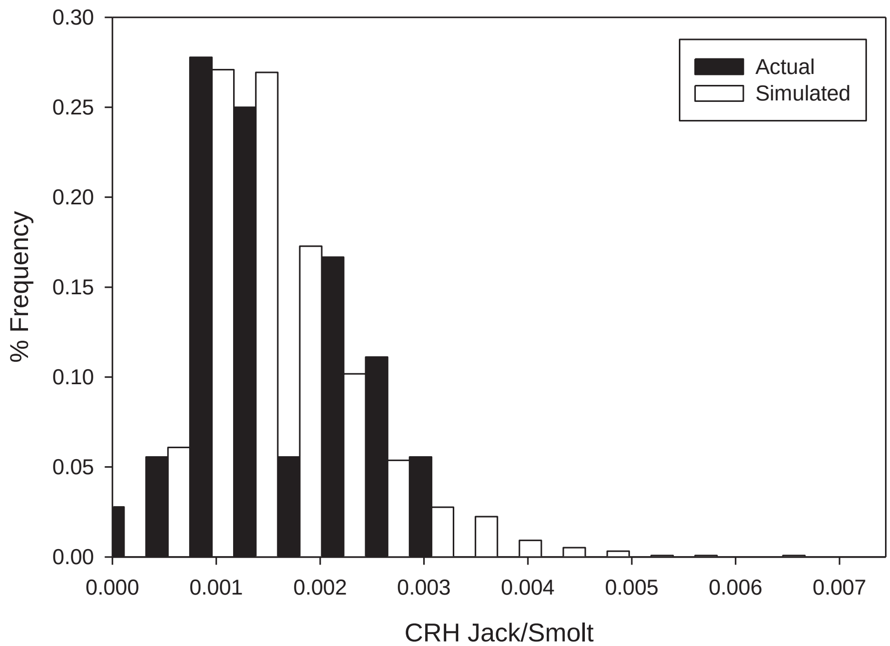
Appendix Table B-1. CRH jack/smolt values and CRH index for recruitment function.

Brood Year	CRH jack/ smolt	CRH index*
1974	0.00199	0.840
1975	0.00299	1.416
1976	0.00224	1.008
1977	0.00201	0.851
1978	0.00195	0.812
1979	0.00128	0.212
1980	0.00220	0.980
1981	0.00104	-0.077
1982	0.00061	-0.819
1983	0.00224	1.010
1984	0.00074	-0.563
1985	0.00251	1.169
1986	0.00186	0.747
1987	0.00126	0.190
1988	0.00200	0.849
1989	0.00056	-0.937
1990	0.00060	-0.852
1991	0.00011	-3.214
1992	0.00034	-1.641
1993	0.00056	-0.944
1994	0.00056	-0.936
1995	0.00032	-1.742
1996	0.00088	-0.313
1997	0.00112	0.031
1998	0.00234	1.068
1999	0.00075	-0.541
2000	0.00176	0.670
2001	0.00126	0.199
2002	0.00096	-0.183
2003	0.00101	-0.112
2004	0.00168	0.599
2005	0.00069	-0.649
2006	0.00267	1.257
2007	0.00114	0.054
2008	0.00120	0.125
2009	0.00073	-0.566

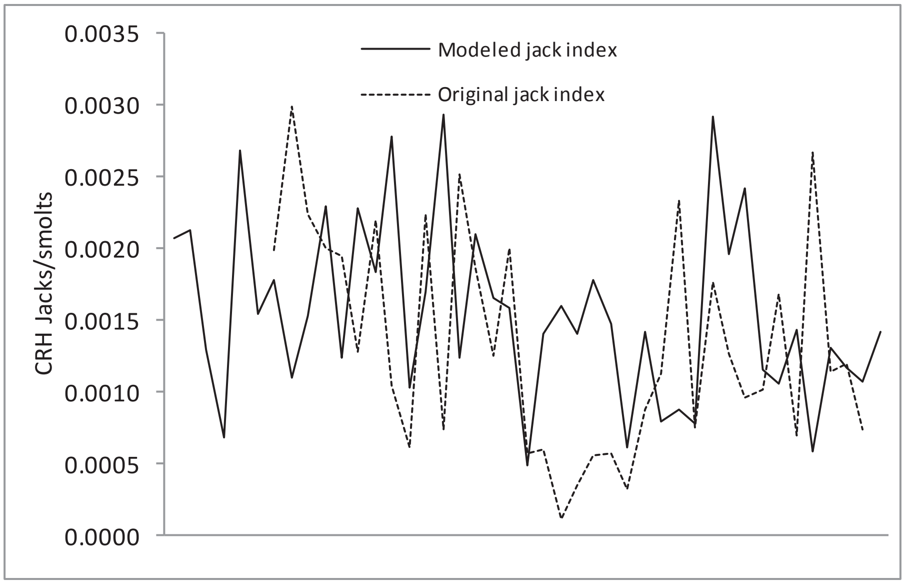
*Index is the deviation of each ln(CRH) value from the mean ln(CRH) value divided by the standard deviation of all ln(CRH) values.

Using a simulation of a single random draw, a visual comparison can be made between frequencies of occurrence in the native data used to build the model and the random draw created by the model (Appendix Figure B-7). Although the stochastic effects in the model will cause the modeled frequencies to be altered in each iteration, multiple replications of this process have confirmed that the shape of the modeled CRH distribution remains similar across iterations and does not substantially deviate from the patterns observed in the native data.

Similarly, a comparison between the original time series of CRH jack/smolt and a simulated series demonstrates a similar range and pattern of occurrence between the observed and model generated indices (Appendix Figure B-8). These assessments indicate that the model is able to create an appropriate replication of the CRH time series for each iteration, and that the modeled CRH values are unlikely to be biased compared to the observed data.



Appendix Figure B-7. Frequency distribution of simulated CRH jack/smolt values and original CRH jack/smolt values for a single random draw.



Appendix Figure B-8. Comparison of actual CRH jack/smolt values and modeled values for an equal time series from a single random draw.

APPENDIX C: VisualBasic Model Code

```
Option Explicit
'Dimension variables
    Public i    'iteration count
    Public y    'year count
    'define populations
    Public pop1
    Public pop2
    Public pop3
    Public pop4
    Public pop5
    Public pop6
    Public pop7
    Public pop8
    Public pop9
    Public pop10
    Public Nyr 'global
    Public iter 'global
    Public Fopt 'fishery type - global
    Public FrateNin 'global
    Public FrateN(110) 'global
    Public FrateCoast(110)
    Public FrateCascade(110)
    Public Fcv 'fishery error'global
    Public Fvar(110) 'global
    'starting spawner abundances
    Public NSpn3ago1 'pop1
    Public NSpn2ago1
    Public NSpn1ago1
    Public NSpn3ago2 'pop2
    Public NSpn2ago2
    Public NSpn1ago2
    Public NSpn3ago3 '
    Public NSpn2ago3
    Public NSpn1ago3
    Public NSpn3ago4 '
    Public NSpn2ago4
    Public NSpn1ago4
    Public NSpn3ago5 '
    Public NSpn2ago5
    Public NSpn1ago5
    Public NSpn3ago6 '
    Public NSpn2ago6
    Public NSpn1ago6
    Public NSpn3ago7 '
    Public NSpn2ago7
    Public NSpn1ago7
    Public NSpn3ago8 '
    Public NSpn2ago8
    Public NSpn1ago8
    Public NSpn3ago9 '
    Public NSpn2ago9
    Public NSpn1ago9
    Public NSpn3ago10 'pop10
    Public NSpn2ago10
    Public NSpn1ago10
    Public alpha1 'pop1 alpha
    Public alpha2
    Public alpha3
    Public alpha4
    Public alpha5
    Public alpha6
    Public alpha7
    Public alpha8
    Public alpha9
    Public alpha10
    Public beta1 'pop1 beta
    Public beta2
    Public beta3
    Public beta4
    Public beta5
```

```
Public beta6
Public beta7
Public beta8
Public beta9
Public beta10
Public full1 'pop1 full seeding threshold
Public full2
Public full3
Public full4
Public full5
Public full6
Public full7
Public full8
Public full9
Public full10
Public phos1
Public phos2
Public phos3
Public phos4
Public phos5
Public phos6
Public phos7
Public phos8
Public phos9
Public phos10
Public gamma1  'pop1 gamma coefficient for env variable
Public gamma2
Public gamma3
Public gamma4
Public gamma5
Public gamma6
Public gamma7
Public gamma8
Public gamma9
Public gamma10
Public limitS1 'pop1 large spawner number where recruitment no longer declines with increasing spawners
Public limitS2
Public limitS3
Public limitS4
Public limitS5
Public limitS6
Public limitS7
Public limitS8
Public limitS9
Public limitS10
Public limitR1 'pop 1 max recruitment allowed
Public limitR2
Public limitR3
Public limitR4
Public limitR5
Public limitR6
Public limitR7
Public limitR8
Public limitR9
Public limitR10
Public Depopt 'global
Public depthreshold
Public RecrFailThresh1 'pop1 recruitment fail threshold
Public RecrFailThresh2
Public RecrFailThresh3
Public RecrFailThresh4
Public RecrFailThresh5
Public RecrFailThresh6
Public RecrFailThresh7
Public RecrFailThresh8
Public RecrFailThresh9
Public RecrFailThresh10
Public RMSE1 'pop1 std error of resids
Public RMSE2
Public RMSE3
```

```
    Public RMSE4
    Public RMSE5
    Public RMSE6
    Public RMSE7
    Public RMSE8
    Public RMSE9
    Public RMSE10
    Public autocorr1  'pop1 autocorrelation of residuals
    Public autocorr2
    Public autocorr3
    Public autocorr4
    Public autocorr5
    Public autocorr6
    Public autocorr7
    Public autocorr8
    Public autocorr9
    Public autocorr10
    Public fit1 'hatch fitness pop1
    Public fit2
    Public fit3
    Public fit4
    Public fit5
    Public fit6
    Public fit7
    Public fit8
    Public fit9
    Public fit10
    Public hatch1 'washington 2010-2011 avg hatch escape (Oregon = 0)
    Public hatch2
    Public hatch3
    Public hatch4
    Public hatch5
    Public hatch6
    Public hatch7
    Public hatch8
    Public hatch9
    Public hatch10
    Public CRT1  'critical risk threshold pop1
    Public CRT2
    Public CRT3
    Public CRT4
    Public CRT5
    Public CRT6
    Public CRT7
    Public CRT8
    Public CRT9
    Public CRT10
    Public Gen  'Weighted mean generation time by species for calc of moving avg - glboal
'state variables
    Public fraction1(5000, 110) 'fraction of seeding pop1
    Public fraction2(5000, 110)
    Public fraction3(5000, 110)
    Public fraction4(5000, 110)
    Public fraction5(5000, 110)
    Public fraction6(5000, 110)
    Public fraction7(5000, 110)
    Public fraction8(5000, 110)
    Public fraction9(5000, 110)
    Public fraction10(5000, 110)
    Public seed1(110)
    Public seed2(110)
    Public seed3(110)
    Public seed4(110)
    Public seed5(110)
    Public seed6(110)
    Public seed7(110)
    Public seed8(110)
    Public seed9(110)
    Public seed10(110)
    Public Mindex1(5000, 110)
```

```
Public Mindex2(5000, 110)
Public Mindex3(5000, 110)
Public Mindex4(5000, 110)
Public Mindex5(5000, 110)
Public Mindex6(5000, 110)
Public Mindex7(5000, 110)
Public Mindex8(5000, 110)
Public Mindex9(5000, 110)
Public Mindex10(5000, 110)
Public spmeanCoast(5000, 110)
Public spmeanCascade(5000, 110)
Public seedCoast(110)
Public seedCascade(110)
Public spmean(5000, 110)
Public tgFrateN(110) '
Public tgFrateCoast(110)
Public tgFrateCascade(110)
Public tgFrateClack(110)
Public tgFrateSandy(110)
Public NspnN1(5000, 110) 'natural origin spawners pop1
Public NspnN2(5000, 110) 'pop2
Public NspnN3(5000, 110)
Public NspnN4(5000, 110)
Public NspnN5(5000, 110)
Public NspnN6(5000, 110)
Public NspnN7(5000, 110)
Public NspnN8(5000, 110)
Public NspnN9(5000, 110)
Public NspnN10(5000, 110)
Public NocnN1(5000, 110)      'natural origin ocean recruits pop1
Public NocnN2(5000, 110)
Public NocnN3(5000, 110)
Public NocnN4(5000, 110)
Public NocnN5(5000, 110)
Public NocnN6(5000, 110)
Public NocnN7(5000, 110)
Public NocnN8(5000, 110)
Public NocnN9(5000, 110)
Public NocnN10(5000, 110)
Public NEscN1(5000, 110) 'natural escaping fishery pop1
Public NEscN2(5000, 110) 'natural escaping fishery
Public NEscN3(5000, 110)
Public NEscN4(5000, 110)
Public NEscN5(5000, 110)
Public NEscN6(5000, 110)
Public NEscN7(5000, 110)
Public NEscN8(5000, 110)
Public NEscN9(5000, 110)
Public NEscN10(5000, 110)
Public NAdN1(5000, 110) 'natural adults returning to freshwater
Public NAdN2(5000, 110) 'natural adults returning to freshwater
Public NAdN3(5000, 110)
Public NAdN4(5000, 110)
Public NAdN5(5000, 110)
Public NAdN6(5000, 110)
Public NAdN7(5000, 110)
Public NAdN8(5000, 110)
Public NAdN9(5000, 110)
Public NAdN10(5000, 110)
Public NHarN1(5000, 110) 'natural adults harvested pop1
Public NHarN2(5000, 110) 'natural adults harvested
Public NHarN3(5000, 110)
Public NHarN4(5000, 110)
Public NHarN5(5000, 110)
Public NHarN6(5000, 110)
Public NHarN7(5000, 110)
Public NHarN8(5000, 110)
Public NHarN9(5000, 110)
Public NHarN10(5000, 110)
```

```
'working variables
Public MIndex(5000, 110) 'global environ index for recr formula and Matrix
Public OPIHrand(110) 'global
Public OPIHmean 'global
Public OPIHdev 'global
Public OPIHcorr 'global
Public OPIHvar(5000, 110) 'global
Public lastopihvar
Public OPIHind(5000, 110) 'global variable for random gen of CLRS series
Public OPIH(5000, 110)
Public OPIHJacks(110) 'both pops
Public Z1(110) 'pop1 svar random driver
Public Z2(110)
Public Z3(110)
Public Z4(110)
Public Z5(110)
Public Z6(110)
Public Z7(110)
Public Z8(110)
Public Z9(110)
Public Z10(110)
Public SRvar1(5000, 110) 'pop1 recr variation
Public SRvar2(5000, 110)
Public SRvar3(5000, 110)
Public SRvar4(5000, 110)
Public SRvar5(5000, 110)
Public SRvar6(5000, 110)
Public SRvar7(5000, 110)
Public SRvar8(5000, 110)
Public SRvar9(5000, 110)
Public SRvar10(5000, 110)
Public eSRvarLast1 'pop1
Public eSRvarLast2
Public eSRvarLast3
Public eSRvarLast4
Public eSRvarLast5
Public eSRvarLast6
Public eSRvarLast7
Public eSRvarLast8
Public eSRvarLast9
Public eSRvarLast10
Public Nsp1 'pop1
Public Nsp2
Public Nsp3
Public Nsp4
Public Nsp5
Public Nsp6
Public Nsp7
Public Nsp8
Public Nsp9
Public Nsp10

'counter variables
Public a '1 esc freq counter for pop 1
Public b '2
Public c '3
Public d '4
Public e '5
Public f '6
Public g '7
Public h '8
Public m '9
Public o '10
Public n
Public x
Public j
Public s
Public q
Public p
Public r
```

```
Public ss
Public pp
Public qq
Public k
Public CountEsc1(110)
Public CountEsc2(110)
Public CountEsc3(110)
Public CountEsc4(110)
Public CountEsc5(110)
Public CountEsc6(110)
Public CountEsc7(110)
Public CountEsc8(110)
Public CountEsc9(110)
Public CountEsc10(110)
Public CounttgF(110)
Public CountF(110)
Public CntFrate(5000, 110)
Public CntSeed1
Public CntSeed2
Public CntSeed3
Public CntSeed4
Public CntSeed5
Public CntSeed6
Public CntSeed7
Public CntSeed8
Public CntSeed9
Public CntSeed10
Public CntSeedCoast
Public CntSeedCascade
Public CntSeedN
Public CntGenetic1 'gen <CRT long term
Public CntGenetic2
Public CntGenetic3
Public CntGenetic4
Public CntGenetic5
Public CntGenetic6
Public CntGenetic7
Public CntGenetic8
Public CntGenetic9
Public CntGenetic10
Public CntGeneticST1 'gen < CRT short term
Public CntGeneticST2
Public CntGeneticST3
Public CntGeneticST4
Public CntGeneticST5
Public CntGeneticST6
Public CntGeneticST7
Public CntGeneticST8
Public CntGeneticST9
Public CntGeneticST10
Public CntFull1
Public CntFull2
Public CntFull3
Public CntFull4
Public CntFull5
Public CntFull6
Public CntFull7
Public CntFull8
Public CntFull9
Public CntFull10
Public CntFullST1
Public CntFullST2
Public CntFullST3
Public CntFullST4
Public CntFullST5
Public CntFullST6
Public CntFullST7
Public CntFullST8
Public CntFullST9
Public CntFullST10
```

```
Public MovGenAvg1(5000, 110)
Public MovGenAvg2(5000, 110)
Public MovGenAvg3(5000, 110)
Public MovGenAvg4(5000, 110)
Public MovGenAvg5(5000, 110)
Public MovGenAvg6(5000, 110)
Public MovGenAvg7(5000, 110)
Public MovGenAvg8(5000, 110)
Public MovGenAvg9(5000, 110)
Public MovGenAvg10(5000, 110)
Public flagGR1(5000) 'flag <crt gens
Public flagGR2(5000)
Public flagGR3(5000)
Public flagGR4(5000)
Public flagGR5(5000)
Public flagGR6(5000)
Public flagGR7(5000)
Public flagGR8(5000)
Public flagGR9(5000)
Public flagGR10(5000)
Public flagGRST1(5000) 'flag <crt short term
Public flagGRST2(5000)
Public flagGRST3(5000)
Public flagGRST4(5000)
Public flagGRST5(5000)
Public flagGRST6(5000)
Public flagGRST7(5000)
Public flagGRST8(5000)
Public flagGRST9(5000)
Public flagGRST10(5000)
Public flagfull1(5000, 110)
Public flagfull2(5000, 110)
Public flagfull3(5000, 110)
Public flagfull4(5000, 110)
Public flagfull5(5000, 110)
Public flagfull6(5000, 110)
Public flagfull7(5000, 110)
Public flagfull8(5000, 110)
Public flagfull9(5000, 110)
Public flagfull10(5000, 110)
Public ENEsc1 'sum natural spawners long term
Public ENEsc2
Public ENEsc3
Public ENEsc4
Public ENEsc5
Public ENEsc6
Public ENEsc7
Public ENEsc8
Public ENEsc9
Public ENEsc10
Public ENEsc201 'sum natural spawners short term
Public ENEsc202
Public ENEsc203
Public ENEsc204
Public ENEsc205
Public ENEsc206
Public ENEsc207
Public ENEsc208
Public ENEsc209
Public ENEsc2010
Public ENocnN1 'sum natural recruits long term
Public ENocnN2
Public ENocnN3
Public ENocnN4
Public ENocnN5
Public ENocnN6
Public ENocnN7
Public ENocnN8
Public ENocnN9
Public ENocnN10
```

```
    Public EFrateCascade 'sum fishing rates for calc of mean
    Public EFrateCoast
    Public GNSpn(5000) 'per run gen spn numbers
    Public GNSpnE 'running sum gen spn
    Public NEscNAvg1(110)
    Public NEscNAvg2(110)
    Public NEscNAvg3(110)
    Public NEscNAvg4(110)
    Public NEscNAvg5(110)
    Public NEscNAvg6(110)
    Public NEscNAvg7(110)
    Public NEscNAvg8(110)
    Public NEscNAvg9(110)
    Public NEscNAvg10(110)
    Public FIR(5, 5) 'global
    Public seedN(110) 'global
    Public MSIN(110) 'global
    Public CntCell1(5) 'for pop1 freq of matrix cell
    Public CntCell2(5)
    Public CntCell3(5)
    Public CntCell4(5)
    Public CntCell5(5)
    Public CntCell6(5)
    Public CntCell7(5)
    Public CntCell8(5)
    Public CntCell9(5)
    Public CntCell10(5)
    Public CntCellCoast(5)
    Public CntCellCascade(5)
    Public CntCellSeedN(5)


Public Sub RunModel()
'Initialize inputs
    Nyr = Cells(3, 2)
    'x = Rnd(-1234567)   ' initializes random number seed so that the same sequence of random numbers are generated for any simulation – currently disabled
    eSRvarLast1 = 0
    eSRvarLast2 = 0
    eSRvarLast3 = 0
    eSRvarLast4 = 0
    eSRvarLast5 = 0
    eSRvarLast6 = 0
    eSRvarLast7 = 0
    eSRvarLast8 = 0
    eSRvarLast9 = 0
    eSRvarLast10 = 0
    iter = Cells(2, 2)
    Fcv = Cells(6, 2) 'CV for fishery rate error
    Fopt = Cells(4, 2) 'choose fishery rate selection type 1=fixed, 2=matrix
    OPIHmean = -6.755363717 '
    OPIHdev = 0.527221348   ' "sig"
    OPIHcorr = 0.264960395 ' "rho"
    Depopt = Cells(7, 2)
    depthreshold = Cells(8, 2)
    FrateNin = Cells(5, 2) 'Opt 1: fixed ER- global if selected
    Gen = 3 'coho  - global
    'GLOBAL coho matrix rate selection cells (R,C)
    FIR(1, 1) = Cells(4, 9)
    FIR(1, 2) = Cells(4, 10)
    FIR(1, 3) = Cells(4, 11)
    FIR(1, 4) = Cells(4, 12)
    FIR(2, 1) = Cells(5, 9)
    FIR(2, 2) = Cells(5, 10)
    FIR(2, 3) = Cells(5, 11)
    FIR(2, 4) = Cells(5, 12)
    FIR(3, 1) = Cells(6, 9)
    FIR(3, 2) = Cells(6, 10)
    FIR(3, 3) = Cells(6, 11)
```

```
FIR(3, 4) = Cells(6, 12)
FIR(4, 1) = Cells(7, 9)
FIR(4, 2) = Cells(7, 10)
FIR(4, 3) = Cells(7, 11)
FIR(4, 4) = Cells(7, 12)
FIR(5, 1) = Cells(8, 9) 'line these out if you drop a Par Seed category
FIR(5, 2) = Cells(8, 10)
FIR(5, 3) = Cells(8, 11)
FIR(5, 4) = Cells(8, 12)
pop1 = Cells(11, 2)
pop2 = Cells(11, 3)
pop3 = Cells(11, 4)
pop4 = Cells(11, 5)
pop5 = Cells(11, 7)
pop6 = Cells(11, 8)
pop7 = Cells(11, 9)
pop8 = Cells(11, 10)
pop9 = Cells(11, 11)
pop10 = Cells(11, 12)
NSpn3ago1 = Cells(12, 2)
NSpn2ago1 = Cells(13, 2)
NSpn1ago1 = Cells(14, 2)
NSpn3ago2 = Cells(12, 3)
NSpn2ago2 = Cells(13, 3)
NSpn1ago2 = Cells(14, 3)
NSpn3ago3 = Cells(12, 4)
NSpn2ago3 = Cells(13, 4)
NSpn1ago3 = Cells(14, 4)
NSpn3ago4 = Cells(12, 5)
NSpn2ago4 = Cells(13, 5)
NSpn1ago4 = Cells(14, 5)
NSpn3ago5 = Cells(12, 7)
NSpn2ago5 = Cells(13, 7)
NSpn1ago5 = Cells(14, 7)
NSpn3ago6 = Cells(12, 8)
NSpn2ago6 = Cells(13, 8)
NSpn1ago6 = Cells(14, 8)
NSpn3ago7 = Cells(12, 9)
NSpn2ago7 = Cells(13, 9)
NSpn1ago7 = Cells(14, 9)
NSpn3ago8 = Cells(12, 10)
NSpn2ago8 = Cells(13, 10)
NSpn1ago8 = Cells(14, 10)
NSpn3ago9 = Cells(12, 11)
NSpn2ago9 = Cells(13, 11)
NSpn1ago9 = Cells(14, 11)
NSpn3ago10 = Cells(12, 12)
NSpn2ago10 = Cells(13, 12)
NSpn1ago10 = Cells(14, 12)
alpha1 = Cells(16, 2)
alpha2 = Cells(16, 3)
alpha3 = Cells(16, 4)
alpha4 = Cells(16, 5)
alpha5 = Cells(16, 7)
alpha6 = Cells(16, 8)
alpha7 = Cells(16, 9)
alpha8 = Cells(16, 10)
alpha9 = Cells(16, 11)
alpha10 = Cells(16, 12)
beta1 = Cells(17, 2)
beta2 = Cells(17, 3)
beta3 = Cells(17, 4)
beta4 = Cells(17, 5)
beta5 = Cells(17, 7)
beta6 = Cells(17, 8)
beta7 = Cells(17, 9)
beta8 = Cells(17, 10)
beta9 = Cells(17, 11)
beta10 = Cells(17, 12)
gamma1 = Cells(18, 2)
```

```
gamma2 = Cells(18, 3)
gamma3 = Cells(18, 4)
gamma4 = Cells(18, 5)
gamma5 = Cells(18, 7)
gamma6 = Cells(18, 8)
gamma7 = Cells(18, 9)
gamma8 = Cells(18, 10)
gamma9 = Cells(18, 11)
gamma10 = Cells(18, 12)
RMSE1 = Cells(19, 2) 'std error for model
RMSE2 = Cells(19, 3)
RMSE3 = Cells(19, 4)
RMSE4 = Cells(19, 5)
RMSE5 = Cells(19, 7)
RMSE6 = Cells(19, 8)
RMSE7 = Cells(19, 9)
RMSE8 = Cells(19, 10)
RMSE9 = Cells(19, 11)
RMSE10 = Cells(19, 12)
autocorr1 = Cells(20, 2) 'autocorr
autocorr2 = Cells(20, 3)
autocorr3 = Cells(20, 4)
autocorr4 = Cells(20, 5)
autocorr5 = Cells(20, 7)
autocorr6 = Cells(20, 8)
autocorr7 = Cells(20, 9)
autocorr8 = Cells(20, 10)
autocorr9 = Cells(20, 11)
autocorr10 = Cells(20, 12)
full1 = Cells(22, 2)
full2 = Cells(22, 3)
full3 = Cells(22, 4)
full4 = Cells(22, 5)
full5 = Cells(22, 7)
full6 = Cells(22, 8)
full7 = Cells(22, 9)
full8 = Cells(22, 10)
full9 = Cells(22, 11)
full10 = Cells(22, 12)
phos1 = Cells(23, 2) 'phos pop1
phos2 = Cells(23, 3)
phos3 = Cells(23, 4)
phos4 = Cells(23, 5)
phos5 = Cells(23, 7)
phos6 = Cells(23, 8)
phos7 = Cells(23, 9)
phos8 = Cells(23, 10)
phos9 = Cells(23, 11)
phos10 = Cells(23, 12)
hatch1 = Cells(24, 2) ' pop1 hatchery
hatch2 = Cells(24, 3)
hatch3 = Cells(24, 4)
hatch4 = Cells(24, 5)
hatch5 = Cells(24, 7)
hatch6 = Cells(24, 8)
hatch7 = Cells(24, 9)
hatch8 = Cells(24, 10)
hatch9 = Cells(24, 11)
hatch10 = Cells(24, 12)
fit1 = Cells(25, 2) 'fitness pop1 hatchery
fit2 = Cells(25, 3)
fit3 = Cells(25, 4)
fit4 = Cells(25, 5)
fit5 = Cells(25, 7)
fit6 = Cells(25, 8)
fit7 = Cells(25, 9)
fit8 = Cells(25, 10)
fit9 = Cells(25, 11)
fit10 = Cells(25, 12)
'constraints
```

```
    limitS1 = Cells(26, 2)
    limitS2 = Cells(26, 3)
    limitS3 = Cells(26, 4)
    limitS4 = Cells(26, 5)
    limitS5 = Cells(26, 7)
    limitS6 = Cells(26, 8)
    limitS7 = Cells(26, 9)
    limitS8 = Cells(26, 10)
    limitS9 = Cells(26, 11)
    limitS10 = Cells(26, 12)
    limitR1 = Cells(27, 2)
    limitR2 = Cells(27, 3)
    limitR3 = Cells(27, 4)
    limitR4 = Cells(27, 5)
    limitR5 = Cells(27, 7)
    limitR6 = Cells(27, 8)
    limitR7 = Cells(27, 9)
    limitR8 = Cells(27, 10)
    limitR9 = Cells(27, 11)
    limitR10 = Cells(27, 12)
    RecrFailThresh1 = Cells(28, 2)
    RecrFailThresh2 = Cells(28, 3)
    RecrFailThresh3 = Cells(28, 4)
    RecrFailThresh4 = Cells(28, 5)
    RecrFailThresh5 = Cells(28, 7)
    RecrFailThresh6 = Cells(28, 8)
    RecrFailThresh7 = Cells(28, 9)
    RecrFailThresh8 = Cells(28, 10)
    RecrFailThresh9 = Cells(28, 11)
    RecrFailThresh10 = Cells(28, 12)
    'risk criteria
    CRT1 = Cells(31, 2)
    CRT2 = Cells(31, 3)
    CRT3 = Cells(31, 4)
    CRT4 = Cells(31, 5)
    CRT5 = Cells(31, 7)
    CRT6 = Cells(31, 8)
    CRT7 = Cells(31, 9)
    CRT8 = Cells(31, 10)
    CRT9 = Cells(31, 11)
    CRT10 = Cells(31, 12)
'done reading in pop data

'Clear summary statistics from prior runs, initialize new
    CntSeed1 = 0
    CntSeed2 = 0
    CntSeed3 = 0
    CntSeed4 = 0
    CntSeed5 = 0
    CntSeed6 = 0
    CntSeed7 = 0
    CntSeed8 = 0
    CntSeed9 = 0
    CntSeed10 = 0
    CntSeedCascade = 0
    CntSeedCoast = 0
    CntSeedN = 0
    CntGenetic1 = 0
    CntGenetic2 = 0
    CntGenetic3 = 0
    CntGenetic4 = 0
    CntGenetic5 = 0
    CntGenetic6 = 0
    CntGenetic7 = 0
    CntGenetic8 = 0
    CntGenetic9 = 0
    CntGenetic10 = 0
    CntGeneticST1 = 0
    CntGeneticST2 = 0
    CntGeneticST3 = 0
```

```
CntGeneticST4 = 0
CntGeneticST5 = 0
CntGeneticST6 = 0
CntGeneticST7 = 0
CntGeneticST8 = 0
CntGeneticST9 = 0
CntGeneticST10 = 0
CntFull1 = 0
CntFull2 = 0
CntFull3 = 0
CntFull4 = 0
CntFull5 = 0
CntFull6 = 0
CntFull7 = 0
CntFull8 = 0
CntFull9 = 0
CntFull10 = 0
CntFullST1 = 0
CntFullST2 = 0
CntFullST3 = 0
CntFullST4 = 0
CntFullST5 = 0
CntFullST6 = 0
CntFullST7 = 0
CntFullST8 = 0
CntFullST9 = 0
CntFullST10 = 0
ENEsc1 = 0
ENEsc2 = 0
ENEsc3 = 0
ENEsc4 = 0
ENEsc5 = 0
ENEsc6 = 0
ENEsc7 = 0
ENEsc8 = 0
ENEsc9 = 0
ENEsc10 = 0
ENEsc201 = 0
ENEsc202 = 0
ENEsc203 = 0
ENEsc204 = 0
ENEsc205 = 0
ENEsc206 = 0
ENEsc207 = 0
ENEsc208 = 0
ENEsc209 = 0
ENEsc2010 = 0
ENocnN1 = 0
ENocnN2 = 0
ENocnN3 = 0
ENocnN4 = 0
ENocnN5 = 0
ENocnN6 = 0
ENocnN7 = 0
ENocnN8 = 0
ENocnN9 = 0
ENocnN10 = 0
EFrateCoast = 0
EFrateCascade = 0

  For a = 1 To 100
  CountEsc1(a) = 0
  Next a
  For b = 1 To 100
  CountEsc2(b) = 0
  Next b
  For c = 1 To 100
  CountEsc3(c) = 0
  Next c
  For d = 1 To 100
```

```
    CountEsc4(d) = 0
    Next d
    For e = 1 To 100
    CountEsc5(e) = 0
    Next e
    For f = 1 To 100
    CountEsc6(f) = 0
    Next f
    For g = 1 To 100
    CountEsc7(g) = 0
    Next g
    For h = 1 To 100
    CountEsc8(h) = 0
    Next h
    For m = 1 To 100
    CountEsc9(m) = 0
    Next m
    For o = 1 To 100
    CountEsc10(o) = 0
    Next o
For j = 1 To 100
    CounttgF(j) = 0
    CountF(j) = 0
Next j

For j = 1 To 5
    For k = 1 To 5
    CntFrate(j, k) = 0
    Next k
Next j

For j = 1 To 5
    CntCell1(j) = 0 'will be used to tally up freq of seed fractions per pop
    CntCell2(j) = 0
    CntCell3(j) = 0
    CntCell4(j) = 0
    CntCell5(j) = 0
    CntCell6(j) = 0
    CntCell7(j) = 0
    CntCell8(j) = 0
    CntCell9(j) = 0
    CntCell10(j) = 0
    CntCellCoast(j) = 0
    CntCellCascade(j) = 0
    CntCellSeedN(j) = 0

Next j

    'freq distribs of fish numbers

    ss = 150
    qq = 150
    pp = 150

For y = 1 To Nyr + 3
    NEscNAvg1(y) = 0
    NEscNAvg2(y) = 0
    NEscNAvg3(y) = 0
    NEscNAvg4(y) = 0
    NEscNAvg5(y) = 0
    NEscNAvg6(y) = 0
    NEscNAvg7(y) = 0
    NEscNAvg8(y) = 0
    NEscNAvg9(y) = 0
    NEscNAvg10(y) = 0
    MSIN(y) = 0
    fraction1(i, y) = 0
    fraction2(i, y) = 0
    fraction3(i, y) = 0
    fraction4(i, y) = 0
```

```
        fraction5(i, y) = 0
        fraction6(i, y) = 0
        fraction7(i, y) = 0
        fraction8(i, y) = 0
        fraction9(i, y) = 0
        fraction10(i, y) = 0
        flagfull1(i, y) = 0
        flagfull2(i, y) = 0
        flagfull3(i, y) = 0
        flagfull4(i, y) = 0
        flagfull5(i, y) = 0
        flagfull6(i, y) = 0
        flagfull7(i, y) = 0
        flagfull8(i, y) = 0
        flagfull9(i, y) = 0
        flagfull10(i, y) = 0
        Fvar(y) = 0
        tgFrateN(y) = 0
        tgFrateSandy(y) = 0
        tgFrateClack(y) = 0
        tgFrateCoast(y) = 0
        tgFrateCascade(y) = 0
        FrateN(y) = 0
        seed1(y) = 0
        seed2(y) = 0
        seed3(y) = 0
        seed4(y) = 0
        seed5(y) = 0
        seed6(y) = 0
        seed7(y) = 0
        seed8(y) = 0
        seed9(y) = 0
        seed10(y) = 0
    Next y

    For i = 1 To iter
        GNSpn(i) = 1
        flagGR1(i) = 0
        flagGR2(i) = 0
        flagGR3(i) = 0
        flagGR4(i) = 0
        flagGR5(i) = 0
        flagGR6(i) = 0
        flagGR7(i) = 0
        flagGR8(i) = 0
        flagGR9(i) = 0
        flagGR10(i) = 0
        flagGRST1(i) = 0
        flagGRST2(i) = 0
        flagGRST3(i) = 0
        flagGRST4(i) = 0
        flagGRST5(i) = 0
        flagGRST6(i) = 0
        flagGRST7(i) = 0
        flagGRST8(i) = 0
        flagGRST9(i) = 0
        flagGRST10(i) = 0

    Next i

'Model Iterations
For i = 1 To iter
For y = 1 To Nyr + 3
        MovGenAvg1(i, y) = 0
        MovGenAvg2(i, y) = 0
        MovGenAvg3(i, y) = 0
        MovGenAvg4(i, y) = 0
        MovGenAvg5(i, y) = 0
        MovGenAvg6(i, y) = 0
        MovGenAvg7(i, y) = 0
```

```
  MovGenAvg8(i, y) = 0
  MovGenAvg9(i, y) = 0
  MovGenAvg10(i, y) = 0
  OPIHrand(y) = Sqr(-2 * Log(Rnd())) * Sin(6.28318 * Rnd()) 'random for OPIH only
     If y = 1 Then OPIH(i, y) = Exp(OPIHrand(y) + OPIHdev + OPIHmean) '
    Else: OPIH(i, y) = Exp(OPIHcorr * (Log(lastopihvar) - OPIHmean) + OPIHrand(y) * OPIHdev * Sqr(1 - OPIHcorr ^ 2) + OPIHmean)  '
     End If
  lastopihvar = OPIH(i, y)
  OPIHind(i, y) = (OPIH(i, y) - 0.001471) / 0.001037 'convert OPIH to normalized values

'Estimate recruits (for bookkeeping purposes recruits assumed to be 1 year old -
'ie their number is stored in year immediately following spawner year)
  Nsp1 = 1 '
  Nsp2 = 1
  Nsp3 = 1
  Nsp4 = 1
  Nsp5 = 1
  Nsp6 = 1
  Nsp7 = 1
  Nsp8 = 1
  Nsp9 = 1
  Nsp10 = 1

  If y > 1 Then
     Nsp1 = NspnN1(i, y - 1) '
     Nsp2 = NspnN2(i, y - 1)
     Nsp3 = NspnN3(i, y - 1)
     Nsp4 = NspnN4(i, y - 1)
     Nsp5 = NspnN5(i, y - 1)
     Nsp6 = NspnN6(i, y - 1)
     Nsp7 = NspnN7(i, y - 1)
     Nsp8 = NspnN8(i, y - 1)
     Nsp9 = NspnN9(i, y - 1)
     Nsp10 = NspnN10(i, y - 1)

  'Natural recruits - estimate annual variation based on variance input
  Z1(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd()) 'random for pop1 svar
  Z2(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
  Z3(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
  Z4(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
  Z5(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
  Z6(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
  Z7(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
  Z8(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
  Z9(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())
  Z10(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd())

  Mindex1(i, y) = OPIHind(i, y) * gamma1
  Mindex2(i, y) = OPIHind(i, y) * gamma2
  Mindex3(i, y) = OPIHind(i, y) * gamma3
  Mindex4(i, y) = OPIHind(i, y) * gamma4
  Mindex5(i, y) = OPIHind(i, y) * gamma5
  Mindex6(i, y) = OPIHind(i, y) * gamma6
  Mindex7(i, y) = OPIHind(i, y) * gamma7
  Mindex8(i, y) = OPIHind(i, y) * gamma8
  Mindex9(i, y) = OPIHind(i, y) * gamma9
  Mindex10(i, y) = OPIHind(i, y) * gamma10

  If y = 1 Then
     SRvar1(i, y) = (RMSE1 * Sqr(1 - (autocorr1 ^ 2))) * Z1(y) 'first year
     SRvar2(i, y) = (RMSE2 * Sqr(1 - (autocorr2 ^ 2))) * Z2(y)
     SRvar3(i, y) = (RMSE3 * Sqr(1 - (autocorr3 ^ 2))) * Z3(y)
     SRvar4(i, y) = (RMSE4 * Sqr(1 - (autocorr4 ^ 2))) * Z4(y)
     SRvar5(i, y) = (RMSE5 * Sqr(1 - (autocorr5 ^ 2))) * Z5(y)
     SRvar6(i, y) = (RMSE6 * Sqr(1 - (autocorr6 ^ 2))) * Z6(y)
     SRvar7(i, y) = (RMSE7 * Sqr(1 - (autocorr7 ^ 2))) * Z7(y)
     SRvar8(i, y) = (RMSE8 * Sqr(1 - (autocorr8 ^ 2))) * Z8(y)
     SRvar9(i, y) = (RMSE9 * Sqr(1 - (autocorr9 ^ 2))) * Z9(y)
     SRvar10(i, y) = (RMSE10 * Sqr(1 - (autocorr10 ^ 2))) * Z10(y)
     Else
```

```
        SRvar1(i, y) = (autocorr1 * eSRvarLast1) + (RMSE1 * Sqr(1 - (autocorr1 ^ 2)) * Z1(y))
        SRvar2(i, y) = (autocorr2 * eSRvarLast2) + (RMSE2 * Sqr(1 - (autocorr2 ^ 2)) * Z2(y))
        SRvar3(i, y) = (autocorr3 * eSRvarLast3) + (RMSE3 * Sqr(1 - (autocorr3 ^ 2)) * Z3(y))
        SRvar4(i, y) = (autocorr4 * eSRvarLast4) + (RMSE4 * Sqr(1 - (autocorr4 ^ 2)) * Z4(y))
        SRvar5(i, y) = (autocorr5 * eSRvarLast5) + (RMSE5 * Sqr(1 - (autocorr5 ^ 2)) * Z5(y))
        SRvar6(i, y) = (autocorr6 * eSRvarLast6) + (RMSE6 * Sqr(1 - (autocorr6 ^ 2)) * Z6(y))
        SRvar7(i, y) = (autocorr7 * eSRvarLast7) + (RMSE7 * Sqr(1 - (autocorr7 ^ 2)) * Z7(y))
        SRvar8(i, y) = (autocorr8 * eSRvarLast8) + (RMSE8 * Sqr(1 - (autocorr8 ^ 2)) * Z8(y))
        SRvar9(i, y) = (autocorr9 * eSRvarLast9) + (RMSE9 * Sqr(1 - (autocorr9 ^ 2)) * Z9(y))
            SRvar10(i, y) = (autocorr10 * eSRvarLast10) + (RMSE10 * Sqr(1 - (autocorr10 ^ 2)) * Z10(y))
      End If

        eSRvarLast1 = SRvar1(i, y) ' for autocorrelated reference
        eSRvarLast2 = SRvar2(i, y)
        eSRvarLast3 = SRvar3(i, y)
        eSRvarLast4 = SRvar4(i, y)
        eSRvarLast5 = SRvar5(i, y)
        eSRvarLast6 = SRvar6(i, y)
        eSRvarLast7 = SRvar7(i, y)
        eSRvarLast8 = SRvar8(i, y)
        eSRvarLast9 = SRvar9(i, y)
        eSRvarLast10 = SRvar10(i, y)

        'Stock-recruitment calculation
NocnN1(i, y) = ((Nsp1 * alpha1) / (1 + ((alpha1 / beta1) * Nsp1))) * Exp(Mindex1(i, y)) * Exp(SRvar1(i, y))
NocnN2(i, y) = ((Nsp2 * alpha2) / (1 + ((alpha2 / beta2) * Nsp2))) * Exp(Mindex2(i, y)) * Exp(SRvar2(i, y))
NocnN3(i, y) = ((Nsp3 * alpha3) / (1 + ((alpha3 / beta3) * Nsp3))) * Exp(Mindex3(i, y)) * Exp(SRvar3(i, y))
NocnN4(i, y) = ((Nsp4 * alpha4) / (1 + ((alpha4 / beta4) * Nsp4))) * Exp(Mindex4(i, y)) * Exp(SRvar4(i, y))
NocnN5(i, y) = ((Nsp5 * alpha5) / (1 + ((alpha5 / beta5) * Nsp5))) * Exp(Mindex5(i, y)) * Exp(SRvar5(i, y))
NocnN6(i, y) = ((Nsp6 * alpha6) / (1 + ((alpha6 / beta6) * Nsp6))) * Exp(Mindex6(i, y)) * Exp(SRvar6(i, y))
NocnN7(i, y) = ((Nsp7 * alpha7) / (1 + ((alpha7 / beta7) * Nsp7))) * Exp(Mindex7(i, y)) * Exp(SRvar7(i, y))
NocnN8(i, y) = ((Nsp8 * alpha8) / (1 + ((alpha8 / beta8) * Nsp8))) * Exp(Mindex8(i, y)) * Exp(SRvar8(i, y))
NocnN9(i, y) = ((Nsp9 * alpha9) / (1 + ((alpha9 / beta9) * Nsp9))) * Exp(Mindex9(i, y)) * Exp(SRvar9(i, y))
NocnN10(i, y) = ((Nsp10 * alpha10) / (1 + ((alpha10 / beta10) * Nsp10))) * Exp(Mindex10(i, y)) * Exp(SRvar10(i, y))

        If NocnN1(i, y) > limitR1 Then NocnN1(i, y) = limitR1  'guards against unrealistic recruitment that exceeds observed range
        If NocnN2(i, y) > limitR2 Then NocnN2(i, y) = limitR2
        If NocnN3(i, y) > limitR3 Then NocnN3(i, y) = limitR3
        If NocnN4(i, y) > limitR4 Then NocnN4(i, y) = limitR4
        If NocnN5(i, y) > limitR5 Then NocnN5(i, y) = limitR5
        If NocnN6(i, y) > limitR6 Then NocnN6(i, y) = limitR6
        If NocnN7(i, y) > limitR7 Then NocnN7(i, y) = limitR7
        If NocnN8(i, y) > limitR8 Then NocnN8(i, y) = limitR8
        If NocnN9(i, y) > limitR9 Then NocnN9(i, y) = limitR9
        If NocnN10(i, y) > limitR10 Then NocnN10(i, y) = limitR10

        If Depopt = 1 Then
        NocnN1(i, y) = NocnN1(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp1)) '
        NocnN2(i, y) = NocnN2(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp2))
        NocnN3(i, y) = NocnN3(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp3))
        NocnN4(i, y) = NocnN4(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp4))
        NocnN5(i, y) = NocnN5(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp5))
        NocnN6(i, y) = NocnN6(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp6))
        NocnN7(i, y) = NocnN7(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp7))
        NocnN8(i, y) = NocnN8(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp8))
        NocnN9(i, y) = NocnN9(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp9))
         NocnN10(i, y) = NocnN10(i, y) * (1 - Exp((Log(1 - 0.95) / (depthreshold - 1)) * Nsp10))
        End If

        If Nsp1 < RecrFailThresh1 Then NocnN1(i, y) = 0  'assume critical depensation
        If Nsp2 < RecrFailThresh2 Then NocnN2(i, y) = 0
        If Nsp3 < RecrFailThresh3 Then NocnN3(i, y) = 0
        If Nsp4 < RecrFailThresh4 Then NocnN4(i, y) = 0
        If Nsp5 < RecrFailThresh5 Then NocnN5(i, y) = 0
        If Nsp6 < RecrFailThresh6 Then NocnN6(i, y) = 0
        If Nsp7 < RecrFailThresh7 Then NocnN7(i, y) = 0
        If Nsp8 < RecrFailThresh8 Then NocnN8(i, y) = 0
        If Nsp9 < RecrFailThresh9 Then NocnN9(i, y) = 0
        If Nsp10 < RecrFailThresh10 Then NocnN10(i, y) = 0
```

```
'annual number of adult escapement
If y > 2 Then
    NAdN1(i, y) = NocnN1(i, y - 2)
    NAdN2(i, y) = NocnN2(i, y - 2)
    NAdN3(i, y) = NocnN3(i, y - 2)
    NAdN4(i, y) = NocnN4(i, y - 2)
    NAdN5(i, y) = NocnN5(i, y - 2)
    NAdN6(i, y) = NocnN6(i, y - 2)
    NAdN7(i, y) = NocnN7(i, y - 2)
    NAdN8(i, y) = NocnN8(i, y - 2)
    NAdN9(i, y) = NocnN9(i, y - 2)
    NAdN10(i, y) = NocnN10(i, y - 2)
End If


If y = 4 Then
    fraction1(i, y) = NEscN1(i, y - 3) / full1 '
    fraction2(i, y) = NEscN2(i, y - 3) / full2
    fraction3(i, y) = 510 / full3 'hard coded wild + adjusted hatchery spawners for Washington pops
    fraction4(i, y) = 132 / full4
    fraction5(i, y) = NEscN5(i, y - 3) / full5
    fraction6(i, y) = NEscN6(i, y - 3) / full6
    fraction7(i, y) = 1101 / full7
    fraction8(i, y) = 1506 / full8
    fraction9(i, y) = 1369 / full9
    fraction10(i, y) = 391 / full10
ElseIf y = 5 Then
    fraction1(i, y) = NEscN1(i, y - 3) / full1 '
    fraction2(i, y) = NEscN2(i, y - 3) / full2
    fraction3(i, y) = 369 / full3
    fraction4(i, y) = 389 / full4
    fraction5(i, y) = NEscN5(i, y - 3) / full5
    fraction6(i, y) = NEscN6(i, y - 3) / full6
    fraction7(i, y) = 1019 / full7
    fraction8(i, y) = 291 / full8
    fraction9(i, y) = 1169 / full9
    fraction10(i, y) = 448 / full10
ElseIf y = 6 Then
    fraction1(i, y) = NEscN1(i, y - 3) / full1 '
    fraction2(i, y) = NEscN2(i, y - 3) / full2
    fraction3(i, y) = 440 / full3 'hard coded for Wash mean of 2010 and 2011
    fraction4(i, y) = 261 / full4
    fraction5(i, y) = NEscN5(i, y - 3) / full5
    fraction6(i, y) = NEscN6(i, y - 3) / full6
    fraction7(i, y) = 1060 / full7
    fraction8(i, y) = 899 / full8
    fraction9(i, y) = 1269 / full9
    fraction10(i, y) = 420 / full10
End If

If y > 6 Then
    fraction1(i, y) = NEscN1(i, y - 3) / full1 '
    fraction2(i, y) = NEscN2(i, y - 3) / full2
    fraction3(i, y) = (NEscN3(i, y - 3) + (hatch3 * fit3)) / full3
    fraction4(i, y) = (NEscN4(i, y - 3) + (hatch4 * fit4)) / full4
    fraction5(i, y) = NEscN5(i, y - 3) / full5
    fraction6(i, y) = NEscN6(i, y - 3) / full6
    fraction7(i, y) = (NEscN7(i, y - 3) + (hatch7 * fit7)) / full7
    fraction8(i, y) = (NEscN8(i, y - 3) + (hatch8 * fit8)) / full8
    fraction9(i, y) = (NEscN9(i, y - 3) + (hatch9 * fit9)) / full9
    fraction10(i, y) = (NEscN10(i, y - 3) + (hatch10 * fit10)) / full10
End If
    If fraction1(i, y) >= 1 Then flagfull1(i, y) = 1 Else flagfull1(i, y) = 0
    If fraction2(i, y) >= 1 Then flagfull2(i, y) = 1 Else flagfull2(i, y) = 0
    If fraction3(i, y) >= 1 Then flagfull3(i, y) = 1 Else flagfull3(i, y) = 0
    If fraction4(i, y) >= 1 Then flagfull4(i, y) = 1 Else flagfull4(i, y) = 0
    If fraction5(i, y) >= 1 Then flagfull5(i, y) = 1 Else flagfull5(i, y) = 0
    If fraction6(i, y) >= 1 Then flagfull6(i, y) = 1 Else flagfull6(i, y) = 0
    If fraction7(i, y) >= 1 Then flagfull7(i, y) = 1 Else flagfull7(i, y) = 0
    If fraction8(i, y) >= 1 Then flagfull8(i, y) = 1 Else flagfull8(i, y) = 0
```

```
If fraction9(i, y) >= 1 Then flagfull9(i, y) = 1 Else flagfull9(i, y) = 0
If fraction10(i, y) >= 1 Then flagfull10(i, y) = 1 Else flagfull10(i, y) = 0


If fraction1(i, y) >= 1 Then fraction1(i, y) = 1
If fraction2(i, y) >= 1 Then fraction2(i, y) = 1
If fraction3(i, y) >= 1 Then fraction3(i, y) = 1
If fraction4(i, y) >= 1 Then fraction4(i, y) = 1
If fraction5(i, y) >= 1 Then fraction5(i, y) = 1
If fraction6(i, y) >= 1 Then fraction6(i, y) = 1
If fraction7(i, y) >= 1 Then fraction7(i, y) = 1
If fraction8(i, y) >= 1 Then fraction8(i, y) = 1
If fraction9(i, y) >= 1 Then fraction9(i, y) = 1
If fraction10(i, y) >= 1 Then fraction10(i, y) = 1

End If
'pop specific seeds
If y > 3 Then
If fraction1(i, y) > 0.75 Then
seed1(y) = 1
   ElseIf fraction1(i, y) > Cells(5, 8) Then seed1(y) = 2
   ElseIf fraction1(i, y) > Cells(6, 8) Then seed1(y) = 3
   ElseIf fraction1(i, y) > Cells(7, 8) Then seed1(y) = 4
   ElseIf fraction1(i, y) <= Cells(7, 8) Then seed1(y) = 5
   Else: seed1(y) = 0
End If
If fraction2(i, y) > 0.75 Then
seed2(y) = 1
   ElseIf fraction2(i, y) > Cells(5, 8) Then seed2(y) = 2
   ElseIf fraction2(i, y) > Cells(6, 8) Then seed2(y) = 3
   ElseIf fraction2(i, y) > Cells(7, 8) Then seed2(y) = 4
   ElseIf fraction2(i, y) <= Cells(7, 8) Then seed2(y) = 5
   Else: seed2(y) = 0
End If
If fraction3(i, y) > 0.75 Then
   seed3(y) = 1
   ElseIf fraction3(i, y) > Cells(5, 8) Then
   seed3(y) = 2
   ElseIf fraction3(i, y) > Cells(6, 8) Then seed3(y) = 3
   ElseIf fraction3(i, y) > Cells(7, 8) Then seed3(y) = 4
   ElseIf fraction3(i, y) <= Cells(7, 8) Then seed3(y) = 5
   Else: seed3(y) = 0
End If
If fraction4(i, y) > 0.75 Then
seed4(y) = 1
   ElseIf fraction4(i, y) > Cells(5, 8) Then seed4(y) = 2
   ElseIf fraction4(i, y) > Cells(6, 8) Then seed4(y) = 3
   ElseIf fraction4(i, y) > Cells(7, 8) Then seed4(y) = 4
   ElseIf fraction4(i, y) <= Cells(7, 8) Then seed4(y) = 5
   Else: seed4(y) = 0
End If
If fraction5(i, y) > 0.75 Then
seed5(y) = 1
   ElseIf fraction5(i, y) > Cells(5, 8) Then seed5(y) = 2
   ElseIf fraction5(i, y) > Cells(6, 8) Then seed5(y) = 3
   ElseIf fraction5(i, y) > Cells(7, 8) Then seed5(y) = 4
   ElseIf fraction5(i, y) <= Cells(7, 8) Then seed5(y) = 5
   Else: seed5(y) = 0
End If
If fraction6(i, y) > 0.75 Then
seed6(y) = 1
   ElseIf fraction6(i, y) > Cells(5, 8) Then seed6(y) = 2
   ElseIf fraction6(i, y) > Cells(6, 8) Then seed6(y) = 3
   ElseIf fraction6(i, y) > Cells(7, 8) Then seed6(y) = 4
   ElseIf fraction6(i, y) <= Cells(7, 8) Then seed6(y) = 5
   Else: seed6(y) = 0
End If
If fraction7(i, y) > 0.75 Then
seed7(y) = 1
   ElseIf fraction7(i, y) > Cells(5, 8) Then seed7(y) = 2
```

```
    ElseIf fraction7(i, y) > Cells(6, 8) Then seed7(y) = 3
    ElseIf fraction7(i, y) > Cells(7, 8) Then seed7(y) = 4
    ElseIf fraction7(i, y) <= Cells(7, 8) Then seed7(y) = 5
    Else: seed7(y) = 0
End If
 If fraction8(i, y) > 0.75 Then
 seed8(y) = 1
    ElseIf fraction8(i, y) > Cells(5, 8) Then seed8(y) = 2
    ElseIf fraction8(i, y) > Cells(6, 8) Then seed8(y) = 3
    ElseIf fraction8(i, y) > Cells(7, 8) Then seed8(y) = 4
    ElseIf fraction8(i, y) <= Cells(7, 8) Then seed8(y) = 5
    Else: seed8(y) = 0
End If
 If fraction9(i, y) > 0.75 Then
 seed9(y) = 1
    ElseIf fraction9(i, y) > Cells(5, 8) Then seed9(y) = 2
    ElseIf fraction9(i, y) > Cells(6, 8) Then seed9(y) = 3
    ElseIf fraction9(i, y) > Cells(7, 8) Then seed9(y) = 4
    ElseIf fraction9(i, y) <= Cells(7, 8) Then seed9(y) = 5
    Else: seed9(y) = 0
End If
If fraction10(i, y) > 0.75 Then
seed10(y) = 1
    ElseIf fraction10(i, y) > Cells(5, 8) Then seed10(y) = 2
    ElseIf fraction10(i, y) > Cells(6, 8) Then seed10(y) = 3
    ElseIf fraction10(i, y) > Cells(7, 8) Then seed10(y) = 4
    ElseIf fraction10(i, y) <= Cells(7, 8) Then seed10(y) = 5
    Else: seed10(y) = 0
End If
End If
'end pop specific seeds

'calc stratum mean fractions
spmeanCoast(i, y) = (fraction1(i, y) + fraction2(i, y) + fraction3(i, y) + fraction4(i, y)) / 4 'coast strat mean seed
spmeanCascade(i, y) = (fraction5(i, y) + fraction6(i, y) + fraction7(i, y) + fraction8(i, y) + fraction9(i, y) + fraction10(i, y)) / 6 'casc strat
mean seed

'step to count where Coast and Cascade stratum mean seeds fall on seeding criteria
If y > 3 Then
If spmeanCoast(i, y) > Cells(4, 8) Then
seedCoast(y) = 1
    ElseIf spmeanCoast(i, y) > Cells(5, 8) Then seedCoast(y) = 2
    ElseIf spmeanCoast(i, y) > Cells(6, 8) Then seedCoast(y) = 3
    ElseIf spmeanCoast(i, y) > Cells(7, 8) Then seedCoast(y) = 4
    ElseIf spmeanCoast(i, y) <= Cells(7, 8) Then seedCoast(y) = 5
    Else: seedCoast(y) = 0
End If
If spmeanCascade(i, y) > 0.75 Then
seedCascade(y) = 1
    ElseIf spmeanCascade(i, y) > Cells(5, 8) Then seedCascade(y) = 2
    ElseIf spmeanCascade(i, y) > Cells(6, 8) Then seedCascade(y) = 3
    ElseIf spmeanCascade(i, y) > Cells(7, 8) Then seedCascade(y) = 4
    ElseIf spmeanCascade(i, y) <= Cells(7, 8) Then seedCascade(y) = 5
    Else: seedCascade(y) = 0
End If
End If
'end stratum mean seeds
'calc min fraction to use for harvest rate determination (this model)
If spmeanCoast(i, y) < spmeanCascade(i, y) Then spmean(i, y) = spmeanCoast(i, y) Else spmean(i, y) = spmeanCascade(i, y)

If spmean(i, y) > 0.75 Then
seedN(y) = 1
    ElseIf spmean(i, y) > Cells(5, 8) Then seedN(y) = 2
    ElseIf spmean(i, y) > Cells(6, 8) Then seedN(y) = 3
    ElseIf spmean(i, y) > Cells(7, 8) Then seedN(y) = 4
    ElseIf spmean(i, y) <= Cells(7, 8) Then seedN(y) = 5
    Else: seedN(y) = 0
End If
```

```
If OPIH(i, y) >= (Cells(3, 12)) Then
MSIN(y) = 4
   ElseIf OPIH(i, y) >= (Cells(3, 11)) Then
   MSIN(y) = 3
   ElseIf OPIH(i, y) >= (Cells(3, 10)) Then
   MSIN(y) = 2
   ElseIf OPIH(i, y) < (Cells(3, 10)) Then
   MSIN(y) = 1
   Else: MSIN(y) = 0
End If

If y > 3 Then
   If Fopt = 2 Then  ' use coho matix
   tgFrateClack(y) = FIR(seed5(y), MSIN(y))
   tgFrateSandy(y) = FIR(seed6(y), MSIN(y))
   tgFrateCoast(y) = FIR(seedN(y), MSIN(y))
   tgFrateCascade(y) = FIR(seedCascade(y), MSIN(y))
   'tgFrateN(y) = (tgFrateClack(y) + tgFrateSandy(y)) / 2 'target F rate
   Else 'Fopt = 1 fixed rate
   tgFrateCoast(y) = FrateNin
   tgFrateCascade(y) = FrateNin
   End If
End If

'fishery rate variance
Fvar(y) = Sqr(-2 * Log(Rnd())) * Sin(6.283185 * Rnd()) * (Fcv * tgFrateN(y))
FrateCoast(y) = tgFrateCoast(y) + Fvar(y)
FrateCascade(y) = tgFrateCascade(y) + Fvar(y)

'Number escaping fishery
NEscN1(i, y) = NAdN1(i, y) * (1 - FrateCoast(y))
NEscN2(i, y) = NAdN2(i, y) * (1 - FrateCoast(y))
NEscN3(i, y) = NAdN3(i, y) * (1 - FrateCoast(y))
NEscN4(i, y) = NAdN4(i, y) * (1 - FrateCoast(y))
NEscN5(i, y) = NAdN5(i, y) * (1 - FrateCascade(y))
NEscN6(i, y) = NAdN6(i, y) * (1 - FrateCascade(y))
NEscN7(i, y) = NAdN7(i, y) * (1 - FrateCascade(y))
NEscN8(i, y) = NAdN8(i, y) * (1 - FrateCascade(y))
NEscN9(i, y) = NAdN9(i, y) * (1 - FrateCascade(y))
NEscN10(i, y) = NAdN10(i, y) * (1 - FrateCascade(y))


'Natural Escapement to spawners
If y = 1 Then
   NspnN1(i, y) = NSpn3ago1
   NspnN2(i, y) = NSpn3ago2
   NspnN3(i, y) = NSpn3ago3
   NspnN4(i, y) = NSpn3ago4
   NspnN5(i, y) = NSpn3ago5
   NspnN6(i, y) = NSpn3ago6
   NspnN7(i, y) = NSpn3ago7
   NspnN8(i, y) = NSpn3ago8
   NspnN9(i, y) = NSpn3ago9
   NspnN10(i, y) = NSpn3ago10
   NEscN1(i, y) = NSpn3ago1
   NEscN2(i, y) = NSpn3ago2
   NEscN3(i, y) = 223 ‘hard coded values for Washington – better to add to input page
   NEscN4(i, y) = 38
   NEscN5(i, y) = NSpn3ago5
   NEscN6(i, y) = NSpn3ago6
   NEscN7(i, y) = 989
   NEscN8(i, y) = 886
   NEscN9(i, y) = 1281
   NEscN10(i, y) = 301
   ElseIf y = 2 Then
   NspnN1(i, y) = NSpn2ago1
   NspnN2(i, y) = NSpn2ago2
   NspnN3(i, y) = NSpn2ago3
   NspnN4(i, y) = NSpn2ago4
   NspnN5(i, y) = NSpn2ago5
```

```
    NspnN6(i, y) = NSpn2ago6
    NspnN7(i, y) = NSpn2ago7
    NspnN8(i, y) = NSpn2ago8
    NspnN9(i, y) = NSpn2ago9
    NspnN10(i, y) = NSpn2ago10
    NEscN1(i, y) = NSpn2ago1
    NEscN2(i, y) = NSpn2ago2
    NEscN3(i, y) = 223
    NEscN4(i, y) = 23
    NEscN5(i, y) = NSpn2ago5
    NEscN6(i, y) = NSpn2ago6
    NEscN7(i, y) = 997
    NEscN8(i, y) = 268
    NEscN9(i, y) = 1140
    NEscN10(i, y) = 442
    ElseIf y = 3 Then
    NspnN1(i, y) = NSpn1ago1
    NspnN2(i, y) = NSpn1ago2
    NspnN3(i, y) = NSpn1ago3
    NspnN4(i, y) = NSpn1ago4
    NspnN5(i, y) = NSpn1ago5
    NspnN6(i, y) = NSpn1ago6
    NspnN7(i, y) = NSpn1ago7
    NspnN8(i, y) = NSpn1ago8
    NspnN9(i, y) = NSpn1ago9
    NspnN10(i, y) = NSpn1ago10
    NEscN1(i, y) = NSpn1ago1
    NEscN2(i, y) = NSpn1ago2
    NEscN3(i, y) = 223
    NEscN4(i, y) = 31
    NEscN5(i, y) = NSpn1ago5
    NEscN6(i, y) = NSpn1ago6
    NEscN7(i, y) = 993
    NEscN8(i, y) = 577
    NEscN9(i, y) = 1211
    NEscN10(i, y) = 372
    Else
    NspnN1(i, y) = NEscN1(i, y) + hatch1 '
    NspnN2(i, y) = NEscN2(i, y) + hatch2
    NspnN3(i, y) = NEscN3(i, y) + hatch3
    NspnN4(i, y) = NEscN4(i, y) + hatch4
    NspnN5(i, y) = NEscN5(i, y) + hatch5
    NspnN6(i, y) = NEscN6(i, y) + hatch6
    NspnN7(i, y) = NEscN7(i, y) + hatch7
    NspnN8(i, y) = NEscN8(i, y) + hatch8
    NspnN9(i, y) = NEscN9(i, y) + hatch9
    NspnN10(i, y) = NEscN10(i, y) + hatch10
End If

If NspnN1(i, y) > limitS1 Then NspnN1(i, y) = limitS1
If NspnN2(i, y) > limitS2 Then NspnN2(i, y) = limitS2
If NspnN3(i, y) > limitS3 Then NspnN3(i, y) = limitS3
If NspnN4(i, y) > limitS4 Then NspnN4(i, y) = limitS4
If NspnN5(i, y) > limitS5 Then NspnN5(i, y) = limitS5
If NspnN6(i, y) > limitS6 Then NspnN6(i, y) = limitS6
If NspnN7(i, y) > limitS7 Then NspnN7(i, y) = limitS7
If NspnN8(i, y) > limitS8 Then NspnN8(i, y) = limitS8
If NspnN9(i, y) > limitS9 Then NspnN9(i, y) = limitS9
If NspnN10(i, y) > limitS10 Then NspnN10(i, y) = limitS10

'update iteration totals
NEscNAvg1(y) = NEscNAvg1(y) + NEscN1(i, y)
NEscNAvg2(y) = NEscNAvg2(y) + NEscN2(i, y)
NEscNAvg3(y) = NEscNAvg3(y) + NEscN3(i, y)
NEscNAvg4(y) = NEscNAvg4(y) + NEscN4(i, y)
NEscNAvg5(y) = NEscNAvg5(y) + NEscN5(i, y)
NEscNAvg6(y) = NEscNAvg6(y) + NEscN6(i, y)
NEscNAvg7(y) = NEscNAvg7(y) + NEscN7(i, y)
NEscNAvg8(y) = NEscNAvg8(y) + NEscN8(i, y)
NEscNAvg9(y) = NEscNAvg9(y) + NEscN9(i, y)
```

```
NEscNAvg10(y) = NEscNAvg10(y) + NEscN10(i, y)
ENocnN1 = ENocnN1 + NocnN1(i, y)
ENocnN2 = ENocnN2 + NocnN2(i, y)
ENocnN3 = ENocnN3 + NocnN3(i, y)
ENocnN4 = ENocnN4 + NocnN4(i, y)
ENocnN5 = ENocnN5 + NocnN5(i, y)
ENocnN6 = ENocnN6 + NocnN6(i, y)
ENocnN7 = ENocnN7 + NocnN7(i, y)
ENocnN8 = ENocnN8 + NocnN8(i, y)
ENocnN9 = ENocnN9 + NocnN9(i, y)
ENocnN10 = ENocnN10 + NocnN10(i, y)
ENEsc1 = ENEsc1 + NEscN1(i, y)
ENEsc2 = ENEsc2 + NEscN2(i, y)
ENEsc3 = ENEsc3 + NEscN3(i, y)
ENEsc4 = ENEsc4 + NEscN4(i, y)
ENEsc5 = ENEsc5 + NEscN5(i, y)
ENEsc6 = ENEsc6 + NEscN6(i, y)
ENEsc7 = ENEsc7 + NEscN7(i, y)
ENEsc8 = ENEsc8 + NEscN8(i, y)
ENEsc9 = ENEsc9 + NEscN9(i, y)
ENEsc10 = ENEsc10 + NEscN10(i, y)

If y < 24 Then
   ENEsc201 = ENEsc201 + NEscN1(i, y) '20 y average
   ENEsc202 = ENEsc202 + NEscN2(i, y)
   ENEsc203 = ENEsc203 + NEscN3(i, y)
   ENEsc204 = ENEsc204 + NEscN4(i, y)
   ENEsc205 = ENEsc205 + NEscN5(i, y)
   ENEsc206 = ENEsc206 + NEscN6(i, y)
   ENEsc207 = ENEsc207 + NEscN7(i, y)
   ENEsc208 = ENEsc208 + NEscN8(i, y)
   ENEsc209 = ENEsc209 + NEscN9(i, y)
   ENEsc2010 = ENEsc2010 + NEscN10(i, y)
   EFrateCoast = EFrateCoast + FrateCoast(y) 'just summing frate across runs....(for average calc later)
   EFrateCascade = EFrateCascade + FrateCascade(y) 'just summing frate across runs....(for average calc later)

End If


a = (Int(NEscN1(i, y) / 150) + 1)
   If a > 100 Then a = 100
   If a < 1 Then a = 1
   CountEsc1(a) = CountEsc1(a) + 1
b = (Int(NEscN2(i, y) / 150) + 1)
   If b > 100 Then b = 100
   If b < 1 Then b = 1
   CountEsc2(b) = CountEsc2(b) + 1
c = (Int(NEscN3(i, y) / 150) + 1)
   If c > 100 Then c = 100
   If c < 1 Then c = 1
   CountEsc3(c) = CountEsc3(c) + 1
d = (Int(NEscN4(i, y) / 150) + 1)
   If d > 100 Then d = 100
   If d < 1 Then d = 1
   CountEsc4(d) = CountEsc4(d) + 1
e = (Int(NEscN5(i, y) / 150) + 1)
   If e > 100 Then e = 100
   If e < 1 Then e = 1
   CountEsc5(e) = CountEsc5(e) + 1
f = (Int(NEscN6(i, y) / 150) + 1)
   If f > 100 Then f = 100
   If f < 1 Then f = 1
   CountEsc6(f) = CountEsc6(f) + 1
g = (Int(NEscN7(i, y) / 150) + 1)
   If g > 100 Then g = 100
   If g < 1 Then g = 1
   CountEsc7(g) = CountEsc7(g) + 1
h = (Int(NEscN8(i, y) / 150) + 1)
   If h > 100 Then h = 100
   If h < 1 Then h = 1
```

```
   CountEsc8(h) = CountEsc8(h) + 1
m = (Int(NEscN9(i, y) / 150) + 1)
   If m > 100 Then m = 100
   If m < 1 Then m = 1
   CountEsc9(m) = CountEsc9(m) + 1
o = (Int(NEscN10(i, y) / 150) + 1)
   If o > 100 Then o = 100
   If o < 1 Then o = 1
   CountEsc10(o) = CountEsc10(o) + 1
j = (Int(100 * tgFrateN(y) / 2.5) + 1)
   If y > 3 Then
   If j > 20 Then j = 20
   If j < 1 Then j = 1
   CounttgF(j) = CounttgF(j) + 1
   End If
j = (Int(100 * FrateN(y) / 2.5) + 1)
   If y > 3 Then
   If j > 20 Then j = 20
   If j < 1 Then j = 1
   CountF(j) = CountF(j) + 1
   End If


If y > 3 Then
For k = 0 To Gen - 1
   MovGenAvg1(i, y) = MovGenAvg1(i, y) + (NEscN1(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg2(i, y) = MovGenAvg2(i, y) + (NEscN2(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg3(i, y) = MovGenAvg3(i, y) + (NEscN3(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg4(i, y) = MovGenAvg4(i, y) + (NEscN4(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg5(i, y) = MovGenAvg5(i, y) + (NEscN5(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg6(i, y) = MovGenAvg6(i, y) + (NEscN6(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg7(i, y) = MovGenAvg7(i, y) + (NEscN7(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg8(i, y) = MovGenAvg8(i, y) + (NEscN8(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg9(i, y) = MovGenAvg9(i, y) + (NEscN9(i, y - k) / (Gen + 0.0000000001))
   MovGenAvg10(i, y) = MovGenAvg10(i, y) + (NEscN10(i, y - k) / (Gen + 0.0000000001))
Next k
End If
If y > 3 Then
   If MovGenAvg1(i, y) < CRT1 Then flagGR1(i) = 1
   If MovGenAvg2(i, y) < CRT2 Then flagGR2(i) = 1
   If MovGenAvg3(i, y) < CRT3 Then flagGR3(i) = 1
   If MovGenAvg4(i, y) < CRT4 Then flagGR4(i) = 1
   If MovGenAvg5(i, y) < CRT5 Then flagGR5(i) = 1
   If MovGenAvg6(i, y) < CRT6 Then flagGR6(i) = 1
   If MovGenAvg7(i, y) < CRT7 Then flagGR7(i) = 1
   If MovGenAvg8(i, y) < CRT8 Then flagGR8(i) = 1
   If MovGenAvg9(i, y) < CRT9 Then flagGR9(i) = 1
   If MovGenAvg10(i, y) < CRT10 Then flagGR10(i) = 1
   CntFull1 = CntFull1 + flagfull1(i, y)
   CntFull2 = CntFull2 + flagfull2(i, y)
   CntFull3 = CntFull3 + flagfull3(i, y)
   CntFull4 = CntFull4 + flagfull4(i, y)
   CntFull5 = CntFull5 + flagfull5(i, y)
   CntFull6 = CntFull6 + flagfull6(i, y)
   CntFull7 = CntFull7 + flagfull7(i, y)
   CntFull8 = CntFull8 + flagfull8(i, y)
   CntFull9 = CntFull9 + flagfull9(i, y)
   CntFull10 = CntFull10 + flagfull10(i, y)
End If

If y > 3 And y < 24 Then
   If MovGenAvg1(i, y) < CRT1 Then flagGRST1(i) = 1
   If MovGenAvg2(i, y) < CRT2 Then flagGRST2(i) = 1
   If MovGenAvg3(i, y) < CRT3 Then flagGRST3(i) = 1
   If MovGenAvg4(i, y) < CRT4 Then flagGRST4(i) = 1
   If MovGenAvg5(i, y) < CRT5 Then flagGRST5(i) = 1
   If MovGenAvg6(i, y) < CRT6 Then flagGRST6(i) = 1
   If MovGenAvg7(i, y) < CRT7 Then flagGRST7(i) = 1
   If MovGenAvg8(i, y) < CRT8 Then flagGRST8(i) = 1
   If MovGenAvg9(i, y) < CRT9 Then flagGRST9(i) = 1
```

```
            If MovGenAvg10(i, y) < CRT10 Then flagGRST10(i) = 1

            CntFullST1 = CntFullST1 + flagfull1(i, y)
            CntFullST2 = CntFullST2 + flagfull2(i, y)
            CntFullST3 = CntFullST3 + flagfull3(i, y)
            CntFullST4 = CntFullST4 + flagfull4(i, y)
            CntFullST5 = CntFullST5 + flagfull5(i, y)
            CntFullST6 = CntFullST6 + flagfull6(i, y)
            CntFullST7 = CntFullST7 + flagfull7(i, y)
            CntFullST8 = CntFullST8 + flagfull8(i, y)
            CntFullST9 = CntFullST9 + flagfull9(i, y)
            CntFullST10 = CntFullST10 + flagfull10(i, y)

            CntCell1(seed1(y)) = CntCell1(seed1(y)) + 1
            CntCell2(seed2(y)) = CntCell2(seed2(y)) + 1
            CntCell3(seed3(y)) = CntCell3(seed3(y)) + 1
            CntCell4(seed4(y)) = CntCell4(seed4(y)) + 1
            CntCell5(seed5(y)) = CntCell5(seed5(y)) + 1
            CntCell6(seed6(y)) = CntCell6(seed6(y)) + 1
            CntCell7(seed7(y)) = CntCell7(seed7(y)) + 1
            CntCell8(seed8(y)) = CntCell8(seed8(y)) + 1
            CntCell9(seed9(y)) = CntCell9(seed9(y)) + 1
            CntCell10(seed10(y)) = CntCell10(seed10(y)) + 1
            CntCellCoast(seedCoast(y)) = CntCellCoast(seedCoast(y)) + 1
            CntCellCascade(seedCascade(y)) = CntCellCascade(seedCascade(y)) + 1
            CntCellSeedN(seedN(y)) = CntCellSeedN(seedN(y)) + 1
        End If
        If y > 3 And y < 24 Then
        CntFrate(seedN(y), MSIN(y)) = CntFrate(seedN(y), MSIN(y)) + 1  'counts freq of Frate combo cells for ALL pops 20 yr only
        End If

        If y > 3 And y < 24 Then
        CntSeed1 = CntSeed1 + seed1(y)    'counts 20 yr seed freq for pop1 for creating mean
        CntSeed2 = CntSeed2 + seed2(y)
        CntSeed3 = CntSeed3 + seed3(y)
        CntSeed4 = CntSeed4 + seed4(y)
        CntSeed5 = CntSeed5 + seed5(y)
        CntSeed6 = CntSeed6 + seed6(y)
        CntSeed7 = CntSeed7 + seed7(y)
        CntSeed8 = CntSeed8 + seed8(y)
        CntSeed9 = CntSeed9 + seed9(y)
        CntSeed10 = CntSeed10 + seed10(y)
        CntSeedCoast = CntSeedCoast + seedCoast(y)   'counts seeds for coast stratum mean
        CntSeedCascade = CntSeedCascade + seedCascade(y)  'counts seeds for cascade stratum mean
        CntSeedN = CntSeedN + seedN(y)
        End If


  Next y
GNSpnE = GNSpnE + (GNSpn(i) ^ (1 / Nyr))

If flagGR1(i) = 1 Then CntGenetic1 = CntGenetic1 + 1
If flagGR2(i) = 1 Then CntGenetic2 = CntGenetic2 + 1
If flagGR3(i) = 1 Then CntGenetic3 = CntGenetic3 + 1
If flagGR4(i) = 1 Then CntGenetic4 = CntGenetic4 + 1
If flagGR5(i) = 1 Then CntGenetic5 = CntGenetic5 + 1
If flagGR6(i) = 1 Then CntGenetic6 = CntGenetic6 + 1
If flagGR7(i) = 1 Then CntGenetic7 = CntGenetic7 + 1
If flagGR8(i) = 1 Then CntGenetic8 = CntGenetic8 + 1
If flagGR9(i) = 1 Then CntGenetic9 = CntGenetic9 + 1
If flagGR10(i) = 1 Then CntGenetic10 = CntGenetic10 + 1

If flagGRST1(i) = 1 Then CntGeneticST1 = CntGeneticST1 + 1
If flagGRST2(i) = 1 Then CntGeneticST2 = CntGeneticST2 + 1
If flagGRST3(i) = 1 Then CntGeneticST3 = CntGeneticST3 + 1
If flagGRST4(i) = 1 Then CntGeneticST4 = CntGeneticST4 + 1
If flagGRST5(i) = 1 Then CntGeneticST5 = CntGeneticST5 + 1
If flagGRST6(i) = 1 Then CntGeneticST6 = CntGeneticST6 + 1
If flagGRST7(i) = 1 Then CntGeneticST7 = CntGeneticST7 + 1
If flagGRST8(i) = 1 Then CntGeneticST8 = CntGeneticST8 + 1
```

```
    If flagGRST9(i) = 1 Then CntGeneticST9 = CntGeneticST9 + 1
    If flagGRST10(i) = 1 Then CntGeneticST10 = CntGeneticST10 + 1


Next i
Call RunModelOutputs
End Sub

Public Sub RunModelOutputs()
'Output summary statistics to model page
    Sheet3.Cells(34, 2) = CntGenetic1 / (iter + 0.0000000001) 'full run <CRT
    Sheet3.Cells(34, 3) = CntGenetic2 / (iter + 0.0000000001)
    Sheet3.Cells(34, 4) = CntGenetic3 / (iter + 0.0000000001)
    Sheet3.Cells(34, 5) = CntGenetic4 / (iter + 0.0000000001)
    Sheet3.Cells(34, 7) = CntGenetic5 / (iter + 0.0000000001) '
    Sheet3.Cells(34, 8) = CntGenetic6 / (iter + 0.0000000001) '
    Sheet3.Cells(34, 9) = CntGenetic7 / (iter + 0.0000000001)
    Sheet3.Cells(34, 10) = CntGenetic8 / (iter + 0.0000000001) '
    Sheet3.Cells(34, 11) = CntGenetic9 / (iter + 0.0000000001) '
    Sheet3.Cells(34, 12) = CntGenetic10 / (iter + 0.0000000001) '
    Sheet3.Cells(35, 2) = CntGeneticST1 / (iter + 0.0000000001) 'short term only <CRT
    Sheet3.Cells(35, 3) = CntGeneticST2 / (iter + 0.0000000001)
    Sheet3.Cells(35, 4) = CntGeneticST3 / (iter + 0.0000000001)
    Sheet3.Cells(35, 5) = CntGeneticST4 / (iter + 0.0000000001)
    Sheet3.Cells(35, 7) = CntGeneticST5 / (iter + 0.0000000001)
    Sheet3.Cells(35, 8) = CntGeneticST6 / (iter + 0.0000000001)
    Sheet3.Cells(35, 9) = CntGeneticST7 / (iter + 0.0000000001) '
    Sheet3.Cells(35, 10) = CntGeneticST8 / (iter + 0.0000000001) '
    Sheet3.Cells(35, 11) = CntGeneticST9 / (iter + 0.0000000001) '
    Sheet3.Cells(35, 12) = CntGeneticST10 / (iter + 0.0000000001) '
    Sheet3.Cells(36, 2) = CntSeed1 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 3) = CntSeed2 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 4) = CntSeed3 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 5) = CntSeed4 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 7) = CntSeed5 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 8) = CntSeed6 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 9) = CntSeed7 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 10) = CntSeed8 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 11) = CntSeed9 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(36, 12) = CntSeed10 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(37, 2) = ENEsc1 / ((iter * Nyr) + 0.0000000001) 'sends avg spawner number to output on model page
    Sheet3.Cells(37, 3) = ENEsc2 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(37, 4) = ENEsc3 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(37, 5) = ENEsc4 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(37, 7) = ENEsc5 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(37, 8) = ENEsc6 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(37, 9) = ENEsc7 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(37, 10) = ENEsc8 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(37, 11) = ENEsc9 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(37, 12) = ENEsc10 / ((iter * Nyr) + 0.0000000001)
    Sheet3.Cells(38, 2) = ENEsc201 / ((iter * 20) + 0.0000000001)  'sends 20y avg spawner number output on model page
    Sheet3.Cells(38, 3) = ENEsc202 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(38, 4) = ENEsc203 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(38, 5) = ENEsc204 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(38, 7) = ENEsc205 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(38, 8) = ENEsc206 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(38, 9) = ENEsc207 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(38, 10) = ENEsc208 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(38, 11) = ENEsc209 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(38, 12) = ENEsc2010 / ((iter * 20) + 0.0000000001)
    Sheet3.Cells(39, 2) = CntFullST1 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 3) = CntFullST2 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 4) = CntFullST3 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 5) = CntFullST4 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 7) = CntFullST5 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 8) = CntFullST6 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 9) = CntFullST7 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 10) = CntFullST8 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 11) = CntFullST9 / ((iter * 20) + 0.000000001)
    Sheet3.Cells(39, 12) = CntFullST10 / ((iter * 20) + 0.000000001)
```

```
Sheet3.Cells(40, 2) = CntFull1 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 3) = CntFull2 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 4) = CntFull3 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 5) = CntFull4 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 7) = CntFull5 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 8) = CntFull6 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 9) = CntFull7 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 10) = CntFull8 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 11) = CntFull9 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(40, 12) = CntFull10 / ((iter * Nyr) + 0.000000001)
Sheet3.Cells(41, 5) = CntSeedCoast / ((iter * 20) + 0.0000000001)
Sheet3.Cells(41, 12) = CntSeedCascade / ((iter * 20) + 0.000000001)
Sheet3.Cells(58, 2) = CntSeedN / ((iter * 20) + 0.000000001)
Sheet3.Cells(41, 2) = EFrateCoast / ((iter * 20) + 0.0000000001)
Sheet3.Cells(41, 7) = EFrateCascade / ((iter * 20) + 0.0000000001)

'Escapement frequency distribution (total spawners) HERE
For a = 1 To 100
    Sheet4.Cells(2 + a, 3) = CountEsc1(a) ' spawners
Next a
For b = 1 To 100
    Sheet4.Cells(2 + b, 4) = CountEsc2(b)
Next b
For c = 1 To 100
    Sheet4.Cells(2 + c, 5) = CountEsc3(c) ' spawners
Next c
For d = 1 To 100
    Sheet4.Cells(2 + d, 6) = CountEsc4(d) ' spawners
Next d
For e = 1 To 100
    Sheet4.Cells(2 + e, 7) = CountEsc5(e) ' spawners
Next e
For f = 1 To 100
    Sheet4.Cells(2 + f, 8) = CountEsc6(f) ' spawners
Next f
For g = 1 To 100
    Sheet4.Cells(2 + g, 9) = CountEsc7(g) ' spawners
Next g
For h = 1 To 100
    Sheet4.Cells(2 + h, 10) = CountEsc8(h) ' spawners
Next h
For m = 1 To 100
    Sheet4.Cells(2 + m, 11) = CountEsc9(m) ' spawners
Next m
For o = 1 To 100
    Sheet4.Cells(2 + o, 12) = CountEsc10(o) ' spawners
Next o



'avg annual nos
For j = 1 To Nyr + 3
    Sheet4.Cells(106, j + 1) = NEscNAvg1(j) / (iter + 0.0000000001) ' Wild spawners
    Sheet4.Cells(107, j + 1) = NEscNAvg2(j) / (iter + 0.0000000001) '
    Sheet4.Cells(108, j + 1) = NEscNAvg3(j) / (iter + 0.0000000001)
    Sheet4.Cells(109, j + 1) = NEscNAvg4(j) / (iter + 0.0000000001)
    Sheet4.Cells(110, j + 1) = NEscNAvg5(j) / (iter + 0.0000000001)
    Sheet4.Cells(111, j + 1) = NEscNAvg6(j) / (iter + 0.0000000001)
    Sheet4.Cells(112, j + 1) = NEscNAvg7(j) / (iter + 0.0000000001)
    Sheet4.Cells(113, j + 1) = NEscNAvg8(j) / (iter + 0.0000000001)
    Sheet4.Cells(114, j + 1) = NEscNAvg9(j) / (iter + 0.0000000001)
    Sheet4.Cells(115, j + 1) = NEscNAvg10(j) / (iter + 0.0000000001)
Next j

'This is OK
For j = 1 To 5
  For k = 1 To 4
    Sheet3.Cells(61 + j, 1 + k) = CntFrate(j, k) 'full ESU Frate selected - frequency
    Next k
```

```
  Next j

    For s = 1 To 5
      Sheet3.Cells(46 + s, 2) = CntCell1(s) 'count up cell values for par seed for pop 1 20 yrs
      Sheet3.Cells(46 + s, 3) = CntCell2(s)
      Sheet3.Cells(46 + s, 4) = CntCell3(s)
      Sheet3.Cells(46 + s, 5) = CntCell4(s)
      Sheet3.Cells(46 + s, 7) = CntCell5(s)
      Sheet3.Cells(46 + s, 8) = CntCell6(s)
      Sheet3.Cells(46 + s, 9) = CntCell7(s)
      Sheet3.Cells(46 + s, 10) = CntCell8(s)
      Sheet3.Cells(46 + s, 11) = CntCell9(s)
      Sheet3.Cells(46 + s, 12) = CntCell10(s)
      Sheet3.Cells(52 + s, 5) = CntCellCoast(s)
      Sheet3.Cells(52 + s, 12) = CntCellCascade(s)
    Next s

  For j = 1 To 20
      Sheet4.Cells(119 + j, 2) = CountF(j) ' Actual Fishing rate
  Next j

  For j = 1 To 20
      Sheet4.Cells(119 + j, 3) = CounttgF(j) ' Target Fishing rate
  Next j


'Output year data for last run

  'apply labels
  r = 2
  Sheet8.Cells(r, 1) = "y"
    r = r + 1
  Sheet8.Cells(r, 1) = pop1
      r = r + 1
  Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "NocnN(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "WildEscN(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "NAdN(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "MovGenAvg(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "SRvar(i, y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "Recr Co-var (y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "Fraction of full (y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "Seed (y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "  "
      r = r + 1

  Sheet8.Cells(r, 1) = pop2
      r = r + 1
  Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "NocnN(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "WildEscN(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "NAdN(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "SRvar(i, y)"
      r = r + 1
  Sheet8.Cells(r, 1) = "Recr Co-var(y)"
```

```
        r = r + 1
    Sheet8.Cells(r, 1) = "Fraction of Full (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Seed (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "  "
        r = r + 1

     Sheet8.Cells(r, 1) = pop3
        r = r + 1
    Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NocnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "WildEscN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NAdN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "SRvar(i, y)"
        r = r + 1
   Sheet8.Cells(r, 1) = "Recr Co-var(y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Fraction of Full (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Seed (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "  "
        r = r + 1

    Sheet8.Cells(r, 1) = pop4
        r = r + 1
    Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NocnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "WildEscN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NAdN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "SRvar(i, y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Recr Co-var(y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Fraction of Full (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Seed (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "  "
        r = r + 1

    Sheet8.Cells(r, 1) = "Coast Stratum"
        r = r + 1
    Sheet8.Cells(r, 1) = "Mean Fraction of Full"
        r = r + 1
    Sheet8.Cells(r, 1) = "SeedCoastal"
        r = r + 2

     Sheet8.Cells(r, 1) = pop5
        r = r + 1
    Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NocnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "WildEscN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NAdN(i,y)"
```

```
        r = r + 1
    Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "SRvar(i, y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Recr Co-var(y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Fraction of Full (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Seed (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "  "
        r = r + 1

    Sheet8.Cells(r, 1) = pop6
        r = r + 1
    Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NocnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "WildEscN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NAdN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "SRvar(i, y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Recr Co-var(y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Fraction of Full (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Seed (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "  "
        r = r + 1

    Sheet8.Cells(r, 1) = pop7
        r = r + 1
    Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NocnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "WildEscN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NAdN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "SRvar(i, y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Recr Co-var(y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Fraction of Full (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "Seed (y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "  "
        r = r + 1

    Sheet8.Cells(r, 1) = pop8
        r = r + 1
    Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NocnN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "WildEscN(i,y)"
        r = r + 1
    Sheet8.Cells(r, 1) = "NAdN(i,y)"
        r = r + 1
```

```
Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "SRvar(i, y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Recr Co-var(y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Fraction of Full (y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Seed (y)"
     r = r + 1
Sheet8.Cells(r, 1) = "  "
     r = r + 1

Sheet8.Cells(r, 1) = pop9
     r = r + 1
Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "NocnN(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "WildEscN(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "NAdN(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "SRvar(i, y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Recr Co-var(y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Fraction of Full (y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Seed (y)"
     r = r + 1
Sheet8.Cells(r, 1) = "  "
     r = r + 1

Sheet8.Cells(r, 1) = pop10
     r = r + 1
Sheet8.Cells(r, 1) = "TotSpnN(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "NocnN(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "WildEscN(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "NAdN(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "MovGenAvg2(i,y)"
     r = r + 1
Sheet8.Cells(r, 1) = "SRvar(i, y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Recr Co-var(y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Fraction of Full (y)"
     r = r + 1
Sheet8.Cells(r, 1) = "Seed (y)"
     r = r + 1
Sheet8.Cells(r, 1) = "  "
     r = r + 1

 Sheet8.Cells(r, 1) = "Cascade Stratum"
     r = r + 1
Sheet8.Cells(r, 1) = "Mean Fraction of Full"
     r = r + 1
Sheet8.Cells(r, 1) = "SeedCascade"
     r = r + 2

Sheet8.Cells(r, 1) = "All Populations"
     r = r + 1
Sheet8.Cells(r, 1) = "OPIH jacks"
     r = r + 1
```

```
 Sheet8.Cells(r, 1) = "Seed Category(y)"
        r = r + 1
 Sheet8.Cells(r, 1) = "Survival Category(y)"
        r = r + 1
 Sheet8.Cells(r, 1) = "FrateN(y)"
        r = r + 1
 Sheet8.Cells(r, 1) = "Fvar(y)"
        r = r + 1


 'insert result values
 For n = 1 To Nyr + 3
    r = 2
 Sheet8.Cells(r, n + 1) = n 'year number
        r = r + 2 'bypasses repeating the Pop name
 Sheet8.Cells(r, n + 1) = NspnN1(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NocnN1(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NEscN1(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NAdN1(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = MovGenAvg1(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = SRvar1(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = Mindex1(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = fraction1(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = seed1(n)
        r = r + 3 'nother space

Sheet8.Cells(r, n + 1) = NspnN2(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NocnN2(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NEscN2(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NAdN2(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = MovGenAvg2(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = SRvar2(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = Mindex2(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = fraction2(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = seed2(n)
        r = r + 3 'nother space

 Sheet8.Cells(r, n + 1) = NspnN3(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NocnN3(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NEscN3(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = NAdN3(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = MovGenAvg3(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = SRvar3(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = Mindex3(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = fraction3(iter, n)
        r = r + 1
 Sheet8.Cells(r, n + 1) = seed3(n)
```

```
        r = r + 3 'nother space

    Sheet8.Cells(r, n + 1) = NspnN4(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NocnN4(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NEscN4(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NAdN4(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = MovGenAvg4(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = SRvar4(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = Mindex4(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = fraction4(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = seed4(n)
        r = r + 3 'nother space

    Sheet8.Cells(r, n + 1) = spmeanCoast(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = seedCoast(n)
        r = r + 3

    Sheet8.Cells(r, n + 1) = NspnN5(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NocnN5(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NEscN5(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NAdN5(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = MovGenAvg5(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = SRvar5(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = Mindex5(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = fraction5(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = seed5(n)
        r = r + 3 'nother space

    Sheet8.Cells(r, n + 1) = NspnN6(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NocnN6(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NEscN6(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NAdN6(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = MovGenAvg6(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = SRvar6(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = Mindex6(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = fraction6(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = seed6(n)
        r = r + 3 'nother space

    Sheet8.Cells(r, n + 1) = NspnN7(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NocnN7(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = NEscN7(iter, n)
        r = r + 1
```

```
Sheet8.Cells(r, n + 1) = NAdN7(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = MovGenAvg7(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = SRvar7(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = Mindex7(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = fraction7(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = seed7(n)
    r = r + 3 'nother space

Sheet8.Cells(r, n + 1) = NspnN8(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NocnN8(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NEscN8(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NAdN8(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = MovGenAvg8(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = SRvar8(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = Mindex8(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = fraction8(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = seed8(n)
    r = r + 3 'nother space

Sheet8.Cells(r, n + 1) = NspnN9(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NocnN9(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NEscN9(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NAdN9(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = MovGenAvg9(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = SRvar9(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = Mindex9(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = fraction9(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = seed9(n)
    r = r + 3 'nother space

Sheet8.Cells(r, n + 1) = NspnN10(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NocnN10(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NEscN10(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = NAdN10(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = MovGenAvg10(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = SRvar10(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = Mindex10(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = fraction10(iter, n)
    r = r + 1
Sheet8.Cells(r, n + 1) = seed10(n)
    r = r + 3 'nother space
```

```
    Sheet8.Cells(r, n + 1) = spmeanCascade(iter, n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = seedCascade(n)
        r = r + 3

    Sheet8.Cells(r, n + 1) = OPIH(iter, n) 'opih jack value for year
        r = r + 1
    Sheet8.Cells(r, n + 1) = seedN(n) 'spawer fraction category for ER
        r = r + 1
    Sheet8.Cells(r, n + 1) = MSIN(n) 'survival category USED for ER
        r = r + 1
    Sheet8.Cells(r, n + 1) = tgFrateN(n)
        r = r + 1
    Sheet8.Cells(r, n + 1) = Fvar(n)
        r = r + 1

    Next n


End Sub
```

ADDENDUM

Prepared 10/8/2013 by Chris Kern, ODFW

At the Methodology Review on October 1, 2013, the members of the Scientific and Statistical Committee (SSC) Salmon Subcommittee asked the authors to consider two additional analyses for inclusion into the final document that will be distributed to the full SSC.

The two requests were:

1) Provide an assessment of how well the matrix of parental seeding and marine survival performs in predicting actual recruitment. This assessment would be based on examination of the two populations with substantial run reconstruction information; the Sandy and the Clackamas. The assessments is contained in Section 1 of this addendum, and is intended, to the extent possible, to mimic analyses used to establish the original matrix-based strategy for OCN coho, as contained in PFMC Amendment 13 and the subsequent "OCN Workgroup" report. Because the assessment was found to have some bearing on issue 2, it is presented first.

2) Provide an assessment of the effect of selection of time period in the spawner-recruit analyses, specifically for the Clackamas population. The time series used (1974-2009) resulted in a fitted spawner-recruit model that had a visible bias in residuals – recruit numbers in the more recent years in the series are consistently over-predicted and numbers in early years are under-predicted. This issue was discussed by the authors in a distinct section of the original document, and examples illustrating the effects of a more recent time series (with unbiased residual errors) were presented. However, given the feedback at the October 1 meeting, a more complete treatment of this issue is provided here-in. Accordingly, this addendum contains a full set of analyses that replicate those provided in the "Example Harvest Strategy Risk Assessments" section of the original document. For reasons described in the original document, an argument can still be made that the original analysis is still the more appropriate one to use. However, there is value in providing additional context regarding this issue so that readers can more fully evaluate the effects. This analysis constitutes Section 2 of this addendum.

SECTION 1 – Evaluation of parental seeding, marine survival, and estimated historic recruitment for Clackamas and Sandy populations

As part of the SSC review the authors were asked to test the assumption that the matrix combination of "parental escapement versus marine survival of jacks" reflects real recruitment, using the Clackamas and Sandy data sets as the basis for testing. The first step was simply to plot the time series' of wild recruits, hatchery smolt-to-jack survival, and hatchery smolt-to-adult survival.

As shown in Figure 1, for the Clackamas population, the three variables appear to follow similar trends over the period 1974-2009. However, there appears to be a change in the relationship between Clackamas recruits and the other two variables beginning in the early 1990s. There does not appear to be a change in the relationship between smolt-to-jack and smolt-to-adult survival rates at any point during the time series; this relationship is consistent across the series, and this has been confirmed by testing regressions of various time series'.

For the Sandy population, although the time series is ten years shorter than the Clackamas series, for the periods where they overlap (1984-2009), the patterns of the two populations appear to be similar. As with the Clackamas, there appears to be a change in the early 1990s in the relationship between Sandy wild recruits and the other two variables (Figure 2).

Both the smolt-to-jack (Figure 3) and smolt-to-adult (Figure 4) survival rates are positively correlated to the estimated number of wild recruits for both populations. However, these relationships are relatively weak.

Because the relationship between number of recruits and survival rates appears to have changed around 1993, the time series was shortened to 1993-2009 only and the above plots were repeated. Figures 5 and 6 show this time series for all three variables for each population. Based on this apparent change at around 1993, the 1993-2009 time series was also used to re-assess the spawner-recruit functions for both populations (see Section 2).

The apparent improved correlation between number of recruits and survival rates using the shorter time series is displayed in Figures 7 and 8. The relationships between recruits and survival rates are fairly strong for the Clackamas population, though weaker for the Sandy. However, if the 2008 data point for the Sandy is excluded, the relationships are much stronger. The estimated recruits for this data point are largely derived from an estimated spawning return of 3,500 wild fish in 2011 – the largest estimated return in the period 1984-2012. This estimate had a 95% confidence interval of 1,000 fish.

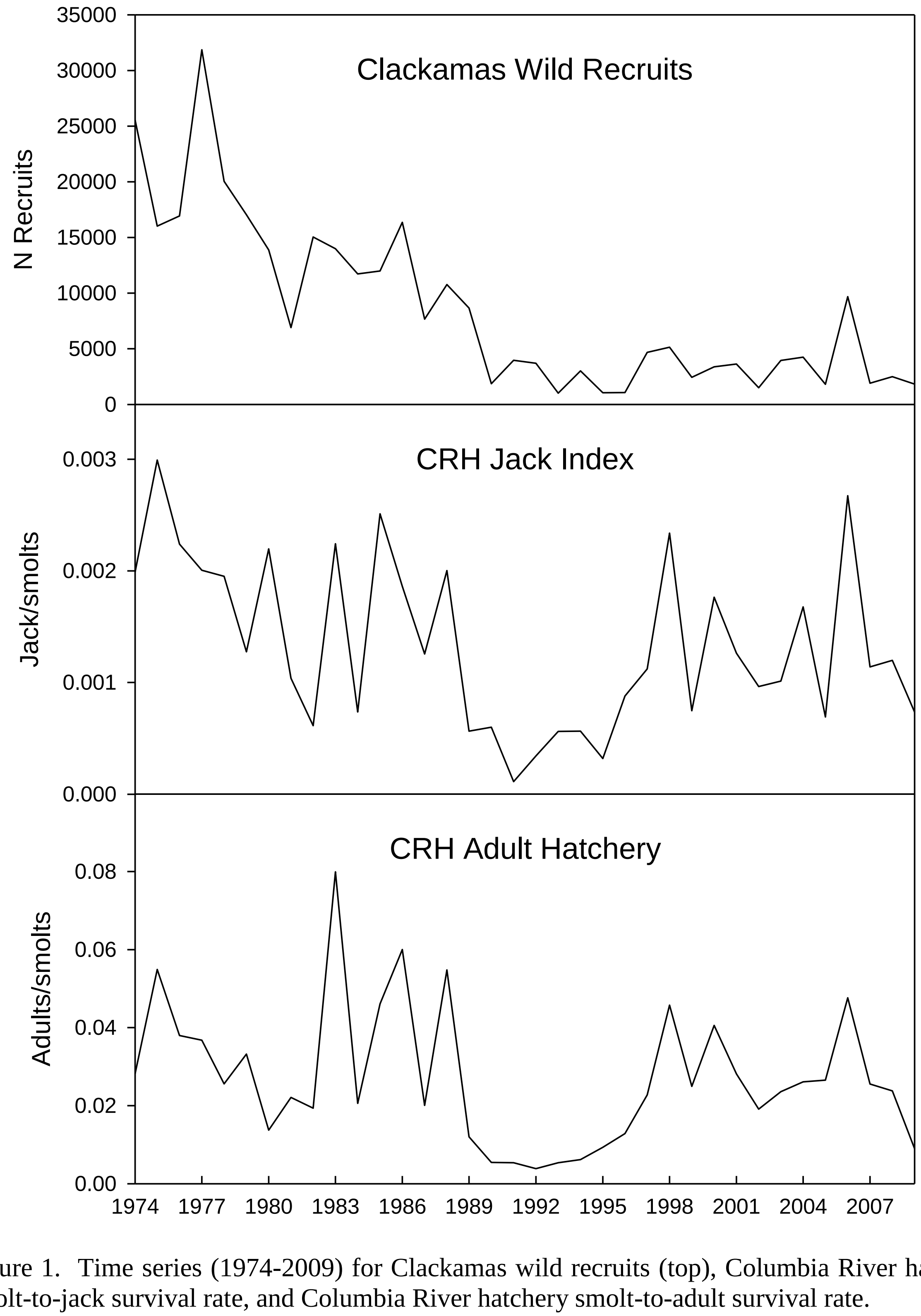


Figure 1. Time series (1974-2009) for Clackamas wild recruits (top), Columbia River hatchery smolt-to-jack survival rate, and Columbia River hatchery smolt-to-adult survival rate.

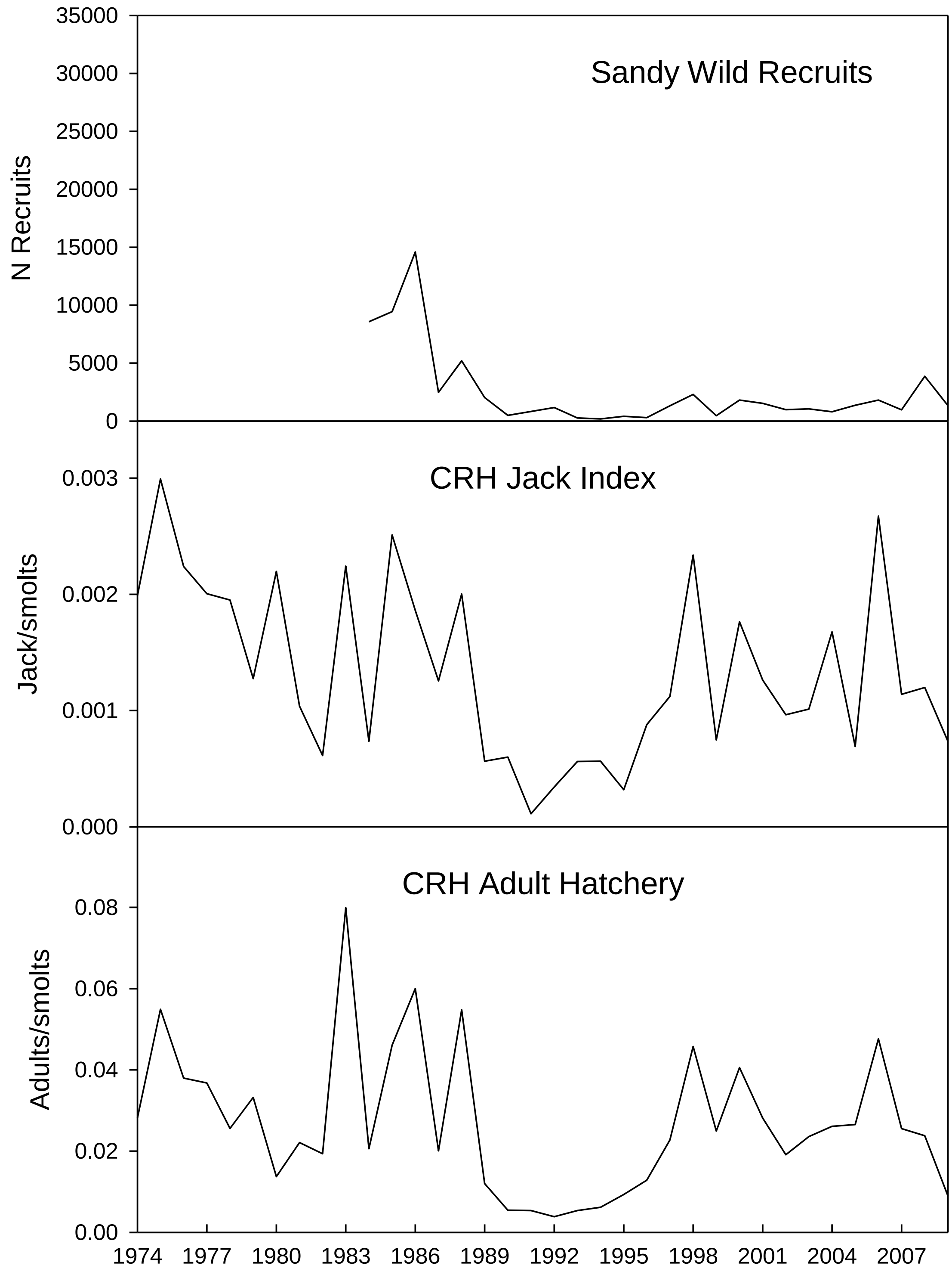


Figure 2. Time series (1974-2009) for Sandy wild recruits (top), Columbia River hatchery smolt-to-jack survival rate, and Columbia River hatchery smolt-to-adult survival rate.

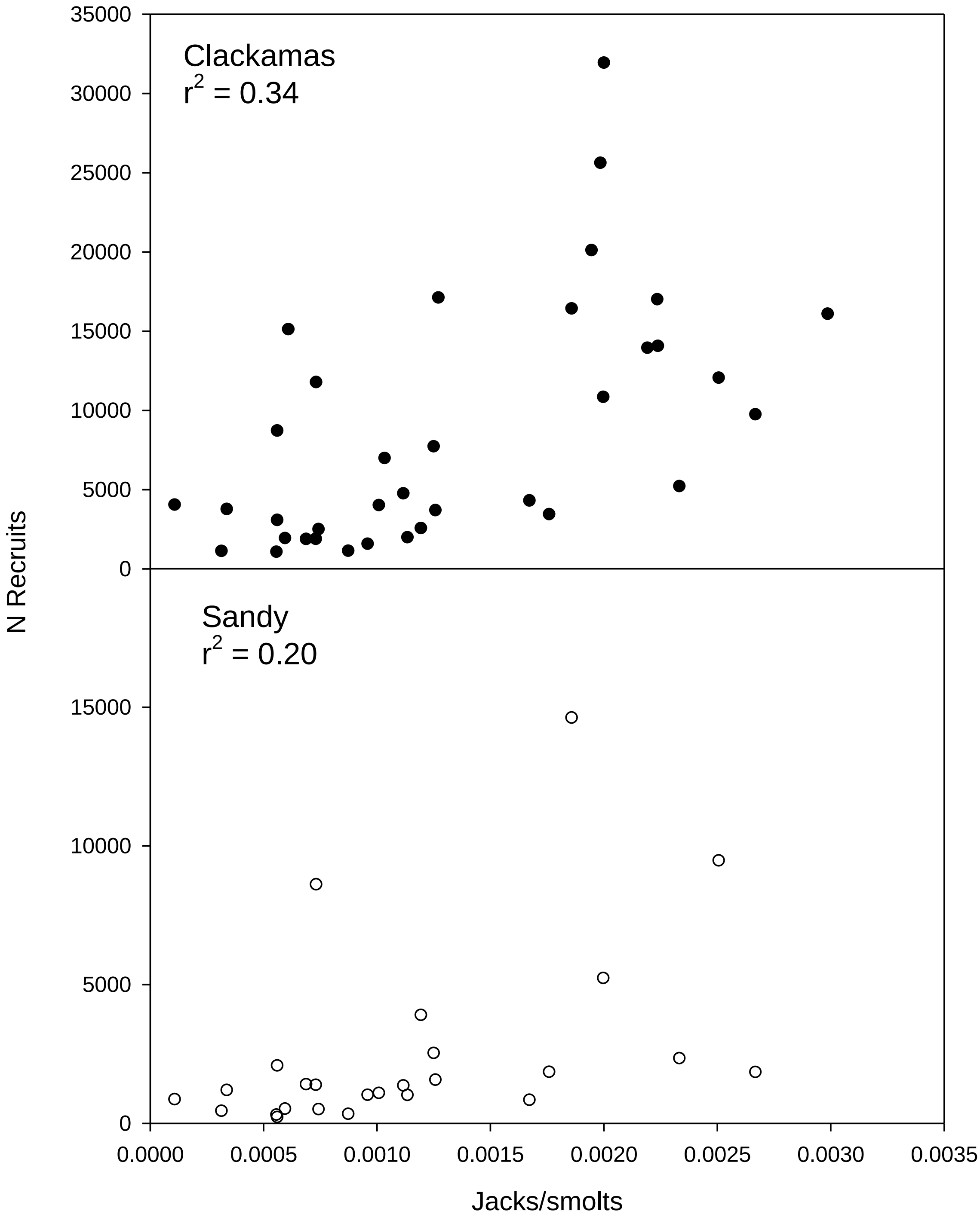


Figure 3. Relationship between smolt-to-jack survival and total wild recruits for Clackamas (top; 1974-2009) and Sandy (bottom; 1984-2009).

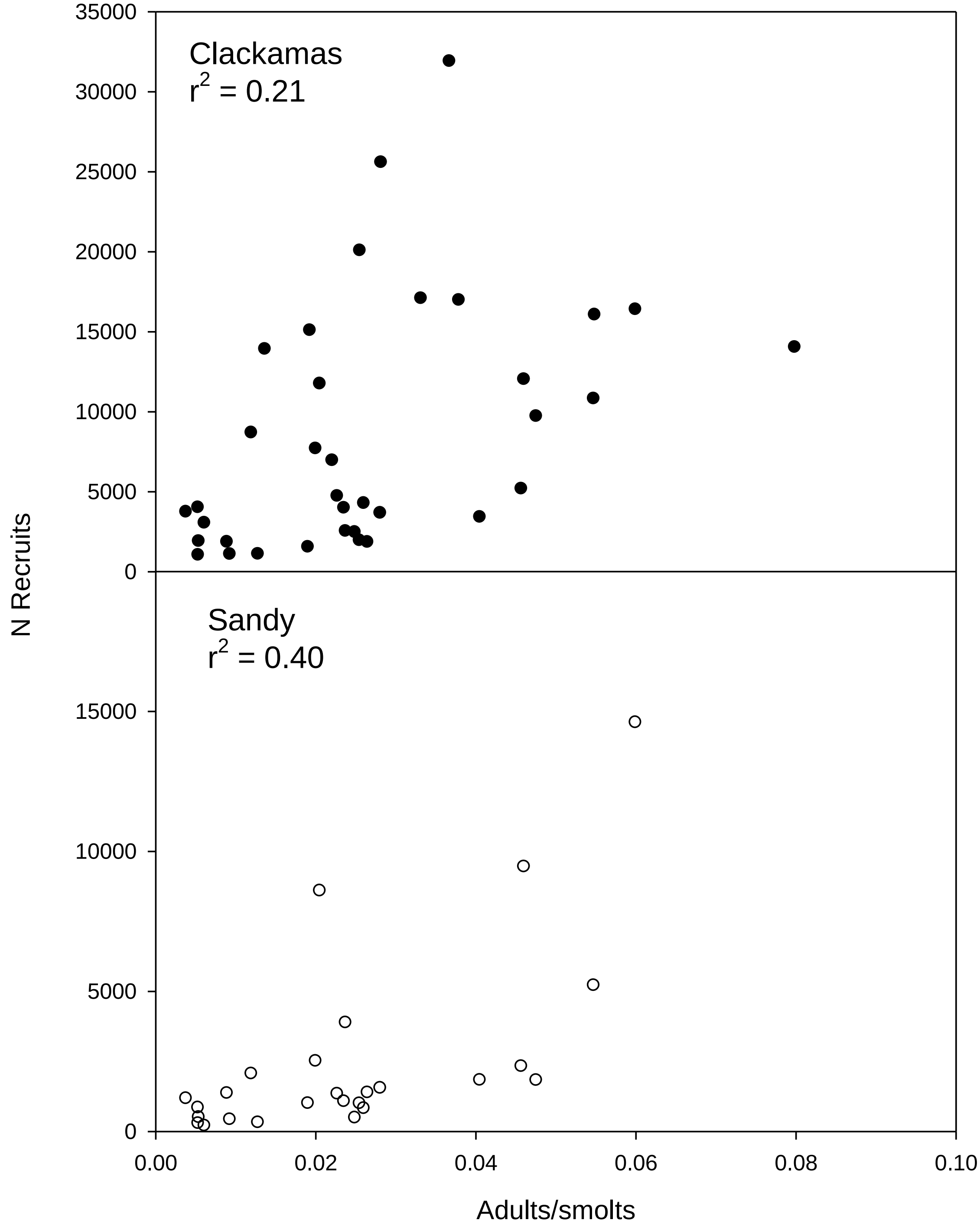


Figure 4. Relationship between smolt-to-adult survival and total wild recruits for Clackamas (top; 1974-2009) and Sandy (bottom; 1984-2009).

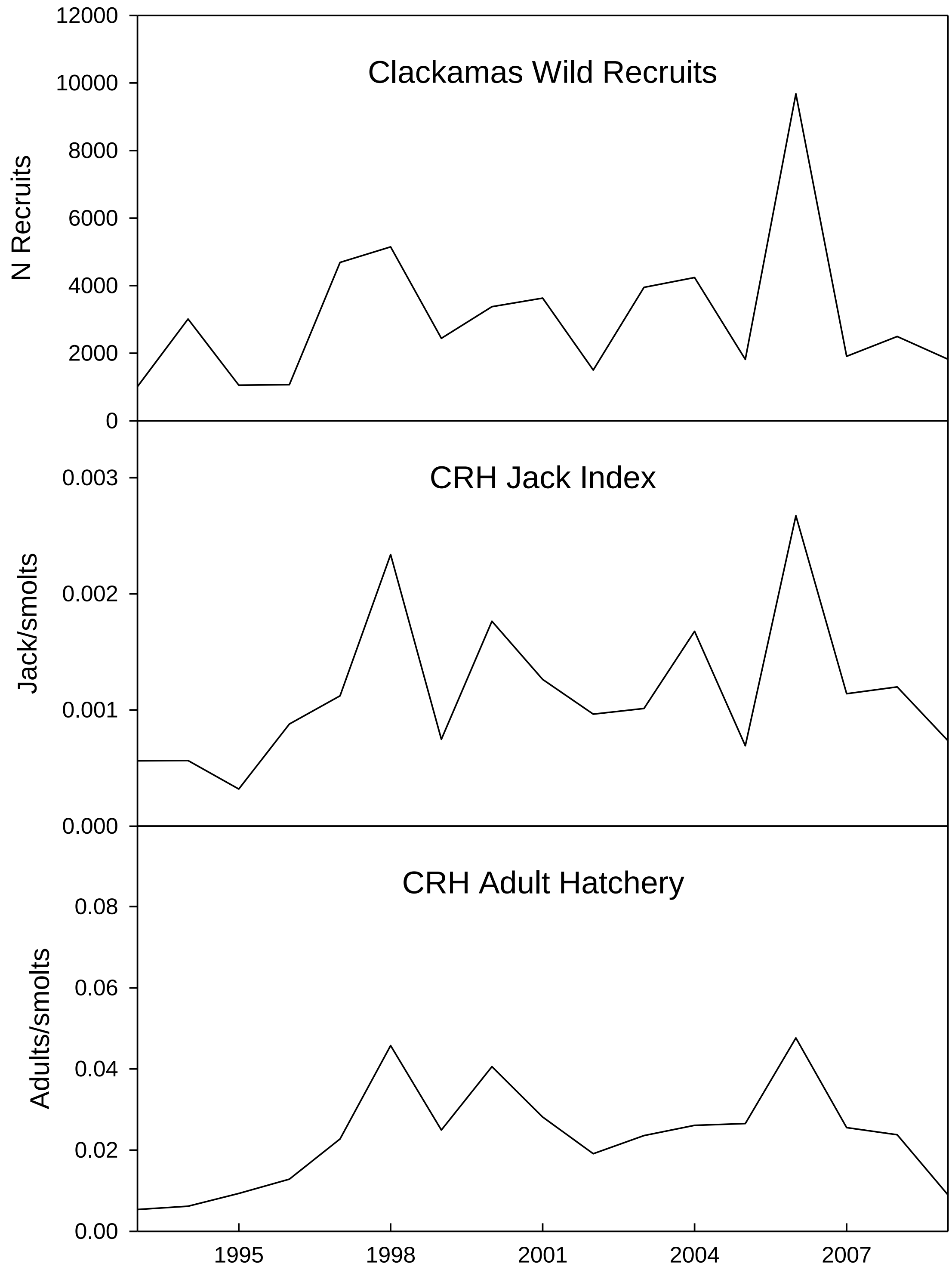


Figure 5. Time series **(1993-2009)** for Clackamas wild recruits (top), Columbia River hatchery smolt-to-jack survival rate, and Columbia River hatchery smolt-to-adult survival rate.

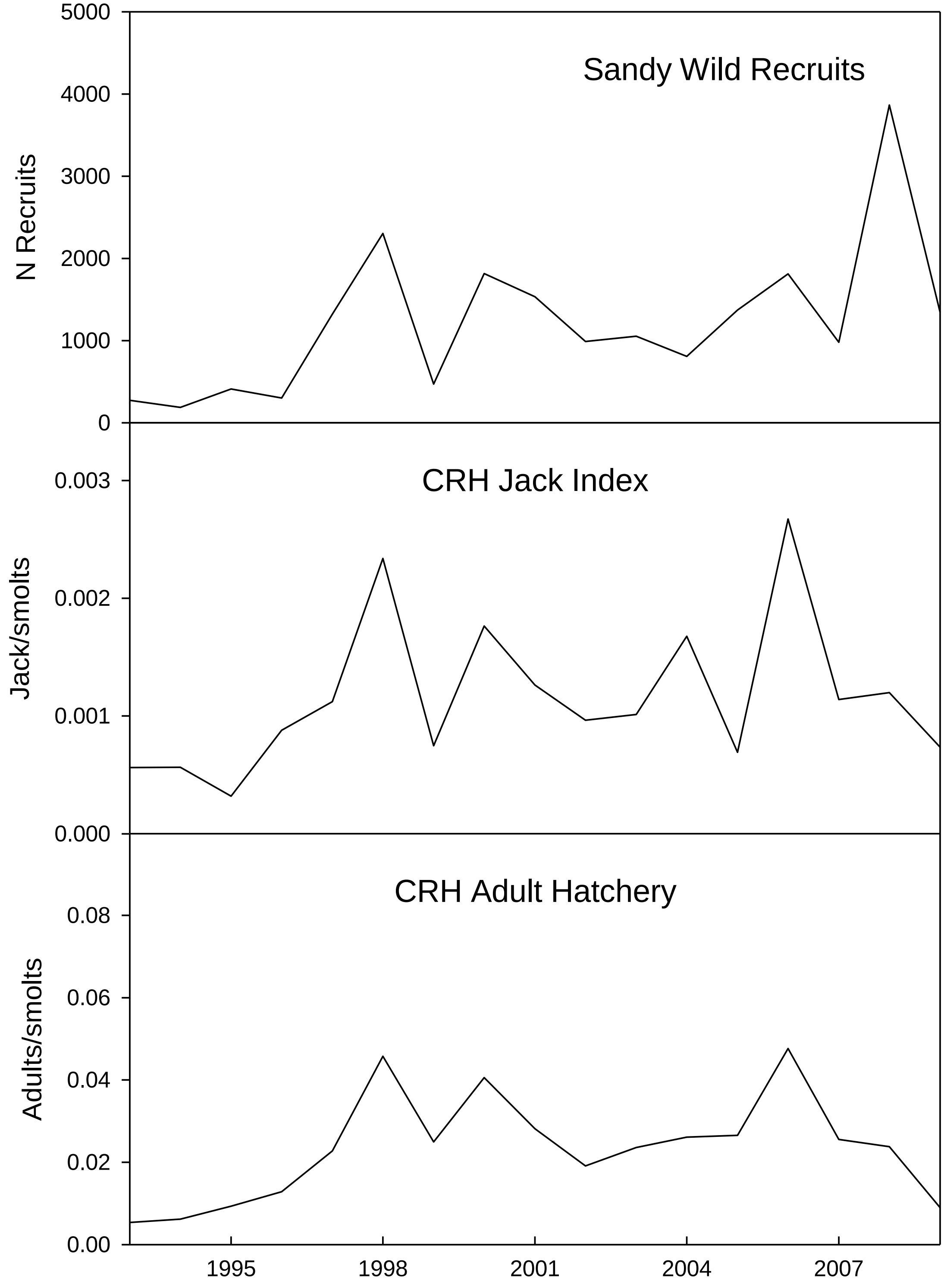


Figure 6. Time series **(1993-2009)** for Sandy wild recruits (top), Columbia River hatchery smolt-to-jack survival rate, and Columbia River hatchery smolt-to-adult survival rate.

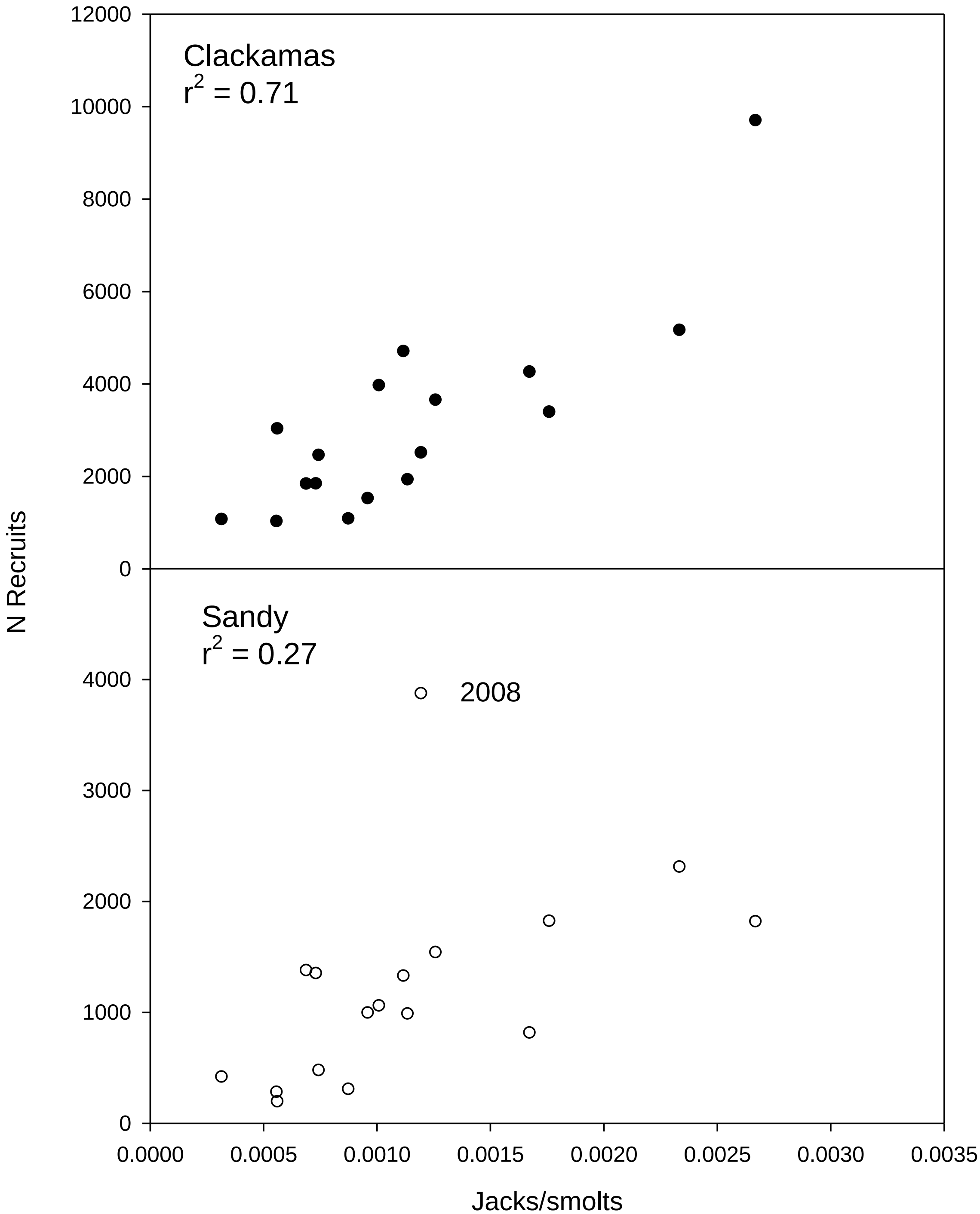


Figure 7. Relationship between smolt-to-jack survival and total wild recruits for Clackamas (top) and Sandy (bottom), 1993-2009 only. If 2008 data point for Sandy is excluded $r^2 = 0.58$.

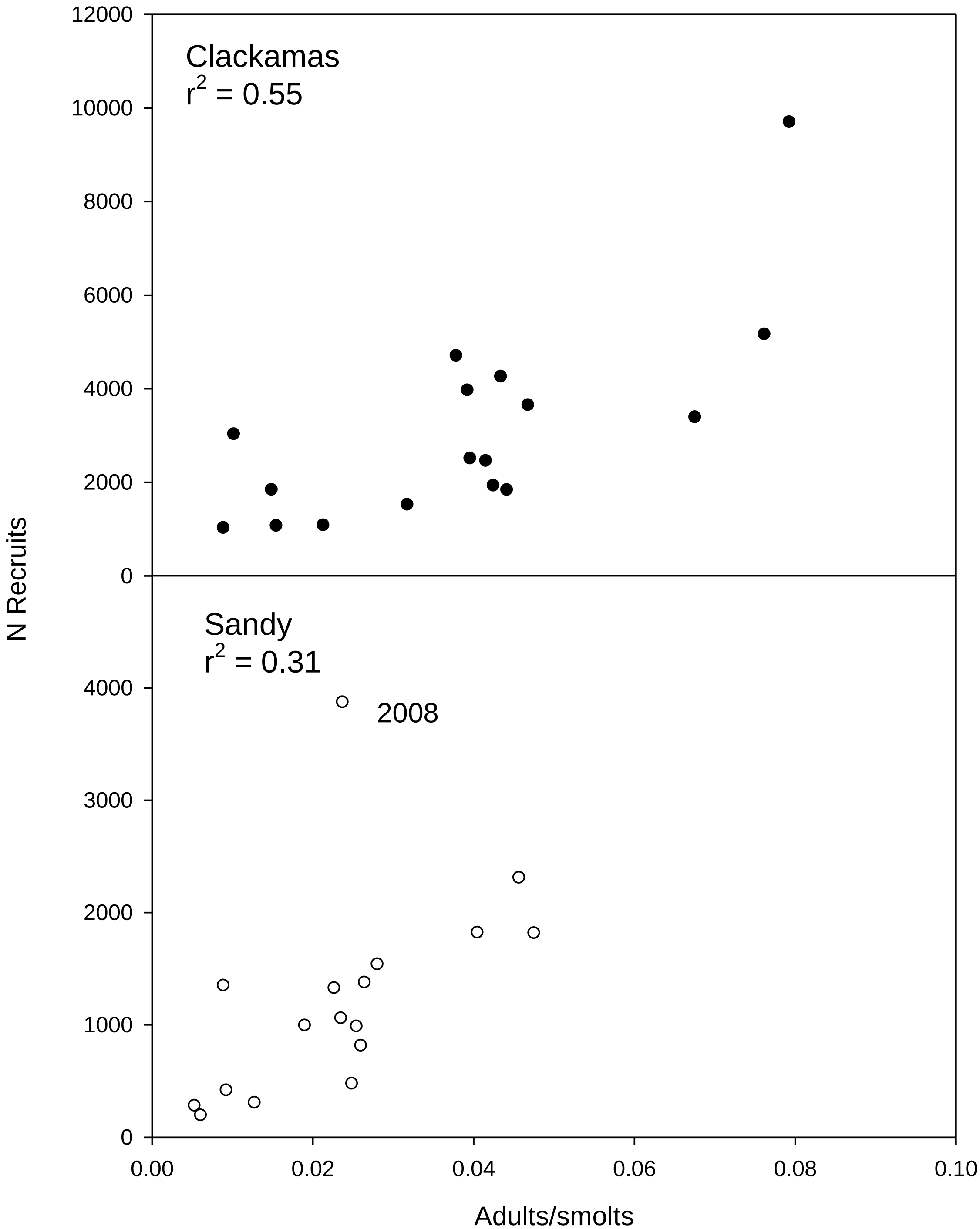


Figure 8. Relationship between smolt-to-adult survival and total wild recruits for Clackamas (top) and Sandy (bottom), 1993-2009 only. If 2008 data point for Sandy is excluded $r^2 = 0.69$.

Overall, it appears reasonable to conclude that the estimated abundance of wild recruits follows patterns similar to those observed in jack and hatchery adult survival rates. However, the relationships are likely not strong enough to be considered truly predictive in generating point estimates of recruit abundance. This may indicate that continuation of the current strategy for expressing expected abundance using categorical responses rather than numerically-predictive models is the more appropriate approach given current data availability.

To further examine the effectiveness of this approach, an exercise conducted during both the A-13 and OCN workgroup processes for establishing harvest rules for OCN coho was repeated here. Specifically, an attempt was made to replicate Table 5 from PFMC Amendment 13. This table sorts hatchery adult survival, then groups years with similar survival rates and pairs them with the estimated number of recruits per spawner from the same year. In the case of PFMC Table 5 the survival values are based on all OPI-area fish, whereas in our example, the survival values are based on Columbia River fish only - the two sets of values are extremely similar.

In the A13 analysis, three marine survival categories were established: hatchery adult survival of >5%, 2.5-5%, and <2.5%. These represented approximate wild recruit-per-spawner values of >5, 2.5, and <2, respectively. The OCN workgroup analysis added a fourth category for very low marine survival <1% (recruits-per-spawner <1). These categorical definitions were replicated in our analysis. One weakness in this approach is that recruits-per-spawner is not expected to be solely related to marine survival, but also to spawner abundance and potentially other factors. This weakness was also recognized and noted in prior efforts.

Table 1 displays the results of this analysis for all available years 1974-2009 for both populations. In many cases, the adult hatchery survival rate does not correctly predict the recruits-per-spawner category. For the Sandy, over 26 total years, ten are predicted correctly, nine are under-predicted, and seven are over-predicted. For the Clackamas, over 36 total years, 13 are predicted correctly, 15 are under-predicted, and eight are over-predicted. In only five cases was the correct category missed by more than one interval; three for the Sandy and two for the Clackamas. Only two of these cases (one in each population) were over-predictions of recruits-per-spawner. Importantly, for both populations, the adult survival rate either correctly predicts or under-predicts recruits-per-spawner in the most critical category of marine survival (<1). The current definition of critically low marine survival is effective in identifying years in which extremely low recruits-per-spawner (<1) could be expected.

Figures 9 and 10 display an alternative view of this information for the years 1993-2009 only, which may be easier to interpret. For both populations, there is substantial overlap between recruits-per-spawner values at different survival rate categories. In comparing recruits-per-spawner to smolt-to-jack survival rate, which is the metric that would be used in implementing the matrix, it appears that there is even more overlap among recruits-per-spawner values over varying survival rates (Figures 11 and 12).

Table 1. Prediction of marine survival categories from Columbia River hatchery coho smolt-to-jack and smolt-to-adult survival rates (1974-2009). "Y" indicates that the hatchery adult survival rate correctly predicts the R/S value category. In cases where it does not, "C" indicates which R/S category would have been correct. Values for the years 1974-1983 are not available for the Sandy.

			Sandy Population							Clackamas Population						
	Survival Rate		Wild			R/S Range				Wild			R/S Range			
Brood Yr	Jack	Adult	S	R	R/S	>5	2-5	1-2	<1	S	R	R/S	>5	2-5	1-2	<1
High Adult Hatchery Marine Survival																
1983	0.224%	7.993%								2,183	13,993	6.4	Y			
1986	0.186%	6.003%	1,780	14,593	8.2	Y				4,503	16,356	3.6		C		
1975	0.299%	5.494%								1,761	16,024	9.1	Y			
1988	0.200%	5.480%	1,735	5,196	3.0		C			2,203	10,777	4.9		C		
		Range	1735-1780	5196-14593	3-8.2					1761-4503	10777-16356	3.6-9.1				
		Mean	1758	9895	5.6					2822	14386	6.0				
Medium Adult Hatchery Marine Survival																
2006	0.267%	4.764%	923	1,810	2.0		Y			3,464	9,679	2.8		Y		
1985	0.251%	4.610%	1,665	9,439	5.7	C				3,459	11,989	3.5		Y		
1998	0.234%	4.577%	311	2,303	7.4	C				801	5,146	6.4	C			
2000	0.176%	4.059%	847	1,815	2.1		Y			3,006	3,375	1.1			C	
1976	0.224%	3.798%								1,835	16,938	9.2	C			
1977	0.201%	3.678%								1,544	31,862	20.6	C			
1979	0.128%	3.322%								1,765	17,044	9.7	C			
1974	0.199%	2.823%								1,551	25,549	16.5	C			
2001	0.126%	2.814%	1,600	1,533	1.0			C		3,575	3,631	1.0			C	
2005	0.069%	2.655%	856	1,371	1.6			C		1,301	1,818	1.4			C	
2004	0.168%	2.610%	1,213	808	0.7				C	2,874	4,243	1.5			C	
1978	0.195%	2.560%								1,450	20,036	13.8	C			
2007	0.114%	2.554%	687	980	1.4			C		3,608	1,910	0.5				C
1999	0.075%	2.497%	198	470	2.4		Y			703	2,439	3.5		Y		
		Range	198-1665	470-9439	0.7-7.4					703-3608	1818-31862	0.5-20.6				
		Mean	922	2281	2.7					2210	11119	6.5				
Low Adult Hatchery Marine Survival																
2008	0.120%	2.380%	1,277	3,866	3.0		C			1,694	2,494	1.5			Y	
2003	0.101%	2.361%	1,348	1,052	0.8				C	2,507	3,949	1.6			Y	
1997	0.112%	2.276%	145	1,321	9.1	C				2,332	4,686	2.0			Y	
1981	0.104%	2.212%								2,065	6,914	3.3		C		
1984	0.074%	2.059%	925	8,579	9.3	C				1,353	11,719	8.7	C			
1987	0.126%	2.007%	1,390	2,492	1.8			Y		1,899	7,660	4.0		C		
1982	0.061%	1.936%								3,037	15,041	5.0		C		
2002	0.096%	1.912%	382	988	2.6		C			1,981	1,502	0.8				C

1980	0.220%	1.373%						3,624	13,877	3.8	C		
1996	0.088%	1.284%	220	300	1.4	Y		811	1,066	1.3		Y	
1989	0.056%	1.203%	2,508	2,042	0.8		C	2,811	8,653	3.1	C		
			145-	300-	0.8-			811-	1066-	0.8-			
		Range	2508	8579	9.3			3624	15041	8.7			
		Mean	1024	2580	3.6			2192	7051	3.2			
					Very Low Adult Hatchery Marine Survival								
1995	0.032%	0.934%	810	410	0.5		Y	2,578	1,055	0.4			Y
2009	0.073%	0.899%	1,493	1,343	0.9		Y	7,982	1,822	0.2			Y
1994	0.056%	0.617%	700	188	0.3		Y	3,336	3,011	0.9			Y
1990	0.060%	0.546%	443	491	1.1	C		1,361	1,868	1.4		C	
1993	0.056%	0.539%	233	273	1.2	C		887	1,009	1.1		C	
1991	0.011%	0.537%	1,718	833	0.5		Y	3,562	3,971	1.1		C	
1992	0.034%	0.387%	916	1,164	1.3	C		3,881	3,707	1.0			Y
			233-	188-	0.3-			887-	1009-	0.2-			
		Range	1718	1343	1.3			7982	3971	1.4			
		Mean	902	672	0.8			3370	2349	0.9			

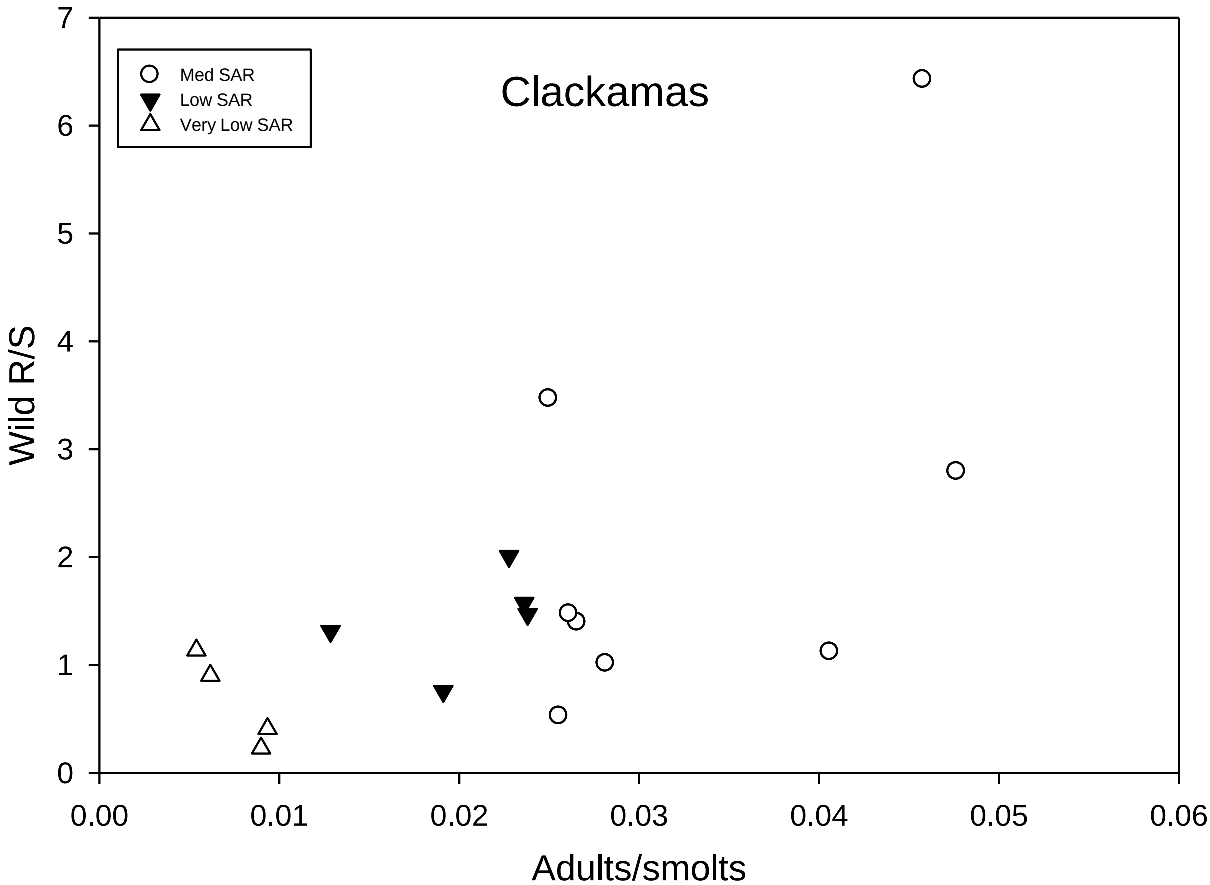


Figure 9. Relationship between hatchery smolt-to-adult survival rate and wild recruits-per-spawner, Clackamas population 1993-2009.

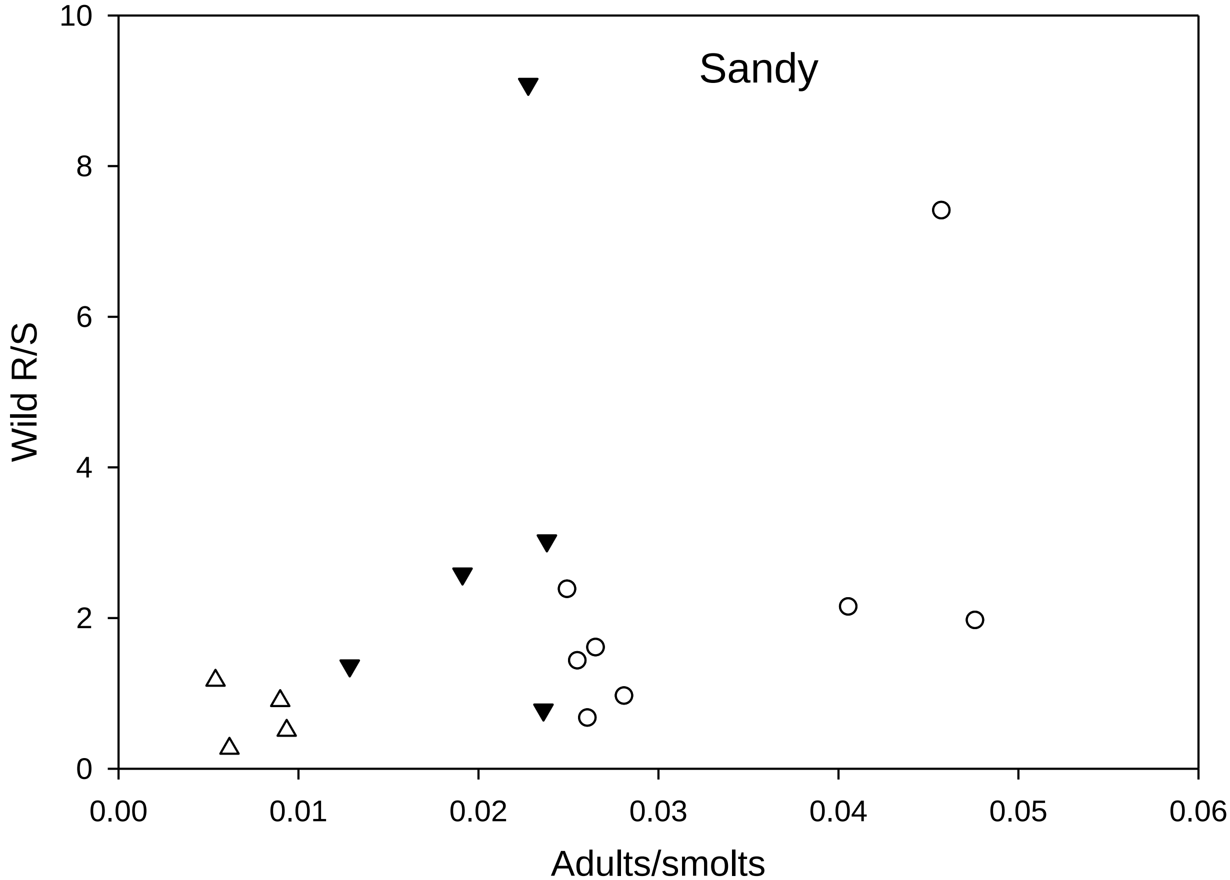


Figure 10. Relationship between hatchery smolt-to-adult survival rate and wild recruits-per-spawner, Sandy population 1993-2009.

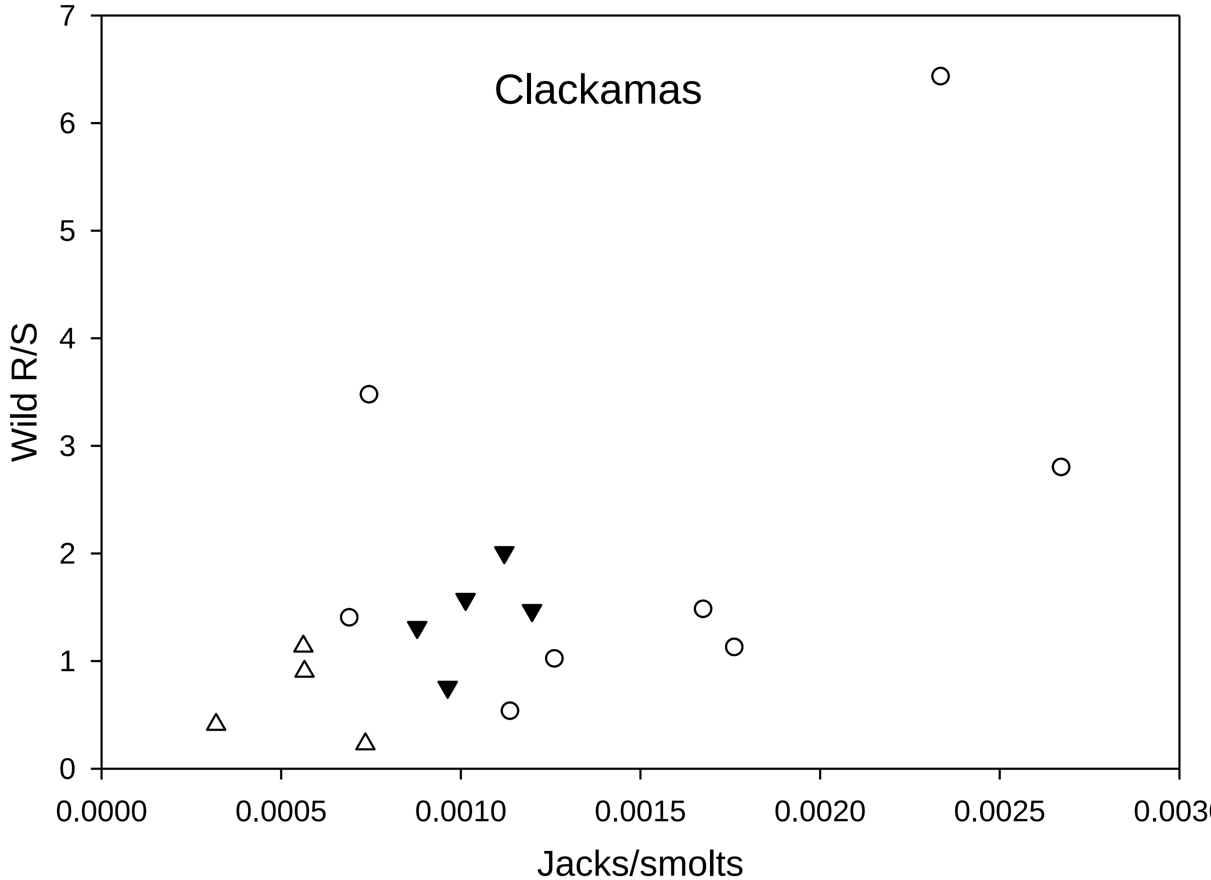


Figure 11. Relationship between smolt-to-jack survival rate and wild recruits-per-spawner, Clackamas population 1993-2009.

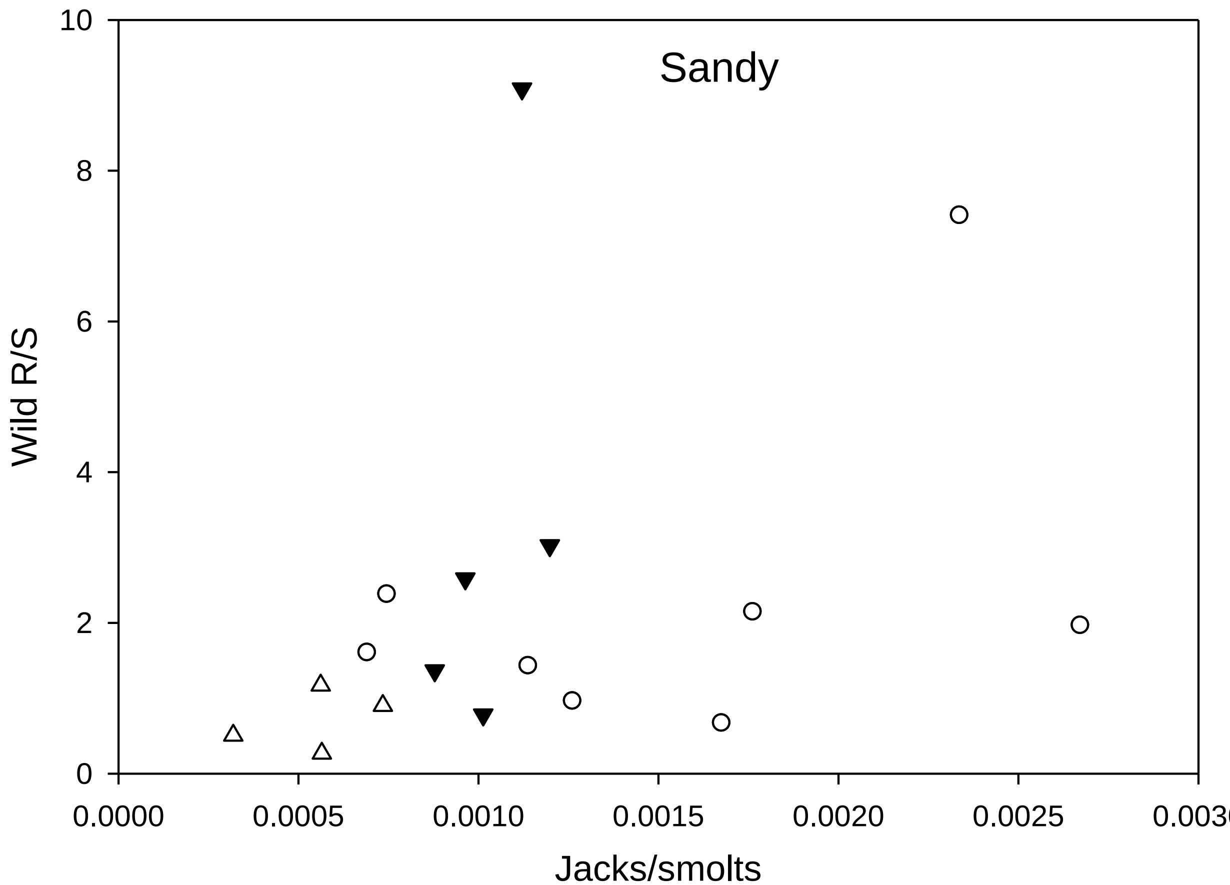


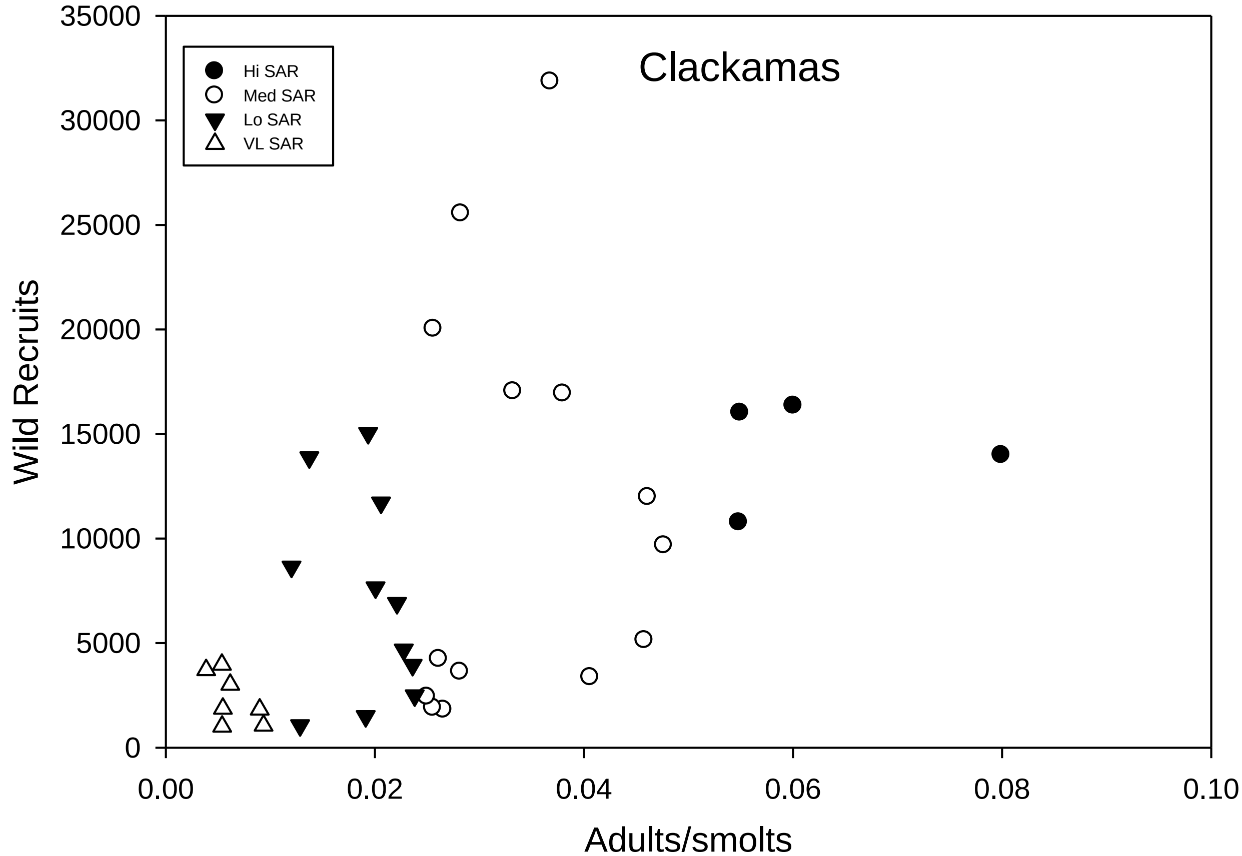
Figure 12. Relationship between smolt-to-jack survival rate and wild recruits-per-spawner, Sandy population 1993-2009.

The survival rates appear to do a better job of predicting actual number of recruits for predicting recruits-per-spawner, although there is still substantial overlap of recruit abundances among varying survival rates (Figures 13 and 14). However, as in the recruits-per-spawner example, the jack-to-smolt survival rate is less predictive than the smolt-to-adult survival rate (Figures 15 and 16).

Overall, the use of a survival rate, whether smolt-to-adult (which is not available for preseason planning) or smolt-to-jack (which is available for preseason planning) to predict a point estimate of either recruits-per-spawner or abundance of recruits for the Clackamas and Sandy populations is not ideal. The survival rates are, however, positively associated to both recruits-per-spawner and abundance of recruits for both populations.

Despite the fact that hatchery fish survival rates have somewhat limited predictive ability, there are no viable alternatives for projecting future abundance. Current return forecasts for the Clackamas and Sandy populations are based upon three-year "brood line" average spawner abundances. These are, by definition, terminal return forecasts only, and do not address projected pre-fishery ocean abundance of these stocks. In both populations, estimates of the abundance of jack coho are unavailable and/or believed to be unreliable due to recovery biases.

This precludes the use of sibling regression methods for forecasts. Even less information is available for other LCN populations.



Figures 13. Relationship between hatchery smolt-to-adult survival rate and number of wild recruits, Clackamas population 1974-2009.

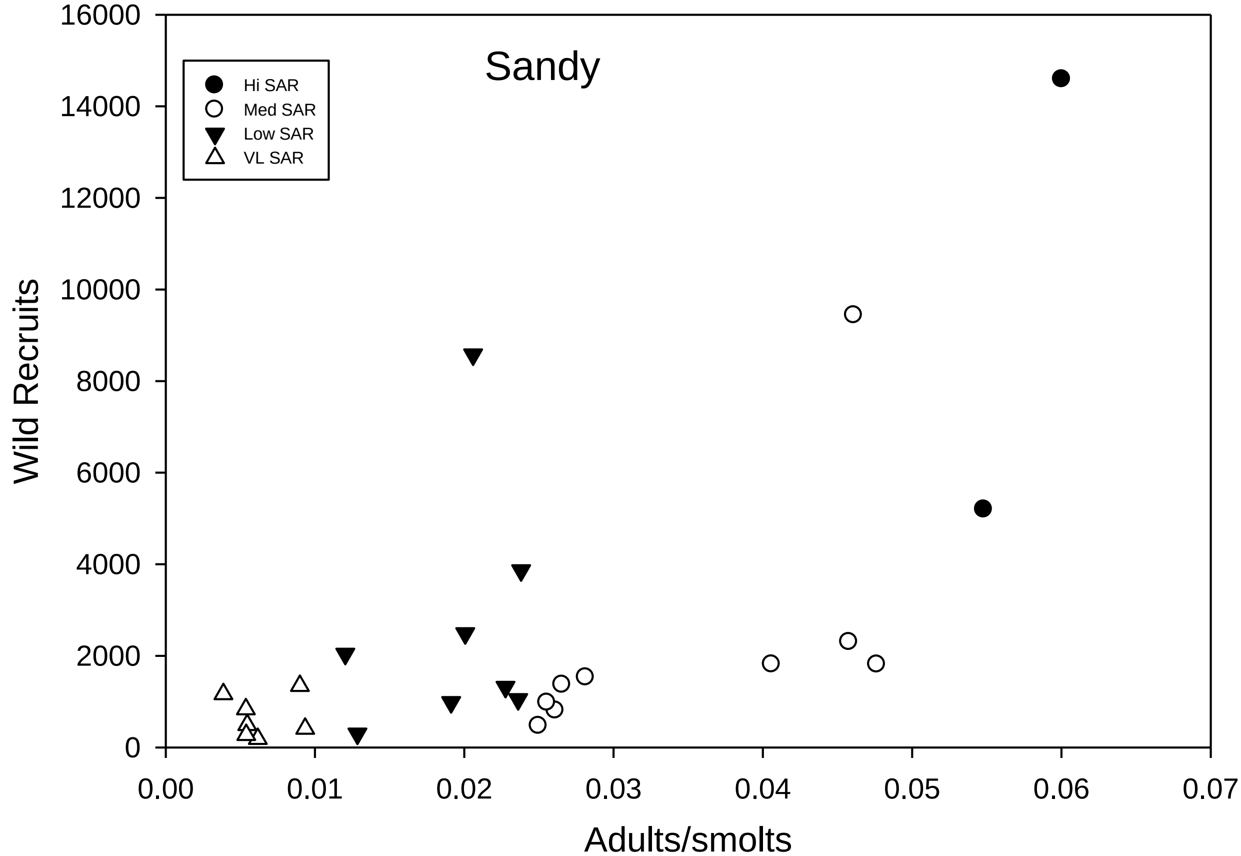


Figure 14. Relationship between hatchery smolt-to-adult survival rate and number of wild recruits, Sandy population 1984-2009.

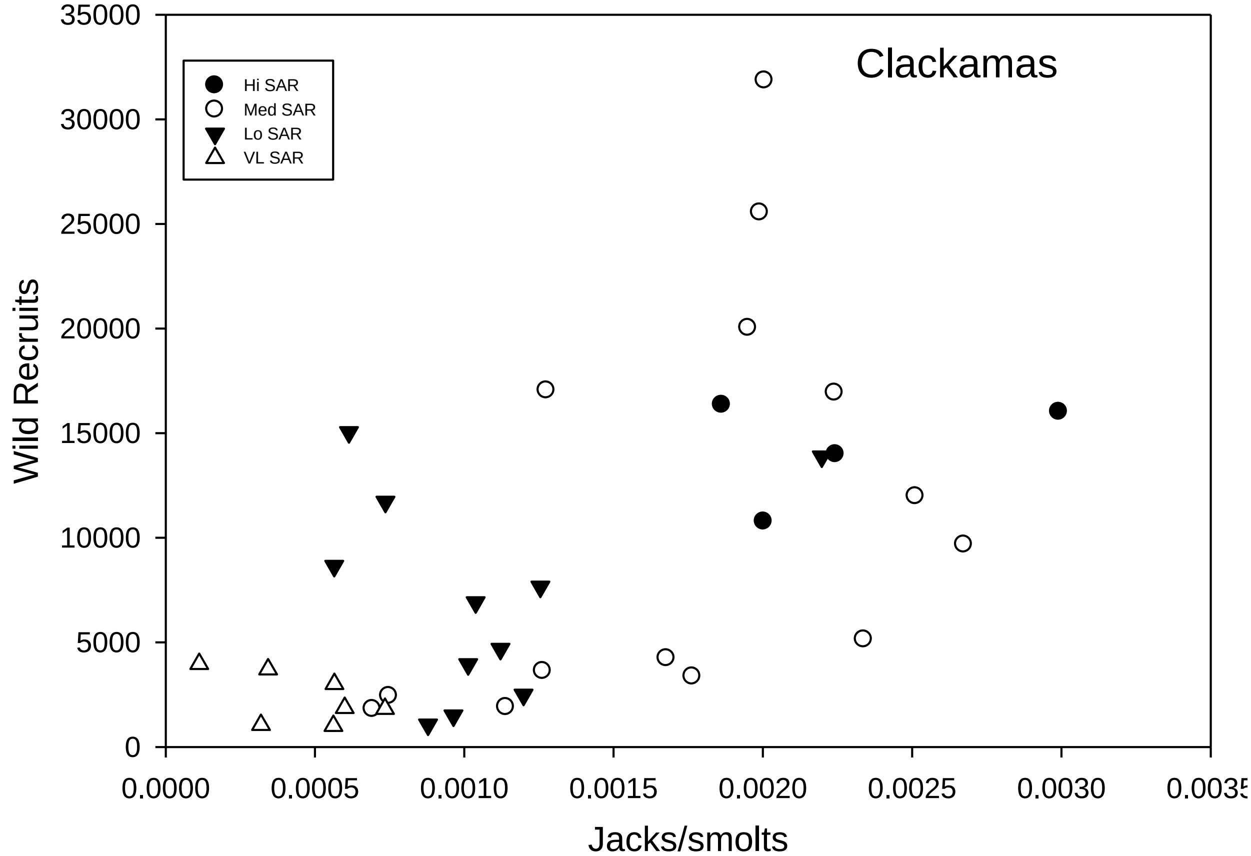


Figure 15. Relationship between smolt-to-jack survival rate and number of wild recruits, Clackamas population 1974-2009.

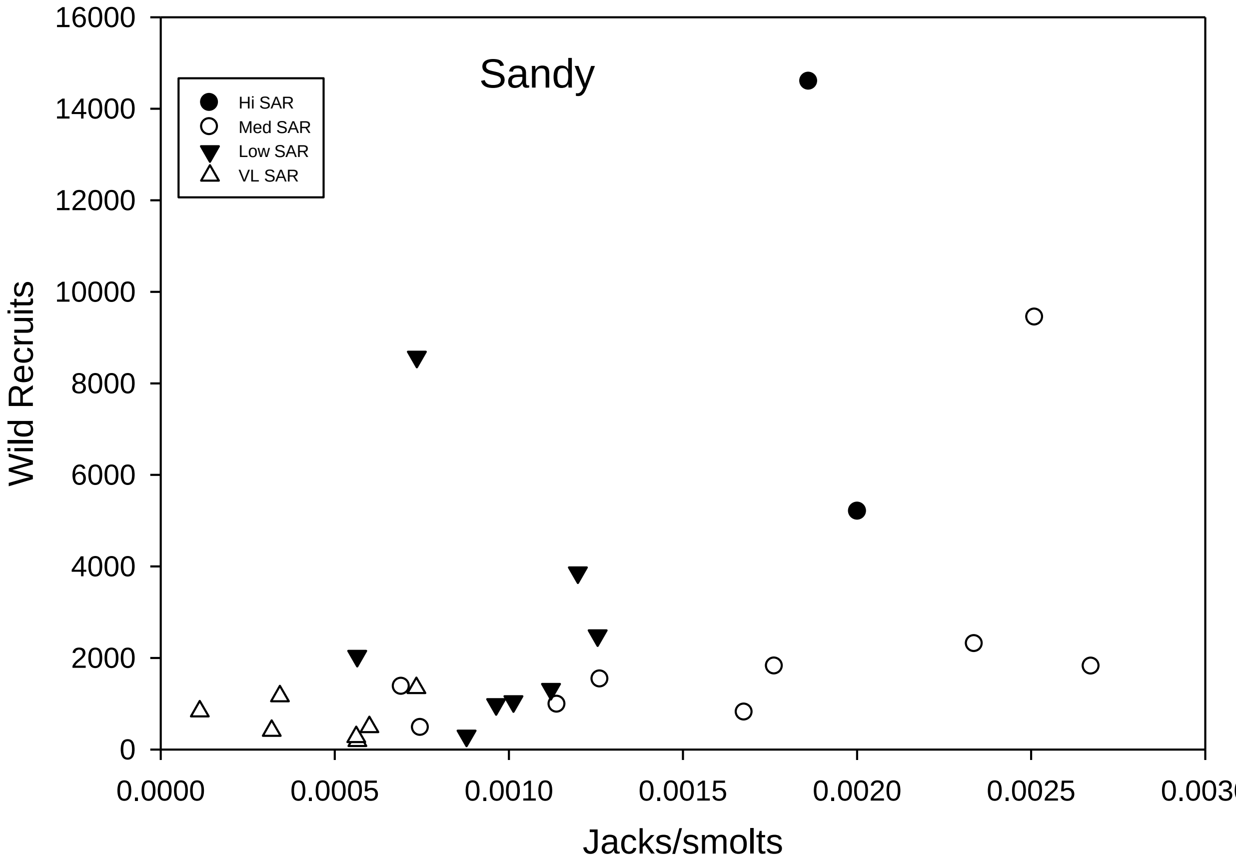


Figure 16. Relationship between smolt-to-jack survival rate and number of wild recruits, Sandy population 1984-2009.

Because the matrix approach also considers the level of parental abundance in categorizing future production of recruits, the relationship between the fraction of 100% full parental seeding and abundance of recruits was examined for the two populations. As shown in Figures 17 and 18, there is a general positive relationship between the level of parental seeding and the number of wild recruits. However, there is also significant variation in this relationship, which may or may not be explainable by marine survival, which is not considered in this portion of the analysis.

As was apparent in the examination of survival and recruitment, it appears that the level of parental escapement is more associated with absolute recruit abundance than it is with recruits-per-spawner, though this may be an artifact of the necessary exclusion of marine survival effects. For the Clackamas population there is an apparent non-linear negative relationship between parental abundance and recruits-per-spawner (Figure 19). This is consistent with the expectation that recruits-per-spawner should decline with increasing spawner abundance. However, for the Sandy population, this pattern is not as readily apparent (Figure 20).

In conclusion, the continued use of the matrix approach of considering categorical parental abundance and categorical forecasted marine survival is likely the best available technique for projecting expected future abundance for use in preseason fishery planning. The method certainly has weaknesses and improvements should be sought. However, considering the lack of suitable alternatives, this method appears to be the only viable option at this time. Future work should prioritize further examination of the marine survival aspect of the matrix, hopefully incorporating new information from life-cycle monitoring sites in both Oregon and Washington.

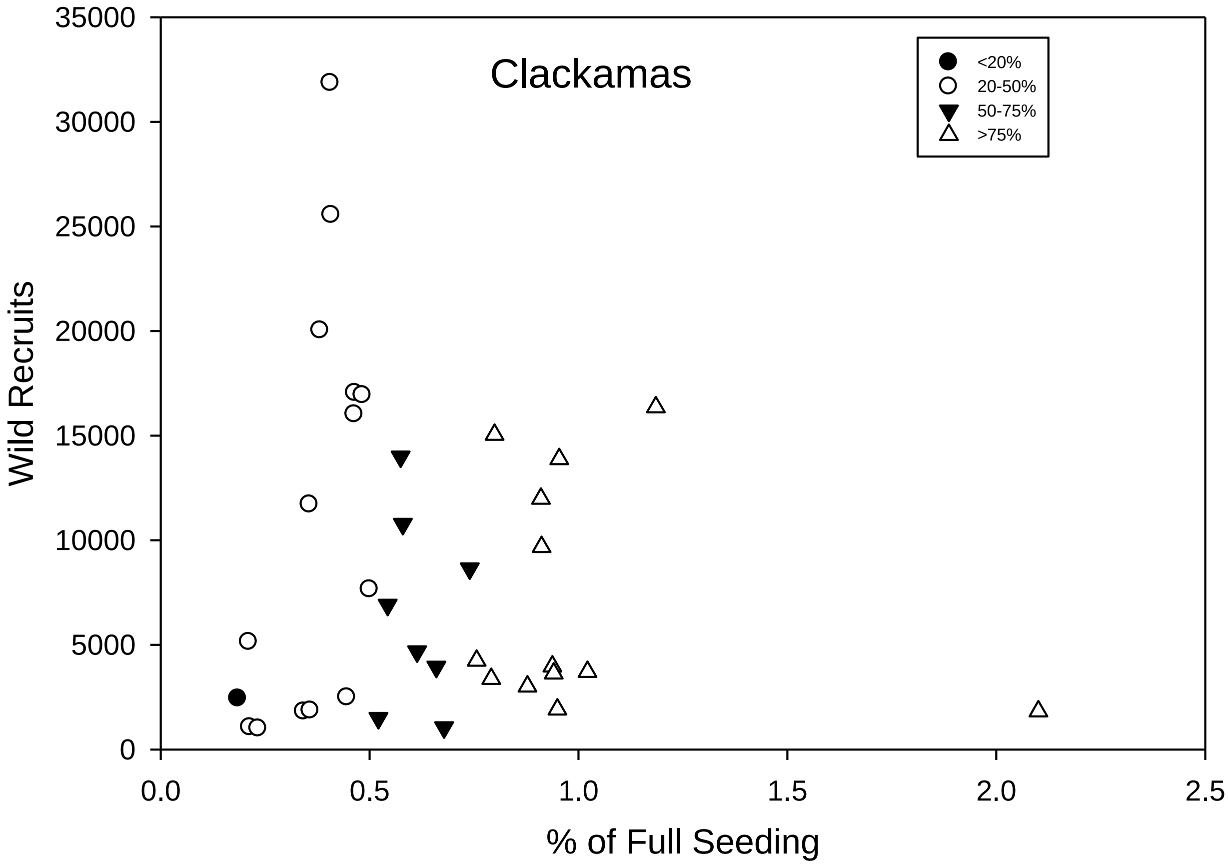


Figure 17. Relationship between fraction of full seeding and number of wild recruits, Clackamas population, 1974-2009.

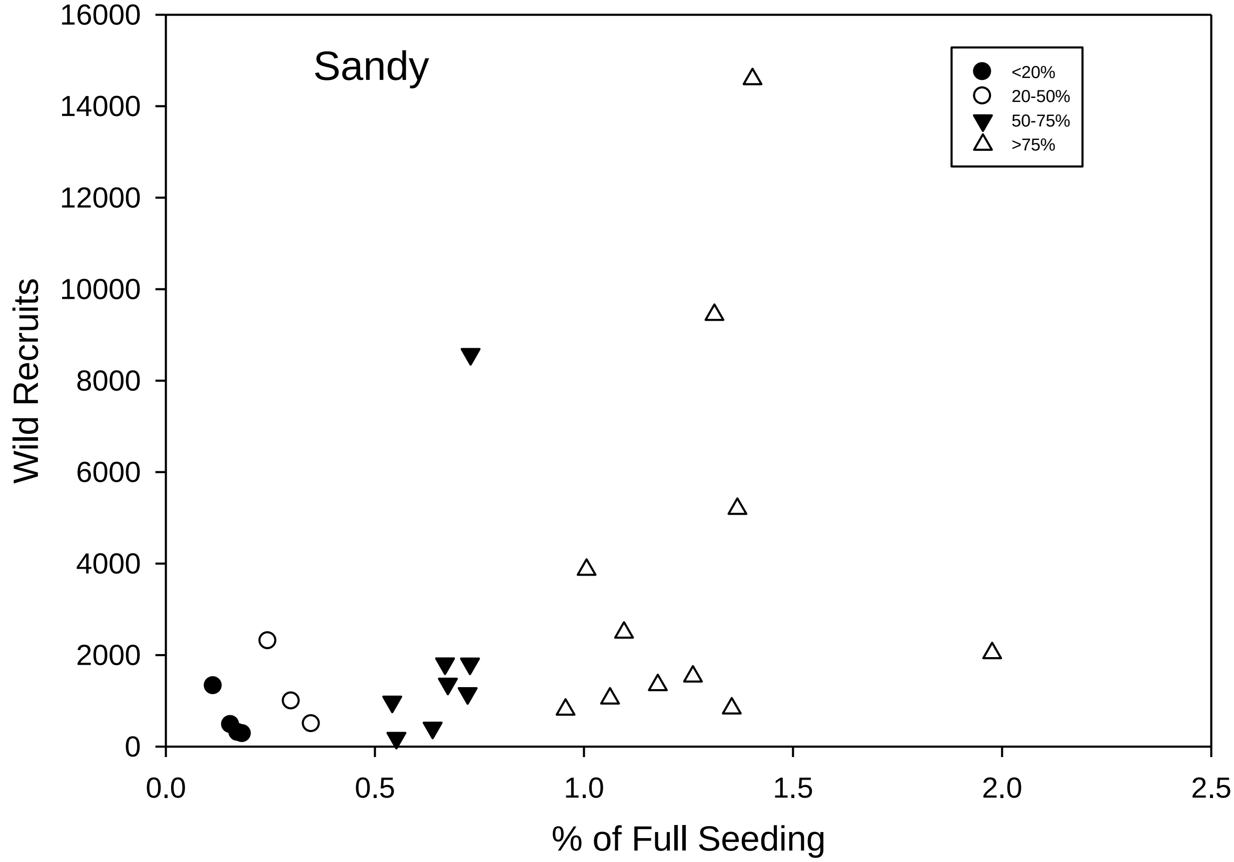


Figure 18. Relationship between fraction of full seeding and number of wild recruits, Sandy population, 1984-2009.

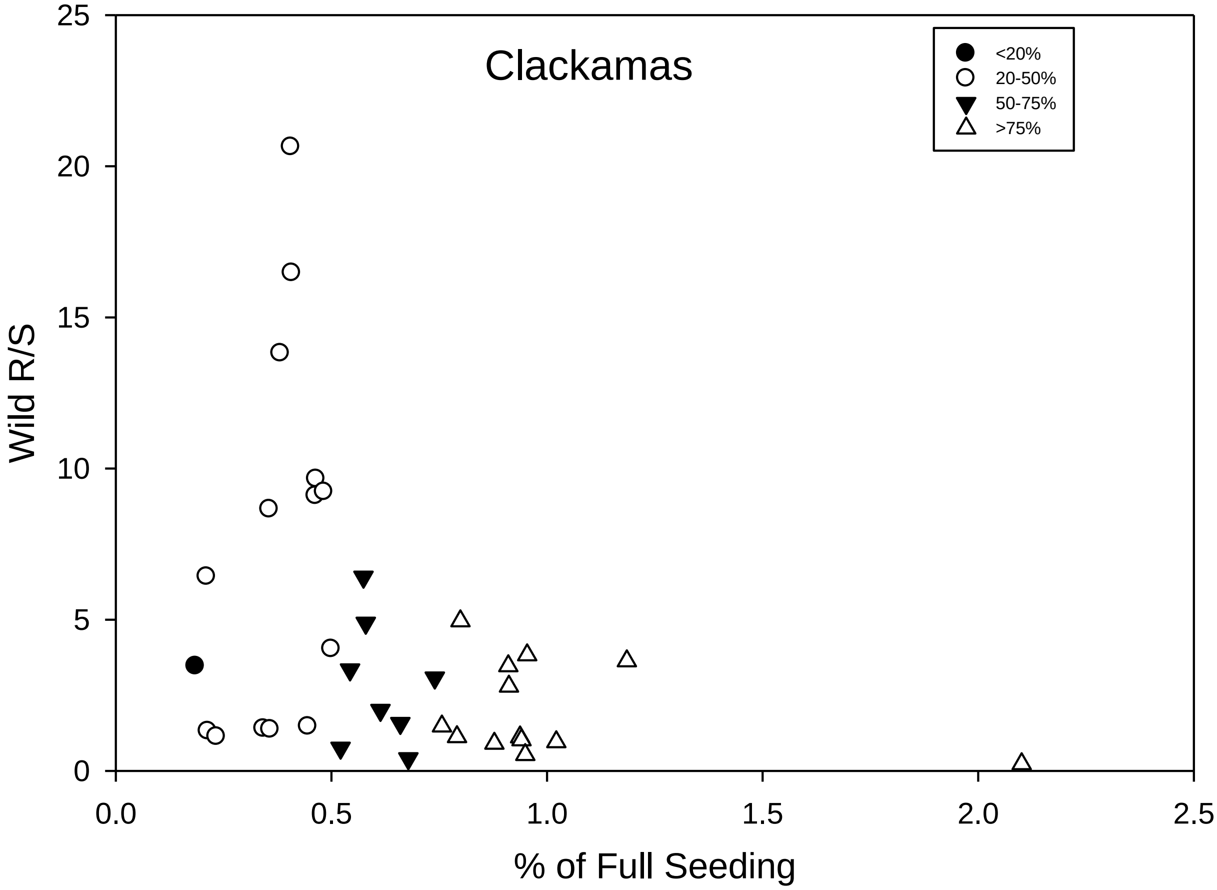


Figure 19. Relationship between fraction of full seeding and wild recruits-per-spawner, Clackamas population, 1974-2009.

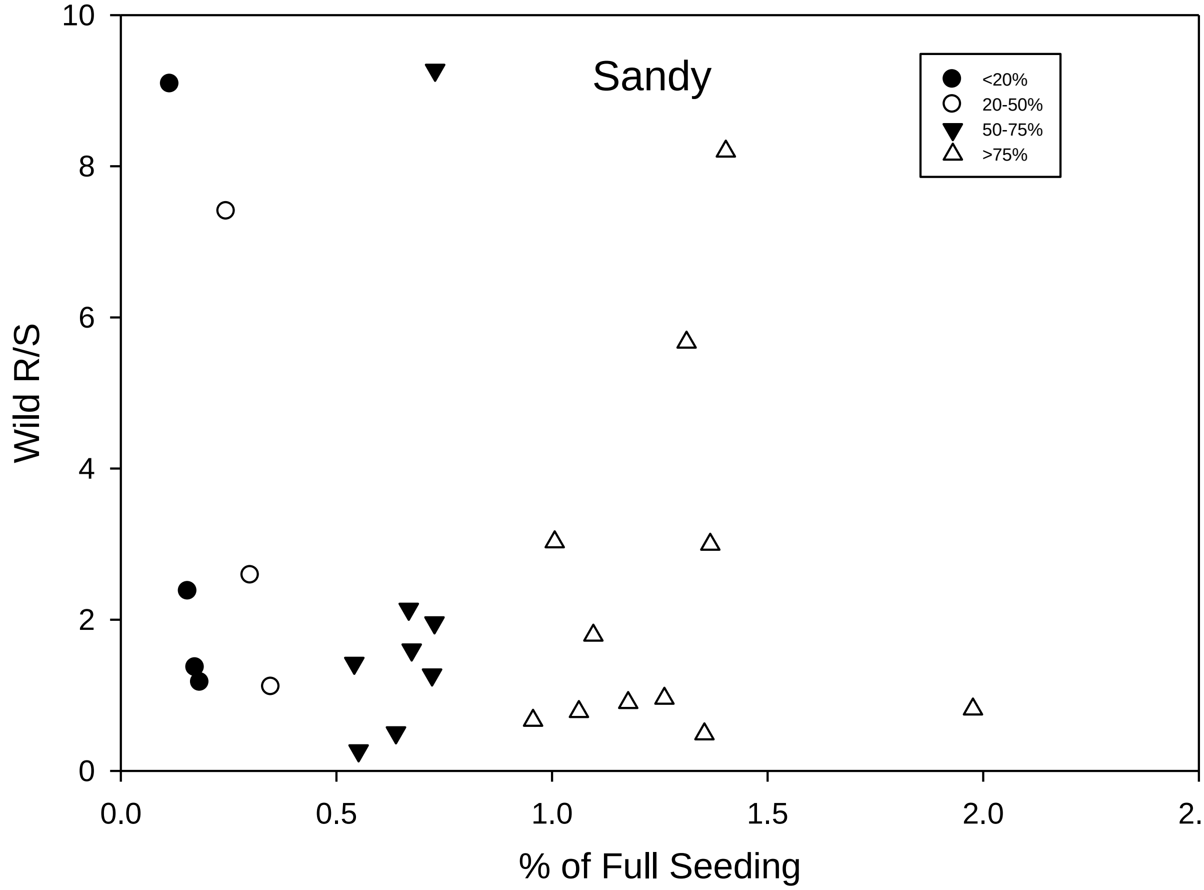


Figure 20. Relationship between fraction of full seeding and wild recruits-per-spawner, Sandy population, 1984-2009.

SECTION 2 – Assessment of the effects of a shortened spawner-recruit time series for Clackamas and Sandy populations.

The run reconstruction time series for fitting spawner-recruit functions for the Clackamas population was shortened in order to remove observed temporal bias in residuals from the fitted model when the 1974-2009 time series was used. As discussed in Section 1, the shortened time series was 1993-2009. Because changes in recruitment patterns shown in Section 1 were apparent in both the Clackamas and Sandy populations, both populations were re-assessed.

As shown in Figures 21 and 22, the resultant models yield residuals that are not temporally biased, as was the case with the longer time series. As expected, the shortened time series also results in lower overall error in the fitted model for both populations. This is directly translated to lower stochasticity in the PVA as was noted in the original report.

Because the data series' for the Clatskanie and Scappoose populations is short, only eight data points each, we opted to infer the error and autocorrelation values for these populations from the mean of the error rates for the Sandy and Clackamas populations (see pages 21 and 22 of original document). Thus, changes in the Clackamas and Sandy populations from the use a different time series have an effect on the Clatskanie and Scappoose as well. When the shorter time series is used, the autocorrelation of the residuals for the Clackamas and Sandy populations changes sign, from a positive value in the original data set to a negative value in the reduced data set. Because the PVA includes autocorrelation of errors at a one-year time lag, this difference also affects outcomes of the PVA. In models in which the simulated status of the Clackamas and Sandy populations and in models in which the simulated status of all populations are considered concurrently, this will affect risk assessments for all populations, as demonstrated in Figure 6 of the original document (page 19). PVA parameters for the four Oregon populations resulting from the shortened time series are shown in Table 2.

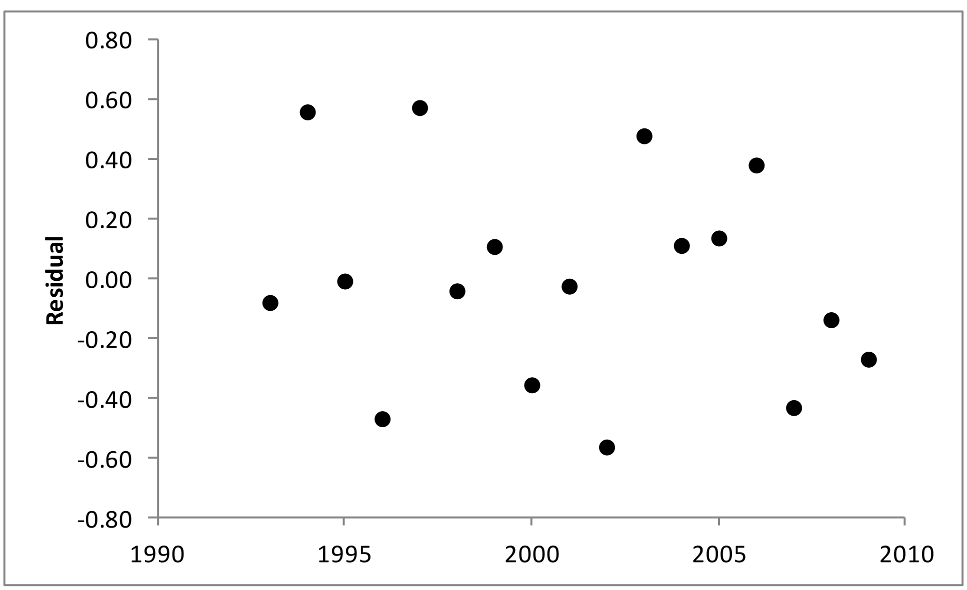


Figure 21. Residuals for fitted Clackamas model, 1993-2009.

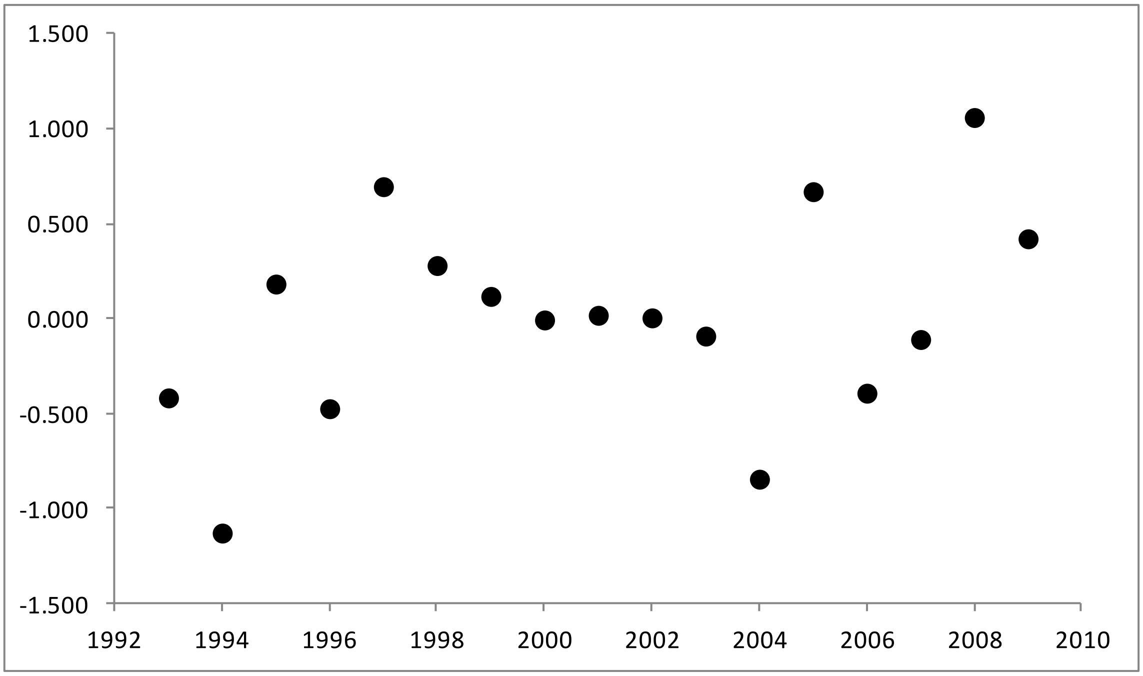


Figure 22. Residuals for fitted Sandy model, 1993-2009.

Table 2. PVA parameters for Oregon populations using 1993-2009 Clackamas and Sandy time series'.

	Clatskanie	Scappoose	Clackamas	Sandy
α	2.22	1.22	3.44	3.99
β	3356	4433	3552	1618
γ	0.346	0.331	0.548	0.690
Standard deviation of residuals	0.454*	0.454*	0.354	0.554
Autocorrelation	-0.177*	-0.177*	-0.293	-0.062

*Values are the mean of values for the Sandy and Clackamas populations.

To provide examples of the effects of these changes, the ten models that were presented and discussed in the section titled "Example Harvest Strategy Risk Assessments" of the original report (see pages 37-51) were reproduced. Full descriptions of each of those models are provided in the original report.

As was discussed in the section titled "Implications of time series selection for Oregon populations" on pages 17-20 of the original report, and as shown in Figure 6 of the original report (page 19), the change in data has minimal effects on most populations. However, risk values for certain populations, most notably the Clackamas and Clatskanie, are substantially lower (essentially 0%) with the shortened data set.

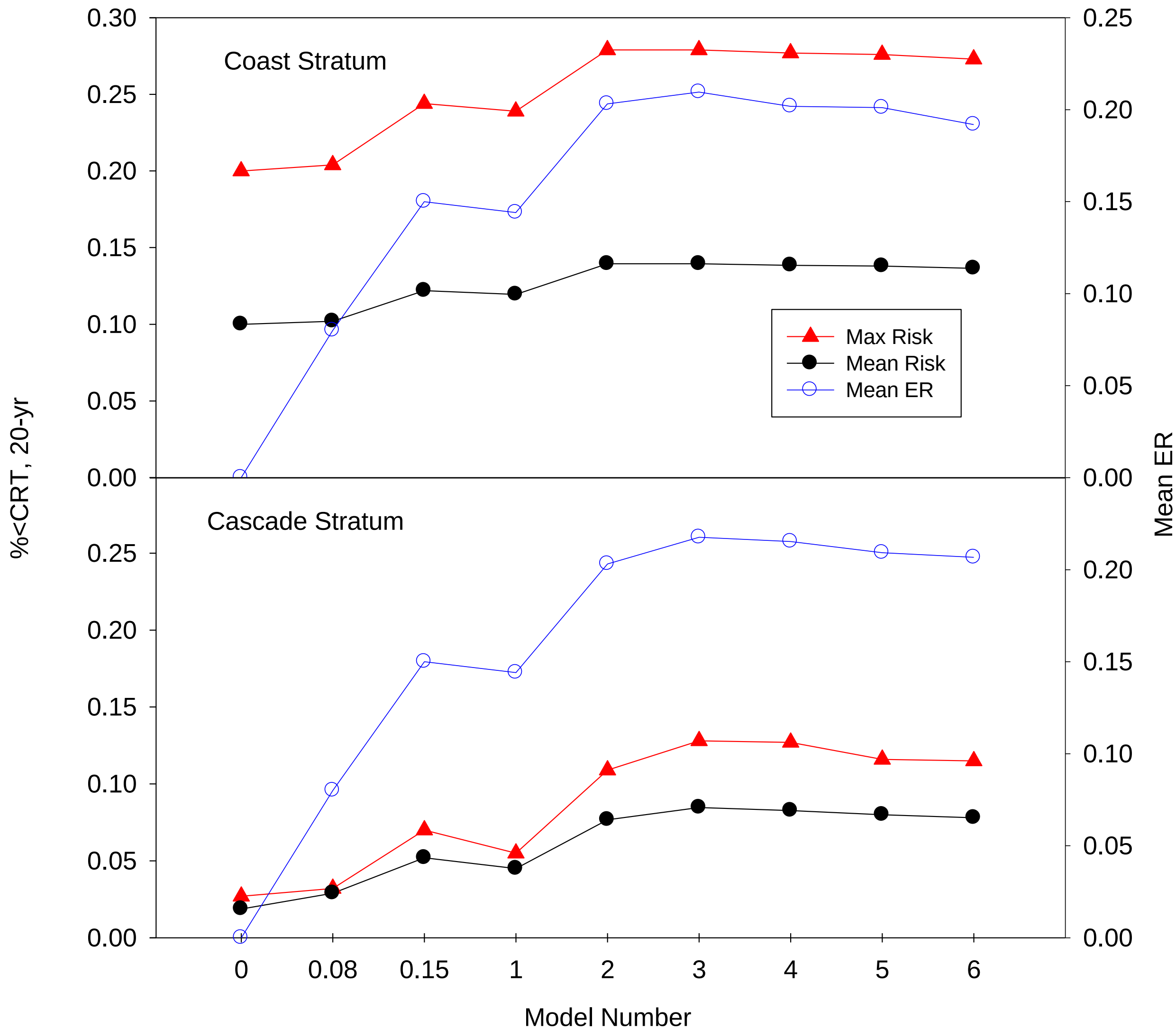


Figure 23. “Aggregate” stratum risks (%<CRT) and mean exploitation rates for 20-year simulations under example harvest structures. Replicates Figure 13, page 42 of original document. Revisions reflect the effects on risk associated with a shortened time series in Clackamas and Sandy population run reconstructions.

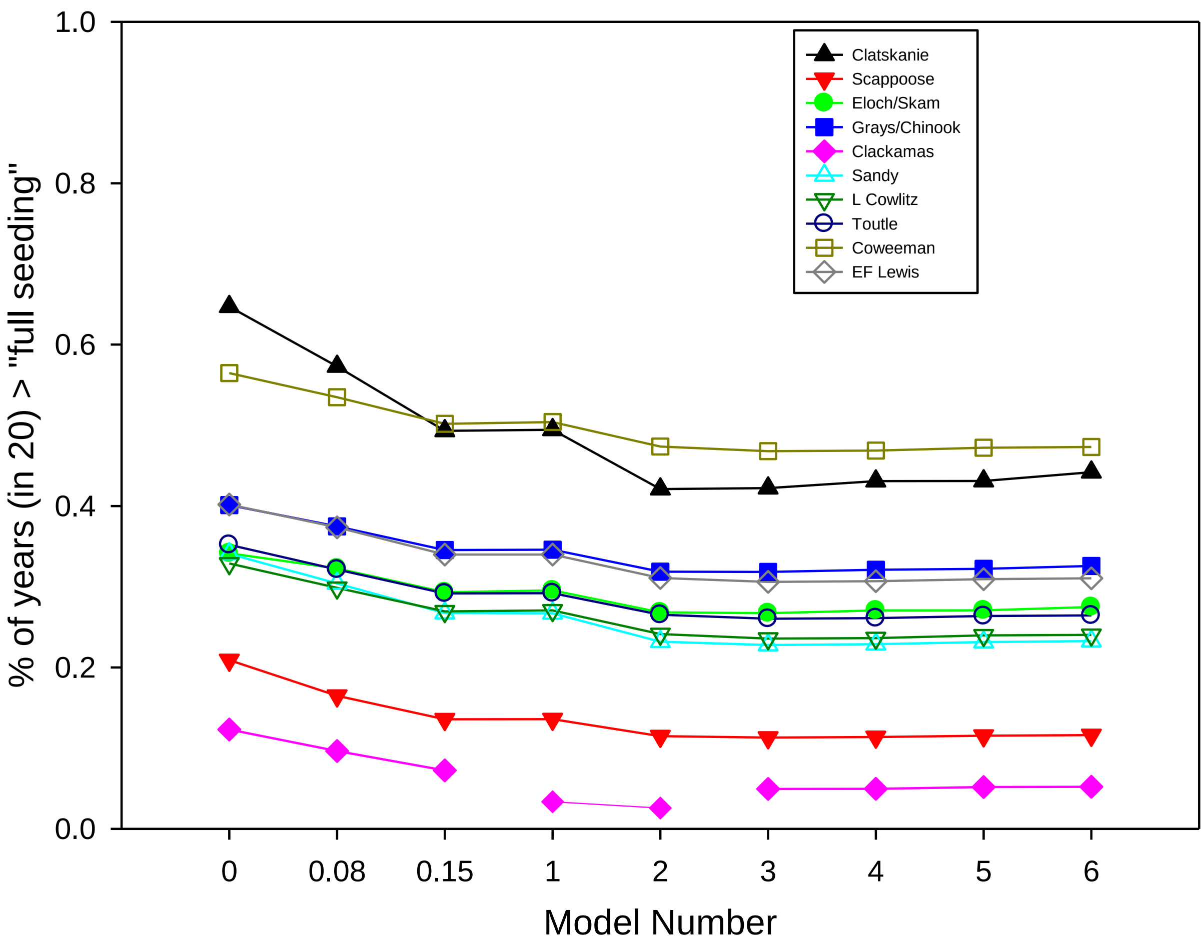


Figure 24. Frequency of annually exceeding 100% full-seeding in a 20-year time span for all populations under each example harvest structure. Replicates Figure 14, page 43 of original document. Revisions reflect the effects on risk associated with a shortened time series in Clackamas and Sandy population run reconstructions.

Table 3. Extinction risk estimates (%<CRT) for 20-year simulations of example harvest structures. Replica of Table 18, page 44.

	Coast				Cascade						Avg ER	
Model	Clatskanie	Scappoose	Eloch/Skam	Grays/Chinook	Clackamas	Sandy	L Cowlitz	Toutle	Coweeman	EF Lewis	Coast	Cascade
0%	0.000	0.070	0.200	0.700	0.000	0.018	0.011	0.006	0.027	0.485	0%	
8%	0.000	0.210	0.204	0.712	0.000	0.032	0.027	0.010	0.028	0.547	8%	
15%	0.000	0.474	0.244	0.750	0.000	0.070	0.044	0.018	0.042	0.628	15%	
1	0.000	0.459	0.239	0.748	0.000	0.055	0.041	0.019	0.039	0.626	14.41%	
2	0.000	0.689	0.279	0.773	0.000	0.109	0.057	0.023	0.064	0.702	20.32%	
3	0.000	0.711	0.279	0.779	0.000	0.128	0.060	0.023	0.066	0.708	20.96%	21.77%
4	0.000	0.683	0.277	0.777	0.000	0.127	0.057	0.023	0.064	0.708	20.18%	21.54%
5	0.000	0.684	0.276	0.775	0.000	0.116	0.060	0.023	0.064	0.700	20.11%	20.93%
6	0.000	0.647	0.273	0.772	0.000	0.115	0.057	0.023	0.062	0.701	19.18%	20.68%

Table 4. Extinction risk estimates (%<CRT) for 100-year simulations of example harvest structures. Replica of Table 19, page 44.

	Coast				Cascade					
Model	Clatskanie	Scappoose	Eloch/Skam	Grays/Chinook	Clackamas	Sandy	L Cowlitz	Toutle	Coweeman	EF Lewis
0%	0.000	0.479	0.348	0.839	0.000	0.079	0.061	0.017	0.147	0.967
8%	0.000	0.899	0.429	0.874	0.000	0.216	0.111	0.037	0.196	0.979
15%	0.001	0.999	0.507	0.923	0.000	0.392	0.175	0.062	0.272	0.997
1	0.000	0.999	0.494	0.913	0.000	0.327	0.162	0.059	0.256	0.995
2	0.001	1.000	0.567	0.948	0.000	0.553	0.227	0.083	0.346	0.999
3	0.001	1.000	0.570	0.949	0.000	0.604	0.245	0.086	0.365	0.999
4	0.001	1.000	0.563	0.947	0.000	0.592	0.240	0.086	0.357	0.999
5	0.001	1.000	0.564	0.945	0.000	0.576	0.235	0.084	0.351	0.999
6	0.001	1.000	0.558	0.942	0.000	0.562	0.230	0.083	0.343	0.999

Table 5. Fraction of annual spawner abundances exceeding 100% full-seeding for 20-year simulations of example harvest structures. Replica of Table 20, page 45.

	Coast				Cascade					
Model	Clatskanie	Scappoose	Eloch/Skam	Grays/Chinook	Clackamas	Sandy	L Cowlitz	Toutle	Coweeman	EF Lewis
0%	0.647	0.209	0.341	0.401	0.123	0.341	0.329	0.352	0.565	0.402
8%	0.573	0.165	0.323	0.375	0.096	0.304	0.299	0.321	0.535	0.374
15%	0.493	0.136	0.293	0.345	0.072	0.267	0.269	0.292	0.502	0.340
1	0.494	0.136	0.295	0.346	0.033	0.267	0.271	0.292	0.504	0.340
2	0.421	0.115	0.268	0.319	0.026	0.232	0.241	0.265	0.474	0.311
3	0.422	0.113	0.267	0.318	0.049	0.228	0.236	0.260	0.468	0.306
4	0.431	0.114	0.271	0.321	0.050	0.229	0.236	0.261	0.469	0.307
5	0.431	0.115	0.271	0.322	0.052	0.231	0.240	0.264	0.472	0.309
6	0.442	0.116	0.275	0.326	0.052	0.233	0.240	0.264	0.473	0.310

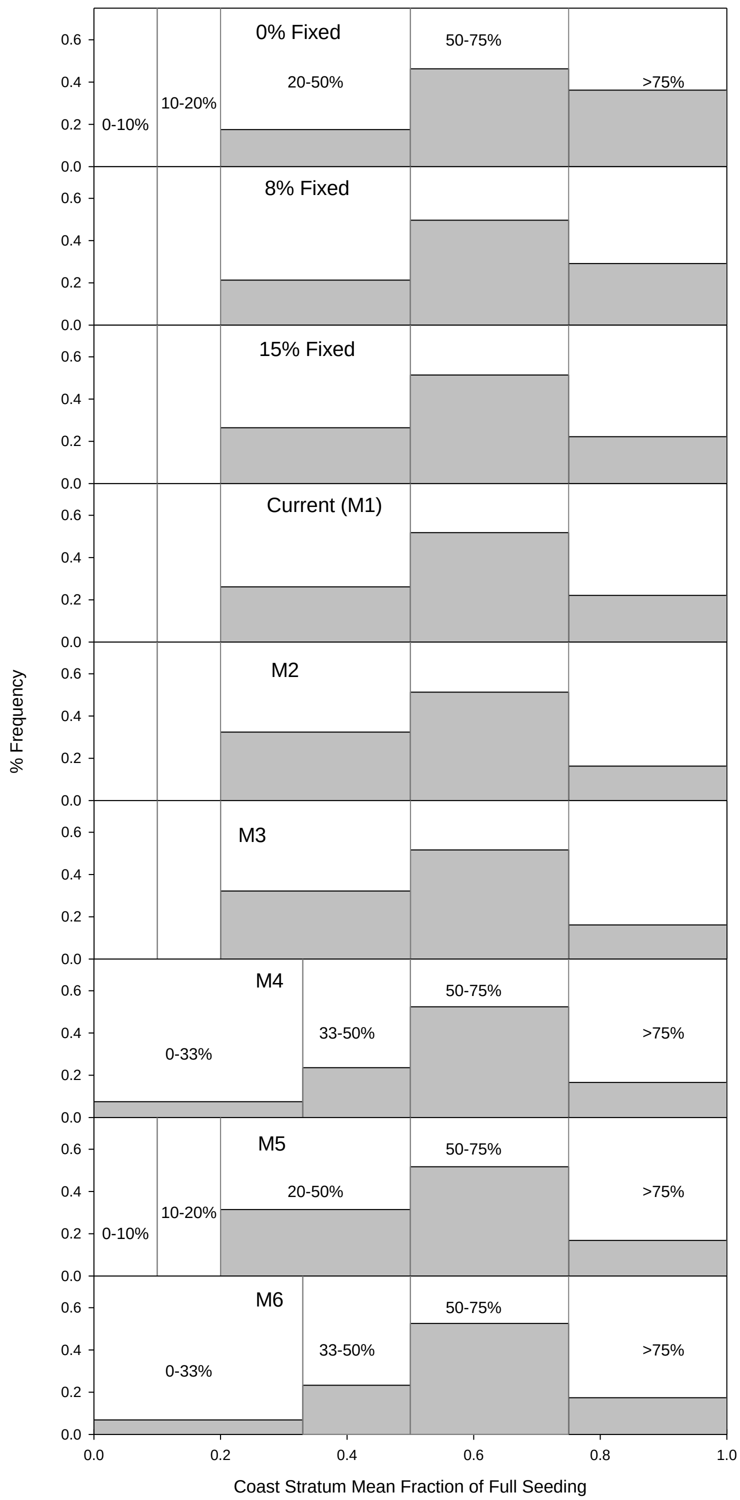


Figure 25. Frequency of occurrence of the mean fraction of full seeding for each model for the Coast stratum. Note differences in category delineations for Models 4 and 6 compared to remaining models. Vertical lines denote parental seeding category boundaries and labels are provided in each category for reference. Replicates Figure 15, page 47.

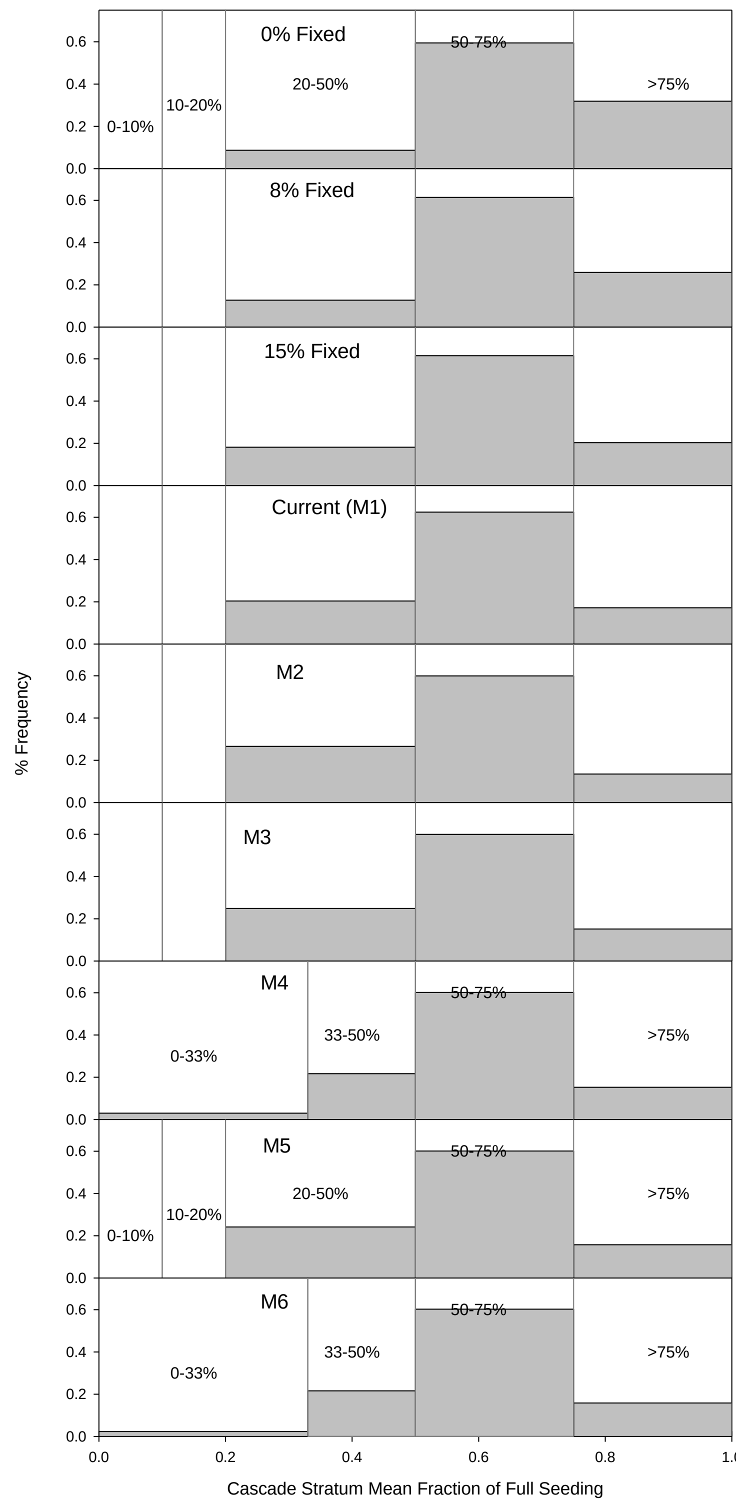


Figure 26. Frequency of occurrence of the mean fraction of full seeding for each model for the Cascade stratum. Note differences in category delineations for Models 4 and 6 compared to remaining models. Vertical lines denote parental seeding category boundaries and labels are provided in each category for reference. Replicates Figure 16, page 48.

Table 6. Frequency of ESU annual minimum full-seeding fractions for example harvest structures. Note different category delineations for Models 4 and 6. Fractions may not sum to 100% due to rounding. Replicates Table 21, page 49.

Parental Seeding (% of Full)	Model Label: 0%	8%	15%	M1	M2	M3	M5
>0.75	19%	14%	9%	8%	6%	6%	7%
0.5-0.75	57%	55%	52%	51%	45%	46%	47%
0.2-0.5	25%	31%	39%	41%	49%	47%	46%
0.1-0.2	0%	0%	0%	0%	0%	0%	0%
<0.1	0%	0%	0%	0%	0%	0%	0%

(alternate fractions)	M4	M6
>0.75	6%	7%
0.5-0.75	47%	48%
0.33-0.5	36%	36%
0.0-0.33	10%	9%

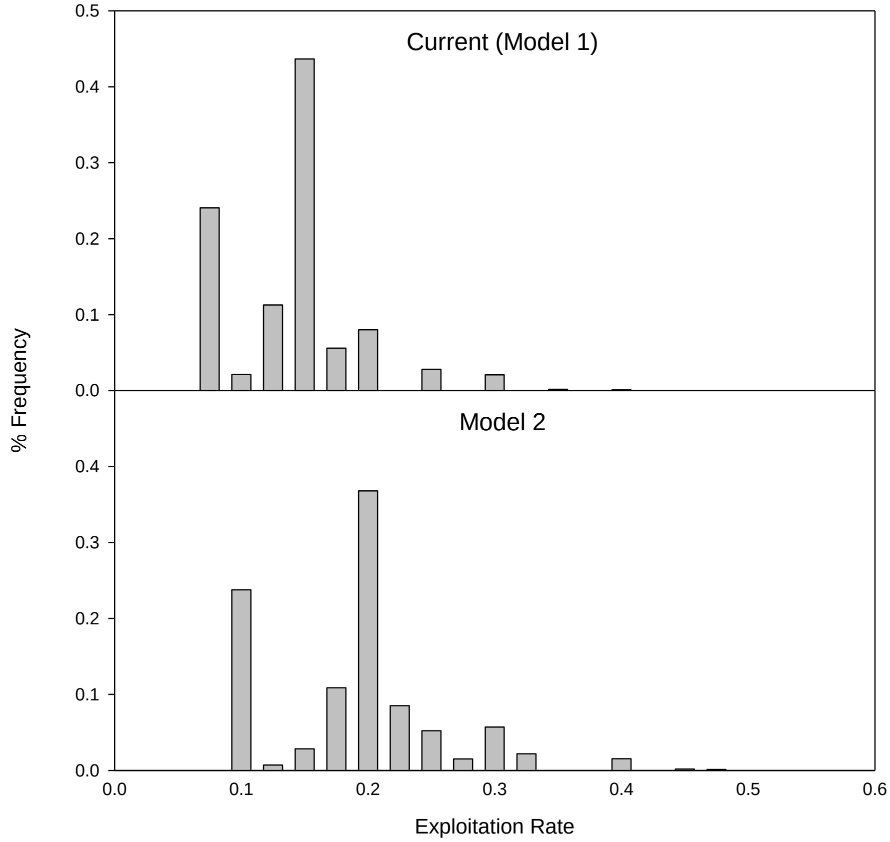


Figure 27. Frequency of exploitation rates in Models 1 and 2 (both based on Sandy/Clackamas status only). Increments of x-axis are 2.5% exploitation rate. Replicates Figure 17, page 50.

Table 7. Model 3, frequencies of occurrence in harvest matrix from Table 3. Exploitation rates in each cell are shown in parentheses for reference. Fractions may not sum to 100% due to rounding. Replicates Table 22, page 50.

Parental Seeding (% of Full)	Marine Survival: Critical		Low		Medium		High	
>0.75	1%	(<0.117)	3%	(<0.214)	2%	(<0.405)	0%	(<0.574)
0.5-0.75	11%	(<0.117)	21%	(<0.214)	14%	(<0.292)	0%	(<0.498)
0.2-0.5	12%	(<0.117)	21%	(<0.214)	15%	(<0.227)	0%	(<0.344)
0.1-0.2	0%	(<0.117)	0%	(<0.163)	0%	(<0.181)	0%	(0.199)
<0.1	0%	(0.0-0.117)	0%	(0.0-0.117)	0%	(0.0-0.117)	0%	(0.0-0.117)

Table 8. Model 4, frequencies of occurrence in harvest matrix from Table 15. Exploitation rates in each cell are shown in parentheses for reference. Fractions may not sum to 100% due to rounding. Replicates Table 23, page 51.

Parental Seeding	Marine Survival							
(% of Full)	Critical		Low		Medium		High	
>0.75	1%	(<0.117)	3%	(<0.214)	2%	(<0.405)	0%	(<0.574)
0.5-0.75	11%	(<0.117)	21%	(<0.214)	15%	(<0.292)	0%	(<0.498)
0.33-0.50	9%	(<0.117)	16%	(<0.214)	11%	(<0.227)	0%	(<0.344)
<0.33	2%	(0.0-0.117)	5%	(0.0-0.117)	3%	(0.0-0.117)	0%	(0.0-0.117)

Table 9. Model 5, frequencies of occurrence in harvest matrix from Table 16. Exploitation rates in each cell are shown in parentheses for reference. Fractions may not sum to 100% due to rounding. Replicates Table 24, page 51.

Parental Seeding	Marine Survival							
(% of Full)	Critical		Low		Medium		High	
>0.75	1%	(<0.080)	3%	(<0.214)	2%	(<0.405)	0%	(<0.574)
0.5-0.75	11%	(<0.080)	21%	(<0.214)	14%	(<0.292)	0%	(<0.498)
0.2-0.5	11%	(<0.080)	20%	(<0.214)	14%	(<0.227)	0%	(<0.344)
0.1-0.2	0%	(<0.080)	0%	(<0.163)	0%	(<0.181)	0%	(0.199)
<0.1	0%	(0.0-0.080)	0%	(0.0-0.080)	0%	(0.0-0.080)	0%	(0.0-0.080)

Table 10. Model 6, frequencies of occurrence in harvest matrix from Table 17. Exploitation rates in each cell are shown in parentheses for reference. Fractions may not sum to 100% due to rounding. Replicates Table 25, page 51.

Parental Seeding	Marine Survival							
(% of Full)	Critical		Low		Medium		High	
>0.75	2%	(<0.080)	3%	(<0.214)	2%	(<0.405)	0%	(<0.574)
0.5-0.75	11%	(<0.080)	21%	(<0.214)	15%	(<0.292)	0%	(<0.498)
0.33-0.50	9%	(<0.080)	16%	(<0.214)	11%	(<0.227)	0%	(<0.344)
<0.33	2%	(0.0-0.080)	4%	(0.0-0.080)	3%	(0.0-0.080)	0%	(0.0-0.080)

Incorporating recent empirical information on sublegal encounters into FRAM modeling

Pete McHugh and Angelika Hagen-Breaux
Washington Department of Fish and Wildlife
600 Capitol Way N
Olympia, WA 98501

Larrie LaVoy
NOAA-Fisheries
510 Desmond Dr S.E. Suite 103
Lacey, WA 98503

October 9, 2013

Pacific Fisheries Management Council
Methodology Review
November, 2013

Abstract
FRAM projections of total sublegal encounters for fisheries operating under minimum size limit regulations differ substantially from recent field observations for some fisheries. While the basis for differences is not known, FRAM's current structure allows for *ad hoc* calibration of base period sublegal encounter rates through the use of a simple multiplicative adjustment factor, thereby providing users a means to greatly improve correspondence between model-projected and actual sublegal encounters in the absence of a full model calibration. We assembled available sampling data on fishery encounters of sublegal Chinook, developed and tested a set of simple computational algorithms to incorporate these data directly into modeling (i.e., to estimate adjustment factors), and evaluated the influence of this change on key model outputs (e.g., exploitation rates [ER] on stocks of conservation concern). Overall, 'recalibrating' FRAM's current base period to produce fishery-level sublegal encounters totals consistent with recent data introduced minimal change when assessed in terms of stock-specific impacts, despite the fact that changes in sublegal encounter totals were substantial for some individual fisheries. Across eight years of validation runs, the average shift in total ER for Lower Columbia River natural tule Chinook was +0.2%, whereas total ERs changed by *ca*. -0.5% for several stocks of Puget Sound Chinook. We recommend that this modeling change be considered for adoption during 2014 preseason modeling for at least four reasons: (1) it improves fishery-level projections of total sublegal encounters, (2) it strengthens the link between ongoing monitoring activities and fishery modeling, (3) it minimally changes past (and future) assessments of stock-level impacts, and (3) it lays the foundation for improved size limit modeling, also under consideration during the 2013 review.

Introduction
Accurate projections of fishery impacts on non-landed sublegal Chinook salmon are needed to reliably estimate total mortality for fisheries operating under minimum size limit regulations. The Fishery Regulation Assessment Model (FRAM) is presently used to make such projections for a number of commercial troll and recreational Chinook fisheries, both in a preseason planning and postseason evaluation context. However, comparisons of FRAM projections of total sublegal encounters to sampling estimates cast doubt on the model's ability to accurately capture the current behavior of fisheries and/or populations with respect to this parameter. Based on recent validation runs (2003-2010 fishery years), for example, FRAM projects sublegal encounters values up to 10 times greater than estimates generated from independent sampling data, with some of the largest over-predictions occurring for northern (Alaska, Canada) sport and troll fisheries, as well as for Puget Sound sport fisheries (Figure 1, Appendix A). Noteworthy under-predictions have also been documented, particularly for southern Canadian sport fisheries (e.g., Georgia Strait, projection *ca.* 10% of sampling value; Appendix A).

The basis for deviations between FRAM projections and sampling observations is not known, but hypothesized factors relevant for some fisheries include: (1) major reductions in the WDFW 'delayed release' yearling hatchery program, which produced fish with a higher affinity towards residency within Puget Sound, (2) changes in size limits relative to the base period that are not adequately addressed through FRAM's algorithms, (3) changes in fishing techniques and/or tackle that differentially affect catchability for fish of different sizes, and/or (4) variability and/or a systematic change in the marine distribution of early life stages relative to base period fishery years. It is also possible that the algorithms, parameters (e.g., von Bertalanffy growth functions), and/or inputs that lead to FRAM's projection of sublegal encounters (described below) for a particular fishery are flawed in some way. Lastly, differences may relate to errors in stock assignment for sublegal encounters, an issue which is not addressed by the modeling change described here.

Given that sublegal impacts represent a significant component of total fishery-related mortality for many stocks and fisheries, errors in sublegal encounter projections may translate into erroneous conclusions regarding the effects of particular fishing scenarios on stocks of concern and/or the availability of fish to particular fisheries in subsequent time steps. To help address these concerns, we devised a method that incorporates recent fishery sampling estimates of sublegal encounters (i.e., from observer programs, logbooks, test fisheries, etc.) directly into modeling so that errors are minimized. Here, we describe the general approach and the recent observer sampling datasets upon which it is based, as well as characterize its influence on a subset of relevant model outputs.

The proposed modeling change

In simple terms, FRAM's projection of sublegal encounters (*Sublegals*) for a given fishery (F) and time step (T) combination is a function of four factors, two types of inputs associated with a particular model run and two types of parameters associated with the base period (PFMC 2008): (1) the abundance of fish (N_{SA}) by stock (S) and age (A), (2) the stock-age-specific fraction of fish that is below a fishery's minimum size limit ($1\text{-}PV_{SAT}$), (3) sublegal encounter rates (SLER_{FSAT}), also a stock-age-specific base period value, and (4) the size of the current fishery relative to base period levels (λ_{FT}, a fishery scalar). More specifically, total sublegal encounters ($Sublegals_{FT}$) are computed for any given fishery and time step as:

(1) $Sublegals_{\mathrm{FT}} = \sum_{\mathrm{S}=1}^{n\ stock} \sum_{\mathrm{A}=2}^{\max age} Sublegals_{\mathrm{FSAT}}$, where

(2) $Sublegals_{\mathrm{FSAT}} = \lambda_{\mathrm{FT}}\ N_{\mathrm{SA}}\ (1\text{-}PV_{\mathrm{SAT}})\ \mathrm{SLER}_{\mathrm{FSAT}}$,

and PV_{SAT} is computed as the proportion of the size-at-age distribution (assumed normal) projected from stock-specific von Bertalanffy growth equations that exceeds a fishery's minimum size limit (see PFMC 2008 for further details). Thus, many stock-specific inputs and parameters facilitate model projections of sublegal encounters for a given fishery, thereby making it difficult to isolate which component(s) contribute most to model error and to resolve it in the absence of a full model calibration to recent fishery and population data and/or modification to base period SLER estimation procedures.

The FRAM base period additionally contains a little-used parameter that allows for *ad hoc* calibration of model projections to observations, the fishery-age-time step-specific sublegal encounter rate adjustment factor (k_{FAT}). This factor is included as a simple multiplier in equation 2 and applies identically to all stocks within a particular fishery-age-time step combination:

(3) $Sublegals_{\mathrm{FSAT}} = \lambda_{\mathrm{FT}}\, N_{\mathrm{SA}}\, (1\text{-}PV_{\mathrm{SAT}})\, \mathrm{SLER}_{\mathrm{FSAT}}\, k_{\mathrm{FAT}}$

Thus, it effectively rescales FRAM's projection of total sublegal encounters for a given FAT cell to achieve a target value while still retaining the stock composition generated by unmodified calculations. We propose to use this adjustment factor as a means to 'recalibrate' FRAM and reduce error in sublegal impact projections.

Conceptually, the set of k_{FAT} values that will enable FRAM to make sublegal encounter projections consistent with recent observations, defined by target sublegal:legal encounter ratios (i.e., target ratios), can be generated through a simple iterative process. Sequential model runs are completed with $k_{\mathrm{FAT}(i)}$ set to 1.000 for the first (i = 1) iteration and recomputed between runs as

(4) $$k_{\mathrm{FAT}(i+1)} = k_{\mathrm{FAT}(i)} \frac{R_{target}}{R_{FRAM}}$$

where R_{target} is the empirical estimate of the sublegal-to-legal sized Chinook ratio and R_{FRAM} is the equivalent value projected by FRAM for a given *FAT* cell. This process is repeated until the quantity $\frac{R_{target}}{R_{FRAM}}$ approaches 1.000 for all fishery-time step combinations; testing and evaluation across a range of model runs indicates that convergence can be achieved in 3-4 iterations. Additionally, given that sampling data on sublegal encounters are typically *not* age specific, the iterative K_{FAT} calculations encompass all ages (i.e., the resulting adjustment is constant across ages). As a consequence, K_{FAT}-adjusted FRAM projections of sublegal encounters retain the same stock *and age* composition that would be projected in unmodified runs.

Given a set of recent empirical estimates, the general approach outlined above can be implemented during the preseason modeling process in at least two ways. First, the target empirical estimates (R_{target}) of sublegal:legal ratios can be taken as precise values expected for fisheries in the absence of some other information (e.g., preseason forecast of sublegal encounters). This approach requires modelers to find relevant K_{FAT} values each year, as well as possibly update them during the preseason process if there are major changes in forecasts or fisheries inputs (e.g., updated quotas for Pacific Salmon Treaty fishery quotas). The second approach takes a retrospective view and requires modelers to find a single set of K_{FAT} values that on average achieve target ratios across a selected set of postseason FRAM validation runs. Under this method, a single set of K_{FAT} values would be incorporated into the base period and the FRAM-projected sublegal:legal ratio would be expected to deviate from year to year around the original empirical target. We explored both approaches and determined that the first one is more appropriate for preseason modeling, as it (1) provides a more consistent link to the original empirical target, (2) will be insensitive to other modeling changes under discussion (e.g., Rankis briefing, PFMC 2013a), and (3) will allow for efficient updating of empirical targets as new data become available. The model runs described throughout the remainder of this document are all based upon the year-specific adjustment method.

Empirical estimates of sublegal:legal encounter ratios

We compiled sampling estimates of sublegal and legal encounters for all model fisheries subject to minimum size limit regulations and for which the necessary sampling data have been collected in the last decade (2003+). Although data quantity (i.e., number of years covered, number of encounters observed within a year) and quality (i.e., the rigor of observation methods used) varied widely for the FRAM fisheries under consideration, there were few time-area strata for which an estimate was unavailable. Across fisheries, we acquired between two (Southern California Troll) and ten (Area 5 Sport) years of data, with an average number of encounters observed within time-area strata within years ranging from 24 (Area 3:4 Sport) to 681 (Area 8-1 Sport).

We classified the methods used to enumerate or estimate sublegal and legal encounters into four categories: (1) <u>Creel interviews</u>: anglers report the number of legal and sublegal fish encountered during dockside or phone interviews; this method was used widely in sport fisheries for all jurisdictions. (2) <u>Onboard observations</u>: trained observers ride on board vessels and keep detailed accounts of encounters; this method was used primarily for commercial troll and sport (charter) monitoring on the Washington coast. (3) <u>Trip logs</u>: commercial or recreational fishers record information on the composition of encounters whilst on the water in written (forms, log books) or electronic formats and report them to management agencies on a mandatory or voluntary basis; this method was used widely to monitor Canadian troll and sport (charter/lodge) fisheries, as well as in Puget Sound sport; and (4) <u>Test fisheries</u>: agency or contract personnel fish in a manner similar to the fleet at large and record encounter data, collect samples, etc.; the use of this method to date has been limited to monitoring activities associated with Puget Sound mark-selective sport fisheries. We also identified an 'Other' category given the existence of unique approaches applied on a limited basis in a few locations (e.g., ADFG's regression-based method for SEAK Troll; CTC 2011). Although data collected via the different methods are susceptible to varying degrees of bias, they were viewed as being similarly reliable for the immediate purpose of sublegal:legal ratio estimation.

Using the assembled dataset, we estimated the mean sublegal:legal ratio (i.e., the mean of ratios, not the ratio of means [sums]) for each fishery-time step combination for use as the R_{target} values in the computations outlined above under the assumption that the mean of distribution of ratios observed in the past approximates what will be seen in the future, on average (Table 1). ratio of means, ,Mean sublegal:legal ratios ranged nearly two orders of magnitude across fisheries, with the highest values being observed in Puget Sound sport fisheries during winter periods (time steps 1 and 4) and the lowest in the BC Queen Charlotte Islands sport fishery during the summer. Additionally, a comparison of the new target values with those projected by FRAM in the last set of validation runs (2003-10) illustrates that the level of deviation between model projections and the new sampling-based targets varies widely from fishery to fishery (Appendix A-B). Agreement between projected and target ratios was evident for some fisheries (e.g., Area 13 Sport, time step 1), whereas substantial over- (e.g., Southeast Alaska Troll, all time periods) or under-projection (e.g., Area 1 Sport during the summer) of ratios was evident elsewhere.

An evaluation of the proposed modeling change

Given patterns of over- and under-projection on the whole, we anticipated that transitioning to a sampling-informed sublegal modeling framework would improve projection accuracy at the fishery level but not necessarily cause major shifts in impact projections for any single stock. To evaluate this expectation, we implemented the procedure outlined under 'The proposed modeling change' for each of eight years of post-season validation runs (2003-2010, Jan. 2013 release) using the sublegal:legal ratios summarized in Table 1 as R_{target} values, and subsequently compared relevant results to those from the original, unmodified validation run set. In particular, we evaluated three general results. First, we assessed how closely FRAM-projected sublegal:legal ratios matched target ratios simply to verify that the draft computational algorithms developed during the preparation of this document were working properly; this was deemed to be the case for all fisheries, time steps, and fishing years. Second, we evaluated the extent to which the modeling change affected the total exploitation rate on Lower Columbia River natural (LCN) tule Chinook, given the significance of this stock to annual fishery planning activities. Lastly, we evaluated the influence of the modeling change on impact estimates for Puget Sound Chinook stocks relative to their various impact ceilings.

Based on the eight years of validation runs, it appears that incorporating recent sublegal encounters observations into modeling will on average add 0.2% (i.e., in absolute [ER_{adj}-ER_{unadj}] terms, equivalent to a 0.6% relative [(ER_{adj}-ER_{unadj})/ ER_{unadj}] increase) to the LCN tule Chinook total exploitation rate (ER; Table 3, Figure 3). However, the effect of the modeling change also varied among years, ranging from a 0.8% drop (2007) to a 0.9% increase (2005) in total ER. Given the magnitude of total ERs observed between 2003 and 2010 (range 33-52%), the 0.2% average increase may be inconsequential from a practical standpoint.

For Puget Sound Chinook, the proposed modeling change led to a reduction in total ER that was relatively consistent across stocks and years (Table 4). This is due to the combined effect of lower sublegal encounters in West Coast of Vancouver Island troll and sport fisheries, as well in Puget Sound sport fisheries. Absolute total ER reductions ranged from 0.0 (Nisqually) to 1.5% (Hoko) and averaged 0.5% across stocks. Somewhat counter intuitively, total ER reductions were generally accompanied by minor increases (*ca*. 0.1%) in southern US (SUS) total and preterminal (PT) ERs, a phenomenon that typically occurs when Canadian impacts are lessened and more fish are passed on to US fisheries in later time steps. Despite an overall, albeit minor, increase in SUS impacts, the net effect of the modeling change on Mid-Hood Canal Chinook, the stock that has most often driven fishery planning within Puget Sound in recent years, is towards a lower projection of sublegal encounters and total mortality (*ca*. absolute 0.1% reduction in SUS PT ER).

Summary

The proposed modeling change provides a timely means to incorporate recent sampling observations into ongoing modeling activities, in the absence of a full calibration. In doing so, the change resolves current deficiencies associated with sublegal impact projections using the current FRAM base period and will thus improve the accuracy of model projections of sublegal as well as total fishery encounters (note, however, that the change does not address/consider matters of accuracy at the stock level). The proposed change also allows modelers to take advantage of costly monitoring data, thereby strengthening the (otherwise ephemeral and unwieldy) link between FRAM and fishery monitoring data. Furthermore, implementing this method in conjunction with the Hagen-Breaux et al. size limit modeling change (PFMC 2013b) presents an opportunity to quantitatively assess alternative minimum size limit proposals, which are of interest in Puget Sound but until now have been stymied by model limitations. Importantly, all of these perceived benefits are realized with minimal alteration to the conclusions one might draw about stocks of concern in past (and future) evaluations of fishery scenarios. Given these findings, we recommend that the modeling change described here be considered for implementation during the 2014 preseason modeling and planning process.

References

CTC (Chinook Technical Committee). 2011. Development of the Technical Basis for a Chinook Salmon Total Mortality Management Regime for the PSC AABM Fisheries. February 2011. Pacific Salmon Commission, Report TCCHINOOK (11)-2. Vancouver, British Columbia.

Pacific Fishery Management Council (PFMC). 2008. Fishery Regulation Assessment Model (FRAM) – technical documentation for coho and Chinook. Pacific Fishery Management Council, Portland, Oregon.

Pacific Fishery Management Council (PFMC). 2013a. Standardized Method to Calculate Chinook Age 2 FRAM Stock Recruit Scalars, Based Upon the Age 3 Forecast. Pacific Fishery Management Council, Briefing Book, November 2013.

Pacific Fishery Management Council (PFMC). 2013b. Correction to FRAM Algorithms for Modeling Size Limit Changes. Pacific Fishery Management Council, Briefing Book, November 2013.

Table 1. Recent empirical estimates (mean, range) of sublegal:legal ratios for FRAM model fisheries and time steps, generated via sampling or other means. Data type abbreviations are: Int = dockside or phone interviews, Log = mandatory or voluntary trip logs (books, electronics, forms), OB = onboard observations, Oth = other methods (e.g., ADFG's regression-based method), and TF = test fishery.

Fishery	Fish. No.	Estimate (min-max) Time 1	Time 2	Time 3	Dataset details data type	Years	Ave. obs/ year	Source	Comments
	1	0.31 (0.22-0.40)	0.31 (0.22-0.40)	0.31 (0.22-0.40)	OB, Oth	2007-2012	not avail.	ADFG	
SE Alaska Sport	3	0.57 (0.50-0.68)	0.57 (0.50-0.68)	0.57 (0.50-0.68)	Int	2007-2011	not avail.	ADFG	
BC Outside Sport	8	0.00	0.00	0.00	Int, Log	2007-2012	not avail.	CDFO	No sublegal encounters
BC No/Cent Troll	9	0.11 (0.063-0.218)	0.11 (0.063-0.218)	0.11 (0.063-0.218)	Log	2007-2012	not avail.	CDFO	
BC WCVI Troll	10	0.10 (0.040-0.161)	0.10 (0.040-0.161)	0.10 (0.040-0.161)	Log	2007-2012	not avail.	CDFO	
BC WCVI Sport	11	0.20 (0.11-0.34)	0.20 (0.11-0.34)	0.20 (0.11-0.34)	Int, Log	2007-2012	not avail.	CDFO	
BC Georgia Strait Troll	12	NA	NA	NA	NA		not avail.		No fishery in recent years
BC N Georgia Strait Sport	13	0.61 (0.74-1.79)	0.61 (0.74-1.79)	0.61 (0.74-1.79)	Int	2007-2012	not avail.	CDFO	
BC S Georgia Strait Sport	14	1.07 (0.23-1.13)	1.07 (0.23-1.13)	1.07 (0.23-1.13)	Int	2007-2012	not avail.	CDFO	
BC JDF Sport	15	0.44 (0.16-1.38)	0.44 (0.16-1.38)	0.44 (0.16-1.38)	Int	2007-2012	not avail.	CDFO	
NT Area 3:4:4B Troll	16	NA	0.93 (0.72-1.43)	0.48 (0-1.70)	OB	2003-2006	T2: 587, T3: 350	WDFW	
Tr Area 3:4:4B Troll	17	0.93 (0.72-1.43)	0.93 (0.72-1.43)	0.48 (0-1.70)	OB	2003-2007	T2: 587, T3: 350	WDFW	Based on NT Troll observations
NT Area 3:4 Sport	18	NA	1.11 (0.16-2.18)	1.11 (0.16-2.18)	OB	2005-2011	24	WDFW	
NT Area 2 Troll	20	NA	1.14 (0.69-2.34)	1.20 (0.14-3.30)	OB	2003-2007	T2: 671, T3: 434	WDFW	
Tr Area 2 Troll	21	NA	1.14 (0.69-2.34)	1.20 (0.14-3.30)	OB	2003-2007	T2: 671, T3: 434	WDFW	Based on NT Troll observations
NT Area 2 Sport	22	NA	0.66 (0.09-2.00)	0.66 (0.09-2.00)	OB	2005-2011	176	WDFW	
Area 1 Troll	26	NA	4.48	4.68	Oth	NA	NA	NA	Est'd from A1 sport obs. and A2 Troll:Sport ratio.
Area 1 Sport	27	NA	2.58 (0.36-6.70)	2.58 (0.36-6.70)	OB	2005-2011	111	WDFW	used MOR

Table 1 Continued.

Fishery	Fish. No.	Estimate (min-max)			Dataset details				
		Time 1	Time 2	Time 3	data type	Years	Ave. obs/ year	Source	Comments
Central OR Troll	30	0.47 (0.13-0.82)	1.08 (0.79-1.39)	1.08 (0.79-1.39)	Int	2005, 2011	not avail.		KMZ values
Central OR Sport	31	0.92 (0.34-2.03)	0.58 (0.24-0.85)	0.68 (0.25-1.41)	Int	2005,2011-12	not avail.		KMZ values; no T1 SL enc's in current base period
KMZ Troll	32	0.47 (0.13-0.82)	1.08 (0.79-1.39)	1.08 (0.79-1.39)	Int	2005, 2011	not avail.		
KMZ Sport	33	0.92 (0.34-2.03)	0.58 (0.24-0.85)	0.68 (0.25-1.41)	Int	2005,2011-12	not avail.		
So Calif. Troll	34	0.47 (0.13-0.82)	0.36 (0.07-0.66)	0.60 (0.30-0.90)	Int	2005, 2011	not avail.		no T1 SL enc's in current base period
So Calif. Sport	35	0.92 (0.34-2.03)	0.61 (0.36-1.09)	0.49 (0.28-0.68)	Int	2005,2011-12	not avail.		
NT Area 7 Sport	36	0.24 (0.07-0.64)	NA	0.60 (0.15-1.38)	TF, Log, Int	2003-12 (T2-3), 2007-11 (T1)	T1: 185, T2-3: 647	WDFW	
Tr JDF Troll	41	NA	NA	NA					No recent est's available
NT Area 5 Sport	42	1.92 (0.38-3.39)	NA	0.77 (0.09-2.16)	TF, Log, Int	2003-12	T1: 170, T2-3: 274	WDFW	
NT Area 8-1 Sport	45	3.65 (1.45-12.02)	NA	NA	TF, Log	2005-11	T1: 683	WDFW	
NT Area 9 Sport	53	2.52 (0.95-5.36)	NA	0.95 (0.12-2.33)	TF, Log	2007-12	T1: 224, T2-3: 93	WDFW	
NT Area 6 Sport	54	1.06 (0.34-5.21)	NA	0.03 (0.00-0.06)	TF, Log, Int	2003-11 (T1), 2003-7 (T2-3)	T1: 434, T2-3: 91	WDFW	
NT Area 10 Sport	56	6.10 (2.88-9.21)	NA	1.22 (0.35-2.24)	TF, Log	2007-12	T1: 290, T2-3: 58	WDFW	
NT Area 11 Sport	57	1.96 (0.30-3.17)	1.30	0.64 (0.22-1.48)	TF, Log	2007-12 (T2-3), 2009-11 (T1/4)	T1: 84, T2-3:	WDFW	TS2 value is interpolated for T1 and T3
NT Area 12 Sport	64	3.31 (1.82-5.40)	NA	1.87 (0.31-5.05)	Int	2003-11 (T2-3), 2003-9 (T1/4)	T1: 327, T2-3: 253	WDFW	
NT Area 13 Sport	67	9.37 (0.88-25.86)	4.93	1.47 (0.56-3.26)	Int	2003-6 (T2-3), 2003-11 (T1/4)	T1: 140, T2-3: 604	WDFW	TS2 value is interpolated for T1 and T3

Table 2. Comparison of different summary statistics characterizing the central tendency of sublegal:legal ratio distributions for Puget Sound marine areas 5-13. MOR (outlined) is the mean of ratios, which was selected for modeling; ROM is the ratio of means (sums); and Geom. Mean is the geometric mean. N is the number of seasons (years) for which estimates were available.

Marine Area	Winter (Time 1 & 4)							Summer (Time 2-3)						
	N	min	max	MOR	ROM	Geom. Mean	Median	N	min	max	MOR	ROM	Geom. Mean	Median
5	11	0.38	3.39	1.92	2.04	1.61	1.51	10	0.09	2.16	0.77	0.84	0.60	0.60
6	11	0.34	5.21	1.06	0.66	0.71	0.62	5	0.00	0.06	0.03	0.04	0.00	0.03
7	5	0.07	0.64	0.24	0.28	0.18	0.17	10	0.15	1.38	0.60	0.66	0.51	0.56
8	7	1.45	12.02	3.65	3.73	2.70	1.96	--	--	--	--	--	--	--
9	5	0.95	5.36	2.52	2.23	2.07	1.63	6	0.12	2.33	0.95	0.85	0.64	0.92
10	5	2.88	9.21	6.10	5.65	5.67	6.76	6	0.35	2.24	1.22	1.13	0.92	1.19
11	3	0.30	3.17	1.96	1.56	1.32	2.42	6	0.22	1.48	0.64	0.59	0.52	0.59
12	9	1.82	5.40	3.31	3.53	3.02	3.36	8	0.31	5.05	1.87	1.69	1.26	1.26
13	9	0.88	25.86	9.37	8.84	5.59	5.53	4	0.56	3.26	1.47	1.45	1.13	1.04

Table 3. Effects of incorporating updated sublegal:legal ratios into 2003-2010 FRAM validation runs on the total exploitation rate for Lower Columbia River natural tule Chinook. Values denoted as 'FRAM' are from the base unmodified validation runs whereas those labeled 'Adj. FRAM' are those from runs with encounter rate adjustment values that yield the sampling estimate.

	Sublegal method		Change in ER (Adj. FRAM - FRAM)	
Year	**FRAM**	**Adj. FRAM**	**absolute**	**relative**
2003	0.392	0.397	0.005	1.3%
2004	0.437	0.439	0.002	0.5%
2005	0.520	0.529	0.009	1.7%
2006	0.435	0.440	0.005	1.1%
2007	0.494	0.486	-0.008	-1.6%
2008	0.298	0.299	0.001	0.3%
2009	0.386	0.382	-0.004	-1.0%
2010	0.330	0.337	0.007	2.1%
		mean:	0.002	0.6%

Table 4. Average (min,max) change in relevant exploitation rate (ER) metrics for Puget Sound Chinook from a comparison of the base 2003-2010 validation runs with those based on updated sublegal encounter rate adjustments. ER types are total (Tot.), southern US (SUS), and SUS preterminal (PT), whereas management criteria are defined as RER = Recovery ER and CERC = Critical ER Ceiling; CERC is the impact limit reference when a stock's escapement falls or is projected to fall below a specified threshold. The ER category most often referenced for each stock is highlighted in gray.

-	2003-2010 Validation Run Average			Absolute difference (adj. FRAM - FRAM)			Relative difference ([Abs. diff]/FRAM)			Management Criteria			
Stock	**Tot. ER**	**SUS ER**	**PT ER**	**Tot. ER**	**SUS ER**	**PT ER**	**Tot. ER**	**SUS ER**	**PT ER**	**RER**	**type**	**CERC**	**type**
Spring/Early:													
Nooksack	0.244 (0.189-0.305)	0.038 (0.025-0.053)	0.013 (0.007-0.017)	-0.003 (-0.006,-0.001)	-0.001 (-0.003,0.000)	-0.001 (-0.003,0.000)	-1.3% (-1.9%,-0.2%)	-2.5% (-7.4%,0.3%)	-9.9% (-26.1%,0.5%)	7%	SUS	7%	SUS
Skagit	0.216 (0.152-0.270)	0.101 (0.074-0.120)	0.070 (0.037-0.112)	-0.002 (-0.005,0.001)	-0.003 (-0.004,0.000)	-0.003 (-0.005,-0.001)	-0.8% (-1.9%,0.7%)	-2.5% (-4.2%,-0.6%)	-4.4% (-11.2%,-0.7%)	38%	Total	18%	SUS
White	0.203 (0.147-0.310)	0.180 (0.128-0.271)	0.089 (0.024-0.221)	-0.011 (-0.048,-0.001)	-0.015 (-0.056,-0.003)	-0.016 (-0.061,-0.003)	-4.6% (-16.3%,-0.6%)	-6.9% (-20.6%,-1.9%)	-15.9% (-30.3%,-4.4%)	20%	Total	15%	SUS
Dungeness	0.361 (0.277-0.452)	0.055 (0.038-0.085)	0.049 (0.037-0.075)	-0.010 (-0.015,-0.006)	0.000 (-0.003,0.002)	0.000 (-0.004,0.002)	-2.8% (-3.8%,-1.6%)	0.6% (-3.5%,3.8%)	0.1% (-7.0%,3.8%)	10%	SUS	6%	SUS
Summer/Fall:													
Skagit	0.457 (0.345-0.662)	0.143 (0.056-0.321)	0.043 (0.026-0.067)	-0.002 (-0.004,-0.001)	0.000 (0.000,0.000)	0.000 (-0.001,0.000)	-0.5% (-1.1%,-0.1%)	0.1% (0.1%,0.2%)	-0.3% (-1.5%,0.1%)	50%	Tot	17/15%	SUS
Stillaguamish	0.197 (0.136-0.335)	0.090 (0.055-0.194)	0.088 (0.054-0.192)	-0.006 (-0.020,0.000)	-0.005 (-0.017,0.002)	-0.005 (-0.017,0.002)	-3.2% (-6.0%,0.2%)	-5.4% (-13.1%,1.7%)	-5.5% (-13.6%,1.7%)	25%	Tot	15%	SUS
Snohomish	0.258 (0.207-0.335)	0.132 (0.094-0.195)	0.102 (0.075-0.146)	-0.004 (-0.010,0.001)	-0.004 (-0.011,0.001)	-0.004 (-0.012,0.001)	-1.5% (-3.3%,0.6%)	-2.5% (-6.9%,1.0%)	-3.5% (-9.8%,1.2%)	21%	Tot	15%	SUS
Lake Wa. (Cedar)	0.394 (0.248-0.549)	0.184 (0.104-0.262)	0.098 (0.058-0.132)	-0.001 (-0.004,0.001)	0.001 (-0.001,0.004)	0.001 (-0.002,0.003)	-0.3% (-1.0%,0.3%)	0.7% (-0.5%,2.2%)	0.8% (-1.5%,3.7%)	20%	SUS	10%	PT SUS
Green	0.544 (0.271-0.649)	0.335 (0.128-0.421)	0.098 (0.058-0.132)	-0.001 (-0.004,0.001)	0.001 (0.000,0.004)	0.001 (-0.002,0.003)	-0.2% (-0.8%,0.2%)	0.5% (-0.1%,1.8%)	0.8% (-1.5%,3.7%)	15%	PT SUS	12%	PT SUS
Puyallup	0.590 (0.510-0.710)	0.381 (0.276-0.512)	0.098 (0.058-0.132)	-0.001 (-0.003,0.001)	0.001 (-0.001,0.006)	0.001 (-0.002,0.003)	-0.2% (-0.6%,0.1%)	0.3% (-0.3%,1.4%)	0.8% (-1.5%,3.7%)	50%	Tot	12%	PT SUS
Nisqually	0.773 (0.665-0.830)	0.598 (0.472-0.667)	0.191 (0.124-0.291)	0.000 (-0.004,0.003)	0.004 (-0.003,0.009)	0.003 (-0.015,0.012)	0.0% (-0.5%,0.3%)	0.7% (-0.5%,1.9%)	0.8% (-9.3%,4.6%)	56%	Tot		
Western Strait-Hoko	0.275 (0.221-0.345)	0.060 (0.031-0.128)	0.058 (0.031-0.110)	-0.015 (-0.030,-0.007)	0.001 (-0.002,0.003)	0.001 (-0.002,0.003)	-5.2% (-8.8%,-2.4%)	1.8% (-1.6%,3.4%)	1.8% (-1.6%,3.4%)	10%	SUS	6%	SUS
Elwha	0.356 (0.276-0.454)	0.050 (0.036-0.073)	0.048 (0.034-0.073)	-0.010 (-0.014,-0.006)	0.000 (-0.004,0.002)	0.000 (-0.004,0.002)	-2.9% (-4.4%,-1.7%)	0.2% (-7.0%,4.1%)	0.2% (-7.0%,4.1%)	10%	SUS	6%	SUS
Mid-Hood Canal	0.278 (0.218-0.370)	0.099 (0.077-0.117)	0.098 (0.075-0.117)	-0.003 (-0.006,0.000)	-0.001 (-0.005,0.003)	-0.001 (-0.005,0.003)	-1.0% (-2.5%,0.0%)	-0.7% (-4.7%,2.3%)	-0.7% (-4.7%,2.4%)	15%	PT SUS	12%	PT SUS
Skokomish	0.624 (0.556-0.688)	0.448 (0.367-0.510)	0.112 (0.086-0.136)	-0.002 (-0.004,0.000)	0.000 (-0.003,0.003)	-0.001 (-0.005,0.003)	-0.3% (-0.6%,0.0%)	0.0% (-0.5%,0.7%)	-1.0% (-4.7%,2.5%)	50%	Tot	12%	PT SUS

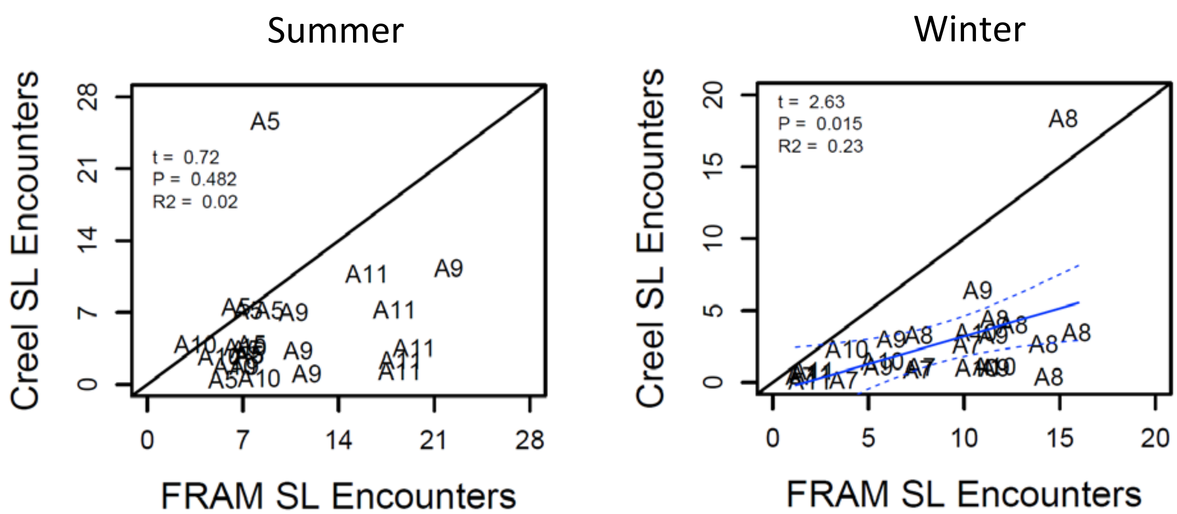


Figure 1. Comparison of FRAM projections and creel estimates of sublegal encounters (in 1,000s of fish) for summer (left panel) and winter (right panel) Puget Sound mark-selective sport fisheries with intensive creel studies (marine areas 5-11), 2003-2012. Each data point represents a marine area ("A#") and year combination. The solid line is the line of equality; the presence of a regression line (and confidence intervals) if displayed denotes that a significant relationship exists between Creel and FRAM values.

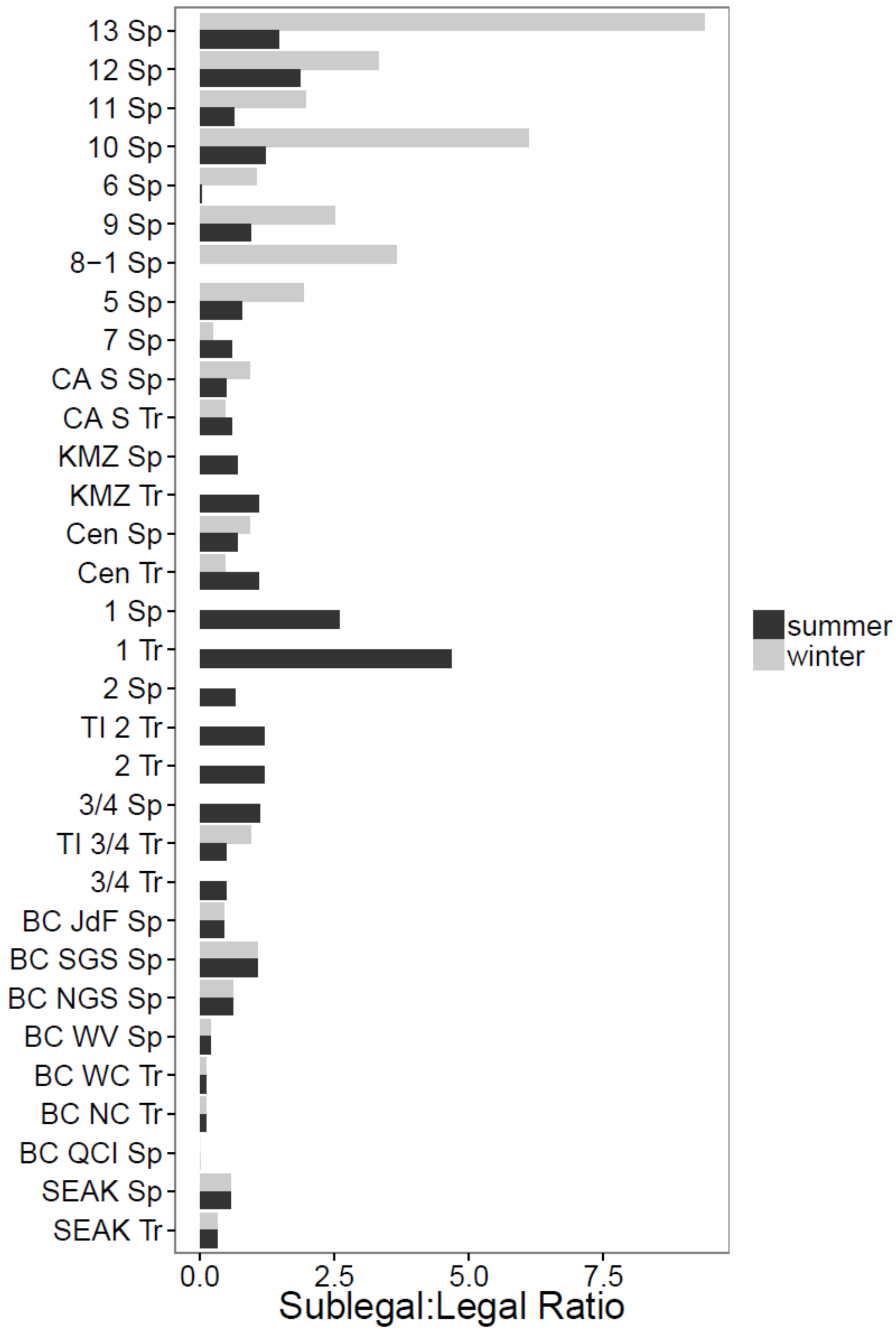


Figure 2. Sampling estimates of the sublegal:legal ratio for FRAM model fisheries during winter (time 1 and 4) and summer (time 3) model time steps (see Table 1 for methodological details). Displayed values are the mean of annual values for a particular season-area combination.

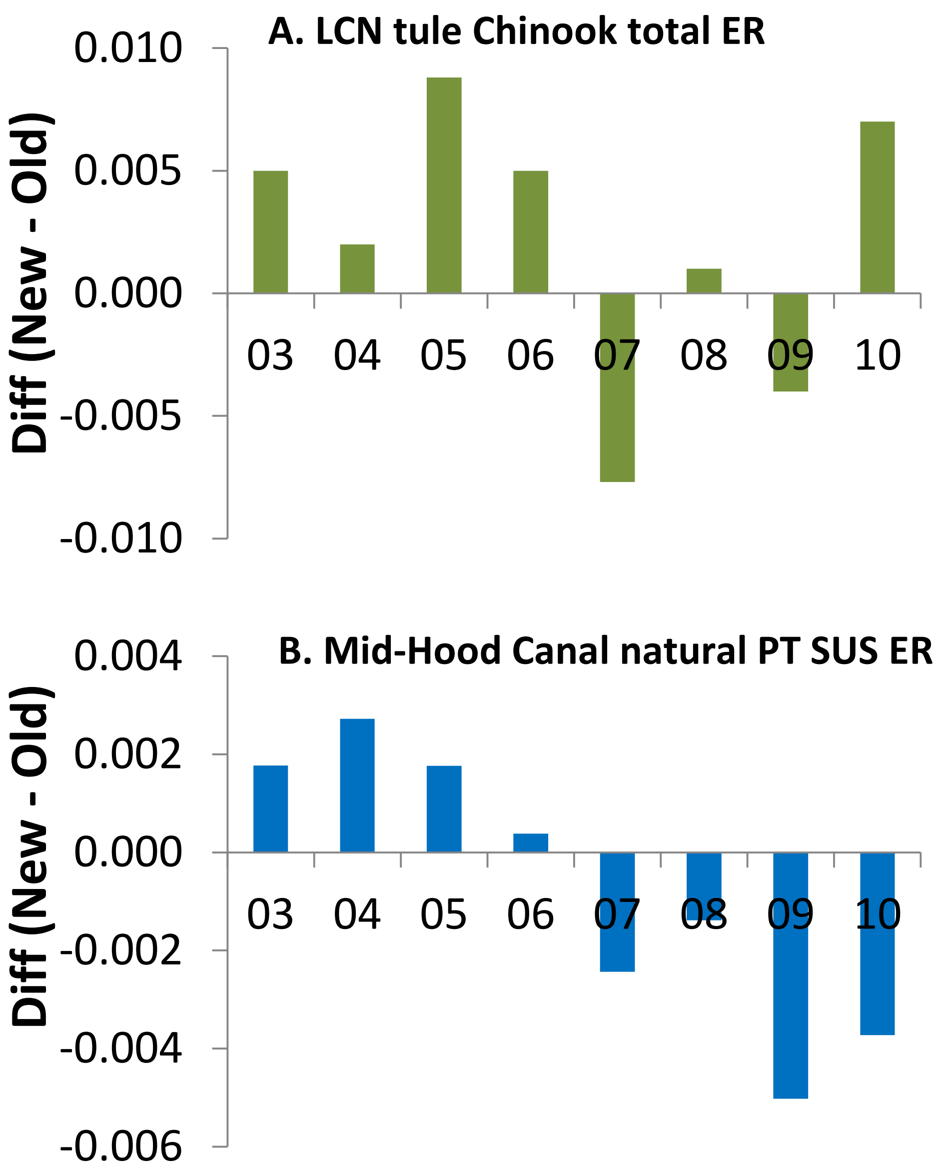
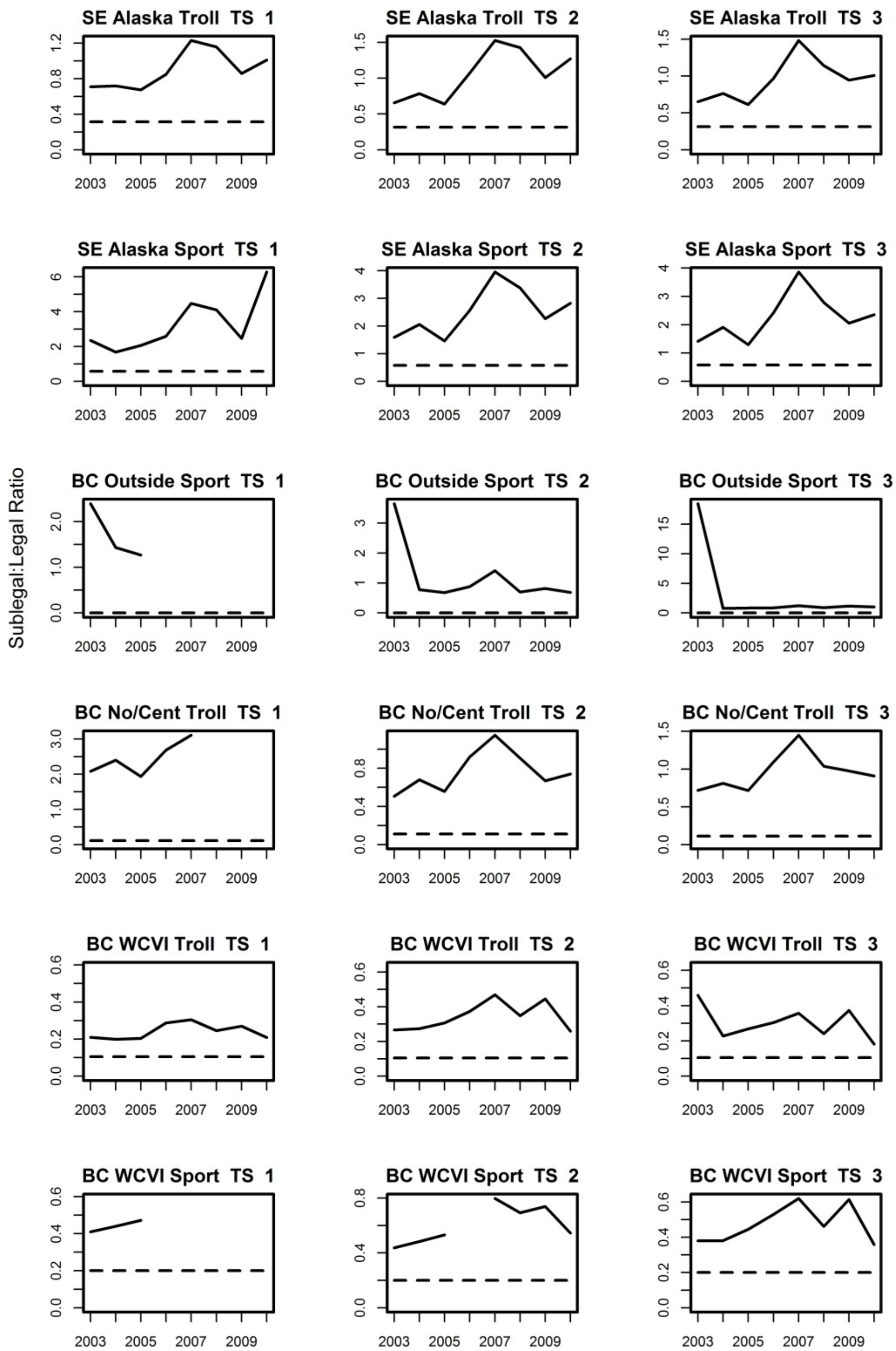
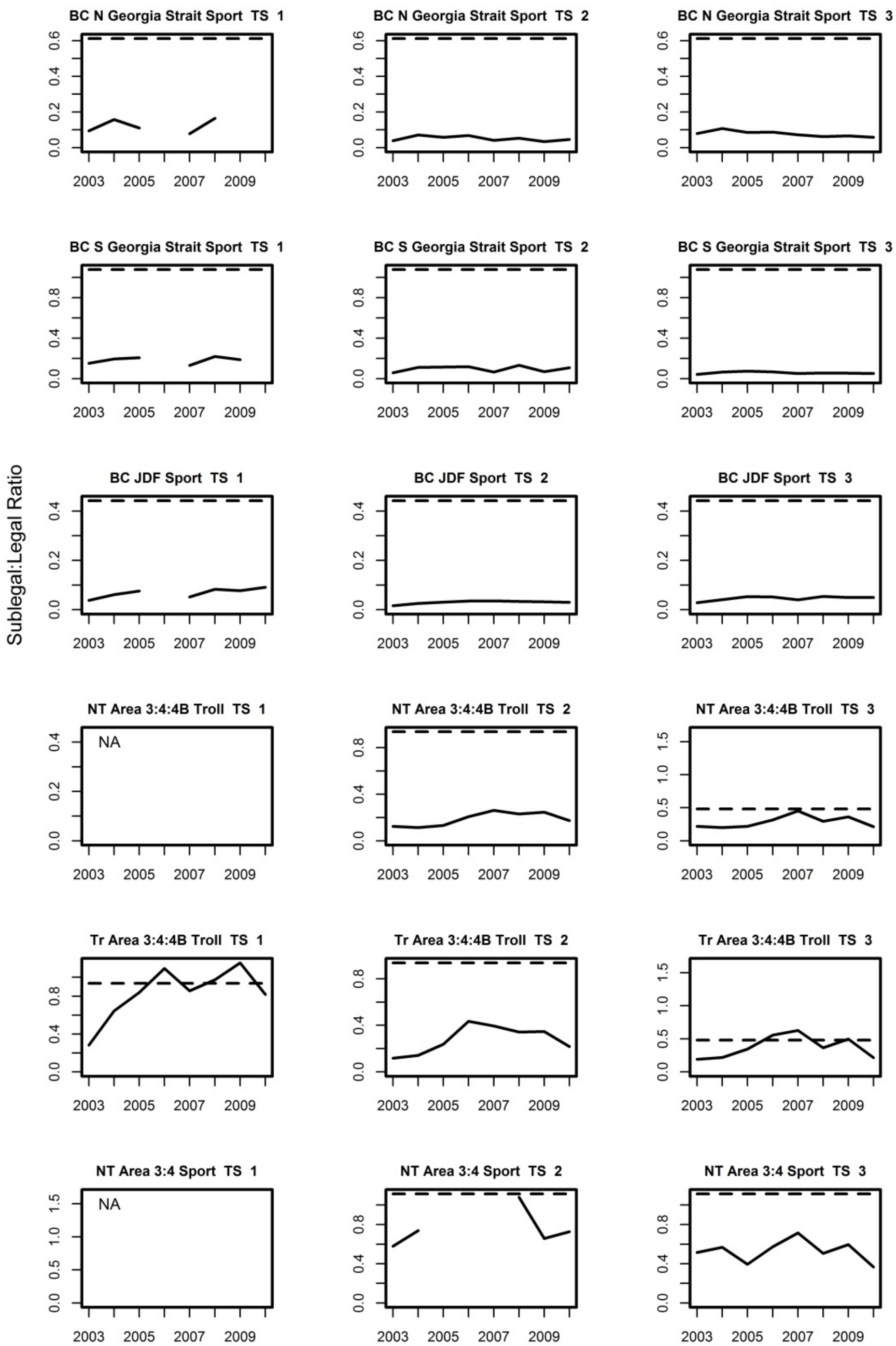


Figure 3. Difference ('Diff') between adjusted ('New') and unadjusted ('Old') estimates of (A) total exploitation rate for Lower Columbia River Natural Tule Chinook and (B) preterminal (PT) Southern US (SUS) exploitation rate for Mid-Hood Canal natural fall fingerlings.

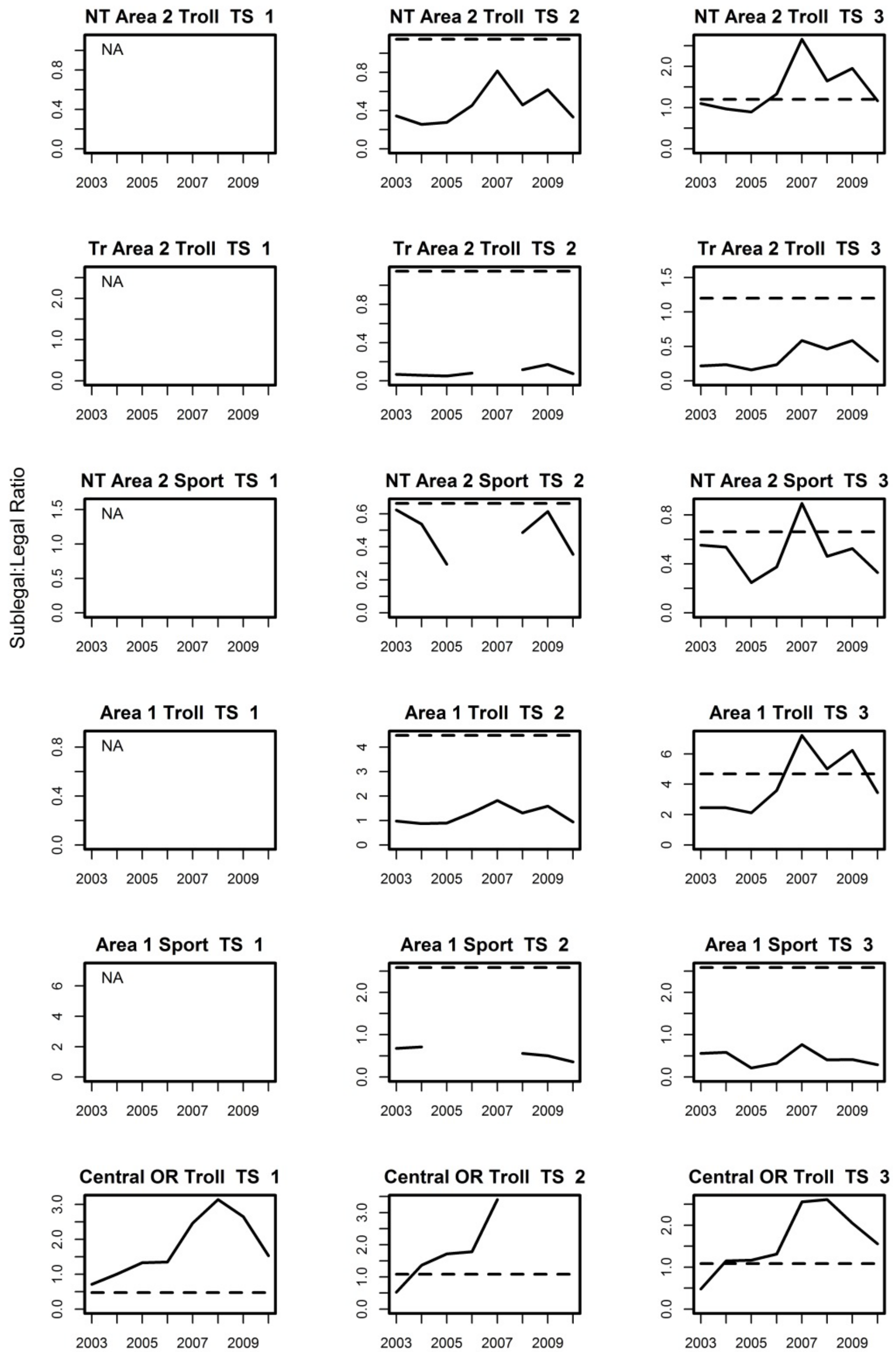
Appendix A. 2003-2010 FRAM validation run (Jan 2013 version) projections of sublegal:legal ratios (solid line) relative to recent empirical estimates (horizontal dashed reference line) by FRAM fishery and time step. "NA" denotes that: (1) a fishery was closed during a time step in the reference years, (2) the current base period lacks a sublegal encounter rate for a fishery/time step, and/or (3) recent empirical estimates are not available for a fishery/time step combination.



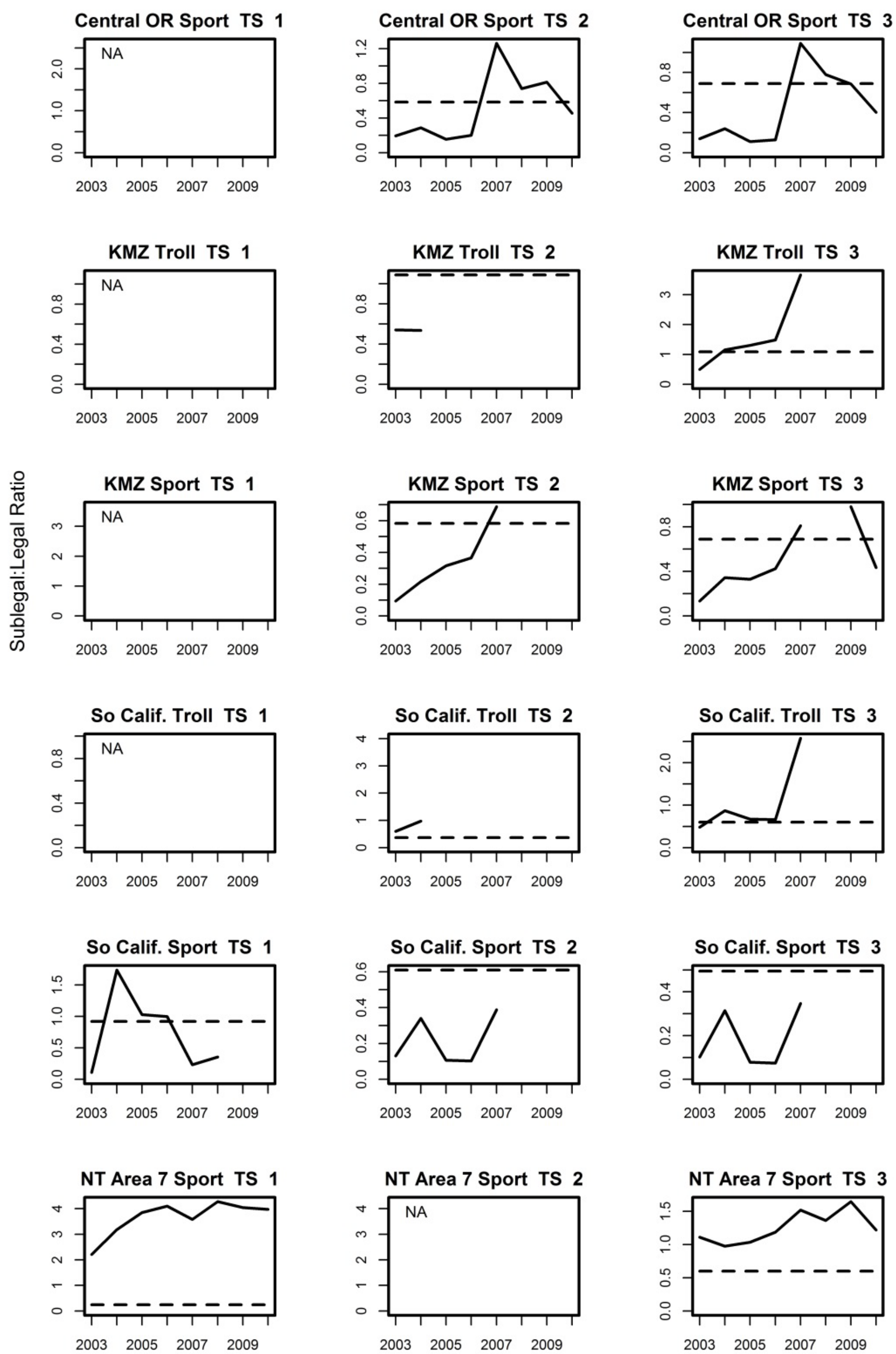
Appendix A Continued.



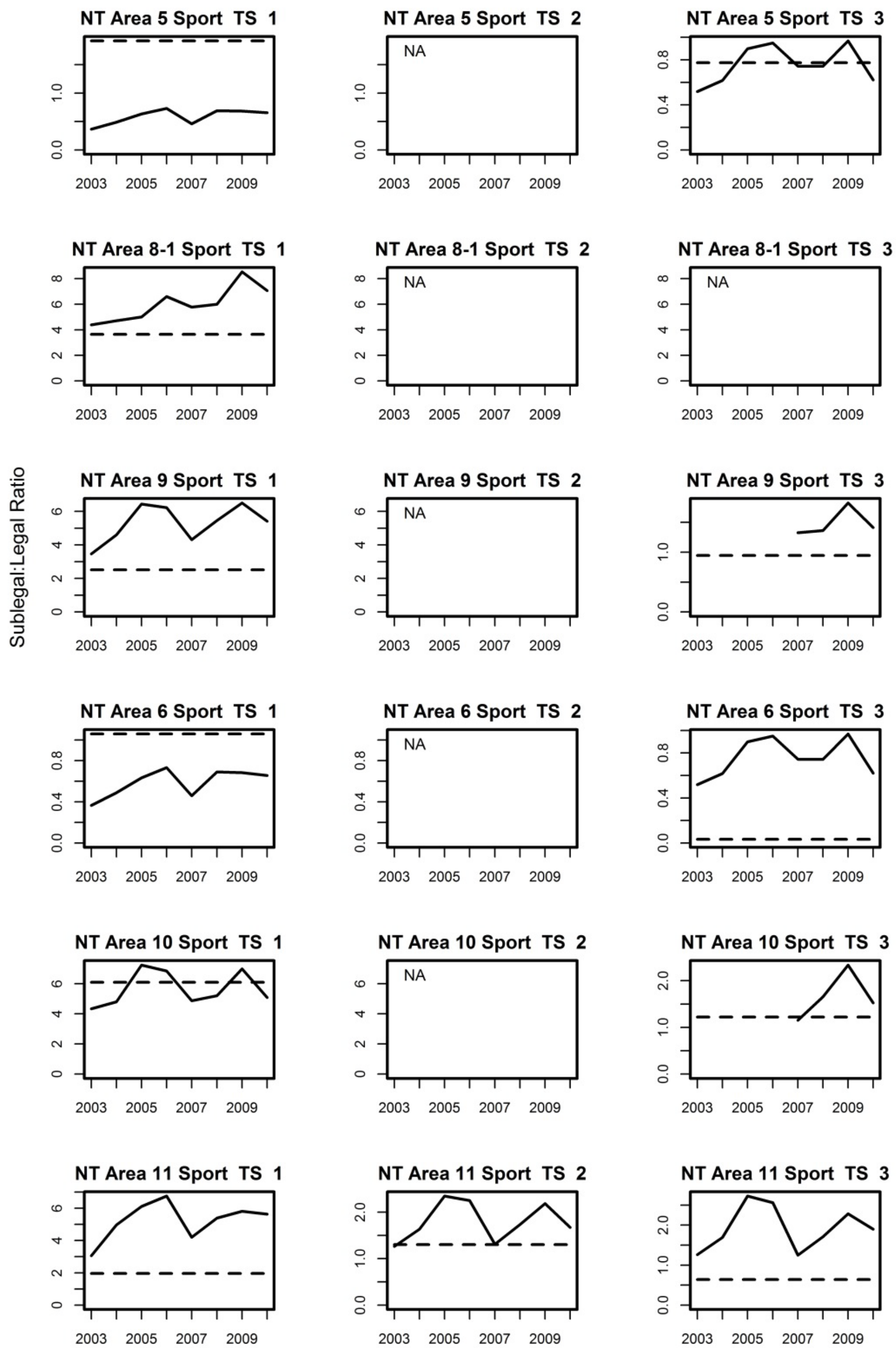
Appendix A Continued.



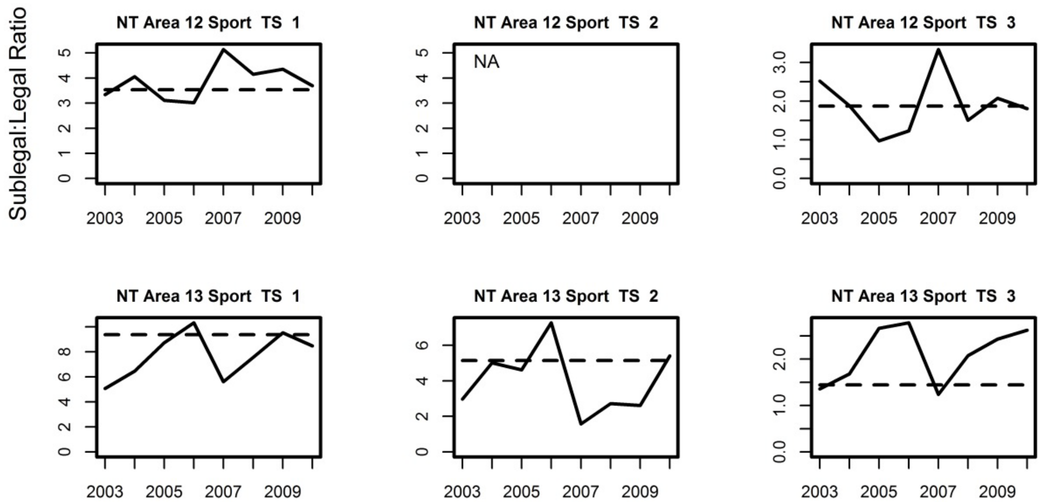
Appendix A Continued.



Appendix A Continued.



Appendix A Continued.



Appendix B. 2003-2010 FRAM validation run (Jan 2013 version) projections of sublegal:legal ratios for model fisheries and time steps and the recent empirical estimate (based on sampling or otherwise, see Table 1) of the sublegal:legal ratio for that stratum. "NA" denotes that: (1) a fishery was closed during a time step in the reference years, (2) the current base period lacks a sublegal encounter rate for a fishery/time step, and/or (3) recent empirical estimates are not available for a fishery/time step combination.

FRAM No.	Fishery Name	Mean FRAM S:L Ratio (Min-Max)			Target (Empirical Est) S:L Ratio		
		TS 1	TS 2	TS 3	TS 1	TS 2	TS 3
1	SE Alaska Troll	0.90 (0.67-1.23)	1.05 (0.64-1.53)	0.95 (0.61-1.48)	0.31	0.31	0.31
3	SE Alaska Sport	3.25 (1.68-6.28)	2.51 (1.46-3.95)	2.26 (1.30-3.86)	0.58	0.58	0.58
8	BC Outside Sport	1.70 (1.27-2.39)	1.20 (0.68-3.65)	3.15 (0.79-18.48)	0.00	0.00	0.00
9	BC No/Cent Troll	2.44 (1.93-3.10)	0.77 (0.51-1.15)	0.96 (0.71-1.45)	0.11	0.11	0.11
10	BC WCVI Troll	0.24 (0.20-0.31)	0.34 (0.26-0.47)	0.30 (0.18-0.46)	0.11	0.11	0.11
11	BC WCVI Sport	0.44 (0.41-0.47)	0.60 (0.44-0.80)	0.47 (0.36-0.62)	0.20	0.20	0.20
13	BC N Georgia Strait Sport	0.12 (0.08-0.16)	0.05 (0.03-0.07)	0.08 (0.06-0.11)	0.61	0.61	0.61
14	BC S Georgia Strait Sport	0.18 (0.13-0.22)	0.10 (0.06-0.13)	0.06 (0.04-0.08)	1.08	1.08	1.08
15	BC JDF Sport	0.07 (0.04-0.09)	0.03 (0.02-0.04)	0.05 (0.03-0.05)	0.44	0.44	0.44
16	NT Area 3:4:4B Troll	NA	0.19 (0.11-0.26)	0.28 (0.20-0.45)	NA	0.94	0.48
17	Tr Area 3:4:4B Troll	0.83 (0.28-1.15)	0.28 (0.12-0.43)	0.38 (0.19-0.63)	0.94	0.94	0.48
18	NT Area 3:4 Sport	NA	0.75 (0.58-1.08)	0.53 (0.37-0.71)	NA	1.11	1.11
20	NT Area 2 Troll	NA	0.44 (0.25-0.82)	1.46 (0.89-2.66)	NA	1.15	1.20
21	Tr Area 2 Troll	NA	0.09 (0.05-0.17)	0.35 (0.16-0.59)	NA	1.15	1.20
22	NT Area 2 Sport	NA	0.48 (0.29-0.62)	0.49 (0.25-0.89)	NA	0.66	0.66
26	Area 1 Troll	NA	1.22 (0.88-1.82)	4.07 (2.12-7.22)	NA	4.48	4.68
27	Area 1 Sport	NA	0.56 (0.36-0.71)	0.44 (0.21-0.77)	NA	2.59	2.59
30	Central OR Troll	1.77 (0.71-3.14)	1.79 (0.52-3.41)	1.61 (0.48-2.61)	0.47	1.09	1.09
31	Central OR Sport	NA	0.51 (0.15-1.26)	0.45 (0.11-1.09)	NA	0.58	0.69

Appendix B Continued.

FRAM No.	Fishery Name	Mean FRAM S:L Ratio (Min-Max)			Target (Empirical Est) S:L Ratio		
		TS 1	TS 2	TS 3	TS 1	TS 2	TS 3
32	KMZ Troll	NA	0.65 (0.54-0.82)	1.66 (0.50-3.66)	NA	1.09	1.09
33	KMZ Sport	NA	0.39 (0.09-0.69)	0.49 (0.13-0.98)	NA	0.58	0.69
34	So Calif. Troll	NA	1.86 (0.60-4.01)	1.13 (0.48-2.57)	NA	0.37	0.60
35	So Calif. Sport	0.65 (0.11-1.74)	0.20 (0.10-0.39)	0.17 (0.07-0.35)	0.92	0.61	0.50
36	NT Area 7 Sport	3.65 (2.21-4.28)	NA	1.26 (0.98-1.64)	0.24	NA	0.60
42	NT Area 5 Sport	0.59 (0.37-0.73)	NA	0.76 (0.52-0.97)	1.92	NA	0.77
45	NT Area 8-1 Sport	6.01 (4.38-8.53)	NA	NA	3.65	NA	NA
53	NT Area 9 Sport	5.30 (3.46-6.50)	NA	1.48 (1.32-1.82)	2.52	NA	0.95
54	NT Area 6 Sport	0.59 (0.37-0.73)	NA	0.76 (0.52-0.97)	1.06	NA	0.03
56	NT Area 10 Sport	5.68 (4.34-7.25)	NA	1.67 (1.15-2.34)	6.10	NA	1.22
57	NT Area 11 Sport	5.24 (3.06-6.76)	1.80 (1.26-2.35)	1.92 (1.25-2.73)	1.96	1.30	0.64
64	NT Area 12 Sport	3.86 (3.02-5.14)	NA	1.92 (0.97-3.34)	3.31	NA	1.87
67	NT Area 13 Sport	7.72 (5.07-10.32)	4.02 (1.58-7.26)	2.11 (1.24-2.78)	9,37	4.93	1.47

Correction to FRAM Algorithms for Modeling Size Limit Changes

Angelika Hagen-Breaux, Pete McHugh, James Packer
Washington Department of Fish and Wildlife
600 Capitol Way N
Olympia, WA 98501

October 8, 2013

Pacific Fisheries Management Council
Salmon Methodology Review
November, 2013

Abstract

The Fishery Regulation Assessment Model (FRAM) for Chinook salmon was designed to allow for evaluation of changes in fishery catches and stock impacts resulting from changes in minimum size limit regulations. Changes in minimum size limits occur occasionally in hook and line salmon fisheries. In recent years, changes in minimum size limits for Chinook salmon in Puget Sound sport fisheries have been discussed during pre-season management meetings. As part of these discussions, the FRAM methodology and supporting data was reviewed and determined to be flawed in its ability to accurately evaluate changes in size limits.

FRAM uses different rates to model encounters of legal and sublegal fish. These rates are computed during the calibration process and are based on landed catch and encounter information during the base period years (1976-1984). As such, they reflect the size limit conditions as they existed at the time.

When size limits are modeled in FRAM, each fish smaller than the size limit is treated as a sublegal fish. Sublegal encounter rates are used to compute releases and release mortalities. Conversely, each fish larger than the size limit is deemed legal. Legal encounter rates are used to estimate catch in non-selective fisheries. As the size limit is changed, a portion of the population (with sizes between the old and the new size limit) that previously received a sublegal encounter rate will receive a legal encounter rate or vice versa. This leads to the total number of computed encounters varying with size limits, an incorrect outcome, if effort remains constant.

At the 2012 Salmon Methodology Review, WDFW presented a method to fix this known FRAM problem. The corrected equations hold total encounters constant, regardless of the modeled size limit. In a first round of evaluations FRAM computes the encounters under base period size limits and then adjusts encounters computed under new size limit regulations to match the original encounters.

Several issues were raised by the Statistical and Scientific Review Committee (SSC) at last year's meeting. The main concern was the change in mortalities for all fisheries that had experienced size limit changes since the base period, causing significant increases in exploitation rates of key listed stocks. Additionally, there was a general discomfort with FRAM's sublegal encounter rates. It was decided that WDFW should investigate how to model size limit changes through an "external to FRAM approach" based on recent field data (i.e., length-frequency data for all Chinook encounters in recreational test fisheries) to estimate impacts to sublegal and legal sized Chinook. During the 2013 pre-season process size limits were not changed, but encounters of sublegal Chinook in Puget Sound sport fisheries were modeled using this "external approach" in conjunction with recent year field data.

For the October 2013 Salmon Methodology Review , the Model Evaluation Workgroup (MEW) has been tasked with incorporating recent information on sublegal encounters for all fisheries for which data exist. Along with this assignment, we revisited last year's size-limit methodology, because updating sublegal encounters remedies to some extent the two main concerns brought forth at the 2012 methodology review. Updating sublegal/legal ratios did not result in large exploitation rate changes and brings FRAM's estimates of encounters in line with field data. Because encounters would be calibrated to recent year observations and as such reflecting recent year size limit conditions, those fisheries that experienced size limit changes since the base period would no longer need to be adjusted.

The size limit correction method described here would be an interim measure until a new Chinook FRAM calibration allows incorporation of new size limit algorithms.

Introduction

During the 2013 North of Falcon/PFMC pre-season process several size limit proposals were discussed for Puget Sound sport fisheries. Ultimately, none of these were adopted, but new size limit proposals might be revisited for the 2014 season.

FRAM's algorithms for evaluating size limit changes are problematic, because two different rates are used to calculate the mortality of sublegal and legal Chinook. Sublegal fish are assigned a sublegal encounter rate and legal fish, a different, legal exploitation rate. The status of a fish as legal versus sublegal is a function of the size limit. If a fish is greater than the size limit it is considered legal and can be retained, unless there are additional restrictions as in mark selective fisheries. A fish that is smaller than the size limit is considered sublegal and must be released.
The mortality of encounters is computed as:

$$\text{Mortality}_{\text{Legal}} = \text{Abundance} * \text{Proportion Legal} * \text{FisheryScalar} * \text{LegalEncounterRate}$$
$$\text{Mortality}_{\text{Sublegal}} = \text{Abundance} * \text{ProportionSublegal} * \text{FisheryScalar} * \text{SublegalEncounterRate} * \text{ReleaseMortalityRate}$$

Legal encounter rates under base period size limits were calculated for each stock, age, fishery and time step using CWT recoveries. Sublegal encounter rates were developed for each fishery using the relationship between landed catch and sublegal release information from several data sources such as interview data, log books, observer programs etc. These rates are computed during the calibration process and are based on data collected from the base period years (1976-1984).

When the size limit is changed the proportion of the fish between the old and the new size limit will experience a different encounter rate (Figures 1-3). Hence the number of encounters changes with the size limit. All things being equal, this is an incorrect outcome, as the size limit is evaluated after a fish is encountered and should therefore not influence the number of encounters.

Figure 1. Encounters as a function of cohort size and size limit dependent encounter rates. BP SL is the base period size limit.

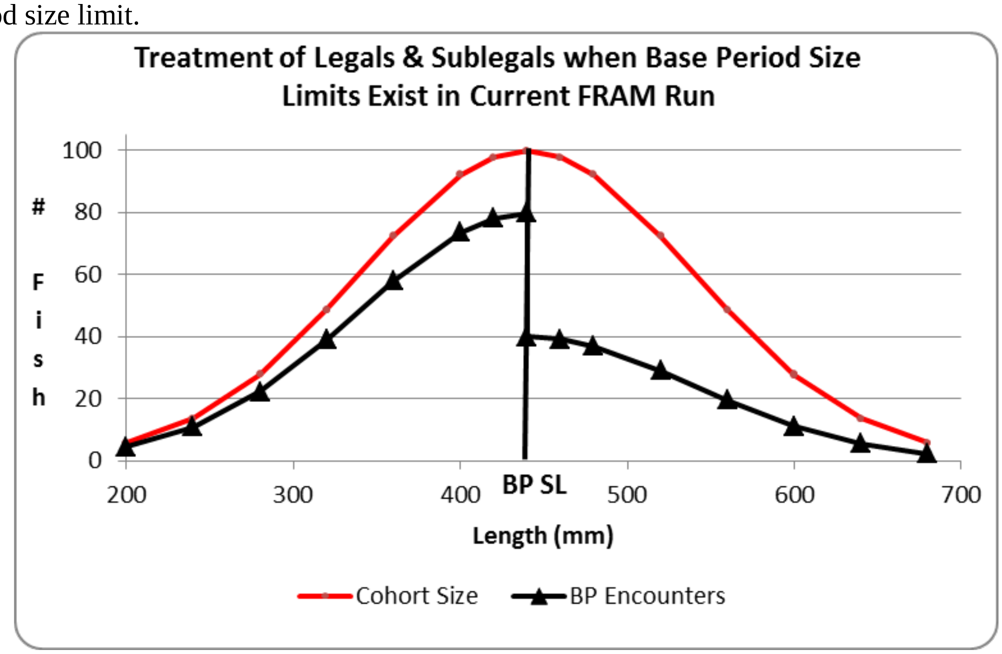


Figure 2. Treatment of Legals and Sublegals when the New Size Limit (FRAM SL) is smaller than the Base Period Size Limit. The blue striped area designates the catch that FRAM is underestimating when the size limit is lowered.

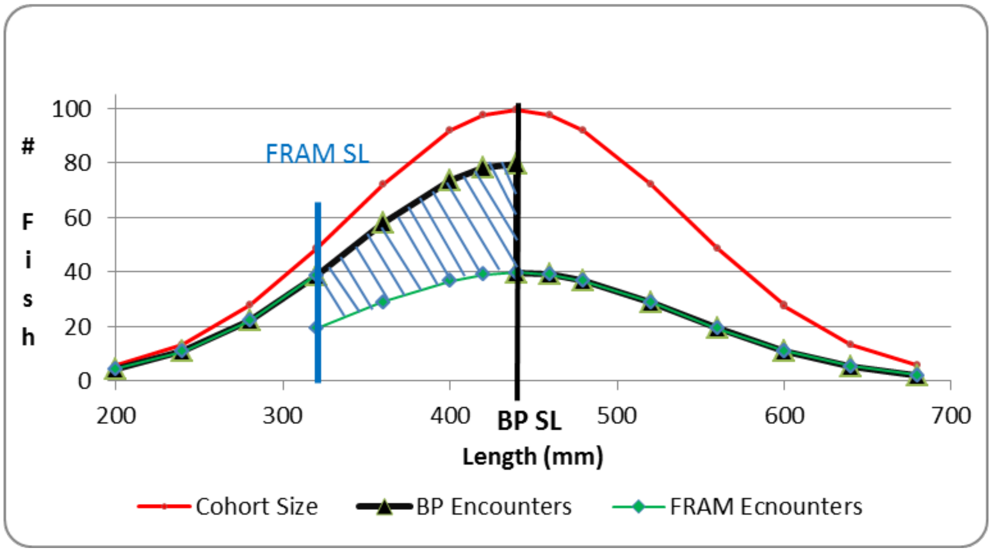
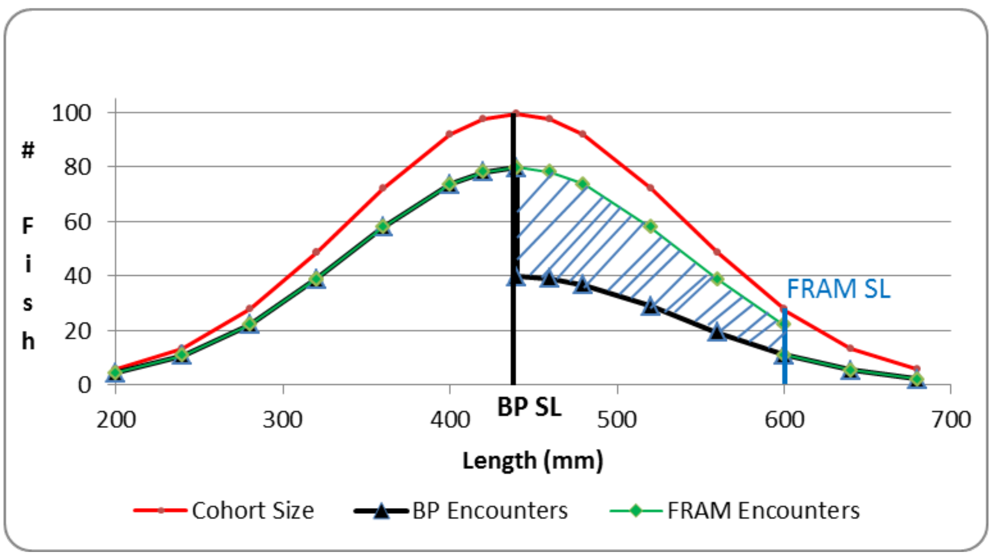


Figure 3. Treatment of Legals and Sublegals when the New Size Limit is larger than the Base Period Size Limit. The blue striped area designates the number of encounters that FRAM is overestimating when the size limit is increased.



The proposed size limit correction recalculates encounters in the area between the old size limit and the new size limit to match those under base period size limit regulations. For each fishery with size limit changes since the base period, the encounters computed with the size limit correction match encounters under base period size limits, regardless of what minimum size limit is specified, but are different from the encounters in the “uncorrected” FRAM (Table 1).

Table 1. Sample output of the size limit corrected FRAM and the uncorrected FRAM (old FRAM). Encounters by legal/sublegal status at different size limits with 480 mm reflecting the base period size limit.

	Size Limit Corrected FRAM			Old FRAM		
Size Limit	Legal Encounters	Sublegal Encounters	Total Encounters	Legal Encounters	Sublegal Encounters	Total Encounters
425	2651	8825	**12856**	3663	8825	**12488**
480 (BP)	1996	10860	**12856**	1996	10860	**12856**
520	942	11914	**12856**	942	10860	**11802**

Size limits were changed numerous times since the base period. The size limit correction resets encounters in these fisheries to those that would have been estimated under base period size limit conditions. This change in encounters produces significant increases in exploitation rates on key natural stocks, such as mid-Hood Canal and Lower Columbia River natural Chinook, even if no size limits or other fishery inputs (i.e. scalars, quotas, etc.) are changed and exacerbates the known discrepancy between FRAM encounter estimates and recent sampling observations. WDFW and other agencies have been collecting encounter estimates for many years via angler interviews, on board observer programs, test fisheries, log books, and trip reports. These observed sublegal encounter estimates are generally much lower in Puget Sound marine sport fisheries than FRAM estimates. Given the availability of these data, it was decided that it would be more prudent to update sublegal encounters before implementing the size limit correction. For 2013 pre-season modeling, WDFW used these data sources to produce recent relationships between legal and sublegal encounters in order to adjust FRAM computed sublegal encounters in Puget Sound sport fisheries. The MEW was tasked with expanding this approach to all fisheries for which data exist. In conjunction with the sublegal encounters update (reviewed in McHugh et al. document), we propose that the size limit correction be reconsidered for use during 2014 preseason modeling, albeit on a reduced basis. Specifically, we propose that the algorithm only be applied to fisheries for which alternative minimum size limits are being considered given that fishery-level patterns of sublegal encounters will, in a sense, be 'recalibrated' to recent data in all fisheries with size limits differing from base period values. In the following sections, we (1) briefly review the basic algorithms and parameters associated with FRAM's consideration of size limits, (2) characterize the new (and improved) size limit correction, (3) consider the effects of implementing the correction on key modeling outputs, and (4) verify the realism of the correction by comparing model projections of changes in catch relative to what test fishery data suggest might occur.

Methods

FRAM Encounter Algorithms

FRAM models legal and sublegal Chinook encounters through the use of the von Bertalanffy growth equation for stocks that contribute to each fishery. The mean size of each stock at the midpoint of the time step is evaluated against the stock-specific growth equation to estimate the proportion vulnerable by stock, age, and time step. The algorithms from the PFMC (2008) (pgs. 18-19) FRAM documentation are as follows:

(27) $KTime_{s,a,t} = (Age_s - 1) \times 12 + \overbrace{MidTimeStep(Months)}$

(28) $MeanSize_{s,a,t} = \overbrace{L_s} \times (1-(\exp(-\overbrace{K}_s) \times (\overbrace{KTime_{s,a}} - \overbrace{T0_s})))$

(29) $StdDev_{s,a,t} = \overbrace{CV_{s,a}} \times \overbrace{MeanSize_{s,a,t}}$

The distribution of Chinook sizes by age at a particular time is assumed to be normal with a variance that was calculated using lengths from CWT recovery data. Evaluation of the normal distribution is done using a calculation method developed for the original WDF/NBS Chinook model.

(31) $Z = (\underbrace{MinSize_{f,t}} - \overbrace{Meansize_{s,a,t}}) \Big/ StdDev_{s,a}$

(32) $A1 = AbsZ \;*\; (0.000005383 \;*\; AbsZ + 0.0000488906) + 0.0000380036$

(33) $A2 = AbsZ \;*\; (AbsZ * A1 + 0.0032776263) + 0.0211410061$

(34) $A3 = 1/(1 + AbsZ \;*\; (AbsZ \;*\; A2 + 0.049867347))$

(35) $A4 = 1 - (0.5 \;*\; A3^{16})$

$PV_{s,a,t} = 1 - A4$ *(if* $Z > 0$*)*

$PV_{s,a,t} = A4$ *(if* $Z < 0$*)*

Where:
$KTime_{s,a}$ = Time for estimate of growth equation for stock *s*, age *a*
$PV_{s,a,t}$ = Proportion vulnerable for stock *s*, age *a*, at time step *t*
L_s = Von Bertalanffy growth parameter for stock *s (Max Size)*
K_s = Von Bertalanffy growth parameter for stock *s (Slope)*
$T0_s$ = Von Bertalanffy growth parameter for stock *s (Time Zero)*,
$CV_{s,a}$ = Coefficient of variation of size distribution at $KTime_{s,a}$ for stock *s*, age *a*
$MinSize_{f,t}$ = Minimum size limit for fishery *f*, time step *t*
$MeanSize_{s,a,t}$ = Mean total length of a fish of stock *s* at age *a* at time step *t*
AbsZ = Absolute value of Z

For Chinook, the sublegal and legal size encounters are stock- and age- specific and are calculated using the von Bertalanffy growth curves described above. The calculations for sublegal sized Chinook are shown below:

(36) $SubLegProp_{s,a,t} = 1 - PV_{s,a,t}$

(37) $SubLegPop_{s,a,t} = Cohort_{s,a,t} \times SubLegProp_{s,a,t}$

Where all components are defined previously and ($1-PV_{s,a,t}$) is the proportion of the cohort for stock *s*, age *a*, not vulnerable to the gear at time step *t* .

Base Period Sublegal Encounter Rate Calculations

The Chinook FRAM base-period Sublegal Encounter Rate is calculated from the individual CWT-based stock catch estimates, externally estimated target sublegal encounter rates (i.e., sampling-based sublegal:legal encounter ratios), and stock/age sublegal population estimates. This methodology was used to match model estimates of sublegal encounters with observed base-period sublegal encounters and to estimate sublegal encounters for stock/age cohorts that did not have CWT recoveries in a fishery because of the minimum size limit restriction.

The sublegal encounter rates used in FRAM are computed in four major steps during the calibration (calibration program ChCal).

1. Compute Legal Encounters by Fishery and Time Step

$$TimeCatch_{f,t} = \sum_{s,a} (BaseCWTRec_{s,a,f,t} * PEF_s)$$

2. Compute Sublegal Encounters by Fishery and Time Step

$$TotSubEnc_{f,t} = TimeCatch_{f,t} * TargetEncRate_{f,t}$$

3. Split Sublegal Encounters into Stocks and Ages[1]

$$SubLegEnc_{s,a,f,t} = TotSubEnc_{f,t} * PropSubPop_{s,a} * StockCatchProp_{s,f}$$

$$PropSubPop_{s,a} = \frac{SubLegalPop_{s,a}}{SubLegalPop_s}$$

$$StockCatchProp_{s,f} = \frac{LandedCatch_{s,f}}{LandedCatch_f}$$

4. Compute Sublegal Encounter Rates

$$SubER_{s,a,f,t} = SubLegEnc_{s,a,f,t} / (Cohort_{s,a,t} * SubLegalProp_{s,a,t})$$

Where:

$TimeCatch_{f,t}$ = Base Period Catch by Fishery and Time Step
$BaseCWTRec_{s,a,f,t}$ = Base Period CWT Recoveries by Stock, Age, Fishery, Time Step
PEF_s = Base Period Production Expansion Factor
$TotSubEnc_{s,f}$ = Base Period Sublegal Encounters by Fishery and Time Step
$TargetEncRate_{f,t}$ = Base Period Sublegal to Legal Ratio by Fishery and Time Step
$PropSubPop_{s,a}$= Proportion of the Sublegal Population of a Stock that is of a Given Age
$SubLegalPop_{s,a}$= Number of Sublegal fish of a Given Stock and Age
StockCatchProp= Proportion of the Legal Encounters of a Fishery that is of a Given Stock

[1] Methods for estimating the stock and age composition of sublegal encounters for a fishery and time step are under review for the new base period development. Because CWT returns could not be used to directly estimate the magnitude nor stock and age composition of the sublegals encountered, calculations of the sublegal encounter rate depend on fishery- and time step-specific Target Encounter Rates. This both decouples the legal and sublegal encounter rates for a stock/age combination and means the likelihood of a fish being encountered in FRAM depends on size limit regulations rather than ecology and fishing gear.

$BaseShaker_{s,a,f,t}$ = Base Period Sublegal Mortalities by Stock, Age, Fishery, Time Step
$SubLegEnc_{s,a,f,t}$ = Base Period Sublegal Encounters by Stock, Age, Fishery, Time Step
$SubER_{s,a,f,t}$ = Base Period Sublegal Encounter Rate by Stock, Age, Fishery, Time Step
$SubLegalProp_{s,a,t}$=Proportion of the Cohort that is Sublegal by Stock, Age, Time Step
$FishScalar_{f,t}$ = Fishery Scalar by Fishery and Time Step. Used to scale base period exploitation rate to current fishery effort.
$RelRate_{f,,t}$ = Release Mortality Rate

Proposed Evaluation of Minimum Size Limit Change

The method for calculating the Chinook FRAM base-period sublegal encounter rates does not allow for a simple algorithm to evaluate a change from the base-period minimum size limit. This is primarily due to the target sublegal encounter rate (TargetEncRate) and the stock/fishery catch proportion (StockCatchProp) variables used to calculate base-period encounters. The combination of these two variables results in an uneven distribution of legal and sublegal sized fish by stock and age for most fisheries and time steps. The simplest approach, and that which was presented during the 2012 model review, for evaluating a size limit change from the base period is to calculate the legal and sublegal encounters for both the base period and new minimum size limit and then adjust the differences so that total encounters remains constant. Encounter differences occur in the region between the base period size limit and the new minimum size limit (Figures 1-3).

When the new size limit is less than the base-period size limit, the difference in sublegal encounters between the base size-limit and the new size-limit becomes legal encounter that is added to the legal encounters evaluated at the base-period size limit. The difference in encounters is used in this case because it incorporates the base-period sublegal encounter rates, which are always different than the base-period exploitation rates. It also allows for legal encounter estimates for stock and age combinations that do not have base-period exploitation rates because of the base-period minimum size limit restriction. This adds an important element of realism because there are stock-age combinations that would not have appeared in legal encounters under base period conditions, but may under the new limit. Importantly, this change also has the potential to produce modeling results that may otherwise seem counterintuitive (e.g., exploitation rate reductions for key stocks), as it allows for fishery quotas to be filled with stock-age combinations that were previously sublegal, thereby providing relief for others.

When the new size limit is greater than the base-period size limit, the difference in legal encounters between the new size limit and the base-period size limit becomes sublegal encounters. This encounter difference is added to the calculated sublegal encounters from the base-period size limit to get total sublegal encounters. The difference in legal encounters is used in this case because base-period CWT recoveries can be used to estimate an actual observed difference.

When New Size Limit is Less Than Base-Period Size Limit:

$BaseSizeLimitSublegalMortality_{s,a,f,t} = SubER_{s,a,f,t} * BaseSubLegalPop_{s,a,t} * RelRate_{f,t} * FishScalar_{f,t}$

$NewSizeLimitSublegalMortality_{s,a,f,t} = SubER_{s,a,f,t} * NewSubLegalPop_{s,a,t} * RelRate_{f,t} * FishScalar_{f,t}$

$BaseSizeLimitSubEncounters_{s,a,f,t} = BaseSizeLimitSublegalMortality_{s,a,f,t}/RelRate_{f,t}$

$NewSizeLimitSubEncounters_{s,a,f,t} = NewSizeLimitSublegalMortality_{s,a,f,t}/RelRate_{f,t}$

$SublegalEncounterDiff_{s,a,f,t} = BaseSizeLimitSubEncounters_{s,a,f,t} - NewSizeLimitSubEncounters_{s,a,f,t}$

$BaseSizeLimitLegalEncounters_{s,a,f,t} = Cohort_{s,a,t} * BPER_{s,a,f,t} * FishScalar_{f,t} * BasePV_{s,a,t} * SHRS_{s,f,t}$

$$\boxed{\mathbf{NewLegalEncounters_{s,a,f,t} = BaseSizeLimitLegalEncounters_{s,a,f,t} + SublegalEncounterDiff_{s,a,f,t}}}$$

When New Size Limit is Greater Than Base-Period Size Limit:

$NewSizeLimitLegalEncounters_{s,a,f,t} = Cohort_{s,a,t} * BPER_{s,a,f,t} * FishScalar_{f,t} * NewPV_{s,a,t} * SHRS_{s,f,t}$

$LegalEncounterDiff_{s,a,f,t} = BaseSizeLimitLegalEncounters_{s,a,f,t} - NewSizeLimitSubEncounters_{s,a,f,t}$

$$\boxed{\mathbf{NewSublegalEncounters_{s,a,f,t} = BaseSizeLimitSubEncounters_{s,a,f,t} + LegalEncounterDiff_{s,a,f,t}}}$$

Where:
$BaseSubLegalPop_{s,a,t}$ = Sublegal Population at Base Period Size Limit by Stock, Age, And Time Step
$NewSubLegalPop_{s,a,t}$ = Sublegal Population at New Size Limit by Stock, Age, And Time Step
$BasePV_{s,a,t}$ = Base Period Proportion Vulnerable by Stock, Age, and Time Step
$NewPV_{s,a,t}$ = Proportion Vulnerable by Stock, Age, and Time Step under new size limit regulation
$SHRS_{s,f,t}$ = Stock Specific Exploitation Rate Scalar by Fishery and Time Step (default = 1)

The size limit modeling approach proposed for use during 2014 preseason would follow the methods outlined above, with one important difference. The algorithm's implementation will no longer hinge upon whether a given fishery's size limit differs from what was in effect during the base period, a departure in methodology facilitated by the recalibration of sublegal encounter rates to those observed under recent minimum size limits (PFMC 2013). Thus, the computations required to maintain constant encounters when size limits are increased or decreased will reference the size limit(s) in effect during the years used to update the sublegal encounter rates.

Results

FRAM validation runs for 2003 to 2010 fishing years were adjusted to produce updated sublegal/legal ratios. All fisheries in these model runs were converted to scalar fisheries (rate based fisheries) in order to prevent fixed (quota) fishery inputs from interfering with the evaluation of new size limit regulations. Results of these model runs were reported in "Incorporating Recent Empirical Information on Sublegal Encounters into FRAM Modeling" (PFMC, 2013). These runs were then used to model size limit changes with the new size limit methodology described here. Size limits for Puget Sound marine sport fisheries (mark-selective and nonselective) were altered from 22 in. total length (520 mm fork length, the modeled FRAM value) to 20 in. total length (480 mm fork length, the modeled FRAM value). When the new size limit is smaller than the reference size limit, the size limit correction adjusts legal encounters by the difference in sublegal encounters between a run at reference size limits and a run at new size limit. The size limit correction produces encounters at 20 in. that closely match the number of encounters at 22 inches. The sum of the sublegal and legal Chinook should be identical. Small differences are due to time step effects and rounding issues in FRAM (Tables 2-3).

Table 2. Comparison of FRAM Encounters at 22 in. and 20 in. Size Limits in the Summer (Time 3)

Average Encounters (2003-2010) Time 3

	22"			20"		
Area	Sub Enc	Leg Enc	S/L Ratio	Sub Enc	Leg Enc	S/L Ratio
7	1188	1980	0.600	1019	2147	0.475
5	3816	4034	0.946	3395	4449	0.763
8.1/8.2	0	0		0	0	
9	3816	4034	0.946	3395	4449	0.763
6	75	2212	0.034	66	2220	0.030
10	2218	1813	1.223	1967	2062	0.954
11	4898	7652	0.640	4421	8118	0.545
12	2058	1213	1.696	1783	1484	1.202
13	2407	1633	1.474	2230	1807	1.234

Figure 4. FRAM Chinook Encounters of Sublegals and Legals in Puget Sound Marine Sport Fishery Areas at 22 inch and 20 inch Size Limits in the Summer (Time 3)

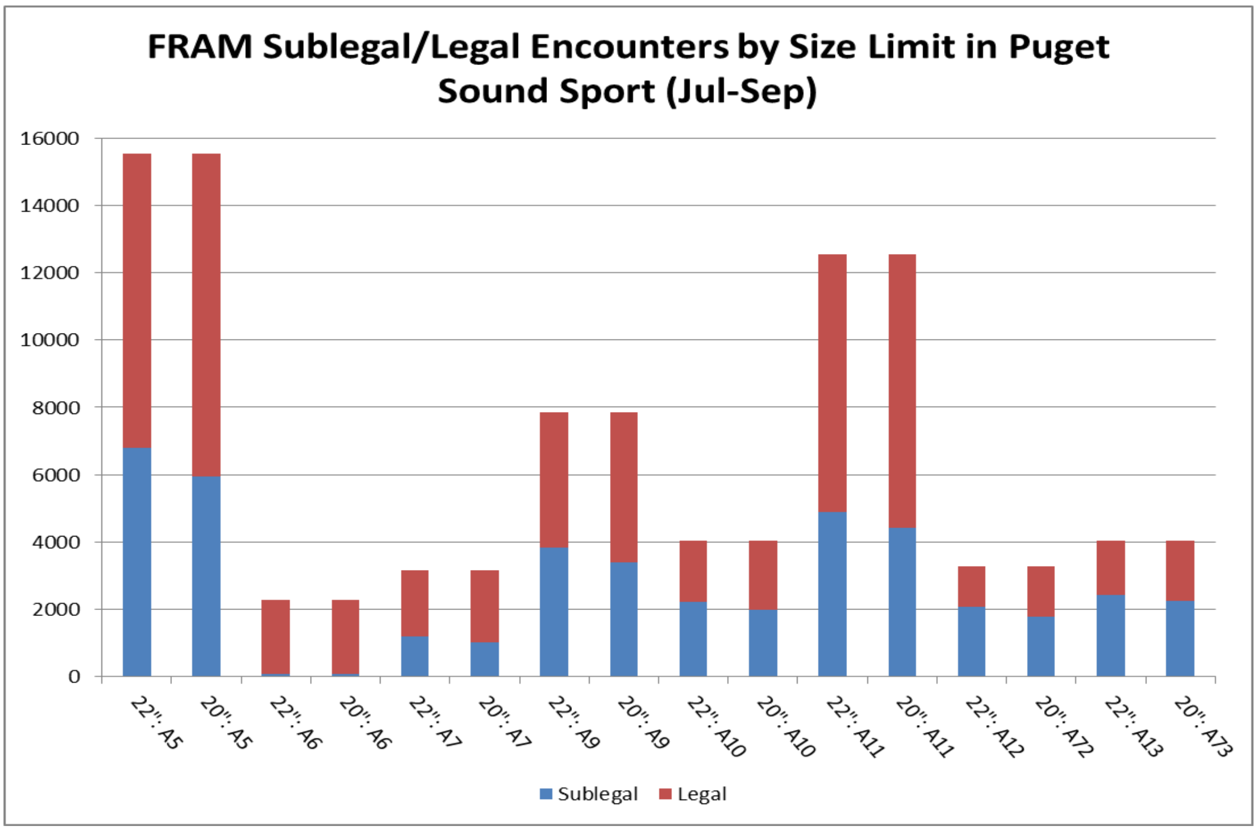
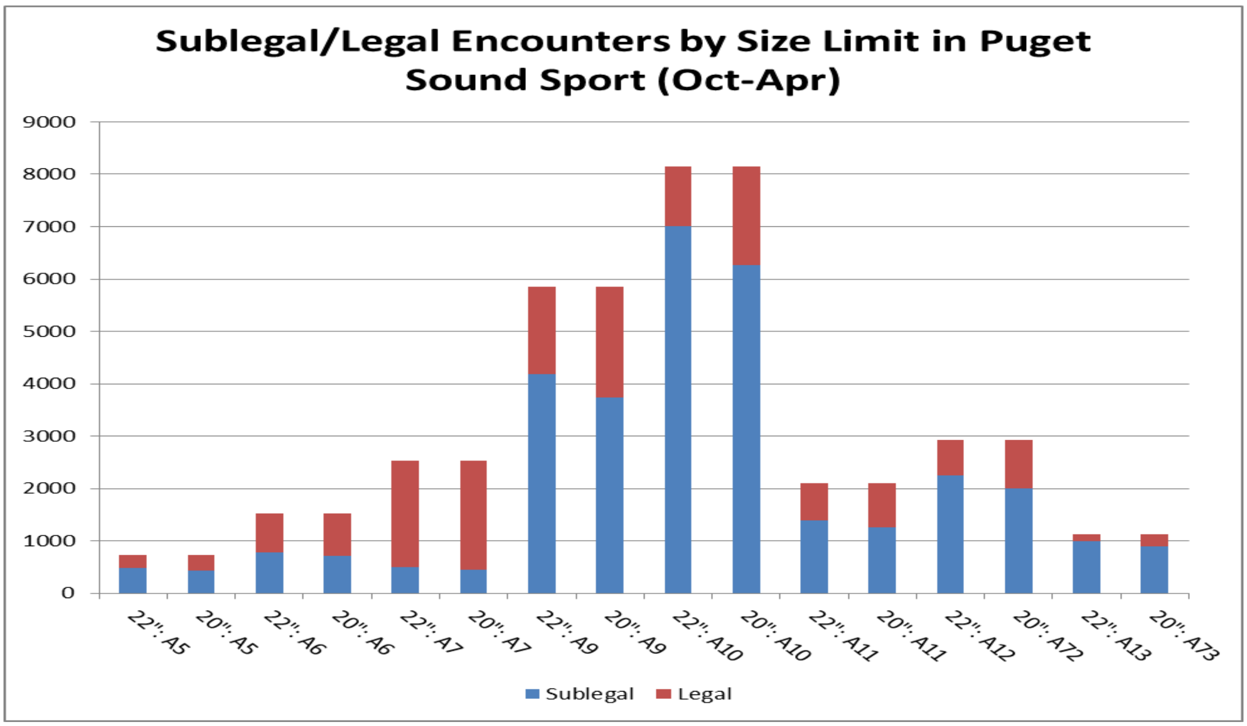


Table 3. Comparison of FRAM Encounters at 22 in. and 20 in. Size Limits in the Winter (Time 4)

Average Encounters (2003-2010) Time 4

Area	22" Sub Enc	22" Leg Enc	22" S/L Ratio	20" Sub Enc	20" Leg Enc	20" S/L Ratio
7	494	2041	0.242	442	2089	0.211
5	4185	1663	2.517	3745	2099	1.784
8.1/8.2	6103	1673	3.648	5459	2316	2.357
9	4185	1663	2.517	3745	2099	1.784
6	787	744	1.058	705	824	0.856
10	7006	1148	6.104	6258	1895	3.303
11	1397	712	1.963	1251	858	1.458
12	2255	681	3.313	2010	924	2.176
13	1002	119	8.393	898	224	4.011

Figure 5. FRAM Chinook Encounters of Sublegals and Legals in Puget Sound Marine Sport Fishery Areas at 22 inch and 20 inch Size Limits in the Winter (Time 4)

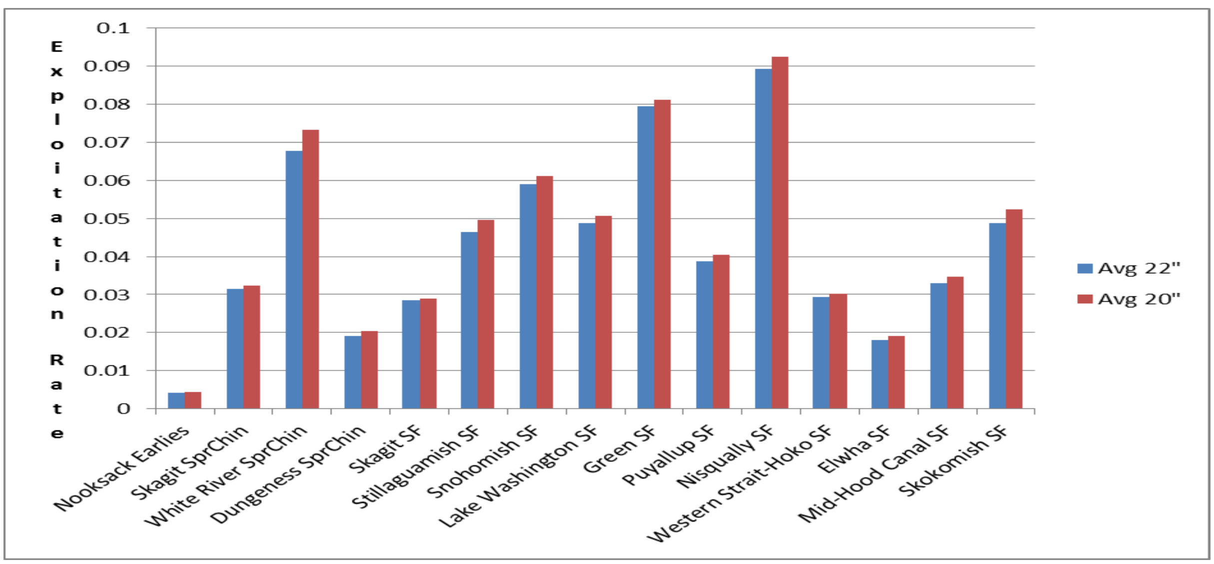


Reductions in size limits, particularly in non-selective fisheries, result in increases in exploitation rates (more fish are landed). Exploitation rate increases are typically quite small. The average exploitation rate increase for a change in size limit from 22 in. to 20 in. was 0.19% and ranged from 0.014% to 0.54% (Table 4, Figure 6).

Table 4. 2003-10 Average Exploitation Rates in Puget Sound Marine Sport at 22 in. and 20 in. Size Limits

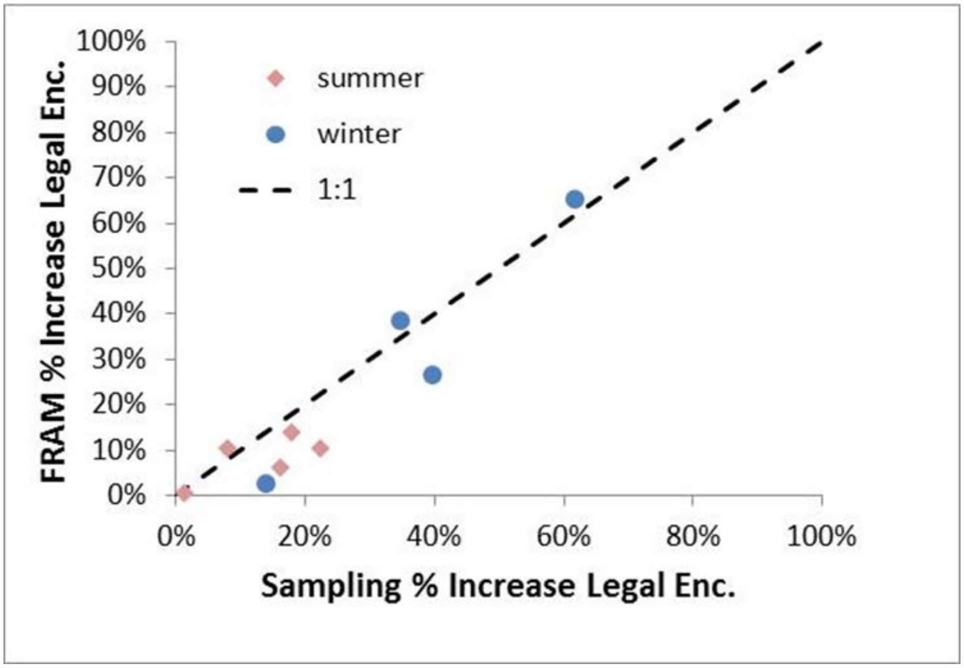
	2003-2010			
Puget Sound Chinook Stocks	**Avg 22"**	**Avg 20"**	**Avg Relative Increase**	**Avg Absolute Increase**
Spring/Early:				
Nooksack (n)	0.424%	0.438%	3.4%	0.014%
Skagit (n)	3.139%	3.230%	2.9%	0.091%
White	6.772%	7.316%	8.0%	0.543%
Dungeness	1.918%	2.034%	6.0%	0.115%
Summer/Fall:				
Skagit	2.860%	2.892%	1.1%	0.032%
Stillaguamish (n)	4.648%	4.962%	6.7%	0.314%
Snohomish (n)	5.900%	6.102%	3.4%	0.202%
Lake Wa. (Cedar R.)	4.878%	5.054%	3.6%	0.175%
Green	7.942%	8.113%	2.2%	0.171%
Puyallup	3.875%	4.051%	4.5%	0.176%
Nisqually	8.921%	9.244%	3.6%	0.323%
Western Strait-Hoko	2.938%	3.013%	2.6%	0.075%
Elwha	1.808%	1.914%	5.8%	0.105%
Mid-Hood Canal tribs. (n)	3.293%	3.465%	5.2%	0.172%
Skokomish	4.883%	5.236%	7.2%	0.353%

Figure 6. 2003-10 Average Exploitation Rates in Puget Sound Marine Sport at 22 in. and 20 in. Size Limits



In addition to verifying that the size limit correction held encounters constant and quantifying its effect on total ERs, we evaluated the accuracy of model-projected increases in total legal encounters at the fishery level. Length-frequency data from marine sport test fisheries were used to quantify the number of legal and sublegal Chinook encountered relative to 22 in. and 20 in. limits, and the corresponding relative increase in legal encounters that might be expected with the size limit reduction. The sampling data projected increase in legal encounters with a size limit decrease corresponds well with FRAM estimates (Figure 7). The average increase in legal encounters for the summer period is 8% using FRAM and 13% using sampling data. The average increase in the winter period is 33% using FRAM and 38% using sampling data.

Figure 7. FRAM and Sampling Data Estimates of the Increase in Legal Encounters when Size Limit Changes from 22" to 20"



Discussion

Considerations and Issues Related to Size Limit Changes

FRAM has several modeling constants that are unique to sublegal and legal encounters. Since sublegal/legal status is determined by the size limit, a change in the size limit will cause a change in the designation for Chinook between the old and the new size limit and consequently a change in the rates that are unique to either sublegal or legal size fish. Thus, a modeling correction was needed in order to hold encounters constant across alternative minimum size limit scenarios, but it also affects other modeling parameters.

Drop-Off

Drop-off results when a fish is hooked, but lost before it is brought onboard or onshore. Drop-off mortality is computed as 5% of the legal encounters. When the size limit is decreased, legal encounters increase, resulting in an increase of drop-off mortality. The size limit correction does not address this issue. However, the increase in mortality is considered negligible and in the case of legal unmarked fish released in mark selective fisheries helps to compensate for a potential under-estimate in mortality (see next paragraph).

Release Mortality

The release mortality in Puget Sound marine sport fisheries is 10% for legal Chinook and 20% for sublegal Chinook. In FRAM, each legal fish encountered is landed in a non-selective fishery. Differing release mortality rates can become an issue in mark-selective fisheries where all unmarked fish are required to be released (legal and sublegal). Because the legal release mortality is smaller than the sublegal release mortality, fish between 22” and 20” will experience a lower release mortality rate when the size limit is reduced even though their fate is exactly the same (release in MSF). The size limit correction does not address this issue. Size limits have changed numerous times for many fisheries since the base period and have never resulted in adjustments to mortality rates such as these. The size limit change most likely to be considered for 2014 is relatively small (2” reduction) and for Puget Sound sport fisheries only, where a 20” size limit has existed previously. The studies used to develop the release mortality rates did not focus on size definitions of salmon (“A Review of Recent Studies of Hooking Mortality…”). Release mortality estimates are commonly considered to be rough estimates and do not lend themselves to differentiation of small changes in size limit.

Additionally, when unmarked fish between 20” and 22” inches get reassigned to “legal” status they also experience a 5% drop-off mortality and a variable unmarked retained rate. Some of legal unmarked fish encountered are mistakenly retained in mark-selective fisheries. In the most recent FRAM model these rates varied between 1% and 8% depending on fishery and time step. At an unmarked retained rate of 5.56%, effective legal and sublegal mortality rates are equal, resulting in constant mortality estimates for runs with different size limits. Thus, while reclassifying a fish from sublegal to legal introduces a lower release mortality rate, which may be of concern in ESA-related evaluations, there are compensating mechanisms that help to keep the realized mortality rate approximately constant (Table 5).

Table 5. Example of Sublegal and Legal Release Mortality Rates as a Function of % Unmarked Retained

UM Retained	0%	3%	6%	9%	12%
Drop-Off	5%	5%	5%	5%	5%
Legal RelMort	10%	10%	10%	10%	10%
Sublegal RelMort	20%	20%	20%	20%	20%
Effective Rate Legal	15%	17.7%	20.4%	23.1%	25.8%
Effective Rate Sublegal	20%	20%	20%	20%	20%

Mark Release Rate

A portion of the legal marked fish encountered in a mark-selective fishery is voluntarily released by anglers. Currently FRAM assigns a 13% release rate to legal marked fish encountered. It could be argued that this rate might increase if the size limit were to decrease, because a greater number of smaller and potentially less desirable fish would be legal. Again, the size limit correction does not address this issue, but data collected from mark-selective fisheries at new size limits would be analyzed post-season. If the data reveal an increase in the mark-release rate or some underlying relationship between mark release rate and fish size, this modeling parameter would be adjusted in subsequent model runs.

Conclusion

The biggest improvement of the new method is that an “arbitrary” change in size limit no longer causes fluctuations in total fishery encounters. It allows the model to function as initially intended and provides an easy to apply framework for modeling size limit changes during the hectic preseason management period. The new method, when applied to updated sublegal encounters (PFMC 2013) produces logical changes in exploitation rates and landed mortalities that agree fairly well with field data. On average, landed mortalities are lower using FRAM than using estimates from field data. While the differences are generally small, it may be desirable for key Puget Sound sport fisheries to “pad” FRAM’s estimates of sublegal encounters to meet or exceed field estimates. If necessary, the data collected from these new fisheries could be used to make adjustments to sublegal/legal ratios for future modeling as described in PFMC 2013.

The MEW is in the process of devising a new FRAM base period. For this base period, recent data will be analyzed with regard to the relationship between legal and sublegal encounters in order to update FRAM’s sublegal encounter rates. Once these rates are updated and calibrated to recent size limits, adjustments to sublegal encounters will no longer be necessary. For this new base period, modelers will also evaluate current procedures for assigning stock and age composition to sublegal encounters and methods for modeling alternative size limits.
Thus, the corrected size limit algorithms presented here and proposed for use in 2014 pre-season modeling would be a stop-gap approach until a new Chinook FRAM calibration allows incorporation of new size limit algorithms.

References

Pacific Fishery Management Council (PFMC). October 2008. Fishery Regulation Assessment Model (FRAM) – Technical Documentation for Coho and Chinook. Pacific Fishery Management Council, Salmon Document Library

Pacific Fishery Management Council (PFMC). October 2008. Fishery Regulation Assessment Model (FRAM) – Base Data Development. Pacific Fishery Management Council, Salmon Document Library

Pacific Fishery Management Council (PFMC). November 2012 C3a Attachment 5. Review of Modifications to Chinook FRAM Size Limit Algorithms Implemented to Allow Evaluation of Size Limit Changes. Pacific Fishery Management Council, Briefing Book

Pacific Fishery Management Council (PFMC). November 13. Incorporating Recent Empirical Information on Sublegal Encounters into FRAM Modeling. Pacific Fishery Management Council, Briefing Book

NWIFC, Puget Sound Treaty Tribes, and WDFW. August, 1993. “A Review of Recent Studies of Hooking Mortality for Chinook and Coho Salmon with Recommendations for Fishery Management and Future Research”

Appendix

Appendix Table 1. Base Period and Current Size Limits by Fishery (converted to fork length in millimeters).

Fishery	Base Period				Current FRAM			
Fishery	Time 1	Time 2	Time 3	Time 4	Time 1	Time 2	Time 3	Time 4
SEAK Troll	670	670	670	670	670	670	670	670
SEAK Net	100	100	100	100	****	100	100	****
SEAK Sport	670	670	670	670	670	670	670	670
N/C BC Net	100	100	100	100	****	100	100	****
WCVI Net	100	100	100	100	100	100	100	100
GS Net	100	100	100	100	100	100	100	100
Canada JDF Net	100	100	100	100	100	****	100	100
Outside BC Sport	300	300	300	300	300	300	300	300
N/C BC Troll	620	620	620	620	670	670	670	670
WCVI Troll	620	620	620	620	550	550	550	550
WCVI Sport	620	620	620	620	600	600	600	600
GS Troll	480	480	480	480	620	620	620	620
No GS Sport	430	430	430	430	620	620	620	620
So GS Sport	430	430	430	430	620	620	620	620
BC JDF Sport	430	430	430	430	620	620	620	620
NT Area 3:4:4B Troll	670	670	670	670	****	670	670	****
T Area 3:4:4B Troll	570	570	570	570	570	570	570	570
NT Area 3:4 Sport	570	570	570	570	****	570	570	****
N Wash. Coastal Net	100	100	100	100	****	100	100	****
NT Area 2 Troll	670	670	670	670	****	670	670	****
T Area 2 Troll	670	670	670	670	****	570	570	****
NT Area 2 Sport	570	570	570	570	****	570	570	****
NT G. Harbor Net	100	100	100	100	****	****	100	****
T G. Harbor Net	100	100	100	100	****	****	100	****
Willapa Bay Net	100	100	100	100	****	****	100	****
Area 1 Troll	670	670	670	670	****	670	670	****
Area 1 Sport	570	570	570	570	****	570	570	****
Columbia River Net	100	100	100	100	100	****	100	100
Buoy 10 Sport	570	570	570	570	****	****	570	****
Central OR Troll	620	620	620	620	640	670	670	640
Central OR Sport	520	520	520	520	570	570	570	570

KMZ Troll	620	620	620	620	640	670	670	670
KMZ Sport	520	520	520	520	570	570	570	570
S. Calif. Troll	620	620	620	620	620	670	670	620
S. Calif.Sport	520	520	520	520	480	570	570	480
NT Area 7 Sport	480	480	480	480	520	520	520	520
NT Area 6A:7:7A Net	100	100	100	100	100	****	100	100
T Area 6A:7:7A Net	100	100	100	100	100	****	100	100
NT Area 7B-7D Net	100	100	100	100	100	****	100	100
T Area 7B-7D Net	100	100	100	100	100	****	100	100
T JDF Troll	520	520	520	520	520	520	520	520
NT Area 5 Sport	480	480	480	480	520	520	520	520
NT JDF Net	100	100	100	100	100	****	100	100
T JDF Net	100	100	100	100	100	100	100	100
NT Area 8-1 Sport	480	480	480	480	520	520	520	520
NT Skagit Net	100	100	100	100	100	****	100	100
T Skagit Net	100	100	100	100	100	100	100	100
NT Area 8D Sport	480	480	480	480	****	****	520	****
NT St/Snohomish Net	100	100	100	100	100	****	100	100
T St/Snohomish Net	100	100	100	100	100	100	100	100
NT Tulalip Bay Net	100	100	100	100	100	****	100	100
T Tulalip Bay Net	100	100	100	100	100	****	100	100
NT Area 9 Sport	480	480	480	480	520	520	520	520
NT Area 6 Sport	100	100	100	100	520	520	520	520
T Area 6B:9 Net	100	100	100	100	520	****	520	520
NT Area 10 Sport	480	480	480	480	520	520	520	520
NT Area 11 Sport	480	480	480	480	520	520	520	520
NT Area 10:11 Net	100	100	100	100	100	****	100	100
T Area 10:11 Net	100	100	100	100	100	****	100	100
NT Area 10A Sport	480	480	480	480	520	****	520	520
T Area 10A Net	100	100	100	100	520	****	520	520
NT Area 10E Sport	100	100	100	100	520	****	520	520
T Area 10E Net	100	100	100	100	520	****	520	520
NT Area 12 Sport	480	480	480	480	520	520	520	520
NT Hood Canal Net	100	100	100	100	100	****	100	100
T Hood Canal Net	100	100	100	100	100	****	100	100
NT Area 13 Sport	480	480	480	480	520	520	520	520
NT SPS Net	100	100	100	100	100	****	100	100
T SPS Net	100	100	100	100	100	****	100	100
NT Area 13A Net	100	100	100	100	100	****	100	100
T Area 13A Net	100	100	100	100	100	****	100	100
Freshwater Sport	100	100	100	100	100	****	100	100

Freshwater Net	100	100	100	100	****	100	100	****

Appendix Tables 2-18. Sublegal and Legal Encounters at 22 in. and 20 in. Size Limits by Area, Time Step, and Year

Area 7 Sport Time 3

Year	22" Sub Enc	22" Leg Enc	22" S/L Ratio	20" Sub Enc	20" Leg Enc	20" S/L Ratio
2003	1252	2087	0.600	1055	2282	0.462
2004	811	1351	0.600	694	1467	0.473
2005	946	1577	0.600	832	1690	0.492
2006	1231	2052	0.600	1063	2219	0.479
2007	1732	2886	0.600	1525	3091	0.493
2008	1087	1811	0.600	907	1987	0.457
2009	1456	2426	0.600	1257	2622	0.479
2010	988	1646	0.600	817	1814	0.450

Area 7 Sport Time 4

Year	22" Sub Enc	22" Leg Enc	22" S/L Ratio	20" Sub Enc	20" Leg Enc	20" S/L Ratio
2003	227	938	0.242	203	960	0.212
2004	140	577	0.242	125	591	0.211
2005	270	1115	0.242	242	1142	0.211
2006	520	2147	0.242	464	2200	0.211
2007	576	2381	0.242	515	2435	0.212
2008	691	2857	0.242	618	2925	0.211
2009	635	2624	0.242	570	2684	0.212
2010	893	3689	0.242	796	3779	0.211

Area 5 Sport Time 3

Year	22" Sub Enc	22" Leg Enc	22" S/L Ratio	20" Sub Enc	20" Leg Enc	20" S/L Ratio
2003	7009	9055	0.774	5857	10203	0.574
2004	9215	11906	0.774	8032	13083	0.614
2005	3791	4898	0.774	3446	5241	0.657
2006	6006	7760	0.774	5477	8286	0.661
2007	4955	6402	0.774	4339	7017	0.618
2008	4659	6019	0.774	4068	6605	0.616
2009	9626	12438	0.774	8605	13453	0.640
2010	8996	11622	0.774	7811	12802	0.610

Area 5 Sport Time 4

Year	22" Sub Enc	22" Leg Enc	22" S/L Ratio	20" Sub Enc	20" Leg Enc	20" S/L Ratio
2003	612	319	1.920	549	382	1.438
2004	244	127	1.920	217	151	1.434
2005	344	179	1.920	308	214	1.440
2006	509	265	1.920	457	318	1.436
2007	346	180	1.920	310	217	1.431
2008	605	315	1.920	540	376	1.436
2009	758	395	1.920	681	472	1.444
2010	449	234	1.920	400	279	1.434

Area 8.1/8.2 Sport Time 4

Year	22" Sub Enc	22" Leg Enc	22" S/L Ratio	20" Sub Enc	20" Leg Enc	20" S/L Ratio
2003	5811	1593	3.648	5180	2221	2.333
2004	4720	1294	3.648	4214	1799	2.343
2005	7902	2166	3.648	7066	3001	2.354
2006	7122	1952	3.648	6378	2695	2.367
2007	10325	2830	3.648	9235	3917	2.358
2008	5117	1403	3.648	4582	1937	2.366
2009	6489	1779	3.648	5821	2446	2.380
2010	1338	367	3.648	1194	510	2.339

Area 9 Sport Time 3

Year	22" Sub Enc	22" Leg Enc	22" S/L Ratio	20" Sub Enc	20" Leg Enc	20" S/L Ratio
2003	0	0		0	0	
2004	0	0		0	0	
2005	0	0		0	0	
2006	0	0		0	0	
2007	9270	9799	0.946	8194	10860	0.755
2008	7932	8385	0.946	7031	9265	0.759
2009	4994	5279	0.946	4535	5730	0.791
2010	8335	8812	0.946	7399	9735	0.760

Area 9 Sport Time 4

Year	22" Sub Enc	22" Leg Enc	22" S/L	20" Sub	20" Leg	20" S/L

			Ratio	Enc	Enc	Ratio
2003	2784	1106	2.517	2488	1397	1.780
2004	3131	1244	2.517	2802	1573	1.781
2005	1744	693	2.517	1563	873	1.790
2006	7440	2956	2.517	6663	3729	1.787
2007	7315	2906	2.517	6534	3680	1.776
2008	3560	1414	2.517	3186	1787	1.783
2009	5865	2330	2.517	5258	2932	1.793
2010	1638	651	2.517	1465	823	1.781

Area 6 Sport Time 3

Year	22" Sub Enc	Leg Enc	S/L Ratio	20" Sub Enc	Leg Enc	S/L Ratio
2003	117	3435	0.034	98	3453	0.028
2004	93	2727	0.034	81	2737	0.030
2005	42	1233	0.034	38	1237	0.031
2006	28	819	0.034	25	820	0.031
2007	47	1378	0.034	41	1383	0.030
2008	39	1135	0.034	34	1141	0.030
2009	142	4163	0.034	127	4176	0.030
2010	95	2803	0.034	83	2815	0.029

Area 6 Sport Time 4

Year	22" Sub Enc	Leg Enc	S/L Ratio	20" Sub Enc	Leg Enc	S/L Ratio
2003	584	552	1.058	523	611	0.857
2004	328	310	1.058	293	343	0.855
2005	486	459	1.058	436	509	0.857
2006	1013	957	1.058	908	1062	0.855
2007	904	854	1.058	808	947	0.853
2008	751	710	1.058	674	788	0.856
2009	1363	1288	1.058	1223	1424	0.859
2010	868	820	1.058	776	908	0.854

Area 10 Sport Time 3

Year	22" Sub Enc	Leg Enc	S/L Ratio	20" Sub Enc	Leg Enc	S/L Ratio
2003	0	0		0	0	
2004	0	0		0	0	
2005	0	0		0	0	

2006	0	0		0	0	
2007	2855	2335	1.223	2492	2694	0.925
2008	2691	2200	1.223	2382	2504	0.951
2009	2755	2253	1.223	2495	2509	0.994
2010	9439	7718	1.223	8364	8788	0.952

Area 10 Sport Time 4

	22"			20"		
Year	Sub Enc	Leg Enc	S/L Ratio	Sub Enc	Leg Enc	S/L Ratio
2003	7075	1159	6.104	6323	1909	3.312
2004	4615	756	6.104	4129	1242	3.324
2005	3504	574	6.104	3144	934	3.366
2006	4334	710	6.104	3883	1162	3.343
2007	24321	3984	6.104	21667	6634	3.266
2008	6731	1103	6.104	6020	1812	3.322
2009	3764	617	6.104	3371	1006	3.351
2010	1705	279	6.104	1525	459	3.320

Area 11 Sport Time 3

	22"			20"		
Year	Sub Enc	Leg Enc	S/L Ratio	Sub Enc	Leg Enc	S/L Ratio
2003	5031	7861	0.640	4402	8474	0.519
2004	4155	6492	0.640	3759	6879	0.546
2005	3937	6150	0.640	3643	6439	0.566
2006	5149	8045	0.640	4785	8403	0.569
2007	9614	15023	0.640	8508	16107	0.528
2008	5922	9253	0.640	5363	9793	0.548
2009	2316	3619	0.640	2134	3798	0.562
2010	3057	4777	0.640	2777	5053	0.550

Area 11 Sport Time 4

	22"			20"		
Year	Sub Enc	Leg Enc	S/L Ratio	Sub Enc	Leg Enc	S/L Ratio
2003	1256	640	1.963	1123	772	1.454
2004	919	468	1.963	824	564	1.460
2005	1186	604	1.963	1063	726	1.466
2006	1991	1014	1.963	1787	1219	1.466
2007	2913	1484	1.963	2598	1798	1.445
2008	1033	526	1.963	925	633	1.463
2009	1389	708	1.963	1246	849	1.467

2010	489	249	1.963	438	299	1.461

Area 12 Sport Time 3

	22"			20"		
Year	Sub Enc	Leg Enc	S/L Ratio	Sub Enc	Leg Enc	S/L Ratio
2003	1582	933	1.696	1429	1082	1.321
2004	2647	1561	1.696	2346	1858	1.263
2005	3511	2070	1.696	2820	2755	1.023
2006	2439	1438	1.696	2017	1857	1.086
2007	3516	2073	1.696	3265	2319	1.408
2008	1206	711	1.696	1021	893	1.144
2009	960	566	1.696	859	665	1.292
2010	600	354	1.696	508	445	1.142

Area 12 Sport Time 4

	22"			20"		
Year	Sub Enc	Leg Enc	S/L Ratio	Sub Enc	Leg Enc	S/L Ratio
2003	1401	423	3.313	1254	570	2.199
2004	1266	382	3.313	1130	517	2.186
2005	1633	493	3.313	1442	684	2.109
2006	2448	739	3.313	2163	1022	2.117
2007	2296	693	3.313	2060	927	2.223
2008	2515	759	3.313	2239	1033	2.168
2009	4960	1497	3.313	4441	2013	2.207
2010	1517	458	3.313	1350	624	2.164

Area 13 Sport Time 3

	22"			20"		
Year	Sub Enc	Leg Enc	S/L Ratio	Sub Enc	Leg Enc	S/L Ratio
2003	2019	1370	1.474	1818	1566	1.161
2004	1599	1085	1.474	1477	1206	1.225
2005	2420	1642	1.474	2276	1784	1.275
2006	2862	1942	1.474	2713	2089	1.299
2007	5035	3416	1.474	4566	3876	1.178
2008	2299	1560	1.474	2143	1710	1.253
2009	1990	1350	1.474	1880	1459	1.288
2010	1032	700	1.474	969	763	1.270

Area 13 Sport Time 4

	22"	20"

Year	Sub Enc	Leg Enc	S/L Ratio	Sub Enc	Leg Enc	S/L Ratio
2003	571	68	8.393	513	129	3.970
2004	604	72	8.393	542	135	4.015
2005	1074	128	8.393	963	237	4.054
2006	2342	279	8.393	2094	515	4.068
2007	1956	233	8.393	1748	448	3.904
2008	1251	149	8.393	1124	278	4.049
2009	218	26	8.393	202	50	4.064
2010	0	0		0	0	

Expected future performance of abundance forecast models with application to Sacramento River fall Chinook salmon

Arliss J. Winship[a,b,*] Michael R. O'Farrell[b]
William H. Satterthwaite[b,c] Brian K. Wells[b]
Michael S. Mohr[b]

[a] Institute of Marine Sciences, University of California, Santa Cruz

[b] Fisheries Ecology Division, Southwest Fisheries Science Center,
National Marine Fisheries Service, NOAA, 110 Shaffer Road, Santa Cruz, CA 95060, USA

[c] Center for Stock Assessment Research, Applied Mathematics and Statistics,
University of California, Santa Cruz, CA 95064, USA

* Corresponding author

Current address: Biogeography Branch, Center for Coastal Monitoring and Assessment,
National Centers for Coastal Ocean Science, National Ocean Service, NOAA,
1305 East-West Hwy, SSMC-4, 9th Floor, Silver Spring, MD 20910, USA
Tel: +1-301-713-3028,
E-mail: arliss.winship@noaa.gov

September 13, 2013

Abstract

The management of Pacific salmon fisheries relies heavily on abundance forecasts, and there is continued interest in their improvement. Using Sacramento River fall Chinook salmon as a case study, we evaluated the scope for improving the current forecast approach that relates the Sacramento Index (SI; an index of adult age 3–5 ocean abundance) to jack (estimated age 2) spawning escapement from the previous year. Alternative models added effects of density dependence, local environmental conditions, the abundance of the previous cohort, and trends or autocorrelation in the jack-to-SI relationship. Forecast performance was assessed with two cross-validation frameworks allowing evaluation of bias, accuracy, the ability of the models to track trends in the SI, and the potential for forecast errors to be of sufficient magnitude to cause management errors. Several models achieved higher accuracy than the current model, but no single model performed best across all criteria, and substantial forecast error remained across all approaches considered. Models incorporating trends or temporal autocorrelation in the jack-to-SI relationship demonstrated potential for modest forecast improvements with relatively little additional model complexity.

Introduction

Management of Pacific salmon (*Oncorhynchus* spp.) along the west coast of North America relies heavily on annual abundance forecasts. Abundance forecasts for key stocks along the U.S. west coast are used to define annual catch limits and exploitation rate ceilings through the use of harvest control rules (PFMC, 2012a). These stock-specific limits to exploitation rates lead to constrained ocean fisheries through the practice of weak-stock management and are also used to configure terminal-area fisheries. Overforecasting of abundance results in higher allowable exploitation rates and the potential reduction of spawners to suboptimal levels. On the other hand, underforecasting of abundance results in lower allowable exploitation rates and foregone catch (Bocking and Peterman, 1988). Ideally, forecasts should be unbiased in the long term, be able to predict short-term variation in population abundance, and be able to track trends in population abundance. Despite their central role in salmon fishery management, many abundance forecasts have been characterized as relatively inaccurate (Adkison and Peterman, 2000) and a source of management uncertainty (Holt and Peterman, 2006).

In practice, many abundance forecast models currently used for salmon management are variants of the 'sibling model' (Peterman, 1982), where age-specific estimates of freshwater returns are used to forecast ocean abundance or freshwater returns of older members of the same cohort at a later time. Freshwater returns of salmon at early ages (i.e., at age 2) provide an indication of cohort strength as they have survived the high and variable mortality rates associated with early life and have effectively integrated the sources of mortality encountered up to that stage. Yet variation in sibling relationships can be substantial (Noakes et al., 1990), and a variety of factors could contribute to that variation. There has been interest in developing more complex abundance forecast models in an attempt to reduce forecast errors. Some of these models incorporate environmental and biotic variables along with salmon freshwater return data (e.g., Roth et al., 2007; Wang et al., 2009; Rupp et al., 2012; Burke et al., 2013). However, it is not yet clear whether incorporation of environmental or biotic variables into salmon forecast models result in substantial improvements in future forecast performance relative to simpler models (Haeseker et al., 2005). Methods and metrics used to assess future performance of abundance forecast models differ among studies, hence expected future forecast skill can be difficult to assess. Furthermore, it generally remains unclear whether the improvement in forecast performance would be large enough to improve harvest management (Walters, 1989).

The annual, pre-fishery forecast of the abundance index for Sacramento River fall Chinook salmon (SRFC) can have a strong effect on the configuration of ocean fisheries off California and Oregon, USA. SRFC are the largest contributing stock to the mixed-stock commercial and recreational fisheries in this area (O'Farrell et al., 2013), and the stock abundance was historically large enough that it did not constrain ocean fisheries. However, SRFC experienced a steep decline beginning in the early 2000s (Lindley et al., 2009), prompting the development of the Sacramento Index (SI), an index of adult (age 3–5) SRFC ocean abundance. Very low SI forecasts led to complete closures or heavily constrained ocean salmon fisheries off California and Oregon from 2008–2010.

Since its initial development in 2008, the SI has been forecast with a zero-intercept linear model with jack (estimated age-2) spawning escapement as the independent variable (e.g., see Figure II-2 in PFMC, 2013a). In most years, the data used to fit the SI forecast model were SI estimates from 1990 through the year prior to the forecast year and jack spawning escapement data from 1989 through two years prior to the forecast year. The SI was well forecast in 2008 but was overforecast from 2009–2012. In 2012, use of the status-quo forecast model and data range would have predicted a record value of the SI (approximately 2.2 million), but the Pacific Fishery Management Council's (PFMC) Salmon Technical Team did not view this forecast as credible and for this one year limited the SI data used for forecasting to the most recent three years (2009–2011), resulting in a much lower forecast (approximately 819,000 fish). Examined retrospectively, this adjustment to the data range was warranted; the SI in 2012 was approximately 618,000 fish (PFMC, 2013a).

The recent history of overforecasting the SI has led to several hypotheses regarding why the well-defined, linear jack-to-SI relationship for years 1990–2008 had apparently broken down. One leading hypothesis for the recent poor forecast performance was that the jack spawning escapement data, which only confer information about the age-3 cohort, would tend to overforecast the multi-cohort SI in situations when year class strength was increasing from one year to the next. Under such a scenario, the SI would be largely composed of the age-3 cohort, while past data used to fit the jack-to-SI relationship were composed of SI values where older age classes were more fully represented (PFMC, 2012b). Another hypothesis for the change in the jack-to-SI relationship was that a change in the average age-2 maturation rate had occurred, with myriad environmental and genetic explanations proposed for this shift. While it is not currently clear what mechanisms led to the recent history of overforecasting the SI, an investigation into alternative models and data for forecasting the SI is justified.

Using the SI as a case study, we evaluated a variety of salmon abundance forecast models and compared the performance of these models to the status quo approach. The alternative models included intercept-only models, models with jack spawning escapement variables, and models with both jack spawning escapement and environmental variables. The environmental variables considered were previously demonstrated to be related to growth and age at maturity for California Chinook salmon (Wells et al., 2007). The models covered linear and nonlinear functional relationships, temporal trends and autocorrelation in the jack-to-SI relationship, and multivariate statistical methodology. Performance was evaluated using two cross-validation procedures and several measures of forecast error. We judged a forecast model good if it produced unbiased, accurate out-of-sample forecasts that tracked trends in the SI. Translations of forecast errors into management errors, defined as allowing exploitation rates that would result in conservation errors (under-escapement) or fishery errors (foregone fishing opportunity), were used to further evaluate model performance. This multi-faceted approach to forecast evaluation was designed to provide realistic expectations for future performance.

Methods

Data

The SI in year t is calculated as the sum of three estimates: ocean harvest from the period between 1 September in year $t-1$ and 31 August in year t, river harvest in year t, and spawner escapement in year t, each derived from different data sources and methods as described in O'Farrell et al. (2013). We used SI values from 1983–2012 in our analysis (Fig. 1; PFMC, 2013a).

The jack data were estimates of the total number of age-2 spawners returning to natural areas and hatcheries each year. Various methods were used to derive these estimates (O'Farrell et al., 2013; PFMC, 2013b). Jack spawning escapement was estimated, in general, on the basis of a length threshold, and this threshold varied among sites and over time. We used jack data from 1981–2011 in our analysis (Fig. 1; PFMC, 2013b).

Eight local environmental variables were chosen (Table 1) for their potential to explain variability in the survival and maturation rates of fish in the ocean (Wells et al., 2007, 2008). The variables represented sea surface temperature, wind speed and direction, curl, strength and timing of upwelling, and sea level height off the coast of Central California (Fig. 2). The data for these environmental variables were obtained from publicly accessible online sources (Table 1). For each variable, except STI_39N, three average seasonal values were calculated for each year—spring (March–May), summer (June–August), and fall (September–November)—resulting in a total of 22 variables related to the environment. We assumed that the relationship between the SI in year t and the number of jacks in year $t-1$ was influenced by environmental conditions during year $t-1$, the period leading up to and around the time that age-2 fish either return to spawn or remain in the ocean. In other words, the SI in year t was assumed to be partially a function of the environment in year $t-1$. We analyzed environmental data from 1982–2011.

Models

We evaluated 13 models for forecasting the SI (Table 2). Two of these were intercept-only models (Models 1 and 6, the arithmetic and geometric means, respectively, of the SI time series), one was the model currently used to forecast the SI as a function of the number of jacks the previous year (Model 2), and the remaining 11 models were modifications or extensions of Model 2 that covered a range of functional relationships between the SI and previous numbers of jacks and environmental conditions.

Models 2–5 were zero-intercept models that assumed a proportional relationship between the SI and previous numbers of jacks. Models 7–13 were on the log scale with respect to the SI and the number of jacks, allowing for a nonlinear power relationship between these variables on the arithmetic scale that could capture density dependence in the jack-to-SI relationship (Peterman, 1981). Such density dependence could arise from density dependence in the maturation or survival rates, for example.

Models 2 and 7 assumed that the SI was a function of only the number of jacks the previous year. However, the SI indexes the ocean abundance of fish aged 3 and older, thereby representing fish from multiple cohorts. Only the age-3 component of the SI would belong to the same cohort as jacks from the previous year. Models 3 and 9 therefore assumed that the SI was a function of the number of jacks in the previous two years, thus incorporating additional information about the abundance of the next oldest cohort (i.e., the age-4 component of the SI).

Models 4 and 10 were analogous to Models 2 and 7, but in these models the expected ratio of the SI to the number of jacks the previous year was allowed to change over time following a relatively simple, smooth, nonlinear relationship (maximum 3-degree-of-freedom relationship over the 30-year study period). These models were intended to capture gradual changes in average maturation and/or survival rates over time arising from, for example, low-frequency environmental or food web variation. Model 8 also allowed for temporal changes in the expected ratio of the SI to the number of jacks the previous year through autocorrelation in residual errors.

Models 5 and 11–13 allowed environmental variables to modify the jack-to-SI relationship. Model 5 was linear on the arithmetic scale, and environmental effects were incorporated as interactions between the number of jacks the previous year and environmental variables. Model 11 was a multiple linear regression of the log-transformed SI and jack data with main effects of the untransformed environmental variables. To explore nonlinearity in the relationships between environmental variables and the ratio of the SI to the number of jacks we considered Model 12, a generalized additive model (e.g., Rupp et al., 2012) that was similar to Model 11, but whose environmental effects were allowed to be relatively simple smooth functions (≤ 2 degrees of freedom each). Model 13 was a partial least squares regression (PLSR; Geladi and Kowalski, 1986; Mevik and Wehrens, 2007) of log-transformed SI and jack data and untransformed environmental variables. Multivariate statistical techniques such as PLSR or principal component regression allow for the reformulation of explanatory variables as latent variables that are composites of the original explanatory variables, and these models are potentially more efficient for identifying important predictors from a complex set of numerous, often correlated environmental variables (Wells et al., 2008; Burke et al., 2013).

We considered different numbers of variables or latent variables in Models 5 and 11–13. For Models 5, 11, and 12 the number of jacks the previous year was always included and the remaining variables were selected based on the model with the lowest second-order Akaike Information Criterion (AIC_c; Burnham and Anderson, 2002) among all possible models with a given number of variables. We explored 1–6 variables for Models 5 and 11 (including jacks the previous year) and 1–5 variables for Model 12. All variables were included when fitting Model 13, but only 1–6 of the resulting latent variables were considered when predicting the SI.

Forecast performance

The forecast performance of the models was evaluated by comparing the observed SI time series to out-of-sample model predictions of the SI (Chatfield, 1996). Two cross-validation frameworks were used to derive out-of-sample predictions: leave-one-out and one-year-ahead. Under the leave-one-out framework, the data for a given year were withheld when fitting the model, then the fitted model was used to predict the SI for that year. Under the one-year-ahead framework, the model was fit to all of the data available prior to a given year, then the fitted model was used to predict the SI for that year. One-year-ahead predictions were made for 1995–2012. The one-year-ahead framework captured how the models would have been used in practice. The performance of Model 8 was only evaluated with the one-year-ahead framework.

For models that had variables selected on the basis of the data (Models 5, 11, and 12), variable selection was conducted using only the data that the model was fitted to, thereby excluding the out-of-sample data and accounting for model selection uncertainty (Chatfield, 1996; Francis, 2006). For comparison we also examined the forecast performance of these models when variables were selected on the basis of the entire dataset (i.e., the same variables were in the model for every prediction). We also examined the forecast performance of Models 5, 11, and 12 when predictions were averaged across all candidate sets of a given number of variables using Akaike weights derived from AIC_c (Burnham and Anderson, 2002).

Out-of-sample predictions from models of log-transformed data (Models 6–13) were adjusted before they were back-transformed to the arithmetic scale so that the predictions represented the expected SI (Beauchamp and Olson, 1973; Sprugel, 1983; Haeseker et al., 2005):

$$\widehat{\mathrm{SI}}_t = e^{\widehat{\log \mathrm{SI}}_t + 0.5\hat{\sigma}^2} \tag{1}$$

where

$$\hat{\sigma}^2 = \frac{\sum \hat{\epsilon}_t^2}{\mathrm{DF}} \quad , \tag{2}$$

$\widehat{\mathrm{SI}}_t$ is the out-of-sample predicted SI for year t, $\widehat{\log \mathrm{SI}}_t$ is the out-of-sample predicted SI on the log scale for year t, $\hat{\sigma}^2$ is the estimated variance of residual errors on the log scale based on the residuals of the model fitted to the sample data ($\hat{\epsilon}_t$), and DF is the number of residual degrees of freedom for the fitted model. For Model 8, the maximum likelihood estimate of the variance of innovation errors ($\hat{v}_t$) was used for $\hat{\sigma}^2$ in Eq. 1.

Six summary performance metrics were considered (Table 3) that reflected different aspects of forecast error (Zhou, 2003; Haeseker et al., 2005; Francis, 2006). Mean error (ME) and mean percent error (MPE) reflected directional bias in raw and relative forecast errors, respectively, with negative values indicating a tendency to overforecast and positive values a tendency to underforecast. Mean absolute error (MAE) and mean absolute percent error (MAPE) reflected overall forecast accuracy (sensu Walther and Moore, 2005) accounting for systematic bias and year-to-year variation. Root mean square error (RMSE) was a second measure of the absolute magnitude of raw errors, but was more sensitive to large errors than was MAE. Percent variance explained (PVE) was an expression of RMSE relative to the naive intercept-only model and reflected forecast skill. All performance metrics were calculated on the arithmetic scale for all models, and ME, MAE, RMSE, and PVE were also calculated on the log scale for models of log-transformed data (Models 6–13).

We focused on two of the summary metrics, ME and RMSE, on the arithmetic scale when comparing the performance of the alternative forecast models. We judged the forecasts from a model better if they were less biased (ME closer to zero) and more accurate (RMSE closer to zero). In addition to these summary performance metrics we assessed how well the forecasts from each model tracked trends in the SI, for example the recent increase since 2009.

Management performance

The management performance of the models was evaluated by comparing the allowable SRFC fishery exploitation rates specified by the observed and predicted SI time series. Each year the forecast SI is used to specify the allowable SRFC fishery exploitation rate via a harvest control rule (Fig. 3). The fishery exploitation rate (F) then corresponds to an expected spawning escapement of SI $\times$ $(1 - \mathrm{F})$. We considered two types of management errors related to conservation and fishing opportunity, each associated with threshold errors in the allowable exploitation rate (Fig. 3). A conservation error was deemed to occur when the SI was overforecast, and the allowable exploitation rate was high enough to result in under-escapement at a level $\leq$75% of the expected escapement given perfect knowledge of the SI. A fishing opportunity error was deemed to occur when the SI was underforecast and the allowable exploitation rate was <50% of the rate corresponding to the observed SI. While a fishing opportunity error could theoretically occur at any SI value, a conservation error as we defined it could not occur if the true SI was greater than about 300,000 because of the control rule's maximum allowable exploitation rate. The thresholds used to define management errors were chosen to be reasonable representations of the magnitude of errors that would likely concern fishery managers. The SRFC minimum stock size threshold, the spawner escapement level used to determine overfished status (PFMC, 2012a), is defined as 75% of the maximum sustainable yield spawner escapement. For this reason, we used the 75% escapement threshold to define a conservation error. For a fishery error, the 50% threshold was deemed to be a level that would have a clear impact on the amount of fishing opportunity in California and Oregon, and was chosen based on expert judgement.

Results

Forecast performance

The model with the best forecast performance differed between cross-validation frameworks and summary performance metrics (Fig. 4, Tables S1.1 and S1.2). The current management model (Model 2) had the ME closest to zero (least forecast bias) under leave-one-out cross validation excluding the intercept-only model (Model 1) and Model 5 with 6 variables. Under one-year-ahead cross validation several other models exhibited less forecast bias than did Model 2, with Models 8–10 being the least biased. Overall there was a tendency to overpredict the SI.

Excluding the intercept-only models, RMSE was generally greatest under the current management model (Model 2), but for Models 5 and 11–13 this result depended on the number of variables (Fig. 4, Tables S1.1 and S1.2). Models 4 and 10 had the two lowest RMSE under leave-one-out cross validation, and Model 8 had the lowest RMSE under one-year-ahead cross validation. There was substantial unexplained prediction error across all models with RMSE $\geq$250,000 and PVE $\leq$65%.

The models differed in their ability to track trends in the SI during specific time periods (Fig. 5). Under leave-one-out cross validation, the current management model (Model 2) overpredicted the SI at the start of the time series (1983) and predicted a subsequent decrease in the SI through 1987, opposite to the trend in the observed SI during this period. These predictions were driven by a decrease in the number of jacks from 1982–1986. During the most recent four years (2009–2012) Model 2 predicted a greater increase in the SI than was observed, culminating in a very high overprediction for 2012 under both cross-validation frameworks. These predictions were driven by an increase in the number of jacks from 2008–2011. Models that accounted for the number of jacks two years previous (Models 3 and 9) made qualitatively similar predictions early in the time series, but overpredicted somewhat less during the most recent years. Models 4 and 10 overpredicted less at the start of the time series, and much less at the end, because these models allowed for a smooth change over time in the ratio of the SI to the number of jacks the previous year, which was estimated to first increase and then decrease (Fig. 6). Model 8, with its estimated positive autocorrelation in residual errors, also performed well from 2009–2012. Models with environmental variables (Models 5 and 11–13) had more variable SI predictions at the start of the time series, and some of these models with certain numbers of variables (e.g., Model 13 with 3 latent variables; Fig. 5) performed better from 2009–2012 than Model 2. Some years had a large influence on certain summary performance metrics. For example, RMSE was the most sensitive to large errors, so it was more indicative of performance in years when the SI was greatly overpredicted (e.g., 2005 and 2012).

While models with environmental variables (Models 5 and 11–13) were generally able to achieve a lower RMSE than was the current management model, in many cases simpler models had similar or better performance (Fig. 4, Tables S1.1 and S1.2). There were no consistent trends in performance with increasing numbers of variables in these models. Models 5, 11, and 12 were sometimes able to achieve similar performance to the partial least squares regression model (Model 13). Model averaging across candidate models with a given number of variables did not result in consistently better or worse performance. Forecast performance tended to be better, in some cases much better, when variables were selected on the basis of the entire dataset rather than on the basis of only the training data within the cross-validation framework. Thus, accounting for model selection uncertainty decreased apparent forecast performance. There were similarities and differences in the important variables among Models 5, 11, and 12 (Fig. 7; AIC_c-based 'relative variable importance' as defined by Burnham and Anderson, 2002). The relative importance of variables varied when individual years were excluded from the analysis under leave-one-out cross validation, but there was some consistency in the important variables across years. For example, in versions of these models with 4 variables, the number of jacks two years previous and sea level height during the previous fall generally had high relative importance. The important variables frequently changed over time under one-year-ahead cross validation, with some exceptions. For example, sea level height the previous fall was consistently important in 4-variable models.

Management performance

Management errors occurred from 2007 onward, with very few exceptions (Fig. 8). Prior to 2007 the SI was always greater than the threshold at which a conservation error could occur (about 300,000; Fig. 3). Also, prior to 2007 the SI was usually much higher than the threshold at which the harvest control rule specifies a reduction in the allowable exploitation rate, so only a large underprediction could have caused a fishing opportunity management error. Between 2007 and 2011 the SI was below these thresholds creating more opportunity for management errors. Conservation errors occurred with multiple models from 2007–2011. The current management model resulted in a conservation error in 2010 under leave-one-out cross validation and in 2011 under both cross-validation frameworks. In fact, a conservation error occurred in 2011 with all models under both cross-validation frameworks. The frequently large overprediction of the SI in 2012 did not result in conservation errors because the observed SI was above the threshold corresponding to the maximum allowable exploitation rate. Fishing opportunity errors occurred with multiple models in 2007 and 2010. Because the number of management errors with each model was low (Table S1.3), it was difficult to draw conclusions about the relative management performance of the models.

Discussion

A suite of salmon abundance forecast models, with a wide range of complexity, were subjected to a set of rigorous tests and evaluations in an attempt to provide realistic expectations for future performance. Model selection, when relevant, was conducted with training data only. Performance was evaluated by (1) examining metrics that summarized forecast bias and accuracy calculated over all years under two cross-validation frameworks (Fig. 4), (2) visually inspecting the ability of the models to track trends in the SI at different points in time (Fig. 5), and (3) quantifying the interaction between forecast performance and a harvest control rule used for annual fishery management (Fig. 8). Our results suggest that the performance of individual models varied across forecast evaluation methods, complicating the selection of a single best model. While these results are derived from the specific case study of the SI, the findings are similar to those of other salmon forecast analyses (e.g., Haeseker et al., 2005) and are germane to other forecast scenarios.

Inference about future forecast performance based on summary metrics alone should be cautious. A comparison of Model 13 (with 3 latent variables) and Model 2 provides an example where a single year of data greatly influenced perceived relative forecast accuracy. Model 13 exhibited a lower RMSE under both cross-validation frameworks when compared to Model 2. However, much of this performance differential was attributable to particularly high overforecasts by Model 2 in a few individual years. For example under one-year-ahead cross validation, Model 13 had a RMSE of 310,797, while Model 2 had a RMSE of 480,748. Omitting 2012 from the analysis resulted in a RMSE of 316,587 for Model 13 and 349,868 for Model 2. RMSE under leave-one-out cross validation also differed little between these models when 2012 was omitted. As another example, RMSE under one-year-ahead cross validation was lower for Model 10 than for Model 2, but when 2012 was excluded the reverse was true. These results illustrate the sensitivity of the summary performance metrics, and RMSE in particular, to a single large deviation between prediction and observation.

Models in which environmental variables modified the relationship between the SI and the number of jacks in previous years were generally able to achieve better performance than the current forecast model. However, the environmental variables that appeared important sometimes changed depending on the model structure and the data that were used to fit the model. As one-year-ahead cross validation indicated, the variables selected in Models 5 and 11–12 would have changed over time had these models been used for forecasting during the study period. A supplementary analysis (unpublished) where these models were fitted over time using a moving data window or down-weighting more distant data resulted in even more frequent changes in the variables that appeared important. The results presented here do not provide compelling evidence for stable, specific functional relationships between the environmental variables that we examined and the jack-to-SI relationship. Sampling error and collinearity among environmental variables almost certainly contributed to some of the apparent changes in variable importance, the former of which would be expected to decrease with a longer time series. It is also likely that the functional relationships were more complex than our models allowed for (e.g., continuous or discrete temporal changes in the strength of the relationships).

Numerous studies have attempted to model and forecast Pacific salmon population abundance, productivity, and vital rates using environmental variables (e.g., Kope and Botsford, 1990; Adkison and Peterman, 2000; Logerwell et al., 2003; Scheuerell and Williams, 2005; Haeseker et al., 2008; Watters and Bessey, 2008; Fujiwara and Mohr, 2009; Wang et al., 2009; Rogers and Schindler, 2011; Wells et al., 2012; Rupp et al., 2012; Burke et al., 2013). Conditions in the freshwater and marine environments certainly affect salmon growth and survival (Quinn, 2005; Wells et al., 2007; Woodson et al., in press), thereby influencing productivity (Beamish and Mahnken, 2001) and transition rates between life stages (Morita and Fukuwaka, 2006; Snover et al., 2006; Satterthwaite et al., 2010). However, identifying and quantifying functional relationships between specific environmental variables and fish population dynamics are very difficult tasks. Any number of environmental variables can be measured and will exhibit variation over a range of spatial and temporal scales, possibly covarying with each other. Statistically significant correlations between population dynamics and some of these variables are an inevitability, regardless of true functional relationships (Walters and Collie, 1988; Megrey et al., 2005). Furthermore, functional relationships between environmental variables and population dynamics are likely to be highly complex given the chains of mechanisms and interactions involved (Deyle et al., 2013). Forecasting future dynamics on the basis of the environment entails further uncertainty about the stability of functional relationships over time. Because of these difficulties, many models relating fish population dynamics to environmental variables have not withstood the test of time (Myers, 1998; Keyl and Wolff, 2008). For example, Rupp et al. (2012) described how select environmental variables used in forecasts for Oregon Coastal Natural coho salmon (*O. kisutch*) had historically accounted for a large amount of variability in abundance, but ultimately became unreliable predictors.

Models 4, 8, and 10 allowed for changes over time in the ratio of the SI to the number of jacks the previous year, but modelled those changes relatively more phenomenologically, rather than functionally relating the changes to jacks two years previous or to environmental variables. The net effect of factors influencing the ratio was implicitly modelled as a gradual change in the expected ratio over time (Models 4 and 10) or as temporally autocorrelated deviations of the SI from the expected SI (Model 8). One would expect age structure and environmental conditions, which are correlated at time scales greater than one year (Stommel, 1963; Haury et al., 1978; Francis and Hare, 1994), to induce serially correlated changes in the jack-to-SI relationship. The forecast performance of these models was often among the best, sometimes better than that of models that incorporated the effects of age structure and environmental conditions explicitly. These models performed particularly well near the end of the study period. They were reasonably flexible yet relatively parsimonious, and were not subject to the difficulties associated with the use of environmental variables described above. Several studies have found that forecast models incorporating temporal and autoregressive changes in abundance, productivity, and recruitment perform relatively well for Pacific salmon populations (Noakes et al., 1990; Peterman et al., 2000; Haeseker et al., 2005, 2008). An advantage of Model 8 over Models 4 and 10 is that one does not have to make a decision about the degree of flexibility to allow for in the estimated temporal change in the jack-to-SI ratio.

For the particular case of the SI, there were substantial forecast errors across all models considered, suggesting that there may be an upper limit to the expected performance of any model. Attributes of the SI certainly contribute to these errors. The SI is a multi-cohort index of abundance, and the use of jacks, both in the previous year and two years prior, is likely insufficient to fully account for variation in cohort strength hidden within the index. There are unknown but likely high levels of measurement error in estimates of the harvest and spawning escapement components that make up the SI, as well as jack spawning escapement estimates. As monitoring programs have changed over time, it is likely that levels of measurement error have changed as well. We note, however, that substantial improvements in tagging and escapement monitoring programs (Bergman et al., 2012) should result in lower measurement error and enable age-specific abundance forecasts in the future. Nevertheless, many of the data quality and quantity issues that currently exist for SRFC apply to other salmon forecast scenarios and the idea that large levels of error in salmon forecasts are unavoidable has been stated before (e.g., Adkison and Peterman, 2000; Mantua and Francis, 2004; Haeseker et al., 2005). If forecasts are inherently inaccurate, Mantua and Francis (2004) suggest that management should de-emphasize preseason forecasts and rely more heavily on inseason monitoring. While this approach may be feasible for terminal salmon fisheries where spawning escapement can be monitored while the fishery is being conducted, it is more difficult to employ such an approach in mixed-stock ocean fisheries where the bulk of the fishery occurs prior to freshwater return, as is the case with SRFC.

Ultimately, the impacts of forecast error on the risk to the harvested population and on fishing opportunity are the bottom line for fisheries management. Simulations by Walters (1989) suggested that the value of improved pre-season forecasts might be limited unless the forecasts were highly accurate. We found little difference in the frequency of management errors (as we defined them) among the models that we explored. The harvest control rule for SRFC includes some precautionary elements that can buffer abundance forecast error. For example, allowable exploitation rates are never specified to be greater than 90 percent of F_{MSY} (PFMC, 2012a). Coupled simulations of the fish population and the management system would be necessary to assess the long-term value of the fishery and the risk to SRFC under different forecast models (e.g., Peterman et al., 2000; Kaje and Huppert, 2007; Rupp et al., 2012).

Our analysis suggests that there is scope to improve the performance of salmon forecast models that rely solely on estimated constant relationships between the abundances of different components of the population. In the case of predicting the SI from the number of jacks the previous year, we found that incorporating local environmental effects, temporal trends, and autocorrelation in the jack-to-SI relationship had the potential to increase forecast accuracy and the ability to track directional changes in abundance. Models that directly incorporated measures of the environment exhibited improved forecast performance in some cases. However, uncertainty about how the strength of particular environmental effects might change in the future and the relative complexity of these models pose challenges for future forecasts. Models that accounted for changes in the jack-to-SI relationship through time in a more phenomenological manner had among the best performance. These models were relatively parsimonious, were able to adequately track changes in population trajectories, and in the case of the model incorporating autocorrelated errors, imposed relatively little structure on changes in the jack-to-SI relationship over time. For these reasons, we believe the model incorporating autocorrelated errors (Model 8) should be given strong consideration for future forecasting of the SI.

Acknowledgements

Thank you to I. Schroeder for providing some of the environmental data. Thank you to R. Kope and N. Mantua for helpful comments on an earlier version of the manuscript. S. Allen-Moran, A. MacCall, S. Munch, and C. Speir also provided helpful suggestions and insights.

References

Adkison, M. D., and Peterman, R. M. 2000. Predictability of Bristol Bay, Alaska, sockeye salmon returns one to four years in the future. N. Am. J. Fish. Manage. **20**: 69–80.

Bakun, A., and Nelson, C. S. 1991. The seasonal cycle of wind-stress curl in subtropical eastern boundary current regions. J. Phys. Oceanogr. **21**: 1815–1834.

Beamish, R. J., and Mahnken, C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Prog. Oceanogr. **49**: 423–437.

Beauchamp, J. J., and Olson, J. S. 1973. Corrections for bias in regression estimates after logarithmic transformation. Ecology **54**: 1403–1407.

Bergman, J. M., Nielson, R. M., and Low, A. 2012. Central Valley Chinook salmon in-river escapement monitoring plan. Fisheries Branch Administrative Report 2012-1, California Department of Fish and Game, Sacramento, CA, USA. Available from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=42213 (accessed June 2013).

Bocking, R. C., and Peterman, R. M. 1988. Preseason forecasts of sockeye salmon (*Oncorhynchus nerka*): comparison of methods and economic considerations. Can. J. Fish. Aquat. Sci. **45**: 1346–1354.

Bograd, S. J., Schroeder, I., Sarkar, N., Qiu, X., Sydeman, W. J., and Schwing, F. B. 2009. Phenology of coastal upwelling in the California Current. Geophys. Res. Lett. **36**: L01602.

Burke, B. J., Peterson, W. T., Beckman, B. R., Morgan, C., and Daly, E. A. 2013. Multivariate models of adult Pacific salmon returns. PLoS One **8**: e54134.

Burnham, K. P., and Anderson, D. R. 2002. Model selection and multimodel inference: A practical information-theoretic approach (2nd ed.). Springer, New York, NY, USA.

Chatfield, C. 1996. Model uncertainty and forecast accuracy. J. Forecasting **15**: 495–508.

Deyle, E. R., Fogarty, M., Hsieh, C.-h., Kaufman, L., MacCall, A. D., Munch, S. B., Perretti, C. T., Ye, H., and Sugihara, G. 2013. Predicting climate effects on Pacific sardine. Proc. Nat. Acad. Sci. USA **110**: 6430–6435.

Francis, R. C., and Hare, S. R. 1994. Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: a case for historical science. Fish. Oceanogr. **3**: 279–291.

Francis, R. I. C. C. 2006. Measuring the strength of environment-recruitment relationships: the importance of including predictor screening within cross-validations. ICES J. Mar. Sci. **63**: 594–599.

Fujiwara, M., and Mohr, M. S. 2009. Identifying environmental signals from population abundance data using multivariate time-series analysis. Oikos **118**: 1712–1720.

Geladi, P., and Kowalski, B. R. 1986. Partial least-squares regression: a tutorial. Anal. Chim. Acta **185**: 1–17.

Haeseker, S. L., Peterman, R. M., and Su, Z. 2005. Retrospective evaluation of preseason forecasting models for pink salmon. N. Am. J. Fish. Manage. **25**: 897–918.

Haeseker, S. L., Peterman, R. M., and Su, Z. 2008. Retrospective evaluation of preseason forecasting models for sockeye and chum salmon. N. Am. J. Fish. Manage. **28**: 12–29.

Haury, L. R., McGowan, J. A., and Wiebe, P. H. 1978. Patterns and processes in the time-space scales of plankton distributions. *In* Spatial pattern in plankton communities. *Edited by* J. H. Steele, NATO conference series IV: Marine sciences. Plenum Press, New York, NY, USA, pp. 277–327.

Holt, C. A., and Peterman, R. M. 2006. Missing the target: uncertainties in achieving management goals in fisheries on Fraser River, British Columbia, sockeye salmon (*Onchorhynchus nerka*). Can. J. Fish. Aquat. Sci. **63**: 2722–2733.

Kaje, J. H., and Huppert, D. D. 2007. The value of short-run climate forecasts in managing the coastal coho salmon (*Oncorhynchus kisutch*) fishery in Washington State. Nat. Resour. Model. **20**: 321–349.

Keyl, F., and Wolff, M. 2008. Environmental variability and fisheries: what can models do? Rev. Fish Biol. Fish. **18**: 273–299.

Kope, R. G., and Botsford, L. W. 1990. Determination of factors affecting recruitment of Chinook salmon *Oncorhynchus tshawytscha* in Central California. Fish. Bull. **88**: 257–269.

Lindley, S. T., Grimes, C. B., Mohr, M. S., Peterson, W., Stein, J., Anderson, J. T., Botsford, L. W., Bottom, D. L., Busack, C. A., Collier, T. K., Ferguson, J., Garza, J. C., Grover, A. M., Hankin, D. G., Kope, R. G., Lawson, P. W., Low, A., MacFarlane, R. B., Moore, K., Palmer-Zwahlen, M., Schwing, F. B., Smith, J., Tracy, C., Webb, R., Wells, B. K., and Williams, T. H. 2009, July. What caused the Sacramento River fall Chinook stock collapse? U.S.

Department of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-447. Available from http://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-447.pdf (accessed September 2012).

Logerwell, E. A., Mantua, N., Lawson, P. W., Francis, R. C., and Agostini, V. N. 2003. Tracking environmental processes in the coastal zone for understanding and predicting Oregon coho (*Oncorhynchus kisutch*) marine survival. Fish. Oceanogr. **12**: 554–568.

Mantua, N., and Francis, R. C. 2004. Natural climate insurance for Pacific Northwest salmon and salmon fisheries: Finding our way through the entangled bank. *In* Sustainable management of North American fisheries. *Edited by* E. E. Knudsen, D. D. MacDonald, and Y. K. Muirhead, Volume 43 of *American Fisheries Society Symposium*. American Fisheries Society, Bethesda, MD, USA, pp. 127–140.

Megrey, B. A., Lee, Y.-W., and Macklin, S. A. 2005. Comparative analysis of statistical tools to identify recruitment-environment relationships and forecast recruitment strength. ICES J. Mar. Sci. **62**: 1256–1269.

Mevik, B.-H., and Wehrens, R. 2007. The pls package: principal component and partial least squares regression in R. J. Stat. Softw. **18**(2): 1–24.

Morita, K., and Fukuwaka, M.-a. 2006. Does size matter most? The effect of growth history on probabilistic reaction norm for salmon maturation. Evolution **60**: 1516–1521.

Myers, R. A. 1998. When do environment-recruitment correlations work? Rev. Fish Biol. Fish. **8**: 285–305.

Nelson, C. S. 1977. Wind stress and wind stress curl over the California Current. NMFS Report SSRF-714, NOAA, Monterey, CA, USA. Available from http://spo.nmfs.noaa.gov/SSRF/SSRF714.pdf (accessed September 2012).

Noakes, D. J., Welch, D. W., Henderson, M., and Mansfield, E. 1990. A comparison of preseason forecasting methods for returns of two British Columbia sockeye salmon stocks. N. Am. J. Fish. Manage. **10**: 46–57.

O'Farrell, M. R., Mohr, M. S., Palmer-Zwahlen, M. L., and Grover, A. M. 2013. The Sacramento Index (*SI*). U.S. Department of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-512. Available from http://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-512.pdf (accessed September 2013).

Peterman, R. M. 1981. Form of random variation in salmon smolt-to-adult relations and its influence on production estimates. Can. J. Fish. Aquat. Sci. **38**: 1113–1119.

Peterman, R. M. 1982. Model of salmon age structure and its use in preseason forecasting and studies of marine survival. Can. J. Fish. Aquat. Sci. **39**: 1444–1452.

Peterman, R. M., Pyper, B. J., and Grout, J. A. 2000. Comparison of parameter estimation methods for detecting climate-induced changes in productivity of Pacific salmon (*Oncorhynchus* spp.). Can. J. Fish. Aquat. Sci. **57**: 181–191.

PFMC (Pacific Fishery Management Council) 2012a. Pacific Coast Salmon Fishery Management Plan for commercial and recreational salmon fisheries off the coasts of Washington, Oregon, and California as revised through Amendment 16. PFMC, Portland, OR, USA. Available from http://www.pcouncil.org/wp-content/uploads/FMP_through_A-16_Final.pdf (accessed September 2013).

PFMC (Pacific Fishery Management Council) 2012b. Preseason report I: Stock abundance analysis and environmental assessment part 1 for 2012 ocean salmon fishery regulations. Document prepared for the Council and its advisory entities, PFMC, Portland, OR, USA. Available from http://www.pcouncil.org/wp-content/uploads/Preseason_Report_I_2012.pdf (accessed June 2013).

PFMC (Pacific Fishery Management Council) 2013a. Preseason report I: Stock abundance analysis and environmental assessment part 1 for 2013 ocean salmon fishery regulations. Document prepared for the Council and its advisory entities, PFMC, Portland, OR, USA. Available from http://www.pcouncil.org/wp-content/uploads/Preseason_Report_I_2013_FINAL.pdf (accessed June 2013).

PFMC (Pacific Fishery Management Council) 2013b. Review of 2012 ocean salmon fisheries: Stock assessment and fishery evaluation document for the Pacific Coast Salmon Fishery Management Plan. Document prepared for the Council and its advisory entities, PFMC, Portland, OR, USA. Available from http://www.pcouncil.org/wp-content/uploads/salsafe_2012.pdf (accessed June 2013).

Quinn, T. P. 2005. The behavior and ecology of Pacific salmon and trout. American Fisheries Society, Bethesda, MD in association with University of Washington Press, Seattle, WA, USA.

R Core Team 2013. R: A language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing.

Rogers, L. A., and Schindler, D. E. 2011. Scale and the detection of climatic influences on the productivity of salmon populations. Glob. Change Biol. **17**: 2546–2558.

Roth, J. E., Mills, K. L., and Sydeman, W. J. 2007. Chinook salmon (*Oncorhynchus tshawytscha*) – seabird covariation off central California and possible forecasting applications. Can. J. Fish. Aquat. Sci. **64**: 1080–1090.

Rupp, D. E., Wainwright, T. C., and Lawson, P. W. 2012. Effect of forecast skill on management of the Oregon coast coho salmon (*Oncorhynchus kisutch*) fishery. Can. J. Fish. Aquat. Sci. **69**: 1016–1032.

Rupp, D. E., Wainwright, T. C., Lawson, P. W., and Peterson, W. T. 2012. Marine environment-based forecasting of coho salmon (*Oncorhynchus kisutch*) adult recruitment. Fish. Oceanogr. **21**: 1–19.

Satterthwaite, W. H., Beakes, M. P., Collins, E. M., Swank, D. R., Merz, J. E., Titus, R. G., Sogard, S. M., and Mangel, M. 2010. State-dependent life history models in a changing (and regulated) environment: steelhead in the California Central Valley. Evol. Appl. **3**: 221–243.

Scheuerell, M. D., and Williams, J. G. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). Fish. Oceanogr. **14**: 448–457.

Snover, M. L., Watters, G. M., and Mangel, M. 2006. Top-down and bottom-up control of life-history strategies in coho salmon (*Oncorhynchus kisutch*). Am. Nat. **167**: E140–E157.

Sprugel, D. G. 1983. Correcting for bias in log-transformed allometric equations. Ecology **64**: 209–210.

Stommel, H. 1963. Varieties of oceanographic experience. Science **139**: 572–576.

Walters, C. J. 1989. Value of short-term forecasts of recruitment variation for harvest management. Can. J. Fish. Aquat. Sci. **46**: 1969–1976.

Walters, C. J., and Collie, J. S. 1988. Is research on environmental factors useful to fisheries management? Can. J. Fish. Aquat. Sci. **45**: 1848–1854.

Walther, B., and Moore, J. L. 2005. The concepts of bias, precision and accuracy, and their use in testing the performance of species richness estimators, with a literature review of estimator performance. Ecography **28**: 815–829.

Wang, S., Morishima, G., Sharma, R., and Gilbertson, L. 2009. The use of generalized additive models for forecasting the abundance of Queets River coho salmon. N. Am. J. Fish. Manage. **29**: 423–433.

Watters, G. M., and Bessey, C. 2008. Variation in the probability that male coho salmon will mature early: inferences from hierarchical models. Trans. Am. Fish. Soc. **137**: 70–95.

Wells, B. K., Field, J. C., Thayer, J. A., Grimes, C. B., Bograd, S. J., Sydeman, W. J., Schwing, F. B., and Hewitt, R. 2008. Untangling the relationships among climate, prey and top predators in an ocean ecosystem. Mar. Ecol.-Prog. Ser. **364**: 15–29.

Wells, B. K., Grimes, C. B., and Waldvogel, J. B. 2007. Quantifying the effects of wind, upwelling, curl, sea surface temperature and sea level height on growth and maturation of a California Chinook salmon (*Oncorhynchus tshawytscha*) population. Fish. Oceanogr. **16**: 363–382.

Wells, B. K., Santora, J. A., Field, J. C., MacFarlane, R. B., Marinovic, B. B., and Sydeman, W. J. 2012. Population dynamics of Chinook salmon *Oncorhynchus tshawytscha* relative to prey availability in the central California coastal region. Mar. Ecol.-Prog. Ser. **457**: 125–137.

Wood, S. N. 2006. Generalized additive models: An introduction with R. Chapman and Hall/CRC, Boca Raton, FL, USA.

Woodson, L. E., Wells, B. K., Weber, P. K., MacFarlane, R. B., Whitman, G. E., and Johnson, R. C. In press. Size, growth, and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawytscha* during early ocean residence. Mar. Ecol.-Prog. Ser. **000**: 000–000.

Worley, S. J., Woodruff, S. D., Reynolds, R. W., Lubker, S. J., and Lott, N. 2005. ICOADS release 2.1 data and products. Int. J. Climatol. **25**: 823–842.

Zhou, S. 2003. Application of artificial neural networks for forecasting salmon escapement. N. Am. J. Fish. Manage. **23**: 48–59.

Table 1. Environmental variables.

Variable	Description	Units	Resolution	Location	Source
SST	sea surface temperature	°C	monthly; 1° lon/lat	5 cells centered on 235.5°E, 40.5°N 235.5°E, 39.5°N 236.5°E, 38.5°N 236.5°E, 37.5°N 237.5°E, 37.5°N	ICOADS[a]
SCALAR	non-directional (scalar) surface wind speed	m/s	*see SST*	*see SST*	ICOADS[a]
NPSEUDO	northerly pseudo-wind stress; product of scalar and vector surface wind	m^2/s^2	*see SST*	*see SST*	ICOADS[a]
EPSEUDO	easterly pseudo-wind stress; product of scalar and vector surface wind	m^2/s^2	*see SST*	*see SST*	ICOADS[a]
CURL	surface wind-stress curl; influences upwelling and offshore transport[b]	$dynes/cm^2/cm \times 1E10$	monthly, 6-hourly; 15 point locations few ° apart	125°W, 39°N	PFEL[c]
UPWELLING	upwelling index "based on estimates of	t/s/100 m of coast	*see CURL*	*see CURL*	PFEL[c]

Table 1. continued.

Variable	Description	Units	Resolution	Location	Source
	offshore Ekman transport driven by geostrophic wind stress"; "geostrophic winds are derived from ... surface atmospheric pressure fields"[d]				
SLH	sea level height	mm	monthly, hourly, daily; multiple stations around the world	122°27.9'W, 37°48.4'	UHSLC[e]
STI_39N	spring transition index; date on which the cumulative coastal upwelling index (beginning 1 January) begins to increase from its minimum value[f]	day of year	*see CURL for spatial resolution*	*see CURL*	PFEL[c]

[a] International Comprehensive Ocean-Atmosphere Data Set (Worley et al., 2005), available from http://coastwatch.pfeg.noaa.gov/erddap/griddap/esrlIcoads1ge.html

[b] Nelson (1977), Bakun and Nelson (1991)

[c] Pacific Fisheries Environmental Laboratory, available from http://www.pfeg.noaa.gov/products/pfel/modeled/indices/transports/transports.html

[d] http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/how_computed.html

[e] University of Hawaii Sea Level Center, available from http://ilikai.soest.hawaii.edu/uhslc/htmld/d0551W.html. Station 551, San Francisco, California.

[f] Bograd et al. (2009)

Table 2. Alternative models for forecasting the Sacramento Index (SI) as a function of the number of jacks the previous two years and the environment the previous year. Model 2 is currently used to forecast the SI. Model variables, parameters, and terms are defined as follows: J_t - jacks in year t, $\mathrm{E}_{i,t}$ - environmental variable i in year t, β_i - model intercept (β_0) and coefficients, $f_{i(n)}\left(\mathrm{X}_i\right)$ - smooth function of variable X_i with cubic spline basis and maximum n degrees of freedom, ϵ_t - SI residual for year t, ρ - first-order temporal autocorrelation in SI residuals, v_t - 'innovation' for year t, and σ^2 - error variance.

Model	Formula	Error structure	Model selection	Selected terms (X_i)
1	$\mathrm{SI}_t = \beta_0 + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2\right)$	none	
2	$\mathrm{SI}_t = \beta_1 \mathrm{J}_{t-1} + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2 \mathrm{J}_{t-1}\right)$	none	
3	$\mathrm{SI}_t = \beta_1 \mathrm{J}_{t-1} + \beta_2 \mathrm{J}_{t-2} + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2 \mathrm{J}_{t-1}\right)$	none	
4[a,b]	$\mathrm{SI}_t = f_{1(3)}\left(t\right) \mathrm{J}_{t-1} + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2 \mathrm{J}_{t-1}\right)$	none	
5	$\mathrm{SI}_t = \beta_1 \mathrm{J}_{t-1} + \sum_i \beta_i \mathrm{X}_i + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2 \mathrm{J}_{t-1}\right)$	AIC_c	J_{t-2}, $\mathrm{J}_{t-1} \times \mathrm{E}_{j,t-1}$
6	$\log \mathrm{SI}_t = \beta_0 + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2\right)$	none	
7	$\log \mathrm{SI}_t = \beta_0 + \beta_1 \log \mathrm{J}_{t-1} + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2\right)$	none	
8[c]	$\log \mathrm{SI}_t = \beta_0 + \beta_1 \log \mathrm{J}_{t-1} + \epsilon_t$	$\epsilon_t = \rho\epsilon_{t-1} + v_t$, $v_t \sim \mathrm{N}\left(0, \sigma^2\right)$	none	
9	$\log \mathrm{SI}_t = \beta_0 + \beta_1 \log \mathrm{J}_{t-1} + \beta_2 \log \mathrm{J}_{t-2} + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2\right)$	none	
10[a]	$\log \mathrm{SI}_t = \beta_0 + \beta_1 \log \mathrm{J}_{t-1} + f_{1(2)}\left(t\right) + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2\right)$	none	
11	$\log \mathrm{SI}_t = \beta_0 + \beta_1 \log \mathrm{J}_{t-1} + \sum_i \beta_i \mathrm{X}_i + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2\right)$	AIC_c	$\log \mathrm{J}_{t-2}$, $\mathrm{E}_{j,t-1}$
12[a]	$\log \mathrm{SI}_t = \beta_0 + \beta_1 \log \mathrm{J}_{t-1} + \sum_i \mathrm{X}_i + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2\right)$	AIC_c	$\beta_2 \log \mathrm{J}_{t-2}$, $f_{j(2)}\left(\mathrm{E}_{j,t-1}\right)$
13[d]	$\log \mathrm{SI}_t = \beta_0 + \beta_1 \log \mathrm{J}_{t-1} + \beta_2 \log \mathrm{J}_{t-2} + \sum_i \beta_i \mathrm{E}_{i,t-1} + \epsilon_t$	$\epsilon_t \sim \mathrm{N}\left(0, \sigma^2\right)$	none	

[a] Generalized additive model fit with 'mgcv' package (Wood, 2006) for R (R Core Team, 2013)

[b] Varying coefficient model (Wood, 2006)

[c] First-order autoregressive error structure fit with 'arima' function in R (R Core Team, 2013)

[d] Partial least squares regression model fit with 'pls' package (Mevik and Wehrens, 2007) for R (R Core Team, 2013); data were centered and scaled

Table 3. Forecast performance metrics. Symbols are defined as follows: SI_t - observed Sacramento Index in year t, $\widehat{\mathrm{SI}}_t$ - predicted Sacramento Index in year t, and n - sample size. ME, MAE, RMSE, and PVE were also calculated on the log scale for models of log-transformed data (Models 6–13). For calculating PVE, $\mathrm{RMSE_i}$ was the RMSE of the appropriate intercept-only model (Model 1 for PVE on the arithmetic scale, and Model 6 for PVE on the log scale).

Metric	Acronym	Formula
mean error	ME	$\frac{\sum_t \left(\mathrm{SI}_t - \widehat{\mathrm{SI}}_t\right)}{n}$
mean absolute error	MAE	$\frac{\sum_t \left\lvert\mathrm{SI}_t - \widehat{\mathrm{SI}}_t\right\rvert}{n}$
mean percent error	MPE	$100 \times \frac{\sum_t \left[\left(\mathrm{SI}_t - \widehat{\mathrm{SI}}_t\right)/\mathrm{SI}_t\right]}{n}$
mean absolute percent error	MAPE	$100 \times \frac{\sum_t \left\lvert\left(\mathrm{SI}_t - \widehat{\mathrm{SI}}_t\right)/\mathrm{SI}_t\right\rvert}{n}$
root mean square error	RMSE	$\sqrt{\frac{\sum_t \left(\mathrm{SI}_t - \widehat{\mathrm{SI}}_t\right)^2}{n}}$
percent variance explained[a]	PVE	$100 \times \left(1 - \frac{\mathrm{RMSE}^2}{\mathrm{RMSE}_\mathrm{i}^2}\right)$

[a] Francis (2006); forecast skill relative to the naive intercept-only model (RMSE_i)

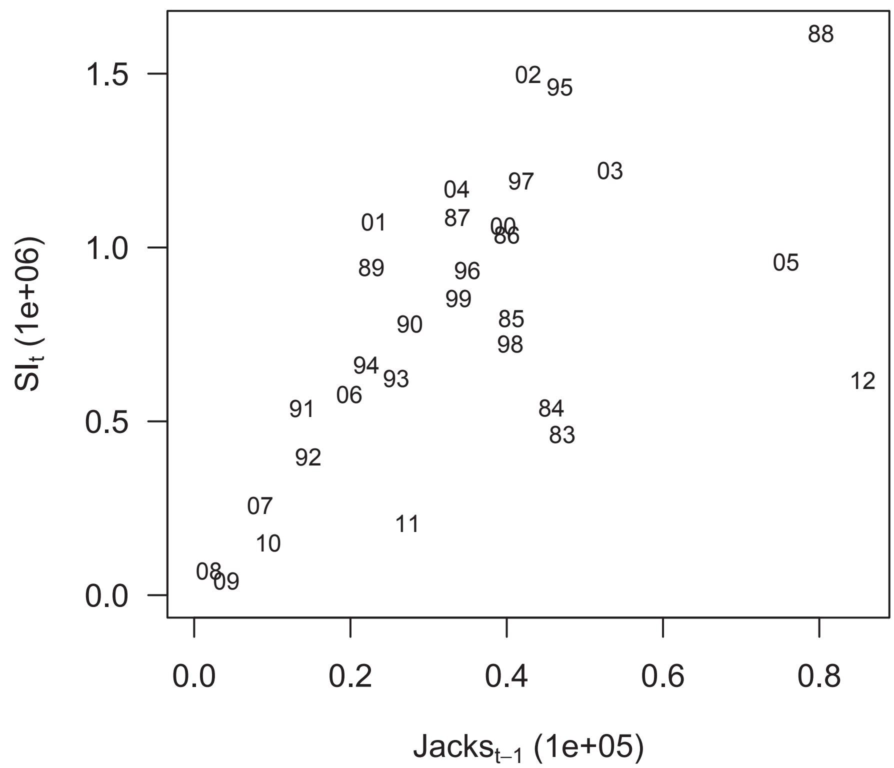


Figure 1. The Sacramento Index (SI) for year t (1983–2012) versus the number of jacks the previous year.

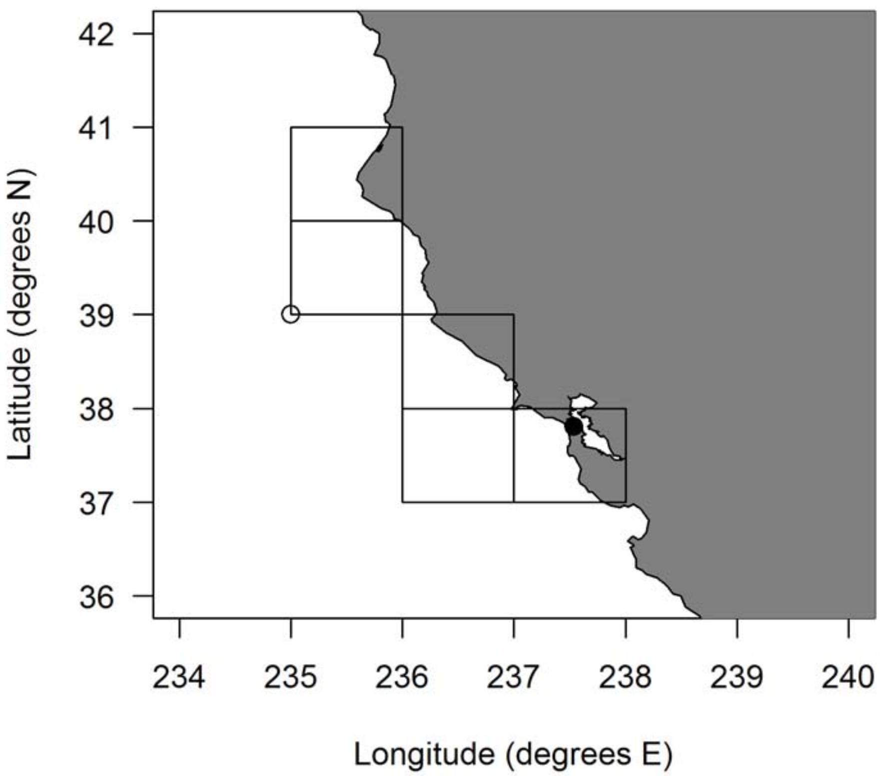


Figure 2. Geographic area from which environmental data were derived. UPWELLING and CURL were derived from the location marked by the open point, SLH was derived from the location marked by the solid point, and SST, SCALAR, NPSEUDO, and EPSEUDO were derived from the indicated 1-degree cells.

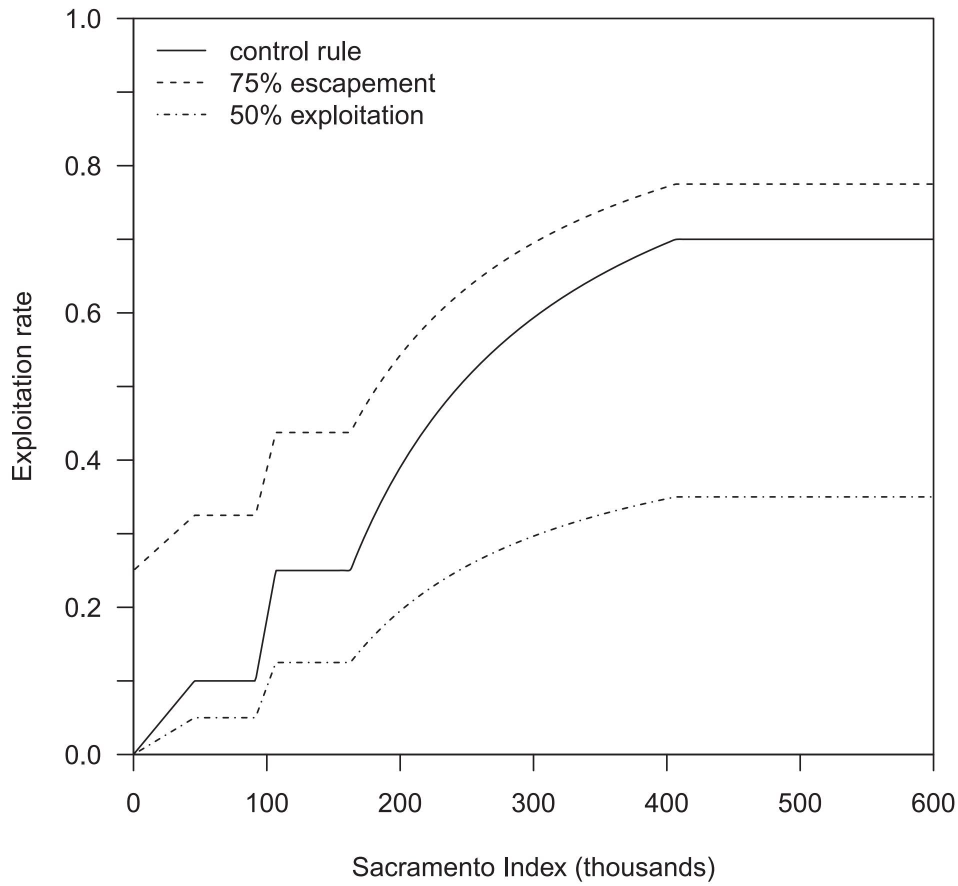


Figure 3. Harvest control rule for Sacramento River Fall Chinook salmon. The solid line indicates the allowable exploitation rate as a function of the Sacramento Index. The upper dashed line indicates the exploitation rate that would result in 75% of the spawning escapement specified by the control rule (threshold for conservation error). The lower dashed-dotted line indicates 50% of the exploitation rate specified by the control rule (threshold for fishing opportunity error).

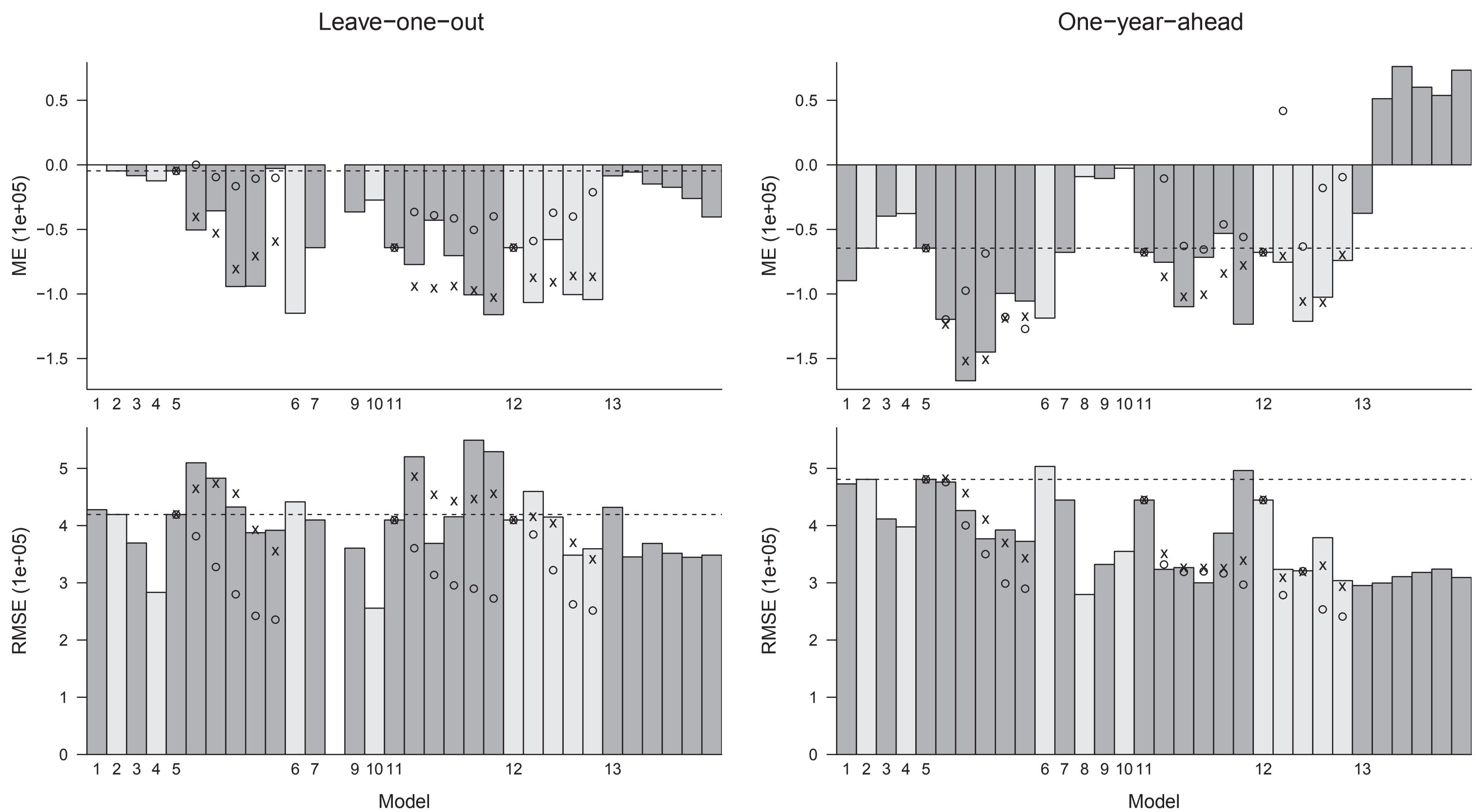


Figure 4. Model forecast performance in leave-one-out and one-year-ahead cross validation. Performance metrics are defined in Table 3. Crosses represent model averaging results and circles represent results when model selection was not included in cross validation (i.e., the model was selected on the basis of the entire dataset). The multiple bars for Models 5 and 11–13 represent the results for sequential numbers of (latent) variables in these models, beginning with one variable. The number of jacks the previous year was always included, so the one-variable versions of Models 5, 11, and 12 had only this variable. The dashed lines reference the performance of Model 2. Leave-one-out cross validation was not conducted for Model 8.

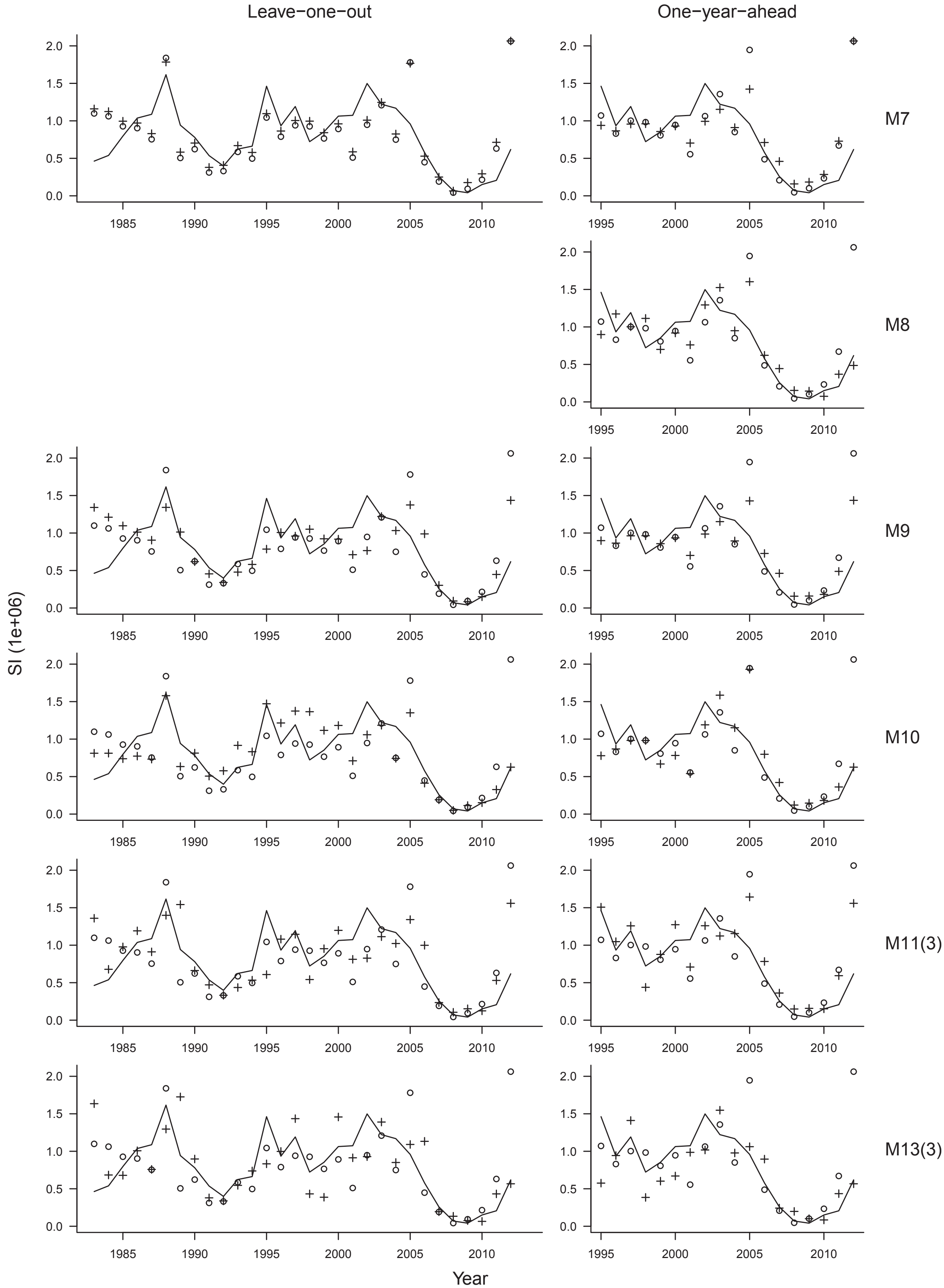


Figure 5. Observed and predicted Sacramento Index (SI) under leave-one-out and one-year-ahead cross validation for Models 2, 7–11, and 13. The latter two models had three variables each. Solid lines represent observations, circles represent predictions under Model 2 (current management model), and crosses represent predictions under the model indicated in the right margin.

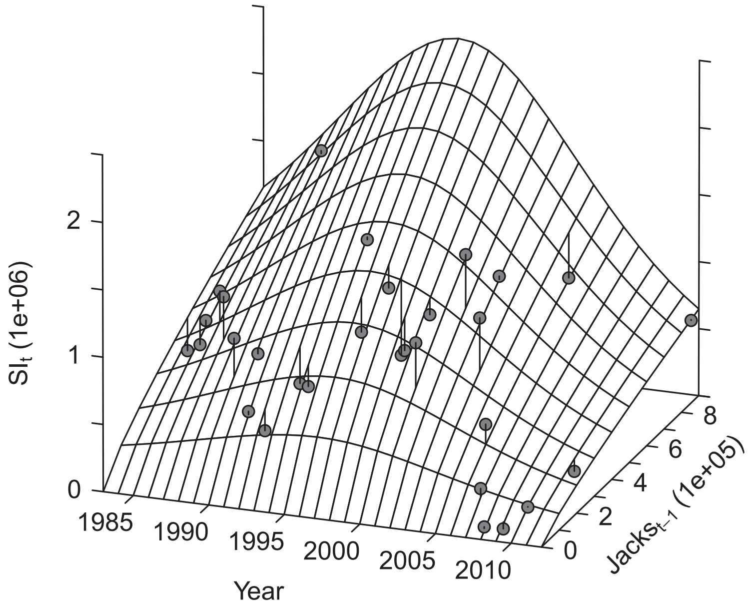


Figure 6. Predicted Sacramento Index (SI) as a function of year and the number of jacks the previous year (Model 10). Grey dots represent the data.

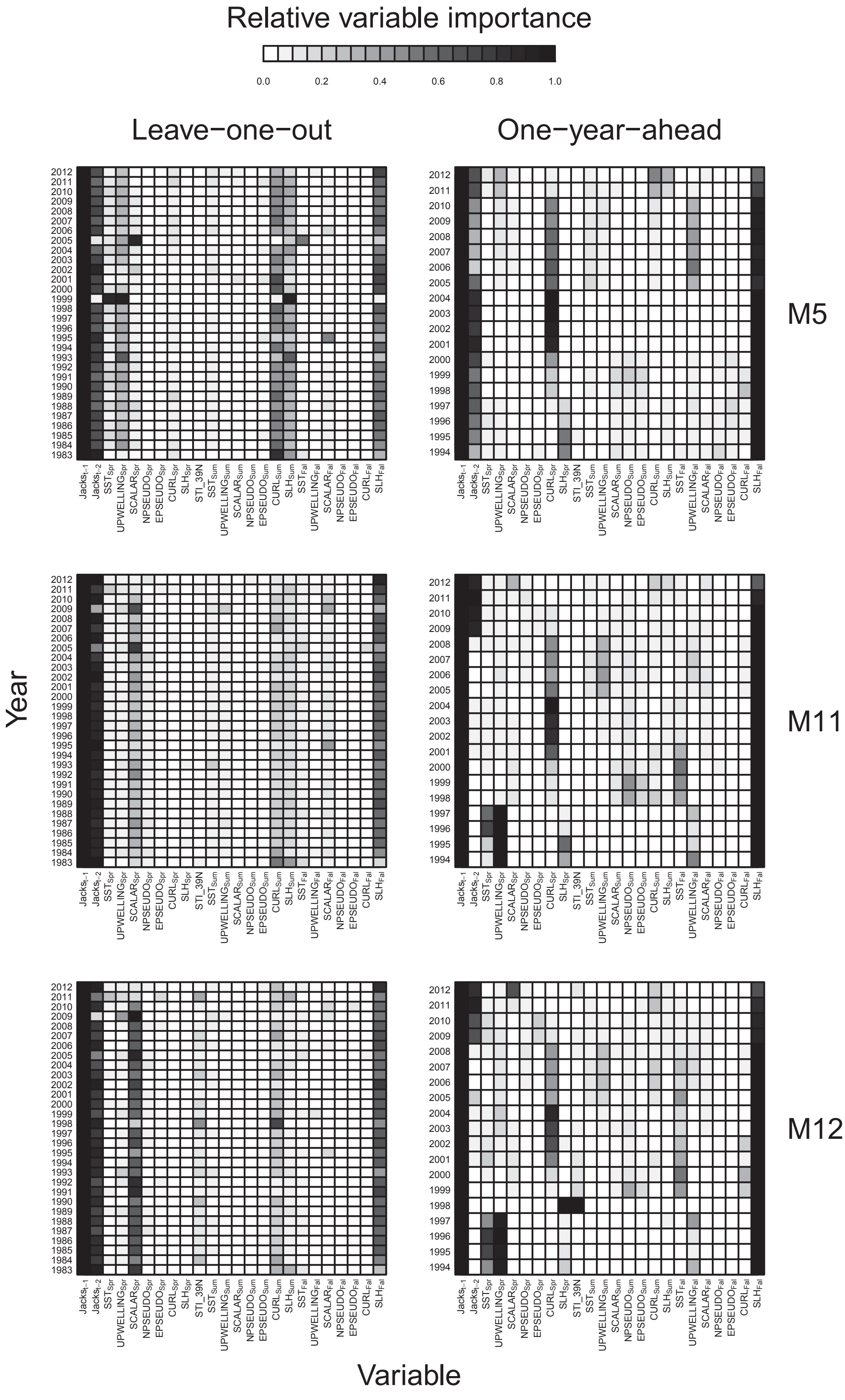


Figure 7. AIC$_c$-based 'relative variable importance' (Burnham and Anderson, 2002) in Models 5, 11, and 12 with 4 variables under leave-one-out and one-year-ahead cross validation. For leave-one-out cross validation, each year represents relative variable importance when data from that year were excluded. For one-year-ahead cross validation, each year represents relative variable importance based on the data available up to and including that year. The number of jacks the previous year (Jacks$_{t-1}$) was always included so its relative importance was always 1. The subscript 't - 1' has been suppressed for environmental variables, which are defined in Table 1.

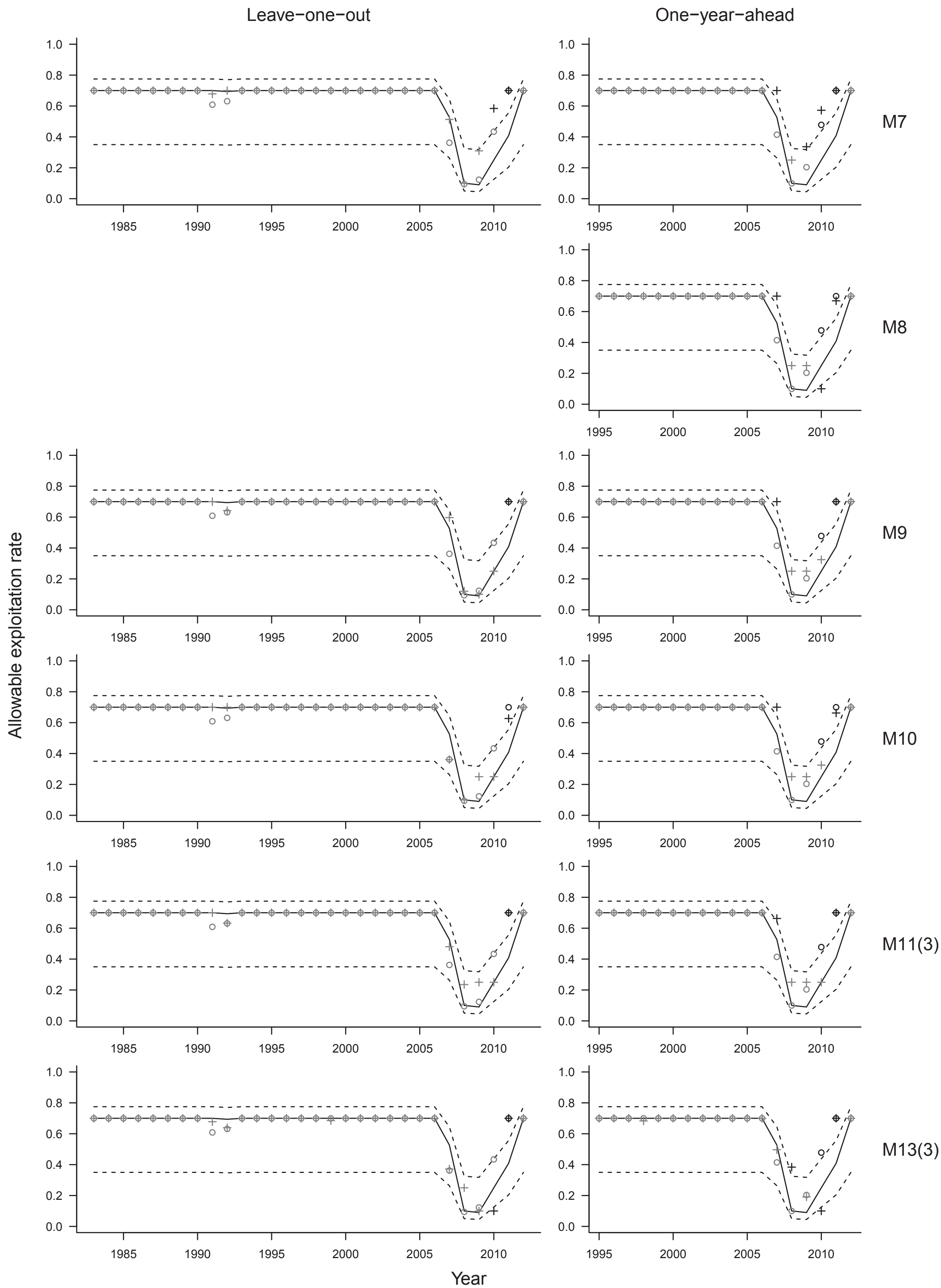


Figure 8. Allowable exploitation rate over time under leave-one-out and one-year-ahead cross-validation for Models 2, 7–11, and 13. The latter two models had three variables each. Solid lines represent the rate corresponding to the observed Sacramento Index (SI), upper and lower dashed lines represent the threshold rates corresponding to conservation and fishing opportunity errors, respectively, circles represent the rate corresponding to the predicted SI under Model 2 (current management model), and crosses represent the rate corresponding to the predicted SI under the model indicated in the right margin. Black symbols indicate management errors.

Supplementary material S1

Table S1.1. Leave-one-out cross-validation performance of alternative models for forecasting the Sacramento Index. Models are defined in Table 2, and performance metrics are defined in Table 3.

Model	# variables	Arithmetic scale						Log scale			
		ME	MAE	MPE	MAPE	RMSE	PVE	ME	MAE	RMSE	PVE
1	0	0	353717	-128	156	427787	0				
2	1	-4668	297309	-16	50	419377	4				
3	2	-8389	265585	-18	42	369555	25				
4	2	-12400	211469	-4	31	283256	56				
5	1	-4668	297309	-16	50	419377	4				
	2	-50419	337914	-24	56	509726	-42				
	3	-35594	297372	-21	47	482794	-27				
	4	-94236	281188	-20	43	432431	-2				
	5	-94018	262022	-20	44	387572	18				
	6	-2790	303255	-11	49	391801	16				
5[a]	1	-4668	297309	-16	50	419377	4				
	2	-40480	292596	-20	48	464182	-18				
	3	-53137	286016	-22	46	473220	-22				
	4	-80935	296105	-22	47	455480	-13				
	5	-70851	255057	-18	42	392273	16				
	6	-59498	246702	-16	42	355056	31				
5[b]	1	-4668	297309	-16	50	419377	4				
	2	131	237141	-13	43	381608	20				
	3	-9472	216207	-16	37	327782	41				
	4	-16450	197063	-12	33	280042	57				
	5	-10610	172802	-12	34	242328	68				
	6	-10011	162592	-12	32	235719	70				
6	0	-114941	364435	-156	175	441469	-6	0	0.641	0.888	0
7	1	-64154	272098	-34	55	409768	8	-0.009	0.412	0.528	65

Table S1.1. continued.

Model	# variables	Arithmetic scale						Log scale			
		ME	MAE	MPE	MAPE	RMSE	PVE	ME	MAE	RMSE	PVE
9	2	-36447	256136	-22	41	360594	29	-0.016	0.343	0.429	77
10	2	-27266	198608	-14	33	255723	64	-0.006	0.294	0.361	83
11	1	-64154	272098	-34	55	409768	8	-0.009	0.412	0.528	65
	2	-77192	341102	-33	58	520302	-48	-0.033	0.44	0.556	61
	3	-42914	261421	-26	48	368960	26	-0.041	0.37	0.485	70
	4	-70307	299517	-28	53	415412	6	-0.046	0.423	0.523	65
	5	-100675	392736	-31	63	549191	-65	-0.047	0.497	0.58	57
	6	-116031	323332	-28	55	529188	-53	-0.033	0.443	0.578	58
11[a]	1	-64154	272098	-34	55	409768	8	-0.009	0.412	0.528	65
	2	-94429	298228	-34	53	485259	-29	-0.052	0.396	0.51	67
	3	-95790	281245	-30	49	453521	-12	-0.054	0.371	0.479	71
	4	-93973	278968	-29	49	442337	-7	-0.049	0.375	0.478	71
	5	-97397	285365	-29	50	446205	-9	-0.043	0.385	0.483	70
	6	-102918	295873	-29	51	455384	-13	-0.036	0.4	0.498	69
11[b]	1	-64154	272098	-34	55	409768	8	-0.009	0.412	0.528	65
	2	-36447	256136	-22	41	360594	29	-0.016	0.343	0.429	77
	3	-38982	230836	-17	37	313906	46	-0.02	0.316	0.384	81
	4	-41426	218403	-17	36	295645	52	-0.024	0.313	0.38	82
	5	-50334	219194	-16	36	289909	54	-0.031	0.315	0.375	82
	6	-39841	202403	-14	33	272681	59	-0.025	0.295	0.352	84
12	1	-64154	272098	-34	55	409768	8	-0.009	0.412	0.528	65
	2	-106608	308835	-34	55	459631	-15	-0.073	0.395	0.526	65
	3	-57860	294744	-22	51	414902	6	-0.006	0.417	0.505	68
	4	-100491	258124	-28	48	348342	34	-0.096	0.362	0.461	73
	5	-104328	266112	-26	44	359470	29	-0.116	0.338	0.428	77
12[a]	1	-64154	272098	-34	55	409768	8	-0.009	0.412	0.528	65
	2	-87596	275161	-30	49	415308	6	-0.047	0.367	0.47	72
	3	-91150	269044	-29	49	403674	11	-0.048	0.346	0.471	72

Table S1.1. continued.

Model	# variables	Arithmetic scale ME	MAE	MPE	MAPE	RMSE	PVE	Log scale ME	MAE	RMSE	PVE
	4	-86222	259554	-27	48	369793	25	-0.043	0.361	0.462	73
	5	-86814	261164	-24	44	340888	37	-0.06	0.352	0.422	77
12[b]	1	-64154	272098	-34	55	409768	8	-0.009	0.412	0.528	65
	2	-58932	231828	-19	39	384563	19	-0.008	0.31	0.419	78
	3	-37064	237002	-17	38	322236	43	-0.017	0.323	0.393	80
	4	-40009	202329	-13	33	262522	62	-0.018	0.294	0.347	85
	5	-21133	194040	-9	27	251642	65	-0.008	0.251	0.3	89
13	1	-8521	313130	-28	55	431908	-2	-0.007	0.435	0.546	62
	2	-5572	270125	-17	45	345258	35	0.006	0.386	0.454	74
	3	-14834	263435	-14	43	368833	26	0.022	0.38	0.476	71
	4	-17385	264838	-14	43	351591	32	0.014	0.39	0.472	72
	5	-26060	248363	-15	43	344582	35	0.001	0.378	0.478	71
	6	-40366	257405	-16	43	348359	34	-0.01	0.386	0.486	70

[a] Model averaging.

[b] Model selection not included in cross validation.

Table S1.2. One-year-ahead cross-validation performance of alternative models for forecasting the Sacramento Index. Models are defined in Table 2, and performance metrics are defined in Table 3.

Model	# variables	Arithmetic scale						Log scale			
		ME	MAE	MPE	MAPE	RMSE	PVE	ME	MAE	RMSE	PVE
1	0	-89697	388747	-228	252	472821	0				
2	1	-64532	317535	-32	59	480748	-3				
3	2	-39731	290653	-29	49	411566	24				
4	2	-37724	261274	-10	39	397725	29				
5	1	-64532	317535	-32	59	480748	-3				
	2	-119659	281818	-39	59	476077	-1				
	3	-167229	262874	-45	57	426301	19				
	4	-144996	253728	-47	61	376898	36				
	5	-99556	275879	-41	59	392318	31				
	6	-105506	270174	-39	58	372433	38				
5[a]	1	-64532	317535	-32	59	480748	-3				
	2	-123772	284232	-40	60	481784	-4				
	3	-152007	277560	-44	58	456339	7				
	4	-151096	262627	-44	58	410355	25				
	5	-119056	245194	-41	55	369343	39				
	6	-117654	229452	-41	53	342570	48				
5[b]	1	-64532	317535	-32	59	480748	-3				
	2	-119659	281818	-39	59	476077	-1				
	3	-97390	256358	-37	52	400452	28				
	4	-68593	243914	-27	45	350233	45				
	5	-117758	199451	-33	44	298842	60				
	6	-127042	190707	-34	43	289831	62				
6	0	-118684	412604	-247	270	503396	-13	-0.36	0.724	1.084	0
7	1	-67765	307624	-59	78	444607	12	-0.21	0.489	0.622	67
8	1	-9105	230730	-27	51	279596	65	-0.075	0.405	0.491	80
9	2	-10538	256871	-40	59	332135	51	-0.133	0.424	0.527	76
10	2	-2633	256182	-28	49	354910	44	-0.088	0.384	0.48	80

Table S1.2. continued.

Model	# variables	Arithmetic scale ME	MAE	MPE	MAPE	RMSE	PVE	Log scale ME	MAE	RMSE	PVE
11	1	-67765	307624	-59	78	444607	12	-0.21	0.489	0.622	67
	2	-75457	229655	-49	63	323488	53	-0.221	0.394	0.559	73
	3	-109867	220946	-46	57	326589	52	-0.234	0.374	0.533	76
	4	-71626	232302	-41	59	300023	60	-0.183	0.396	0.536	76
	5	-53100	274071	-43	66	386791	33	-0.154	0.446	0.596	70
	6	-123440	353400	-43	71	496209	-10	-0.154	0.522	0.626	67
11[a]	1	-67765	307624	-59	78	444607	12	-0.21	0.489	0.622	67
	2	-86780	240228	-51	65	350280	45	-0.229	0.402	0.567	73
	3	-102330	223352	-46	58	325923	52	-0.228	0.372	0.531	76
	4	-100702	231407	-46	58	325689	53	-0.22	0.382	0.535	76
	5	-84263	231923	-43	58	325148	53	-0.192	0.386	0.542	75
	6	-78030	241585	-42	59	338595	49	-0.17	0.407	0.55	74
11[b]	1	-67765	307624	-59	78	444607	12	-0.21	0.489	0.622	67
	2	-10538	256871	-40	59	332135	51	-0.133	0.424	0.527	76
	3	-62778	218924	-37	51	319178	54	-0.175	0.354	0.494	79
	4	-65492	237683	-36	51	319986	54	-0.175	0.365	0.481	80
	5	-46041	229831	-34	50	316578	55	-0.161	0.357	0.479	81
	6	-55839	223728	-26	44	296954	61	-0.123	0.349	0.431	84
12	1	-67765	307624	-59	78	444607	12	-0.21	0.489	0.622	67
	2	-75457	229655	-49	63	323488	53	-0.221	0.394	0.559	73
	3	-121207	223523	-48	59	320990	54	-0.252	0.379	0.538	75
	4	-102529	301181	-47	69	378881	36	-0.203	0.481	0.606	69
	5	-74070	244995	-32	52	303838	59	-0.149	0.397	0.501	79
12[a]	1	-67765	307624	-59	78	444607	12	-0.21	0.489	0.622	67
	2	-70840	224260	-49	63	308659	57	-0.212	0.385	0.545	75
	3	-106017	222219	-49	60	318852	55	-0.237	0.375	0.539	75
	4	-106809	243531	-49	62	329676	51	-0.228	0.394	0.552	74
	5	-69946	233906	-41	58	293000	62	-0.173	0.397	0.533	76

Table S1.2. continued.

Model	# variables	Arithmetic scale						Log scale			
		ME	MAE	MPE	MAPE	RMSE	PVE	ME	MAE	RMSE	PVE
12[b]	1	-67765	307624	-59	78	444607	12	-0.21	0.489	0.622	67
	2	41829	232987	-36	59	278630	65	-0.105	0.425	0.527	76
	3	-63209	219355	-37	51	320449	54	-0.176	0.355	0.495	79
	4	-17854	183956	-32	46	253662	71	-0.14	0.327	0.468	81
	5	-9469	182740	-20	36	241125	74	-0.095	0.29	0.376	88
13	1	-37524	216476	-83	98	295208	61	-0.234	0.455	0.726	55
	2	51251	215086	-22	47	299597	60	-0.043	0.38	0.503	79
	3	76190	230717	-15	47	310797	57	0.018	0.412	0.517	77
	4	60140	238742	-17	50	318147	55	0.001	0.432	0.542	75
	5	53755	238571	-19	53	323993	53	0.005	0.454	0.578	72
	6	73339	226056	-13	48	309322	57	0.04	0.429	0.553	74

[a] Model averaging.

[b] Model selection not included in cross validation.

Table S1.3. Management performance of alternative models for forecasting the Sacramento Index under leave-one-out and one-year-ahead cross validation. The number of conservation (C) and fishing opportunity (F) errors are shown. Models are defined in Table 2.

Model	# variables	Leave-one-out		One-year-ahead	
		C	F	C	F
1	0	5	0	5	0
2	1	1	0	2	0
3	2	1	0	1	0
4	2	1	1	1	0
5	1	1	0	2	0
	2	1	0	2	0
	3	1	0	1	0
	4	1	0	1	1
	5	1	1	1	0
	6	1	3	1	0
5[a]	1	1	0	2	0
	2	1	0	2	0
	3	1	0	1	0
	4	1	0	1	0
	5	1	1	1	0
	6	1	2	1	0
5[b]	1	1	0	2	0
	2	1	0	2	0
	3	1	0	1	0
	4	1	0	1	0
	5	1	1	1	0
	6	1	1	1	0
6	0	5	0	5	0
7	1	2	0	4	0
8	1			2	1
9	2	1	0	2	0

Table S1.3. continued.

Model	# variables	Leave-one-out C	Leave-one-out F	One-year-ahead C	One-year-ahead F
10	2	1	0	2	0
11	1	2	0	4	0
	2	1	0	2	0
	3	1	0	2	0
	4	1	0	1	0
	5	1	2	1	0
	6	1	2	1	1
11[a]	1	2	0	4	0
	2	1	0	2	0
	3	1	0	1	0
	4	1	0	1	0
	5	1	0	1	0
	6	1	2	1	0
11[b]	1	2	0	4	0
	2	1	0	2	0
	3	1	0	1	0
	4	1	0	1	0
	5	1	1	1	0
	6	1	1	1	0
12	1	2	0	4	0
	2	2	0	2	0
	3	1	1	2	0
	4	1	0	2	0
	5	1	1	1	0
12[a]	1	2	0	4	0
	2	1	0	2	0
	3	1	0	1	0
	4	1	0	1	0

Table S1.3. continued.

Model	# variables	Leave-one-out C	Leave-one-out F	One-year-ahead C	One-year-ahead F
	5	1	1	1	0
12[b]	1	2	0	4	0
	2	2	0	4	0
	3	1	0	1	0
	4	1	0	1	0
	5	1	1	1	0
13	1	2	0	4	0
	2	2	0	2	0
	3	1	1	2	1
	4	1	1	2	1
	5	1	2	2	1
	6	1	2	2	1

[a] Model averaging.

[b] Model selection not included in cross validation.

Status Determination Criteria for Willapa Bay Natural Coho

Salmon Technical Team
and
Washington Department of Fish and Wildlife

Prepared by:
Robert Kope
Northwest Fishery Science Center
National Marine Fisheries Service
2725 Montlake Blvd E
Seattle, WA 98077

Introduction

When the Council took final action on Amendment 16 to the Salmon FMP at the June, 2011 meeting in Spokane, among other things, Willapa Bay natural coho were added to the FMP. Because this stock is not currently included in the Pacific Salmon Treaty, they are subject to the annual catch limit (ACL) requirement. In addition, regardless of whether or not they are subject to the ACL requirement, they require specification of S_{MSY}, and status determination criteria (SDC). We currently report on the escapement of this stock in our annual review of Ocean Salmon Fisheries, and list a WDFW escapement goal of 13,090, but there is no FMP goal. The WDFW goal is based on watershed area, so it could be argued that it is an estimate of S_{MSY}, but that has not been done; the goal has not been reviewed or adopted by the Council, and there is no estimate of F_{MSY}. We also have no F_{MSY} proxy for tier 2 coho stocks (stocks with no direct estimate of F_{MSY}), so we have no basis for developing SDC or an ACL control rule. Consequently, the status quo is that S_{MSY}, SDC (MSST, OFL, FMFT), as well as ACL are all undefined.

The purpose of this report is to develop SDC for Willapa Bay natural coho from evaluation of spawner-recruit data.

Background

Willapa Bay coho were historically managed for hatchery production. Hatcheries are located on Forks Creek (Willapa River), Nemah River, and Naselle River. In the mid-1990s WDFW began monitoring natural spawning escapement and established natural escapement goals based on available habitat, assuming that habitat in the Willapa Bay drainage was half as productive as that in the lower Columbia River tributaries (Table 1).

In addition to ocean recreational and commercial fisheries, within Willapa Bay, there are commercial net fisheries, and recreational fisheries both in the bay itself, and freshwater fisheries in the tributaries.

Data and Methods

WDFW monitors spawning escapement and fisheries in Willapa Bay. The STT reports terminal catch data and spawning escapement in Appendix Table B-24 of our annual Review of Ocean Salmon Fisheries (STT 2013). Data in this table include natural spawners, hatchery spawners, terminal run, and terminal catches in gillnet and sport fisheries. However, WDFW maintains a more detailed dataset used for run reconstruction. The run reconstruction allocates catches to individual rivers and to hatchery and natural production on the basis of timing, location, and mark status. The run reconstruction backs natural and hatchery origin spawners out to terminal run size (Table 2). Spawner data used in this analysis were total natural are spawners regardless of origin, with no discounting for the effectiveness hatchery origin spawners in natural areas. Recruits were calculated by expanding the terminal run of natural origin adults by the preterminal ocean exploitation rates for unmarked fish calculated using the fishery regulation assessment model (FRAM).

While CWT data are available for hatchery fish from Forks Creek, Naselle, and Nemah Hatcheries in Willapa Bay, natural production is unmarked. During the time period for which data are available, mark-selective ocean fisheries have been implemented. Because there have been mixtures of mark-selective and non-selective fisheries within fisheries in individual years, there is no easy way to infer exploitation rates on unmarked fish from CWT data. In order to infer incidental mortality on unmarked fish from CWT data, it would be necessary to examine the time and location of each tag recovery and determine whether or not the fishery in which it was recovered was mark-selective in that port on that date. Thus pre-terminal exploitation rates for unmarked fish from FRAM provide a more consistent and convenient framework for generating pre-harvest recruit estimates, and were used for this analysis (Table 3). This is consistent with the methods used for other Washington coast coho stocks.

A stochastic Ricker spawner-recruit relationship (SRR) was fitted to the data. The SRR was of the form:

(1) $$R_{t+3} = \alpha S_t e^{-\beta S_t + \varepsilon_t}$$

where R is natural origin pre-harvest recruits, S is natural area spawners, and ε assumed to be normally distributed independent errors with mean 0 and variance σ^2. The SRR was fitted by least squares regression after transforming it:

(2) $$\ln\left({R_{t+3}}/{S_t}\right) = \ln(\alpha) - \beta S_t + \varepsilon_t$$

Parameter estimates were corrected for process error, with estimation bias and measures of precision of parameter and reference point estimates derived by bootstrapping 100,000 samples using the methods described in STT (2005).

Results and Discussion

The bias corrected parameter estimates along with MSY reference points are presented in Table 4, along with bootstrapped estimates of bias and precision. The fit of the Ricker spawner-recruit relationship is shown in Figure 1. The estimated S_{MSY} of 17,200 natural area spawners is somewhat higher than the current WDFW escapement goal of 13,090 spawners for the aggregate of all subcomponents of the Willapa Bay coho stock based on habitat area (Table 1). However, the agency goal is for natural origin spawners, while the analysis presented here used all spawners in natural areas regardless of origin. Since 1996, natural origin spawners have accounted for approximately 79% of the total spawning escapement to natural areas. Applying this average percentage of natural origin spawners, the S_{MSY} value of 17,200 equates to 13,600 natural origin spawners. This is surprisingly similar to the current escapement goal.

The estimated F_{MSY} of 0.75 from this analysis is somewhat higher than values estimated for other Washington coastal coho stocks. Those ranged from 0.59 for the Quillayute River, to 0.69 for the Hoh River and Grays Harbor. However, despite Willapa Bay having a higher estimated maximum sustainable exploitation rate than other Washington coastal coho stocks, this rate was exceeded in 2005, 2005, and 2009.

<u>Recommendations</u>

The STT currently reports spawning escapement for Willapa Bay coho in terms of natural origin and hatchery origin fish. Current agency goals are also expressed in these terms. From a pragmatic standpoint, it makes more sense to have an escapement goal (and SDC) based on the number of fish actually spawning, rather than on a portion of the natural spawning escapement. This is consistent with escapement goals on for other Washington coho stocks, and with the SDC the Council has adopted for Klamath River fall Chinook. The analysis presented here supports reference points of $F_{MSY} = 0.75$, and $S_{MSY} = 17,200$.

Based on these reference points the recommended SDC are:

MFMT = $F_{MSY} = 0.75$,

and

MSST = $0.5*S_{MSY} = 8,600$.

While other Washington coastal coho and Puget Sound coho stocks are exempt from the ACL requirement by virtue of being managed under an international agreement, Willapa Bay coho are not. Under the FMP, as a tier 1 stock, Willapa Bay coho would thus have an ACL set by the $F_{ABC} = 0.95*F_{MSY} = 0.71$.

References

STT. 2013. Review of 2012 Ocean Salmon Fisheries. Pacific Fishery Management Council. Portland, OR. February 2013. 364p.

STT 2005. Klamath River fall Chinook stock-recruitment analysis. Agenda Item G.1.b, Pacific Fishery Management Council. September, 2005. 31p.

Table 1. Current WDFW coho natural spawning escapement goals for Willapa Bay based on habitat area.

Watershed	Escapement Goal	Hatchery Program
North River/Smith Creek	5,286	No
Willapa River	4,030	Yes
Palix River	251	No
Nemah River	994	Yes
Naselle River	2,091	Yes
Bear River	438	No
Total	13,090	

Table 2. Summary of the terminal run reconstruction. Spawning escapement is separated into natural spawning and hatchery spawning, and fish are identified as either natural origin (NOR), or hatchery origin (HOR). Numbers that fed into the spawner-recruit analysis are indicated in bold.

	Spawners					Terminal Catch				Terminal Run Size	
	Natural			Hatchery		Recreational		Commercial			
Year	NOR	HOR	total	HOR	NOR	NOR	HOR	NOR	HOR	NOR	HOR
1996	15,711	25,824	**41,535**	23,071	-	796	3,256	7,953	30,369	24,460	82,520
1997	4,934	2,879	**7,813**	3,520	-	360	446	504	1,022	5,799	7,866
1998	13,804	1,971	**15,775**	4,814	-	297	555	5,687	7,453	19,788	14,793
1999	9,628	4,404	**14,032**	18,307	-	331	2,505	3,866	1,601	**13,825**	26,817
2000	23,031	3,648	**26,679**	25,500	3	177	1,603	3,702	6,624	**26,913**	37,375
2001	48,404	7,752	**56,156**	46,607	-	2,082	3,607	6,350	25,562	**56,836**	83,528
2002	52,722	13,702	**66,424**	41,136	-	1,500	4,185	15,395	44,037	**69,616**	103,061
2003	46,469	9,474	**55,943**	59,323	235	1,639	4,087	16,926	49,541	**65,269**	122,425
2004	36,437	7,996	**44,433**	13,224	202	968	1,393	9,190	7,336	**46,797**	29,949
2005	21,904	10,654	**32,558**	34,511	103	977	2,915	42,509	6,492	**65,493**	54,572
2006	12,009	2,292	**14,301**	5,796	297	342	464	9,934	10,014	**22,583**	18,565
2007	18,022	2,502	**20,524**	6,741	180	412	543	5,167	3,051	**23,781**	12,837
2008	14,778	3,784	**18,561**	8,704	120	540	687	11,067	5,632	**26,505**	18,806
2009	45,354	5,296	**50,650**	17,517	301	2,999	3,462	38,792	36,625	**87,447**	62,899
2010	76,434	16,594	93,028	23,581	139	1,311	3,618	16,698	21,414	**94,582**	65,207
2011	31,047	8,254	39,301	17,360	216	2,092	3,726	18,488	29,685	**51,843**	59,025
2012	20,024	4,323	24,347	12,846	232	2,735	2,317	13,913	11,978	**36,904**	31,464

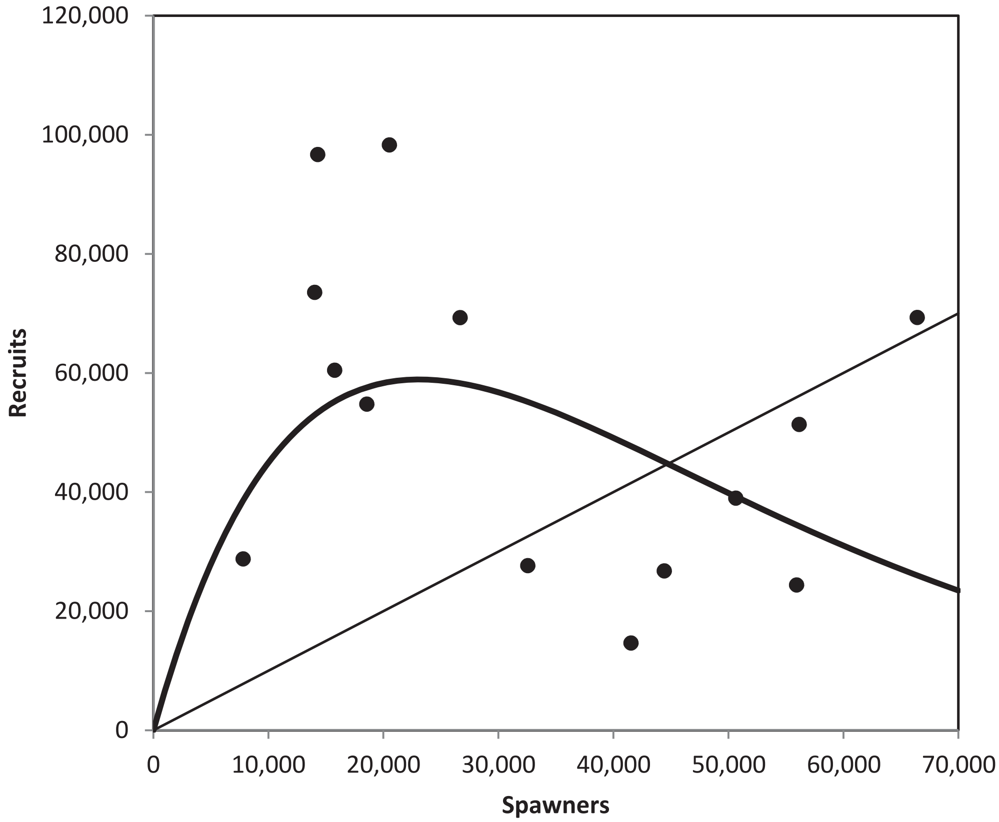
Table 3. Spawning escapement and recruitment data used for Willapa Bay coho. Spawners include both natural origin fish and hatchery origin fish that spawned in natural areas. Recruits include only natural origin fish.

Return Year	Total ER	Ocean ER	Natural Esc (inc hatchery strays)	NOR Esc	NOR Terminal Run	NOR Adult Recruits (NOR TR/(1-OcnER))
1996	42%	14%	**41,535**	15,711	24,549	28,489
1997	22%	10%	**7,813**	4,934	5,823	6,432
1998	54%	5%	**15,775**	13,804	19,824	20,721
1999	24%	4%	**14,032**	9,628	14,061	**14,394**
2000	36%	6%	**26,679**	23,034	26,992	**28,684**
2001	46%	6%	**56,156**	48,404	56,959	**60,322**
2002	70%	5%	**66,424**	52,722	69,672	**73,487**
2003	69%	6%	**55,943**	46,704	65,408	**69,144**
2004	48%	9%	**44,433**	36,639	46,819	**51,327**
2005	76%	5%	**32,558**	22,007	65,594	**69,218**
2006	88%	7%	**14,301**	12,306	22,609	**24,355**
2007	43%	11%	**20,524**	18,202	23,805	**26,739**
2008	50%	4%	**18,561**	14,898	26,546	**27,602**
2009	61%	9%	**50,650**	45,655	87,732	**96,378**
2010	46%	4%	93,028	76,573	94,582	**98,294**
2011	92%	5%	39,301	31,263	51,843	**54,764**
2012	na	5% est.	24,347	20,256	36,904	**38,983**

Table 4. Parameter estimates and reference points for Willapa Bay coho from fitting a Ricker spawner-recruit relationship to Willapa Bay coho data with correction for process error. Estimates of bias and precision based on 100,000 bootstrap replicates.

	Point estimate	Bootstrap mean	Bootstrap cv	90% lower bound	90% upper bound
α	6.91	7.24	30.8%	4.14	11.33
β	0.0000433	0.0000433	18.5%	0.0000302	0.0000566
S_{MSY}	17,200	17,300	12.5%	14,300	21,200
F_{MSY}	0.75	.71	8.8%	0.62	0.83

Figure 1. Fit of Ricker spawner-recruit relationship to Willapa Bay coho data including correction for process error. Spawners are in terms of total natural spawners, both hatchery and natural origin. Recruits are in terms of natural origin recruits.



Agenda Item C.2.a
Attachment 7
November 2013

Conservation Objective for Southern Oregon coastal Chinook

Todd Confer
Matt Falcy

Oregon Department of Fish and Wildlife

September 2013

Table of Contents

Introduction

The current conservation objective for Southern Oregon coastal Chinook (SOCC) in the Pacific Coast Salmon Fishery Management Plan was based on information and reports that are now outdated. SOCC stocks are included as an unspecified portion of an aggregate Oregon coast natural adult spawner goal of 60-90 spawners per mile. As a result of the Amendment 16 process SOCC were classified as a component stock of the Southern Oregon Northern California complex regulated by Annual Catch Limits that use Klamath River fall Chinook as the indicator stock. Oregon Department of Fish and Wildlife (ODFW) recently completed the *Conservation Plan for Fall Chinook Salmon in the Rogue Species Management Unit* (Rogue Plan) and it was adopted by the Oregon Fish and Wildlife Commission in January, 2013 (ODFW 2013). The Rogue Plan covers the geographic area and fall Chinook stocks that are defined as SOCC.

Analyses used in developing the Rogue Plan are described in detail in the plan itself and its appendices, which may be found at:

http://www.dfw.state.or.us/fish/CRP/rogue_fall_chinook_conservation_plan.asp

and

http://dfw.state.or.us/fish/CRP/docs/rogue_fall_chinook/Rogue_fall
Chinook_Plan_Final_Appendixes_1-11-13.pdf

Development of new conservation objectives may be implemented without plan amendment upon approval by the Council. The Rogue Plan provides new information and data analyses for use in updating the current conservation objective for SOCC.

Methods and Results

Spawner and Freshwater Escapement Estimates For Rogue River Basin Fall Chinook

There are five populations of fall Chinook present in the Rogue River Basin. The populations are generally defined as Upper Rogue, Middle Rogue, Lower Rogue, Applegate, and Illinois. Availability of adult fall Chinook abundance data within these populations varies markedly. An overview of the sources of available data follows. Only those data sets which covered at least five consecutive years are described. Also described is the relevance of the data to the development of the Rogue Plan.

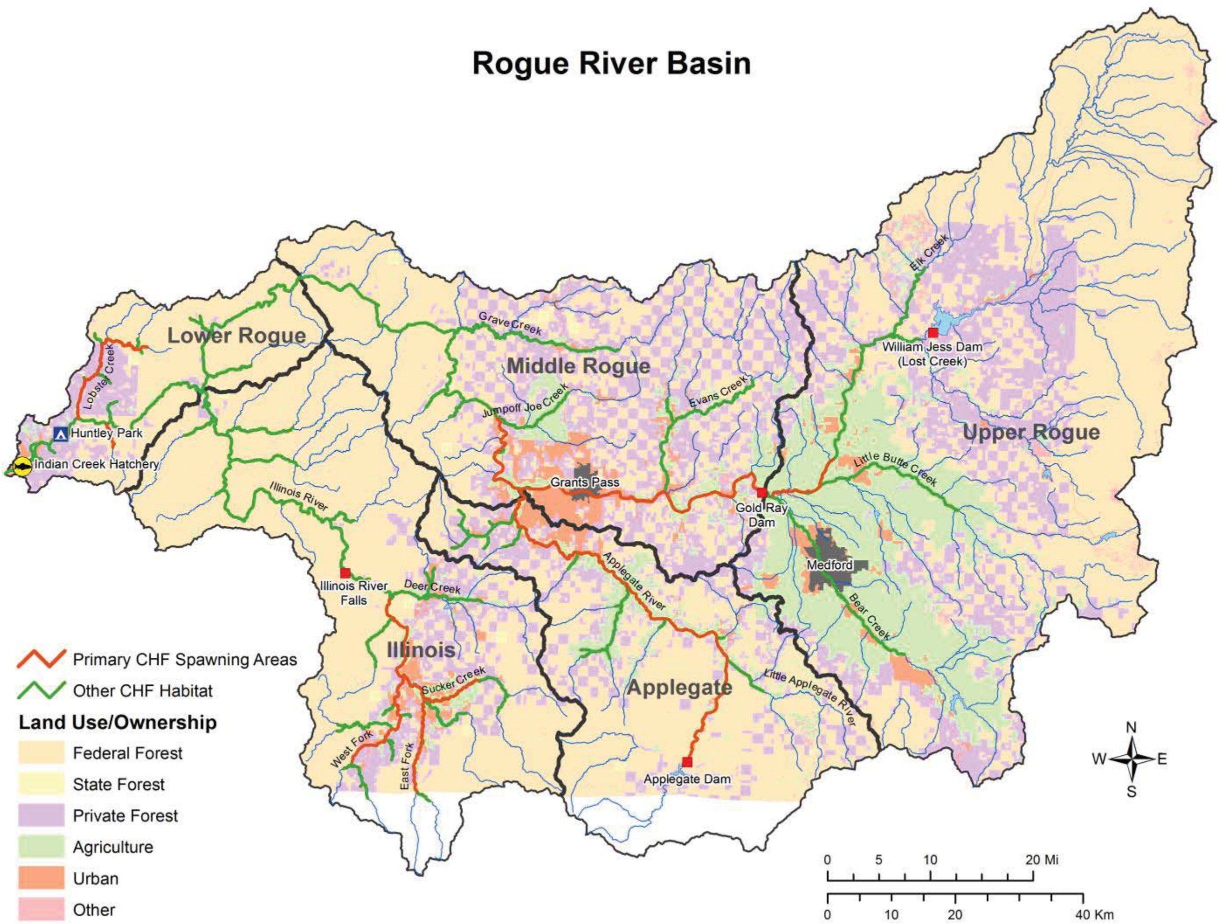


Figure 1. Spatial distribution of independent populations of fall Chinook salmon in the Rogue stratum of the Species Management Unit. The boundaries of the different population areas are shown as black lines.

Lower Rogue population:
Spawners (live and dead fall Chinook) were counted in portions of various tributary streams during 1986-2010. This database was directly relevant to the purpose of the Rogue Plan because spawner abundance could be estimated for the entire population, criteria could be developed in

relation to desired status and conservation status, and monitoring is ongoing and expected to continue for the foreseeable future.

Middle Rogue population:
Carcasses were counted within two survey areas located on the mainstem of the Rogue River during 1974-2004. The areas surveyed included Valley of the Rogue State Park - the city of Rogue River (RM 113-111) and Lathrop's Landing - Robertson Bridge (RM 97-87). This database was judged to not be directly relevant to the purpose of the Rogue Plan because the data could not be used to estimate spawner abundance for the entire population, and monitoring has been terminated and is not expected to be implemented again within the foreseeable future. As a result it was judged there was minimal value in trying to craft criteria for desired status or conservation status for this population.

Upper Rogue population:
Fish passage at Gold Ray Dam (RM 125) was estimated at a counting station during 1942-2009. In August 2010, the fish counting station became inoperable with the removal of Gold Ray Dam. Substitution of spawning surveys to estimate fall Chinook spawner abundance is not possible because of the spatial and temporal overlap in spring and fall Chinook spawning in this area (ODFW 1991). With the loss of the fish counting station, it was judged there was minimal value in trying to craft criteria for desired status or conservation status for this population.

Illinois population:
Spawners (live and dead fall Chinook) were counted within portions of three tributary streams (Mendenhall Creek, Elk Creek, and Sucker Creek) during 1996-2004. This database was judged to not be directly relevant to the purpose of the Rogue Plan because the data could not be used to estimate spawner abundance for the entire population, and monitoring has been terminated and is not expected to be implemented again within the foreseeable future. In addition, ODFW staff judged that fall Chinook spawn primarily in the mainstem, and in the East and West Forks. It is currently unknown whether spawner counts in the smaller tributaries may be representative of spawning escapement throughout the entire basin. As a result of these factors, it was judged there was minimal value in trying to craft criteria for desired status or conservation status for this population.

Applegate population:
Carcasses were counted within three survey areas located on the mainstem of the Applegate River, and in Slate Creek, during 1974-2004. The areas surveyed in the Applegate River included the town of Applegate - Williams Creek (RM 25-20), the town of Murphy - Hog Ranch (RM 13-11), and Highway 199 - the mouth (RM 4-0). The Slate Creek survey covered the lowest 5.0 miles of Slate Creek. This database was judged to not be directly relevant to the purpose of the Rogue Plan because the data could not be used to estimate spawner abundance for the entire population. Monitoring has been terminated and is not expected to be implemented again within the foreseeable future. As a result, it was judged there was minimal value in trying to craft criteria for desired status or conservation status for this population.

Aggregate populations

Migrating adults were captured during 1976-2010 with a 300' beach seine fished at Huntley Park (RM 8) three days weekly during July 15-October 28 (ODFW 1992). Each day, sampling began early in the morning and continued until the seine had been fished 15 times. This sampling effort was standardized in 1978 and tagging studies indicated that all of the fall Chinook populations in the Rogue River Basin are susceptible to capture (ODFW 1992).

The Oregon Game Commission (OGC, now ODFW) began beach seining near the mouth of the Rogue River in 1974 in order to capture adult salmonids that entered the Rogue River. Initially, the sampling was designed to collect fish in order to obtain life history information and to estimate freshwater escapement through the use of mark-recapture methods. Mark-recapture efforts were terminated after 1976 when it became apparent that mortality rates of tagged Chinook salmon resulted in biased estimates of freshwater escapement (Cramer 1979). Instead, catch per unit of seining effort was used as an index of abundance. This approach continued through the 1980s, although it became apparent that unusually high flows in 1983 and 1984 affected the efficacy of sampling with the beach seine at the Huntley Park site.

Establishment of a run of hatchery coho salmon in the early 1980s afforded an opportunity to generate annual estimates of seining efficiency. Available data indicated that few coho salmon died during upstream migration, few hatchery fish strayed to spawn naturally, and at the time, there was no directed freshwater fishery for coho salmon. Seining efficiency on coho salmon of hatchery origin was estimated, compared to flow at time of seine capture, and a catch efficiency model was developed (ODFW 1989). This flow-based model was subsequently used to estimate freshwater escapement for other runs of anadromous salmonids, including fall Chinook (ODFW 1989; ODFW 1992; ODFW 1994).

In 1992, ODFW determined that the flow-based model significantly underestimated the number of fall Chinook that returned to the Rogue River. During some years, known numbers of fall Chinook exceeded the estimate produced by the flow-based model. Known numbers of fall Chinook included: (1) those that passed the fish counting station at Gold Ray Dam, (2) those recovered as carcasses during spawning surveys, and (3) those estimated to be harvested by anglers based on returns of salmon-steelhead cards. In light of these results, ODFW subsequently termed estimates derived from the flow-based model as the “Huntley Park Index” of fall Chinook freshwater escapement, to differentiate it from a formal abundance estimate.

Estimating fall Chinook Passage at Huntley Park

ODFW has developed two methods to estimate the number of fall Chinook that passed Huntley Park. Both methods entail expansion of the Huntley Park Index. The first method uses the results of mark-recapture efforts during 2000-2002 to calibrate the passage index. The second method uses historic fall Chinook passage estimates at Gold Ray Dam to calibrate the passage index. Both methods resulted in similar passage estimates at Huntley Park and a description of each method follows.

Calibration of Huntley Park Index with mark-recapture estimates:
ODFW has tried twice (once during 1975-76 and once during 2000-2002) to estimate fall Chinook escapement in the Rogue River using mark-recapture methods. Freshwater returns were estimated to be about 63,000 fish in 1975 and about 93,000 fish in 1976 (Table 1). However, these estimates were judged to be inflated by disproportionately high mortality of tagged fish (Smith et al. 1978).

Instances of significant prespawning mortality decreased markedly after the mid-1980s as water release strategies at Lost Creek Dam were modified to increase flow during critical periods of fall Chinook migration (ODFW 1992). The only instance of significant prespawning mortality occurred during the drought year of 2001 (Satterthwaite 2002). The decrease in fall Chinook prespawning mortality led ODFW to attempt another series of mark-recapture efforts with fall Chinook during 2000-2002. Resultant mark-recapture estimates of the number of fall Chinook that passed Huntley Park during these years ranged between 126,000 and 405,000 fish (Table 1).

Table 1. Petersen mark-recapture estimates of the number of fall Chinook salmon that entered the Rogue River, 1975-2002 and associated data relevant to the calibration of the Huntley Park Index of freshwater escapement. River physical factors are reported as mean daily maximum values during August at Agness (RM 30).

	Mark-recapture		Huntley	River physical factors	
Year	estimate (95% CI)		Index	Flow (cfs)	Temperature (F)
1975	63,235	(47,160-87,655)	37,175	1,716	--
1976	92,977	(61,807-147,043)	23,469	2,149	71
2000	126,085	(88,540-208,919)	40,047	2,317	73
2001	404,660	(192,880-616,440)	42,577	1,762	74
2002	203,267	(150,057-290,622)	80,545	2,027	72

All of the mark-recapture estimates listed in Table 1 are believed to be inflated to some degree because of delayed mortality among tagged fish. Bias related to tagging mortality was judged to be differentially high in 2001 because of low flow and extensive prespawning mortality (Satterthwaite 2002). Consequently, the 2001 estimate was excluded from further consideration. Tagging related mortality was assumed to be 10% in the other years, resulting in adjusted mark-recapture estimates of 113,476 in 2000 and 182,940 in 2002. The escapement estimates exceeded the Huntley Passage Indexes by 2.70-fold in 2000 and 2.27- fold in 2002. The average (2.485) of these values was used to expand the Huntley Passage Index for the period of record. Expanded values were then used as estimates of the total number of fall Chinook that passed Huntley Park. Resultant estimates are shown as "Method 1" in Table 2.

Calibration of Huntley Park Index with Gold Ray Dam counts:
ODFW has estimated fish passage at Gold Ray Dam since 1942. All passing fish were counted during 1942-1947. During 1948-92, fish were counted eight hours daily, five days weekly. Partial count sampling designs were intended to estimate biweekly passage with an average error of less than 10% (Li 1948). Since 1993, passage has been estimated with 24-hour, seven day per

week video recordings; a procedure which is assumed to have minimal uncertainty. Chinook salmon that pass the counting station by August 15 are classified as spring Chinook, while later migrants are classified as fall Chinook (ODFW 2000).

ODFW tagged numerous fall Chinook in the lower Rogue during 1974-78 and looked for tags on carcasses found during spawning surveys. Most tags were recovered in the Middle Rogue, Applegate, and Lower Rogue population areas. However, five tags were recovered upstream of Gold Ray Dam (Upper Rogue population area). All of these fish had been captured and tagged at Huntley Park between July 15 and August 4 and were considered early-run fall Chinook. Remaining tag recoveries indicated that later migrating fall Chinook eventually spawned in population areas farther downstream in the Rogue River Basin (ODFW 1992). Early-run fish are therefore defined as those fall Chinook that pass Huntley Park before August 4.

Application of radio-tags to a few fall Chinook caught at Huntley Park in 2008 (ODFW 2009) afforded the opportunity to examine the assumption that early-run fall Chinook migrate upstream to spawning areas above Gold Ray Dam. There were three early-run fall Chinook tagged at Huntley Park that passed Gold Ray Dam. One passed on August 11 and was therefore classified as a spring Chinook. The other two passed after August 5 and were thus classified as fall Chinook. Another three fall Chinook were tagged at Huntley Park after August 4 and were subsequently detected on spawning grounds downstream of Gold Ray Dam.

The OGC tagged large numbers of fall Chinook near the mouth of the Rogue River in 1970 and in 1971 during a summer steelhead research project (Everest 1973). Efforts to recover tagged fall Chinook were limited to a few spawning surveys, but 36 tagged fall Chinook were trapped at Gold Ray Dam. The mean date of tagging at the river's mouth was August 11 (95% CI = ±4 days). These results, coupled with the 1974-78 tag recoveries, confirmed that early-run fall Chinook primarily spawn upstream of Gold Ray Dam. Assuming that all early-run fish pass the Gold Ray Dam counting station, an appropriate expansion factor could be developed for the Huntley Park Index.

The early-run component of the Huntley Passage Index accounted for an average of 40% (95% CI for arc-sine transformed data = 17-64%) of the early-run fall Chinook that subsequently reached Gold Ray Dam during 1992-2008. Data from years prior to 1992 were not included because of concern that the population of fall Chinook in the upper Rogue was still increasing during that time relative to fall Chinook in the remainder of the basin (ODFW 2000). Because 17 years (1992-2008) of data are available, it was judged that effects due to variations in fall Chinook migration timing would likely be mostly cancelled provided that annual variations in fall Chinook migration timing were random in nature. Assuming that 40% of fish passing Huntley Park are reflected in the Huntley Park Index, an expansion factor of 2.5 (1/40%) was used to produce the Huntley Park estimates referred to as "Method 2" in Table 2.

Table 2. Four abundance metrics for abundance of fall Chinook salmon in the Rogue River Basin, 1974-2010.

Year	Total known[a]	Huntley Index[b]	Passage at Huntley Park Method 1[c]	Passage at Huntley Park Method 2[d]
1974	--	42,656	106,021	106,660
1975	--	37,175	92,383	92,940
1976	--	23,469	58,329	58,680
1977	12,697	32,038	79,615	80,095
1978	18,501	74,575	185,321	186,438
1979	13,239	69,730	173,281	174,325
1980	6,497	33,478	83,194	83,695
1981	13,552	41,420	102,942	103,563
1982	10,568	55,735	138,506	139,340
1983	9,314	21,464	53,336	53,658
1984	8,336	18,212	45,257	45,530
1985	20,282	36,109	89,722	90,263
1986	39,760	98,314	244,291	245,763
1987	51,204	65,133	161,857	162,833
1988	61,078	33,930	84,319	85,423
1989	24,787	38,767	96,337	96,918
1990	9,472	10,187	25,315	25,468
1991	10,749	7,544	18,747	18,860
1992	13,403	31,288	77,751	78,220
1993	22,515	19,002	47,220	47,505
1994	30,740	33,114	82,290	82,786
1995	28,580	35,444	88,079	88,610
1996	20,283	27,004	67,105	67,509
1997	10,056	24,625	61,193	61,562
1998	12,435	19,967	49,618	49,917
1999	9,500	23,710	58,920	59,275
2000	21,624	42,047	104,489	105,118
2001	29,095	42,577	105,805	106,442
2002	42,491	80,545	200,157	201,363
2003	57,760	94,231	234,167	235,577
2004	--	63,561	157,950	158,902
2005	--	25,821	64,167	64,553
2006	--	17,972	44,660	44,929
2007	--	20,366	50,740	50,914
2008	--	17,336	43,080	43,340
2009	--	30,453	75,676	76,132
2010	--	26,633	66,184	66,582

[a] *Carcasses were not surveyed after 2003 and only three areas were surveyed during 1974-76.*
[b] *Index values for 1974-77 were adjusted for non-standardized sampling (ODFW 1992).*
[c] *Huntley Park Index calibrated with mark-recapture estimates from 2000 and 2002.*
[d] *Huntley Park Index calibrated with 1992-2009 passage estimates at Gold Ray Dam.*

In summary, the Gold Ray Dam counts provide an accurate abundance estimate of the Upper Rogue population and tag recoveries indicate that this population passes Huntley Park by August 5. A comparison of the Huntley Park Index, calculated only for the period July 15-August 5, with the Gold Ray dam counts resulted in the conclusion that fall Chinook passage at Huntley Park is best estimated with the application of a 2.5X expansion factor (0.40/Huntley Park Index).

Estimation of Life History Parameters

Aggregate populations:
Scale interpretations were used to estimate the origin and age composition of fall Chinook that entered the Rogue River during 1974-1988 (ODFW 1992). Scales were also used to estimate fall Chinook age composition for the 2007-2011 returns. The age composition of the 1989-2006 returns was estimated based on length-at-age criteria developed from scale samples obtained from the 2007-2011 returns. Annual proportions of hatchery fish within the 1989-2011 returns were estimated by expanding the number of fin-clipped fish caught at Huntley Park by the mark rates among cohorts released from hatcheries in the Rogue River Basin. Fin-clipped fish were assigned to specific brood years based on their length. Final estimates of fall Chinook passage at Huntley Park can be found in Table 3.

All spawners were assumed to be naturally produced fish. During 1991-2004, ODFW recovered about 80,000 fall Chinook carcasses during spawner surveys conducted throughout the Rogue River Basin. Only 54 of those fish were marked with adipose fin clips and expansions for the proportions of smolts indicated that hatchery fish composed about 0.2% of the spawners, which was judged to be insignificant.

Table 3. Estimated number of adult fall Chinook salmon that passed Huntley Park and the estimated age composition of naturally produced fish, 1974-2011.

Return	Passage Estimate			Proportion by Age				
Year	Natural	Hatchery	Total[1]	Age 2	Age 3	Age 4	Age 5	Age 6
1974	106,021	0	106,021	0.189	0.271	0.461	0.070	0.009
1975	92,383	0	92,383	0.118	0.195	0.567	0.113	0.008
1976	58,329	0	58,329	0.414	0.174	0.343	0.069	0.000
1977	79,615	0	79,615	0.676	0.167	0.129	0.028	0.000
1978	185,321	0	185,321	0.162	0.377	0.405	0.056	0.000
1979	173,281	0	173,281	0.054	0.101	0.802	0.044	0.000
1980	83,010	184	83,194	0.343	0.110	0.284	0.262	0.000
1981	101,429	1,513	102,942	0.258	0.486	0.175	0.073	0.010
1982	134,684	3,822	138,506	0.274	0.266	0.432	0.027	0.001
1983	45,441	7,895	53,336	0.148	0.487	0.336	0.030	0.000
1984	42,255	3,002	45,257	0.231	0.374	0.360	0.029	0.005
1985	84,141	5,582	89,722	0.581	0.110	0.261	0.048	0.000
1986	229,858	14,433	244,291	0.373	0.497	0.113	0.016	0.001
1987	147,944	13,914	161,857	0.210	0.398	0.364	0.028	0.000
1988	79,078	5,241	84,319	0.144	0.198	0.606	0.052	0.000
1989	89,144	7,193	96,337	0.170	0.323	0.421	0.070	0.016
1990	23,915	1,400	25,315	0.183	0.370	0.395	0.051	0.000
1991	18,364	383	18,747	0.184	0.476	0.309	0.031	0.000
1992	76,456	1,295	77,751	0.415	0.232	0.277	0.069	0.008
1993	46,668	552	47,220	0.228	0.598	0.128	0.040	0.006
1994	80,707	1,584	82,290	0.164	0.435	0.357	0.043	0.001
1995	82,745	5,334	88,079	0.224	0.510	0.215	0.046	0.005
1996	64,445	2,660	67,105	0.243	0.380	0.338	0.036	0.003
1997	58,860	2,333	61,193	0.302	0.386	0.241	0.061	0.010
1998	47,732	1,886	49,618	0.142	0.577	0.257	0.024	0.000
1999	56,350	2,570	58,920	0.333	0.264	0.287	0.093	0.023
2000	100,701	3,787	104,489	0.128	0.581	0.216	0.070	0.004
2001	103,026	2,778	105,805	0.259	0.274	0.314	0.134	0.020
2002	196,948	3,209	200,157	0.217	0.318	0.313	0.119	0.033
2003	224,139	10,027	234,167	0.086	0.287	0.425	0.173	0.029
2004	152,081	5,869	157,950	0.130	0.197	0.446	0.188	0.040
2005	61,323	2,843	64,167	0.079	0.281	0.455	0.158	0.026
2006	41,845	2,815	44,660	0.162	0.254	0.428	0.134	0.023
2007	46,778	4,264	51,041	0.070	0.326	0.343	0.256	0.005
2008	39,495	3,751	43,246	0.384	0.181	0.336	0.099	0.000
2009	73,883	2,369	76,252	0.185	0.419	0.342	0.055	0.000
2010	63,849	2,335	66,184	0.223	0.348	0.390	0.038	0.002
2011	97,875	3,044	109,919	0.308	0.242	0.397	0.052	0.001

[1] Total is from Method 1, Table 2.

Estimation of Freshwater Harvest

Aggregate populations: Freshwater harvest (includes the estuary) was estimated from salmon-steelhead cards (punchcards) returned to ODFW by anglers. ODFW (1992) reported estimates of total harvest for 1956-1984. Estimates for later years were obtained from ODFW records. Harvest estimates from salmon-steelhead cards do not include jacks; which are almost all age 2 fish (ODFW 1992). Harvest of jacks was estimated based on their proportion among fall Chinook captured at Huntley Park (i.e., it was assumed that the freshwater fishery did not selectively harvest fall Chinook of different ages).

Estimates of fall Chinook harvest were segregated into areas upstream and downstream of Huntley Park. Angler harvest downstream of Huntley Park was assumed to equal the salmon-steelhead card estimates applicable to the Rogue River downstream of Elephant Rock (RM 3). Estimates for this area were only available for 1993 and later years. During this period, the area downstream of Elephant Rock accounted for an average of 53% (95% CI = 48-58% as estimated from arcsine transformed data). The mean estimate of harvest distribution was applied to years prior to 1993 in order to estimate angler harvest downstream of Elephant Rock.

Table 4. Estimates of population and harvest metrics for aggregated populations of naturally produced fall Chinook salmon in the Rogue River Basin, 1972-2006 brood years.

Brood year	Ocean harvest	River[a] return	River Harvest[a] Below Huntley	River Harvest[a] Above Huntley	Total river harvest	Brood harvest rate	Recruits	Parent Spawners[b]
1972	64,832	41,380	1,125	989	2,115	0.668	100,232	--
1973	98,268	32,036	1,246	1,095	2,341	0.882	114,121	--
1974	212,244	97,548	1,712	1,505	3,218	0.744	289,621	82,518
1975	479,073	233,165	1,572	1,382	2,954	0.732	658,090	78,840
1976	105,752	48,979	444	390	834	0.756	141,072	32,474
1977	60,128	30,961	433	380	813	0.722	84,397	23,486
1978	176,491	110,628	1,642	1,444	3,086	0.630	285,148	134,691
1979	182,635	53,266	942	828	1,769	0.489	377,237	29,875
1980	73,955	42,684	1,198	1,053	2,252	0.320	238,336	23,206
1981	19,258	43,052	1,572	1,382	2,954	0.365	60,935	65,448
1982	45,547	40,631	1,157	1,017	2,173	0.578	82,591	92,768
1983	120,683	179,001	5,409	4,754	10,163	0.450	290,726	37,696
1984	84,580	122,570	9,563	8,406	17,968	0.509	201,344	31,683
1985	51,980	59,010	4,616	4,058	8,674	0.565	107,284	33,414
1986	27,551	42,414	2,981	2,620	5,601	0.486	68,221	140,969
1987	17,434	22,151	2,071	1,831	3,902	0.576	37,061	109,293
1988	3,721	34,422	2,578	2,337	4,915	0.228	37,919	58,733
1989	3,751	29,509	1,892	1,883	3,775	0.229	32,910	68,177
1990	8,882	67,132	6,456	6,666	13,122	0.292	75,470	17,403
1991	6,890	60,663	4,884	3,841	8,725	0.232	67,192	12,581
1992	9,291	73,109	5,536	3,671	9,207	0.226	82,007	42,112
1993	4,353	43,522	2,429	2,019	4,448	0.185	47,566	29,866
1994	3,294	42,572	1,909	1,418	3,327	0.145	45,622	60,887
1995	4,810	55,370	2,598	1,874	4,472	0.155	59,722	59,464
1996	11,699	59,517	2,623	2,430	5,054	0.241	69,616	44,949
1997	27,674	126,338	5,523	5,139	10,662	0.255	150,542	38,785
1998	50,222	139,168	4,503	5,952	10,455	0.330	183,635	38,864
1999	65,609	194,007	6,007	7,682	13,688	0.311	254,879	35,293
2000	68,144	147,337	4,559	5,743	10,302	0.372	210,998	82,935
2001	22,469	65,713	2,066	2,448	4,514	0.312	86,379	63,555
2002	9,134	49,755	2,629	1,650	4,279	0.230	58,211	144,954
2003	6,902	32,407	1,864	955	2,819	0.250	38,938	191,999
2004	5,004	34,601	1,917	1,101	3,017	0.205	39,173	124,571
2005	124	38,319	3,400	1,383	4,783	0.128	38,442	53,208
2006	1,987	66,201	5,301	2,355	7,656	0.140	68,654	32,873

[a] *Includes estuary.*

[b] *Age 3-6; includes hatchery fish.*

Estimation of Spawning Escapement

Aggregate populations:
Spawning escapement in the Rogue River Basin was estimated as:

Passage estimates at Huntley Park - (prespawning mortality + angler harvest)

Fall Chinook in the Rogue River are susceptible to high rates of prespawning mortality during years of low flow and warm water temperatures. Rates of prespawning mortality were estimated during 1978-1986 (ODFW 1992) and during 2001 (Satterthwaite 2002). Prespawning mortality rates in all other years were assumed to equal 2% because there were no anecdotal reports of significant prespawning mortality in years after 1986 (2001 excepted).

Estimation of Ocean Fishery Impacts

Annual exploitation rates on age 3 and age 4 fish in the ocean fisheries were assumed to equal those estimated for fall Chinook salmon of Klamath River Basin origin, as reported by the Pacific Fishery Management Council (PFMC 2010). Ocean exploitation rates on age 5 and age 6 fish were assumed to equal those on age 4 fish. These assumptions had to be made because there were no consistent releases of CWT marked fall Chinook from hatcheries within the Rogue River Basin that would allow for direct estimation of exploitation rates in the ocean fisheries.

The assumption of equal ocean exploitation rates on age 3 and age 4 fish of Rogue and Klamath origin appeared reasonable because (1) Rogue and Klamath fall Chinook exhibit indistinguishable catch distribution patterns in the ocean fisheries (Table 5) and (2) freshwater returns of fall Chinook in the Rogue and Klamath rivers are positively correlated to each other (*see* Comparisons to Other Populations, page 69 in the Rogue Plan). Weitkamp (2010) also documented very similar ocean landing distributions of Chinook salmon released from hatcheries in the Southern Oregon - Northern California ecoregion.

Table 5. Comparisons of landing distributions of CWT-marked fall Chinook salmon released from hatcheries in the Rogue and Klamath River basins, 1987-2003 brood years. Data incorporated in the analyses include only those CWT groups released after the month of August. Comparisons were made with paired t-tests of arcsine transformed data. Data from Iron Gate and Trinity River hatcheries in the Klamath River Basin were pooled because no difference in landing distributions could be detected (paired t-test $P = 0.52$).

	Mean by Stock		*P* for
	Rogue	Klamath	difference
Proportion landed in California and Oregon	0.99	0.99	0.76
Proportion landed in Oregon only	0.43	0.45	0.38

Estimation of Ocean Abundance

Cohort reconstructions (Ricker 1975) were employed to estimate the number of naturally-produced fall Chinook that resided in the ocean during the spring prior to onset of any fishing mortality. Estimation procedures began with age 6 fish and ended with age 3 fish and were analogous to those employed by Hankin and Healy (1986) and Mohr (2006). Estimates of cohort abundance began with age 6 fish because all naturally-produced fall Chinook of Rogue River Basin origin mature at ages 2-6. The abundance of younger cohorts were estimated as the sum of (1) the number of fish that resided in the ocean during the succeeding year, (2) natural mortality, (3) harvest in the ocean fisheries, and (4) the number of fish that returned to the river.

For each cohort, we used the equation:

$$N_i = \frac{\dfrac{N_{i+1}}{1 - A_i} + E_i}{1 - u_i}$$

where

N_i = number of age i fish resident in the ocean prior to fishing during year t,
N_{i+1} = number of age i+1 fish resident in the ocean during the next year,
A_i = rate of natural mortality for age i cohorts resident in the ocean between years t and t+1,
u_i = exploitation rate of age i fish in the ocean during year t, and
E_i = freshwater return of age i fish during year t.

Estimation of Recruitment

For each cohort (brood year), recruitment was estimated as the sum of the estimated freshwater returns of age 3-6 fall Chinook under a scenario of no ocean fishing mortality (as termed “adult equivalents” by Mohr (2006)).

Population Models

For each population, we assessed the relationship between the abundance of spawners on a given year and the resulting number of adult progeny (recruits) produced by those spawners. This spawner-recruit analysis yields information about trans-generational population dynamics that is subsequently used to assess extinction risk in a population viability analysis (PVA). This appendix begins by describing spawner-recruit analysis and then goes on to describe how results from this analysis are used in a PVA.

Spawner-Recruit Relationships

Annual estimates of spawner abundance and recruits produced for each population were used to assess the shape and strength of relationship between estimates of spawners and recruits. A simple straight linear relationship between spawners and recruits is biologically unrealistic because, among other reasons, it suggests that there is no upper limit to the number of recruits that can be produced. Thus, a nonlinear relationship between spawners and recruits is more appropriate. We considered the two most common relationships commonly used by fish scientists; the Ricker (1954) and Beverton-Holt (1957) curves.

The Ricker curve (Ricker, 1954):

$$R = \alpha S e^{-\beta_{RK} S} \qquad \textit{Eq. 1}$$

and the Beverton-Holt function (Beverton and Holt, 1957):

$$R = \frac{\alpha S}{1 + \frac{\alpha}{\beta_{BH}} S} \qquad \textit{Eq. 2}$$

Both functions model recruit abundance (*R*) as a two-parameter function of spawner abundance (*S*). In both equations, α represents “intrinsic productivity,” which is the number of recruits produced per spawner as spawner abundance approaches zero. This value therefore represent the reproductive output when animals are uninhibited by density-dependent effects, and is an important component of population resiliency. The meaning of the β parameter is different in the two functions, and so we denote this difference by using subscripts RK and BH in equations 1 and 2 above. In a Ricker function, β_{RK} indicates the rate of decline in recruit abundance (*R*) as spawner abundance (*S*) increases. There are different algebraic ways of writing the Beverton-Holt function (*see* Equations 7-9 below), but as it is written in Equation 2, the β_{BH} parameter represents the asymptote of recruit abundances as *S* increases. Example Ricker and Beverton-Holt functions are plotted in Figure 2. The Ricker function (red) assumes that recruitment drops at very high spawner abundances while the Beverton-Holt function (blue) assumes that recruitment asymptotes as spawner abundance increases. The maximum sustained yield occurs at the spawner abundance (S_{MSY}) with the maximum vertical distance (dotted) between the model (colored) and population replacement (black). In the absence of fishing mortality, spawner abundance will reach equilibrium at N_{eq}.

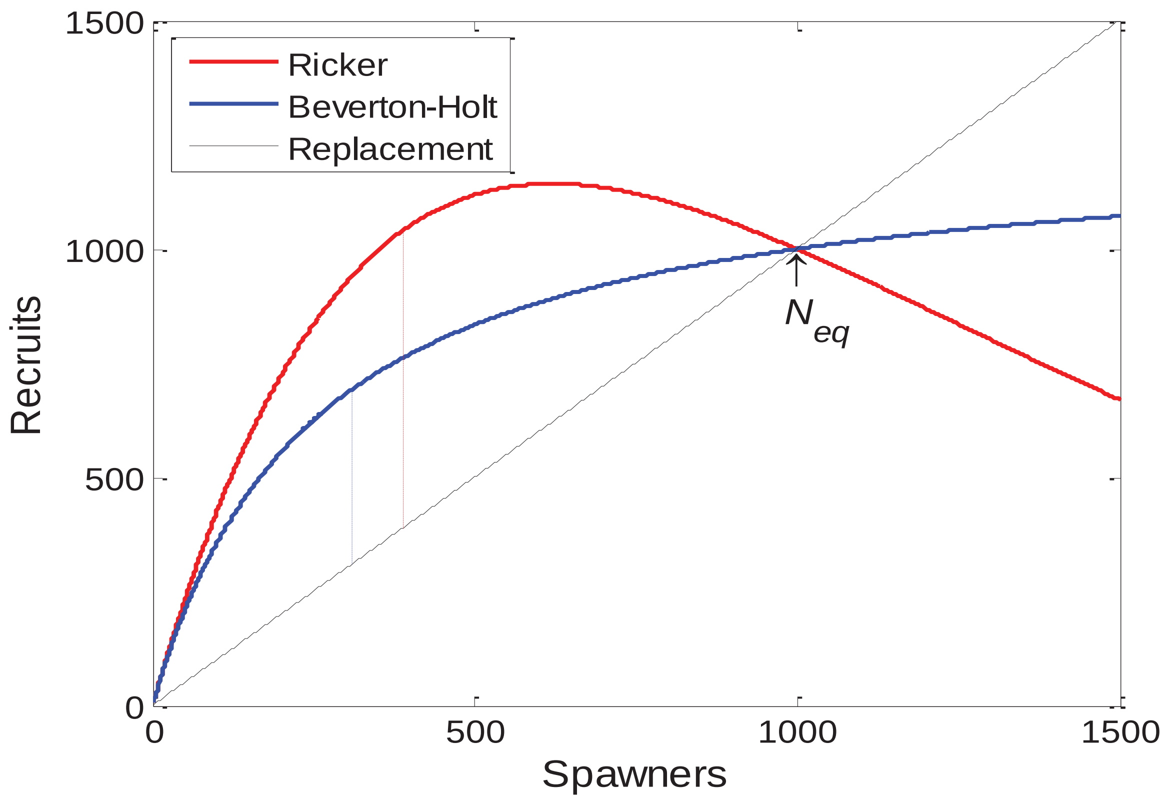


Figure 2. Example Ricker and Beverton-Holt functions.

Both functions in Figure 2 assume α = 5. Values of β were selected for each function so that they cross the replacement line (spawners = recruits) at a point corresponding to 1000 spawners and recruits•. The point where the function crosses the replacement line is denoted N_{eq}. If there was no harvest, then all recruits would become spawners, and abundance of spawners would be in equilibrium at N_{eq}.

Maximum sustained yield is a mathematical concept that can be derived from spawner-recruit relationships. It is the maximum number of animals that can be harvested such that the abundance of animals escaping harvest should produce an equally harvestable surplus of recruits. Graphically, the number of spawners that produces MSY (S_{MSY}) is the point on the x-axis of a spawner-recruit plot where there is maximum vertical distance between recruits and the replacement line (Figure F 2). Attempts to manage fish abundances to attain MSY have been implicated in the overfishing and collapse of many fisheries (Larkin 1977; Finley 2011). Although we do not advocate MSY-based fish management, we nonetheless compute S_{MSY} because we define critical conservation abundance as 50% of the 75th percentile of our estimate of S_{MSY} (*see* next section).

• Solve Equation 1 and Equation 2 for R=S, call the result Neq, then rearrange for β to obtain:

$$\beta_{RK} = \frac{\log(\alpha)}{N_{eq}}, \beta_{BH} = \frac{N_{eq}\alpha}{\alpha - 1}$$

For the Ricker and Beverton-Holt functions, S_{MSY} is, respectively:

$$S_{MSY} = \frac{\ln(\alpha)}{\beta_{RK}}\left(0.5 - 0.07\ln(\alpha)\right) \qquad \textit{Eq. 3}$$

$$S_{MSY} = \beta_{BH}\sqrt{\frac{1}{\alpha}} - \frac{\beta_{BH}}{\alpha}\ , \qquad \textit{Eq. 4}$$

Statistical Fits of Spawner-Recruit Relationships:

We used Bayesian methods to fit spawner-recruit functions for two reasons. First, as noted above, the spawner-recruit relationship is used to drive trans-generational population dynamics in the PVAs. An important aspect of any PVA is incorporation of statistical uncertainty in underlying parameters. Bayesian methods yield probability densities for the parameters of the spawner-recruit functions whereas non-Bayesian (i.e. "frequentist") methods yield point estimates. Thus, Bayes' method provides results that can be directly used to simulate parameter uncertainty in a PVA, which is one reason why Bayesian methods are appealing to conservation biologists (Wade 2002).

The second reason we used Bayesian methods to fit spawner-recruit relationships derives from our desire to characterize uncertainty in our estimate of S_{MSY}. Fifty percent of S_{MSY} has been used as a critically low abundance for triggering conservation action (AHSAC 2011). However, since S_{MSY} is never known perfectly, we define critically low abundance as 50% of the 75th percentile of the estimate of S_{MSY}. This definition of a critically low abundance explicitly acknowledges uncertainty in S_{MSY}, and in response reduces the conservation risk associated with overestimating the true value of S_{MSY}. Stated another way, when ambiguity in the data increases, fish managers should respond more conservatively. Since S_{MSY} is computed from α and β parameters (*see* Equations 3 and 4), our assessment of statistical uncertainty in S_{MSY} depends on uncertainty in both of those parameters as well as their covariance. Quantifying uncertainty in S_{MSY} is therefore a very complex problem. Indeed, an exact analytical solution is not known to science. However, the Bayesian statistical paradigm offers a method for numerically estimating uncertainty in S_{MSY}. S_{MSY} can be computed as Markov Chain Monte Carlo (MCMC) methods sample from parameter posterior distributions (Haddon 2011). This yields a probability density of S_{MSY}, which, unlike results of frequentist methods, can be used to make probability statements about the value of S_{MSY}.

We modeled recruits as a log-normally distributed random variable. Specifically, we let

$\log(R) \sim \text{Normal}(\mu,\tau)$ *Distribution 1*

and, for the Ricker function, we get

$\mu = \log(\alpha)+\log(S) - \beta_{RK} * S.$ *Eq. 5*

If environmental covariates are included in the Ricker function, then we have:

$\mu = \log(\alpha)+\log(S) - \beta_{RK}*S + \gamma_1 Env_1 + \gamma_2 Env_2.$ *Eq. 6*

We had difficulty getting Beverton-Holt models to converge, so we tried several parameterizations of the Beverton-Holt function. Specifically, we explored three:

$\mu = \log(\alpha)+\log(S) - \log(1+ \alpha / \beta_{BH}*S)$ {logarithmic version of Equation 2} *Eq. 7*

$\mu = \log(S) - \log(1/\exp(\alpha) + S/\exp(\beta_{BH}))$ *Eq. 8*

$\mu = \log(a)+\log(S) - \log(b + S).$ *Eq. 9*

As in Equation 6, we included environmental covariates to the Beverton-Holt function by simply including them as additive terms.

We used WinBUGS to carry out MCMC fitting of our spawner-recruit functions. Here, we follow WinBUGS distributional notation and note that τ in Distribution 1 is the precision of the normal distribution, where $\tau = 1/\sigma^2$. We first transform τ to the more familiar standard deviation, σ, and then let

$\sigma \sim$ Uniform(0,6) *Distribution 2*

We also tried the more common:
$\tau \sim$Gamma(0.005, 0.005) *Distribution 3*

and found that the choice of prior parameterizations had little effect of our posterior results. For the intrinsic productivity parameter of both Ricker and Beverton-Holt functions, we specified noninformative priors with:

$\alpha \sim$ Uniform(0,10). *Distribution 4*

The prior distribution we used for β_{RK} is
$\beta_{RK} \sim$ Normal(μ = 0.0000001, τ = 0.005), *Distribution 5*

but we also explored the effects of assuming
$\beta_{RK} \sim$ Uniform(0.00001, 0.005). *Distribution 6*

We tried a host of different prior distributions for Beverton-Holt functions given in equations 7-9 because of the difficulty we experienced getting good convergence. Specifically, we tried normal, lognormal, and uniform priors in conjunction with several different non-informative parameterizations of these distributions. We did not obtain satisfactory fits and good evidence to support the use of Beverton-Holt functions for any of the populations we modeled. Thus, all of the spawner-recruit models presented in the Rogue Plan were derived from the Ricker function.

We always ran two Markov chains, and typically allowed them "burn-in" for 5,000 iterations. We obtained a total of 3,500 samples from each chain, after thinning the chains out to every 31^{st} iteration. We plotted the "trace" of the resulting samples and computed Gelman-Rubin statistics to verify that the chains had properly mixed. For many models, including all those assuming a Beverton-Holt function, we did not obtain good evidence of convergence. If we were not able to remedy the convergence problem by adjusting the length of the burn-in and making minor adjustments to the prior distribution values and/or starting values, we concluded that the model was not well suited to the data and abandoned further attempts to fit the model.

We looked at the resulting parameter estimates to ensure that there were not any biologically unrealistic values. For example, if non-informative normal priors are used for the parameters in *Equation 9* (a Beverton-Holt function), then we frequently obtained huge uncertainty intervals that include negative values. Since the parameters of *Equation 9* represent non-negative entities, we did not entertain results with negative estimates. Using such the results of such models in our PVA would have carried absurd assumptions into our estimates of extinction risk. As noted above, we were unable to obtain satisfactory results for any population using the Beverton-Holt function.

We included environmental covariates (Tables 6 and 7) in the spawner-recruit modeling for two reasons. First, it provides an opportunity to possibly better quantify, the effects of primary factors that have been previously shown to limit recruitment within fall Chinook populations of the Rogue SMU. Second, scatterplots of our spawner and recruit data look nothing like the recruitment functions we attempted to fit. Including environmental covariates provides a means of getting better parameter estimates if the covariates can significantly account for some of the apparent randomness in the spawner-recruit data. Covariates were z-transformed so that values approximately come from a standard normal distribution in order to improve convergence performance. Descriptions of the chosen covariates, and the rationale associated with those choices, can be found in the Rogue Plan (*see* Spawner Abundance, page 60 and page 88).

We computed a Deviance Information Criterion (DIC) for each model. DIC is a Bayesian analogue of Akaike Information Criterion (AIC), which represents the tradeoff between model fit and complexity (Spiegelhalter et al. 2002). Much like AIC, a practical rule of thumb is that models receiving DIC scores within 1-2 of the "best" (i.e. smallest DIC) deserve consideration, whereas scores 2-7 greater than the "best" have considerably less support (Table 8). The fitted model parameters for the three best models, determined by DIC, are provided in Table 9.

Table 6. Estimated mean annual survival rates of coded-wire tagged juvenile spring Chinook salmon released at Cole M. Rivers Hatchery during September and October, 1980-2004 brood years.

Brood Year	Ocean Survival Rate[a]	Normalized Survival Rate
1980	0.0824	0.6143
1981	0.0646	0.1623
1982	0.0930	0.8837
1983	0.1449	2.2027
1984	0.0597	0.0369
1985	0.1144	1.4275
1986	0.0283	-0.7619
1987	0.0179	-1.0257
1988	0.0237	-0.8771
1989	0.0272	-0.7885
1990	0.0374	-0.5291
1991	0.1062	1.2174
1992	0.0859	0.7032
1993	0.0623	0.1039
1994	0.0107	-1.2084
1995	0.0544	-0.0986
1996	0.0104	-1.2169
1997	0.0914	0.8434
1998	0.1155	1.455
1999	0.0778	0.4972
2000	0.0735	0.3869
2001	0.0400	-0.4638
2002	0.0095	-1.2391
2003	0.0142	-1.1188
2004	0.0108	-1.2063

[a] *Estimated survival to age 2 in the ocean before the onset of any fishing mortality.*

Table 7. Indicators of freshwater environmental conditions experienced by naturally produced fall Chinook salmon in the Rogue River Basin, 1969-2009.

	July-Aug flow[a]		Peak flow[b]		Oct-Nov[c]	
Year	Mean	Normalized	Mean	Normalized	Mean	Normalized
1969/70	1,404	-1.309	59,200	0.931	107	-1.100
1970/71	1,130	-1.765	87,100	1.994	409	0.392
1971/72	2,191	0.004	82,500	1.818	253	-0.378
1972/73	1,799	-0.650	13,400	-0.814	96	-1.153
1973/74	932	-2.094	96,400	2.348	992	3.276
1974/75	2,045	-0.240	56,000	0.809	80	-1.231
1975/76	2,149	-0.068	26,800	-0.303	273	-0.278
1976/77	1,985	-0.341	1,950	-1.250	53	-1.367
1977/78	916	-2.121	44,600	0.375	363	0.165
1978/79	2,216	0.044	18,600	-0.616	76	-1.253
1979/80	2,130	-0.099	38,400	0.138	283	-0.231
1980/81	2,069	-0.200	16,100	-0.711	75	-1.259
1981/82	1,970	-0.365	78,700	1.674	612	1.396
1982/83	2,621	0.720	73,300	1.468	521	0.947
1983/84	2,966	1.294	32,500	-0.086	767	2.162
1984/85	3,409	2.031	19,000	-0.601	806	2.358
1985/86	2,405	0.359	32,400	-0.090	268	-0.303
1986/87	2,328	0.231	22,600	-0.463	307	-0.112
1987/88	2,282	0.155	16,400	-0.700	249	-0.397
1988/89	1,844	-0.575	25,300	-0.361	393	0.317
1989/90	2,464	0.458	13,700	-0.803	312	-0.084
1990/91	1,983	-0.344	18,300	-0.627	291	-0.189
1991/92	2,166	-0.039	7,590	-1.035	279	-0.247
1992/93	1,534	-1.092	20,800	-0.532	234	-0.472
1993/94	2,895	1.175	4,950	-1.136	306	-0.113
1994/95	1,441	-1.246	16,800	-0.684	237	-0.458
1995/96	2,767	0.963	28,700	-0.231	314	-0.077
1996/97	2,528	0.564	90,800	2.135	485	0.771
1997/98	2,707	0.862	39,000	0.161	369	0.194
1998/99	3,157	1.612	43,400	0.329	638	1.524
1999/00	3,419	2.048	21,200	-0.517	265	-0.320
2000/01	2,376	0.312	3,010	-1.210	272	-0.286
2001/02	1,434	-1.258	13,000	-0.829	94	-1.162
2002/03	1,911	-0.463	34,800	0.001	305	-0.118
2003/04	2,042	-0.245	20,770	-0.533	266	-0.312
2004/05	2,040	-0.248	24,600	-0.387	308	-0.106
2005/06	2,273	0.140	78,200	1.655	333	0.019
2006/07	2,627	0.729	29,400	-0.204	282	-0.236
2007/08	2,029	-0.267	22,400	-0.471	328	-0.006
2008/09	2,988	1.331	18,000	-0.639	274	-0.273

[a] *Mean flow (cfs) at Agness when juveniles reared in freshwater.*

[b] *Greatest mean daily flow (cfs) at Grants Pass when eggs and alevins incubated in the gravel.*

[c] *Mean flow (cfs) at Applegate town when adults migrated and spawned in the Applegate River.*

Table 8. Deviance Information Criterion scores for Ricker spawner-recruit models fitted to the populations of naturally produced Rogue fall Chinook salmon. The model with the lowest DIC is marked with an asterisk, along with models with similar (<2 difference) DICs.

Model Covariate(s)	Deviance Information Criterion score
Survival rate to age 2 for CWT-marked CHS (Table 6)	45.0*
Survival rate and Jul-Aug flow (Tables 6 and 7)	45.6*
Survival rate and peak flow (Tables 6 and 7)	46.4*
Jul-Aug rearing flow (Table 7)	51.7
None	53.9
Oct-Nov spawning flow (Table 7)	55.3
Peak flow during incubation (Table 7)	55.8

Table 9. Parameter values of the best fit Ricker stock-recruitment models built for the aggregated populations of naturally produced fall Chinook salmon in the Rogue River Basin, 1980-2004 brood years.

Model 1: $\ln Recruits = \ln\alpha + \ln Spawners - \beta*Spawners + e1*survival\ rate$

Parameter	Coefficient	95%CI
Ricker α	4.07	2.11 – 6.28
Ricker β	1.57x10-5	9.76x10-6 – 2.24x10-5
e1[a]	0.37	0.14 – 0.61

Model 2: $\ln Recruits = \ln\alpha + \ln Spawners - \beta*Spawners + e1*survival\ rate + e2*peak\ flow$

Parameter	Coefficient	95%CI
Ricker α	3.92	2.03 – 6.16
Ricker β	1.56x10-5	0.88x10-5 – 2.17x10-5
e1[a]	0.38	0.15 – 0.61
e2[b]	-0.10	-0.38 – -0.17

Model 3: $\ln Recruits = \ln\alpha + \ln Spawners - \beta*Spawners + e1*survival\ rate + e2*summer\ flow$

Parameter	Coefficient	95%CI
Ricker α	3.93	2.03 – 6.01
Ricker β	1.56x10-5	0.95x10-5 – 2.20x10-5
e1[a]	0.32	0.08 – 0.57
e2[c]	0.16	-0.12 – 0.43

Population Viability Analysis

Population viability analysis (PVA) is a quantitative assessment of a population's risk of extinction (Morris and Doak 2002). Extinction risk can be characterized as either (1) mean time to extinction or (2) probability of extinction over some time horizon, typically 100 years. Here, we adopt the latter meaning of extinction risk. Since we are interested in the probability of extinction over 100 years, we require a principled, empirically-based method of simulating population dynamics through time. The purpose of this section is to describe how the spawner-recruit assessments are used to drive a PVA simulator.

A spawner-recruit curve is a model of trans-generational dynamics, and can therefore simulate population dynamics through time. However, to function as proper PVA, assumptions about (1) statistical uncertainty, (2) harvest, and (3) critically low abundance are needed. These three components of the PVA are addressed below.

Statistical Uncertainty: A deterministic spawner-recruit curve describes the number of recruits *expected* from some number of spawner. Clearly, however, observations of recruitment do not perfectly match this expectation. Rather, there is considerable deviation from this expectation every year. If these deviations are not incorporated into a simulation of a spawner-recruit relationship, then the simulated populations will converge on a stable age distribution and a stable spawner size (N_{eq} in Appendix Figure F-1). It is the principled incorporation of statistical uncertainty that distinguishes a PVA from other forms of population projection. To incorporate stochasticity, we simply compute the variance of the residuals in a spawner-recruit curve and then incorporate those deviations into the simulation. We also compute the lag-1 autocorrelation of the spawner-recruit residuals so that observed trends above or below the spawner-recruit curve are included in our simulations. With estimates of the variance and lag-1 autocorrelation on hand, a 100-year time series of simulated spawner-recruit residuals (or "environmental deviates") was computed using the formula:

$$\varepsilon_t = \rho\varepsilon_{t-1} + \sqrt{\sigma^2}\sqrt{1-\rho^2}\,N(0,1) \qquad \textit{Eq. 10}$$

where ρ is the estimate of the lag-1 autocorrelation of the residuals, σ^2 is the variance of the residuals and $N(0,1)$ is a standard normal deviate. At each time-step of the PVA, the corresponding ε_t was added to the expected number of recruits for a given number of spawners. This adds stochasticity to the otherwise deterministic spawner-recruit function. Note that this procedure assumes a homoscedastic distribution of random deviates.

As noted in the section above on statistically fitting spawner-recruit relationships, it is important for the PVA to incorporate uncertainty in parameter estimates. Indeed, a motivation for using Bayesian methods to fit the spawner-recruit curves is that it permits us to make probability statements about different spawner-recruit parameter values instead of only point estimates. For each population, we randomly drew values of the spawner-recruit curve from their posterior probability distributions 1,000 times. For each of these draws, residual variance and autocorrelation were recomputed, and then the PVA was repeated 50 times. Thus, the PVA was repeated a total of 50,000 times for each population. The frequency of extinction events among these 50,000 replicates is extinction risk as reported in the Rogue Plan. For the Rogue Plan extinction is defined as population abundance falling below a quasi-extinction threshold of 950 spawners for three consecutive years in the PVA simulations (*see* Viability of the Species Management Unit, page 111 in the Rogue Plan).

Harvest:
Chinook return to the spawning grounds at different ages, and these differences must be captured in the PVA. If **a** is a vector of the probabilities of spawning at different ages, then **a***R is a vector containing the number of fish that will return to the spawning grounds at different ages. The values for **a** represent the observed mean age composition of age 2-6 NP fall Chinook

spawners for the period of record (**a** = 0.207, 0.366, 0.324, 0.091, 0.011 for the Rogue populations and **a** = 0.072, 0.183, 0.572, 0.168, 0.004) for the coastal populations). Thus, under a scenario of no harvest for the Rogue populations, if brood year 1 produces 1,000 recruits (*R*), then the model estimates that 366 of these fish will return to spawn three years later. These fish would spawn with 414 two-year olds if brood year 2 produces 2,000 recruits; again under the assumption of no harvest. The total number of spawners in a given simulated year is obtained by summing the products of recruits produced in previous years and the probabilities of spawning at different ages; and then removing harvested fish. Specifically, spawner abundance on a given year (S_t) is:

$$S_t = \sum_{i=1}^{6} R_{t-i} a_i (1 - H) \qquad \textit{Eq. 11}$$

where *H* is the estimated brood harvest rate. Note that *H* and **a** were needed to construct the original spawner-recruit dataset. Harvested fish were included in the number of recruits in the original spawner-recruit dataset. *Equation 11* removes the same number of fish before they spawn, which reflects the real-world harvest process.

Simulations of the Rogue populations incorporated brood harvest rates that were scaled to simulated values of population abundance. This procedure was implemented because brood harvest rates of fall Chinook in the ocean fisheries are dependent on the stock size of Klamath fall Chinook, and the abundance of Klamath fall Chinook and Rogue NP fall Chinook are correlated (*see* Comparisons to Other Populations, page 69 in the Rogue Plan). A function for brood harvest rates was incorporated into the PVA to replicate this process (Figure 3).

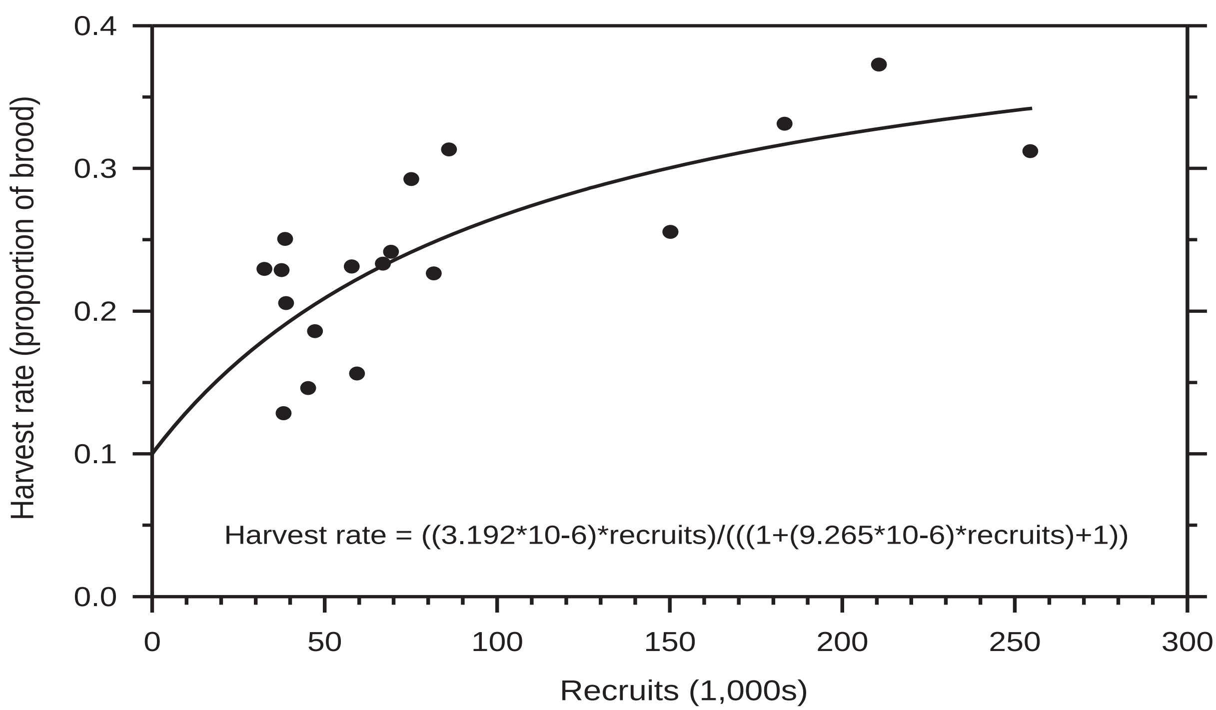


Figure 3. Harvest rate function used in the population viability assessment of naturally produced fall Chinook salmon within aggregated populations of the Rogue River Basin. The function also incorporates a baseline harvest rate of 0.10 for freshwater harvest.

Estimated S_{MSY}:

Population models developed for the Rogue aggregate populations were used to generate estimates of S_{MSY}. To account for model uncertainty, modeled estimates of S_{MSY} were bootstrapped by re-sampling the spawner and recruit data 1,000 times and refitting the best recruitment model. The upper 75th percentiles of these bootstrapped estimates were chosen as the most appropriate metrics for the numerical component of conservation criteria for Rogue fall Chinook spawner escapements.

Model point estimates, and bootstrap estimates of the 75th percentile, for the number of spawners estimated for maximum sustained yield within independent populations of naturally produced Rogue fall Chinook salmon. The table also conveys a rounded value proposed for the MSST conservation criteria (50% of the 75th percentile of S_{MSY}). Values included in the table below reflect estimates generated from population models that included smolt survival rates and summer flow as environmental covariates.

	S_{MSY} estimate		Proposed Conservation
	Point Estimate	75th Percentile	Criteria (MSST)
Rogue Aggregate	34,992	36,880	18,440

Discussion

Subpart D of the federal Magnuson-Stevens Act includes National Standard 1 (§600.310). This standard describes conservation and management measures designed to prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery managed by the federal government. Status determination criteria to determine overfished stocks are to be based on minimum stock size thresholds and must be expressed in terms of spawning biomass or other measure of reproductive potential, and should equal whichever of the following is greater: one-half (50%) of the spawning stock needed to maintain MSY, or the minimum stock size at which rebuilding to attain MSY would be expected to occur within ten years.

In 2011, the Pacific Fisheries Management Council (PFMC) adopted Amendment 16 to the Pacific Coast Salmon Plan. Included in Amendment 16 are status determination criteria related to minimum stock size thresholds (MSST) and these criteria options (Ad Hoc Salmon Amendment Committee 2011) functionally serve the same purpose as conservation criteria included in the Rogue Plan. ODFW agrees with the Ad Hoc Salmon Amendment Committee (2011) conclusion that a definition of MSST as 0.5* S_{MSY} is appropriate because salmon populations are relatively productive compared to other managed fish species. Consequently, this guidance was used to identify appropriate conservation criteria for fall Chinook spawning escapements in the Rogue SMU.

Table 10. Current conservation objective and reference points governing harvest control rules and status determination criteria for SOCC.

Stocks in Fishery	Conservation Objective	S_{MSY}	MSST	MFMT (F_{MSY})	ACL
Southern Oregon	Unspecified portion of an aggregate 150,000 to 200,000 natural adult spawners for Oregon coast streams measured by 60-90 fish per mile in index streams (Thompson 1977 and McGie 1982). ODFW developing specific conservation objectives for spring and fall stocks that may be implemented without plan amendment upon approval by the Council.	60 fish per mile in index streams	30 fish per mile in index streams	78% Proxy (SAC 2011a)	Component stock of SONC complex; ACL indicator stock is KRFC

Recommendations

ODFW proposes that the current conservation objective and reference points shown in Table 10 be replaced with those shown in Table 11.

Table 11. Proposed conservation objective and reference points governing harvest control rules and status determination criteria for SOCC.

Stocks in Fishery	Conservation Objective	S_{MSY}	MSST	MFMT (F_{MSY})	ACL
Southern Oregon	At least 41,000 naturally produced adults passing Huntley Park in the Rogue River annually to meet S_{MSY}. MSST would be reached at 20,400 measured at Huntley Park. S_{MSY} and MSST values must be inflated by to account for pre-spawn losses between Huntley Park and spawning areas (ODFW 2013).	36,880	18,440	78% Proxy (SAC 2011a)	Component stock of SONC complex; ACL indicator stock is KRFC

References

AHSAC (Ad Hoc Salmon Amendment Committee). 2011. Final environmental assessment and initial regulatory impact review for Pacific coast salmon plan amendment 16: classifying stocks, revising status determination criteria, establishing annual catch limits and accountability measures, and de minimis fishing provisions. Pacific Fisheries Management Council, Portland.

Beverton, R.J.H., and S.J. Holt. 1957. On the dynamics of exploited fish populations. United Kingdom Ministry of Agriculture and Fisheries. Fisheries Investigations (series 2) 19:1-533.

Cramer, S.P. 1979. Rogue Basin Fisheries Evaluation Program, annual report. Oregon Department of Fish and Wildlife, Fish Research Project, DACW 57-77-C-0027, March, Annual Progress Report, Portland.

Everest, F.H. 1973. Ecology and management of summer steelhead in the Rogue River. Oregon State Game Commission, Fishery Research Report 7, Corvallis, Oregon.

Finley, C. 2011. All the Fish in the Sea: Maximum Sustained Yield and the Failure of Fisheries Management. The University of Chicago Press, Chicago, Illinois.

Haddon, M. 2011. Modelling and Quantitative Methods in Fisheries. Second Edition. Chapman and Hall/CRC, Boca Raton, Florida.

Hankin, D.G., and M.C. Healey. 1986. Dependence of exploitation rates for maximum yield and stock collapse on age and sex structure of Chinook salmon (*Oncorhynchus tshawytscha*) stocks. Canadian Journal of Fisheries and Aquatic Sciences 43:1746-1759.

Larkin, P.A. 1977. An epitaph for the concept of maximum sustained yield. Transactions of the American Fisheries Society 106:1-11.

Li, J.C.R. 1948. A sampling plan for estimating the number of fish crossing Gold Ray Dam on the Rogue River. Unpublished report to the Oregon State Game Commission, Portland.

Mohr, M.S. 2006. The cohort reconstruction model for Klamath River fall Chinook salmon. Unpublished document. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, California.

Morris, W.F. and D.F. Doak. 2002. Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis. Sinauer Associates, Inc, Sunderland, Maryland.

ODFW (Oregon Department of Fish and Wildlife). 1989. Effects of Lost Creek Dam on coho salmon in the Rogue River. Phase II completion report. Oregon Department of Fish and Wildlife, Fish Research Project DACW 57-77-C-0033, Completion Report, Portland.

ODFW (Oregon Department of Fish and Wildlife). 1991. Effects of Lost Creek Dam on the distribution and time of chinook salmon spawning in the Rogue River upstream of Gold Ray Dam. Oregon Department of Fish and Wildlife, Fish Research Project DACW 57-77-C-0033, Special Report, Portland.

ODFW (Oregon Department of Fish and Wildlife). 1992. Effects of Lost Creek Dam on fall chinook salmon in the Rogue River. Phase II completion report. Oregon Department of Fish and Wildlife, Fish Research Project DACW 57-77-C-0033, Completion Report, Portland.

ODFW (Oregon Department of Fish and Wildlife). 2009. Efficacy of radio-tagging spring Chinook salmon in the Rogue River. Oregon Department of Fish and Wildlife, Salem, Oregon.

ODFW (Oregon Department of Fish and Wildlife). 2013. Conservation plan for Fall Chinook Salmon in the Rogue Species Management Unit. Oregon Department of Fish and Wildlife, Salem, OR.

PFMC (Pacific Fishery Management Council). 2010. Preseason report I. Stock abundance analysis for 2010 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Satterthwaite, T.D. 2002. Effects of reservoir releases on adult salmon during a drought year. Supplemental Report Number 1. Lost Creek Dam Evaluation Project. Oregon Department of Fish and Wildlife, Portland.

Smith, A.K., B.P.McPherson, S.P. Cramer, and J.T. Martin. 1978. Rogue Basin Fisheries Evaluation Program, adult salmonid studies. Oregon Department of Fish and Wildlife, Fish Research Project, DACW 57-75-C-0109, Annual Progress Report, Portland.

Spiegelhalter, D.J., N.G. Best, B.P. Carlin, and A. van der Linde. 2002. Bayesian measures of model complexity and fit. Journal of the Royal Statistical Society, Series B 64:583-639.

Wade, P.A. 2002. Bayesian population viability analysis. In Bessinger, S.R. and D.R. McCullough (Eds.) Population Viability Analysis. The University of Chicago Press, Chicago, Illinois.

Weitkamp, L.A. 2010. Marine distributions of Chinook salmon from the west coast of North America determined by coded wire tag recoveries. Transactions of the American Fisheries Society 139: 147-170.

2013 Salmon Methodology Review

Standardized Method to Calculate Chinook Age2 FRAM Stock Recruit Scalars, Based Upon the Age3 Forecast

October 9, 2013

Prepared by Andy Rankis, MEW

BACKGROUND

FRAM abundance inputs for Chinook at age 2 received extra focus during the investigation of why, for most sampled Puget Sound marine sport fisheries, 'FRAM estimated Total Encountered Sublegals' deviated significantly from 'Observed Total Sublegal' sized Chinook. Age 2 Chinook are the major component of model estimated Sublegal Encounters. Annual forecasts of expected Chinook abundance, by stock, are perhaps the most important component of pre-season FRAM modeling. Those forecasts are transformed into age specific FRAM 'recruit scalars' (ages 2 through 5) for model input (designated as : Age2, Age3, Age4, and Age5). Presently there is very little substance to most Age2 forecasts. Chinook FRAM will advance the Age2 cohort to Age3 cohort in the final timestep, magnifying exploitation rate errors due to poor Age2 forecasts.

From California through British Columbia, a variety of forecasting methods are used. Some regional stock forecasts are by age class, some are for total "ocean" or Terminal Runsize (TRS) which gets portioned into age class; but almost all forecasts are based upon data for age 3 through age 6 Chinook, which dominate the historic terminal (or mature) runsize and coded wire tags (CWT) recovery datasets. The provided forecasts are converted to the required FRAM abundance units (recruit scalars) at the start of the first timestep. Age 2 Chinook contribute very few CWT recoveries and usually are a very small, often ignored, component of TRS. The regionally produced forecasts for many stocks don't include age 2 components; thus the required Age2 model input is creatively generated by staff assigned to pre-season model preparation.

So what does the FRAM model use for required Age2 abundance? When required input is missing, the modelers may resort to:

1. Using base period level abundance (FRAM recruit scalar of 1.0).
2. Apply an adjustment to recruit scalar of 1.0.
3. Re-use the input recruit scalar from the preceding year.
4. Or apply an adjustment to previous year recruit scalar.

Appendix Table A presents the pre-season Age2 abundance scalars used for PFMC pre-season modeling for 2004 through 2013. Some Age2 abundance scalars are seen to change year to year, some do not; none are based upon solid survival rate data. In theory these Age2 recruit scalars are supposed to reflect changing smolt production levels as compared to the Age2 base period levels, with consideration to recent survival patterns.

Chinook FRAM is set up with four sequential timesteps **(Table 1).** For input into the model, the forecast expectations of abundance for the terminal runsizes (end of timestep 3 for summer/fall stocks) need to be expanded to 'ocean abundance' values at the beginning of the first timestep. A variety of methods have been used to do this. A standard method is to produce a set of FRAM ocean abundance recruit scalars that, when modeled with a recent "average fishery regime," produce a set of output TRS values matching that year's TRS forecasts. Age2 Chinook are again not part of this methodology. The fishery induced mortalities, primarily due to release mortality rates, of Age2 Chinook can be a significant component of exploitation rate calculations. Escapement is calculated in timestep 3 after pre-terminal fishery mortality, maturity of remaining cohorts, and terminal fishery mortality upon the mature cohort. At the beginning of timestep 4, all cohorts age. The Age2 Chinook become Age3; and the influence of poor Age2 forecasts amplifies as the higher Adult Equivalence (AEQ) mortality at Age3 affects Exploitation Rate (ER) calculations. This timestep 4 Age3 fishery mortality may have no relationship to the stocks' escapements when the Age2 recruit scalar was not provided as part of (or consistent with) the regionally produce annual forecasts. For some stocks the difference in abundance of Age3 in timestep 1 and timestep 4 has surpassed an order of magnitude due only to the Age2 recruit scalar.

For timestep 4 FRAM will recycle the timestep 1 recruit scalars for Age2 fish, while Age3, Age4, and Age5 abundances are from the aging of the younger cohorts. Because of the potential importance of catch of Age3 fish in timestep 4 for ER calculations, basing Age2 stock recruit scalars upon a more reliable forecast is desirable. **The proposal is to calculate NewAge2 stock recruit scalars that will "age up" in timestep 4 to produce Age3 abundance that match the original Age3 timestep 1 stock abundances.** These Age2 recruit scalars will be used in timesteps 1 and 4, as FRAM presently does. There will be no change to present methodology to obtain values for Age3 through Age5 recruit scalars. Stock escapement (sum of Age3 through 5) values should not change, or change very little.

Table 1. Chinook FRAM timesteps, and which timesteps' fishery related mortality counts toward exploitation rate calculations and which determine escapement.

		Fishing Mortality	
Timestep	Months	Included in ER Calculations?	Affects escapement?
Time 1	Preceding October-April	no	yes
Time 2	May-June (of management year)	yes	yes
Time 3	July-Sept (of management year)	yes	yes
Time 4	Octr-April (of management year)	yes	no

The structure of Chinook FRAM is such that Age2 abundance has almost no affect upon TRS or estimates of spawner escapement. The FRAM model is for a “fishing year”, and mature runsize (age 3 through 5) produces spawner escapement values. When management focus shifted from staying above minimum escapement values to staying below Exploitation Rate (ER) caps, then mortality of Age2 Chinook potentially became a significant factor. Age2 mortality is included in ER calculations but the potential Age2 escapement is not. Most Age2 fishery related mortality is ‘release mortality’. All fishery mortality is adjusted by Adult Equivalence Value (AEQ) that discounts mortality of younger fish. In combination this greatly reduces Age2 mortalities in ER calculations. By FRAM stock:

$$\mathrm{ER} = \frac{\sum_{t=2}^{4}(\mathbf{F_{a2}} + \mathrm{F_{a3}} + \mathrm{F_{a4}} + \mathrm{F_{a5}})}{\sum_{t=2}^{4}(\mathbf{F_{a2}} + \mathrm{F_{a3}} + \mathrm{F_{a4}} + \mathrm{F_{a5}}) + \sum_{t=1,a=3,4,5}^{3}\mathrm{Esc}}$$

Where:

a = age

t = timestep

F = fishing related mortality

Esc = escapement

And where:

$$\sum \mathrm{F_{a3}} = \sum(\mathrm{F_{a3,t2}} + \mathrm{F_{a3,t3}} + \mathbf{F_{a3,t4}})$$

There are essentially two types of abundance inputs affecting ER calculations:

1. Values based upon TRS forecasts, and
2. Values based upon largely artificial Age2 forecasts (yellow highlighted bolded values)

Note that the Age2 forecast determines the abundance of Age3 Chinook in timestep 4, thus , initial Age2 recruit scalars can contribute to a big part of the fishery mortality in the numerator, especially in timestep 4 when they ‘age-up’ to Age3 (higher AEQ mortality and usually higher BPERs) but do not contribute to the escapement in the denominator. This can be problematic if Age3 timestep 1 and Age3 timestep 4 abundances are largely mismatched.

Basing Age2 abundance upon the Age3 forecast would add consistency to ER calculations.

METHODS

To explore and apply this alternative Age2 forecast method, the final pre-season 2008 and 2012 PFMC Chinook FRAM model runs were used. The same versions of FRAM and supporting 'base data' were used for this exercise as were used in each of these two pre-season years. The forward moving calculation (for each stock) to produce Age3 abundance for timestep 4 starts with the Age2 forecast for timestep 1 and proceeds through timestep 3 (the 2 year olds age up to 3's for timestep 4). The FRAM calculations can be represented as:

(1) $$Cohort_{age3,time4} = Cohort_{age2,time1} \prod_{t=1}^{3} [(1-N_t) * (1-F_t) * (1-M_t)]$$

Where:

Cohort = stock cohort abundance
N = natural mortality rate
F = fishery related mortality rate
M = maturation rate
t = timestep

The objective of the NewAge2 abundance is to produce an Age3 timestep 4 abundance consistent with the forecasted Age3 timestep 1 value. Initially this was done by back-calculating through equation (1). Substituting the Age3 abundance from timestep 1 into Age3 abundance at timestep 4, and dividing by Age2 natural mortality, fishery mortality, and maturation rates (going backward by timestep) produced the NewAge2 timestep 1 abundance. Then moving forward through equation (1) the NewAge2 abundance produces a timestep 4 abundance of Age3 fish consistent with the pre-season forecast of Age3 fish for timestep 1 and consistent with Age3 escapement in timestep 3.

If all variables, except the initial Age2 and Age3 forecasts, are constants then the process simplifies to:

(2) $$^{Age3,\,t1}/_{Age3,\,t4} * Age2, t1 = New\ Age2, t1$$

Per equation (1), Age3 abundance in timestep 4 is a function of initial Age2 timestep 1 input. Equation (2) will work with any initial Age2 forecast but may require a couple of FRAM iterations to stabilize.

However, the annual fishing mortality rates are not constants. To use equations (1) or (2) for pre-season planning an average (or expected) set of stock specific fishery mortality rates would be necessary. One source for these rates could be average fishery mortality rates from recent year Chinook Validation Runs, a post-season type of FRAM model run. Another source could be pre-season FRAM mortality from the previous year's planned fisheries.

Chinook FRAM Validation Runs have updated age 3 through age 5 abundances based upon observed Terminal Run Size for those age classes, but continue to use the Age2 recruit scalar from the original pre-season model runs. Appling equation (2) to Chinook FRAM Validation Runs (2003 through 2010 fishing years) produced annual sets of post-season NewAge2 stock abundances. It was seen that there existed a very stable stock specific relationship between the Age3 "forecast" and the NewAge2 "forecast". These constants could be used to calculate NewAge2 stock recruit scalars as:

(3) $$NewAge2, s, t1 = Age3, s, t1 * Ks$$

Where:

$$Ks = {}^{Validation\ Run\ NewAge2, s, t1}\!/_{Validation\ Run\ Age3, s, t1}$$

These calculated stock specific constants ranged from 0.79 to 1.0 (Appendix B). For pre-season application the Age3 abundance at timestep 1 can simply be multiplied by the stock specific constant (k_s) to produce the NewAge2 abundance at timestep 1.

Three variations of calculating a NewAge2 abundance based upon the Age3 abundance have been presented, with the purpose of improving pre-season Age2 abundance model input. The resulting NewAge2 abundance estimates are divided by Age2 base period abundance to obtain the NewAge2 recruit scalars:

(4) By stock: NewAge2 Recruit Scalars = NewAge2 forecasts/BasePeriod Age2 Abundance

Practical considerations in pre-season application of the three equations.

Equation (1) is applied within a complicated spreadsheet that requires model parameters (by timestep) for age 2 natural mortality rates, and stock specific fishery and maturation rates. The fishery mortality rates are dependent upon annual fishery inputs, either "adopted" from a particular pre-season model run or averaged from recent Validation Runs.

Equation (2) does not require the step by step calculations of equation (1). This condensed method does require a model run, as does equation (1), to obtain values for the variables.

Equation (3) would be the easiest to apply, or directly code into FRAM. A model run with assumed fishery mortality is not needed. The annual Age3 forecast is simply multiplied by stock specific constants (Ks), as derived from NewAge2 Validation Runs.

The driving variable, in all three equations for the NewAge2 stock abundance estimates, is Age3 at timestep 1. For application of the NewAge2 methodology during pre-season modeling there are two potential sources for the needed Age3 timestep 1 seed abundance. The source of these Age3 abundances could be the annual forecasts. Or the value could be “observed” average Age3 abundance from recent Validation Runs. Neither source is without issue. While the pre-season forecast has inherent forecast error, the Validation Runs lag several years, i.e. for pre-season 2014 planning the most recent Validation year will be 2010.

The lack of consistency between Age3 escapement and Age3 fishery mortality in timestep 4 has been identified as a weakness in Chinook FRAM modeling. Using an average Age3 abundance from Validation Runs would address some concerns about age 3 forecast error, but would introduce error if smolt production and survival has varied since the last set of Validation Runs and the present fishery planning year. Adjustment for hatchery smolt production should be straight forward, but variation in natural production would be difficult to quantify. Differences in annual freshwater and marine survival rates, between the Validation Run years and the present, would need to be addressed.

The age 2 and age 3 cohorts are from different brood years and thus the argument can be made that model input of Age2 abundance should not be expected to be consistent with Age3 input. Possible adjustments for known differences between the Age2 and Age3 brood year smolts (hatchery release levels, marine survival conditions) could also become part of the methodology.

RESULTS

The calculated NewAge2 abundances, within the 2008 and 2012 Final PFMC Chinook model runs, increased the overall age 2 population in the model. Some stocks’ NewAge2 abundances increased dramatically (greater than 2000% relative increase). A few stocks saw a decrease (as much as 100%). The NewAge2 recruit scalars from 2008 and 2012 FRAM model runs, back-calculated through Equation (1), are presented in Appendix Table A for easy comparison to the original recruit scalars used for those two years. **Table 2** presents summary statistics for percent change in Age2 stock abundances, and percent change in total fishery mortality by age, over all stocks. Note that for Age2 cohorts, the percent change in fishery related mortality for each timestep corresponds to the change in Age2 abundance; this is also the case for Age3 fish in timestep 4 (Age2 “aging up”).

Graphic representation of the summary statistics for relative percent change in total fishery related mortality of individual stocks, at age and by timestep, is presented in **Figures 1 through Figure 4** using box-and-whiskers plots. The box-and-whiskers plots encompass the central quartiles of the data (the central 50% of the data values) in the shaded box with the median value indicated by the heavy black line in the box. The box whiskers include all data values not considered outliers or extreme values. Outliers are marked with open circles and are values between 1.5 and 3 box lengths from the upper or lower edges of the box (Hoaglin et al. 1983). Extreme values are marked by asterisks and are more than three box lengths from the upper or lower edges of the box. Age2 and Age3 outliers, above 500% change in total mortality are not presented in the figures but are summarized in **Table 3**. The graphic representation of relative change in total fishery mortality for Age3 Chinook also illustrates the "aging-up" process in timestep 4.

Age4 and Age5 cohorts, as well as Age3 in timesteps 1 through 3, showed very little change in fishery mortality resulting from the incorporation of the NewAge2 abundances. However, progressing through the timesteps, an increasing effect is seen in timestep 4 (Figures 2 and 4). This may be attributed to the NewAge2 change in abundance affect upon how fishery quotas were filled. Even though very few age 2 fish are of legal size, there are a lot of them, and the significant increase in overall NewAge2 abundance did increase landed catch for that age class. This would function to allow more of the older fish to survive into the later timesteps and increase their catch, relative to their catch with original Age2 forecasts. Note that more timestep 3 and especially timestep 4 fisheries are modeled with fishery scalars, while earlier timesteps (1 and 2) have relatively more fishery inputs as fishery quota values. However, the scale of relative increase in timestep 4 of Age4 and Age5 mortality, (as high as 10% to 50% for a couple of stocks) is minor compared to the change in Age2 fishery mortality.

Puget Sound Chinook are presently managed with a maximum fishery exploitation rate upon natural stocks, with spawner escapement as another consideration. Re-running the 2008 and 2012 pre-season Chinook model runs with the respective sets of NewAge2 recruit scalars produced different exploitation rates for many stocks, but had little affect on estimates of spawner escapement. For the 2008 model run **(Table 4)** the affect upon exploitation rates was not as dramatic as seen for the 2012 model run (**Table 5)**.

As an example of NewAge2 recruit scalar affect upon pre-season FRAM outputs we'll look at adjacent Puget Sound fall Chinook stocks, the Unmarked and Marked stocks for <u>Mid Puget Sound Fall Fingerlings (MidPSFF)</u> and for <u>South Puget Sound Fall Fingerling (SPSd FF)</u>. These are very large FRAM stocks, and are major contributors to Puget Sound marine sport catch. In both years there is an increase in ER for the component sub-stocks of FRAM's MidPSFF stock, while a sub-stock of FRAM's SPSdFF stock showed a relatively large drop in ER when modeled with NewAge2 recruit scalars. Specifically, total ER for Unmarked Puyallup Falls increased 1.9% in both years while the Unmarked Nisqually Falls showed a decrease of 0.7% and 2.7% for 2008 and 2012 respectively (Table 4 and Table 5). The relatively very low pre-season Age2 recruit scalars for the MidPSFF stocks produced very few Age3 fish for timestep 4 fisheries; while the relatively high pre-season recruit scalars for the Age2 SPSdFF stocks produced an inflated abundance of Age3 in timestep 4. Appendix Table A presents bolded values for the pre-season recruit scalars (2004-2013) used for these stocks, and also shows the NewAge2 recruit scalars calculated for 2008 and 2012. With NewAge2 recruit scalars, the same direction of change in ER values for these stocks would be expected to occur over the last six years of pre-season modeling since neither of these stocks have changed their rather extreme Age2 recruit scalars since 2008.

The population age structures for these stocks, original pre-season compared to NewAge2, is informative. **Table 6** presents 2012 age abundance by timestep for the MidPSFF stocks; note the low abundance of Age2 Chinook produced by the original Age2 recruit scalar. The original MidPSFF Age2 (47,249 Unmarked) is a fraction of its Age3 abundance (307,429 Unmarked). The original Age2 recruits then ‘age up’ in timestep 4 to an Age3 abundance (27,696 Unmarked). The 307,429 value (timestep 1) is based upon a TRS forecast of Age3 fish, while the 27,696 value (timestep 4) is based upon an Age2 recruit scalar unchanged since pre-season 2008. This is an extreme example. The opposite pattern exists for the SPSdFF stocks. **Table 7** presents the population age structures for a stock (SPSdFF) that has been modeled with relatively high Age2 recruit scalars. For the Unmarked SPSdFF the original escapement of Age3 fish is from a timestep 3 cohort of 22,677, while the timestep 4 fishery mortality of Age3 fish was calculated from an abundance of 78,901 Age3; producing the inflated original pre-season ER for Nisqually Fall Chinook **(Table 5).**

Table 8 presents escapements for selected Columbia River Chinook stocks, before and after Age2 recruit scalars adjustments. Escapements should not change much, if any, because Age2 fish are not included in FRAM calculations of “mature terminal runsize”. Note that escapement occurs in timestep 3 before the Age2 cohort “ages up”. Exploitation rate calculated for Columbia Natural Tule stock uses a brood year approach and thus was not considered sensitive to the Age2 forecasts. The ER value for 2008 did not change but the 2012 ER went up 0.2% (**Table 8**). We speculate this is because of the overall changes in abundance of all stocks contributing to the major fisheries impacting Columbia Natural Tule stocks.

Table 2. Summary statistics, over all stocks, of percent change in Age2 abundance and Total Mortality (by age and timestep) with NewAge2 recruit scalars. Ratios are from preseason 2008 and 2012 model runs, calculated as (NewAge2 – preseasonAge2)/preseasonAge2 values.

2008	Age2	Change in Age2 Total Mortality					Change in Age3 Total Mortality				
	Abundance	1	2	3	4	Total	1	2	3	4	Total
Average:	132.3%	**119.9%**	**134.8%**	**133.0%**	**122.3%**	137.7%	1.8%	0.2%	-0.3%	**141.3%**	-2.8%
Minimum:	-96.7%	-96.5%	-96.6%	-96.5%	-96.4%	-96.5%	0.0%	-0.1%	-4.4%	-96.6%	-83.7%
Maximum:	2993.5%	3194.0%	2993.4%	2986.6%	3225.2%	3061.3%	8.1%	4.2%	2.4%	3004.3%	23.6%
St Dev:	505.5%	535.1%	508.7%	507.7%	541.9%	520.6%	2.0%	0.8%	0.9%	519.1%	14.8%
# of Stocks:	64	56	64	64	56	64	66	66	66	64	66
2012	Age2	Change in Age2 Total Mortality					Change in Age3 Total Mortality				
	Abundance	1	2	3	4	Total	1	2	3	4	Total
Average:	101.6%	112.0%	101.9%	106.1%	116.4%	106.7%	1.0%	0.0%	0.8%	105.9%	-3.5%
Minimum:	-100.0%	-100.0%	-100.0%	-100.0%	-100.0%	-100.0%	0.0%	-0.9%	0.0%	-100.0%	-100.0%
Maximum:	2186.4%	2325.4%	2185.8%	2253.7%	2411.4%	2288.3%	6.1%	2.3%	3.9%	2215.3%	17.6%
St Dev:	360.8%	392.7%	361.1%	369.0%	403.5%	372.4%	1.2%	0.3%	0.7%	366.0%	19.1%
# of Stocks:	63	56	63	63	56	63	62	62	62	63	64

2008	Age2	Change in Age4 Total Mortality					Change in Age5 Total Mortality				
	Abundance	1	2	3	4	Total	1	2	3	4	Total
Average:	132.3%	0.0%	0.0%	-0.4%	1.8%	0.0%	0.0%	0.0%	-0.1%	2.1%	0.2%
Minimum:	-96.7%	0.0%	-0.1%	-6.6%	-1.0%	-5.1%	0.0%	-0.3%	-5.9%	-21.4%	-4.3%
Maximum:	2993.5%	0.1%	0.0%	0.7%	8.5%	2.2%	0.0%	0.0%	1.9%	48.9%	3.8%
St Dev:	505.5%	0.0%	0.0%	1.2%	2.0%	1.0%	0.0%	0.1%	1.2%	9.8%	1.1%
# of Stocks:	64	66	66	66	66	66	63	67	67	63	67
2012	Age2	Change in Age4 Total Mortality					Change in Age5 Total Mortality				
	Abundance	1	2	3	4	Total	1	2	3	4	Total
Average:	101.6%	0.0%	0.0%	0.6%	1.7%	0.5%	-0.1%	0.0%	0.8%	2.9%	1.0%
Minimum:	-100.0%	-0.4%	-0.4%	0.0%	-1.0%	0.0%	-9.1%	-5.8%	-5.8%	-0.4%	-1.3%
Maximum:	2186.4%	0.3%	0.3%	3.4%	5.0%	2.0%	7.7%	7.7%	8.0%	43.6%	9.1%
St Dev:	360.8%	0.1%	0.1%	0.7%	1.5%	0.5%	1.7%	1.2%	2.2%	7.9%	2.1%
# of Stocks:	63	67	67	67	62	67	63	65	65	65	67

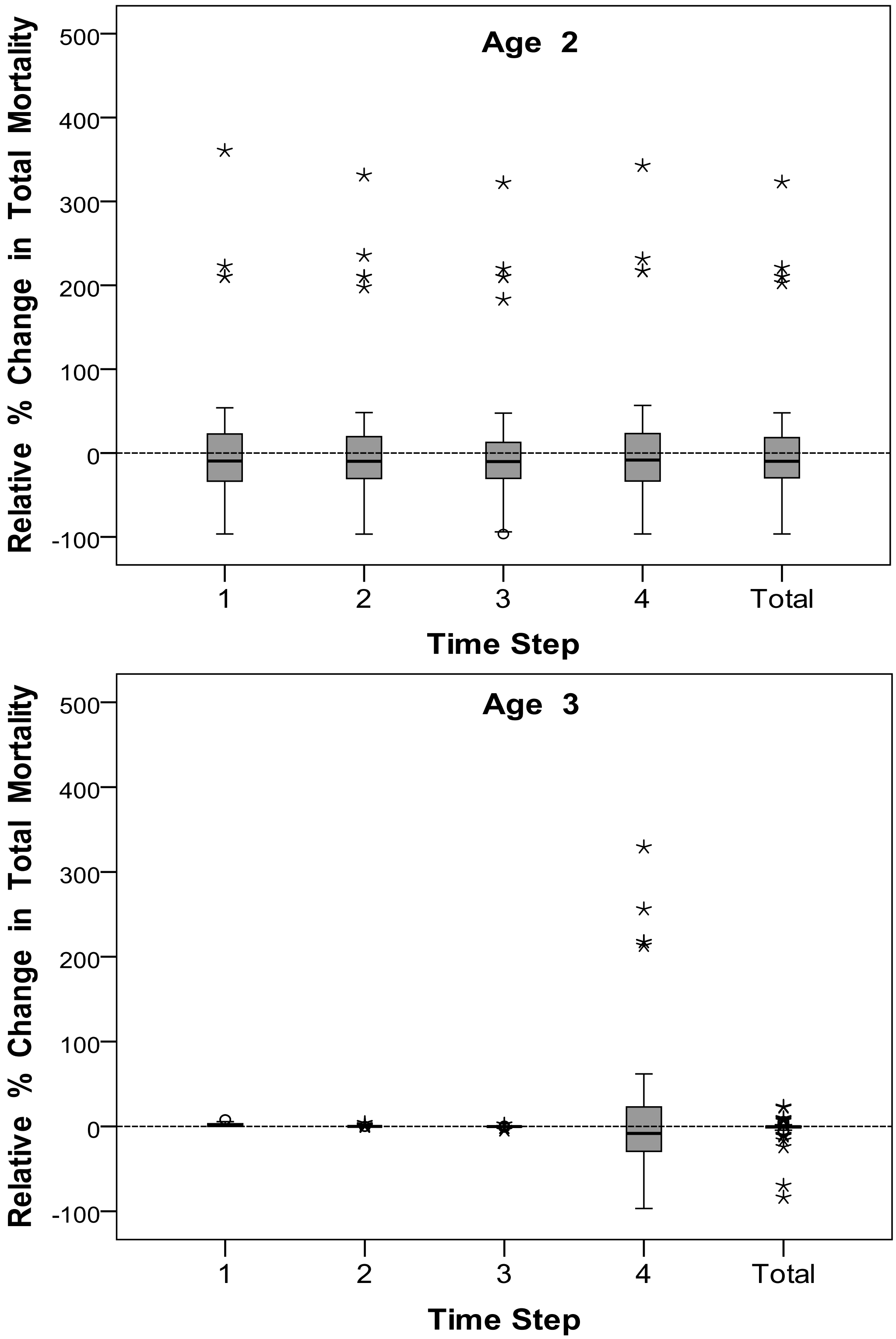


Figure 1. Box-and-whiskers plots of relative change for all stocks in Total Mortality of the Age2 and Age3 cohorts as NewAge2 forecasts were inserted into the 2008 final PFMC Chinook model run. Outliers above 500% removed from plot but are presented in Table 3. See text for quantile and outlier definitions for box-and-whiskers plots.

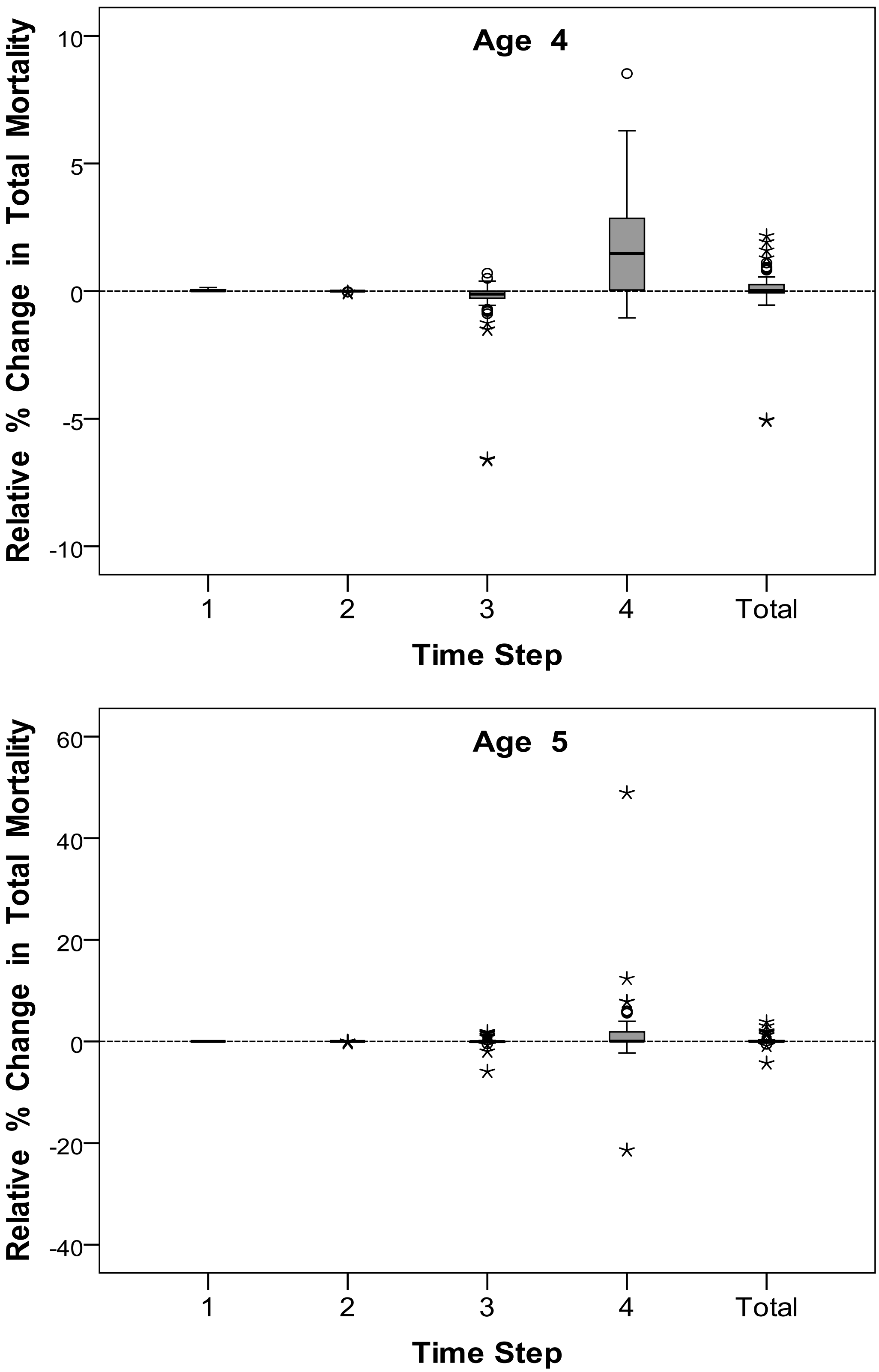
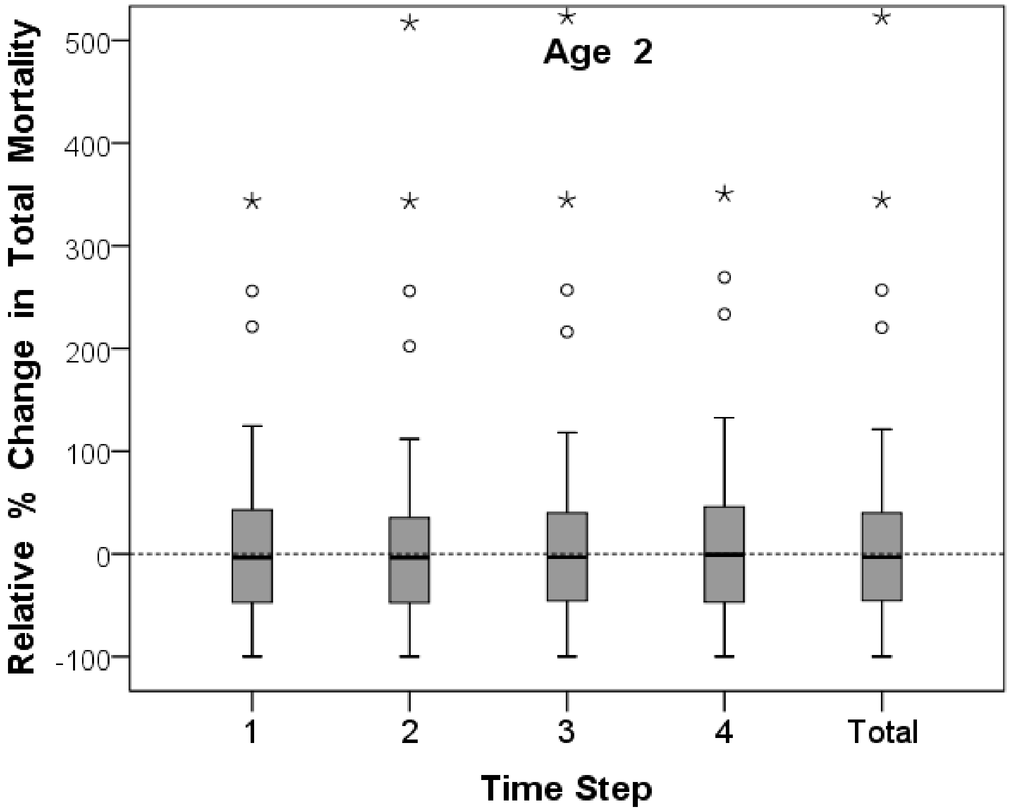


Figure 2. Box-and-whiskers plots of relative change for all stocks in Total Mortality of the Age4 and Age5 cohorts as NewAge2 forecasts were inserted into the 2008 final PFMC Chinook model run. All stocks included in figure.



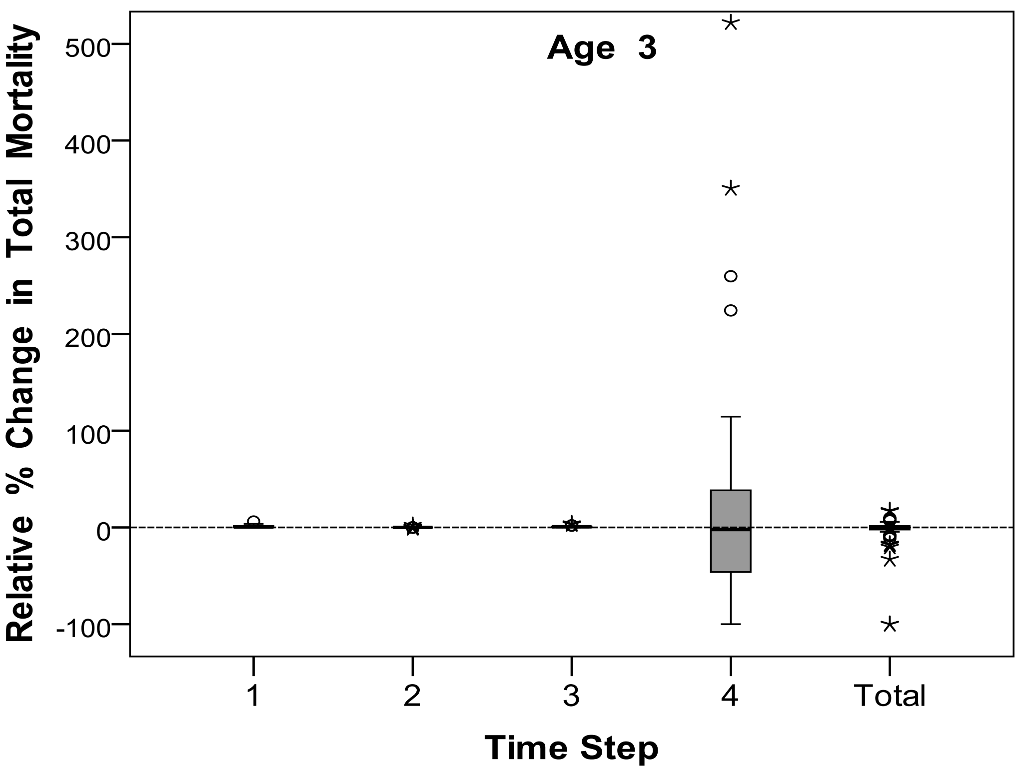


Figure 3. Box-and-whiskers plots of relative change for all stocks in Total Mortality of the Age2 and Age3 cohorts as NewAge2 forecasts were inserted into the 2012 final PFMC Chinook model run. Outliers above 500% removed from plot but are presented in Table 3.

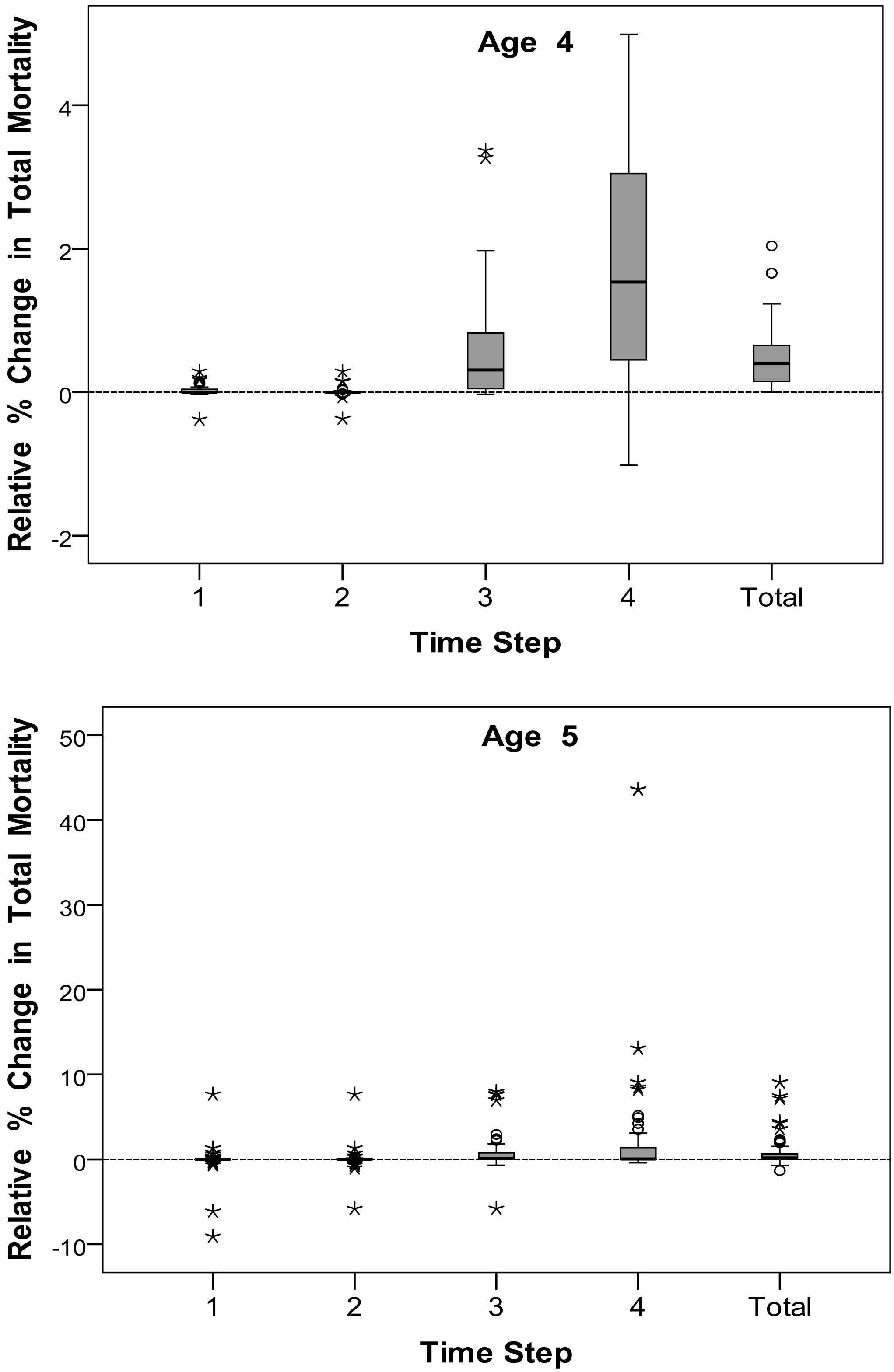


Figure 4. Box-and-whiskers plots of relative change for all stocks in Total Mortality of the Age4 and Age5 cohorts as NewAge2 forecasts were inserted into the 2012 final PFMC Chinook model run. All stocks included in figure

Table 3. Stocks with greatest change in Age2 abundance for 2008 & 2012, and their recruit scalars for preseason 2004 – 2013.

Year	Stock	Age 2 Recruit Scalars			Range of pre-season Age 2 Recruit Scalars
		Original	Adjusted	Percent Change	
2008	U-Skag FF	0.1001	1.646	1544.36%	Ranged from .1488 to .8749 for 2004-2007, dropped to .1001 in 2008 and remained at that level through pre-season 2010. Value was .2886 for 2011 and 2012, and .0149 for 2013.
	M-Skag FF	0.0031	0.0959	2993.55%	Ranged from .0002 to .0234 for 2004-2007, went to .0031 in 2008 and remained at that level through pre-season 2010. Value was .0110 for 2011 and 2012, and .0003 for 2013.
2008	U-SkagFYr	0.1996	2.9937	1399.85%	Ranged from .0391 to .1989 for 2004-2007, went to .1996 for 2008 and 2010, dropped to .1174 for 2009. No Age 2 recruit scalars for 2011 and 2012, but for 2013 value was .0895.
	M-SkagFYr			no forecast for 2008	
2008	U-SnohFYr	0.0293	0.0961	227.99%	Age 2 recruit scalar ranged from .0185 to .1984 for 2004-2013.
	M-SnohFYr	0.0347	0.3681	960.81%	Age 2 recruit scalar ranged from .0347 to .0837 for 2004-2013.
2008	U-MidPSFF	0.0588	1.0096	1617.01%	Ranged from .2136 to .2927 for 2004-2007, but dropped to .0588 for 2008 through pre-season 2013.
	M-MidPSFF	0.2680	0.7787	190.56%	Ranged from .8742 to 1.085 for 2004-2007, dropped to .2680 in 2008 through pre-season 2013.
2008	U-Will Sp	0.1565	0.4856	210.29%	Was .3683 and .3975 for 2004 and 2005, then was .1565 for following years except 2009 when value was .4470.
	M-Will Sp	1.4093	4.3705	210.12%	3.3149 and 3.5771 for 2004 and 2005, then was 1.4089 for following years except 2009 when value was 1.1158.
2008	U-LwGeo S	0.7764	3.3488	331.32%	1.0885 for 2004 and 2005, then at 1.6723 for 2006 and 2007, 0.7764 for 2008-2010, and .7766 for 2011-2013.
	M-LwGeo S	0.0660	0.0496	-24.85%	Age 2 recruit scalar was .0454 for 2004 and 2005, then was .0697 for 2006 and 2007, then 0.0660 for 2008-2013.
2012	U-Skag FF	0.2886	0.6114	111.85%	Age 2 recruit scalar ranged from .1488 to .8749 for 2004-2007, dropped to .1001 in 2008 and remained at that level through pre-season 2010. Value was .2886 for 2011 and 2012, and .0149 for 2013.
	M-Skag FF	0.0110	0.2515	2186.36%	Age 2 recruit scalar ranged from .0002 to .0234 for 2004-2007, went to .0031 in 2008 and remained at that level through pre-season 2010. Value was .0110 for 2011 and 2012, and .0003 for 2013.
2012	U-Tula FF	0.3503	1.058	202.03%	Highly variable Age 2 recruit scalars ranged from 0.3503 (2012) to 24.1551 (2005).
	M-Tula FF	7.4467	3.9027	-47.59%	Highly variable Age 2 recruit scalars ranged from 0.4524 (2004) to 38.4530 (2006).
2012	U-MidPSFF	0.0588	0.4739	705.95%	Ranged from .2136 to .2927 for 2004-2007, but dropped to .0588 for 2008 through pre-season 2013.
	M-MidPSFF	0.2680	2.9749	1010.04%	Ranged from .8742 to 1.085 for 2004-2007, dropped to .2680 in 2008 through pre-season 2013.
2012	U-SPS Fyr	0.0112	0.0097	-13.39%	Ranged from .0196 to .1842 for 2004-2007, dropped to .0112 in 2008 through pre-season 2013.
	M-SPS Fyr	0.1984	1.2178	513.81%	Ranged from 3.3506 to 4.4900 2004-2007, dropped to .1985 in 2008 through pre-season 2013.
2012	U-WA Tule	0.0485	0.0451	-7.01%	Age 2 recruit scalar ranged from 1.7816 to 2.3268 2004-2007, but dropped to .2441 in 2008 and remained at that level through pre-season 2011. For 2012 and 2013 the value was .0485
	M-WA Tule	0.6305	2.2445	255.99%	Age 2 recruit scalar ranged from .0254 to .0331 2004-2007, but rose to .5695 in 2008 and remained at that level through pre-season 2011. For 2012 and 2013 the value was .6305
2012	U-Will Sp	0.1565	1.6976	984.73%	Was .3683 and .3975 for 2004 and 2005, at .1565 for all following years except 2009 when value was .4470.
	M-Will Sp	1.4089	6.2488	343.52%	Was 3.3149 and 3.5771 for 2004 and 2005, at 1.4089 for following years except 2009 when value was 1.1158.
2012	U-CentVal	2.9956	3.6837	22.97%	Stock added to FRAM in 2008. Ranged from .3060 to .3250 for 2009-2011, 2.6746 to 2.9956 for 2012 and 2013.
	M-CentVal	0.1789	1.7927	902.07%	Stock added to FRAM in 2008. Ranged from .0180 to .0194 for 2009-2011, at .1789 for both 2012 and 2013.

Table 4. Comparison of FRAM estimated pre-season 2008 exploitation rates and natural escapements of selected Puget Sound Chinook stocks (MSF compatible) to FRAM results modeling the NewAge2 recruit scalars.

	Model Prediction			
Stock	Total ER	SUS ER	SUS Preterm . ER	Natural Escapement
Spring/Early:				
Nooksack (n)	24.1%	5.1%	1.7%	375
Skagit (n)	32.3%	19.0%	7.7%	1446
White	15.9%	13.9%	1.6%	5585
Dungeness	37.3%	2.7%	2.5%	1033
Summer/Fall:				
Skagit	47.1%	15.8%	4.0%	20253
Stillaguamish (n)	33.0%	14.8%	13.8%	355
Snohomish (n)	25.4%	12.9%	11.7%	4401
Lake Wa. (Cedar R.) (n)	40.4%	20.0%	7.3%	678
Green	56.0%	35.7%	7.3%	9695
Puyallup	47.0%	26.6%	7.3%	1153
Nisqually	71.5%	53.4%	12.5%	1928
Western Strait-Hoko	19.4%	2.3%	2.3%	925
Elwha	38.6%	2.8%	2.6%	2222
Mid-Hood Canal tribs. (n)	30.4%	8.4%	8.3%	57
Skokomish	58.3%	36.8%	8.3%	1207

FRAM Version: **5.3**
FRAM Description: **2008 preseason Final PFMC**
FRAM Run Number: **2108**

	Model Prediction			
Age2 from Age3 forecasts!				
Stock	Total ER	SUS ER	SUS Preterm . ER	Natural Escapement
Spring/Early:				
Nooksack (n)	23.9%	5.1%	1.7%	375
Skagit (n)	32.0%	18.8%	7.4%	1446
White	15.9%	13.9%	1.6%	5585
Dungeness	37.1%	2.7%	2.5%	1033
Summer/Fall:				
Skagit	49.8%	15.9%	4.7%	20260
Stillaguamish (n)	30.7%	12.6%	11.5%	355
Snohomish (n)	20.1%	7.3%	6.1%	4401
Lake Wa. (Cedar R.) (n)	42.6%	22.3%	9.8%	678
Green	57.8%	37.5%	9.8%	9666
Puyallup	48.9%	28.6%	9.8%	1152
Nisqually	70.8%	52.6%	10.7%	1924
Western Strait-Hoko	18.4%	2.2%	2.2%	926
Elwha	38.4%	2.8%	2.6%	2223
Mid-Hood Canal tribs. (n)	30.8%	8.7%	8.6%	57
Skokomish	58.5%	37.0%	8.6%	1207

FRAM Version: **5.3**
FRAM Description: **2008 preseason with NewAge2**
FRAM Run Number: **NewAge2 from Age3; Chin2108**

Table 5. FRAM estimated pre-season 2012 exploitation rates and natural escapements of selected Puget Sound Chinook stocks (MSF compatible) compared to FRAM results with NewAge2 recruit scalars.

	Model Prediction pre-season Chin1512				Model Prediction Age2 from Age3 Chin1512			
					NewAge2 forecasts			
Stock	**Total ER**	**SUS ER**	**SUS Preterm. ER**	**Natural Escapement**	**Total ER**	**SUS ER**	**SUS Preterm. ER**	**Natural Escapement**
Spring/Early:								
Nooksack (n)	35.1%	7.0%	3.0%	309	35.4%	7.2%	3.2%	309
				236				236
				73				73
Skagit (n)	33.1%	18.8%	8.3%	942	33.7%	19.4%	8.9%	938
				468				467
				276				275
				197				197
White	19.2%	18.2%	3.6%	2141	20.2%	19.1%	4.7%	2,141
Dungeness	63.9%	3.4%	3.3%	656	64.6%	4.3%	4.2%	656
Summer/Fall:								
Skagit	40.4%	14.3%	4.9%	8,398	42.9%	14.8%	5.8%	8,390
				5,796				5,790
				288				287
				1,168				1,167
Stillaguamish (n)	23.4%	13.5%	8.2%	338	24.5%	14.7%	9.4%	337
				296				295
				43				43
Snohomish (n)	16.4%	9.1%	7.5%	2,301	15.6%	8.3%	6.6%	2,300
				1,453				1,452
				848				848
Lake Wa. (Cedar R.)	34.1%	17.8%	9.6%	994	36.5%	20.2%	12.2%	993
Green	31.0%	14.6%	9.6%	1,911	33.4%	17.1%	12.2%	1,910
Puyallup	**48.5%**	32.2%	9.6%	2,206	**50.4%**	34.1%	12.2%	2,202
Nisqually	**55.3%**	41.2%	20.7%	1,072	**52.6%**	38.3%	16.6%	1,069
Western Strait-Hoko	21.6%	2.8%	2.8%	2,118	21.5%	2.8%	2.8%	2,117
Elwha	63.2%	3.4%	3.3%	1,887	63.9%	4.2%	4.1%	1,886
Mid-Hood Canal tribs. (n)	25.9%	12.2%	12.0%	196	26.4%	12.7%	12.5%	196
Skokomish	47.9%	34.3%	12.6%	1,889	48.4%	34.8%	13.1%	1,885

FRAM Version:	**2.09**	**FRAM Version:**	**2.11**
FRAM Description:	**2012 preseason Final PFMC**	**FRAM Description:**	**2012 preseason with NewAge2**
FRAM Run Number:	**1512**	**FRAM Run Number:**	**NewAge2 from Age3; Chin1512**

Table 6. Original pre-season 2012 population age structure, for the Unmarked and Marked **Mid Puget Sound Fall Fingerling stocks**, compared to population age structure with NewAge2 abundances.

		2012 **original** abundance at start of Timestep					2012 **NewAge2** abundance at start of Timestep			
Stock	Age	T1	T2	T3	T4		T1	T2	T3	T4
U-MidPSFF	2	**10,366**	7,654	7,021	**10,366**		**83,549**	61,676	56,581	**83,549**
U-MidPSFF	3	**48,968**	39,358	36,755	**6,077**		**48,968**	39,353	36,751	**48,954**
U-MidPSFF	4	12,941	11,094	10,227	29,200		12,941	11,094	10,227	29,185
U-MidPSFF	5	1,232	1,082	985	2,058		1,232	1,082	985	2,058
M-MidPSFF	2	**47,249**	34,884	32,003	**47,249**		**524,476**	387,171	355,186	**524,476**
M-MidPSFF	3	**307,429**	246,289	229,737	**27,696**		**307,429**	246,257	229,707	**307,304**
M-MidPSFF	4	29,118	24,704	22,762	180,445		29,118	24,703	22,762	180,332
M-MidPSFF	5	777	679	618	4,369		777	678	617	4,365

Table 7. Original pre-season 2012 population age structure, for the Unmarked and Marked **South Puget Sound Fall Fingerling stocks**, compared to population age structure with NewAge2 abundances.

		2012 **original** abundance at start of Timestep					2012 **NewAge2** abundance at start of Timestep			
Stock	Age	T1	T2	T3	T4		T1	T2	T3	T4
U-SPSd FF	2	**133,927**	98,908	90,702	**133,927**		**51,078**	37,715	34,585	**51,078**
U-SPSd FF	3	**30,092**	24,145	22,677	**78,901**		**30,092**	24,141	22,673	**30,074**
U-SPSd FF	4	8,139	6,908	6,385	17,572		8,139	6,908	6,385	17,561
U-SPSd FF	5	292	269	259	2,615		292	269	259	2,614
M-SPSd FF	2	**1,575,763**	1,163,741	1,067,181	**1,575,763**		**703,625**	519,533	47,6424	**703,625**
M-SPSd FF	3	**414,536**	331,211	310,779	**928,342**		**414,536**	331,151	310,723	**414,285**
M-SPSd FF	4	84,368	71,036	65,657	236,122		84,368	71,035	65,656	235,958
M-SPSd FF	5	633	582	560	25,623		633	582	560	25,601

Table 8. FRAM estimated pre-season 2008 and pre-season 2012 ocean escapements, and brood year ER, of selected Columbia River Chinook stocks (MSF compatible) compared to results with NewAge2 recruit scalars.

Table 5 PFMC Preseason Report for 2008		
	Adult Ocean Escapement or Other Crit.	
	Chin2108	Chin2108 with NewAge2
Col Upriver Brt	175.9	175.9
Mid-Col Brt	45.2	45.2
Col Lower Hatch	60.4	60.4
Col Nat Tule Brood Year ER	35.9%	35.9%
Col LRW	3.8	3.8
Spring Creek	86.2	86.2

Table 5 PFMC Preseason Report for 2012		
	Adult Ocean Escapement or Other Crit.	
	Chin1512	Chin1512 with NewAge2
Col Upriver Brt	353.0	353.0
Mid-Col Brt	90.7	90.7
Col Lower Hatch	128.4	128.1
Col Nat Tule Brood Year ER	**40.9%**	**41.1%**
Col LRW	16.2	16.2
Spring Creek	60.0	59.9

DISCUSSION

When the initial structure of Chinook FRAM was conceived there was more of a focus on stock escapement (age 3 through 5). The present management focus has shifted to ER caps. The importance of accurate Age2 forecasts appears to have been lost during this transition. Abundances based upon Age2 recruit scalars do contribute a notable part of total fishery mortality.

The lack of data for Age2 survival rates (limited terminal return information, almost no CWT fishery recoveries), and subsequent poor quality of Age2 Chinook forecasts has long been known, but ignored. The work toward an updated Chinook Base Period and the recent work to better model sublegal encounters motivated this effort to address the Age2 forecast dilemma. Although it was surprising to see how stagnant the modeled Age2 annual forecasts had become (Appendix Table A), there often is little alternative when the provided regionally produced forecasts are only for "total runsize" of combined ages 3 through 5, or at best by Age3, Age4, and Age5, with no Age2 forecast. What has not been investigated before is the potential effect of Age2 forecasts on stock specific exploitation rates.

Initially it was expected that the NewAge2 forecasts would raise the ER for some stocks and drop it for others. Since Age2 calculated fishery mortality is significantly reduced by the AEQ factor the changes to ER were not expected to be great (AEQ mortality is used for ER calculations). This was generally the case for 2008 (**Table 4**), while for 2012 (**Table 5**) all but three Puget Sound stocks showed an increase in ER. A couple of stocks had an absolute ER increase in the neighborhood of 2%; one stock saw a drop of nearly 3%. When we struggle during pre-season negotiations to stay below an ESA driven ER cap, often trying to find tenths of a percent reduction, changes of a full percent or more could be disruptive to the present annual fishery structure.

However, the results from re-running 2008 and 2012 with NewAge2 recruit scalars should not be taken as absolute. This present exercise took a narrow focus and only changed the one parameter of Age2 recruit scalars in these two pre-season model runs. With every pre-season there are changes, with usually subtle effects, in the FRAM application and many input parameters. Some changes, or corrected “model glitches” aren’t so subtle. An example is the natural mortality rates used in the 2008 Outfile, or base period input file (**Table 9**). After the 2008 pre-season, it was discovered that the Outfiles used up to that year were created with the wrong natural mortality rates for timestep 4. The 2008 model run with NewAge2 recruits would have produced a different result with the corrected Outfile, but wouldn’t have been directly comparable to the pre-season 2008 product.

Several types of annual input parameters are calculated/calibrated using the post-season Validation Runs. Validation Runs, a type of post-season FRAM run, incorporate observed fishery “catch” and observed Terminal Run Size of stocks’ Age3, 4, and 5 year old fish to back-calculate their initial recruit scalars. But this isn’t the case for the Age2 recruit scalar. Validation Runs have reused the annual pre-season Age2 recruit scalars. If realistic Age2 abundances are provided for Validation Runs then we can expect changes to parameters such as input ‘fishery scalars’ for Puget Sound marine sport retention and non-retention fisheries. The fishery scalar reflects an average “effort” that should produce a model estimated landed catch consistent with observed landed catch. Since, over all FRAM stocks, the NewAge2 recruits increase overall Chinook abundance then reduced ‘fishery scalars’ would be needed to keep model estimated landed catch consistent with observed levels. This applies particularly for timestep 4 fisheries when NewAge2 “age-up”. In general, this should somewhat reduce ERs produced in the NewAge2 versions of pre-season 2008 and 2012 model runs. The largest affect of using NewAge2 recruit methodology may be in the re-distribution of fishery impacts among FRAM stocks contributing to timestep 4 fisheries.

The calculations of, and/or acceptance of, several stocks’ ER caps are based upon FRAM Validation Run results. Validation Runs should be reproduced with realistic Age2 abundances.

The need to use realistic Age2 forecasts is a given, so the issue at hand is when to implement either the presented NewAge2 forecast methodology or alternative realistic methods. Some potential options:

1. Full implementation of a NewAge2 forecast methodology for pre-season 2014.
    a. Option 1: Direct calculation from annual Age3 forecasts.
        i. Model with average, or anticipated fishery mortality rates.
        ii. Apply average NewAge2/Age3 ratio from Validation Runs.
    b. Option 2: Calculation from average Age3 abundances from recent Validation Runs.
        i. Apply average NewAge2/Age3 ratio from Validation Runs.
        ii. Option to simply average NewAge2 abundances from same Validation Runs.
    c. Additional consideration could be considered for brood year specific adjustments to NewAge2 forecasts.

2. Implement a NewAge2 forecast methodology as part of the Chinook Base Period update, with potential corresponding adjustments to ESA stock ER caps, perhaps by 2015 pre-season.

3. Consult with regional biologists regarding limitations of current Age2 forecasts and discuss options for development of Age2 forecasts for preseason 2014.

Table 9. Time period and age-specific rates used by FRAM to simulate Chinook natural mortality

Chinook FRAM Natural Mortality Rates, by age and timestep:					
				2008 Outfile	**2012 Outfile**
	Timestep 1	Timestep 2	Timestep 3	Timestep 4	Timestep 4
Age	Oct. to April	May to June	July to Sept.	Oct. to April	Oct. to April
2	0.2577	0.0816	0.1199	0.1878	0.2577
3	0.1878	0.0577	0.0853	0.1221	0.1878
4	0.1221	0.0365	0.0543	0.0596	0.1221
5	0.0596	0.0174	0.026	0.0596	0.0596

Supplementary Reference

Hoaglin, D. C., F. Mosteller, and J. W. Tukey. 1983. Understanding Robust and Exploratory Data Analysis. John Wiley and Sons, New York. 446 p.

Model Evaluation Workgroup (MEW). 2008. *Fisheries Regulation Assessment Model (FRAM) An Overview for Coho and Chinook v 3.0 .* (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Model Evaluation Workgroup (MEW). 2008. *Fisheries Regulation Assessment Model (FRAM) Technical Documentation for Coho and Chinook v. 3.0.* (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, ortland, Oregon 97220-1384.

Model Evaluation Workgroup (MEW). 2007b. Chinook FRAM Base Data Development (Document prepared for the Council and its advisory entities). Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Appendix Table A. Age2 pre-season recruit scalars for Chinook FRAM stocks, 2004-2013, and recalculated NewAge2 scalars for 2008 and 2012.

StockName	Pre-season Age2 Recruit Scale Factors (2004 through 2013):										New Age2 from Age3	
	Chin1604	Chin2705	Chin3006	Chin3007	**Chin2108**	Chin2309	Chin1010	Chin1811	**Chin1512**	Chin1213	**Chin2108**	**Chin1512**
U-NkSm FF	0.0955	0.0277	0.0261	0.0261	0.0260	0.0260	0.0260	0.0421	0.0421	0.0421	0.0354	0.0394
M-NkSm FF	0.5858	0.3527	0.3039	0.3039	0.3025	0.3025	0.3025	0.7589	0.7589	0.7589	0.2516	0.7232
U-NFNK Sp	1.4734	1.5632	2.1621	1.3230	3.4646	3.4646	3.5330	2.7510	2.7510	0.3986	1.9597	3.8861
M-NFNK Sp	0.5266	0.4368	3.4182	2.0900	5.4732	5.4732	5.6968	6.4250	6.4250	1.0533	6.0060	8.6634
U-SFNK Sp	2.0000	2.0000	5.5803	3.4940	0.1397	0.1397	0.2757	0.2268	0.2268	0.1134	0.1257	0.0174
M-SFNK Sp												
U-Skag FF	0.6479	0.3917	0.8749	0.1488	0.1001	0.0938	0.1001	0.2886	0.2886	0.0149	1.6460	0.6114
M-Skag FF	0.0179	0.0129	0.0234	0.0002	0.0031	0.0030	0.0031	0.0110	0.0110	0.0003	0.0959	0.2515
U-SkagFYr	0.0785	0.0391	0.0929	0.1989	0.1996	0.1174	0.1996			0.0895	2.9937	
M-SkagFYr												
U-SkagSpY	2.1049	1.8550	1.6927	1.8606	1.6838	0.8460	0.8000	0.8001	0.8001	2.4051	1.0416	0.9571
M-SkagSpY	3.4599	1.6712	1.4137	3.1224	2.2491	2.2456	6.6700	10.2810	10.2810	3.5189	2.1238	2.4213
U-Snoh FF	1.1701	1.5732	1.2471	1.0967	1.7176	0.3749	0.7612	0.3794	0.1332	0.0492	0.0986	0.0735
M-Snoh FF	0.3650	0.8131	0.9496	0.6580	1.0262	0.1597	0.1964	0.0978	0.1264	0.1264	0.0338	0.1712
U-SnohFYr	0.1184	0.0903	0.0433	0.0399	0.0293	0.0532	0.1111	0.0687	0.0185		0.0961	0.0102
M-SnohFYr	0.0837	0.0580	0.0375	0.0377	0.0347	0.0831	0.0819	0.0506	0.0741	0.0741	0.3681	0.0747
U-Stil FF	1.8700	1.8235	1.6380	2.5140	1.2792	0.6803	0.5729	0.1718	0.3334	0.2811	0.8362	0.4077
M-Stil FF	0.1321	0.4830	0.5453	0.5594	1.1344	0.3886	0.0731	0.3670	0.8803	1.9448	0.5146	0.4120
U-Tula FF	3.0887	24.1551	16.8750	6.3756	6.7360	2.2918	0.9042	0.6018	0.3503	0.4312	1.1538	1.0580
M-Tula FF	0.4521	2.6244	38.4530	13.0623	24.0240	5.2121	1.8562	2.1398	7.4467	9.5998	2.3645	3.9027
U-MidPSFF	**0.2136**	**0.2145**	**0.2927**	**0.2560**	**0.0588**	**0.0588**	**0.0588**	**0.0588**	**0.0588**	**0.0588**	**1.0096**	**0.4739**
M-MidPSFF	**0.9027**	**1.0858**	**0.9996**	**0.8742**	**0.2680**	**0.2680**	**0.2680**	**0.2680**	**0.2680**	**0.2680**	**0.7787**	**2.9749**
U-UWAc FF	0.6556		0.0008	0.0008								
M-UWAc FF		0.6341	2.4837	2.4344	1.2879	1.2879	1.2879	1.2869	1.2869	1.2869	1.0656	0.2762
U-SPSd FF		**0.4137**	**0.4013**	**0.4575**	**0.6516**	**0.6516**	**0.6516**	**0.6513**	**0.6513**	**0.6513**	**0.2920**	**0.2484**
M-SPSd FF	**3.4844**	**3.6430**	**4.7382**	**5.4015**	**7.6665**	**7.6665**	**7.6665**	**7.6631**	**7.6631**	**7.6631**	**2.6208**	**3.4218**
U-SPS Fyr	0.1842	0.0493	0.0196	0.0223	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0096	0.0097
M-SPS Fyr	3.3506	3.8380	3.9386	4.4900	0.1985	0.1985	0.1985	0.1984	0.1984	0.1984	0.1700	1.2178
U-WhiteSp	15.2435	21.1897	21.1890	21.1890	14.2047	14.2047	14.2047	14.2040	14.2040	14.2040	12.5540	26.3841
M-WhiteSp												
U-HdCl FF	6.4769	6.0283	2.5444	3.8100	1.5058	1.5058	1.5058	0.6890	0.6890	0.5387	1.7813	0.7521
M-HdCl FF	0.3566	0.3339	2.5361	3.8000	2.6081	2.6081	2.6081	9.1590	9.1590	15.2650	3.3694	7.1247
U-HdCl FY	1.8433	2.0137										
M-HdCl FY			2.0000	2.0000	1.6479	1.6479	1.6479	4.4690	4.4690	4.4690	1.2457	5.8899
U-SJDF FF	1.7888	1.9014	2.2414	2.2414	3.9976	3.9976	3.9976	3.9994	3.9994	3.9994	3.1900	7.0841
M-SJDF FF	0.2351	0.2196	0.1709	0.1709								
U-OR Tule	0.8057	0.3130	0.1835	0.1743	0.4530	0.4530	0.4530	0.4507	0.1940	0.1940	0.1837	0.1632

StockName	Pre-season Age2 Recruit Scale Factors (2004 through 2013):										New Age2 from Age3	
	Chin1604	Chin2705	Chin3006	Chin3007	**Chin2108**	Chin2309	Chin1010	Chin1811	**Chin1512**	Chin1213	**Chin2108**	**Chin1512**
M-OR Tule	0.0114	0.0045	0.0026	0.0025	1.0670	1.0670	1.0670	1.0616	1.4550	1.4550	0.4288	0.8320
U-WA Tule	1.7816	2.3268	1.9039	1.8087	0.2441	0.2441	0.2441	0.2430	0.0485	0.0485	0.1012	0.0451
M-WA Tule	0.0254	0.0331	0.0271	0.0257	0.5695	0.5695	0.5695	0.5670	0.6305	0.6305	0.2361	2.2445
U-LCRWild	2.3620	1.9802	1.6926	1.6926	0.3362	0.3362	0.3362	0.3359	0.8250	0.8250	0.3990	0.9032
M-LCRWild	0.0311	0.0260	0.0222	0.0222	0.0083	0.0083	0.0083	0.0083			0.0123	
U-BPHTule	2.4238	1.9903	1.0386	1.0386	0.0503	0.1559	0.0503	0.0500	0.1200	0.1200	0.0684	0.0750
M-BPHTule	0.0296	0.0243	0.0127	0.0127	0.9553	0.8497	0.9553	0.9488	1.2000	1.2000	0.0120	0.8084
U-UpCR Su	7.1304	7.0677	7.8053	7.8053	3.8993	3.8993	3.8993	2.4542	2.4500		0.2310	
M-UpCR Su	1.2583	1.2478	1.3774	1.3774	0.7825	0.7825	0.7825	0.4925	0.4900		4.8400	
U-UpCR Br	8.6140	9.9402	7.9583	7.9583	4.8870	4.8870	4.8870	4.8887	6.2500	6.2500	0.9700	7.3104
M-UpCR Br	0.2600	0.3000	0.2402	0.2402	0.5430	0.5430	0.5430	0.5432	2.3200	2.3200	0.4841	2.7897
U-Cowl Sp												
M-Cowl Sp												
U-Will Sp	0.3683	0.3975	0.1565	0.1565	0.1565	0.4470	0.1565	0.1565	0.1565		0.4876	1.6976
M-Will Sp	3.3149	3.5771	1.4089	1.4089	1.4093	1.1158	1.4093	1.4089	1.4089		4.3889	6.2488
U-Snake F	0.7400	0.7382	0.7400	0.7400	0.7074	0.7074	0.7074	0.8700	0.8700	0.8700	0.6286	0.8394
M-Snake F	1.2600	1.2569	1.2600	1.2600	1.2046	1.2046	1.2046	1.1300	1.1300	1.1300	1.0707	1.0906
U-OR No F	1.9988	1.9988	1.9982	1.9982	0.7917	0.7917	0.7917	0.7918	0.7918	0.7918	0.7542	1.0457
M-OR No F												
U-WCVI Tl	1.2482	1.0617	2.9884	2.9884	0.3532	0.3532	0.3532	0.3532	0.3532	0.3532	0.3255	0.0618
M-WCVI Tl	0.0254	0.0254	0.0608	0.0608	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0064	0.0013
U-FrasRLt	0.5102	0.8810	1.2068	1.2068	3.3900	3.3900	3.3900	3.3899	3.3899	3.3899	2.9662	1.3683
M-FrasRLt	0.0105	0.0187	0.0249	0.0249	0.0720	0.0720	0.0720	0.0720	0.0720	0.0720	0.0630	0.0608
U-FrasREr	5.3955	5.3955	4.0981	4.0981	3.2900	3.2900	3.2900	3.2903	3.2903	3.2903	3.0094	3.2574
M-FrasREr	0.1101	0.1101	0.0836	0.0836	0.0671	0.0671	0.0671	0.0671	0.0671	0.0671	0.0614	0.0663
U-LwGeo S	1.0885	1.0885	1.6723	1.6723	0.7764	0.7764	0.7764	0.7766	0.7766	0.7766	0.5835	0.4035
M-LwGeo S	0.0454	0.0454	0.0697	0.0697	0.0660	0.0660	0.0660	0.0660	0.0660	0.0660	0.0496	0.0345
U-WhtSpYr	3.5393	3.5393	4.0243	4.0243	8.5992	8.5992	8.5992	8.5865	8.5865	8.5865	7.5051	3.4586
M-WhtSpYr												
U-LColNat					0.7140	0.7140	0.7140	0.7113	2.0000	2.0000	0.5117	2.6912
M-LColNat												
U-CentVal					0.3250	0.3060	0.3250	2.6746	2.9956	2.9956	0.2985	3.6837
M-CentVal					0.0194	0.0180	0.0194	0.1597	0.1789	0.1789	0.0178	1.7927
U-WA NCst					0.2610	0.2610	0.2610	0.2610	0.1957	0.1957	0.2362	0.3959
M-WA NCst									0.0653	0.0653		0.1306
U-Willapa					3.4900	3.4900	3.4900	3.4902	0.7366	0.7366	3.1451	0.4875
M-Willapa					0.1930	0.1930	0.1930	0.1930	2.9466	2.9466	0.1739	1.5388
U-Hoko Rv					1.8272	1.8272	1.8272	3.1741	0.8119	6.0384	0.2591	0.4261
M-Hoko Rv					2.6294	2.6294	2.6294	4.6373	0.8192	3.4548	0.3577	0.4907

Appendix Table B. Summary statistics for FRAM stock specific initial Timestep 1 abundance ratios of NewAge2/Age3, as produced from Chinook FRAM Validation Runs (2003-2010)

	Stock specific 2:3 ratios from 2003-2010 Validation Runs.				
StockName	**Mean**	**Median**	**Min**	**Max**	**SD**
U-NkSm FF	0.96	0.96	0.96	0.97	0.00
M-NkSm FF	0.96	0.96	0.96	0.97	0.00
U-NFNK Sp	0.98	0.98	0.98	0.98	0.00
M-NFNK Sp	0.98	0.98	0.98	0.98	0.00
U-SFNK Sp	0.98	0.98	0.98	0.98	0.00
M-SFNK Sp					
U-Skag FF	0.93	0.92	0.92	0.97	0.02
M-Skag FF	0.93	0.92	0.92	0.97	0.02
U-SkagFYr	0.96	0.96	0.96	0.97	0.00
U-SkagSpY	0.98	0.98	0.98	0.98	0.00
M-SkagSpY	0.98	0.98	0.98	0.98	0.00
U-Snoh FF	0.93	0.93	0.93	0.95	0.01
M-Snoh FF	0.93	0.93	0.93	0.95	0.01
U-SnohFYr	0.95	0.95	0.95	0.95	0.00
M-SnohFYr	0.95	0.95	0.95	0.95	0.00
U-Stil FF	0.93	0.93	0.93	0.95	0.01
M-Stil FF	0.93	0.93	0.93	0.94	0.00
U-Tula FF	0.97	0.97	0.97	0.98	0.00
M-Tula FF	0.97	0.97	0.97	0.97	0.00
U-MidPSFF	0.95	0.95	0.95	0.96	0.00
M-MidPSFF	0.95	0.95	0.95	0.96	0.00
U-UWAc FF					
M-UWAc FF	0.88	0.87	0.86	0.89	0.01
U-SPSd FF	0.96	0.96	0.95	0.96	0.00
M-SPSd FF	0.96	0.96	0.95	0.96	0.00
U-SPS Fyr	0.92	0.92	0.92	0.93	0.00
M-SPS Fyr	0.92	0.92	0.92	0.93	0.00
U-WhiteSp	0.96	0.95	0.95	0.96	0.00
U-HdCl FF	0.94	0.94	0.93	0.94	0.00
M-HdCl FF	0.94	0.94	0.93	0.95	0.00
U-HdCl FY	0.95	0.95	0.95	0.96	0.00
M-HdCl FY	0.95	0.95	0.95	0.96	0.00
U-SJDF FF	0.96	0.96	0.95	0.97	0.00
M-SJDF FF	0.96	0.96	0.95	0.97	0.00
U-OR Tule	0.94	0.94	0.94	0.95	0.00
M-OR Tule	0.94	0.94	0.94	0.95	0.01
U-WA Tule	0.97	0.97	0.96	1.00	0.01
M-WA Tule	0.97	0.97	0.96	0.99	0.01
U-LCRWild	0.98	0.98	0.98	0.99	0.00
M-LCRWild	0.98	0.98	0.98	0.99	0.00
U-BPHTule	0.92	0.92	0.92	0.95	0.01
M-BPHTule	0.93	0.92	0.92	0.95	0.01
U-UpCR Su	0.98	0.98	0.97	0.99	0.01
M-UpCR Su	0.98	0.98	0.97	0.99	0.01

Stock specific 2:3 ratios from 2003-2010 Validation Runs.

StockName	Mean	Median	Min	Max	SD
U-UpCR Br	0.97	0.97	0.96	0.97	0.00
M-UpCR Br	0.97	0.97	0.96	0.98	0.00
U-Cowl Sp					
M-Cowl Sp					
U-Will Sp	0.99	0.98	0.98	0.99	0.00
M-Will Sp	0.99	0.98	0.98	0.99	0.00
U-Snake F	0.97	0.97	0.96	0.98	0.01
M-Snake F	0.97	0.96	0.96	0.98	0.01
U-OR No F	0.98	0.98	0.97	0.99	0.01
M-OR No F	0.98	0.98	0.96	1.00	0.01
U-WCVI Tl	0.98	0.98	0.97	0.98	0.00
M-WCVI Tl	0.98	0.98	0.97	1.00	0.01
U-FrasRLt	0.95	0.94	0.94	0.95	0.00
M-FrasRLt	0.95	0.94	0.94	0.95	0.00
U-FrasREr	0.99	0.99	0.98	0.99	0.00
M-FrasREr	0.99	0.99	0.98	0.99	0.00
U-LwGeo S	**0.81**	0.81	0.80	0.83	0.01
M-LwGeo S	**0.81**	0.81	0.79	0.83	0.01
U-WhtSpYr	0.97	0.97	0.97	0.98	0.00
M-WhtSpYr					
U-LColNat	0.96	0.96	0.95	0.96	0.01
U-CentVal	0.97	0.96	0.94	1.00	0.02
M-CentVal	0.97	0.96	0.94	1.00	0.02
U-WA NCst	0.98	0.98	0.98	0.98	0.00
M-WA NCst	0.98	0.98	0.98	0.99	0.00
U-Willapa	0.98	0.98	0.97	0.99	0.00
M-Willapa	0.98	0.98	0.97	0.99	0.00
U-Hoko Rv	0.98	0.98	0.98	0.98	0.00
M-Hoko Rv	0.98	0.98	0.98	0.98	0.00

Mean	0.96
Median	0.97
Min	0.81
Max	0.99
Count	68

MODEL EVALUATION WORKGROUP REPORT ON SALMON METHODOLOGY REVIEW

The Model Evaluation Workgroup (MEW) offers comments on the following Fishery Regulation Assessment Model- (FRAM) related topics as contained in the materials provided for the October Methodology Review Meeting. Because of the Federal government furlough, several members of the MEW were not able to attend the review and provide comments or questions at that time. In addition, the MEW is not attending the presentations of the selected topics at the November Scientific and Statistical Committee Meeting. Our comments include feedback from those that were able to attend the October meeting and by those who did not attend the October review but had reviewed the materials prior to the meeting.

Four topics were presented at the October Methodology Review with MEW as the lead:

1. Incorporate estimates of legal and sublegal Chinook fishery encounters from recent sampling information into FRAM
2. Modifications to FRAM algorithms for assessing sublegal and legal encounters if there are changes in minimum size limits
3. Develop a standardized methodology for calculating Age-2 Chinook forecasts
4. A progress report on the development of a new Chinook FRAM base period

The first three topics are relevant to FRAM modifications that would be considered for 2014 fishery modeling. The fourth topic refers to ongoing work which may be ready for review next year.

The following is a summary of comments for those topics in the Methodology Review that are FRAM-related.

We recommend that the incorporation of recent sampling information on sublegal and legal size Chinook encounters be included for 2014 FRAM modeling. The sublegal and legal size information that is currently in FRAM is outdated, poorly-documented, and shown to produce estimates that are different from recent observations. Recent-year data on sublegal and legal size encounters are now available for many fisheries. FRAM encounter rates should be modified to reflect these observations.

Regarding modification of FRAM algorithms for assessing sublegal and legal encounters if changes in size limits are proposed for modeling, the MEW recommends a limited use of this in 2014. The method for analyzing changes in size limits would only be used in fisheries where model-projected estimates of encounters can be gauged against estimates from relevant sampling data (e.g., sublegal to legal ratios, length frequency data).

We could not come to consensus for 2014 modeling regarding developing a standardized method for calculating Age-2 forecasts. Many regionally-developed annual stock forecasts do not include an Age-2 component, which is required for FRAM Chinook modeling. The use of "place-holder" model input for Age-2 abundance needs to be addressed. Although the method presented at the Review has merit and represents an improvement over status quo, we would like additional time to explore the effects of broad scale abundance changes on other modeling parameters, as well as investigate alternative methods for deriving model inputs for Age-2 abundance.

Refinement of methods for estimating sublegal and legal encounters, algorithms to assess changes in size limits, and rigorous methods for generating Age-2 abundance inputs will be further developed in the new Chinook FRAM base period project that began this last summer. The Methodology Review projects by the MEW were in part products of this FRAM base period development project and reflect our initial efforts towards overall improvement in fishery impact assessment in FRAM.

The new FRAM Chinook base period will migrate FRAM from a model that relies on 30+ year-old coded wire tag data to one that incorporates contemporary coded wire tags information (2007 – 2011 fishing years). We will also update stock and fishery parameters and revise outdated calibration methodologies.

One other model-related topic from the Methodology Review involves the coho stock and population units in the "Harvest Strategy Risk Assessment for Lower Columbia Natural Coho." The stock units in FRAM for lower Columbia natural coho are different than the units described in the risk assessment where the populations are stratified into three geographic/population categories (Coast, Cascade, and Gorge Major Population Groups) without reference to run timing. The FRAM has three coho stock units: Oregon, Washington Early, and Washington Late. Fishery impacts from FRAM for Lower Columbia natural coho would need to be estimated in terms that are consistent with the units described in the harvest strategy risk assessment report. For preseason fishery assessment, a method to coordinate the fishery impact estimates in ocean and in-river models for lower Columbia natural coho would need to be developed by MEW and the Salmon Technical Team, along with state and tribal technical staff.

PFMC
10/31/13

Agenda Item C.2.b
Supplemental ODFW/WDFW PowerPoint Presentation
November 2013

Development of a New Harvest Matrix for Columbia River Coho

Pacific Fishery Management Council
November 1, 2013
Chris Kern – ODFW
Cindy LeFleur - WDFW

Today’s Topics

- **Background**: Why are Washington and Oregon reconsidering the current harvest matrix?
- **Current Harvest Matrix**: How was it developed and what guidance does it provide?
- **Management Goals**: What should a new harvest matrix accomplish?
- **Risk Assessment**: What did Washington and Oregon provide to the Scientific and Statistical Committee to review and what were SSC conclusions?
- **Next Steps**: What is the plan for ultimately adopting a new harvest matrix?

Background

- Discussions on Columbia River coho harvest began in 2006 between Oregon, Washington and NMFS
  - States proposed harvest matrix that was being used by Oregon for their state-listed coho
    - Based on Clackamas and Sandy population status
  - NMFS concerned that this matrix lacked information on other populations in the ESU
- NMFS approved reduced harvest schedule pending further data review
- NMFS agreed to reinitiate consultation once states provided additional biological information

Background

- Abundance-based harvest matrix currently in place for ocean and in-river fisheries
- Lower Columbia River Recovery Plans call for review
- Oregon and Washington produced a risk assessment
  - What is risk to coho populations with current matrix?
  - What is risk with increased harvest rates?
- Risk analysis similar to others reviewed by PFMC
  - Klamath fall Chinook, LCR tule Chinook

Background

- Oregon and Washington:
  - Provided risk assessment to NMFS staff for review and incorporated input prior to October SSC review
  - Provided the risk assessment to SSC for October review
  - Discussed the risk assessment with the SSC Salmon Subgroup on October 1, 2013 and incorporated input
  - Reviewed risk assessment with fishery advisory groups and public on October 8 and 29, 2013
  - Provided revised documents to SSC based on October input
  - Discussed the risk assessment with the SSC and SAS on October 31, 2013.

Current Harvest Matrix

Parental Escapement		**Marine Survival Index** (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	< 8.0%	< 15.0%	< 30.0%	< 45.0%
Medium	0.75 to 0.50 full seeding	< 8.0%	< 15.0%	< 20.0%	< 38.0%
Low	0.50 to 0.20 full seeding	< 8.0%	< 15.0%	< 15.0%	< 25.0%
Very Low	0.20 to 0.10 of full seeding	< 8.0%	< 11.0%	< 11.0%	< 11.0%
Critical	< 0.10 of full seeding	0 – 8.0%	0 – 8.0%	0 – 8.0%	0 – 8.0%

Management Goals of New Matrix

- Consider status of and risks to primary populations in Coastal and Cascade strata when setting exploitation rates
- Provide more harvest than under current matrix when fish are abundant and survival is good
- Retain conservative fisheries management approach when abundance and survival are critically low

Management Goals of New Matrix

- Provide management flexibility
- Enable more harvest of hatchery fish in mark-selective fisheries
- Revisit harvest matrix in 5 years
  - Incorporate new information
    - Updates to Washington population estimates
    - Implementation of additional mark-selective fisheries
    - Improvements in habitat, or other factors

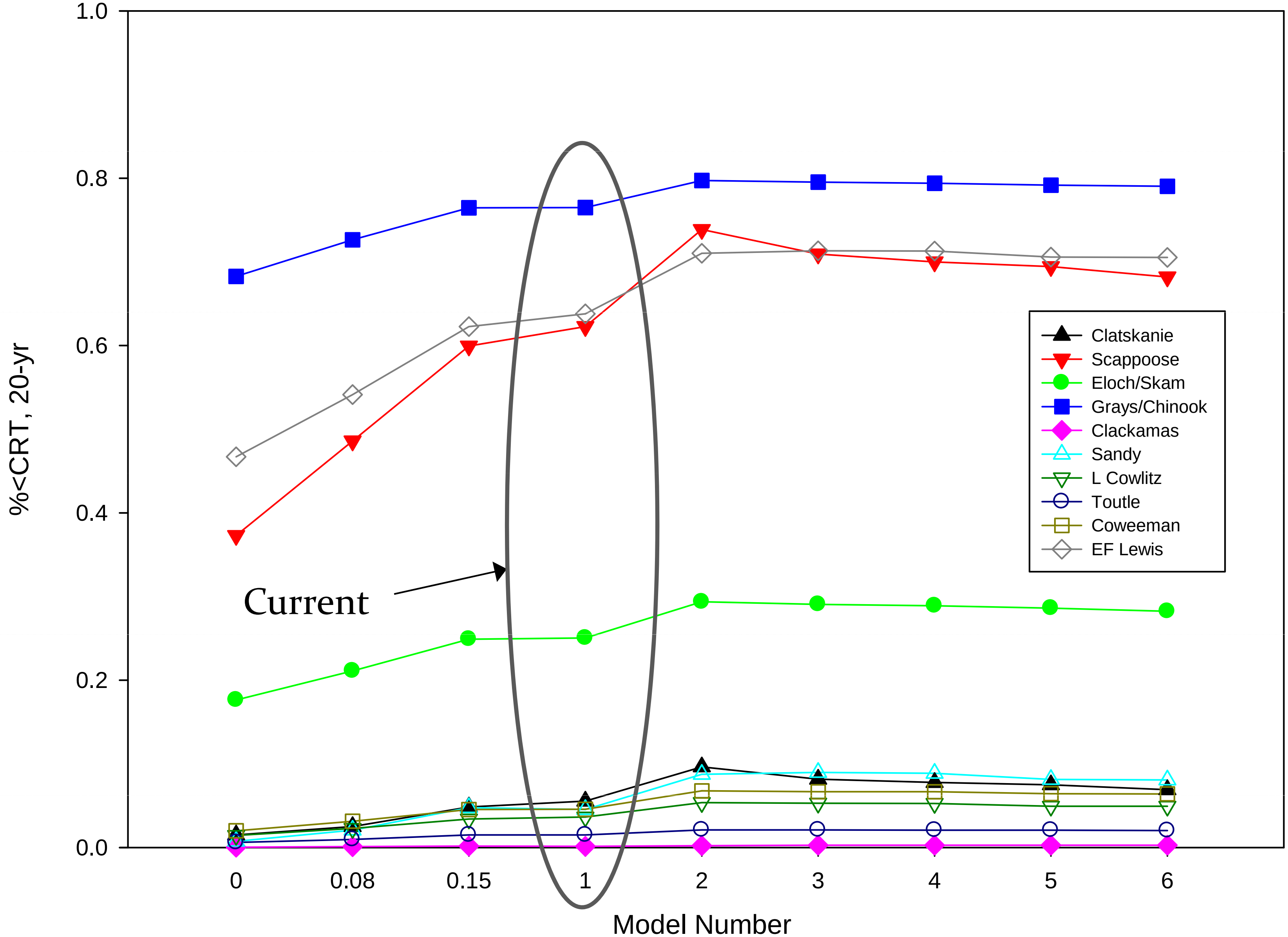
Risk Assessment

- Includes additional populations in Oregon and Washington
  - Total of 10 populations – 4 Oregon, 6 Washington
  - Each is a primary populations in Recovery Plan
    - Objectives are to achieve highest viability for these
  - Covers nearly entire geographic distribution
- Updates information for Oregon populations

Risk Assessment

- Assesses total exploitation rates (ERs) for a range of harvest matrices
  - Fixed ERs from 0%-15%
  - Current matrix
  - Matrix models with additional populations, and with increased ERs as proposed in 2006
- Evaluates risks to each population under a range of harvest structures

Risk Assessment



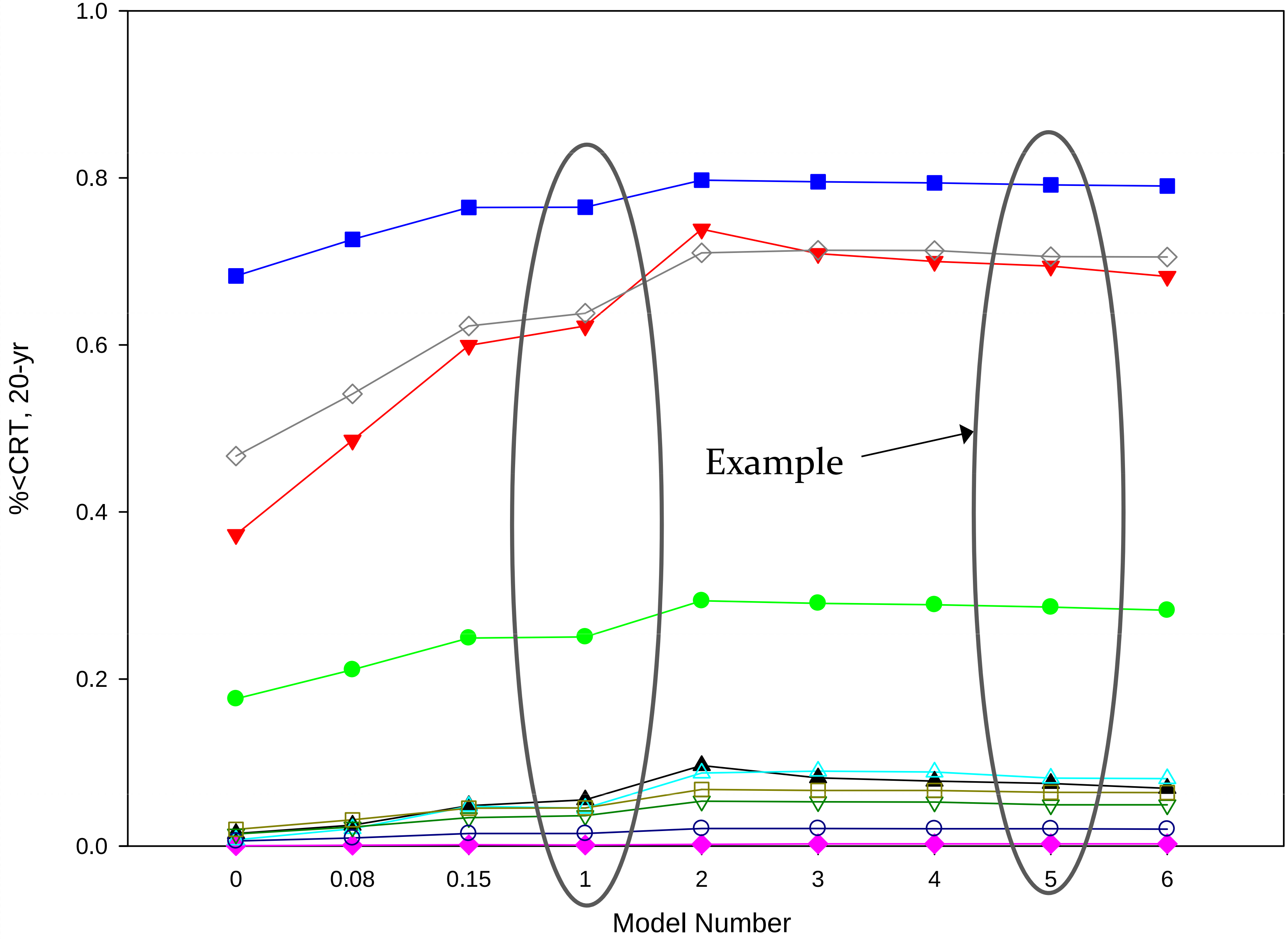
Current Harvest Matrix

Parental Escapement **(Sandy/Clackamas ONLY)**		**Marine Survival Index** (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	< 8.0%	< 15.0%	< 30.0%	< 45.0%
Medium	0.75 to 0.50 full seeding	< 8.0%	< 15.0%	< 20.0%	< 38.0%
Low	0.50 to 0.20 full seeding	< 8.0%	< 15.0%	< 15.0%	< 25.0%
Very Low	0.20 to 0.10 of full seeding	< 8.0%	< 11.0%	< 11.0%	< 11.0%
Critical	< 0.10 of full seeding	0 – 8.0%	0 – 8.0%	0 – 8.0%	0 – 8.0%

Example Matrix that Meets Mgmt Goals

Parental Escapement **(minimum stratum)**		**Marine Survival Index** (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	**< 8%**	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50 full seeding	**< 8%**	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.20 full seeding	**< 8%**	< 21.4%	< 22.7%	< 34.4%
Very Low	0.20 to 0.10 of full seeding	**< 8%**	< 16.3%	< 18.1%	< 19.9%
Critical	< 0.10 of full seeding	**< 8%**	**< 8%**	**< 8%**	**< 8%**

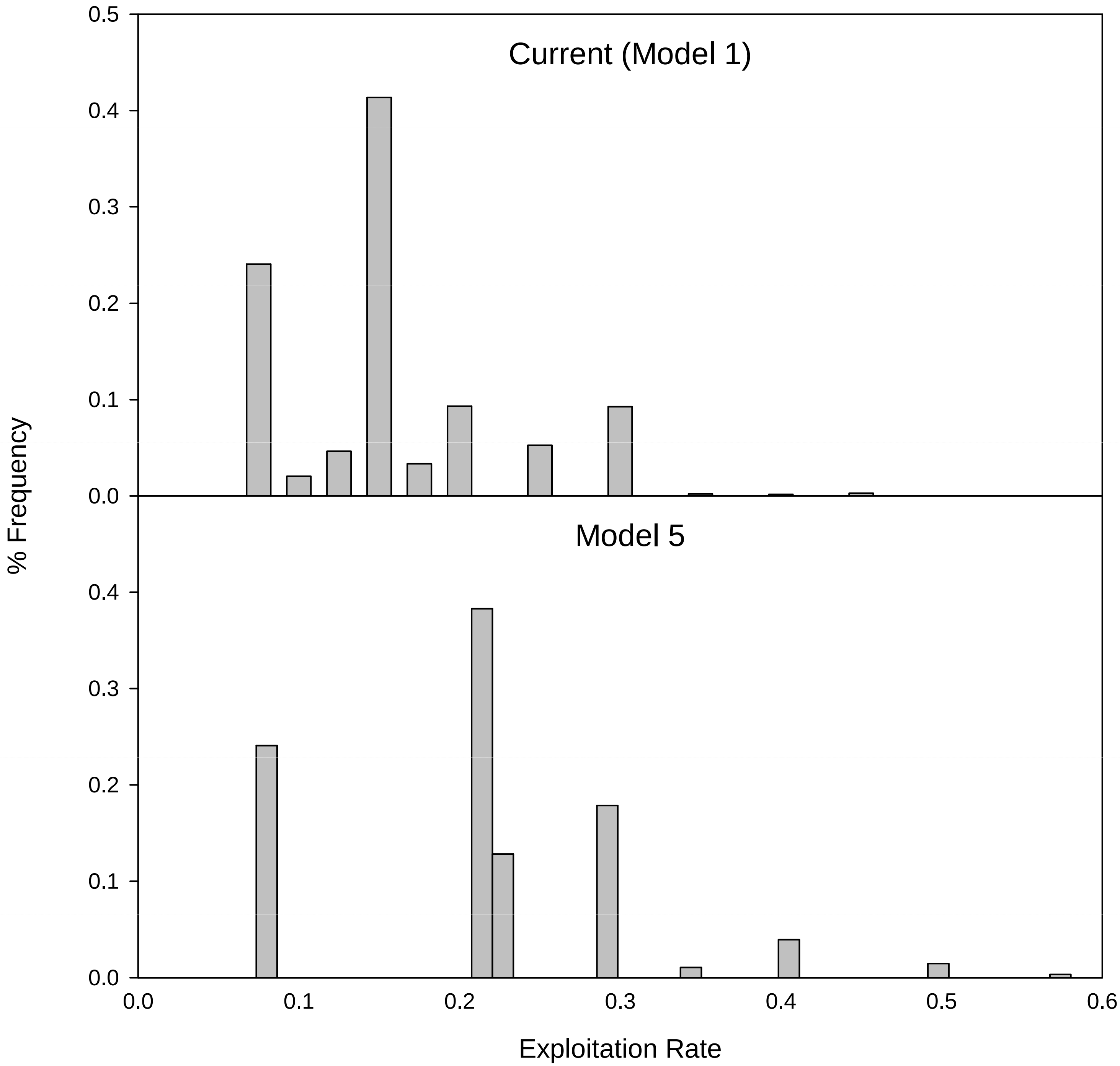
Risk Assessment



Next Steps…

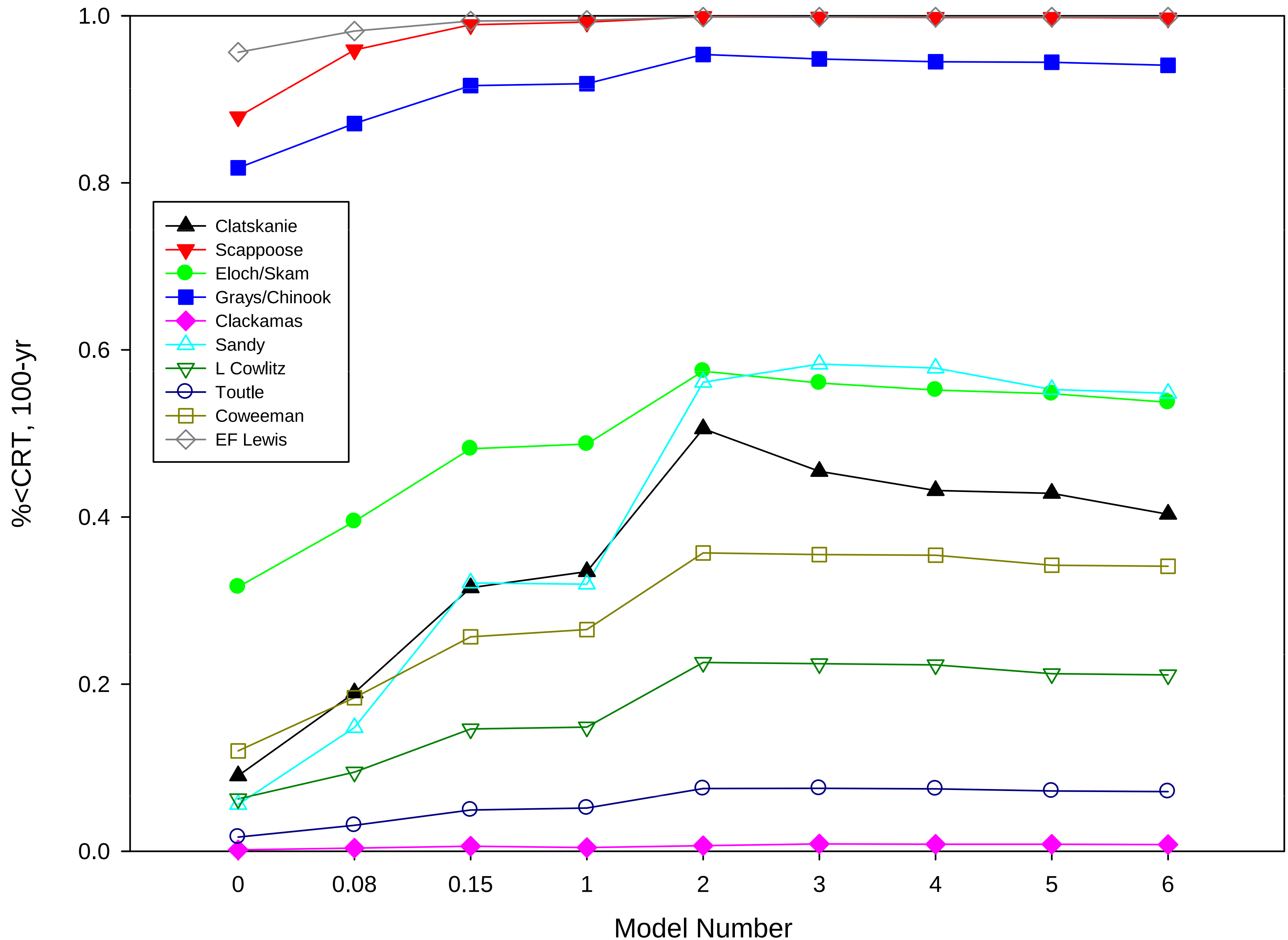
End

Additional Slides: ER Frequencies

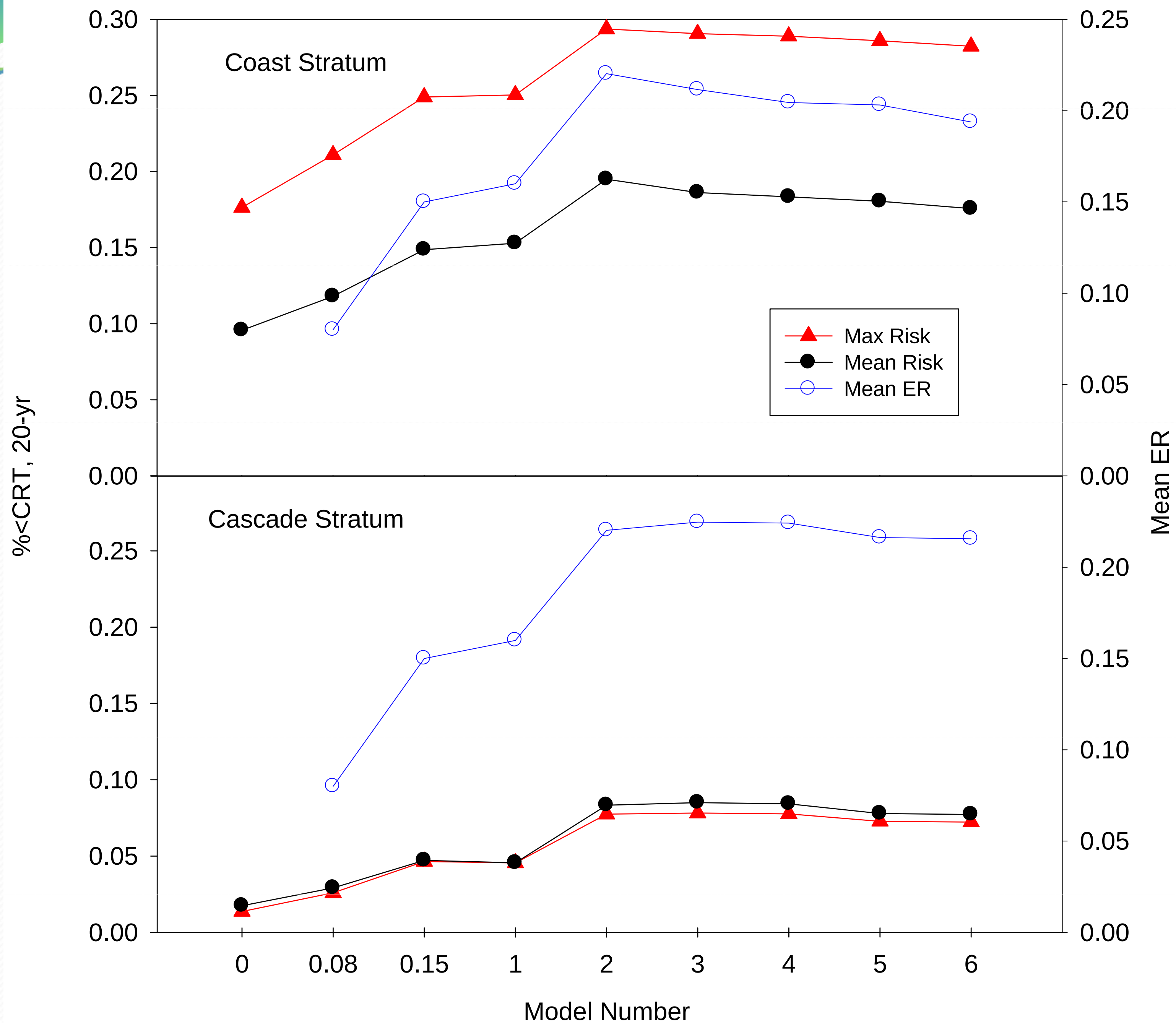


Current (Model 1)
Model 5
% Frequency
Exploitation Rate
0.0
0.1
0.2
0.3
0.4
0.5
0.6

Additional Slides: Harvest Matrices



1.0
0.8
0.6
0.4
0.2
0.0
%<CRT, 100-yr
Clatskanie
Scappoose
Eloch/Skam
Grays/Chinook
Clackamas
Sandy
L Cowlitz
Toutle
Coweeman
EF Lewis
0
0.08
0.15
1
2
3
4
5
6
Model Number



Coast Stratum
Cascade Stratum
Max Risk
Mean Risk
Mean ER
0.30
0.25
0.20
0.15
0.10
0.05
0.00
%<CRT, 20-yr
Mean ER
0
0.08
0.15
1
2
3
4
5
6
Model Number

Model 1

Parental Escapement (Sandy/Clackamas)		**Marine Survival Index** (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	< 8.0%	< 15.0%	< 30.0%	< 45.0%
Medium	0.75 to 0.50 full seeding	< 8.0%	< 15.0%	< 20.0%	< 38.0%
Low	0.50 to 0.20 full seeding	< 8.0%	< 15.0%	< 15.0%	< 25.0%
Very Low	0.20 to 0.10 of full seeding	< 8.0%	< 11.0%	< 11.0%	< 11.0%
Critical	< 0.10 of full seeding	0 – 8.0%	0 – 8.0%	0 – 8.0%	0 – 8.0%

Model 2

Parental Escapement (Sandy/Clackamas)		Marine Survival Index (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	< 11.7%	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50 full seeding	< 11.7%	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.20 full seeding	< 11.7%	< 21.4%	< 22.7%	< 34.4%
Very Low	0.20 to 0.10 of full seeding	< 11.7%	< 16.3%	< 18.1%	< 19.9%
Critical	< 0.10 of full seeding	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%

Model 3

Parental Escapement **(minimum stratum)**		**Marine Survival Index** (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	< 11.7%	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50 full seeding	< 11.7%	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.20 full seeding	< 11.7%	< 21.4%	< 22.7%	< 34.4%
Very Low	0.20 to 0.10 of full seeding	< 11.7%	< 16.3%	< 18.1%	< 19.9%
Critical	< 0.10 of full seeding	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%

Model 4

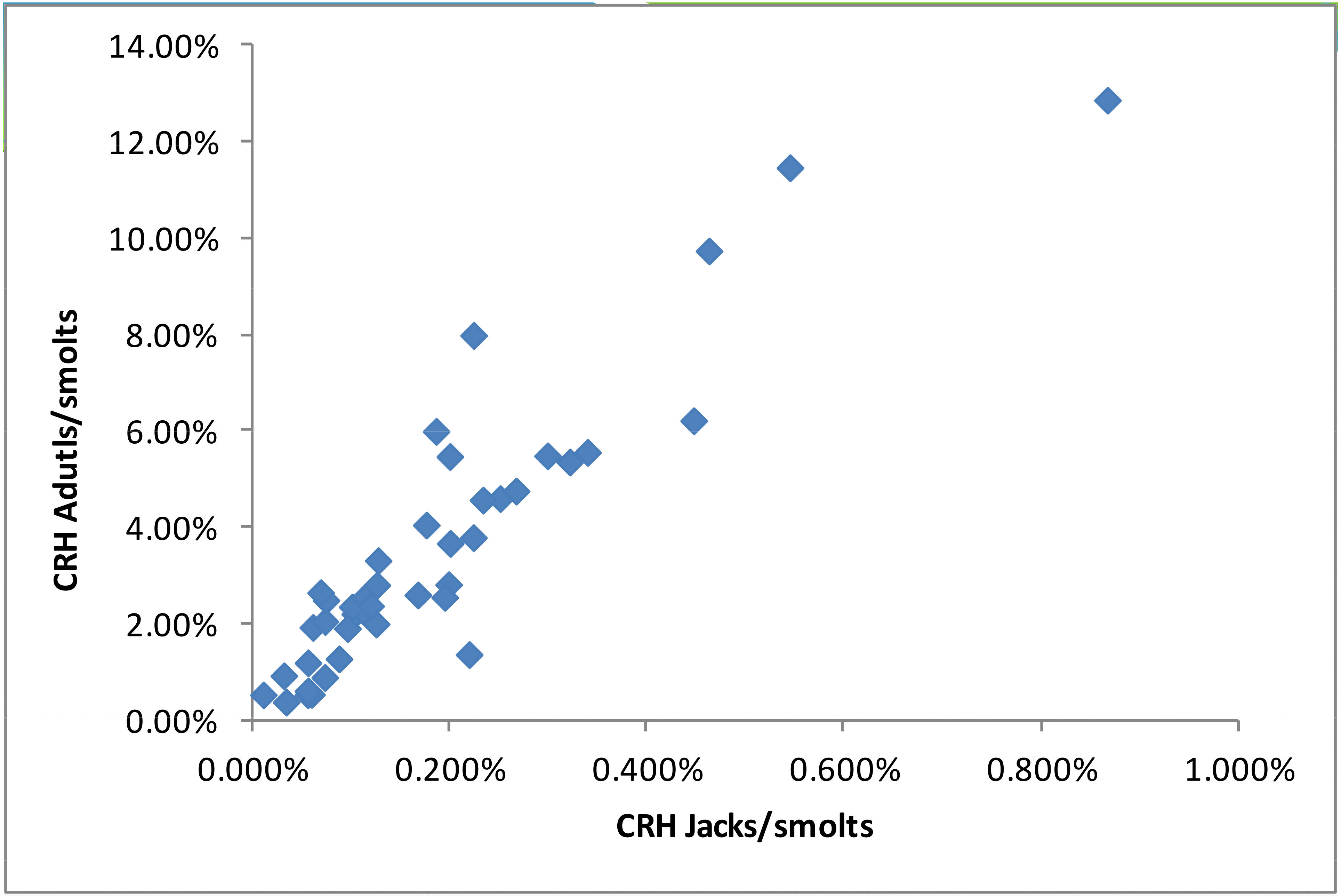
Parental Escapement **(minimum stratum)**		**Marine Survival Index** (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	< 11.7%	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50 full seeding	< 11.7%	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.33 full seeding	< 11.7%	< 21.4%	< 22.7%	< 34.4%
~~Very Low~~	~~0.20 to 0.10 of full seeding~~	~~< 11.7%~~	~~< 16.3%~~	~~< 18.1%~~	~~< 19.9%~~
Critical	< 0.33 of full seeding	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%	0.0 – 11.7%

Model 5

Parental Escapement **(minimum stratum)**		**Marine Survival Index** (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	**< 8%**	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50 full seeding	**< 8%**	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.20 full seeding	**< 8%**	< 21.4%	< 22.7%	< 34.4%
Very Low	0.20 to 0.10 of full seeding	**< 8%**	< 16.3%	< 18.1%	< 19.9%
Critical	< 0.10 of full seeding	**< 8%**	**< 8%**	**< 8%**	**< 8%**

Model 6

Parental Escapement **(minimum stratum)**		**Marine Survival Index** (based on return of jacks per hatchery smolt)			
		Critical (<0.0008)	Low (< 0.0015)	Medium (< 0.0040)	High (> 0.0040)
High	> 0.75 full seeding	**< 8%**	< 21.4%	< 40.5 %	< 57.4%
Medium	0.75 to 0.50 full seeding	**< 8%**	< 21.4%	< 29.2%	< 49.8%
Low	0.50 to 0.33 full seeding	**< 8%**	< 21.4%	< 22.7%	< 34.4%
~~Very Low~~	~~0.20 to 0.10 of full seeding~~	~~< 11.7%~~	~~< 16.3%~~	~~< 18.1%~~	~~< 19.9%~~
Critical	< 0.33 of full seeding	**< 8%**	**< 8%**	**< 8%**	**< 8%**



14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
CRH Adutls/smolts
0.000%
0.200%
0.400%
0.600%
0.800%
1.000%
CRH Jacks/smolts

Slide 29

SALMON ADVISORY SUBPANEL REPORT ON SALMON METHODOLOGY REVIEW

The Salmon Advisory Subpanel (SAS) reviewed the methodologies being considered at this meeting and attended the Scientific and Statistical Committee's (SSC) deliberations, and offers the following recommendations.

The SAS agrees with the improved marine survival predictor for Oregon coastal natural (OCN) coho as well as the proposal to use the existing OCN coho predictor as a fallback, should the life cycle monitoring method fail to produce a prediction.

The SAS supports the proposed improvements to the Sacramento Index predictor and concurs with the SSC on a recommendation to move forward with Model 8. The SAS appreciates efforts to investigate inclusion of environmental indicators in the forecast and encourages further work in this regard.

The SAS supports the inclusion of observed sublegal encounter rates and corrections to the Fishery Regulation Assessment Model to improve the model's ability to assess the effects of proposed size-limit changes. The SAS recommends inclusion of these FRAM improvements in advance of the 2014 preseason process.

The SAS believes the proposed risk assessment provides a promising tool for assessing the relative risks of alternative harvest policies for Lower Columbia natural coho. The SAS appreciates the hard work that has been done on this matter, but suggests that this is only the first step in the process of revising harvest policy. The SAS recommends that the Council, the States, and the National Marine Fisheries Service build on this first step by working with stakeholders and the public to develop alternative harvest strategies in time for implementation in 2015. This stakeholder process should be modeled after the successful review of lower Columbia River tule fall Chinook harvest policies.

PFMC
10/31/13

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON SALMON METHODOLOGY REVIEW

Five topics recommended for review at the abbreviated Salmon Methodology Review were reviewed by the Scientific and Statistical Committee (SSC). SSC comments on each of the topics follow:

Technical revision to the Oregon Coastal Natural (OCN) coho work group harvest matrix

In November 2012 the Council approved using the wild coho salmon jack-to-smolt ratio from the Mill Creek (Yaquina) Life Cycle Monitoring site as a new predictor of marine survival for wild adult coho salmon for use in 2013 management. Approval was provisional, pending further analysis to address SSC recommendations regarding the new predictor and mitigate possible risks from reliance on a single site for predicting marine survival.

An ensemble mean forecast was developed using seven two-variable generalized additive models that incorporate additional biological and oceanographic indicators to predict marine survival. These models are very similar to the preseason models currently used to forecast OCN abundance. The ensemble mean forecast improved performance compared to the 2012 revision relying solely on the Mill Creek jack-to-smolt ratio. The proposed predictor is more robust to a change in any single indicator, and it appropriately limits impact rates when survival is expected to be low but allows harvest opportunity when it is expected to be high.

Three of the seven ensemble models rely on jack-to-smolt ratio data from the Mill Creek. To address concerns about alternative methods for predicting marine survival if there were a catastrophic failure at the Mill Creek site that prevented estimation of the jack-to-smolt ratio, a suite of three-variable environmental models was developed. An ensemble mean of six three-variable models was shown to perform nearly as well as the two-variable ensemble mean described above and was superior to the model relying on the Oregon Production Index Hatchery predictor.

The SSC recommends that the two-variable ensemble mean model be used to predict marine survival for use in the OCN coho salmon harvest matrix. In the event that jack-to-smolt ratio data from Mill Creek are unavailable, the three-variable ensemble mean model should be used. Every year the models should be refit incorporating the most recent data. Variable selection may change over time, and should be reviewed in five years, or when it becomes clear that some models are no longer well-supported statistically.

Lower Columbia Natural (LCN) Coho matrix control rule

Mr. Chris Kern (Oregon Department of Fish and Wildlife) made a presentation to the SSC which included two new analyses suggested at the subcommittee meeting (Addendum to C.2.a, Attachment 2). The primary purpose of the analysis was to incorporate new information from eight populations, in addition to the Clackamas and Sandy populations, into the framework for evaluating alternative harvest management matrices for LCN coho.

Spawner-recruit functions and full seeding levels were developed for all populations. Methods varied depending on available data, accounting for differences between the Washington and Oregon recovery plans. Relative risk and opportunity for a range of harvest strategies and harvest matrices was evaluated using a stochastic population viability analysis (PVA).

One strength of the proposed analysis framework is that it characterizes the relative risk from alternative harvest scenarios to the entire LCN coho evolutionarily significant unit, rather than simply the two healthiest populations (the Sandy and Clackamas). The SSC recommends using the shorter 1993 to 2009 data sets for the Sandy and Clackamas populations

The SSC evaluated the data reconstruction techniques used and technical aspects of the PVA. We did not evaluate any specific scenarios. The analysis framework is suitable for ranking the relative risk of various harvest scenarios. Numerical estimates of extinction risk from the model should be considered as index values only, and in no way represent actual probabilities of extinction. The analysis is complex, and the SSC identified several areas where alternative analytical techniques could be applied. However, the basic technique and application are sound, and relative rankings of scenarios are not likely to be greatly affected by the statistical refinements suggested. The populations used in the analysis do not exactly match those in the Fishery Regulation and Assessment Model (FRAM) model. These differences will need to be reconciled before a resulting harvest strategy can be applied.

Continued monitoring of LCN coho populations should help refine capacity and productivity estimates for Oregon populations and allow for empirical estimates for Washington populations. Investigation of alternative metrics to better represent marine survival of LCN coho, similar to approaches used for the OCN coho harvest matrix, should also be examined.

<u>Incorporation of estimated legal and sublegal Chinook encounters into the Fishery Regulation and Assessment Model (FRAM)</u>

Ms. Angelica Hagen-Breaux (Washington Department of Fish and Wildlife) presented this analysis to the SSC. Recent Chinook FRAM projections of total sublegal encounters for fisheries operating under minimum size limit regulations differ substantially from recent field observations for many fisheries. While the basis for differences is not understood, FRAM's current structure allows for *ad hoc* calibration of base period sublegal encounter rates through the use of a simple multiplicative adjustment factor, thereby providing users the ability to improve correspondence between model-projected sublegal encounters and sublegal encounter estimates based on data from sampled fisheries.

A comprehensive set of available sample-based estimates of sublegal Chinook encounters for a range of modeled fisheries was used to develop and test a set of simple computational algorithms to incorporate these data directly into FRAM modeling (i.e., to estimate the necessary adjustment factors for the model). The effect of the proposed changes on key model outputs (e.g., exploitation rates on stocks of conservation concern) was evaluated. Overall, recalibrating FRAM's current base period to produce fishery-level sublegal encounter totals consistent with recent data introduced minimal changes when assessed in terms of stock-specific impacts even though changes in sublegal encounter totals were substantial for some individual fisheries.

The proposed change to FRAM modeling of sublegal encounters: (1) improves fishery-level projections of total sublegal encounters; (2) strengthens the link between ongoing monitoring activities and fishery modeling; (3) minimally changes past assessments of stock-level impacts; and (4) establishes a foundation for improved size-limit modeling.

The SSC noted that the von Bertalanffy method currently used to estimate growth within a year may not be appropriate and may contribute to poor model performance in this area. Future model revisions could address this issue. Recent size-at-age data are most relevant to current fisheries. The SSC recommends that data be updated annually and older data that may not represent current conditions be dropped from the time series as appropriate.

The SSC recommends the incorporation of the revised sublegal encounter estimates in the FRAM model for 2014.

<u>Modifications to Fishery Regulation and Assessment Model (FRAM) algorithms on sublegal and legal encounters and minimum size limits</u>

Ms. Angelika Hagen-Breaux (Washington Department of Fish and Wildlife) gave a presentation to the SSC on a proposed change to Chinook FRAM which would allow evaluation of proposed size limit changes to FRAM fisheries. Chinook FRAM was originally designed to evaluate changes in fishery catches and stock impacts resulting from changes in minimum size limit regulations. Recent attempts to use this feature revealed the FRAM methodology and supporting data to be flawed.

At the 2012 Salmon Methodology Review, the Washington Department of Fish and Wildlife presented a method to address this size limit problem. Several issues were raised by the SSC at the 2012 review. The SSC recommended not to adopt the changes presented in 2012.

For the October 2013 Salmon Methodology Review, an improved method to estimate sublegal encounters in FRAM was suggested (see previous discussion item). Using updated sublegal encounter rates reduces the exploitation rate changes calculated for key stocks. Because encounters would be calibrated to recent-year observations under the proposed approach, those fisheries that experienced size limit changes since the base period would no longer need to be adjusted; only recent size limit changes would need to be modeled. In addition, the adjustment algorithm was modified to keep total encounters constant.

While this method addresses a known FRAM problem in evaluating proposed changes to fishery size limits, it does not address the problem of FRAM incorrectly allocating sublegal impacts to stocks and age groups. This problem would be addressed by the work currently being done to develop and implement a new Chinook FRAM base period including revisions to the model code dealing with growth.

The SSC recommends incorporating this method in FRAM modeling for 2014. This would be an interim measure until a new Chinook FRAM base period, model code revision, and model calibration allows incorporation of new growth and size limit algorithms.

Alternative forecast methodologies for the Sacramento Fall Chinook Index

Dr. Mike O'Farrell (National Marine Fisheries Service, Southwest Fishery Science Center) presented an analysis of alternative forecast methodologies for the Sacramento Fall Chinook Index (SI) to the SSC. The analysis compared the performance of a variety of potential forecast models for the SI. Models included simple averages, jack to SI regressions with multiple lags, time series models based on autocorrelated error or smooth changes in the jack relationship, and regressions including environmental variables. Models were fitted with data from 1983, in contrast to the shorter time series currently in use. Models were evaluated statistically, and examined for their ability to track recent trends in the SI that have proven challenging to forecast.

Most models out-performed the current model based on "leave one out" and "one year ahead" cross-validation techniques. Some environmental models performed well, but the environmental factors that contributed to the forecast tended to change over time, leading to the conclusion that variable selection in these models was inherently unstable. The authors identified a simple autoregressive error model relating jacks to SI as the most parsimonious and robust alternative. This model allowed for temporal changes in the expected ratio of the SI to the number of jacks the previous year through autocorrelation in residual errors. The performance gains compared with the current model are modest when error is calculated across all years, but the model structure should reduce the risk of extended periods of over- or under-predictions.

The SSC recommends use of the proposed "Model 8" for forecasting the SI in 2014.

PFMC
11/01/13

PRESEASON SALMON MANAGEMENT SCHEDULE FOR 2014

To plan, announce, and meet *Federal Register* deadlines for public hearing sites and the entire preseason salmon management process, staff needs to confirm details of the process prior to the end of November, 2013. The proposed 2014 process and schedule are contained in Agenda Item C.3.a, Attachment 1.

For 2014, Council staff recommends one salmon management option hearing per coastal state, the same schedule as in 2013. The hearings would be:

March 24, 2014   Westport, Washington and Coos Bay, Oregon
March 25, 2014   Eureka, California

In 2014, the March Council meeting will occur in Sacramento, California and the April Council meeting in Vancouver, Washington. Therefore, the public comment period on Sunday of the April meeting in Vancouver also serves as a public comment opportunity. If the states desire to have additional hearings, we suggest they organize and staff them as was done in past years. The table below provides the public attendance at the hearing sites since 1999 for Council reference.

Hearing Site Location[1/]	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Westport	18	24	30	11	16	16	25	26	34	20	27	21	54	25	36
Astoria	14														
Tillamook		13	16 [2/]	18 [2/]											
Coos Bay	31	36	18	40	26	26	105	146	43	60	108	60	19	29	25
Eureka	18	37	12	25	46					167	65	34	41	42	28
Ft. Bragg						27	38								
Santa Rosa		4						500	35						
Moss Landing[2/]	51	50	33	14											

1/ Sites in bold are proposed for Council staffing in 2014.
2/ Hearing staffed by state personnel.

Council Action:

1. **Confirm Council-staffed hearing sites and state intentions for additional hearings.**
2. **Approve staff's overall proposed schedule and process for developing 2014 ocean salmon management measures.**

Reference Materials:

1. Agenda Item C.3.a, Attachment 1: Pacific Fishery Management Council Schedule and Process for Developing 2014 Ocean Salmon Fishery Management Measures.

Agenda Order:

a. Agenda Item Overview   Mike Burner
b. Reports and Comments of Advisory Bodies and Management Entities
c. Public Comment
d. **Council Action**: Adopt a 2014 Preseason Management Schedule

PACIFIC FISHERY MANAGEMENT COUNCIL SCHEDULE AND PROCESS FOR DEVELOPING 2014 OCEAN SALMON FISHERY MANAGEMENT MEASURES

Nov 1-6, 2013	The Council and advisory entities meet at the Hilton Orange County, Costa Mesa, California, to consider any changes to methodologies used in the development of abundance projections or regulatory alternatives.
Jan. 21-24, 2014	The Salmon Technical Team (STT) meet in Portland, Oregon to draft The Stock Assessment and Fishery Evaluation (SAFE) document *Review of 2013 Ocean Salmon Fisheries*. This report summarizes seasons, quotas, harvest, escapement, socioeconomic statistics, achievement of management goals, and impacts on species listed under the Endangered Species Act. (Available early February.)
Feb. 18-24	STT meets in Portland, Oregon to complete *Preseason Report I Stock Abundance Analysis and Environmental Assessment Part 1 for 2014 Ocean Salmon Fishery Regulations*. This report provides key salmon stock abundance estimates and level of precision, harvest, and escapement estimates when recent regulatory regimes are projected on 2014 abundance, and other pertinent information to aid development of management options (Available early March).
Feb. 25 through Mar. 7	State and tribal agencies hold constituent meetings to review preseason abundance projections and range of probable fishery options.
Mar. 8-13	Council and advisory entities meet at the DoubleTree Hotel Sacramento, California to adopt 2014 regulatory alternatives for public review. The Council addresses inseason action for fisheries opening prior to May 1 and adopts preliminary alternatives on March 9, adopts tentative alternatives for STT analysis on March 10, and final alternatives for public review on March 12.
Mar. 12-16	The STT completes *Preseason Report II: Proposed Alternatives and Environmental Assessment Part 2 for 2014 Ocean Salmon Fishery Regulations* (Available March 20).
Mar. 12-31	Management agencies, tribes, and public develop their final recommendations for the regulatory alternatives. North of Cape Falcon Forum meetings are tentatively scheduled for March 17-18 and March 31-April 2.
Mar. 20	Council staff distributes *Preseason Report II: Proposed Alternatives and Environmental Assessment Part 2 for 2014 Ocean Salmon Fishery Regulations* to the public. The report includes the public hearing schedule, comment instructions, alternative highlights, and tables summarizing the biological and economic impacts of the proposed management alternatives.

Mar. 24-25	Sites and dates of public hearings to review the Council's proposed regulatory options are: Westport, Washington (March 24); Coos Bay, Oregon (March 24); and Eureka, California (March 25). Comments on the alternatives will also be taken during the April Council meeting in Vancouver, Washington.
Apr. 5-10	Council and advisory entities meet to adopt final regulatory measures at the Hilton Hotel in Vancouver, Washington. *Preseason Report II: Proposed Alternatives and Environmental Assessment Part 2 for 2014 Ocean Salmon Fishery Regulations*, results from the public hearings, and information developed at the Council meeting are considered during the course of the week. The Council will tentatively adopt final regulatory measures for analysis by the STT on April 5. Final adoption of recommendations to NMFS is tentatively scheduled to be completed on April 8.
Apr. 11-20	The STT and Council staff completes *Preseason Report III: Analysis of Council-Adopted Management Measures for and Environmental Assessment Part 3 2014 Ocean Salmon Fishery Regulations* (Available April 21). Council and NMFS staff completes required National Environmental Policy Act documents for submission.
Apr. 21	Council staff distributes adopted ocean salmon fishing management recommendations, and *Preseason Report III* is available to the public.
May 1	NMFS implements Federal ocean salmon fishing regulations.

PFMC
10/09/13

Agenda Item C.3.b
Supplemental SAS Report
November 2013

SALMON ADVISORY SUBPANEL REPORT ON THE PRESEASON SALMON MANAGEMENT SCHEDULE FOR 2014

The Salmon Advisory Subpanel (SAS) recommends the Council consider holding the proposed March 25 public hearing in Santa Rosa, California rather than Eureka, California. The SAS believes holding the hearing in Santa Rosa would improve accessibility and attendance.

PFMC
10/31/13