Lower Columbia River Tule Chinook Salmon Life-cycle Modeling

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Northwest Fisheries Science Center

Table of contents

Introduction

This report describes results from a life-cycle model for Lower Columbia River (LCR) "tule" Chinook salmon. The model was developed by the staff at the Northwest Fisheries Science Center (NWFSC), in collaboration with biologists from the NMFS Northwest Region, the Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), and the Lower Columbia River Fish Recovery Board (LCFRB)[1]. The modeling effort was initiated at the request of the National Marine Fisheries Service (NMFS) Northwest Region's Sustainable Fisheries and Salmon Recovery Divisions. The purpose of the modeling effort was to help NMFS make decisions regarding appropriate short and long-term harvest impacts on tule Chinook salmon, and to inform implementation of recovery plan strategies aimed at addressing habitat and hatchery constraints on natural production. The current modeling is intended to build on and complement previous and ongoing efforts conducted by the ODFW, WDFW, LCFRB, the Hatchery Science Review Group (HSRG) and others.

Lower Columbia River fall Chinook salmon

LCR Chinook exhibit life-history types based on adult migration timing, including early fall runs ("tules"), late fall run ("brights") and spring-runs (reviewed by Myers 1998). The Lower Columbia Chinook ESU is subdivided into 32 populations, some of which existed historically but are now extinct (Myers et al. 2006) (Figure 1). Of the different life-history types, the tules are subject to the highest level of harvest (Kope 2005), and are the sole focus of this report. Tules are believed to have historically spawned in all of the major Lower Columbia River tributaries, and are still present in most at least at low levels. Tules have been artificially propagated in the Lower Columbia River for decades, and most streams have high proportions of hatchery spawners in their naturally spawning populations. At a broad level, habitat degradation, high levels of past and current hatchery production, and harvest have been identified as factors limiting the recovery of Lower Columbia River tule Chinook salmon (LCFRB 2004).

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NMFS NWR participants: Patty Dornbusch, Peter Dygert.
WDFW participants: Craig Busack (currently with NMFS NWR), Dan Rawding, Cameron Sharpe
ODFW participants: Mark Chilcote (currently with NMFS NWR)

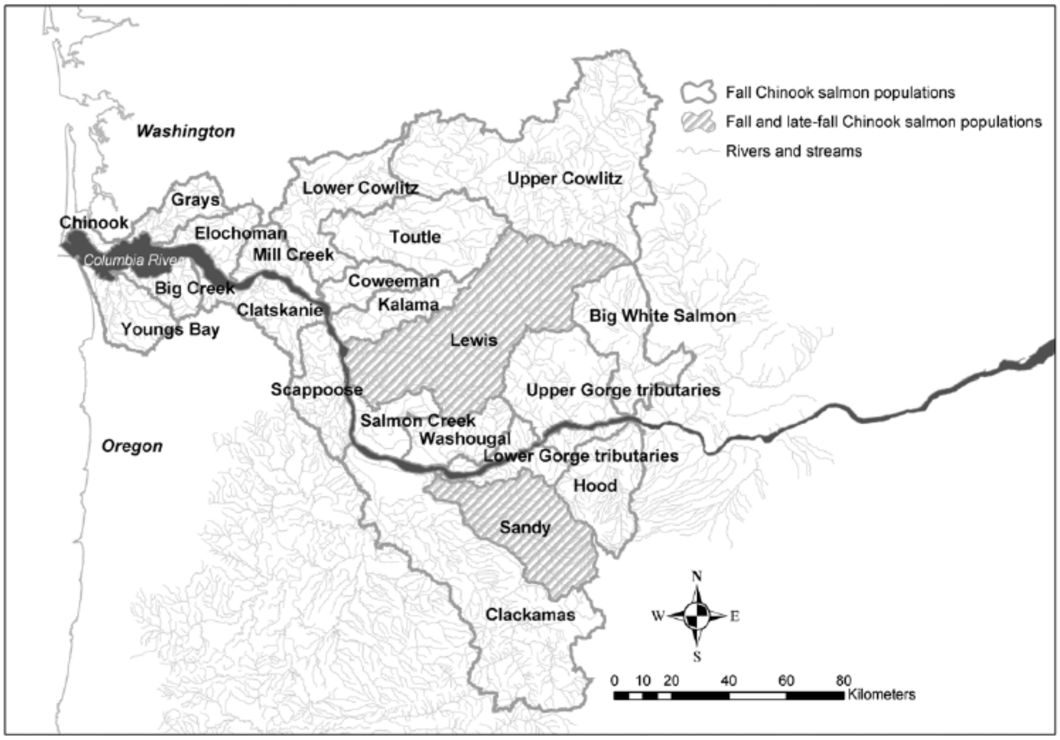

Figure 1 – Fall-run (tule and bright) Chinook salmon populations in the Lower Columbia River identified by the Technical Recovery Team. Reproduced from Myers et al. (2006).

Summary of ESU and population viability criteria

The Willamette/Lower Columbia Technical Recovery Team (WLC-TRT) has developed a hierarchical approach for determining ESU-level viability criteria (Figure 2). Briefly, an ESU is divided into populations (*sensu* McElhany et al. 2000). The risk of extinction of each population is evaluated, taking into account population-specific measures of abundance, productivity, spatial structure and diversity. Populations are then grouped into ecologically and geographically similar *strata*, which are evaluated on the basis of population status. In order to be considered viable, a stratum generally must have at least half of its historically present populations meeting their population-level viability criteria (this is only an approximation -- see McElhany et al. 2006 for details). Populations are identified as primary, contributing, or sustaining, with different viability criteria for each category. Finally, the ESU-level viability criteria require that each of the ESU's strata be viable. The tule fall Chinook populations and strata are listed in Table 1.

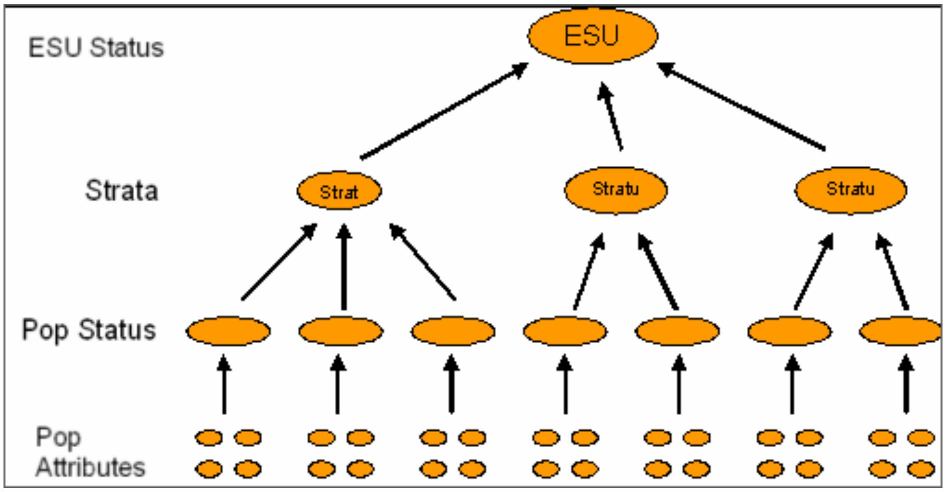

Figure 2 -- Hierarchical approach to ESU viability criteria

The LCFRB has used the WLC-TRT viability criteria to define recovery goals (LCFRB 2004). For tule Chinook, the LCFRB has identified six "primary" populations on which to focus recovery efforts (Table 1). NMFS endorsed the LCFRB plan as an Interim Recovery Plan. The LCFRB plan made certain assumptions about Oregon populations, but the State of Oregon has not yet developed formal recovery goals for Oregon populations. Once Oregon completes the recovery planning process for the Oregon side of the ESU, the two states' plans will need to be combined and reconciled. A final comprehensive recovery plan for the Willamette and Lower Columbia River ESUs will then follow.

The LCFRB plan summarizes information related to the status of the tule populations. That information is summarized in Figure 3. In general, tule Chinook populations appear to fall into three basic risk categories (Ford et al. 2007): relatively low risk populations with relatively little hatchery influence (Coweeman, Lewis), relatively large populations with hatchery programs (Cowlitz, Toutle, Washougal, Kalama), and relatively small populations, some many of which receive high levels of hatchery fish (e.g., Elochomann, Clatskanie).

Table 1 -- Lower Columbia tule Chinook population and basin information.

Strata	State	Population	LCFRB Goal	size category
Coast Fall	WA	Grays	P/S (1)	S/M
	WA	Elochomann	P	S
	WA	Mill/Abernathy/Germany	C/P (1)	S
	OR	Youngs Bay	S	S
	OR	Big Creek	S	M
	OR	Clatskanie	P	S
	OR	Scappoose	S	S
Cascade Fall	WA	Lower Cowlitz	C	L
		Coweeman	P*	S/M
		Toutle	S/P (1)	M
		Kalama	P/S (1)	M
		Lewis/Salmon	P	S/M
		Washougal	P	M

	OR	Sandy	S	M
		Clackamas	C	M
Gorge Fall	WA	Lower Gorge	S	S
		Upper Gorge (includes Wind)	C	S
		Big White Salmon	C	S
	OR	Hood	S	S

Notes:
<u>LCFRB Goal</u>: P=primary population/low risk; P* = primary population/very low risk; C = contributing population/moderate risk; S = sustaining population/maintain current status. Based on the TRT criteria, lower risk < 5% risk of extinction in 100 years; very low risk < 1% risk of extinction in 100 years, and moderate risk < 25% in 100 years. (1) Subsequent to publication of the 2004 LCFRB plan, changes have been proposed for some of the population designations. The proposed changes of January 2010 designate the Grays River as C, Mill/ /Abernathy /Germany as P, Toutle as P, and Kalama as S.
<u>Size category</u> is used to determine the appropriate quasi-extinction threshold for population modeling. Size categories for the Oregon populations are taken directly from the WLC-TRT recommendations (McElhany et al. 2006) and are based on historical km of spawning habitat (<50, 50-150, >150). Size categories for the Washington populations were determined by the work group, based on analogies to the Oregon populations. L = Large = QET of 250/year for four years; M = medium = QET of 150/year for four years; S = small = QET of 50/year for four years.
<u>Average spawners</u> and % hatchery are the mean number of naturally spawning fish in each population and the mean percent hatchery fish among the natural spawners using the most recent data we could obtain. For the Coweeman, Grays, Lewis, Cowlitz, Kalama, Washougal, Elochoman, and Mill/Abernathy/Germany (MAG) populations these were obtained from the Table 12 of the 2008 Technical Advisory Committee (TAC) report, and generally corresponded to return years 2004-2008 for abundance and 2001-2005 for hatchery fraction. For the Clatskanie abundance and hatchery fraction data were obtained from Mark Chilcote (ODFW). Abundance data for the Toutle was obtained from WDFW (2020 report), and hatchery fraction data for that population was assumed to be the same as for the Cowlitz.

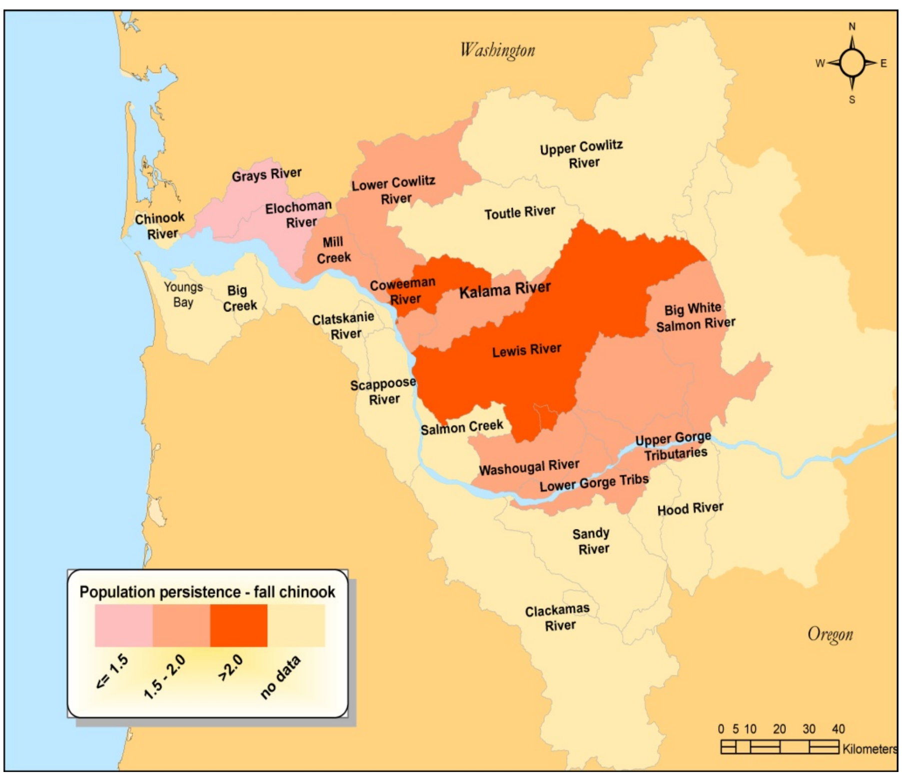

Figure 3 – Summary of tule Chinook population persistence scores from LCFRB (2004). Overall risk to population persistence is scored on a scale from 0-4, where 0 is extinct or at very high risk of

extinction and 4 is very low risk of extinction. Oregon populations are all at a risk level of 1 (Paul McElhany, personal communication).

Harvest consultation history

Lower Columbia River tule Chinook salmon have been historically harvested at high rates, with exploitation rates >70% as recently as the 1980's (Figure 4). From 1999 to 2005, 57% of the harvest is accounted for in US fisheries, with the remaining 43% occurring in British Columbia (Figure 5).

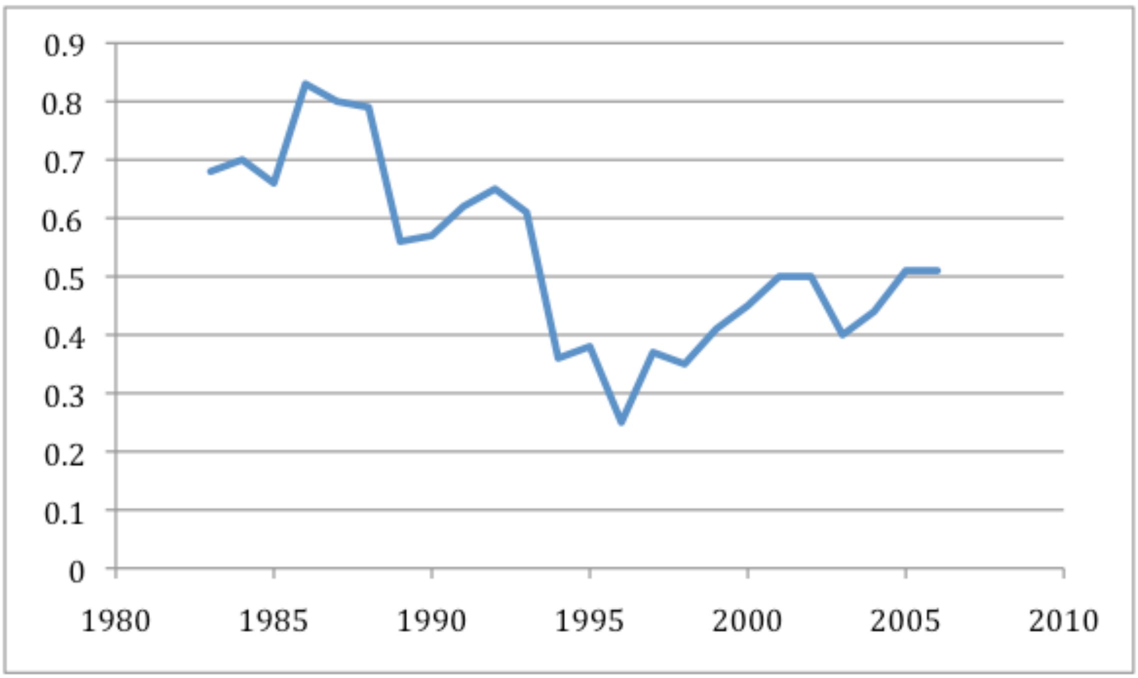

Figure 4 -- Total exploitation rates (adult equivalent) for Lower Columbia River tule Chinook, 1983 – 2006. Rates were estimated by WDFW using the PFMC FRAM model's Lower Columbia Natural Tule stock, and are based on CWT recoveries from seven Lower Columbia River hatchery stocks. See attachment 2 of Working Group (2008) for details.

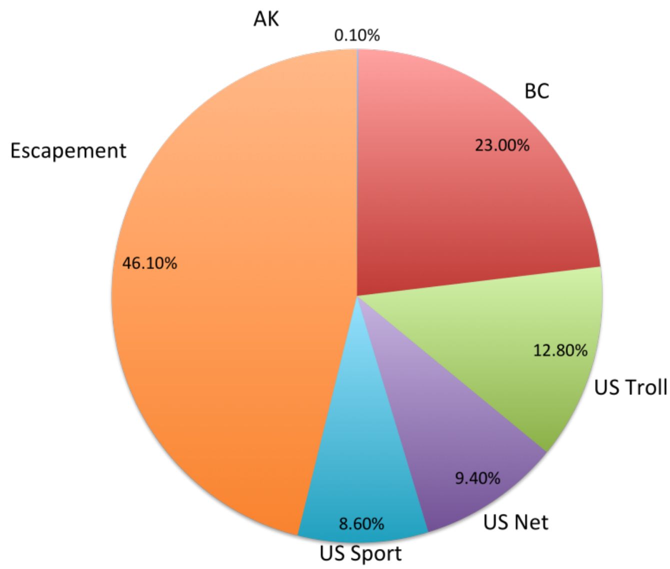

Figure 5 – Distribution of tule Chinook salmon catch, 1999 – 2005. Source: Table E-58 in Pacific Salmon Commission (2007).

NMFS has used a variety of approaches for evaluating the effects of harvest actions on ESA listed salmon (NMFS 2004). For LCR tules, NMFS initially used an analytical approach (Viability Risk Assessment Procedure – VRAP; NMFS (2001)) that involved calculating a "rebuilding exploitation rate" (RER). The RER for a specific population is defined as the maximum exploitation rate that will result in a low probability of the population falling below a specified lower abundance threshold, and a high probability that the population will exceed an upper abundance threshold over a specific time period.

In its initial biological opinions regarding the effects of harvest on LCR tule Chinook, NMFS used the VRAP approach to calculate an RER of 49% for the Coweeman River (Figure 1) tule population (NMFS 2002, 2005). This RER was used as the jeopardy standard for the tule component of the LCR Chinook ESU from 2002 to 2006. Prior to the start of the 2006 preseason planning process NMFS indicated, in its annual guidance letter to the Pacific Fishery Management Council (Council), its intention to review the 49% standard prior to the 2007 season (Lohn and McInnis 2006). This review resulted in formation of a technical work group that expanded the RER analysis to two additional populations (Lewis and Grays Rivers) and explored some additional methods of evaluating RERs based directly on the WLC-TRT viability criteria (McElhany et al. 2003, McElhany et al. 2004, McElhany et al. 2006). The workgroup produced a report in 2007 (Ford et al. 2007), and updated it in 2008 (Working Group 2008). Based in part on the analyses produced by the working group, NMFS lowered its consultation standard to an adult equivalent exploitation rate (AER) of 42% in 2007, 41% in 2008 and 38% in 2009.

In this report we use the SLAM life-cycle model to explore the consequences of a range of exploitation rates in the context of alternative assumptions about future habitat and hatchery activities.

Methods

SLAM Overview

The Species Life-cycle Analysis Modules (SLAM) is a computer program for life-cycle modeling. It is not a single model, but rather a framework and tool for developing a host of models tailored to a specific set of questions or species. SLAM consists of three main components: 1) Life-cycle structure, 2) Scenario, 3) Simulation. The life-cycle structure defines the life-stages and possible transition. The life-cycle structure is developed graphically in SLAM, with boxes representing life-stages and arrows representing possible transitions. The scenario defines a specific set of transition functions and parameters (e.g. survival and capacity) for a given life-cycle. We generally develop multiple scenarios for a single life-cycle structure to explore management questions, such as "What happens if we change survival in a particular transition from x to y?" The final component of the SLAM framework is the simulation. Starting with user defined initial-abundances, the program does a forward simulation for a specified number of years using the rules defined by the life-cycle structure and the scenario parameters. Since scenario parameters are often defined as distributions rather than point estimates and the models often contain annual variability ("process error"), a simulation run often requires generating hundreds or thousands of "trajectories" for describe the distributions of possible outcomes based on the scenario parameters. Results from the simulation consist of the number of individuals at each life-stage for every year for every trajectory, which can be viewed graphically in SLAM or exported for analysis in other software programs. SLAM is free and available at http://www.nwfsc.noaa.gov/trt/slam/slam.cfm.

Tule Life-cycle Structure

A simplified version of the tule life-cycle used for this analysis is shown in Figure 6. This is a fairly generic salmon life-cycle, with spawners, eggs, fry, smolts and and ocean stages. The structure includes a natural spawning component (green) and a hatchery spawning component (orange), which can exchange migrants. One novel feature of this structure for tule analysis is the identification of two different juvenile pathways, termed fry outmigrants and sub-yearling outmigrants. Fry outmigrants leave their tributary stream immediately after emergence, then spend several months rearing in the tributary-mainstem Columbia confluence area before heading toward the outer-estuary. Alternatively, sub-yearling outmigrants rear for several months in the tributary habitat, then pass relatively quickly through the tributary-mainstem confluence area while heading to the outer-estuary. Greater discussion of these alternative pathways is provided in Rawding et al. (2010).

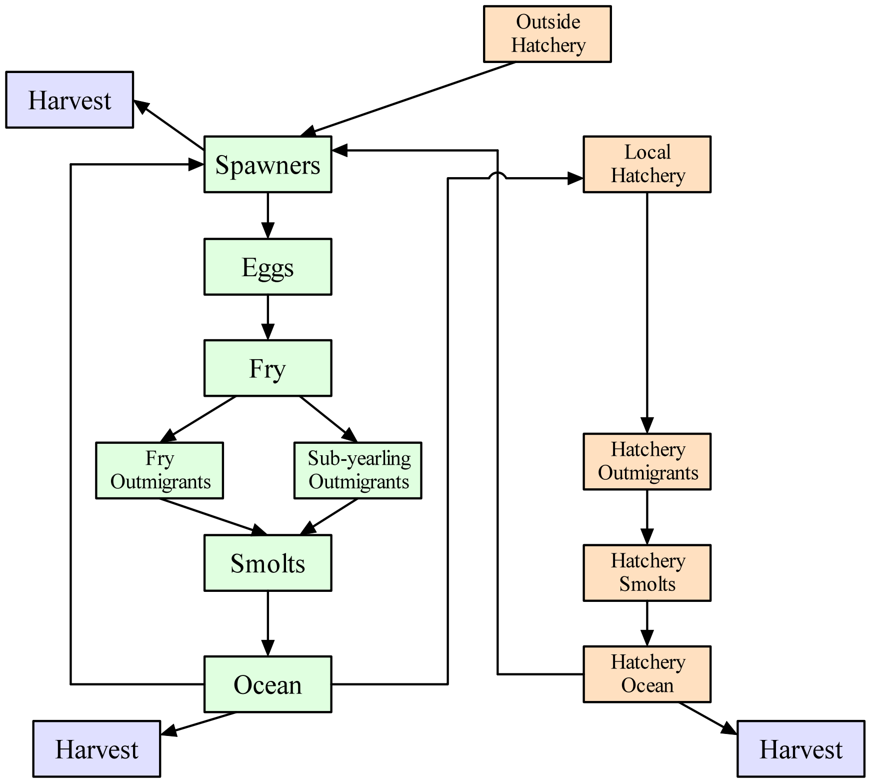

Figure 6 -- Simplified tule Chinook life-cyle

Although the simplified diagram (Figure 6) provides a general overview of the tule model, it does not incorporate age structure or several other complications needed to adequately describe basic tule biology. Figure 7 shows the actual life-cycle structure diagram used for this tule analysis. Most of the additional stages simply add age structure to the ocean, return and spawning stages. Several "holding" stages (i.e. "prespawners" and "Nat. origin juv. in trib") also needed to be added for SLAM to correctly model density dependence. Other features of the SLAM life-cycle structure diagram (i.e. "pHOS_1", "pHOS_2", "pHOS decrement slope", "hatchery fitness scalar", and "Tules from other rivers") are not tule life stages, but are "environmental parameters" related to hatchery modeling. The function of these hatchery parameters is described in the hatchery scenarios section.

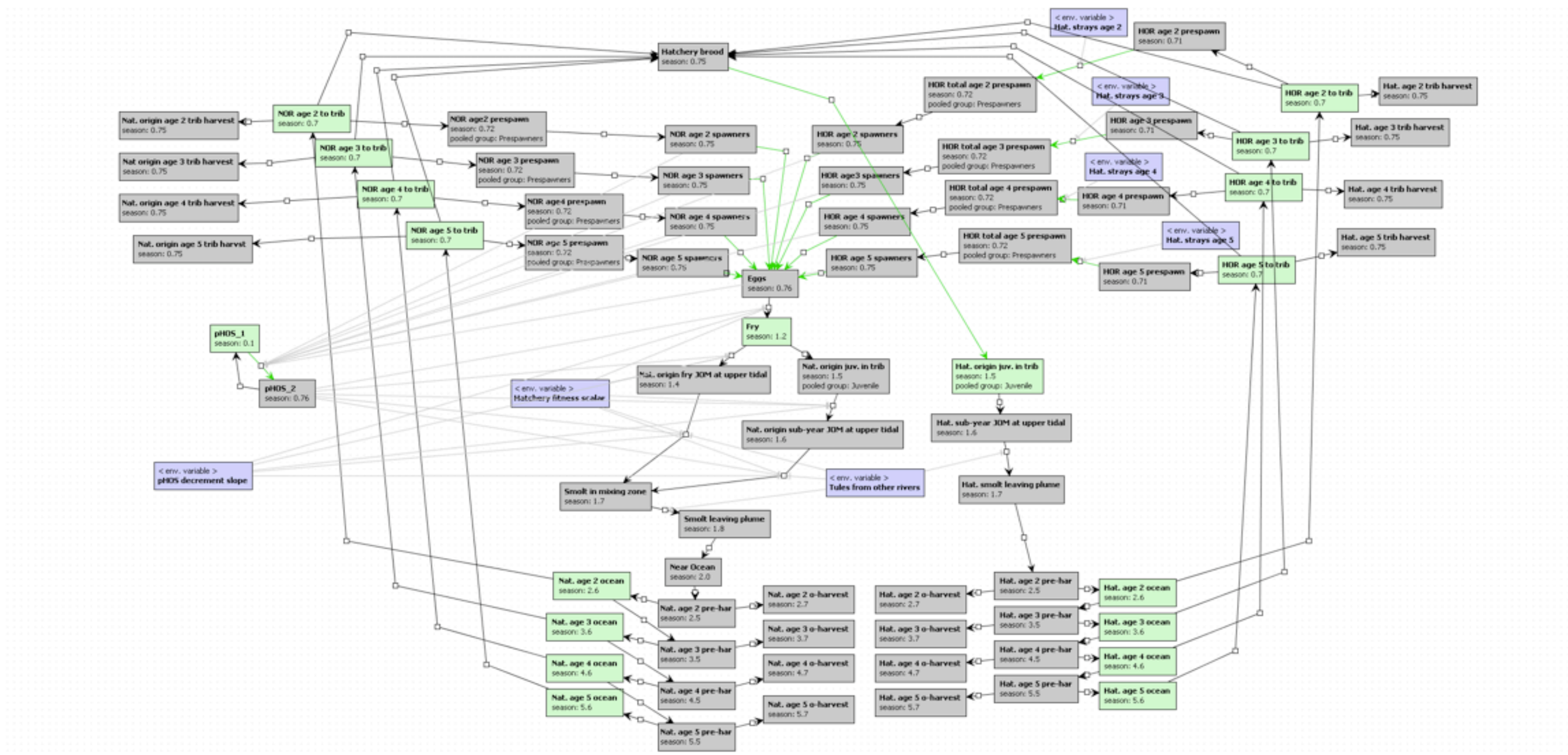

Figure 7 -- Life-cycle structure diagram used for SLAM modeling of LCR tule Chinook populations.

Tule Scenarios: Basic parameterization

A SLAM scenario consists of information on the form of the transition functions, the transitions function parameters (e.g. survival and capacity) and parameters describing “splits” where one “parent” life-stage can branch into two or more “off-spring” life-stages (e.g. fish in the ocean can either stay in the ocean another year or return to spawn). In this section, we will step through the scenario parameters for each of the transitions and splits describing the “base” parameterization. Several alternative harvest, hatchery and habitat scenarios that we explored are described in a later section.

Spawners to Eggs: This is the reproductive transition in the model. We used age-specific egg production parameters with uncertainty described by a triangular distribution (Table 1). The mode values, which were used for all population, are based on estimated averages for the Coweeman and EF Lewis River populations (Rawding et al 2010, Table 2). The uncertainty range is base on expert opinion. We assumed no egg density dependence (though there was a spawner capacity – see pre-spawner to spawner transition).

Table 2 -- Tule SLAM input eggs per spawner at age described by triangular distribution [mode(min-max)], taking into account age specific sex ratio.

Age	*Age2*	*Age3*	*Age4*	*Age5*
Eggs/spawner	0	741 (500-1,000)	3,062 (2,500-3,500)	3,707 (3,000-4,500)

Egg to Fry: Assumed density independent survival estimated from two methods. One method was based on a habitat model driven by sediment deposition (see habitat section of this report). The habitat model was developed only for the Lewis River (additional populations pending). This model indicated a point estimate survival of 21%. The other approach to estimating egg to fry survival relied on mark-recapture survival studies in Mill,, Abernathy, and Germany creeks and the Coweeman River (Rawding et al. 2010, Table3). Estimates were available for years 2004-2007. The average egg to fry survival estimate was 17% ,with a range from 0.1% to 44%. If the three lowest survival values, which are associated with a severe flow event, are eliminated, the average survival was 21%. We parameterized egg to fry survival as a triangular distribution with a mode of 21% and a range from 17% to 26% (i.e. ±5%). Egg to fry survival was also one of only two stages where we added annual variability (the other being early ocean survival). The available data (Rawding et al. 2010) indicate extreme annual variability in egg to fry survival. Both the data and basic mechanistic understanding suggest that the annual survival pattern is likely tied to flow patterns because high flows scour redds. Annual variability was distributed as a triangular distribution with the max +10% of the mode and the min -5% of the mode. This range is generally consistent with the range of values observed by Rawding et al. (2010), though it may not capture the near total mortality observed during high flow events (e.g. during 2006).

Fry to Fry-outmigrants at the upper tidal zone: Fry outmigrants were assumed to leave the tributaries relatively quickly and not experience density dependence within the tributary. Density-independent mortality was estimated assuming that fry following this pathway remain in the tributary for about 2 weeks before moving downstream into intertidal reaches for extended rearing. No direct estimates of mortality during this stage are available from Lower Columbia populations. We assumed that the average survival for the two week transition was 76%, based on an estimate of average weekly mortality (13% per week) derived from the literature for application in model evaluations of Puget Sound restoration opportunities (Greene and Beechie, 2004). We applied an estimate of uncertainty based on expert opinion that was described as a triangular distribution ranging from 71% to 81% (i.e. ±5%). The same base survival estimate was used for all populations.

Fry to subyearling-outmigrants at the upper tidal zone: Subyearling fish rear for several months in tributary habitat and were assumed to potentially experience density dependence. Density dependence was modeled as a hockey-stick function. We recognize that some of the modeling result metrics may be particularly sensitive to the form of the functions incorporating density dependent effects. We intend to evaluate the performance of the model under alternative forms of the function at a later date. Based on an average juvenile mortality rate for fry to presmolt rearing derived for Puget Sound studies (13% mortality per week) and an assumption that juveniles in the subyearling outmigrant pathway spend 12 weeks in upstream tributary habitat, we estimate an average survival for this transition of 25%. Uncertainty based on expert opinion was described as a triangular distribution ranging from 20% to 30% (i.e. ±5%). The same base survival estimate was used for all populations. The capacity estimate for this transition was estimated from a tributary habitat model described in the tributary habitat modeling section of this report. Uncertainty in capacity was described as a triangular distribution using point estimates and min/max values provided by the habitat modeling. Different capacity estimates were generated by the habitat model for each population (Table 3). (Note: The life-stage "Nat. origin juv. in trib" in Figure 7 allows for optional density effects from hatchery fish released in the tributary. We did not use this option in these analyses, so the life-stage is effectively ignored.)

Table 3 -- Tributary subyearing capacity based on habitat model.

Population	Current PE Rearing	Current Min Rearing	Current Max Rearing
Hood	173860	97127	533020
Clatskanie	22427	9849	72501
Elochoman	75067	31566	239299
MAG	17202	8939	109507
Coweeman	95807	51551	420347
Toutle			
Lewis	151570	84997	462271
Scappoose	5123	2687	30324
Washougal	161590	88759	585577

Fry-outmigrants at the upper tidal to Estuary mixing zone: We refer to the area covered in this transition as the "confluence area" because the major area of interest is that surrounding the confluence of the tributary and the mainstem. Fry-outmigrant fish are assumed to rear for several months in confluence habitat and are also assumed to potentially experience density dependence there. Density dependence was modeled as a hockey-stick function. We assumed that the average weekly mortality in intertidal rearing habitats was the same as in freshwater for the base runs in this study. Assuming that the juveniles following this life history pattern rear in the intertidal reaches for 10 weeks before emigrating downstream, we estimate an average survival for this transition of 33%. Uncertainty based on expert opinion was described as a triangular distribution ranging from 28 to 38% (i.e. ±5%). The same base survival estimate was used for all populations. The capacity estimate for this transition was estimated from a confluence habitat model described in the confluence habitat modeling section of this report. Uncertainty in capacity was described as a triangular distribution using point estimates and min/max values provided by the habitat modeling. Different capacity estimates were generated by the habitat model for each population.

Table 4 -- Tributary fry outmigrant capacity in confluence based on habitat model.

Population	Fry outmigrants in Confluence Capacity
East Fork Lewis	94,178 (75,959, 99,927)
Coweeman	52,950 (42,824, 62,550)
Washougal	7,923 (5,349, 17,793)
Clakkanine	58,230 (51,348, 145,392)
Germ/mill/aber	104,899 (104,899, 174,544)
Elochoman	224,460 (224,460, 348,515)

Subyealing-outmigrants at the upper tidal to Estuary mixing zone:
Subyearling outmigrants were assumed to migrate through the confluence-mainstem area relatively quickly and not experience density dependence within this region. Density-independent mortality was estimated based on the amount of time the fish spent in the confluence-mainstem (about X weeks). Based on an average juvenile mortality for Y% per week for fall Chinook in the Skagit [ref- need numbers and citation from Tom], we estimate an average survival for this transition of 76%. Uncertainty based on expert opinion was described as a triangular distribution ranging from 71% to 81% (i.e. ±5%). The same base survival estimate was used for all populations.

Fry to fry-outmigrant and subyearling-outmigrant split: (Note: The description of this split is a bit out of chronological life-history sequence, but it helps to understand tributary and confluence capacity before tacking this split parameterization.) Estimating the fraction of fish in a particular river that migrate out via the fry-outmigrant vs. subyearling-outmigrant pathway was challenging given available data. The approach we took was one that approximated a split based on an ideal free distribution among the pathways based on habitat capacity in the tributary and confluence-area habitats and assumtptions about survival. We estimated the average number of fry need to reach capacity on each of the pathways. The formulas were:

1) $Fry_{subyear\_path} = Capacity_{trib} / fryToTidalSurv_{subyear}$
2) $Fry_{fryJOM\_path} = Capacity_{confluenc}e / tidalToMixingSurv_{fryJOM} / fryToTidalSurv_{fryJOM}$
3) $FractionToSubyearPath = Fry_{subyear\_path} / (Fry_{subyear\_path} + Fry_{fryJOM\_path})$
4) FractionToFryJOMPath = 1 – FractionToSubyearPath

Input values for capacity and survival were drawn from the distribution used in model rather than point estimates and the fraction of fry allocated to each of the pathway was based on the average value from 1,000 simulations.

Smolts in the estuary mixing zone to Smolts leaving the plume: There are no direct data on this transition. Although there is a potential for density dependence in the lower estuary because of the large number of hatchery releases and the degraded habitat, there were no explicit data on this so we assumed density-independence. We assumed a density independent survival value of 70% (±10% in a triangular distribution).

Although there are no direct estimates of this parameter, the product of survivals from fish leaving the estuary to fish at the age 2 ocean stage is consistent with the range of survivals estimated for CWT hatchery releases [ref TAC report]. The CWT estimated average hatchery fish survivals to age 2 ocean in the 1-2% range. The product of point estimate survivals in our base model from the sub-tidal area to age 2 ocean is about 4.5% (= 76% confluence survival * 70% plume survival * 15% near ocean survival * 60% nearOcean to age2ocean survival). We assumed naturally produced fish had higher survivals at these stages than what has been observed for hatchery released fish.

Smolts leaving the plume to near ocean: There are no direct data on this transition. Survival at this stage is assumed to be relative low (15%) and density independent. We did not apply any uncertainty to this estimate (overall uncertainty in the subtidal to age ocean stages in included in other transition parameters).

Although there are no direct estimates of this parameter, the product of survivals from fish leaving the estuary to fish at the age 2 ocean stage is consistent with the range of survivals estimated for CWT hatchery releases [ref TAC report]. The CWT estimated average hatchery fish survivals to age 2 ocean in the 1-2% range. The product of point estimate survivals in our base model from the sub-tidal area to age 2 ocean is about 4.5% (= 76% confluence survival * 70% plume survival * 15% near ocean survival * 60% nearOcean to age2ocean survival). We assumed naturally produced fish had higher survivals at these stages than what has been observed for hatchery released fish.

Annual variability was added to this transition (the only other transition with annual variability was the egg to fry survival). This is assumed to a major stage for ocean mortality with survival being highly dependent on variable ocean conditions (e.g. upwelling conditions, sea surface temperature, PDO cycle, etc). No clear autocorrelation (e.g. decadal oscillations) or environmental covariates (e.g. with ocean indices) were observed in an analysis of run reconstruction data [Shuerell report], so we applied uncorrelated annual variability. Annual variability was defined as with a triangular distribution with a mode of 15% survival, and min/max of 10% to 45%. This distribution of variability produced an overall level of variability in the spawners that was consistent with observed spawner time series. This was not the result of a statistical fit, but is based on rough approximation.

Ocean survivals, ocean harvest and propensity to return: The ocean splits were determined using a cohort model and data from the 2009 Tule harvest BiOp analysis. The cohort model used assumptions about natural ocean mortality, the age structure of the spawner escapement, the relative harvest rates of different aged fish and the relative amount of ocean vs. tributary harvest to estimate ocean parameters at different harvest rates (Table 2). The "tributary" harvest includes mainstem Columbia. The Ocean age X to Age X+1 preharvest survival is the Natural ocean survival. The ocean survival assumptions used in previous harvest analysis were applied (Table 2). The maturation rate defines the Age X ocean to Age X+1 preharvest/ AgeX trib split. The ocean harvest rate defines the Age X preharvest to Age X harvest split percentage. The Trib harvest defines the Age X trib to Age X trib harvest split percentage. The total ER of 55% was modeled to reflect the recent past. 38 was chosen because it was the rate allowed in the most recent tule harvest BiOp. The ERs of 0%, 10%, 20% and 30% were chosen to explore a range of possible values. The values in Table 2 were used for all populations.

The natural ocean survival parameters are based on assumptions used in harvest analysis (e.g. 2009 BiOp). The return age structure was estimated from average age structure the Lewis, Coweeman and Grays populations [ref]. Relative age specific harvest rates for both the ocean and tributary harvest were estimated as the average rate from 2003 to 2007 of the "composite indicator" data compiled for the 2009 harvest BiOp analysis [ref].

Table 5 -- Ocean parameters for tule life-cycle modeling.

Total AEQ Exploitation Rate	Parameter	Age2	Age 3	Age 4	Age 5
	Natural ocean survival	0.6	0.7	0.8	0.9
	Return age structure	0.05	0.18	0.56	0.21
	Maturation Rate	0.01	0.09	0.57	1.0
0%	Ocean harvest	0	0	0	0
	Trib harvest	0	0	0	0
10%	Ocean harvest	0.005	0.021	0.038	0.045
	Trib harvest	0.024	0.027	0.028	0.031
20%	Ocean harvest	0.011	0.045	0.08	0.095
	Trib harvest	0.05	0.057	0.058	0.065
30%	Ocean harvest	0.017	0.07	0.125	0.148
	Trib harvest	0.078	0.089	0.091	0.102
38%	Ocean harvest	0.023	0.093	0.166	0.198
	Trib harvest	0.104	0.199	0.122	0.136
55%	Ocean harvest	0.037	0.153	0.274	0.326
	Trib harvest	0.17	0.195	0.20	0.224

Ocean return to Spawner survival: We assumed no mortality from when fish return from the ocean to the spawner stage (i.e. transitions Age X ocean to Age X toTrib, Age X toTrib to Age X prespawn, and Age X prespawn to Age X spawner).

Spawner Capacity: Spawner capacity was estimated from a habitat model as described in the tributary habitat modeling section. Total spawner abundance of all age classes from both natural and hatchery origin was limited by the spawner ceiling. If the number of spawners was truncated at the ceiling, the pool of spawners maintained the original age structure and natural/hatchery ratios. The point estimate and min-max values provided by the habitat model we input as a triangular distribution (Table 6).

Table 6 -- Spawner capacity estimates.

Population	Current Point Estimate Spawning	Current Min Spawning	Current Max Spawning
Hood	11057	8904	16749
Clatskanie	1614	998	2800
Elochoman	5867	2560	11411
MAG	1823	475	4027
Coweeman	7145	4770	12015
Toutle			
Lewis	12730	7108	14761
Scappoose	655	255	1325
Washougal	10580	8167	16437

Hatchery Fish: The life-cycle structure shown in Figure 7 has the potential to explicitly model the dynamics of the hatchery spawned population (entire right half of the diagram). However, we did not use the explicit hatchery dynamics option in the current analysis. Instead, hatchery fish were added to the pre-spawner pool as "strays" regardless of source. Hatchery fish were assumed to have the same spawner age structure as natural origin fish. The number of hatchery fish in current and recovery conditions are shown in Table 7.

Table 7 -- Number of hatchery fish (see hatchery section for discussion and citations).

Population	hatchery origin spawners last five years ("base")	hatchery origin spawners - recovery plan
Elochoman	1,155	309
MAG	1,631	692
Clatskanie	448	350
Toutle	2,391	ND
Coweeman	128	99
Lewis	280	217
Hood	64	ND
Scappoose	161	130
Washougal	2,346	117

Density Dependence Summary: Density dependence only enters the model in the spawner, subyearling outmigrants in the tributary and fry outmigrants in the confluence stages. Density dependence was modeled with a hockey-stick function.

Annual variability summary: Annual variability only entered the model in the egg to fry and smolts leaving the plume to near ocean density-independent survival stages.

Model Calibration

The base model was parameterized with generic freshwater survival assumptions derived extrapolating from only a few tule populations (for egg to fry survival) or by extrapolating from estimates applied in analyses of fall Chinook in in Puget Sound (primarily the Skagit River. To calibrate the model to spawner time series data, we adjusted the freshwater survival values by a "survival scalar" to match recently observed natural origins abundances. The spawner time series and recent abundance estimates for tule spawners were taken from the TAC report [ref] and are shown in appendix A. The survival scalar was applied equally to the egg to fry, fry to subtidal and subtidal to mixing zone transitions and to both the fry outmigrant and subyearling outmigrant pathways (i.e. newTransitionSurvival = baseTransitionSurvival * survivalScalar^(1/3)). Survival Scalars for two different set of hatchery assumptions (described below) are shown in Table # and ##. Application of the survival scalar required and adjustment to the maxium number of fry to the subyearling pathway because the scalar altered the number of fry needed to reach maximum rearing capacity Table 8 and Table 9.

Table 8 -- Survival scalars and fractions of juveniles in the fry to subyearling pathways, with no pHOS function.

Population	Recent natural origin spawners	Scalar without pHOS Function	Fract. Sub	Fract. Fry
Coweeman	512	1.36	0.76	0.24
Elochoman	123	0.15	0.14	0.86
MAG	554	0.69	0.18	0.82
Lewis	515	1.12	0.65	0.35
Scappoose	33	0.28	0.92	0.08
Washougal	1231	1.2	0.95	0.05
Hood	57	0.8	1	0
Clatskanie	448	0.17	0.14	0.86

Table 9 -- Survival scalars and fractions of juveniles in the fry to subyearling pathways with pHOS function.

Population	Recent natural origin spawners	Scalar Phos= -0.7 Function	Fract. Sub	Fract. Fry
Coweeman	512	1.63	0.74	0.26
Elochoman	123	0.43	0.19	0.81
MAG	554	1.35	0.22	0.78
Lewis	515	1.45	0.67	0.33
Scappoose	33	0.67	0.89	0.11
Hood	1231	1.2	1	0
Washougal	57	2.2	0.96	0.04
Clatskanie	448	0.45	0.19	0.81

Modeling negative effects of hatchery fish – the pHOS Function

The proportion of hatchery-origin spawners (pHOS) can affect survival substantially. Data indicate that in general, the greater pHOS the lower the survival (see discussion in hatchery section). To model this effect in SLAM, we calculated pHOS for every generation, then applied a survival decrement factor to the egg to fry, fry to subtidal and subtidal to mixing zone transitions. The shape of the survival factor vs pHOS curve is discussed in the hatchery section. The effects of the pHOS survival factor were distributed equally among the transtions and along both the fry-outmigrant and subyearling-outmigrant pathways. It was necessary to re-calibrate the model to recent natural origin when using the pHOS function (Table 8 vs. Table 9).

Modeled Scenarios

For every population the following scenarios where analyzed for six total exploitation levels (0%, 10%, 20%, 30%, 38% and 55%) (Table 10):

1. Current habitat and hatchery conditions, assuming no negative effects of hatchery spawners (pHOS slope = 0)
2. Current habitat and hatchery conditions, assuming hatchery fish depress natural survival (pHOS slope = -0.7)
3. Current habitat and hatchery conditions, assuming hatchery strays are reduced to zero and assuming past hatchery straying had no negative effect (pHOS slope = 0).
4. Current habitat and hatchery conditions, assuming hatchery strays are reduced to zero and assuming past straying depressed population fitness (pHOS slope = -0.7)
5. Recovery scenario (currently reflects a subset of proposed actions), assuming no negative effects of hatchery fish: Assumed modeled habitat improvements according to the recovery scenario (see habitat section) and reductions in hatchery strays according to the hatchery recovery scenario (see hatchery section).
6. Recovery scenarios (currently reflects a subset of proposed actions), assuming negative effects of hatchery fish: Assumed modeled habitat improvements

according to the recovery scenario (see habitat section) and reductions in hatchery strays according to the hatchery recovery scenario (see hatchery section).

It is important to recognize that the Recovery scenarios modeled in this draft of the analysis (Feb. 2010) do not include all planned or potential recovery actions. The recovery scenarios include increases in tributary rearing capacity based on an analysis of actions identified in the Lower Columbia recovery plans, and some increases in juvenile survival due to actions to reduce sediment (see habitat section -- Attachment 1). Other actions, such actions to reduce scour or increase habitat quantity or quality in the Columbia River estuary were not modeled.

Both the Washington and Oregon recovery plans set specific objectives by management sector (e.g., freshwater habitat, hatcheries, estuary, harvest) for reducing human induced mortality rates based on analyses of the level of aggregate change needed to reach population specific recovery objectives. We did not conduct an analysis of scenarios that reflect the impact of achieving these targets for this report.

Although not included in the recovery plans, the "no hatchery strays" scenario was included in our modeling for several reasons. First, the recovery plans generally require that the primary populations be viable based on natural production alone and not be dependent upon hatchery supplementation. Including a 'no hatchery strays' scenario helps to evaluate a population's viability in the absence of hatchery strays, even if in reality obtaining truly zero hatchery strays is unlikely to occur under any of the proposed management plans. Second, at least in some populations (Grays, Washougal, Toutle), there is the possibility of using weirs to exclude all or most hatchery fish from spawning naturally. The 'no hatchery strays' scenario can be used as a prediction of population performance under the assumption that all hatchery fish can be effectively removed at these weirs. Finally, because the effects of hatchery reform actions are one of the larger uncertainties facing recovery planners for this ESU, it is useful to test the sensitivity of our model results by exploring a broad range of future hatchery assumptions.

Table 10 – Summary of scenarios modeled

Scenario	Habitat condition	Hatchery stray level	Hatchery fitness effect
1	Current	Current	neutral
2	Current	Current	negative
3	Current	Zero	neutral
4	Current	Zero	negative
5	Recovery plan	Recovery plan	neutral
6	Recovery plan	Recovery plan	negative

Results and Discussion

Interpreting the Survival Scalar

The survival scalar parameters used to calibrate the model (Table 8 and Table 9) provide important information about the perceived status of the population and have large influence on the results of the analysis. The survival scalars indicate how much the survival of the population had to be adjusted relative to generic survival values in order to match the observed estimate of natural origin abundance in the population. If the survival scalar for a particular population was greater than one, model calibration required an assumption that the population had survivals greater than the generic values. Survival scalars less than one indicate populations that required an assumption of lower than generic survival to match recent natural origin returns.

The same survival scalar values that were fit to recent abundance for a given population were used for the different harvest rate, hatchery fish abundance and habitat recovery scenarios. Thus, if a population had a low survival scalar (e.g. Clatskanie and Elochoman) based on current low abundance, the survival for the population was assumed to be relatively low, even under recovery scenarios. The recovery scenarios included increases in habitat capacity and slight increases in egg to fry survival, but the survival scalars were constant.

The assumption of a constant survival scalar was necessary because no model or other basis was available for an informed adjustment of the parameter (with the exception of the pHOS adjustment function). An arbitrary adjustment factor could have been applied to the recovery scenarios (e.g. increase survival scalar by X%) but, as described in the habitat modeling report, the analysis was limited to recovery actions and effects which could be modeled with at least some empirical basis. This restriction is both a strength and limitation of this analysis.

The results of the analysis are sensitive to the value of the survival scalar. Unfortunately, a great deal of uncertainty surrounds this parameter. The survival scalar value is based on the estimate of the number of natural origin spawners. Largely because of the uncertainty in the estimated fraction of hatchery origin spawners (see Appendix B), the number of hatchery origin fish is poorly estimated. For example, a relatively large number of natural origin fish are estimated for the Washougal River, resulting in a large population survival scalar. If hatchery fraction estimation error causes an overestimate of the number of natural spawners, the survival scalar would be biased high, leading to an overly optimistic assessments of the populations future status. Alternative, if the proportion of hatchery fish some populations were biased high, this would cause the survival scalar to be biased low.

Population Abundance and Extinction Risk under Alternative Scenarios

We explored the effects of alternative harvest rates on population abundance and quasi-extinction risk for each of the modeled scenarios.

Scenario 1: Current habitat and hatchery conditions, assuming no negative effects of hatchery spawners (pHOS slope = 0) – Under this scenario natural spawning abundance increased approximately linearly with decreasing harvest rates, although not all populations responded equally (Figure 8). The Washougal, Lewis, and Coweeman had steeper predicted increases with decreasing harvest rates than did the Clatskanie, Elochoman, and Scappose populations. The Hood River population had a less linear response. Rates of quasi-extinction were low at all harvest rates modeled for the four larger populations (Washougal, Lewis, Coweeman, and MAG) and were moderate to high for the four smaller populations (Clatskanie, Elochoman, Scappose and Hood) (Table 11).

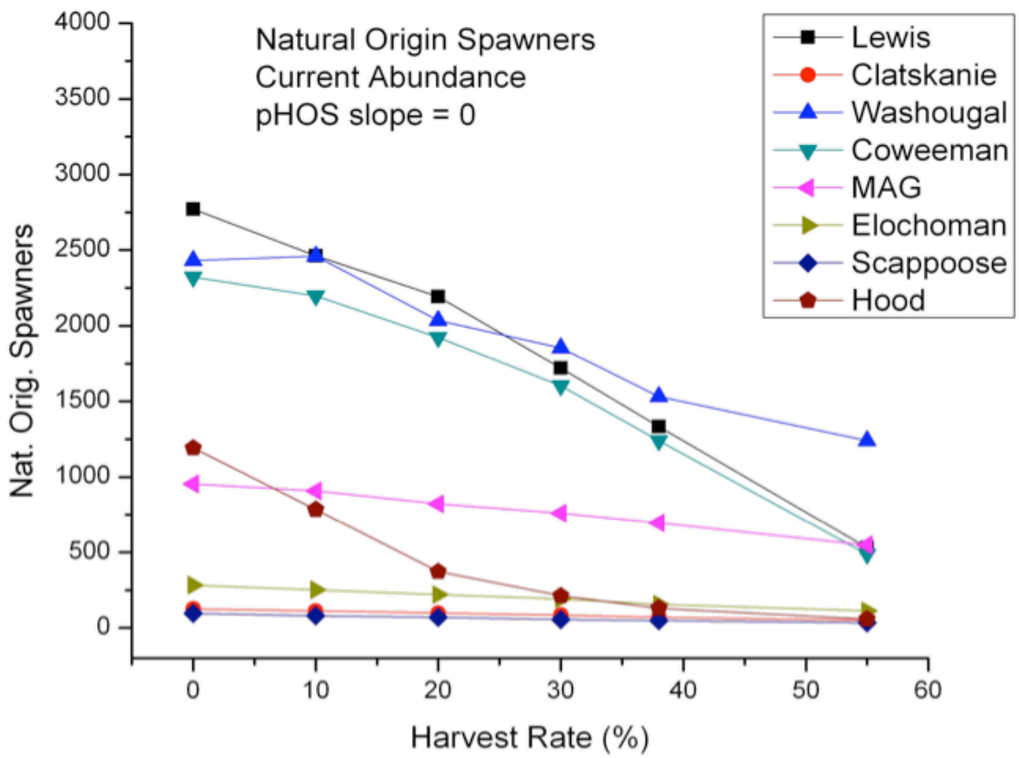

Figure 8 -- Model predicted natural origin spawning abundance the six modeled populations under alternative harvest rate assumptions and baseline (recent) pHOS levels and no negative effects of pHOS on survival rates.

Table 11 -- Probabilities of quasi-extinction for scenario 1 (baseline habitat and pHOS, neutral effect of pHOS on survival) at year 50 and year 100.

		Probability of quasi-extinction (year/QET)			
		In 50 years		In 100 year	
Population	Harvest rate	QET = 50	QET = 150	QET = 50	QET = 150
Coweeman	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0.03	0	0.07
Elochoman	0	0	0.07	0	0.16
	10	0	0.16	0	0.32
	20	0	0.39	0	0.62
	30	0	0.64	0	0.84
	38	0.002	0.89	0.002	0.97
	55	0.004	1	0.016	1
MAG	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0			
Lewis	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0	0	0
Washougal	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0	0	0
Clatskanie	0	0.05	0.985	0.1	1
	10	0.15	1	0.25	1
	20	0.33	1	0.51	1
	30	0.63	1	0.79	1
	38	0.87	1	0.96	1
	55	1	1	1	1
Scappoose	0	0.11	0.725	0.18	0.85
	10	0.26	0.88	0.42	0.96
	20	0.5	0.96	0.68	0.99

	30	0.77	0.98	0.92	1
	38	0.94	1	0.97	1
	55	1	1	1	1
Hood	0	0	0.02	0	0.04
	10	0	0.07	0	0.14
	20	0	0.27	0	0.34
	30	0.02	0.57	0.05	0.66
	38	0.08	0.85	0.13	0.9
	55	0.67	1	0.84	1

Scenario 2: Current habitat and hatchery conditions, assuming hatchery fish depress natural survival (pHOS slope = -0.7) – This scenario is the same as scenario 1, except that it assumes there is a negative effect of naturally spawning hatchery fish on early life-stage survival rates. Introducing the assumption of a negative effect of pHOS generally resulted in higher abundance at lower harvest rates than under the assumption of no negative affects of hatchery fish (Figure 9). The exception was the MAG population, which has essentially the same predicted abundance under both scenarios and 1 and 2. Probabilities of quasi-extintion for most populations were slightly reduced in scenario 2 compared to scenario 1, particularly at low harvest rates. The notable exception was the Coweeman, which had a substantially higher rate of quasi-extinction at the highest (55%) harvest rate under scenario 2 than scenario 1.

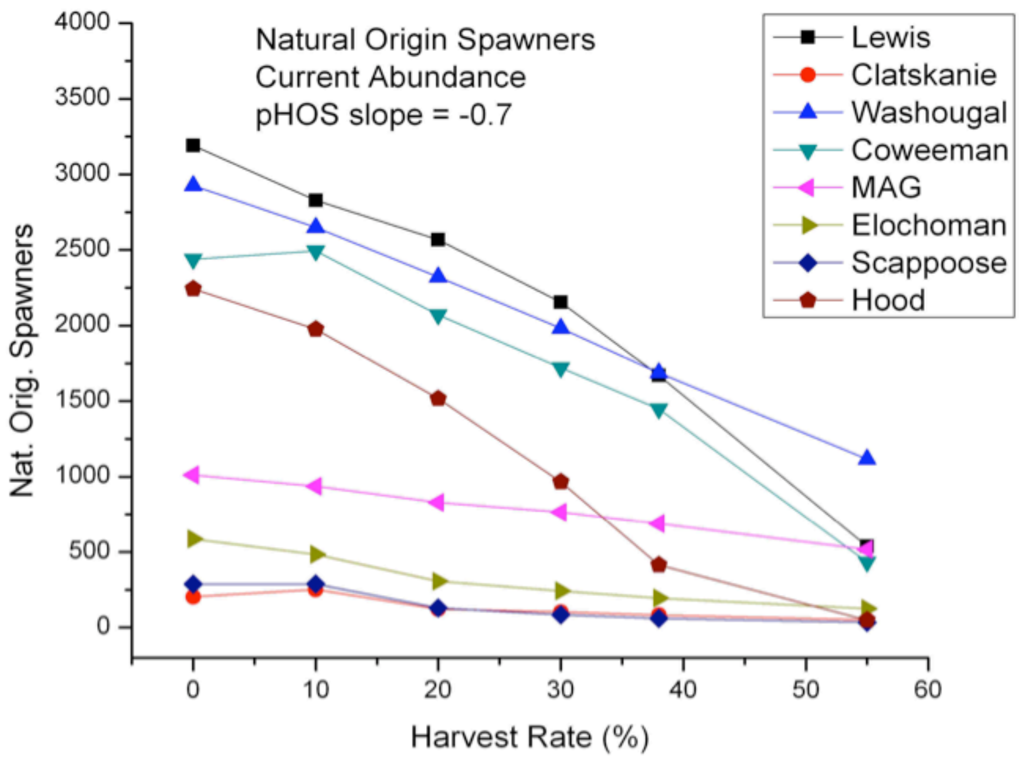

Figure 9 -- Model predicted natural origin spawning abundance for the six modeled populations under alternative harvest rate assumptions, baseline (recent) pHOS levels and assuming a negative relationship between pHOS and population survival rates.

Table 12 -- Probabilities of quasi-extinction for scenario 2 (baseline habitat and pHOS, negative effect of pHOS on survival) at year 50 and year 100.

		Probability of quasi-extinction (year/QET)			
Population	Harvest rate	In 50 years QET = 50	QET = 150	In 100 year QET = 50	QET = 150
Coweeman	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0.14	0.002	0.23
Elochoman	0	0	0	0	0
	10	0	0.01	0	0.02
	20	0	0.13	0	0.23
	30	0	0.27	0	0.44
	38	0	0.62	0	0.8
	55	0.012	0.99	0.028	1
MAG	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0	0	0
Lewis	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0	0	0
Washougal	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0	0	0
Clatskanie	0	0	0.13	0	0.16
	10	0	0.14	0	0.17
	20	0.09	0.64	0.16	0.74
	30	0.28	0.86	0.42	0.93
	38	0.64	0.98	0.77	0.99
	55	1	1	1	1
Scappoose	0	0.01	0.18	0.06	0.25
	10	0.06	0.25	0.11	0.34

	20	0.44	0.76	0.56	0.85
	30	0.74	0.93	0.84	0.98
	38	0.94	0.98	0.96	1
	55	1	1	1	1
Hood	0	0	0	0	0
	10	0	0.002	0	0.002
	20	0	0.03	0	0.04
	30	0.01	0.16	0.04	0.17
	38	0.05	0.41	0.08	0.45
	55	0.7	0.97	0.82	0.99

Scenario 3: Current habitat and hatchery conditions, assuming hatchery strays are reduced to zero and assuming past hatchery straying had no negative effect (pHOS slope = 0) – This scenario is the same as scenario 1, except that pHOS is assumed to be reduced to 0 (no hatchery strays). Under this scenario, all of the populations crashed at the 55% harvest rate, and the Clatskanie, Elochoman, Scappoose, and MAG populations crash even with no harvest (Figure 10). At harvest rates of 38% and below, the Coweeman population had an abundance similar to what it had in scenario 1 (hatchery fish present). In contrast, all of the other populations had substantially lower abundance. At a 55% harvest rate, the probability of quasi-extinction is high (>50%) for all populations (Table 13). The Elochoman, Clatskanie, MAG, Scappoose, and Hood populations have moderate to high probability of quasi-extinction under this scenario even with no harvest. The remaining populations have probabilities of quasi-extinction that increase with increasing harvest rate, but are generally low at harvest rates of 30% or below.

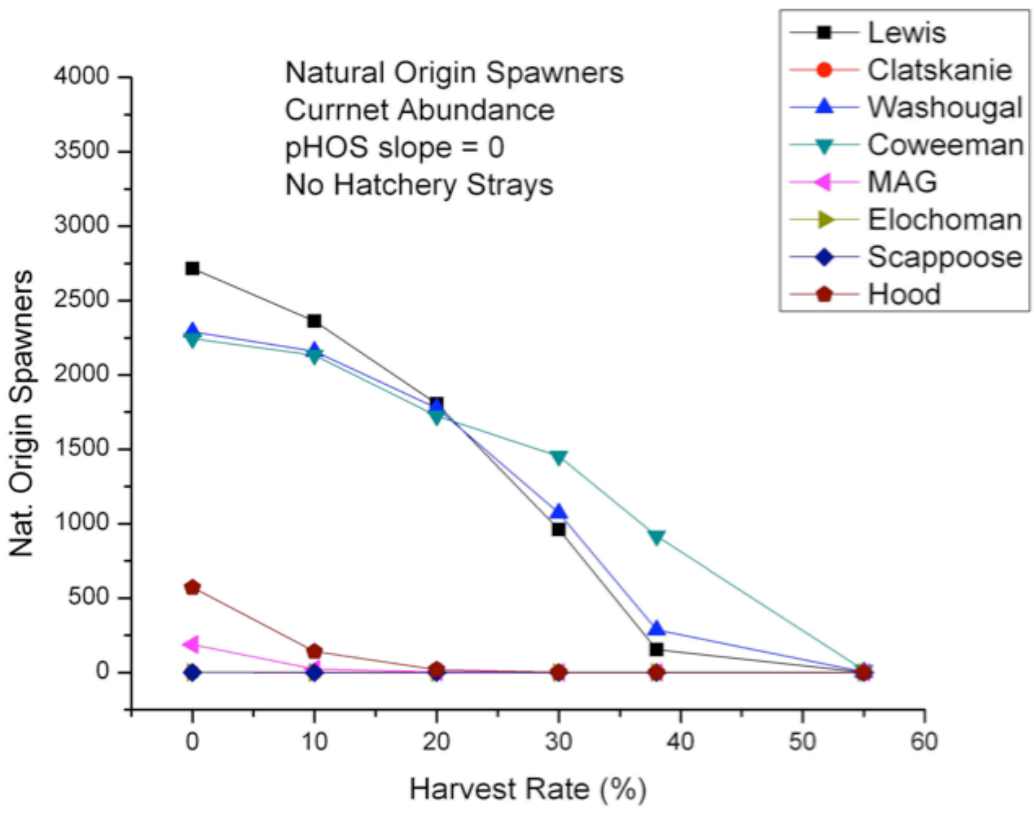

Figure 10 -- Model predicted natural origin spawning abundance the six modeled populations under alternative harvest rate assumptions, no hatchery input (pHOS = 0) and no baseline negative effects of pHOS on survival rates (i.e., no survival increase as pHOS is reduced to 0).

Table 13 -- Probabilities of quasi-extinction for scenario 3 (baseline habitat, zero pHOS, neutral effect of pHOS on survival) at year 50 and year 100.

		Probability of quasi-extinction (year/QET)			
Population	Harvest rate	In 50 years QET = 50	QET = 150	In 100 year QET = 50	QET = 150
Coweeman	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0.01	0.01	0.03
	38	0.01	0.09	0.09	0.16
	55	0.55	0.80	0.84	0.94
Elochoman	0	1	1	1	1
	10	1	1	1	1
	20	1	1	1	1
	30	1	1	1	1
	38	1	1	1	1
	55	1	1	1	1
MAG	0	0.19	0.44	0.75	0.56
	10	0.5	0.75	0.9	0.84
	20	0.76	0.93	0.93	0.96
	30	0.77	0.99	0.99	1
	38	1	1	1	1
	55	1	1	1	1
Lewis	0	0	0	0	0
	10	0	0	0	0
	20	0	0.03	0.2	0.05
	30	0.02	0.15	0.14	0.24
	38	0.2	0.45	0.44	0.6
	55	0.96	0.99	0.99	1
Washougal	0	0	0	0	0
	10	0	0	0	0
	20	0	0.02	0.01	0.04
	30	0.03	0.1	0.07	0.17
	38	0.15	0.38	0.31	0.52
	55	0.74	0.93	0.95	0.98
Clatskanie	0	1	1	1	1
	10	1	1	1	1
	20	1	1	1	1
	30	1	1	1	1
	38	1	1	1	1
	55	1	1	1	1
Scappoose	0	1	1	1	1

	10	1	1	1	1
	20	1	1	1	1
	30	1	1	1	1
	38	1	1	1	1
	55	1	1	1	1
Hood	0	0.14	0.3	0.22	0.35
	10	0.3	0.53	0.42	0.6
	20	0.64	0.85	0.76	0.89
	30	0.91	0.97	0.95	0.98
	38	0.99	1	1	1
	55	1	1	1	1

Scenario 4: Current habitat and hatchery conditions, assuming hatchery strays are reduced to zero and assuming past straying depressed population fitness (pHOS slope = -0.7) – This scenario assumes that pHOS is reduced to zero and that the populations get a proportional fitness boost for this reduction in pHOS compared to baseline conditions. As modeled, however, this fitness boost is not sufficient to 'rescue' the Clatskanie, Elochoman, and Scappoose populations, however, which crash even under the assumption of no harvest mortality (Figure 11). In contrast, all of the other populations remain relatively abundant at harvest rates of 30% and below. Similar to scenario 2, the inclusion of a negative effect of pHOS resulted in a notable increase in most populations at low harvest rates compared to assumption of a neutral effect of pHOS. Probabilities of quasi-extinction were generally somewhat lower than those under scenario 3 (Table 14).

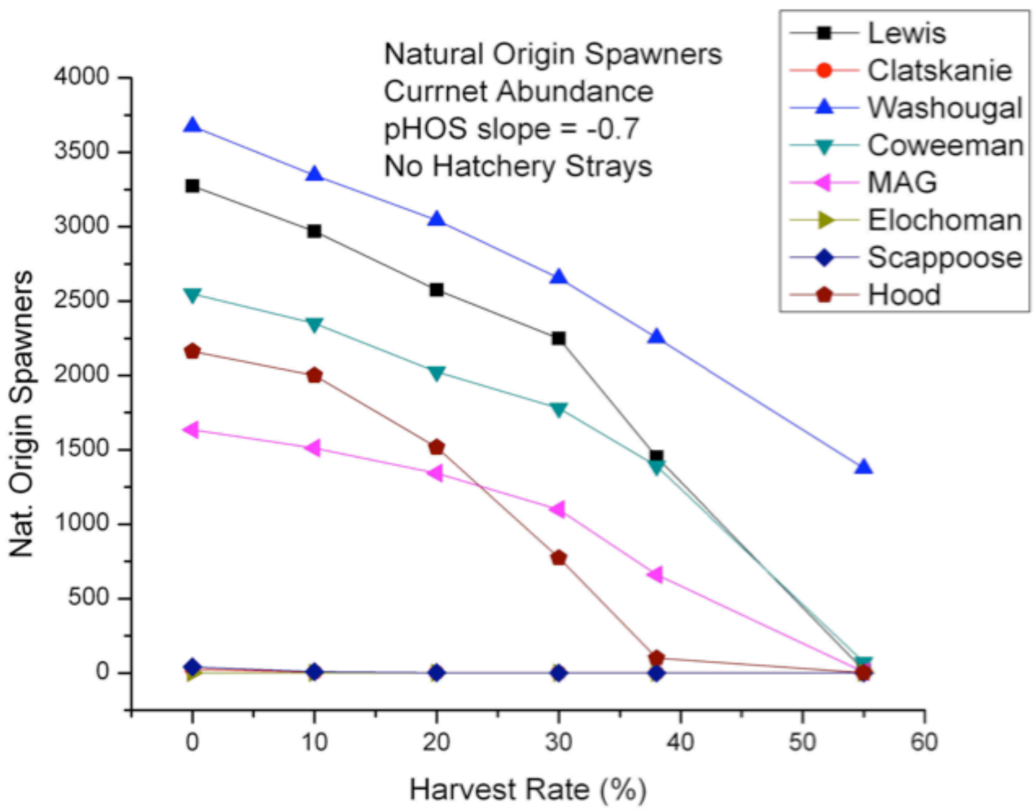

Figure 11 -- Model predicted natural origin spawning abundance for the six modeled populations under alternative harvest rate assumptions, no hatchery input (pHOS = 0), and assuming a negative relationship between pHOS and population survival rates (ie., survival rates improve with lower pHOS).

Table 14 -- Probabilities of quasi-extinction for scenario 4 (baseline habitat, zero pHOS, negative effect of pHOS on survival) at year 50 and year 100.

		Probability of quasi-extinction (year/QET)			
Population	Harvest rate	In 50 years QET = 50	QET = 150	In 100 year QET = 50	QET = 150
Coweeman	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0.002	0	0.006
	38	0.01	0.02	0.03	0.03
	55	0.325	0.65	0.53	0.74
Elochoman	0	0.985	1	1	1
	10	0.99	1	1	1
	20	1	1	1	1
	30	1	1	1	1
	38	1	1	1	1
	55	1	1	1	1
MAG	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0.004	0.03	0.01	0.04
	38	0.06	0.22	0.13	0.23
	55	0.76	0.94	0.93	0.95
Lewis	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0.01	0.01	0.02
	38	0.025	0.08	0.04	0.11
	55	0.575	0.83	0.78	0.89
Washougal	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0.002	0.002	0.004	0.016
Clatskanie	0	0.65	0.76	0.72	0.81
	10	0.9	0.95	0.92	0.96
	20	0.98	0.99	0.99	0.99
	30	0.99	1	1	1
	38	1	1	1	1
	55	1	1	1	1
Scappoose	0	0.51	0.725	0.61	0.76

	10	0.76	0.91	0.875	0.93
	20	0.94	0.98	0.975	0.98
	30	1	1	0.99	1
	38	1	1	1	1
	55	1	1	1	1
Hood	0	0	0	0	0.01
	10	0	0.01	0	0.02
	20	0.01	0.1	0.04	0.12
	30	0.12	0.35	0.18	0.36
	38	0.39	0.71	0.49	0.74
	55	0.97	1	1	1

Recovery scenarios 5 (hatchery fish neutral) and 6 (hatchery fish negative) – Under scenario 5 (recovery actions, no negative effect of hatchery fish) all populations increased in abundance, but the magnitude and temporal trend of the increase differed markedly among populations (Figure 12).

For scenario 5, rates of quasi-extinction were similar to those under scenario 1, with the Coweeman, MAG, Lewis and Washougal generally having relatively low rates of quasi-extinction and the Elochoman, Clatskanie and Scappoose having moderate to high rates of quasi-extinction (Table 15).

Abundance trends under scenario 6 (recovery assumptions, assuming a negative effect of hatchery fish) were generally steeper than those under scenario 5 (neutral effects of hatchery fish), although the trends in the Washougal and MAG populations were relatively flat. The Clatskanie, Elochoman and Scappoose populations increased markedly more at low harvest rates under scenario 6 than under scenario 5 (Figure 13), reflected the assumed benefits of pHOS reductions. Under scenario 6, probabilities of quasi-extinction were generally lower than under scenario 5 (Table 16).

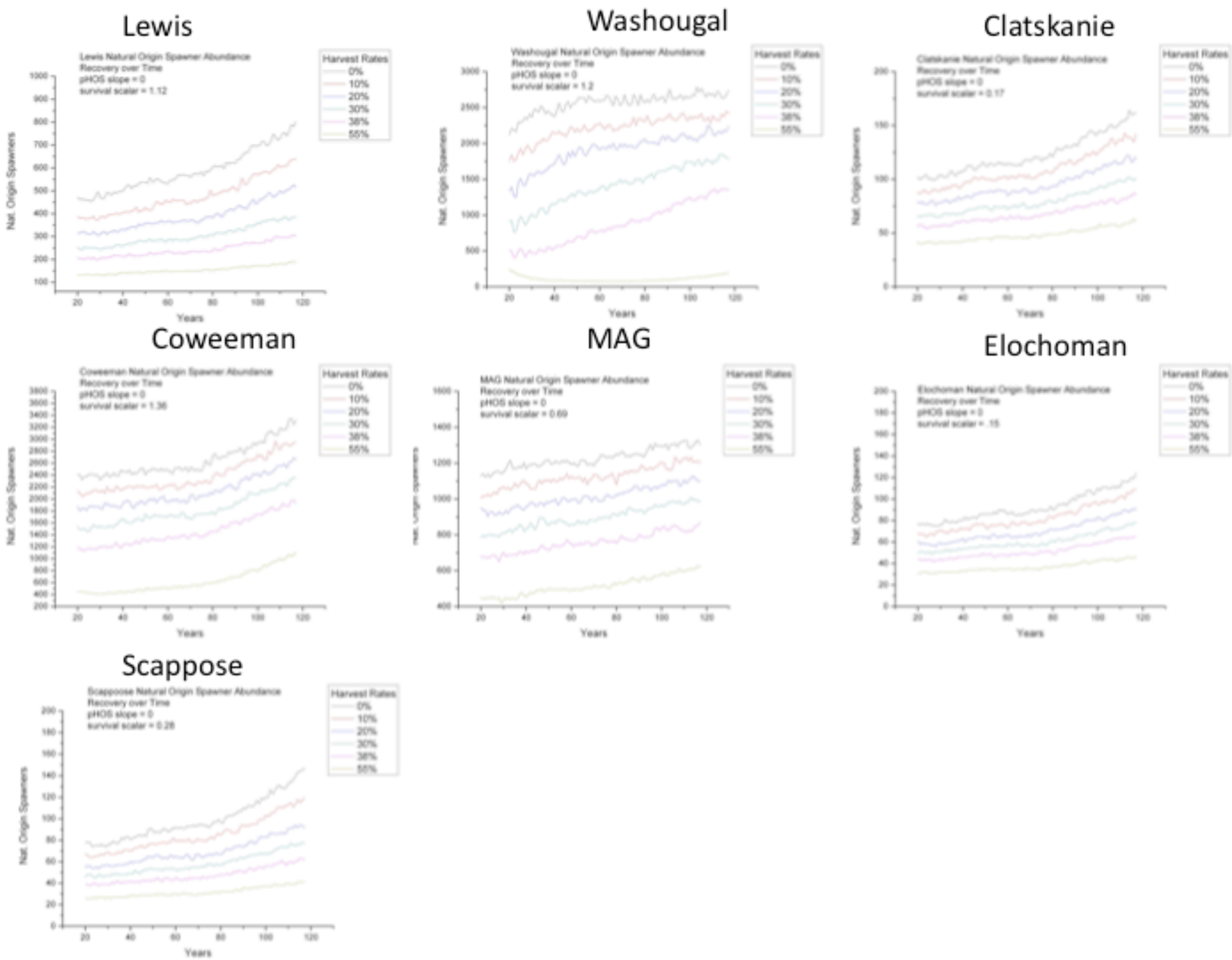

Figure 12 – Modeled abundance over time for scenario 5 (habitat and hatchery recovery actions, neutral effects of hatchery fish on survival) for alternative harvest assumptions. Time frame is 100 years (first twenty years are for model burn equilibration and are not included).

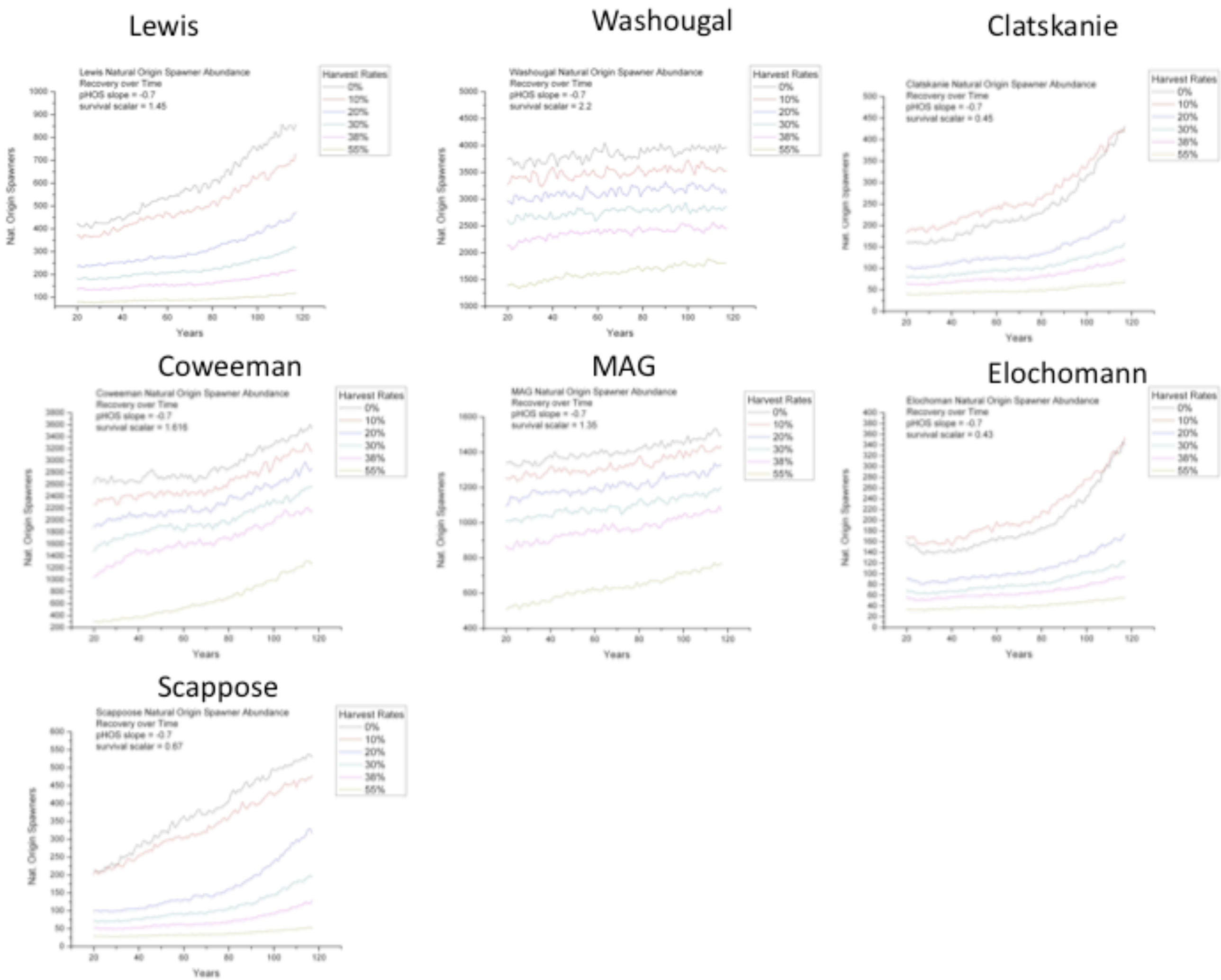

Figure 13 -- Modeled abundance over time for scenario 6 (habitat and hatchery recovery actions, negative effects of hatchery fish on survival) for alternative harvest assumptions. Time frame is 100 years (first twenty years are for model burn equilibration and are not included).

Table 15 – Probabilities of quasi-extinction for scenario 5 (habitat and hatchery recovery actions, neutral effect of pHOS on survival) at year 50 and year 100.

		Probability of quasi-extinction (year/QET)			
Population	Harvest rate	In 50 years QET = 50	QET = 150	In 100 year QET = 50	QET = 150
Coweeman	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0.085	0	0.10
Elochoman	0	0.3	1	0.35	1
	10	0.5	1	0.58	1
	20	0.75	1	0.82	1
	30	0.9	1	0.96	1
	38	0.98	1	1	1
	55	1	1	1	1
MAG	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0	0.002	0	0.002
Lewis	0	0	0	0	0
	10	0	0	0	0.002
	20	0	0.01	0	0.03
	30	0	0.15	0	0.18
	38	0	0.42	0	0.51
	55	0	0.99	0	1
Washougal	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0.03	0	0.04
	38	0.02	0.2	0.024	0.23
	55	0.36	0.83	0.52	0.9
Clatskanie	0	0.03	0.98	0.04	1
	10	0.1	1	0.06	1
	20	0.24	1	0.29	1
	30	0.51	1	0.61	1
	38	0.78	1	0.86	1
	55	0.99	1	1	1

Scappoose	0	0.35	0.96	0.4	0.99
	10	0.52	0.99	0.58	1
	20	0.77	1	0.83	1
	30	0.92	1	0.95	1
	38	0.99	1	1	1
	55	1	1	1	1

Table 16 -- Probabilities of quasi-extinction for scenario 6 (habitat and hatchery recovery actions, negative effect of pHOS on survival) at year 50 and year 100.

		Probability of quasi-extinction (year/QET)			
Population	Harvest rate	In 50 years QET = 50	QET = 150	In 100 year QET = 50	QET = 150
Coweeman	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0
	55	0.01	0.18	0.008	0.28
Elochoman	0	0.04	0.8	0.04	0.85
	10	0.01	0.78	0.02	0.83
	20	0.25	0.99	0.3	1
	30	0.56	1	0.64	1
	38	0.84	1	0.89	1
	55	0.99	1	1	1
MAG	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0
	38	0	0	0	0.002
	55	0	0.008	0	0.008
Lewis	0	0	0.004	0	0.01
	10	0	0.01	0	0.03
	20	0	0.25	0	0.31
	30	0	0.6	0	0.69
	38	0.002	0.9	0.004	0.94
	55	0.225	1	0.27	1
Washougal	0	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	30	0	0	0	0

	38	0	0	0	0
	55	0	0.004	0	0.004
Clatskanie	0	0.006	0.73	0.01	0.64
	10	0	0.58	0	0.97
	20	0.1	0.97	0.13	1
	30	0.3	1	0.34	1
	38	0.55	1	0.63	1
	55	0.98	1	0.99	1
Scappoose	0	0	0.4	0.002	0.4
	10	0.02	0.45	0.03	0.48
	20	0.22	0.93	0.24	0.94
	30	0.44	0.97	0.46	0.99
	38	0.79	1	0.82	1
	55	1	1	1	1

Limiting life-stages, and the number of spawners needed for maximum smolt production

Based on the habitat capacity estimates and life-stage survivals, the modeling results indicate that all of the populations modeled are limited by juvenile rearing capacity rather than spawning capacity since the number of spawners needed to reach juvenile capacity was in every case except the Scappoose population smaller than estimated current spawning capacity (Table 17). For the Washougal, MAG and Scappoose populations, recent average spawning abundance (hatchery and natural origin combined) have exceeded the estimated number of spawners to reach juvenile capacity. In contrast, the Clatskanie, Elochomann, Coweeman, Lewis and Hood populations have had recent average spawning abundance less than that estimated to be needed to reach full juvenile capacity.

Table 17 – Comparison of spawner capacity and the number of spawners needed to reach juvenile capacity, assuming juveniles are optimally divided between the fry migrant and sub-yearling migrant pathways and that the juvenile production relationship can be represented by a Hockey-Stick function. Yellow (light) shading indicates populations potentially "underseeded" and pink (dark) shading indicates potential "over seeding".

Population	Spawner Capacity	Spawners Needed to Reach Juvenile Capacity (base survival)	Spawners Needed to Reach Juvenile Capacity (No pHOSadjusted by scalar)	Spawners Needed to Reach Juvenile Capacity (With pHOS adjusted by scalar	Recent Median Number of Spawners (wild)	Recent Median Number o Spawners (total = wild hatchery)
Hood	11057	2626	2520	2073	57	
Clatskanie	1614	1183	2354	1339	33	330
Elochoman	5867	2297	8611	4481	123	551

Mill/Ger/Ab	1823	1158	1423	932	554	1,367
Coweeman	7145	923	1119	955	512	526
Toutle	47,109				3441	5831
Lewis	12730	1245	1924	1765	515	628
Scappoose	655	834	1772	845	33	330
Washougal	10580	522	1170	978	1231	2800

Table 18 – Estimated number of smolts in the mixing zone (Columbia River mouth) if freshwater habitat is filled to capacity

Population	**Smolt in mixing from fry-JOM if at capacity based on pHOS with scalar**	**Smolt in mixing from sub-year-JOM if at capacity based on pHOS with scalar**	**Total smolt in mixing if both paths at capacity based on pHOS with scalar**
Hood	104900	140413	245313
Clatskanie	58230	42224	100454
Elochoman	224461	137271	361732
MAG	104900	91981	196981
Coweeman	52950	375968	428918
Scappoose	64386	20166	84552
Lewis	94178	397649	491827
Washougal	7923	560713	567636

The estimated number of smolts that would be in the 'mixing zone' if the juvenile habitat is filled to capacity are provided in Table 18. The smolt abundance under alternative harvest assumptions reflects the juvenile rearing capacities of the populations (Figure 14). The primary difference among the scenarios relates to the presence or absence of hatchery fish on the spawning grounds. In scenarios 1 and 2 (hatchery fish present) smolt production is relatively unaffected by harvest rate, except for the Lewis population in which smolts generally increased with decreasing harvest rate. In contrast, in the scenarios without hatchery fish present, most populations exhibited increasing smolt abundance with decreasing harvest rate at the higher harvest rates, with some leveling off of smolt abundance as harvest rate declined. The flat relationship between harvest rate and smolt production seen in some of the scenarios may be sensitive the assumption of a Hockeye-Stock function for juvenile production, and we will explore alternative production functions in future iterations of the model.

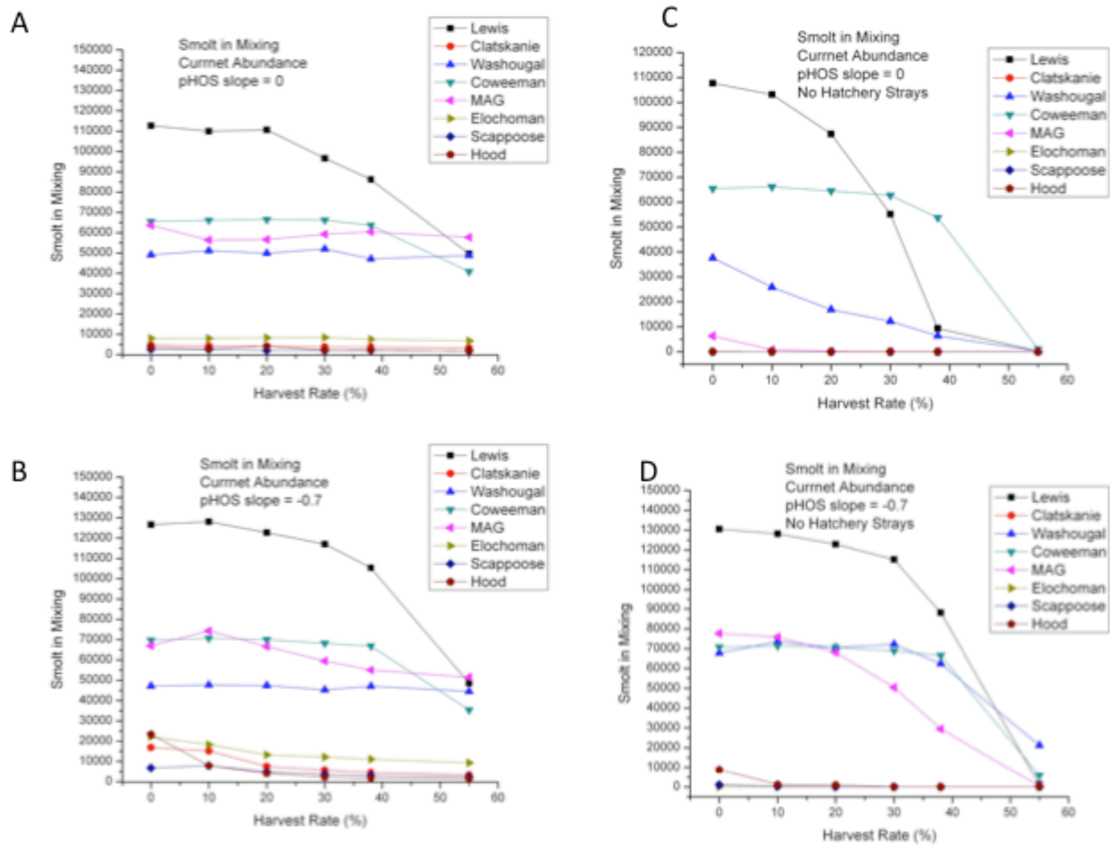

Figure 14 – Abundance of smolts at the Columbia River mouth (mixing zone) under scenarios 1-4 (baseline habitat conditions). A) Scenario 1: Current pHOS, neutral effect of hatchery fish; B) Scenario 2: Current pHOS, negative effect of hatchery fish; C) Scenario 3: pHOS of 0, neutral effect of hatchery fish; D) Scenario 4: pHOS of 0, negative effect of hatchery fish.

Discussion

Current status of the populations – One of the clearest results of this modeling effort are the striking differences in apparent viability among the six populations we modeled. Three populations – Lewis, Coweeman, and Washougal – are relatively large and have low estimated risks of quasi-extinction under a variety of the scenarios we explored, at least at harvest rates below ~30%. Three other populations – Clatskanie, Elochoman and Scappoose – appear to be sustained mostly through hatchery straying under current conditions, and are predicted to be self-sustaining under the 'recovery' actions modeled only at very low harvest rates. The Hood and MAG populations were intermediate between these two cases, could sustain themselves without hatchery input at low harvest rates under current conditions under some modeled assumptions but not others. This basic result – that the populations differ markedly in their current status and ability to sustain harvest – is consistent with previous modeling efforts (Beamesderfer 2009; Ford et al., 2007).

Interpreting these results, however, is tricky. In particular, as we discuss above in the section on survival scalars, the habitat and hatchery models we used do not fully (or even mostly) account for differences in apparent status among these populations. In order to make the model 'fit' the observed abundances, we had to introduce survival scalars to either reduce or increase early life-stage survival in order to make the model produce recently observed abundance under recent harvest rates. Differences in these survival scalars appear to lead to some of the big differences in viability between the populations. Clearly, one important follow up to this effort is to attempt to better understand what is driving differences in abundance between the populations and to account for this explicitly in the model.

Ability to sustain harvest – Our results indicate that the six populations we modeled differ markedly in their ability to sustain harvest. The four larger populations (Lewis, Washougal, Coweeman, MAG) all appear able to remain viable under harvest rates up to 30-38% under most of the scenarios we examined. In contrast, the Clatskanie, Scappoose and Elochoman were not viable at any harvest rate under current conditions, particularly in the absence of hatchery straying. These populations improved under the 'recovery' scenario, but even so had low probabilities of quasi-extinction only under very low rates of harvest. These results appear at least qualitatively consistent with previous modeling efforts, although the exact maximum rate of harvest consistent with viability varies among scenarios and models.

Hatcheries – The way we constructed the model, hatcheries have two counteracting effects on the populations, which are clearly seen in the results. On the one hand, hatchery input can help a population avoid quasi-extinction, particularly at high harvest rates. This is true even when naturally spawning hatchery fish are assumed to have a negative effect on survival. However, hatchery strays can have a negative effect on natural origin abundance, particularly at lower harvest rates, through their depression of natural survival rates. Some populations (MAG, Hood) were particularly sensitive to the assumption of whether or not there was a negative effect of hatchery origin spawners (compare Figure 10 and Figure 11.

Some care is needed in interpreting the rates of quasi-extinction under any of the scenarios that involve hatchery straying (scenarios 1, 2, 5 and 6). The rates of quasi-extinction are based on the proportion of the model runs in which natural origin spawning abundance fell below the quasi-extinction threshold. This means that for populations that receive continual input of hatchery origin fish, hatchery fish will continue to be present even if the population reaches the quasi-extinction threshold. Another important point to note is that populations that have low rates of quasi-extinction only when hatchery fish are present cannot be considered to be naturally self-sustaining.

Capacities and limiting life-stages -- The mainstem confluence area seems to provide more rearing capacity than the tributaries for some populations. Most populations were estimated to have higher current spawning capacities than the number of spawners needed to reach juvenile capacity. These results may be quite sensitive to the assumptions of the habitat model, so some additional sensitivity analyses are warranted.

Recovery scenarios – All of the populations were predicted to increase under the recovery scenarios, but the magnitude and temporal pattern of these increases varied markedly among the populations. In evaluating these scenarios, it is important to emphasize that only a portion of potential recovery actions were modeled, focusing primarily on increases in tributary habitat capacity (and some increases in survival) and reduction in hatchery spawners. Actions in other areas (Columbia mainstem, tributary confluences) that would also be expected to result in increased habitat were not modeled. In addition, some actions that would result in increased survival in the tributaries, in particularly actions that would alter flow or temperature, were not modeled.

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Appendix A: Hatchery Fraction Estimation Error

From the 2006 WLC-TRT viability criteria report appendix G
Paul McElhany

For some species, such as fall chinook, a very small fraction (e.g., 5%) of hatchery spawners are tagged at the hatchery and population level hatchery fraction estimates are made based on the recovery of only a few fish. This can lead to considerable uncertainty in the estimate of the fraction of hatchery origin fish. This appendix explores the probability distribution of hatchery fraction using the current sampling schemes.

The method of estimating the probability distribution of the hatchery fraction takes a Bayesian approach. We take a two stage approach, first estimating the probability distribution for the fraction of hatchery fish in the sample, then estimating the probability distribution for the fraction of hatchery fish in the total population, based on the probability distribution of the sample.

We first calculate the probability of obtaining the observed number of tags from a hypothetical population of Y hatchery fish. This is a binomial probability where the "probability of success" is the fraction of fish of the age class that were tagged at the hatchery; the "number of trials" is Y, the hypothetical population size; and the "number of successes" is the number of observed tags. This probability is calculated for all possible hatchery fish population sizes. The possible hatchery fish population size ranges from a minimum of the number of tags observed (there is a remote chance that the tagged fish are the only hatchery fish in the population) to a maximum of all the fish in the sample.

In the language of Bayesian statistics, these binomial probabilities are "the probability of the data given the hypothesis." What we need is the Bayesian posterior probability, which is "the probability of the hypothesis given the data." That is, the binomial gives the probability of observing Z tags given Y hatchery fish and we need the probability of Y hatchery fish given that Z tags are observed. To calculate the posterior probability, we assume a uniform prior distribution between the number of observed tags and the total number of fish in the sample. The posterior probability for a particular Y is then found by dividing the probability of observing Z tags given Y hatchery fish by the sum of the probabilities of observing Z tags over all possible Ys. This produces the probability distribution for the faction of hatchery fish in the subset of the population sampled for hatchery tags.

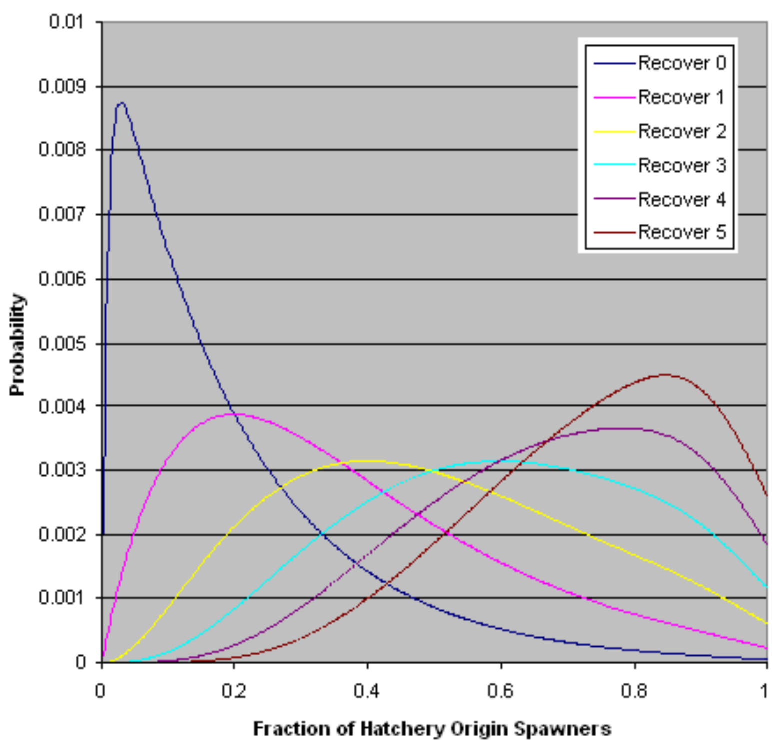
We take a similar approach to estimating the probability distribution of the fraction of hatchery fish in the total population. We find the binomial probability that there are Y hatchery fish in the sample given H hatchery fish in the population. This is then multiplied by the probability (calculated in the previous step) that there are Y hatchery fish in the sample. The probabilities for a given H are summed across Ys to give the probability of the Y distribution given H hatchery fish. To get the posterior distribution (i.e., the probability of H hatchery fish given the distribution of Ys) we divide the probability of the Y distribution given H hatchery fish in the population by the sum of all probabilities of the Y distribution given H hatchery fish.

This approach requires the following data:

- Total population size (N)
- Number of fish in the population sampled for hatchery tags (X)
- Number of tags observed (Z)
- Fraction of fish tagged at hatchery (mark rate)

If the fraction of hatchery fish marked varies every year, we need to deal with the age structure, which gets very messy, but the same basic approach can be applied. In the case where the hatchery mark rate varies, we need the fraction of hatchery fish marked each year and the age structure (ideally of both the hatchery tagged fish and the sample as a whole, as these may differ given the small number of tags recovered).

Sample results for a "typical" Fall chinook population are shown in Figures 1-3. The total population size is 500 spawners, the number of spawners sampled for hatchery tags is 100 and the tag rate at the hatchery is 5% of releases. The different curves show the probability that the population contains a given fraction of hatchery origin spawners if 0, 1, 2, 3, 4, or 5 tagged fish are recovered in the sample of 100. The point estimate fraction of hatchery origin fish for the different number of recoveries are 0%, 20%, 40%, 60%, 80%, and 100%, respectively. This is a difference of 20% in the hatchery fraction estimate based on a recovery difference of only a single fish! Data sets often report only these point estimates. The probability curves show that there is considerable uncertainty.



Attachment 1 -- Habitat Analyses to Support Life Cycle Modeling for Tule Chinook Salmon in the Lower Columbia River

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DRAFT 2/9/10

Introduction

We conducted spatially-explicit analyses to assess the conditions and recovery potential in tributaries for the 9 populations of tule Chinook salmon in the Lower Columbia River that were targeted for high viability in recovery plans (Figure 1). Populations in Washington were: (1) Lewis River, (2) Washougal River, (3) Elochoman River, (4) Coweeman River, (5) Toutle River, and (6) Mill/Germany/Abernathy Creeks, and populations in Oregon were (1) Clatskanie River, (2) Scappoose River, and (3) Hood River.

Our objectives were to answer the following inter-related questions for each population:

> (1) What are the distributions of spawning capacity, rearing capacity, and egg-to-fry survival parameters under current conditions?
>
> (2) What level of improvement in fish parameters might we expect from tributary habitat restoration actions suggested by recovery plans, and when might such improvements occur?

Guided by these questions, we assembled an analytical approach that built on previous exercises. We estimated parameter distributions for freshwater life stages as inputs into the Species Life cycle Analysis Module (SLAM; McElhany 2009). We used a simulation approach to evaluate the timeframe over which freshwater habitat restoration actions might be expected to produce ecological improvements. Specifically, we modeled a recovery scenario for each population designed to mimic actions called for in recovery plans, and modeled the effects of those actions through time. Below, we describe in detail the models we used for each tributary life stage parameter, and the scenarios we modeled.

Methods

Spatially-explicit models

We used models that have been previously described and applied. Our intention for future iterations of this analysis is to add additional models for estimating each parameter. In so doing, we hope to capture more uncertainty associated with the assumptions specific to each model, and therefore to provide more robust information on which to base management decisions.

Fish distributions

The spatial extent of spawning was predicted by Rawding et al. (2009a) for populations in Washington. Briefly, the authors identified the lower-most reaches in which tule Chinook salmon have been observed to spawn (typically at the tidal transition), and the upper-most reaches in which they might be expected to spawn based on known natural or anthropogenic barriers or, in the absence of barriers, based on predictions from a logistic regression model. This model incorporated empirical characteristics of streams where redds have been observed, sometimes over multiple years. The two best models incorporated drainage area and channel gradient. Final model parameters were provided by WDFW and we applied the model to streams in both

Washington and in Oregon to estimate spawning distributions for each population (Appendix A, Figures A1-A9). We included reaches scoring likelihood values ≥ 0.5 to estimate spawning distributions. The choice of this parameter as a cutoff was fairly robust (see Appendix A, Figures A19-A27, where we mapped distributions using a threshold of 0.4, 0.5, and 0.6). The distribution model is based on the uppermost distribution observed (in some cases, from multiple years of observations); in reality, the spawning distribution is variable. Therefore, the model probably slightly over-predicts the spatial extent of spawning in an average year.

We assumed that these spawning distributions also represented the spatial extent for egg-to-fry survival, and further reasoned that they adequately described the majority of habitat used by juveniles for rearing before emigrating the following summer (June or July). We realize that this is a simplification, but chose to stick with this approach to streamline model processing. We therefore used these distributions to summarize capacity and survival model predictions (described below) for each population.

Following review of initial maps by comanagers (see comments in Appendix A), we revised the final spawning distributions (see Appendix A, Figures A10-A18 for a comparison of new and old spatial extents).

Stream characteristics

The stream layer (1:24,000 resolution) and associated attributes of instream characteristics (e.g., channel gradient, bankfull width, depth, valley width) were derived from 10-m digital elevation models (DEMs) using NetStream (Miller 2003) (Table 1). This stream layer was generated for the entire Lower Columbia region; we clipped this layer by population boundaries to enable faster processing.

Riparian seral stage

The seral stage (a measure of ecological succession, in this case referring to a conifer-dominated community) of riparian vegetation was used as a surrogate in our models to describe instream habitats. Here, we assume that when riparian areas are predominantly in a mature seral stage, large coniferous trees are abundantly available to be recruited into stream channels to provide large wood that acts as cover and forms pools, as well as to provide shade. At mid and early seral stages, trees are still available, to a lesser degree. In the fish capacity models, mixed coniferous-deciduous forests, and pure deciduous forests are considered equivalent to an early seral coniferous forest.

Although a variable riparian width model would be ideal, in our models, we designated riparian areas as 60m from water's edge on each bank (i.e., 120 m total, not including the watercourse). We classified the proportion of each seral stage class associated with riparian areas for each reach as follows. To translate tree coverage data from IVMP (1996) into seral stage, we based our approach on that described by Lunetta et al. (1997). See also Steel et al. (2007), Appendix I. For this analysis, we calculated seral stage class for each cell (25m pixel, subsampled to 5m) within the riparian zone, and then aggregated values to get proportional area in each seral stage class for each reach. A cell was classified as "late seral stage" if total tree cover ≥ 70% and the proportion of tree cover that is coniferous was ≥ 70% and conifer size was ≥ 22 inches (55.6

cm). A cell was classified as “mid seral stage” if total tree cover was $\geq$ 70% and the proportion of tree cover that is coniferous was $\geq$ 70% and conifer size was $\geq$ 7 inches (17.8 cm). A cell was classified as “early seral stage” if total tree cover was $\geq$ 70% and the proportion of tree cover that is coniferous was $\geq$ 70% but conifer size was $\leq$ 7 inches (17.8 cm). A cell was classified as “deciduous” if total tree cover was $\geq$ 70% and the proportion of tree cover that is deciduous was $\geq$ 40%, irrespective of tree size (the IVMP data category for size refers only to conifers). A cell was classified as “mixed” if total tree cover was $\geq$ 70% and the proportion of tree cover that is coniferous was $\leq$ 70% and the proportion of tree cover that is deciduous was $\leq$ 40%. A cell was classified as “non-forested” if total tree cover was $\leq$ 70%.

These riparian seral stage classifications were then used to predict instream morphology, based on theory proposed by Montgomery et al. (1999). For each reach between 5 and 50m wide and with a channel gradient $\leq$4%, we classified the proportion of the reach that would be in forced pool-riffle morphology (p_1) and the proportion that would be in plane-bed morphology (p_2) (Lunetta et al. 1997). For reaches classified as having predominantly “late seral stage”, p_1 = 1.0 and p_2 = 0.0; for “mid seral stage”, p_1 = 0.78 and p_2 = 0.22; for “early seral stage”, “deciduous”, or “mixed”, p_1 = 0.74 and p_2 = 0.24; and for “non-forested”, p_1 = 0.35 and p_2 = 0.65 (Table 2).

Riparian seral stage was used to further parse the portions of reaches >10m in forced pool-riffle morphology (i.e., p_1) proportionally into pools (p_P) and riffles (p_R) for use in estimates of rearing capacity. We base our estimates on Bartz et al. (2006), Table S8, which summarizes empirical distributions of pool habitat for 40 subwatersheds in the Snohomish watershed (northwestern WA) ranging in size from tributaries to large mainstems. We used a cumulative distribution function of their estimated historical proportion of pools (Figure 2) to approximate expected conditions with functioning riparian areas. We assumed that late seral stage translates to 60% pools (the 90th percentile of historical values from Table S8), mid seral stage translates to 42% pools (the median value in Table S8), and early seral translates to 35% (the smallest value in Table S8). We further assume non-forested areas to have 25% pools. These estimates compare reasonably with Beechie et al. (1994), Table 3, which lists 45-65% pools for Skagit basin streams having channel gradients between 2 and 4%.

Thus, if a reach were 300m long, and in mid seral stage, 222m (=300*0.74) of the reach would be in forced pool-riffle morphology, and 78m (=300*(1-0.74)) would be in plane-bed morphology. The habitats in the reach would consist of 93.2m of pools (=222*0.42), 128.8m of riffles (=222*(1-0.42)), and 78m of glides.

Spawning capacity

We predicted spawning capacity using the general approach described by Holsinger and Pess (2003), Beechie et al. (2006a) and Bartz et al. (2006). We modeled the number of spawners predicted to fit into each reach using stream characteristics derived from remotely-sensed data (channel gradient, bankfull width, and riparian seral stage) and empirically-based estimates of how fish use habitat. Model parameters and sources are listed in Table 2. We then summed these estimates across all reaches within the predicted distribution of spawners.

In brief, steps for calculating spawner capacity were as follows. First, we filtered out reaches with gradients ≥4% or bankfull widths <5m, where spawning is unlikely. Then, we used at least one of the following two equations to estimate the number of spawners in each reach.

For channels ≥25m bankfull width, we estimated the number of spawners (S) as

$$S = a_r\left(\frac{A_w P_{sp}}{A_r}\right) \qquad \text{Eq [1]}$$

where a_r = the number of adults per redd; A_w= wetted area (m^2); P_{sp}= the proportion of area suitable for Chinook spawning; and A_r = redd area (m^2).

For example, on a reach which is 300m long and 60m wide, and has nominal parameter values (Table 2), S = 2.33(300*60*0.062/15.25) = 170 spawners.

For channels <25m bankfull width, we calculated the number of spawners (S) as

$$S = \sum_{rs=1}^{4} a_r l(p_1 f_1 + p_2 f_2) \qquad \text{Eq [2]}$$

where rs = the proportion of the reach in each of the four classes of riparian seral stage (late, early, mid and nonforested); a_r = the number of adults per redd; l = length of the reach (km); p_1 = the proportion of the reach in forced pool-riffle morphology; p_2 = the proportion of the reach in plane-bed morphology; f_1 = redd frequency (redds·km^{-1}) in forced pool-riffle morphology ; and f_2 = redd frequency (redds·km^{-1}) in plane-bed morphology. Note that $p_1 + p_2$ must sum to 1.0, and the proportions in each seral stage class must sum to 1.0.

For example, on a reach which is 300m (0.3km) long, has nominal parameter values (Table 2), and the proportion of riparian areas in late, mid, and early seral stage, and nonforested are 0.2, 0.4, 0.1, and 0.3, respectively, S = (0.2*(0.3*1.0*36.4*15.25) + (0)) + (0.4*(0.3*0.78*36.4*15.25) + (0.3*0.22*1.77*15.25)) + (0.1*(0.3*0.74*36.4*15.25) + (0.3*0.26*1.77*15.25)) + (0.3*(0.3*0.35*36.4*15.25) + (0.3*0.65*1.77*15.25)) = 33 (late seral) + 53 (mid seral) + 13 (early seral) + 19 (nonforested) = 118 spawners.

We reasoned that lower-gradient channels should be more suitable for redd placement. Therefore, in zero-gradient channels, we set p_1 to 1.0, and in channels with gradients of ≥1%, we set p_1 to values determined by riparian seral stage. For channels with gradients between 0 and 1%, we employed a linear transition in p_1, proportional to the channel's actual gradient.

Similarly, so that there was not an abrupt transition between small and large channels at 25m bankfull width, we applied both equations proportionally to reaches between 5 and 25 m wide. For example, if the channel was 13 m wide, then the capacity was estimated as 0.12 * the estimate predicted by Eq. 1 plus 0.88 * the estimate predicted by Eq. 2. Thus, for a 300m long (and 13m wide) reach, and assuming the same proportions of riparian seral stage as above, S = 0.12*37 + 0.88*118 = 108 spawners.

We calculated distributions of predicted values to incorporate uncertainty in underlying assumptions. Point estimates were calculated using fish parameter values set to means from Montgomery et al. (1999); lower bounds came from medians, and upper bounds came from the 90th percentiles (Table 2). Distributions calculated this way address uncertainty in fish parameters, but not in habitat parameters (i.e., the classification of instream morphology from riparian characteristics). We hope to incorporate stochasticity into future iterations of this analysis.

Rearing capacity (subyearlings)

We predicted rearing capacity for subyearlings using the general approach described by Bartz et al. (2006) and Beechie et al. (1994). We modeled the number of juveniles predicted to fit into each reach using stream characteristics derived from remotely-sensed data (channel gradient, bankfull width, and riparian seral stage) and empirical densities of fish in specific habitats. Model parameters and sources are listed in Table 2. We then summed these estimates across all reaches within the predicted distribution of spawners, which we assumed to represent the dominant reaches used for rearing before parr begin to migrate into lower river reaches.

Fish density parameters came from empirical observations Chinook salmon in various freshwater habitat types (Table 3). Datasets come from published studies, grey literature, and raw datasets ranging geographically from southeastern Alaska to mid-coast Oregon and from 1967 to 2008. We limited data to age-0 Chinook salmon observed in tributaries during spring and summer (i.e., April through August), located in watersheds west of the Cascade Mountain divide.

In brief, steps for calculating rearing capacity were as follows. First, we filtered out reaches with gradients ≥4% or bankfull widths <5m, where conditions are unfavorable for rearing. Then, we used at least one of the following two equations to estimate the number of juveniles in each reach.

For channels >50m wide, we estimated the number of subyearlings rearing (R) as follows

$$R = 2.1 W_E l d_E + A_w p_O d_O \qquad \text{Eq [3]}$$

where W_E= width of the edge habitat (from shore); l=length of the reach; d_E = density of juveniles observed in edge habitat along one river bank; A_w= wetted area of reach (m^2); p_O= the proportional area of off-channel habitat to mainstem habitat; d_O = density of juveniles in off-channel habitats. The width of edge habitat is multiplied by 2 to account for both banks, and by 0.1 to account for mid-channel habitat (Beechie et al. 2005; T. Beechie, p*ersonal communication*).

For channels ≤ 50m wide, we estimated the number of subyearlings rearing (R) as follows

$$R = \sum_{rs=1}^{4} (A_w(p_P d_P + p_R d_R + p_G d_G) + A_w p_O d_O) \quad \text{Eq [4]}$$

where rs = the proportion of the reach in each of the four classes of riparian seral stage (late, early, mid and nonforested); A_w= wetted area of reach (m^2); p_P= the proportion of pools in the reach; p_R= the proportion of riffles in the reach; p_G= the proportion of glides in the reach; p_O= the proportional area of off-channel habitat to mainstem habitat; d_P = density of juveniles observed in pools; d_R = density of juveniles observed in riffles; d_G = density of juveniles observed in glides; d_O = density of juveniles observed in off-channel habitat. Note that the 4 classes of rs must sum to 1.0, and that $p_P + p_R + p_G$ must sum to 1.0; off-channel habitat is additional.

For reaches 10-50m wide, the proportion of pools, riffles, and glides are derived as discussed in the Riparian Seral Stage section above. For reaches 5-10m wide, we assumed pools and riffles to occur in equal proportions within the forced pool-riffle morphology. Habitat-specific densities were calculated separately for tributaries 5-10 m wide and for small mainstems 10-50 m wide.

Our estimates of available off-channel habitat deserve further discussion. Here, we assumed that tributary channels <15 m have zero off-channel habitat, channels 15-50m wide can have side channels, and large rivers >50m can have both side channels and pond habitat in their floodplain (Beechie et al. 2006b). The parameter describing the proportion of side channel to main channel (current = 0.15 and historical = 0.5) was based on aerial photo analysis in the East Fork Lewis River (M. Sheer, *personal communication*) and from Holsinger and Pess (2003). The parameter describing the proportion of pond habitat associated with large rivers (current = 0.02 and historical = 0.1) was an educated guess. Off-channel habitat was assumed to occur only when the floodplain was wide enough, i.e., if valley width was 4 times greater than the channel width (Beechie et al. 2006b).

As with spawning capacity, we applied both equations proportionally to the channel width for reaches between 5 and 50 m wide. For example, if the channel was 35 m wide, then the capacity was estimated as 0.7 * the estimate predicted by Eq. 3, plus 0.3 * the estimate predicted by Eq. 4.

We estimated uncertainty by using 75th percentile values for point estimates, and median and maximum values for lower and upper confidence limits. We suggest that an improvement on this approach (given enough data) would be to estimate parameter distributions with a Monte Carlo approach, randomly drawing densities from the top quartile of the distribution of empirical densities for each of 1000 iterations. Note that although similar in design to the spawner capacity model, this model may under-predict true “ceiling-type” capacity for juveniles because it is based on observed densities that may be influenced by degraded conditions currently present. Using only empirical observations from watersheds where conditions are believed to be relatively pristine, if available, might be a way to counter this.

Egg-to-fry survival

Two factors likely strongly influence egg-to-fry survival for tule Chinook salmon: (1) fine sediment in the spawning gravels, and (2) peak flow. Fine sediment limits oxygenation of eggs in redds and impedes emergence. Peak flow can scour redds if eggs are not buried deeply enough

(Montgomery et al. 1999). For simplicity, our model of survival was based only on the influence of fine sediment. However, we recognize that high flows can have a profound impact on year-to-year survival (Beamer and Pess 1999). Peak flow could be especially important for tules. For instance, Rawding et al. (2009b) found that in 2006, survivals in the Gemany/Abernathy/Mill Creeks basin were much lower than in other years (<3% vs. an average of 21% for non-flood years). Thus, in future iterations of this analysis, we feel that it is essential to include some measure of peak flow.

We modeled egg-to-fry survival for the Lewis River population. At this time, we were unable to extend this analysis to other populations because (1) we were unable to predict spatially-explicit total sediment input by grain size class in other basins, and (2) empirical estimates of reach-level % fine sediment in the substrate were unavailable for other basins. The former would be necessary for identifying what proportion of sediment input was fine, and the latter would be necessary to relate routed (i.e., transported and deposited) fine sediment predictions to basin-specific observed fines. **Therefore, for these analyses, we assumed that the egg-to-fry survival predictions from the Lewis were applicable to other populations. These estimates matched well with estimates derived from empirical data for the Coweeman River and Mill/Abernathy/Germany Creeks (see Rawding et al. 2009b, and our Results & Discussion).**

We modeled egg-to-fry survival for the Lewis River in a two-step process. First, we predicted the amount of fine sediment in each spawnable reach, and then we estimated how likely eggs would be to tolerate that level of fine sediment. The first step involved estimating the amount of sediment entering each reach from both laterally-adjacent hillslopes and from upstream reaches. Our estimates of sediment yield were generated from surface erosion and sediment inputs related to roads. We generated these estimates using a modified Water Erosion Prediction Procedure (WEPP; Flanagan and Livingston 1995; Elliott and Hall 1997). The approach is described fully in Steel et al. 2007, Appendix E. We then routed a portion of the sediment from each reach downstream to the next reach, based on an inverse distance-weighted function, to predict transport and deposition. Finally, we calibrated these values with empirical estimates from the Lewis River basin (Steel et al. 2007, Appendix F).

In the second step, we applied the relationship developed by Jensen et al. 2009 (Figure 3) to predict Chinook salmon egg-to-fry survival from fine sediment (<1mm) deposited in each reach. Their approach was to use logistic regression in a meta-analysis of published studies. See also Steel et al. 2007, Appendix K. Our predictions of egg-to-fry survival for each reach included 95% confidence intervals (see Jensen et al. 2009).

For other populations, we provide surface sediment yields expected under current conditions as a qualitative means of assessing whether egg-to-fry survival is likely to be higher or lower in other populations, as compared to the Lewis.

Scenarios

We evaluated several scenarios to predict how changes in the landscape might influence instream habitat conditions and fish responses. Here, we briefly describe each scenario evaluated.

Scenario-planning (Petersen et al. 2003) is a tool that is gaining widespread use. This approach has the potential to help managers understand uncertainty when quantitative estimates of uncertainty are infeasible.

Current

We described, to the best of our ability, the conditions currently present on the landscape (see Table 1), and used these conditions as inputs for modeling spawning capacity, egg-to-fry survival, and subyearling rearing capacity.

Historical

For historical conditions, we made the simple assumption that no roads or anthropogenic instream barriers existed, and that off-channel habitat was present in the proportions at which we observed channel remnants in aerial photos (50% off-channel to mainstem channel area; estimated from M. Sheer, unpublished data in the East Fork Lewis River, and from Holsinger and Pess 2003). Further, we assumed that riparian vegetation was as good as it could be (i.e., everything was set to 100% late seral stage) where it was possible for trees to exist (i.e., not naturally bare, or in shrub or grass vegetation). We used these modified landscape and stream habitat conditions as inputs for modeling spawning capacity, egg-to-fry survival, and subyearling rearing capacity. We recognize that this is a simplification, yet it provides us with a benchmark for targeting what level of restoration is even possible. Table 4 illustrates our specific assumptions.

In the past, fish could likely access habitats above and below the endpoints of the spatial distributions over which we summarized results (Rawding et al. 2009a). However, for simplicity, we used the current distributions to directly compare what could be accomplished on the reaches that fish can access today. This assumption produces a conservative estimate of historical capacities and survivals.

Recovery scenario

Recovery plans for Lower Columbia populations in both WA (LCFRB 2004) and OR (ODFW 2009) suggest the types of restoration (e.g., riparian planting, road decommissioning, barrier removal, etc.) that will likely best address the identified factors that limit salmon production. They also suggest generalized priority locations at which conditions need to be improved. Yet because the final decisions about what types of projects to implement and where to locate them depend on many unknowable factors such as landowner willingness, funding availability, etc., it will be necessary that field surveys be conducted to identify and prioritize a final list of projects. Thus, the recovery plans could not have identified a reach-level plan of action; in fact, they specifically intended the process to be a community-based ground-up effort.

Thus, there are infinite ways in which the recovery plans as written could be implemented. We provide one possibility in order to (1) estimate possible parameter distributions of spawning capacity, egg-to-fry survival, and rearing capacity as inputs to SLAM, (2) to broadly evaluate the level of improvement possible if the suggested habitat restoration actions were implemented and whether these actions are likely to cause targeted improvements in viability, and (3) to evaluate how long it might take to see ecological benefits to restoration actions. This endeavor could be a project of much larger scope; here we simply attempt to take a first step in the right direction. We hope that future iterations of this analysis will include many more possible interpretations of the recovery plans.

For this analysis, we attempted to translate the restoration actions on priority locations from the recovery plans into modeling scenarios for each of the tule populations (except Hood River, which only included actions associated with instream flow that we could not model and a nebulous “basinwide” riparian restoration). We provide a description of the translation approach we implemented in Appendix B, and reproductions of relevant excerpts from the recovery plans for each population in Appendix C. In Appendix D, we provide tables for each population indicating exactly which reaches were identified as priorities for each type of restoration that we could model (first set of columns). To illustrate how actions are spatially distributed, Figure 4 presents actions modeled for the Elochoman population.We hope that by being transparent in our approach and assumptions, that management decisions will be made with the appropriate amount of caution.

Modeling Actions

We could not model every type of action suggested by recovery plans. For example, we could not model actions associated with instream flow, temperature, or dam operations. For actions that we could model (riparian planting or protection, floodplain reconnection, road decommissioning, barrier removal, upland reforestation, or instream placements), we improved the habitat conditions as described in Table 5, and then re-ran the fish models to predict spawning capacity, egg-to-fry survival, and rearing capacity under those altered conditions. Two opposing assumptions make it difficult to assess whether our predictions were conservative or liberal. First, we assumed 100% effectiveness of restoration actions (i.e., that what was implemented was done so perfectly), and that the entire reach selected was treated (even if only a portion of it would have been treated in the real world). This would suggest that our results might be overly optimistic. However, there were many suggested actions in the recovery plans that we could not model, such as effects of instream flow modifications. These omissions might suggest that our results are conservative. Moreover, the actions we modeled perfectly and the actions we could not model at all likely have different effects on habitat and fish.

Time lags

To understand when the benefits of freshwater habitat restoration might be expected, we constructed our restoration scenarios through time. We describe in detail how we modeled time lags in Appendix E. In brief, for each type of restoration we modeled, we considered both implemetation lags (i.e., the time it takes to plan, design, fund, and actually do projects) and ecological lags (i.e., the time from project inception to the time in which fish respond to changes in habitat caused by projects). The sum of these delays equaled the total lag. We used the total lag to allocate restoration projects in each recovery scenario into 4 time steps: <5 years, 5-25 years, 25-50 years, and >50 years. In Appendix D, we provide the final tables showing how scenarios were implemented through time on a reach-level basis for each population (second set of columns).

NetMap

The models and datasets described above will be made publicly available to users at www.netmaptools.org. NetMap's user interfaces and dialog boxes allow users to modify model parameters, to provide alternate data sources, and to design scenarios as they see fit. Thus, users should be able to both reanalyze data as we have described here, to develop and test alternative scenarios, and to build on this approach as better data and models become available. In the future, we plan to conduct sensitivity analyses on model parameters to evaluate prediction uncertainty.

Results & Discussion

Population-specific spawning and rearing capacity predictions are provided in Table 6. In general, populations showed an improvement through time in spawning capacity (Figure 5) and in rearing capacity (Figure 6). To emphasize the degree of uncertainty associated with these predictions, we illustrate the prediction limits for the East Fork Lewis in Figure 7; this pattern is typical of other populations. Note that actual capacity in the Toutle River is likely much lower (perhaps half or less) than what the model predicts, due to the high suspended sediment levels and turbidity caused by Mt. St. Helens. Egg-to-fry survival predictions for the Lewis River are provided in Figure 8. For comparison, targeted abundance and productivity in tributaries from recovery plans are provided in Table 7. Our predicted spawner capacities exceed targeted recovery abundances for spawners, suggesting that spawning habitat should not be limiting, if adequately restored.

We compared our spawning and rearing capacity predictions with those made by the Ecosystem Diagnosis and Treatment (EDT) model for 5 populations in Washington for which registered results were available. Our analysis predicted potential improvement under recovery scenarios through time in addition to current and historical estimates, but results from EDT were only available for historical, current without harvest, and current with harvest scenarios. Thus, we limited our comparison to current without harvest (similar to our "current" scenario) and historical estimates. Our predictions matched reasonably well with those from EDT, especially for the Elochoman population (Table 8). For 3 of the 5 populations, our anlaysis predicted higher spawning capacity than did EDT. Conversely, predictions for rearing capacity by EDT were most similar to our upper confidence limit predictions, which used maximum densities of juveniles observed in the field. In only two cases (EF Lewis and Washougal) did our maximum estimates exceed rearing capacities predicted by EDT. This estimate approximates a "ceiling-type" capacity better than our point estimates, which use 75th percentile values of observed densities. There are several important things to keep in mind when considering comparisons between our analyses and the EDT analyses. First, EDT outputs are from a life cycle analysis, and may be influenced or constrained by factors (e.g., ocean survival) that do not affect our estimates, which are entirely habitat-based. Related, our "capacities" are meant to represent the amount of fish that could fit into the stream, given habitat conditions influenced by our model (i.e., riparian conditions and intrinsic stream characteristics), whereas EDT's "capacities" may better reflect actual numbers of fish expected, which are influenced by other features of their life cycle analysis. Second, EDT included factors such as instream flow, temperature, bed scour, turbidity, and food resources, which we did not model. Third, our juvenile capacity estimates were for non-tidal tributary habitat, whereas EDT included reaches below those used in our analysis (estuary and mainstem Columbia area).

Our predictions for egg-to-fry survival in the Lewis River (Figure 8) matched well with observations for Coweeman and Mill/Abernathy/Germany populations (Rawding et al. 2009b). We predicted survival in the East Fork alone to be 15.5%, and in the East Fork and Cedar Creek combined to be 21.2% under current conditions. Rawding et al. suggested based on empirical data in the Coweeman River, and in Mill, Abernathy, and Germany Creeks, that mean egg-to-fry survival was 17.5% during several recent years. If data from 2006, a year in which flood magnitudes were twice as high as other years, were excluded, mean survival increased to 21.3%. Survival during 2006 was less than 3%, suggesting that scouring flow has significant potential to decrease survival at this life stage. Please see their report for a description of their analysis approach and assumptions.

Figure 9 shows predicted surface erosion inputs for each population, contributed both locally and from more distant sources in the basin. Note that these predictions are for current conditions only, and do not reflect possible contributions from roads or mass wasting sources. These values should be used only for relative comparisons among the basins for ranking possible effects on egg-to-fry survival. They have not been field-verified, and therefore absolute magnitudes should be considered carefully.

Assumptions & Limitations

Here, we outline specific assumptions that went into our analyses which could affect accuracy of predictions, and limitations to our approach. Modeled results should be interpreted with the appropriate amount of caution.

We made the following assumptions:

1. Predicted spawning distributions were reasonably representative of the spatial extents used by spawners, eggs, fry, and juveniles in freshwater rearing habitats.
2. Spawning distributions predicted by Rawding et al. using parameters from their 2007 version of the model were similar to distributions predicted using their 2009 version. See Appendix A for maps showing these comparisons.
3. The threshold value of 0.5 in the spawning distribution model that we applied to create spawning distribution maps was representative of the spatial extent of spawning in a typical year (see Appendix A for a basic sensitivity analysis and Rawding et al. 2009a for an example of annual variation in the upper extent of observed spawning for the Mill/Abernathy/Germany population).
4. Stream and riparian vegetation characteristics derived from geospatial data are reasonably representative of real streams, though they have not been field-verified.
5. Model-specific assumptions (described in the text):
    a. Riparian areas can be represented as the area 60m laterally from each stream bank
    b. Seral stage is related to tree cover and conifer size.
    c. Instream morphology classes (i.e., proportion pools, riffles, and glides) are related to riparian seral stage and channel width and gradient.

    d. Estimated parameters describing off-channel habitat availability and usability are reasonable.
    e. Spawning capacity is related to parameters describing how many redds could fit into a given area, observed spawner density, and habitat suitability.
    f. Rearing capacity is related to fish density observed in each type of habitat.
    g. Egg-to-fry Survival is directly related to the amount of fine sediment in the substrate where spawning occurs.
6. Our approach to calculating prediction intervals reasonably captures parameter uncertainty.
7. Modeled restoration actions were 100% effective. In other words, what was modeled was implemented perfectly and with perfect response from fish.
8. Modeled restoration actions were effective over the entire length of a selected reach (even if only a portion of it would have been treated in the real world).
9. Estimated improvements used to predict "restored" and "Historical" conditions were reasonable. For example, reconnected floodplains were improved by increasing channel length by 40% and 50%, respectively.
10. Our interpretations of restoration actions noted in recovery plans are one reasonable interpretation of the types of actions and locations called for.
11. Time lag distributions modeled are within reasonable expectations of how long it might take to see fish responses to freshwater habitat restoration.

We note the following limitations:

1. We could not model every type of action suggested by recovery plans. For example, we could not model actions associated with instream flow, temperature, or dam operations.
2. Egg-to-fry survival is likely affected by scouring flows; this was not captured in our model.
3. We could not model egg-to-fry survival for basins other than the Lewis at this time. SLAM analyses assumed that egg-to-fry survival predictions from the Lewis can be applied to other populations (this is a big assumption but predictions do match reasonably well with empirical data from other populations – see Rawding et al. report).
4. The "Historical" scenario was modeled over the spatial extent representing current spawning distributions. Fish were likely able to access much more habitat before human alterations to the system. Thus, true historical capacities and survivals might have been much higher.

Next steps, Future analyses, and Application

In the near-term future (next several months), we plan to:

(1) Make all datasets and tools used in this analysis available publicly via NetMap.

(2) Produce maps of sediment production to help inform where egg-to-fry survival is likely to be higher or lower than predicted for the Lewis population.

(3) Make comparisons of how our predictions relate to: (1) estimates discussed in recovery plans (see especially the capacity and survival parameters used in SLAM models in the Oregon recovery plan), (2) estimates by Jeff Rodgers et al. for Oregon populations of the amount of stream habitat that needs to be restored to see target improvements, and (3) estimated amount of various types of habitat rehabilitation are necessary before improvements in fish responses are perceivable (Roni et al., in prep).

We hope to further improve on these analyses in future iterations by:

(1) Incorporating peak flow into predictions of egg-to-fry survival.

(2) Conduct sensitivity analysis of results to model parameters.

(3) Validate model predictions with empirical data to the extent possible.

(4) Construct multiple interpretations of recovery plans to see how predicted fish responses might differ under alternative assumptions, including those we made about how long such actions would take before effects are observed. Such analyses should help practitioners and managers decide how best to implement the suites of freshwater restoration actions called for in recovery plans.

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Table 1. Geospatial data used in spatially-explicit models estimating tributary habitat life stage parameters. Note that each of these inputs is itself generated from models. These datasets and their metadata for the 9 tule populations will be publicly available at www.netmaptools.org.

Data	Description	Source	Used in which fish model
Stream characteristics	Physical location and characteristics of each stream reach such as length, gradient, channel width, depth, and valley width derived from 10-m digital elevation model	Miller 2003	All models
Fish distributions	Spatial extent of spawning for each population, calculated from logistic regressions of empirical observations, and documented natural and anthropogenic barriers	Rawding et al. 2009(a)	All models
Riparian seral stage	Proportional coverage of coniferous, broadleaf, and tree diameter, classified into seral stage composition for each reach (late-, mid-, and early-coniferous; deciduous; mixed; and non-forested)	IVMP 1996; Lunetta et al. 1997	All models
Fine sediment in spawning gravels	Estimated fine sediment deposition (<1mm) supplied from surface & road erosion and mass wasting on adjacent hillslopes and supplied from upstream, and routed through streams; calibrated with empirical fines in the Lewis River.	Steel et al. 2007 Appendices E&F; Elliot and Hall 1997; Flanagan and Livingston 1995; Lane et al. 1997	Egg-to-fry survival only

Table 2. Parameters used in the spawning and rearing capacity models (those shown are for current conditions). Value = parameters used to predict point estimates; LCI and UCI are parameters for lower and upper confidence intervals, respectively. Abbreviations are as follows: tr = tributary; sm = small mainstems; ls = late seral stage riparian; ms = mid seral stage; es = early seral stage; nf = non-forested riparian; sc = secondary channels; le = lentic habitats; <C> = calculated as described in the text (see Table 1).

Parameter	Case	Value	LCI	UCI	Description	Source or Theory
a_r		2.33	1.9	3.5	mean number of adults per redd	Montgomery et al. 1999
A_r		15.25	15.25	15.25	mean redd area (m^2)	Montgomery et al. 1999
A_w		<C>	<C>	<C>	wetted area (m^2), calculated here as bankfull width (m) x reach length (m)	Derived from DEM
d_E		0.789	0.450	1.830	density of juveniles observed in edge habitat along one river bank	See Table 3
d_G	tr	0.062	0.046	0.297	density of juveniles observed in glides (tributaries)	See Table 3
	sm	0.015	0.010	0.047	density of juveniles observed in glides (small mainstems)	See Table 3
d_O	sc	0.018	0.008	0.075	density of juveniles in secondary channels	See Table 3
	le	0.031	0.028	0.065	density of juveniles in lacustrine off-channel habitats (i.e., ponds)	See Table 3
d_P	tr	0.160	0.083	0.927	density of juveniles observed in pools (tributaries)	See Table 3
	sm	0.213	0.100	1.640	density of juveniles observed in pools (small mainstems)	See Table 3
d_R	tr	0.011	0.005	0.123	density of juveniles observed in riffles (tributaries)	See Table 3
	sm	0.011	0.006	0.032	density of juveniles observed in riffles (small mainstems)	See Table 3
f_1		36.4	6.1	54.3	mean redd frequency ($redds \cdot km^{-1}$) in forced pool-riffle morphology	Montgomery et al. 1999
f_2		1.77	0	6.0	mean redd frequency ($redds \cdot km^{-1}$) in plane-bed morphology	Montgomery et al. 1999
l		<C>	<C>	<C>	length of the reach (km)	Derived from DEM
p_1	ls	1.0	1.0	1.0	the proportion of the reach in forced pool-riffle morphology	Lunetta et al.1997
	ms	0.78	0.78	0.78	the proportion of the reach in forced pool-riffle morphology	Lunetta et al.1997
	es	0.74	0.74	0.74	the proportion of the reach in forced pool-riffle morphology	Lunetta et al.1997
	nf	0.35	0.35	0.35	the proportion of the reach in forced pool-riffle morphology	Lunetta et al.1997
p_G		$= p_2$			the proportion of glides in the reach	Lunetta et al.1997
p_O	sc	0.15	0.15	0.15	the proportional area of off-channel habitat to mainstem habitat	M. Sheer, *unpubl. data*; Holsinger & Pess 2003
	le	0.02	0.02	0.02	the proportional area of off-channel habitat to mainstem habitat	Educated guess
p_P	ls	0.6	0.6	0.6	the proportion of pools in the reach	Bartz et al. 2006, Table S8
	ms	0.42	0.42	0.42	the proportion of pools in the reach	Bartz et al. 2006, Table S8
	es	0.35	0.35	0.35	the proportion of pools in the reach	Bartz et al. 2006, Table S8
	nf	0.25	0.25	0.25	the proportion of pools in the reach	Bartz et al. 2006, Table S8
p_2		$= (1 - p_1)$			the proportion of the reach in plane-bed morphology	Lunetta et al.1997
p_R		$= (1 - p_P)$			the proportion of riffles in the reach	Bartz et al. 2006, Table S8
rs		<C>	<C>	<C>	the proportion of the reach in each of the four classes of riparian seral stage (late, early, mid and nonforested)	Derived from IVMP; Lunetta et al.1997
P_{sp}		0.062	0.062	0.062	proportion of area suitable for Chinook spawning	Holsinger and Pess 2003
W_E		5	5	5	width of the edge habitat (from shore), per bank; edge units assumed to be between 0.5 and 0.75 m deep, on average	T. Beechie, *pers. comm.* Beechie et al. 2005

Table 3. Habitat-specific densities of age-0 Chinook salmon observed during spring or summer months (April-August). Summary statistics (mean, standard deviation, min, and max) were calculated from study means to give equal weight to studies containing different numbers of individual data points. Using the mean and standard deviation, we estimated the median, 75th and 95th percentiles of a lognormal distribution (lognormal because there are often many zeroes in fish count data)*.

	Tributary (5-10m)			Sm Mainstem (10-50m)			Lg Main (>50m)	Off-channel	
	Pool	Glide	Riffle	Pool	Glide	Riffle	Bank	Pond	Side
No. studies	5	3	4	5	3	4	6	2	4
Sources	1 - 5	2,4,5	2 - 5	2,3,5-7	2,5,7	2,3,5,7	6,8-11,14	7,8,13,14	10,13
Mean	0.134	0.051	0.010	0.189	0.012	0.009	0.634	0.028	0.016
Std dev	0.172	0.025	0.016	0.300	0.008	0.010	0.624	0.005	0.025
Min	0	0	0	0	0	0	0.05	0	0
Max	0.927	0.297	0.123	1.640	0.047	0.032	1.830	0.065	0.075
Median	0.083	0.046	0.005	0.100	0.010	0.006	0.450	0.028	0.008
75th %ile	0.160	0.062	0.011	0.213	0.015	0.011	0.789	0.031	0.018
95th %ile	0.419	0.099	0.034	0.633	0.027	0.026	1.120	0.037	0.054

No.	Source	Location	Year(s)
1	Burnett 2001	Elk River, OR	1988-94
2	Roper et al. 1994	S Umpqua River, OR	1989
3	Scarnecchia & Roper 2000	S Umpqua River, OR	1995
4	Tabor et al. 2006	Trib to Lake Washington, WA	2003-4
5	Murray & Rosenau 1989	Lower Fraser River, BC	1980
6	Johnson et al. 1992	Situk River, AK	1989
7	Peter Kiffney, NOAA, unpublished data	Cedar River, WA	2007-8
8	George Pess, NOAA, unpublished data	Elwha River, WA	2005
9	Beechie et al. 2005	Skagit River, WA	1995-6
10	Hayman et al. 1996	Skagit River, WA	1995
11	Beamer & Henderson 1998	Skagit River, WA	1996
12	Lister & Genoe 1970	Big Qualicum River, BC	1967
13	Murphy et al. 1989	Taku & Situk Rivers, AK	1986
14	Swales & Levings 1989	Fraser River, BC	1985

*Code in R (Cran), version 2.7.1:

```
MU <- 0.134 #(a habitat-specific mean, in this case tributary pools)
SD <- 0.172  #(standard deviation for above)
v <- log(1+(SD/MU)^2)
m <- log(MU) - 0.5*v
x <- rlnorm(100000,m,sqrt(v))
quantile(x)
quantile(x,0.95)
```

Table 4. Components altered to model the historical scenario. We based our approach on that described in Steel et al. (2007), Appendix D. Actions affected all reaches within the tule spawning distributions.

Data Layer	How we modeled it	Fish models influenced
Riparian vegetation	Increased by 50%, 40%, 30%, 20%, and 10% in each of 5 successive time steps to 100 yrs; then evenly divided the proportion allocated to early seral between early and nonforested	All
Barriers	Removed all anthropogenic barriers*	All
Sinuosity	Increased by 10% per each of 5 successive time steps to 100 yrs or to max of 2.0; where qualified	All
Off-channel habitat	Increased ratio to 20% for qualifying reaches	Rearing Capacity
Side-channel habitat	Increased ratio to 50% for qualifying reaches	Rearing Capacity
Upland vegetation	Increased by 50%, 40%, 30%, 20%, and 10% in each of 5 successive time steps to 100 yrs	Egg-to-fry Survival
Roads	Removed all roads	Egg-to-fry Survival

* Note that there were no barriers in any of the Washington populations that affected the distribution of tule Chinook. Whether barriers influence tule distributions in Oregon is still being evaluated. As well, because we modeled capacity using the “current extent” for spawning distributions, potential capacity may have been significantly larger in the past.

Table 5. Restoration actions modeled (each acted on individual selected reaches). We based our approach on that described in Steel et al. (2007), Appendix D. Actions affected only reaches selected for that particular type of restoration, and only those reaches within the tule spawning distributions. BFW=bankfull width; RearCapac = rearing capacity.

Action type	How we modeled it	Fish models influenced
Riparian planting*	Improved riparian conditions by increasing total tree cover by 50% in existing proportions of seral stage class; if tree cover reached 100%, moved toward conifer-dominance by adjusting each seral class by 50%	All
Riparian protection*	Improved riparian conditions by increasing total tree cover by 20% in existing proportions of seral stage class; if tree cover reached 100%, moved toward conifer-dominance by adjusting each seral class by 20%	All
Upland reforestation*	Improved upland conditions by increasing total tree cover by 20% in existing proportions of seral stage class; if tree cover reached 100%, moved toward conifer-dominance by adjusting each seral class by 20%	Egg-to-fry survival
Decommission roads	Removed 95% of road length in the area draining laterally to a reach (both banks)	Egg-to-fry survival
Floodplain reconnection†	1. Increased sinuosity by 10% to max of 1.6 (BFW>15m) 2. Increased side channel habitat by 40% (BFW>15m) 3. Increased off channel habitat by 10% (BFW>25m)	All RearCapac RearCapac
Barrier removal‡	Allowed fish passage (limited by upstream gradient or next natural or anthropogenic barrier)	All
Instream placements	Increased final capacity estimates by 10%	Both capacities

* only applied to areas capable of supporting trees (i.e., not naturally rock, shrub, or grass); in this analysis, developed areas were not excluded, thus an existing urban area could be converted to forested conditions.

† only applied to reaches where the channel width was <4 times the valley width.

‡ Note that there were no barriers in any of the Washington populations that affected the distribution of tule Chinook. Whether barriers influence tule distributions in Oregon is still being evaluated.

Table 6. Population-specific spawning and rearing capacity predictions for current conditions and recovery scenarios.

		Spawning Capacity			Rearing Capacity			
Population		Lower	Point	Upper	median	75th %ile	95th %ile	max
Coweeman	Current	4,763	7,162	12,005	51,550	95,810	196,930	420,356
	<5 yrs	4,785	7,197	12,064	51,785	96,250	197,875	422,407
	5-25 yrs	4,902	7,379	12,371	53,351	99,298	204,988	438,064
	25-50 yrs	4,928	7,426	12,455	54,188	101,056	209,926	449,870
	50-100 yrs	4,935	7,520	12,665	56,316	105,853	224,842	488,800
	Maximum	5,465	8,367	14,133	70,402	134,904	303,382	675,906
Clatskanie	Current	1,000	1,612	2,800	9,855	18,577	41,534	90,054
	<5 yrs	1,020	1,644	2,856	10,052	18,946	42,346	91,798
	5-25 yrs	1,135	1,830	3,174	11,413	21,581	48,588	104,168
	25-50 yrs	1,183	1,910	3,314	12,254	23,279	52,990	112,015
	50-100 yrs	1,183	1,910	3,314	12,254	23,279	52,990	112,015
	Maximum	1,383	2,316	4,057	18,225	35,908	88,983	199,736
Elochoman	Current	2,557	5,874	11,421	31,560	57,805	126,463	281,054
	<5 yrs	2,580	5,908	11,476	31,801	58,248	127,334	282,839
	5-25 yrs	2,718	6,102	11,806	33,572	61,664	135,095	299,200
	25-50 yrs	2,771	6,194	11,953	34,894	64,397	142,427	315,564
	50-100 yrs	2,783	6,250	12,074	36,064	67,031	150,649	336,949
	Maximum	3,441	7,525	14,393	51,840	100,300	242,574	554,165
Hood	Current	8,904	11,057	16,749	97,127	173,860	288,287	533,020
	<5 yrs	-	-	-	-	-	-	-
	5-25 yrs	-	-	-	-	-	-	-
	25-50 yrs	-	-	-	-	-	-	-
	50-100 yrs	-	-	-	-	-	-	-
	Maximum	11,018	13,755	20,898	130,850	237,599	426,044	821,288
EF Lewis	Current	7,083	9,402	14,760	85,000	151,579	249,548	462,261
	<5 yrs	7,218	9,568	15,009	86,575	154,390	254,095	470,520
	5-25 yrs	7,876	10,378	16,227	95,220	169,898	281,034	518,876
	25-50 yrs				99,660			

		8,114	10,670	16,666		178,003	297,517	548,785
	50-100 yrs	8,114	10,671	16,669	101,304	181,670	308,865	578,468
	Maximum	8,755	11,544	18,092	115,092	207,758	368,091	705,791
MAG	Current	496	1,830	4,029	8,936	17,202	45,848	109,509
	<5 yrs	501	1,846	4,063	9,014	17,353	46,251	110,469
	5-25 yrs	520	1,921	4,231	9,459	18,248	48,769	116,670
	25-50 yrs	526	1,958	4,308	9,784	18,979	51,042	122,620
	50-100 yrs	539	2,066	4,540	10,783	21,230	58,016	140,829
	Maximum	561	2,314	5,064	13,772	28,009	79,342	196,994

Recovery Scenarios		Spawning Capacity Lower	Point	Upper	Rearing Capacity median	75th %ile	95th %ile	max
Scappoose	Current	258	652	1,325	2,691	5,124	13,165	30,324
	<5 yrs	260	659	1,340	2,724	5,187	13,334	30,724
	5-25 yrs	270	690	1,406	2,894	5,525	14,251	32,822
	25-50 yrs	273	695	1,414	2,960	5,666	14,670	33,771
	50-100 yrs	273	695	1,416	3,083	5,941	15,521	35,997
	Maximum	310	856	1,726	5,292	10,820	30,339	73,637
Toutle	Current	37,118	47,682	73,823	404,375	721,220	1,183,515	2,176,099
	<5 yrs	37,412	48,047	74,376	407,403	726,597	1,192,150	2,191,603
	5-25 yrs	38,812	49,792	77,015	423,470	755,360	1,240,949	2,280,300
	25-50 yrs	39,016	50,057	77,429	427,838	763,895	1,261,267	2,323,489
	50-100 yrs	39,028	50,105	77,552	432,059	773,370	1,290,657	2,400,219
	Maximum	43,650	56,424	87,618	525,033	952,998	1,714,644	3,332,875
Washougal	Current	8,165	10,576	16,447	89,324	162,856	297,205	590,861
	<5 yrs	8,222	10,646	16,552	89,924	163,929	298,970	594,109
	5-25 yrs	8,502	10,993	17,073	93,361	170,094	309,763	613,549
	25-50 yrs	8,574	11,082	17,210	94,827	172,824	315,664	624,671
	50-100 yrs	8,574	11,083	17,211	95,609	174,574	321,080	638,845
	Maximum	9,781	12,749	19,816	127,041	237,745	482,884	1,020,597

Table 7. Biological objectives/targets for adult abundance and productivity improvements (reductions in mortality) in tributaries, from recovery plans (LCFRB 2004; ODFW 2009).

Population	Current adult abundance [1]	Target adult abundance [2]	Productivity improvement (tributaries) [3]
Washington:			
East Fork Lewis	100-700	1,900-3,900	0.53
Washougal	2,000-4,500	5,800	0.47
Coweeman	100-2,100	3,000-4,100	0.44
Toutle	300-5,000	1,000	0.56
Mill/Abernathy/Germany	300-4,000	250-2,000	0.56
Elochoman/Skamokawa	100-2,300	1,400	0.34
Oregon:			
Clatskanie	41	634-1,441	0.20
Scappoose	35	620-1,456	0.02
Hood	26	730-1,507	0.87 [4]

[1] WA: from Table 10 (EF Lewis, Washougal, Coweeman, Toutle, Table 11 (MAG), or Table 12 (Elochoman). OR: wild abundance (1990-2004), from Table 4-8 of Dec09 draft.
[2] WA: from Table 10 (EF Lewis, Washougal, Coweeman, Toutle, Table 11 (MAG), or Table 12 (Elochoman). OR: range is for revised abundance to achieve moderate to very low risk categories, from Table 6-2 of Dec 09 draft.
[3] WA: "Trib. Baseline impacts" from Table 11 (EF Lewis, Washougal, Coweeman, Toutle, Table 12 (MAG), or Table 13 (Elochoman). OR: current tributary mortality minus target tributary mortality. from Apr 09 draft; see also Tables 6-15, 6-16, and 6-21 from the Dec 09 draft.
[4] limited habitat available for restoration unless Powerdal Dam removed; estimated maximum.

Table 8. Capacity estimates produced by the Ecosystem Diagnosis and Treatment (EDT) model and those produced by our analysis (this study). EDT results are the latest registered results run with the following assumptions: (1) fecundity similar to this project, (2) 90% spring migrants (fry) and 10% transient (subyearling), and (3) outmigrant survival ~ 1%. Note that EDT juvenile capacity was calculated for reaches below those used in our analysis (i.e., reaches that overlap with those used in analyses to estimate capacity by T. Cooney and D. Holzer, for lower river and estuarine habitats).

		EDT	EDT	Spawning capacity (this study)			Rearing capacity (this study)		
Population	Scenario	Adult Capacity	Juvenile Capacity	Lower CI	Point Estimate	Upper CI	Lower CI	Point Estimate	Upper CI
Coweeman	Current w/out harvest	2,376	289,726	4,763	7,162	12,005	51,550	95,810	420,356
	Historic potential	3,582	417,392	5,465	8,367	14,133	70,402	134,904	675,906
Mill/Abernathy /Germany	Current w/out harvest	612	185,883	496	1,830	4,029	8,936	17,202	109,509
	Historic potential	936	263,103	561	2,314	5,064	13,772	28,009	196,994
EastFork Lewis	Current w/out harvest	2,136	296,809	7,083	9,402	14,760	85,000	151,579	462,261
	Historic potential	3,530	468,968	8,755	11,544	18,092	115,092	207,758	705,791
Washougal	Current w/out harvest	2,313	443,378	8,165	10,576	16,447	89,324	162,856	590,861
	Historic potential	2,808	561,562	9,781	12,749	19,816	127,041	237,745	1.021 M
Elochoman	Current w/out harvest	2,118	292,390	2,557	5,874	11,421	31,560	57,805	281,054
	Historic potential	2,628	337,256	3,441	7,525	14,393	51,840	100,300	554,165

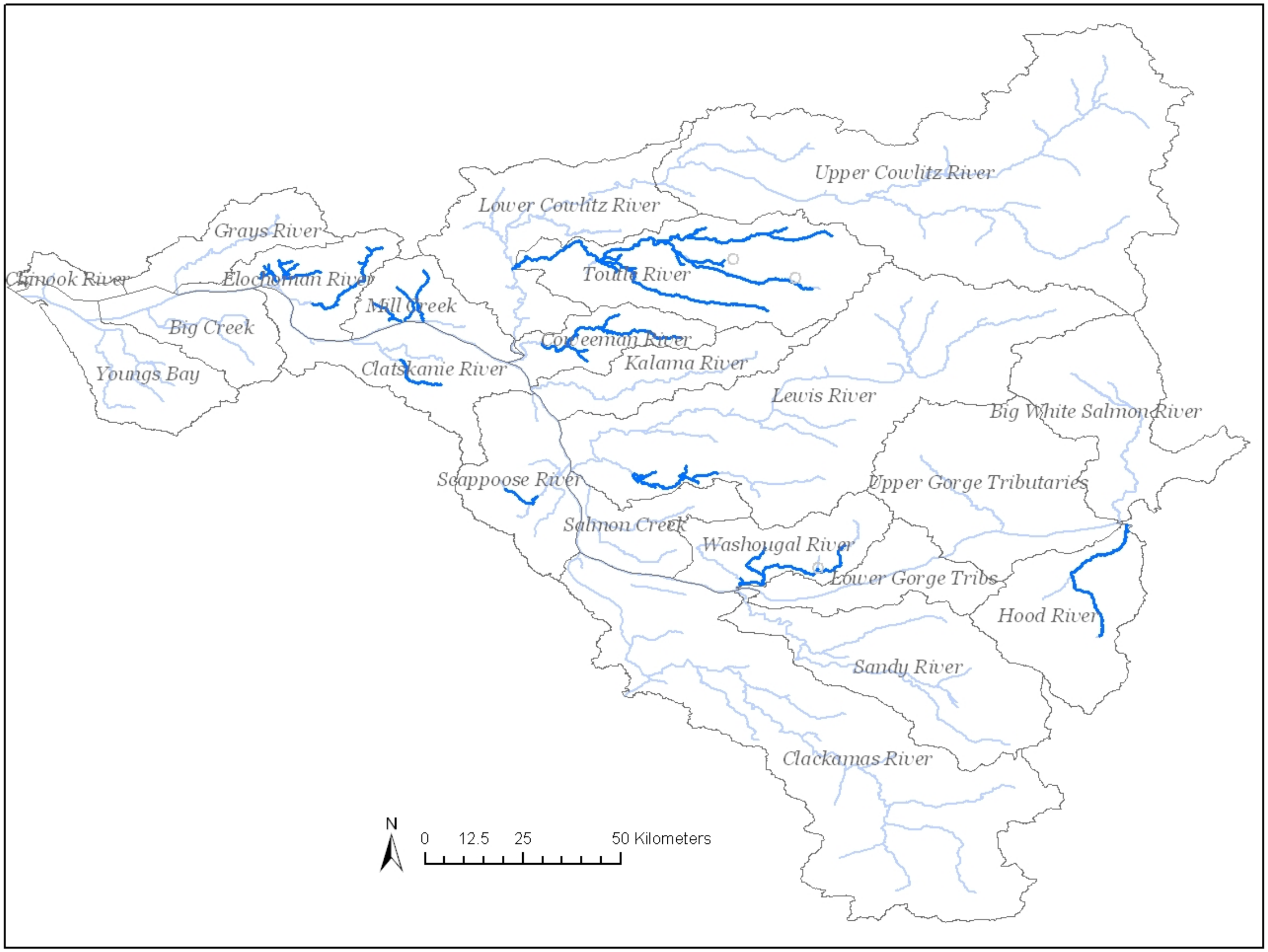


Figure 1. Population boundaries and spawning extent (dark blue lines) of Lower Columbia tule Chinook salmon targeted by recovery plans for high viability, and the focus of these analyses. Detailed maps for individual populations can be found in Appendix A.

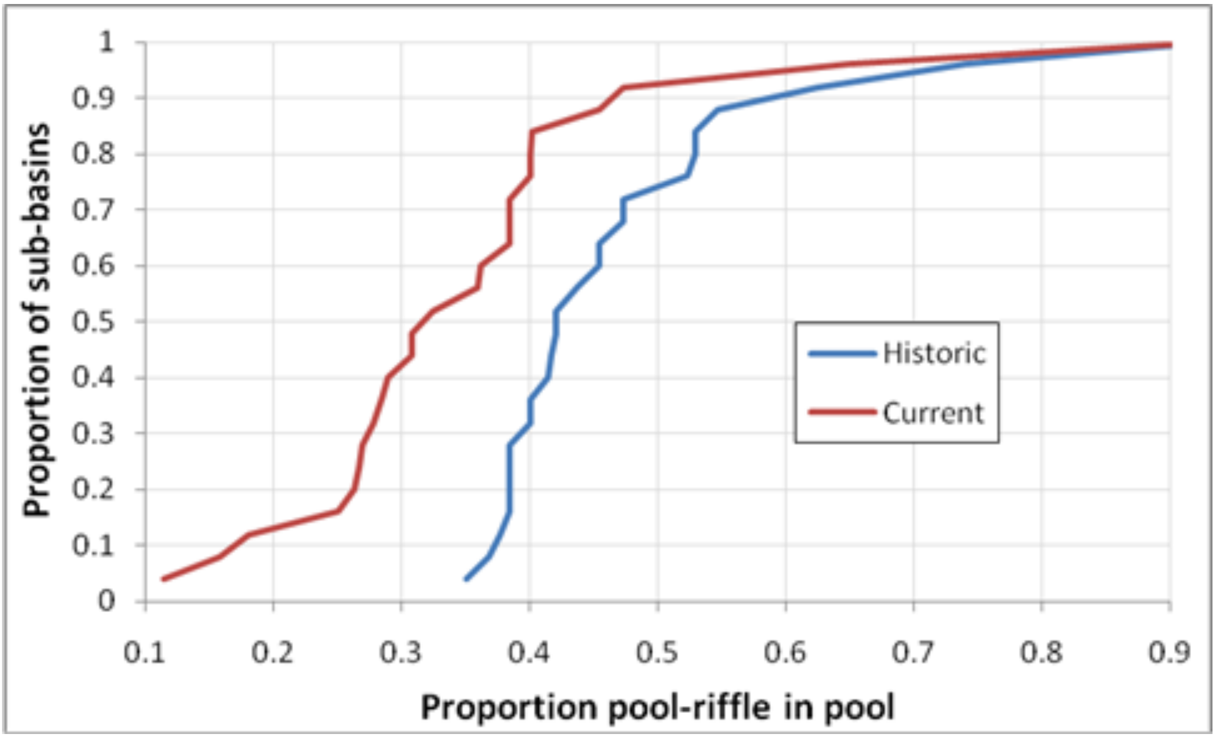


Figure 2. The cumulative distribution of pool habitats from Bartz et al. (2006), Table S8. We used values from the Maximum curve for estimating how to parse reaches with forced pool-riffle morphology into riffles and pools.

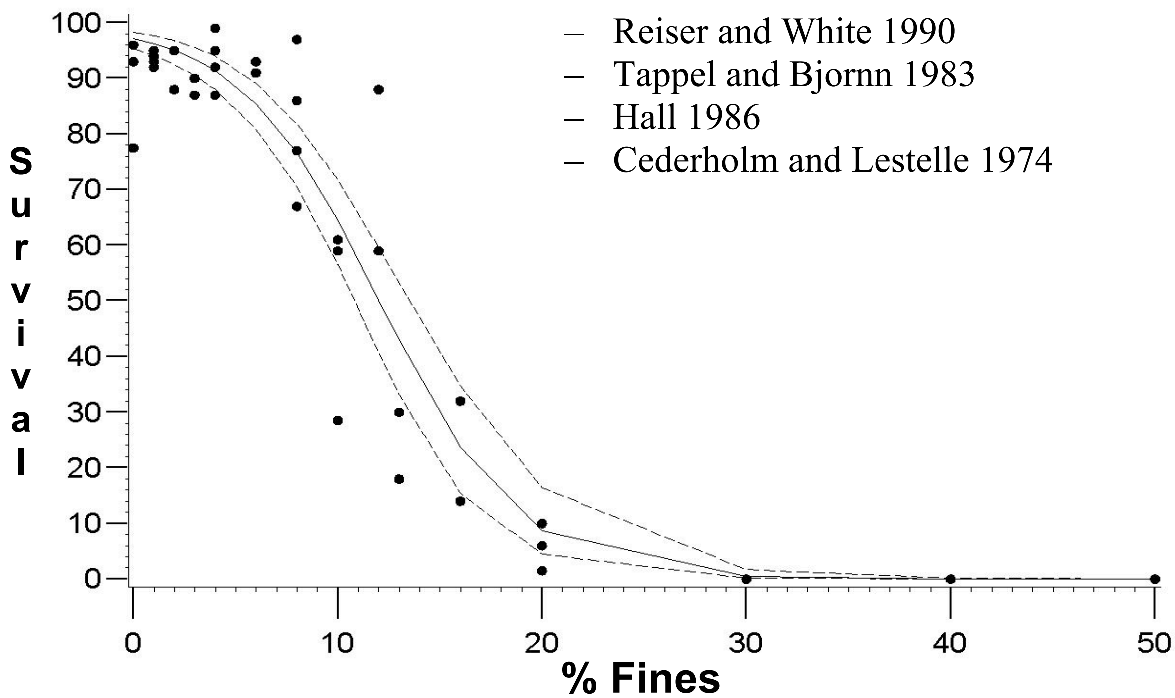


Figure 3. Empirical relationship between eyed egg-to-fry survival of Chinook salmon and the percentage of fine sediment in spawning gravels. The points are from studies used to estimate the relationship. The solid line is the estimated mean survival; the dashed lines are 95% confidence intervals for the mean. Reproduced from Figure K-2 of Steel et al. (2007), Appendix K. See also Jensen et al. (2009).

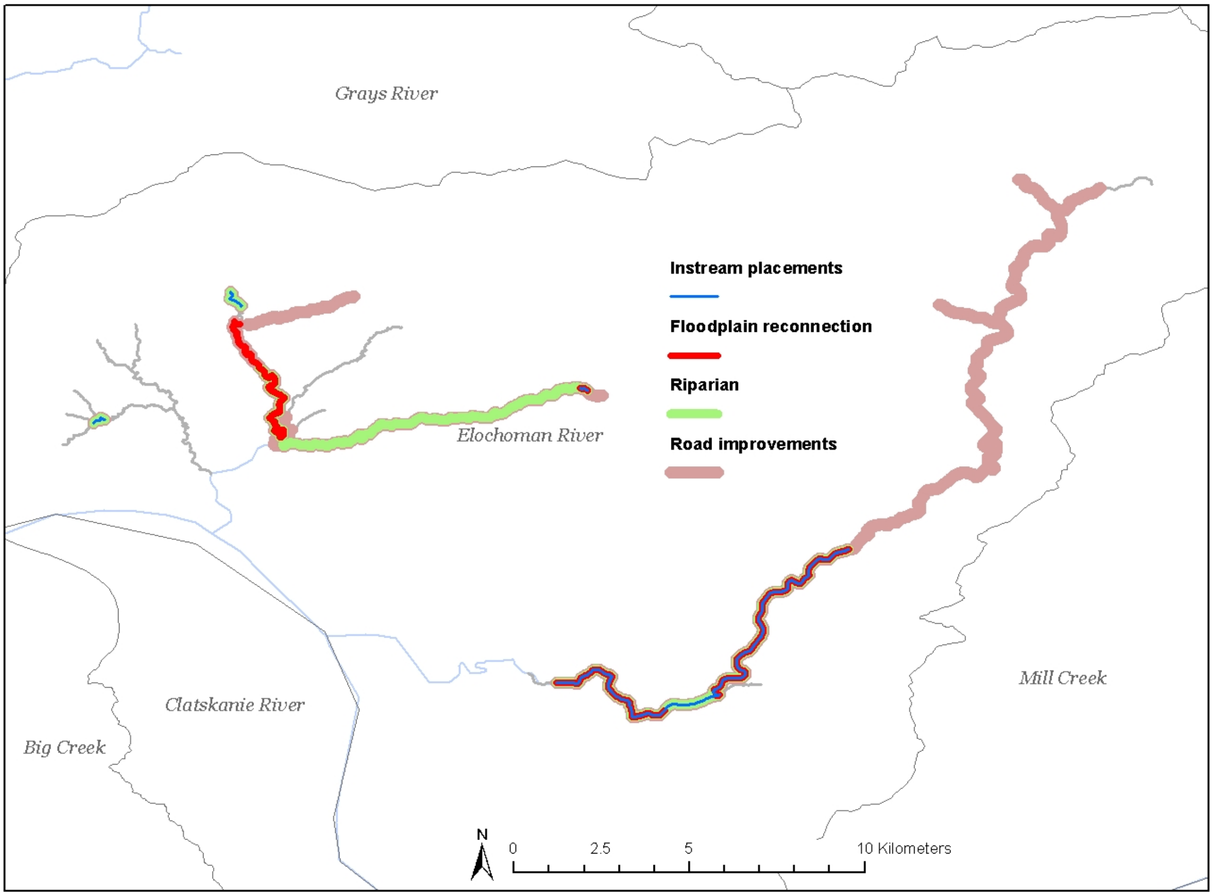


Figure 4. Spatial distribution of restoration actions modeled in the recovery scenario for the Elochoman River population, as translated from 1st priority actions in the recovery plan. Note that road improvements would only have affected egg-to-fry survival, if we were able to model that for this population. Other actions all affected both rearing and spawning capacity.

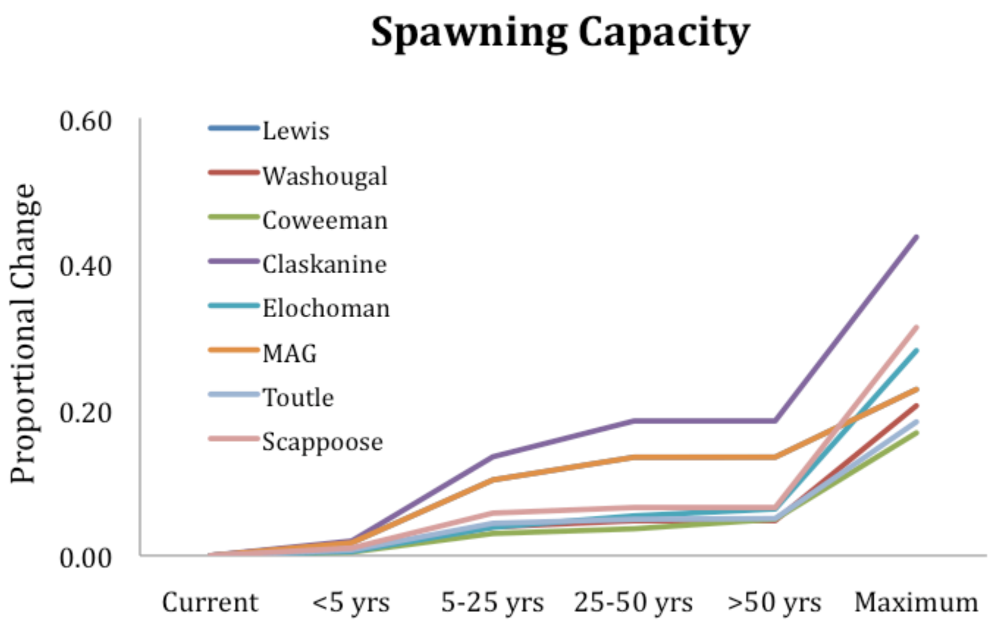


Figure 5. Predicted proportional improvements for spawning capacity in tributaries through time associated with habitat restoration actions in the recovery scenario. Values are point estimates – see Table 6 for variance estimates.

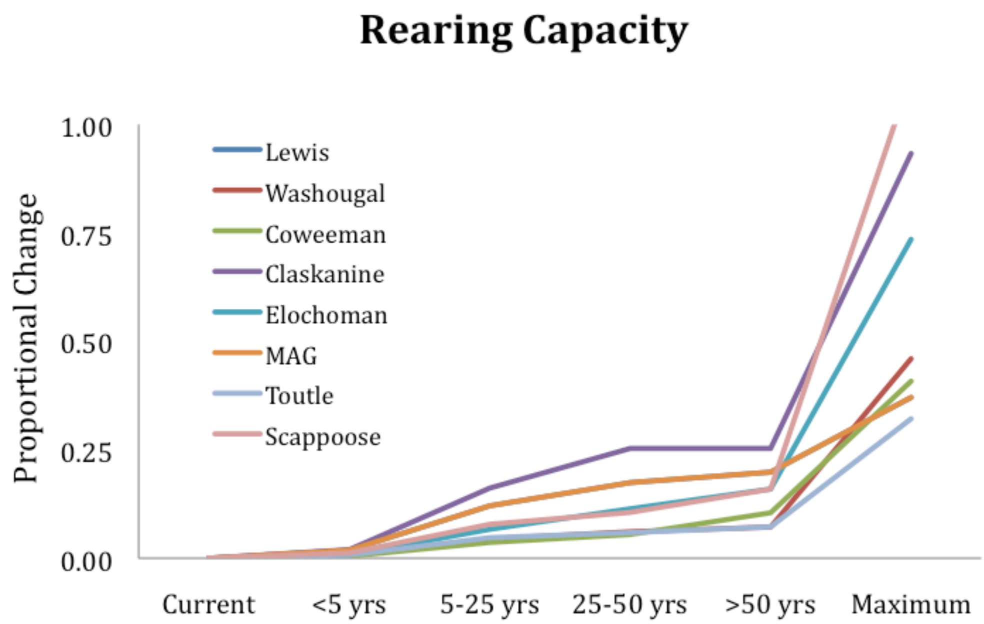


Figure 6. Predicted proportional improvements for subyearling rearing capacity in tributaries through time associated with habitat restoration actions in the recovery scenario. Values are point estimates – see Table 6 for variance estimates.

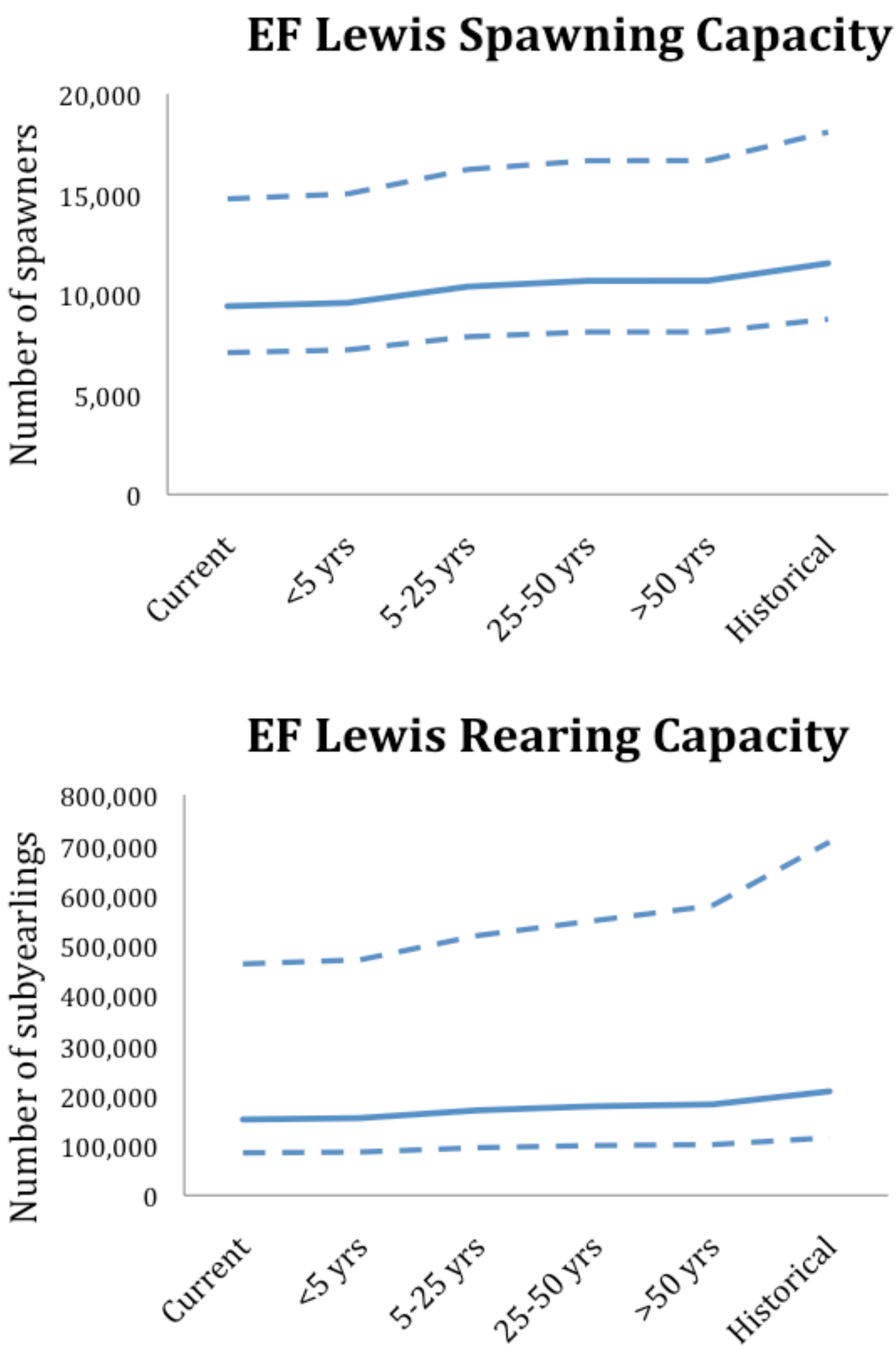


Figure 7. Predicted capacity for spawners (top panel) and subyearling juveniles rearing (bottom panel) in the East Fork Lewis River. Dotted lines are upper and lower prediction limits.

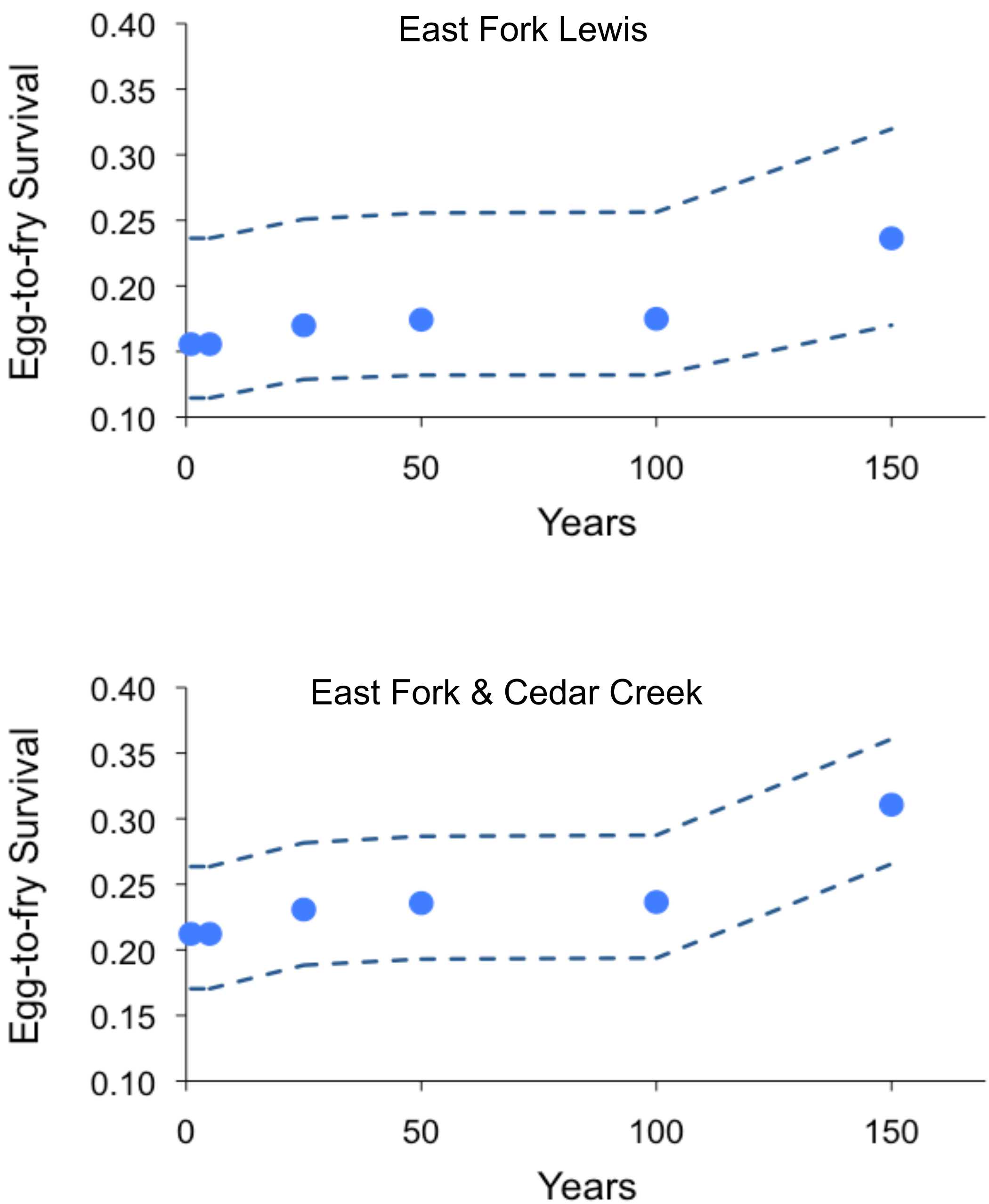
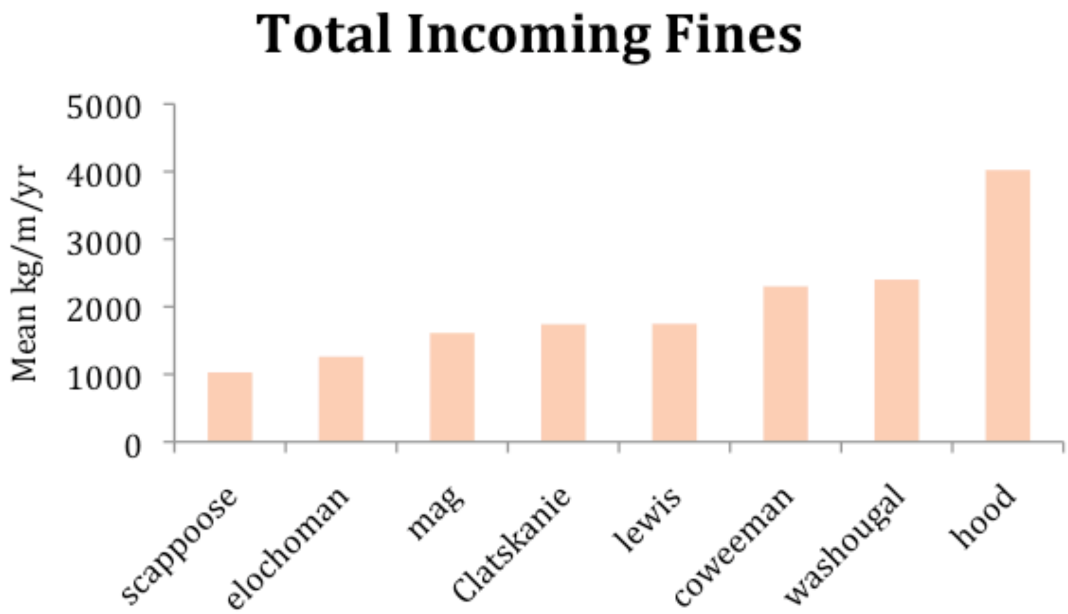


Figure 8. Egg-to-fry survival (predicted based on fine sediment model) for the East Fork Lewis River (top panel) and for both East Fork Lewis and Cedar Creek (bottom panel). The first data point represents current conditions, the next four data points represent the time steps of the recovery plan, and the final data point represents “Maximum” conditions.



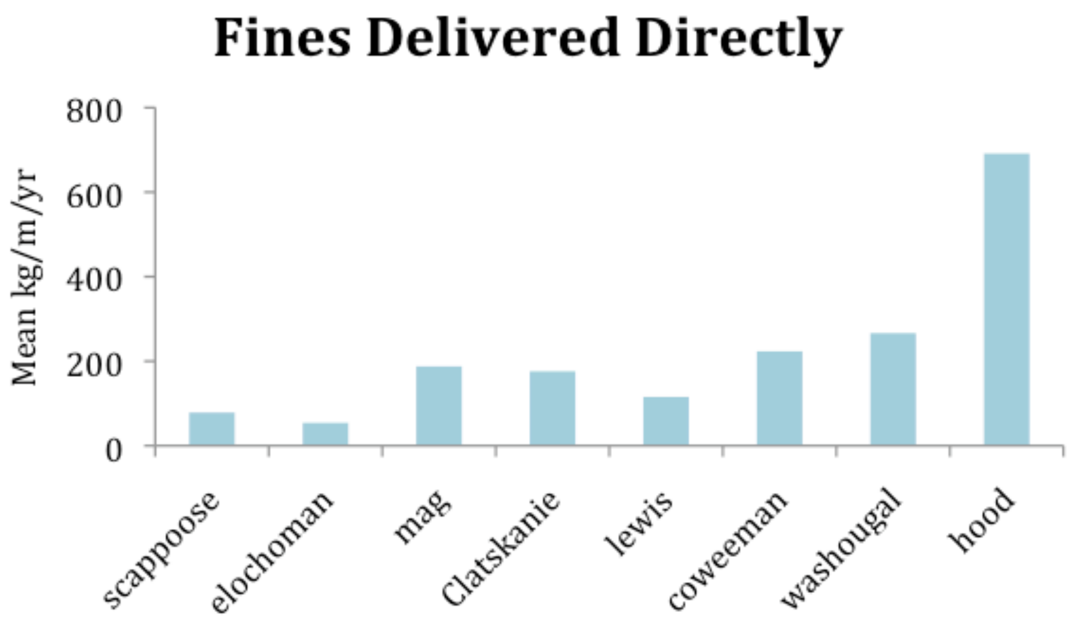


Figure 9. Estimated fine sediment contributed by surface erosion under current conditions that enters the study reaches (those in the spawning distribution for each population). Values are means over a 50-year simulation using the WEPP model. “Total incoming fines” are an estimate of fine sediment from adjacent hillslopes, tributary channels, and from upstream (using an exponential loss function), whereas “fines delivered directly” are from adjacent hillslopes only.

Habitat Appendix A. Spawning Distributions

See Rawding et al. (2009) for a full description of the model used to predict the spawning distribution. We included reaches with modeled likelihoods of $\geq$ 0.5. We then applied a mask to this spatial layer, truncating the distribution at the lower end at points below which fish have not been observed to spawn (Washington) and at tidal reaches (Oregon), and at the upper end when anthropogenic (i.e., culverts, dams) or natural (falls) barriers were known to prevent fish passage.

Figures A1 –A6 show the spatial extent of reaches used to summarize predicted spawning and rearing capacity and egg-to-fry survival for each population in Washington. Colors indicate EDT reaches referenced in the Washington recovery plan (LCFRB 2004), for reference. Note that we did not include all EDT reaches in modeling, but only those where the predicted spawning distribution overlapped.

Figures A7–A9 show the spatial extent of reaches used for Oregon populations, where we applied the same approach. Here, reaches are not identified by EDT reaches because these were not used to identify priority locations, as they were in the Washington recovery plan. Instead, priority locations identified in the recovery plan which affect fall Chinook salmon are shown in color.

Comments from CoManagers

Here, we reproduce the comments provided on the spawning distributions that we used initially as spatial extents for model summaries in this analysis (i.e., the thick blue lines in Figures A10-A18).

Washington Populations

Comments provided by Dan Rawding and Steve VanderPloeg, Washington Dept. Fish & Wildlife

General - The distribution model is based on the uppermost observed distribution, in some cases from multiple years, with the intent of developing a sampling frame. In reality spawning distribution is variable. Therefore, the model probably slightly over-predicts average distribution.

Coweeman. Pretty accurate for upper limit of distribution. In some years, probably with low flow there is no spawning in the mainstem above Browns Creek or any tributaries.

Washougal. Mainstem and Lacamas distributions are accurate. Limited info suggest very limited spawning in Little Washougal. The NF Washougal is wrong. There is a natural waterfall at the downstream end of Skamania Hatchery (lat/long = -122.216151, 45.620489; NAD 83). Therefore, the distribution should be truncated at this point, probably at the end of the first EDT reach in the NF (some maps also refer to the NF as the WF).

Mill/Abernathy/Germany. The model predicts the uppermost observed point in Mill and SF Mill very accurately, and it slightly over predicts Germany, and under predicts Abernathy. Based on the median or mean upper distribution from 2005-09, the model is over-predicting observed spawning distribution.

Lewis. East Fork Lewis mainstem looks good but there is probably limited current spawning in Mason Creek and Rock Creek due to degraded habitat. Predicted Cedar Creek distribution may be a little long. Chelatchie Creek is reasonable but we really don't survey this stream. (note from A. Fullerton – I have surveyed the lower extent of Chelatchie in 2006 and it was primarily beaver ponds).

Toutle. We have very limited data in this system. The Army Corps of Engineers constructed a sediment retention structure (SRS) on the NF Toutle just above the confluence of the Green River. This structure has done its job and stores huge amounts of sediment above the SRS, and provides a very high suspended sediment load in the water. The magnitudes can be accessed from USGS water quality summaries. However, the high sediment loads are likely to severely negatively impact incubation and juvenile survival rates for salmon. Also due to the current low returns Chinook salmon are not likely to ascend as far above the SRS in the mainstem and tributaries. There is poor habitat in Studebaker Creek, and it is unlikely that there are fish in this stream. Green River looks reasonable. Outlet Creek drains Silver Lake, and currently the model predicts spawning in the lake (not possible). There may be some spawning in the lowest EDT reach of Outlet Creek. There is also a complete barrier falls (source: Streamnet) on Hoffstadt Cr (off NF Toutle at -122.411612, 46.331717; NAD 83) and a complete barrier falls (source: Streamnet) on Coldwater Cr (-122.26898, 46.288256; NAD 83).

Elochoman. This population should include both the Elochoman River and Skamokawa Creek (the map we reviewed does not include Skamokawa Creek). I believe we only have one survey for the upper limit in the Elochoman River, and the distribution appeared to be stopped by a low water barrier below the West Fork. However, if this is passable in some years, distributions in the lower West Fork and confluence of North Fork and East Fork are reasonable.

Oregon Populations

Comments provided by Erin Gilbert and Jeff Rodgers, Oregon Dept. Fish & Wildlife

Background – we applied the Rawding et al. logistic regression model to streams generated by NetMap for these populations. We then compared the resulting distributions with two other datalayers: (1) spatially-explicit restoration action priorities proposed as part of the recovery plan, and (2) fall Chinook distribution generated for Oregon state (referred to as NRIMP below).

General Comments– It is clear that the spatial locations of the restoration actions from recovery plans should not be used, or used with caveats, for comparisons with the Rawding distribution. The action locations were derived from opinions of resource managers and there was little QA/QC. The same applies to attributing actions to different species. I notice that some of the actions you are displaying in your maps are not for Fall Chinook (ex: Scappoose action 3). You can identify the actions specific to Fall Chinook using the tables in the Actions maps. Other actions specific to CHF (ex: Scappoose action 8) really seem too high up in the basin so it seems like the actions may not necessarily overlay with spawning and rearing distribution. Scappoose action 8 deals with erosion so it seems like a downstream cumulative impact on CHF.

Of greater concern are the differences with NRIMP distribution. It would be nice if I could say with confidence that NRIMP distribution is accurate and up to date but that is not necessarily the case. That means we have to look at potential "inaccuracy" in both the modeled and NRIMP layers. I've seen differences for other species between NRIMP and the distribution defined by CLAMS modeled streams. One data source that may help are the Chinook surveys just started by the spawning project here at the lab. They have only just completed their first year but those surveys will hopefully inform both NRIMP distribution and efforts such as this.

Revisions

Based on these comments, we have made revisions to spawning distributions that were used for the next iteration of modeled predictions. Two things changed in our revised spawning distributions: (1) we used parameters from the 2009 version of Rawding et al.'s model instead of the 2007 version, and (2) we adjusted distributions based on comments above. The revised distributions are those shown in Figures A1-A9 (and are the same as the thin orange lines in Figures A10-A18).

For Washington, we only removed reaches where reviewers suggested fish could not physically access. However, because we were trying to predict potential capacity under restored conditions, we did not remove reaches where it was suggested that fish may not currently use due to degraded habitat. As well, we added Skamokawa Creek to the Elochoman population.

For Oregon, we limited the distribution to modeled portions that overlapped with the Oregon Fish Distribution Layer ("NRIMP", as referenced above: http://nrimp.dfw.state.or.us/web%20stores/nrimp/pub/gis/k24/meta/fhd.htm), and omitted reaches specifically designated as "tidal". This significantly reduced the distributions of Oregon populations. **CAUTION: Because the NRIMP layer is based on current distribution of fall Chinook (and for which little empirical data is available), this decision may have reduced the predicted spawning distribution to a more confined area than was accessible historically.**

Further Comments on Oregon Populations

(From E. Gilbert on 9 Feb 2010 - too late to include in revisions, but hopefully useful for interpreting results)

After soliciting a review of maps by district biologists Rod French (Hood River) and Tom Murtagh (Clatskanie and Scappoose Rivers), Erin made the following observations. These maps and reviews are available on request.

"Hood: NRIMP distribution mostly accurate. MF and EF Hood: Glacial, snow-melt driven hydrology may explain the model overestimating distribution (different timing of flows, increased power of flow leaves little spawning gravel). Neal Creek: Potential for CHF distribution, but no documentation.

Scappoose and Clatskanie: NRIMP distribution may be inaccurate in places. The district biologist believes the distribution should extend beyond NRIMP in many places. Dikes and tide gates are factors limiting distribution. Modeled hydro layers are not always accurate in low gradient, diked areas.

I will send you the GIS layer of natural barriers I am using (the grey polygons in the maps). Your maps and mine differ some in the barriers used and I think it is due to different rule sets used to identify them. The methodology I used is in a previous e-mail I sent regarding barriers (also attached). And again I am only looking at historic (natural) barriers."

He also suggested using the tidal attribute from the stream layer he sent as a means of removing those reaches from the distribution. Happily, this is exactly what we did.

Sensitivity Analysis of Logistic Model Parameter

We also conducted a basic sensitivity analysis to evaluate the effect of using 0.5 as a cutoff for predicting the upper end of spawning distributions with the Rawding et al. model. Figures A19-A27 show the mapped distribution using cutoff values of 0.4, 0.5, and 0.6. Note that these maps depict the raw prediction by the Rawding et al. model, and distributions have not been truncated by lower and upper points as described above. The predictions do not appear to be overly sensitive to this parameter.

REFERENCES

Rawding, D. et al. 2009. Spawning distributions for tule fall Chinook populations in the Lower Columbia River.

LCFRB (Lower Columbia Fish Recovery Board). 2004. Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan. http://www.lcfrb.gen.wa.us/December%20Final%20%20Plans/lower_columbia_salmon_recovery_a.htm.

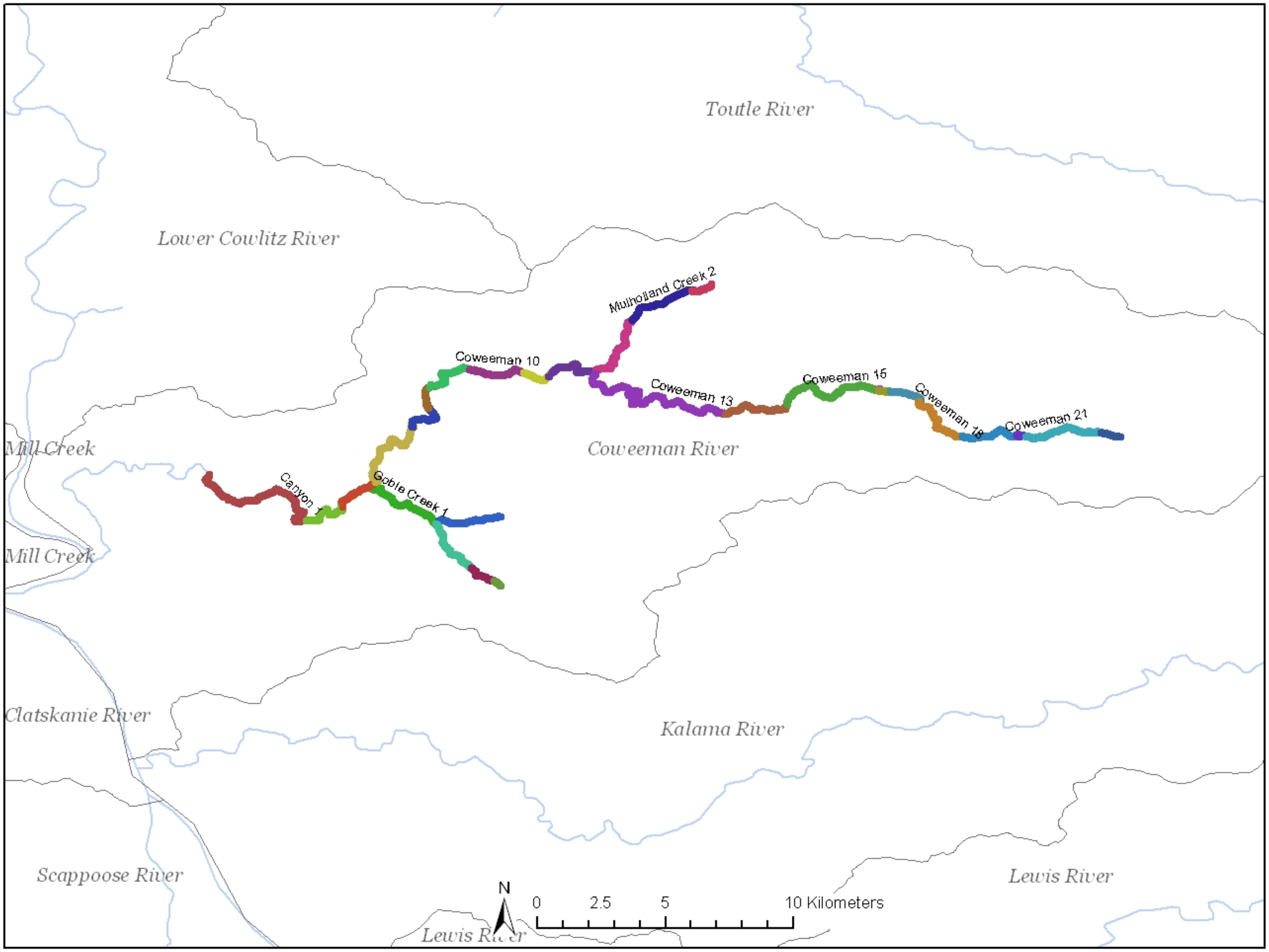


Figure A1. Spatial extent of reaches used to summarize capacity and survival estimates in the Coweeman River.

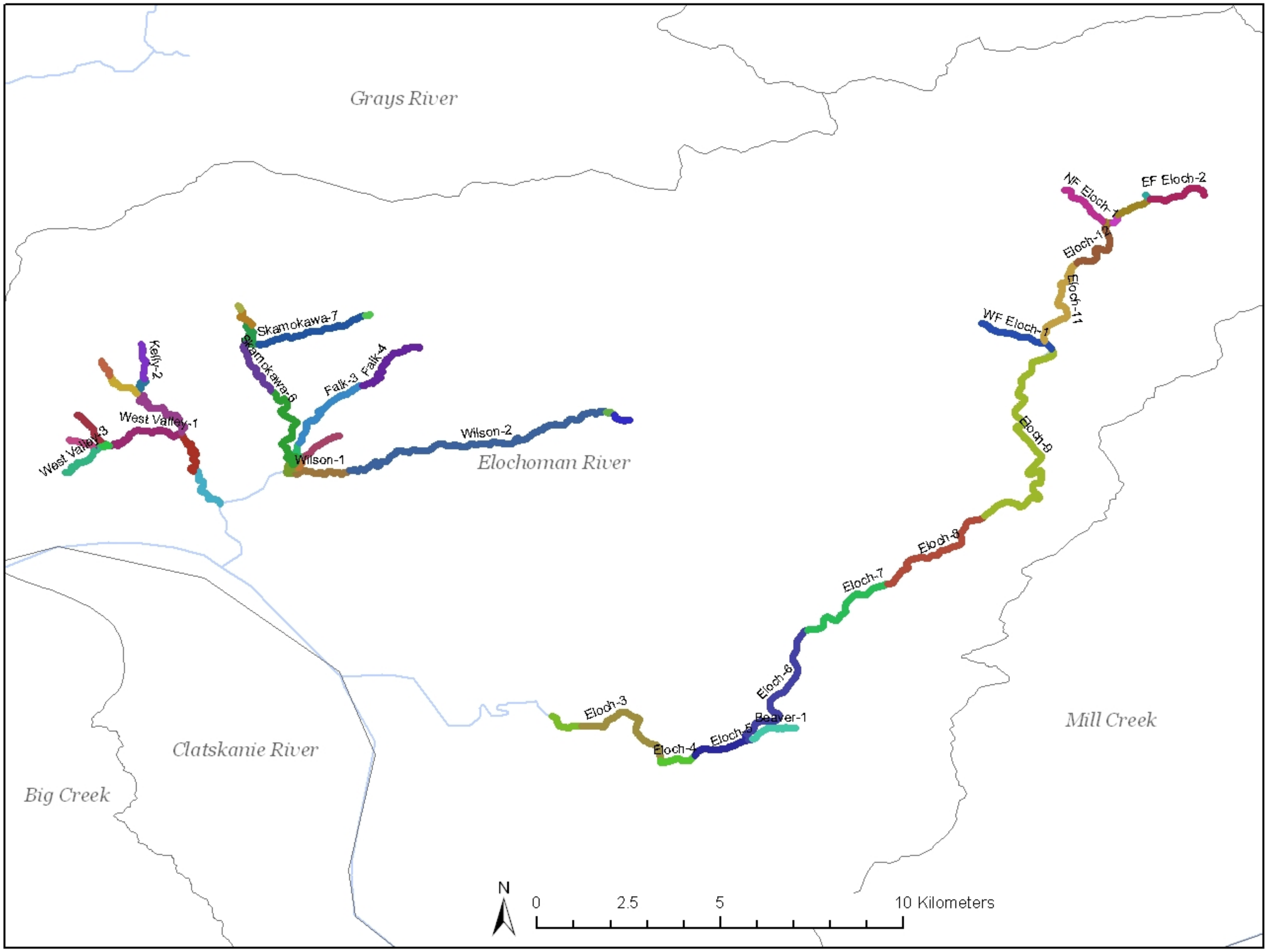


Figure A2. Spatial extent of reaches used to summarize capacity and survival estimates in the Elochoman River.

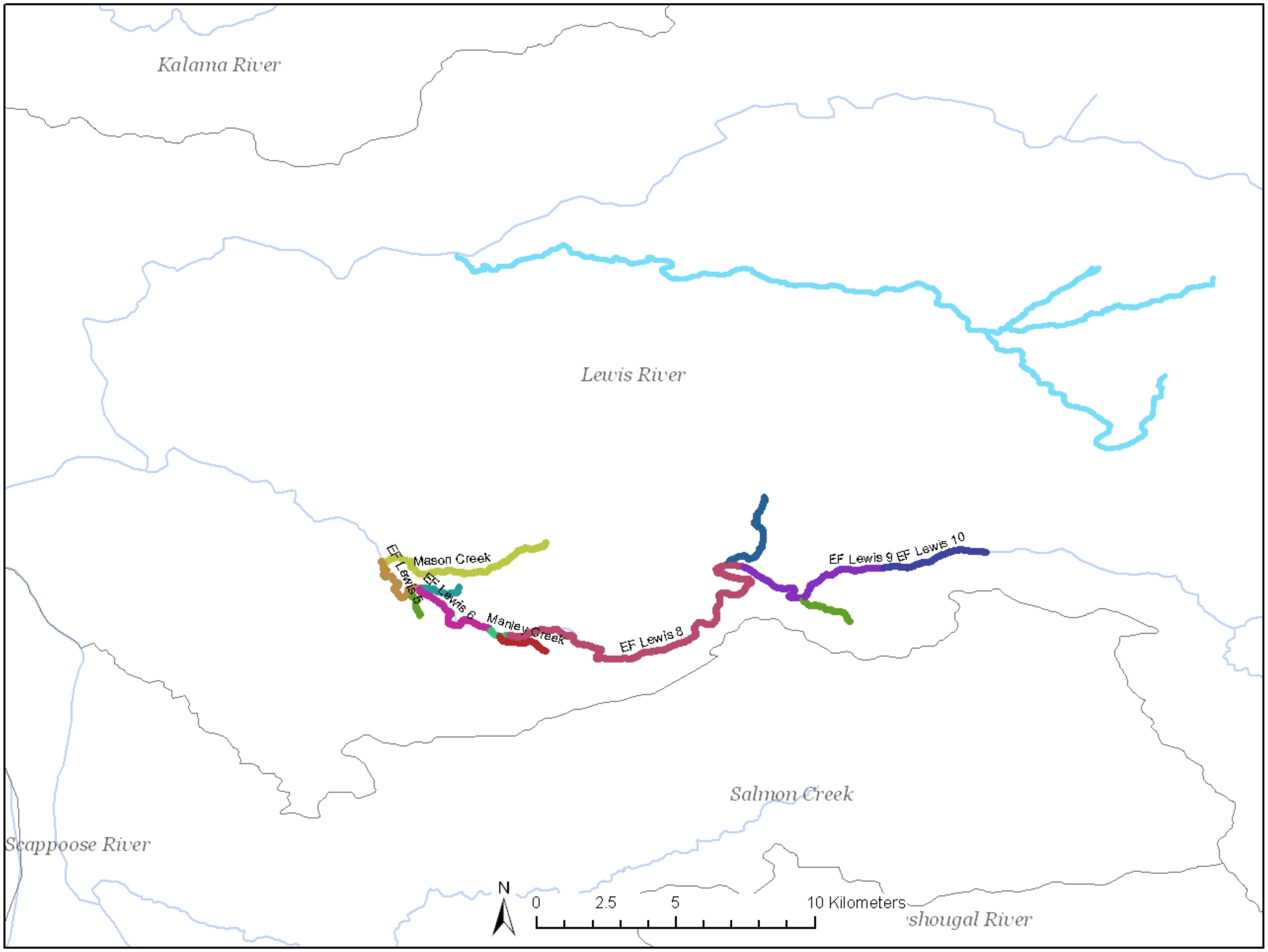


Figure A3. Spatial extent of reaches used to summarize capacity and survival estimates in the Lewis River. Note: models were only run on the East Fork Lewis (possible tule habitat in Cedar Creek, North Fork, is shown in blue).

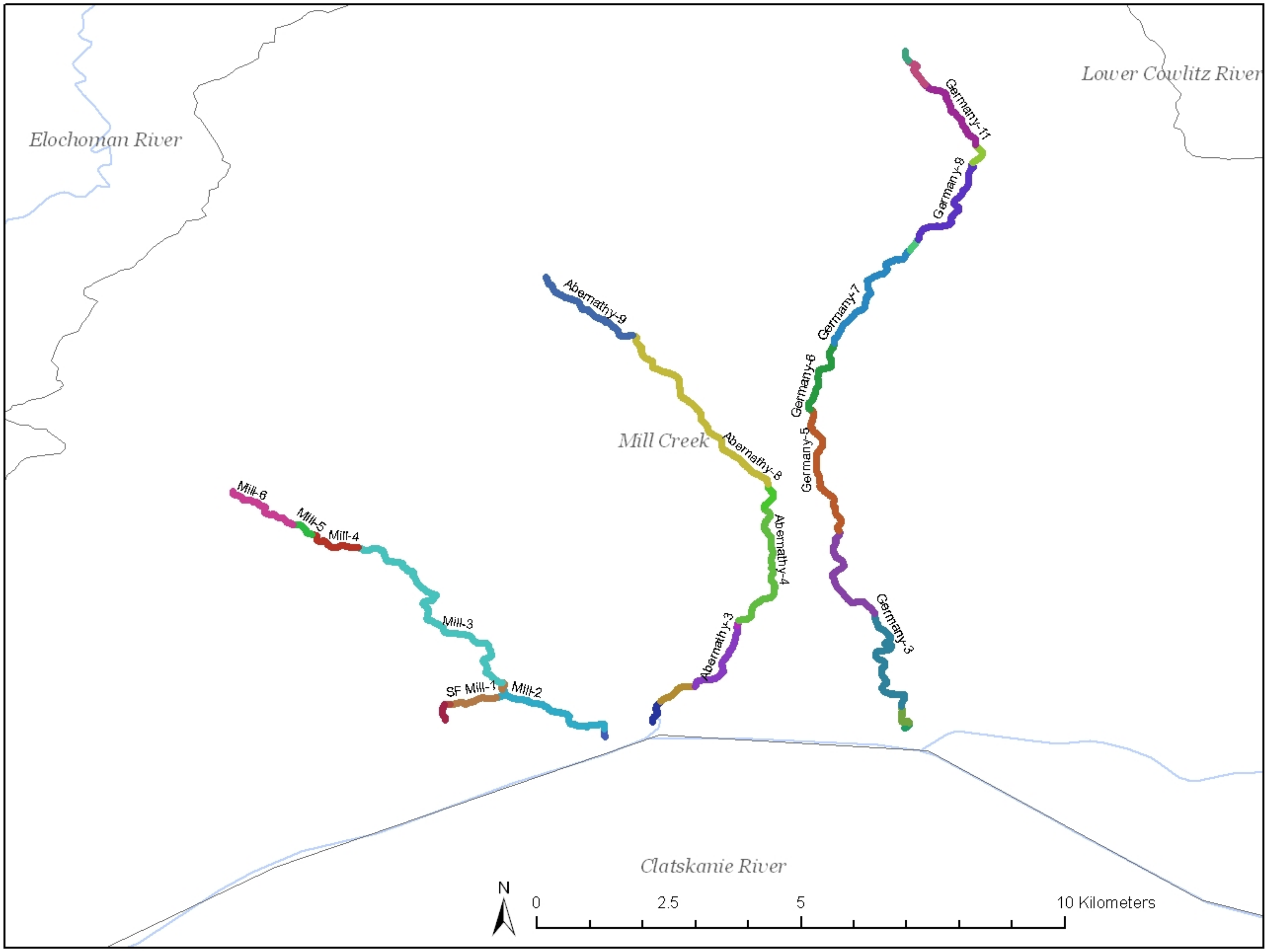


Figure A4. Spatial extent of reaches used to summarize capacity and survival estimates in the Mill/Abernathy/Germany complex.

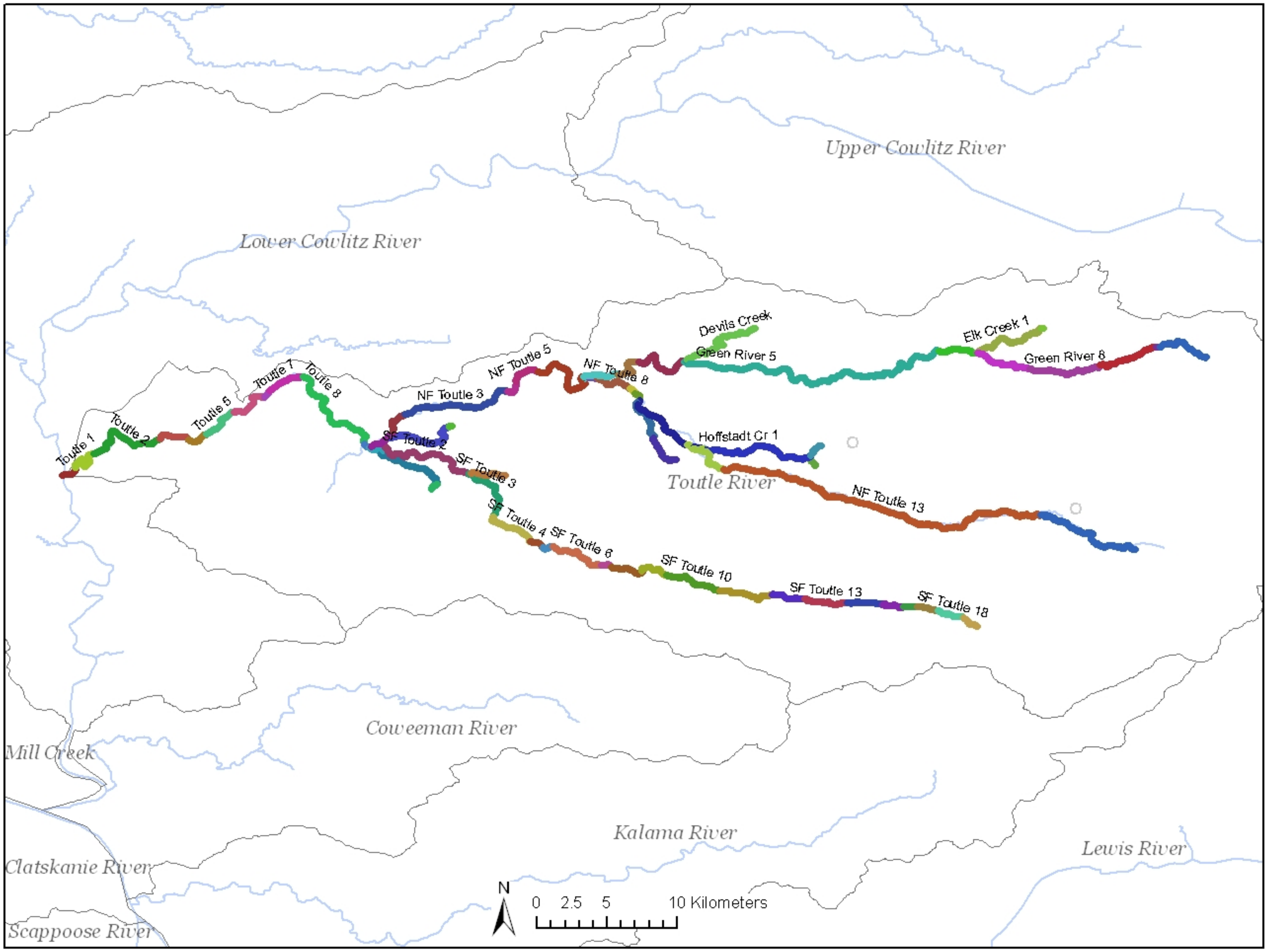


Figure A5. Spatial extent of reaches used to summarize capacity and survival estimates in the Toutle River.

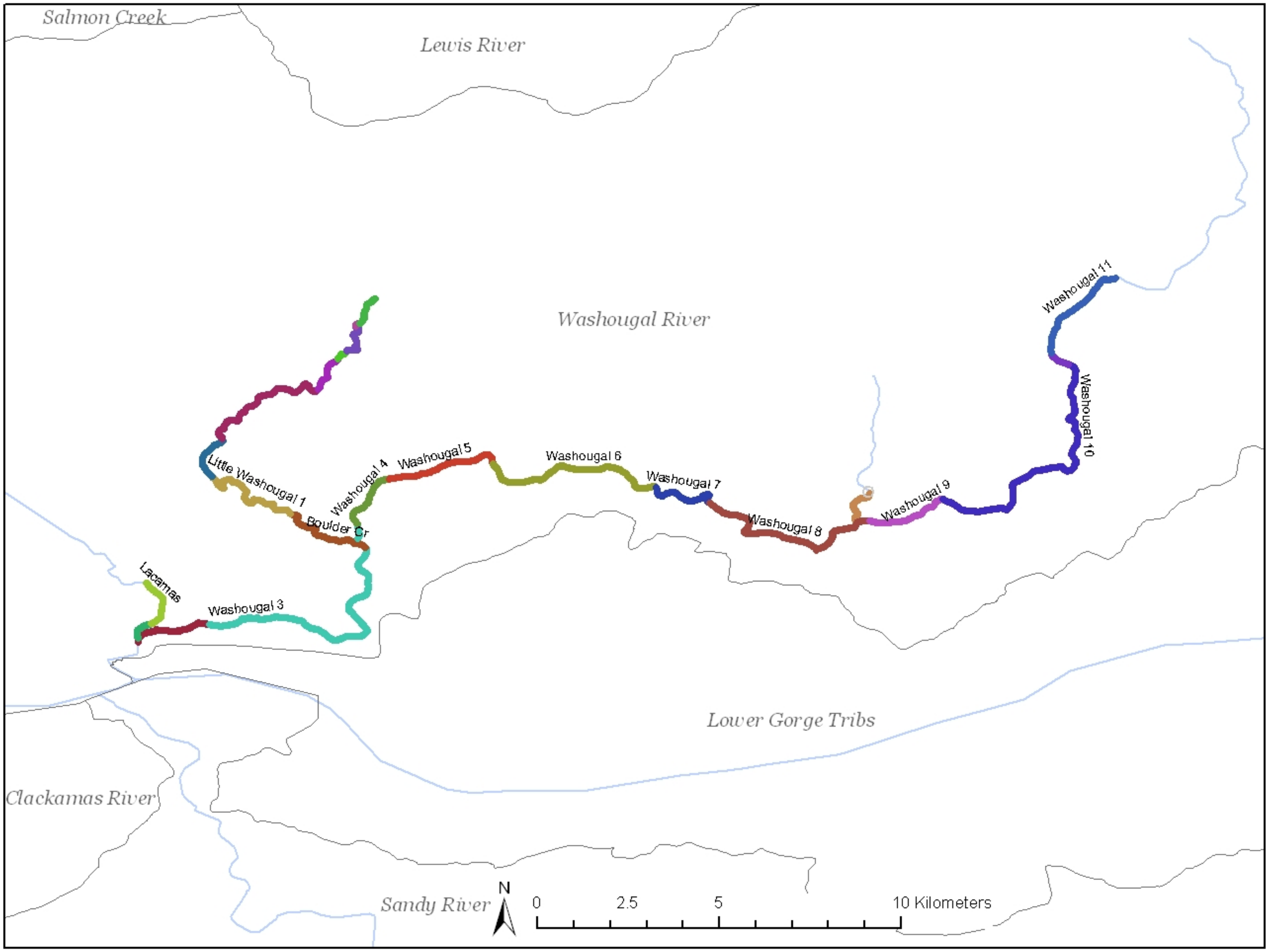


Figure A6. Spatial extent of reaches used to summarize capacity and survival estimates in the Washougal River.

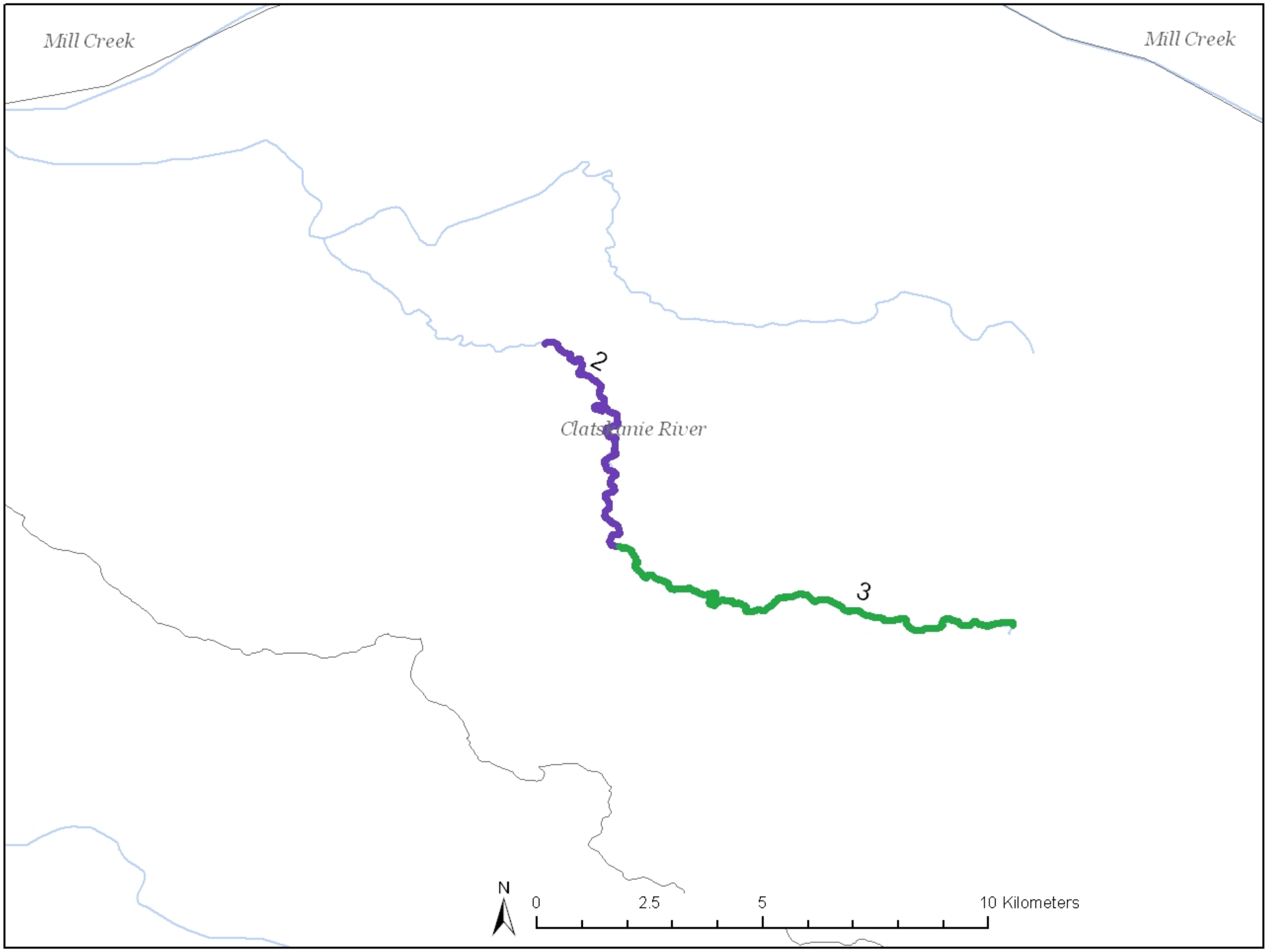


Figure A7. Spatial extent of reaches used to summarize capacity and survival estimates in the Clatskanie River.

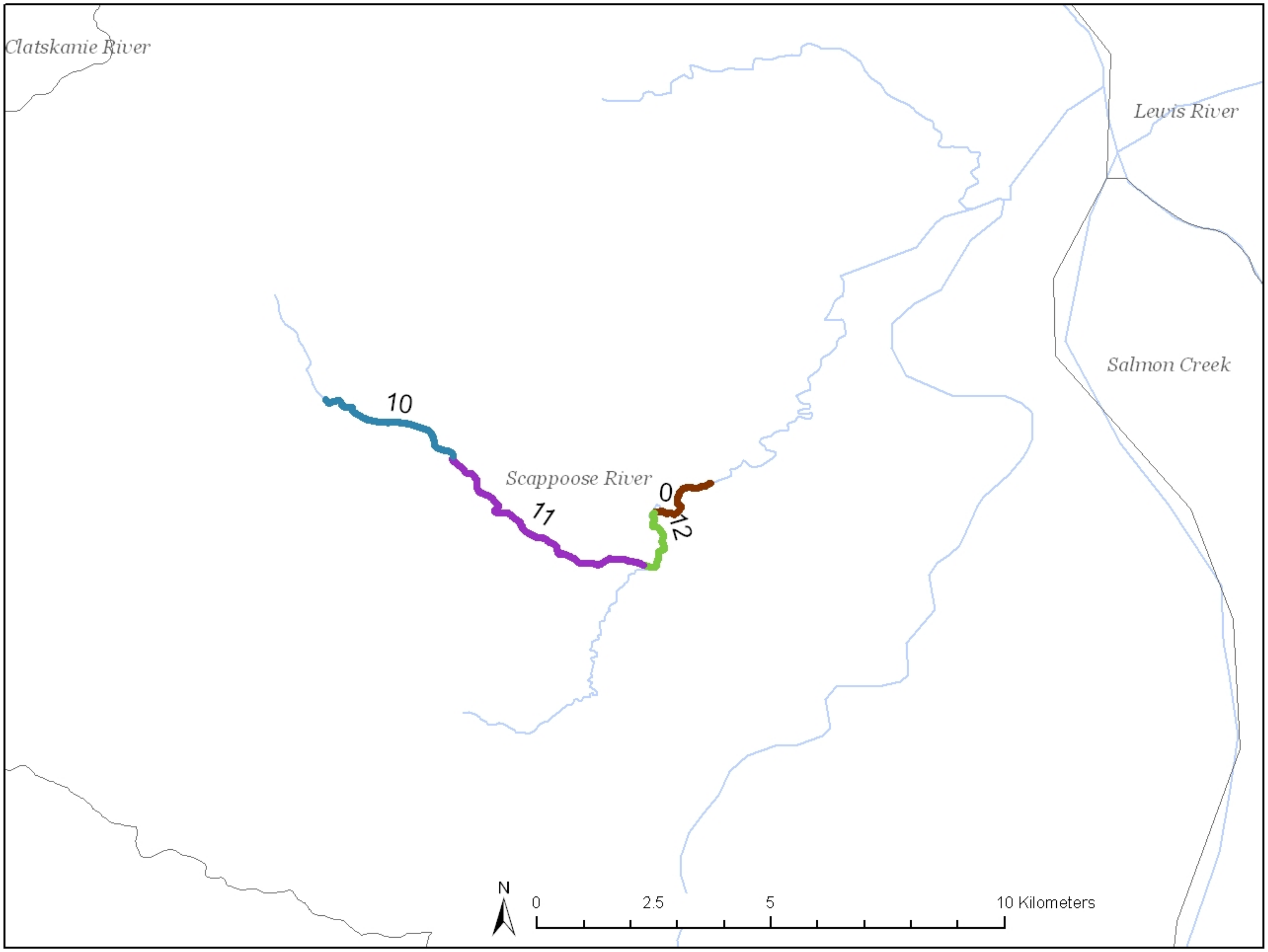


Figure A8. Spatial extent of reaches used to summarize capacity and survival estimates in the Scappoose River.

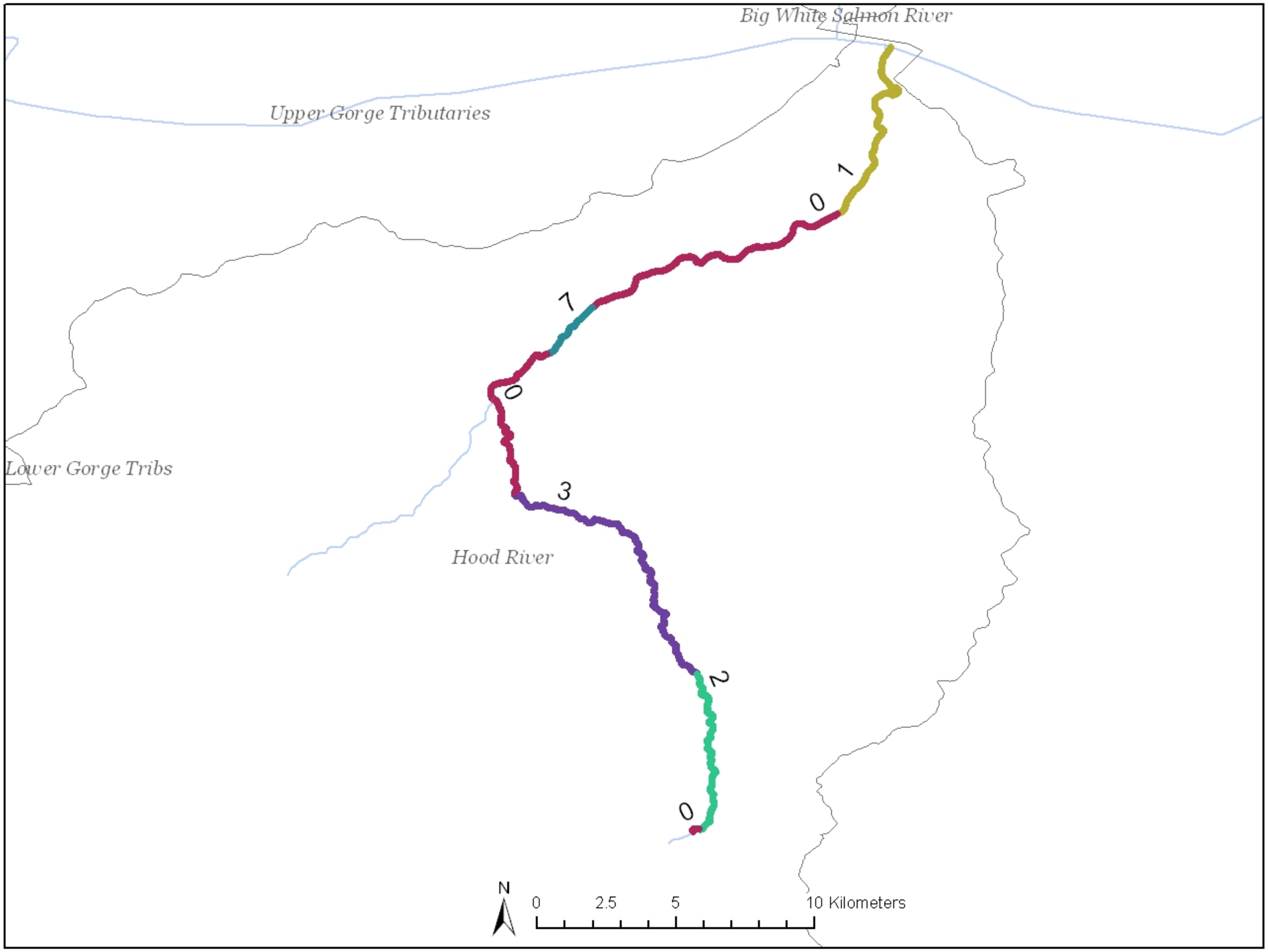


Figure A9. Spatial extent of reaches used to summarize capacity and survival estimates in the Hood River.

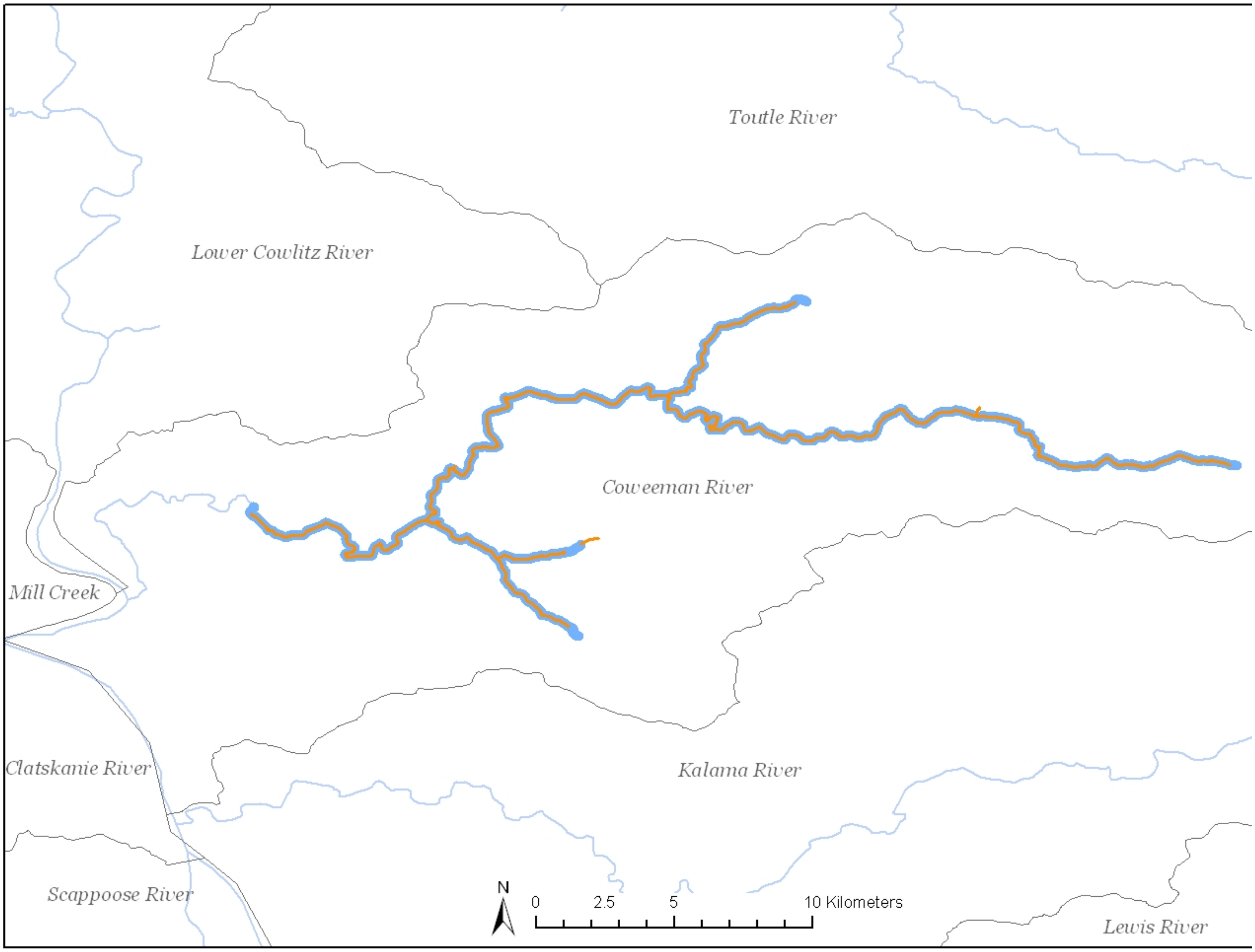


Figure A10. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in the Coweeman River.

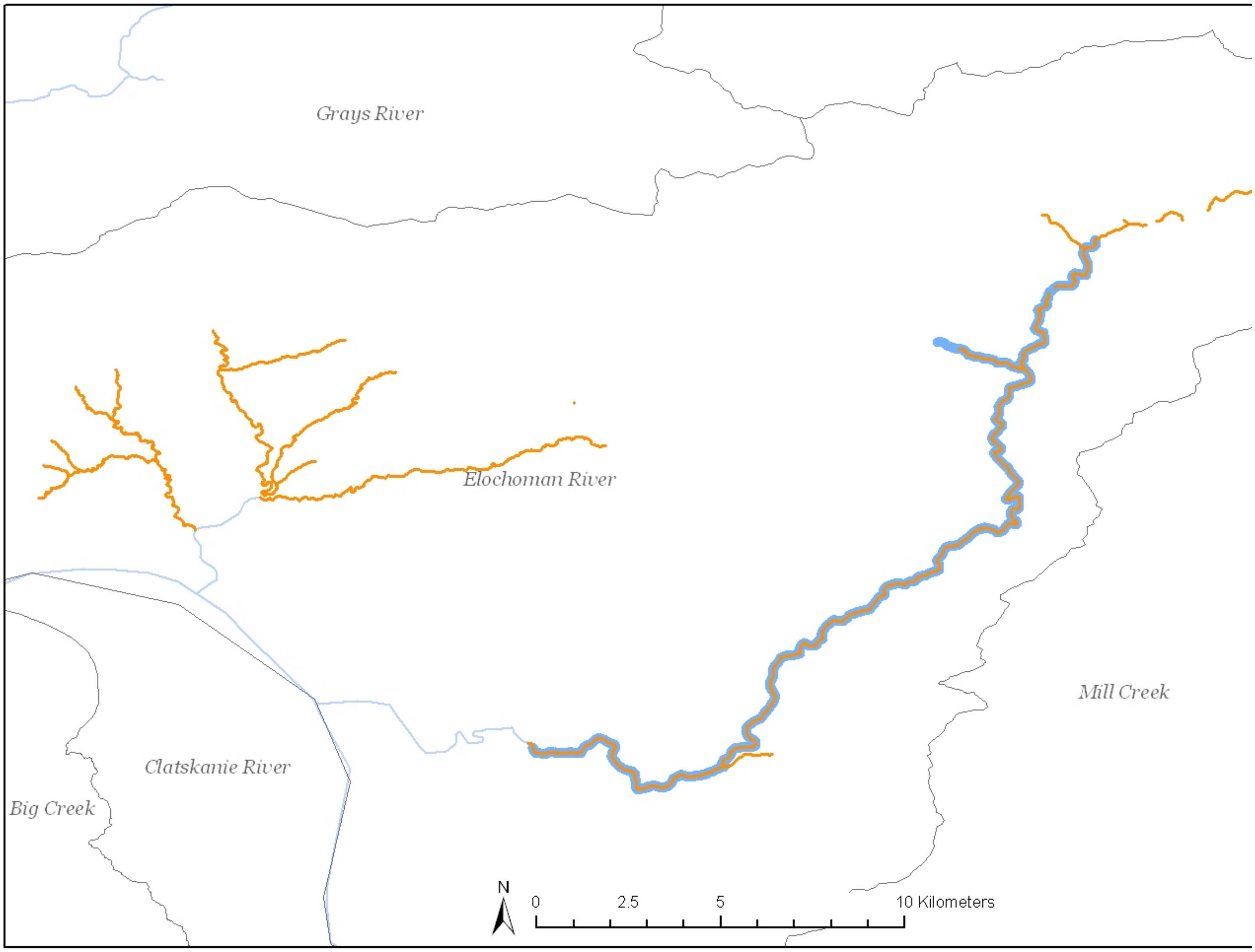


Figure A11. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in the Elochoman River.

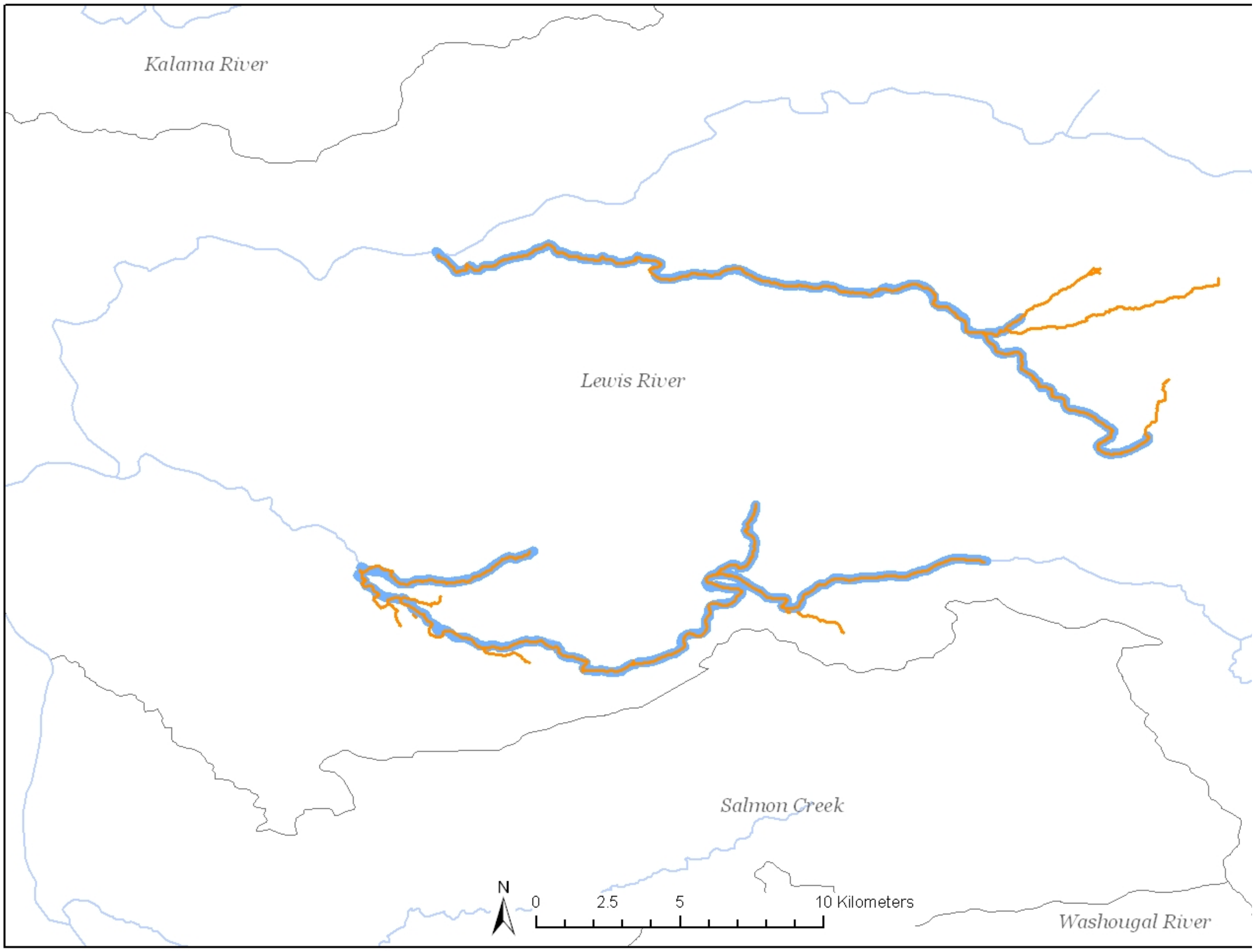


Figure A12. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in the Lewis River.

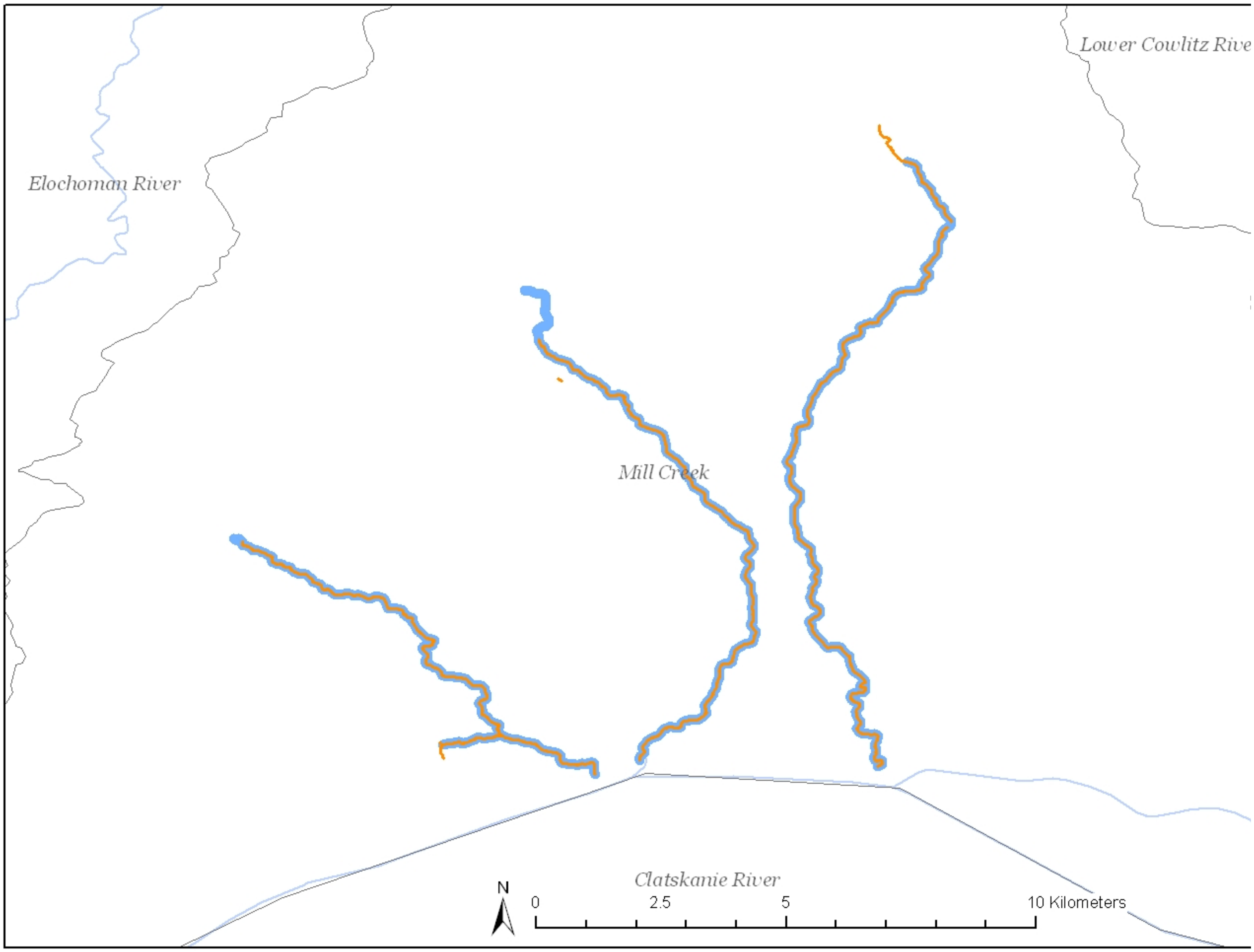


Figure A13. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in Mill/Abernathy/Germany Creeks.

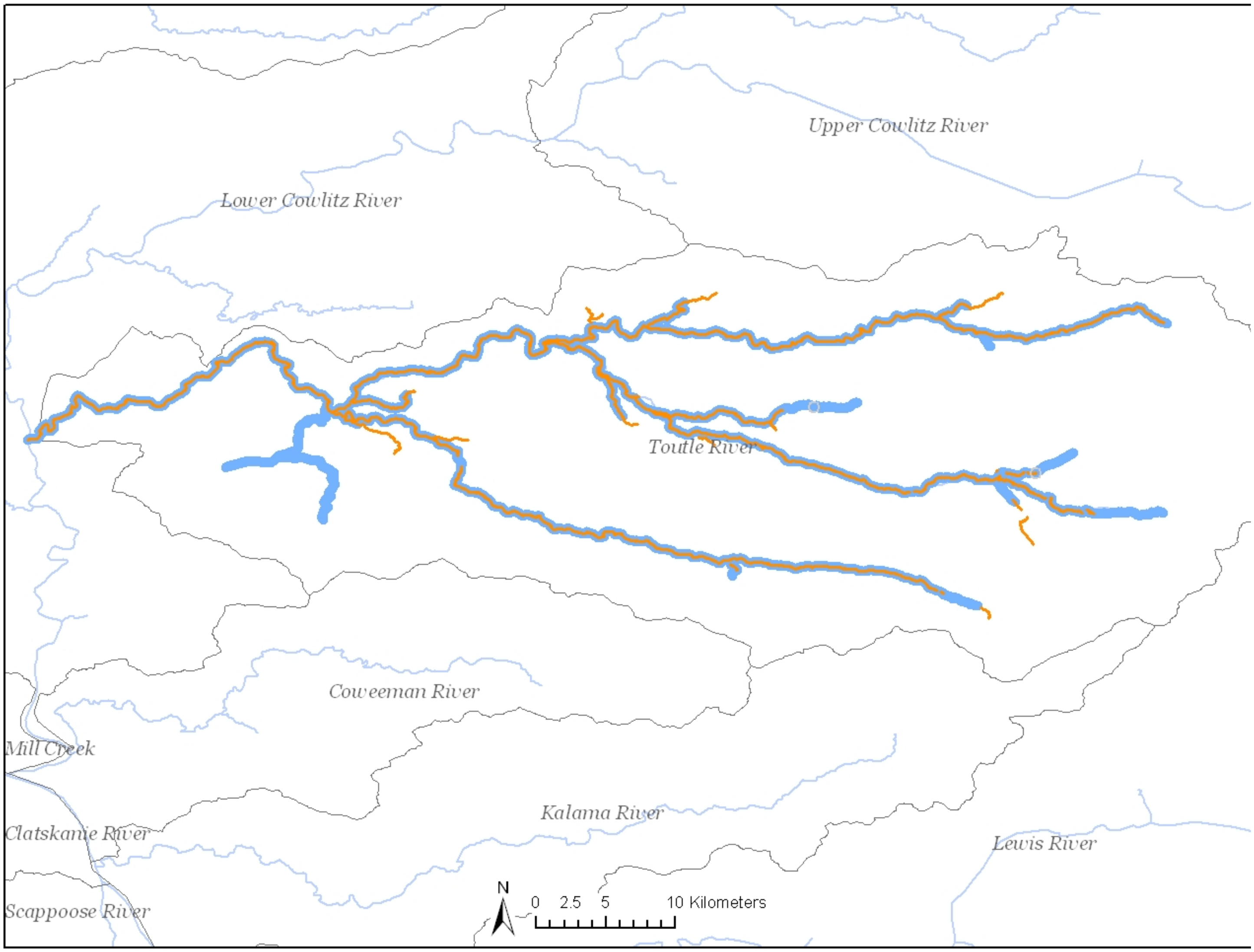


Figure A14. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in the Toutle River.

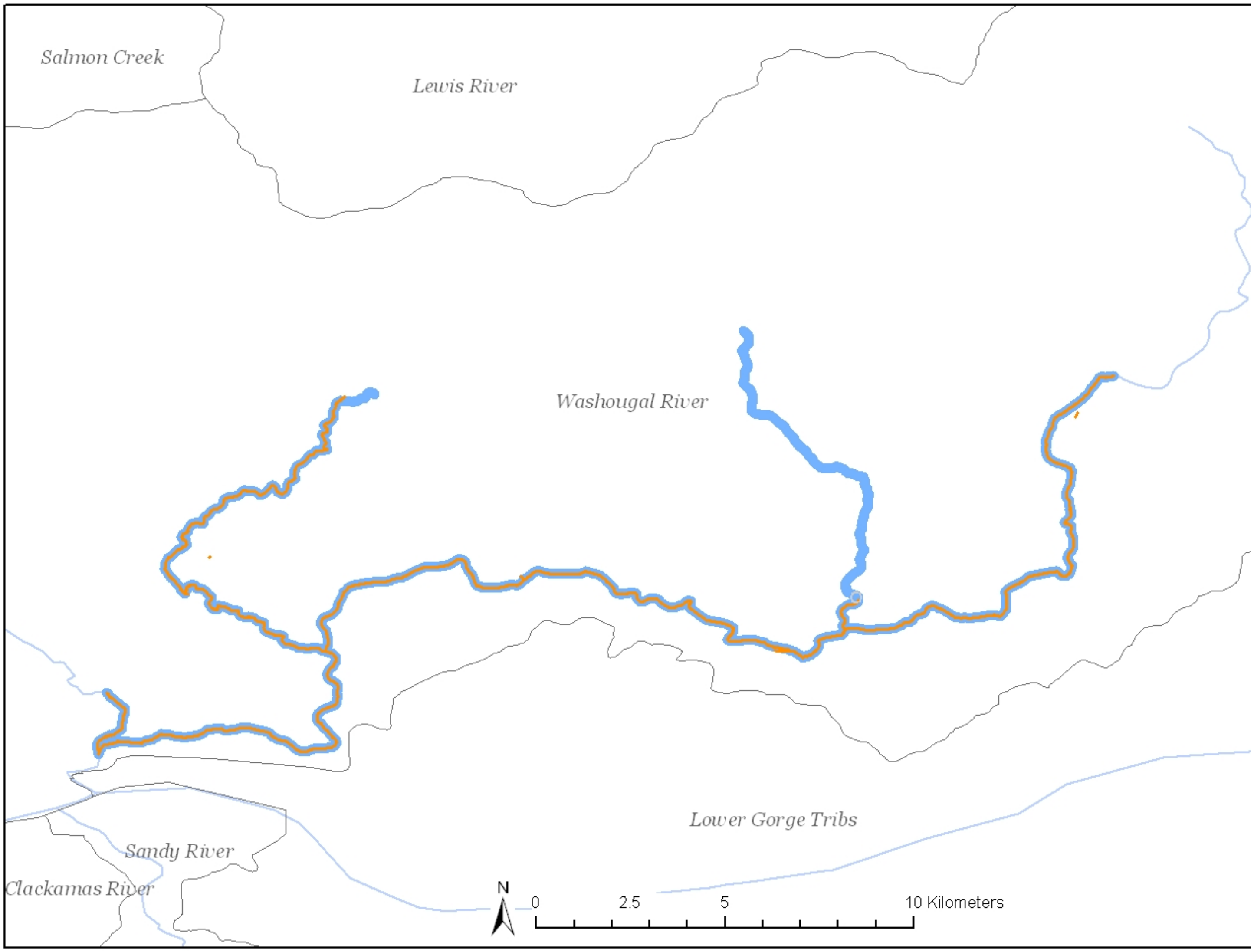


Figure A15. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in the Washougal River.

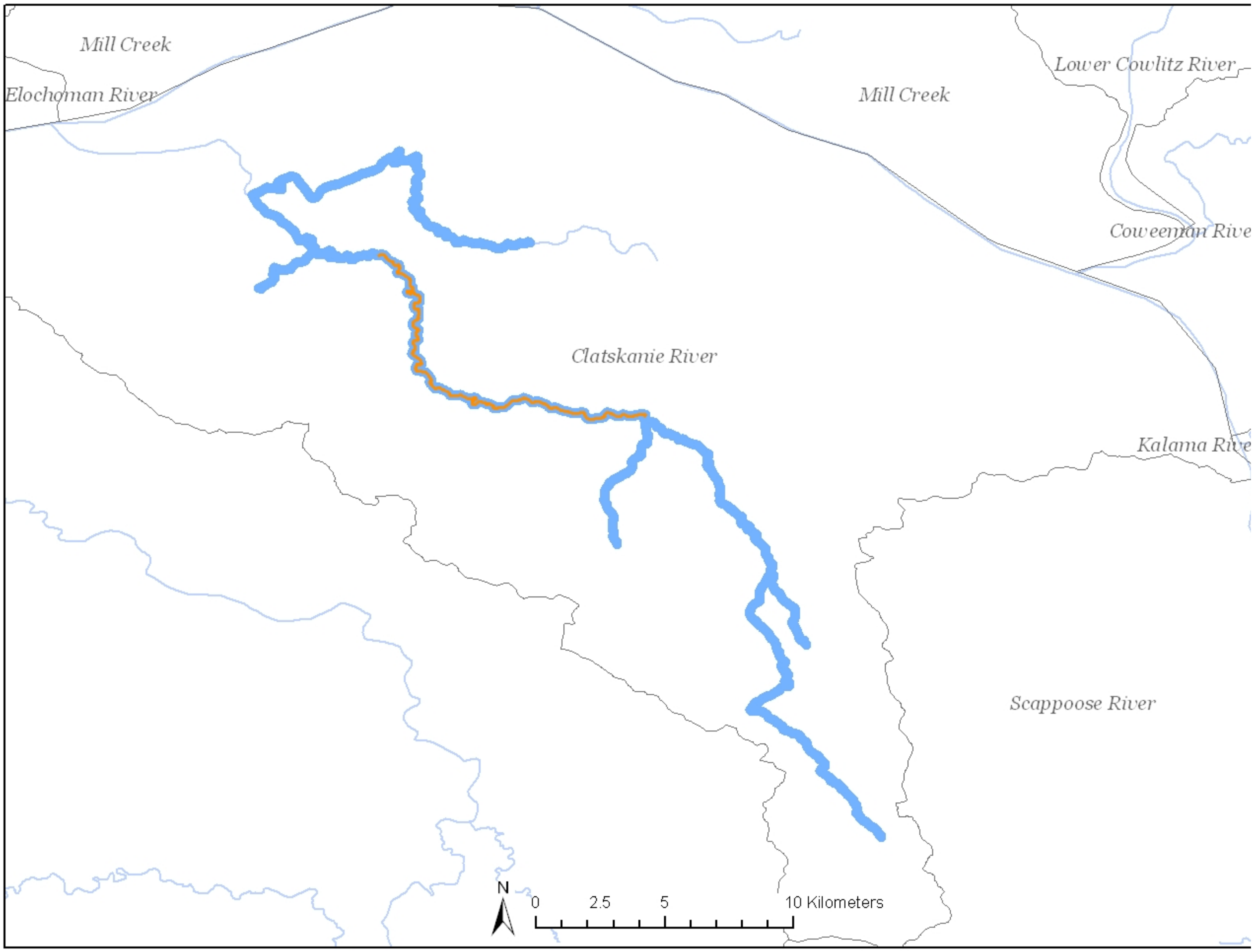


Figure A16. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in the Clatskanie River.

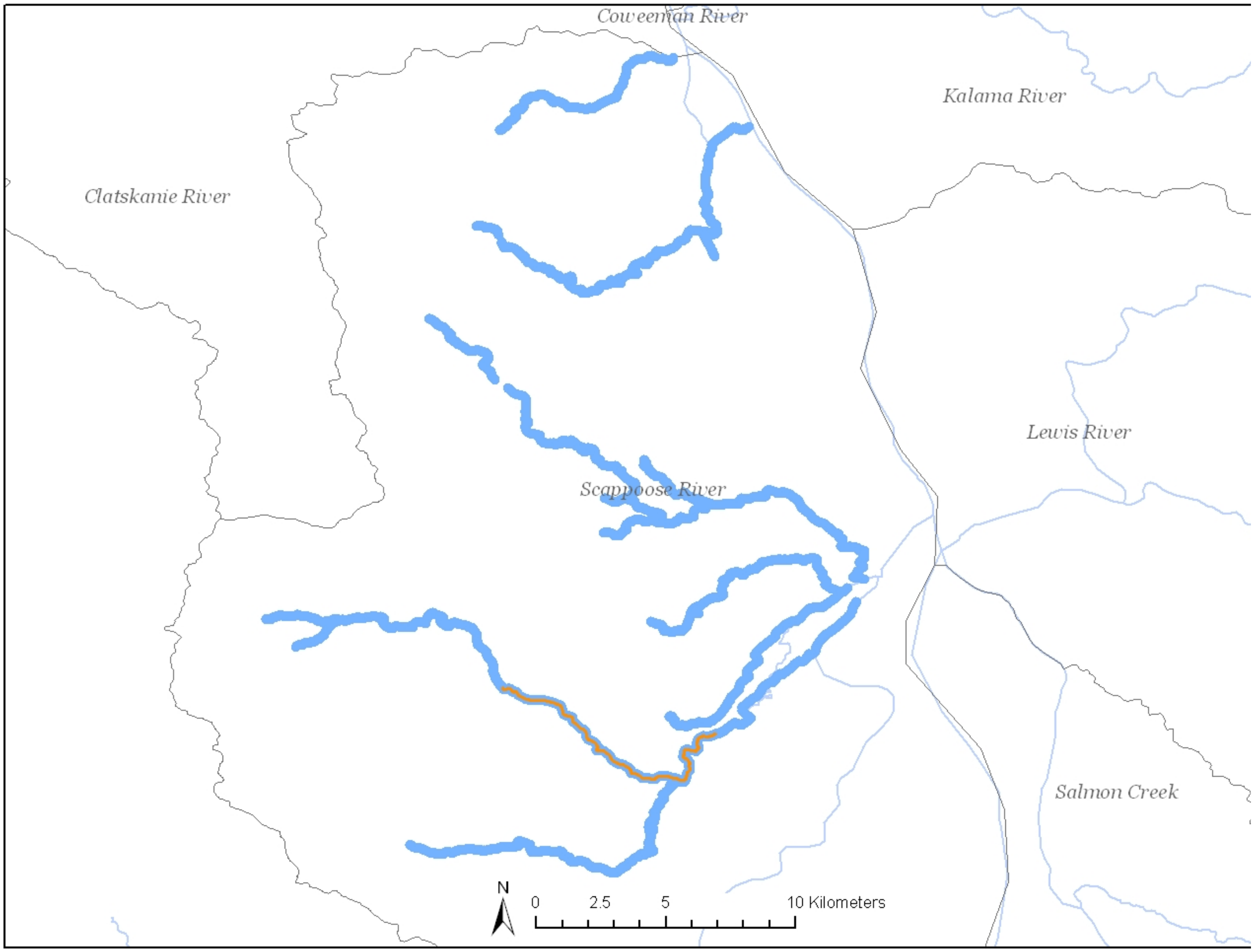


Figure A17. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in the Scappoose River.

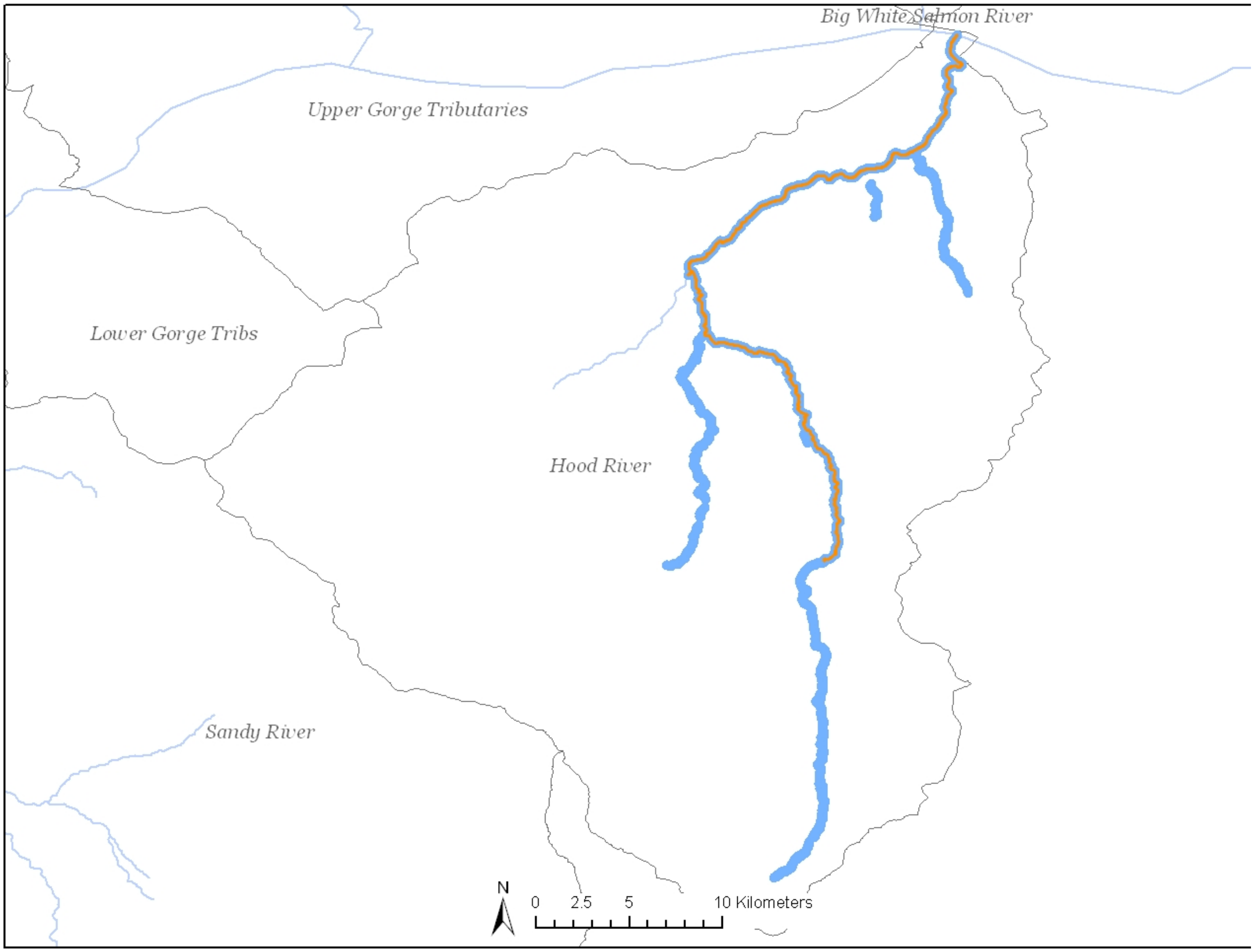


Figure A18. Comparison of old (thick blue line) and revised (thin orange line) spawning distribution in the Hood River.

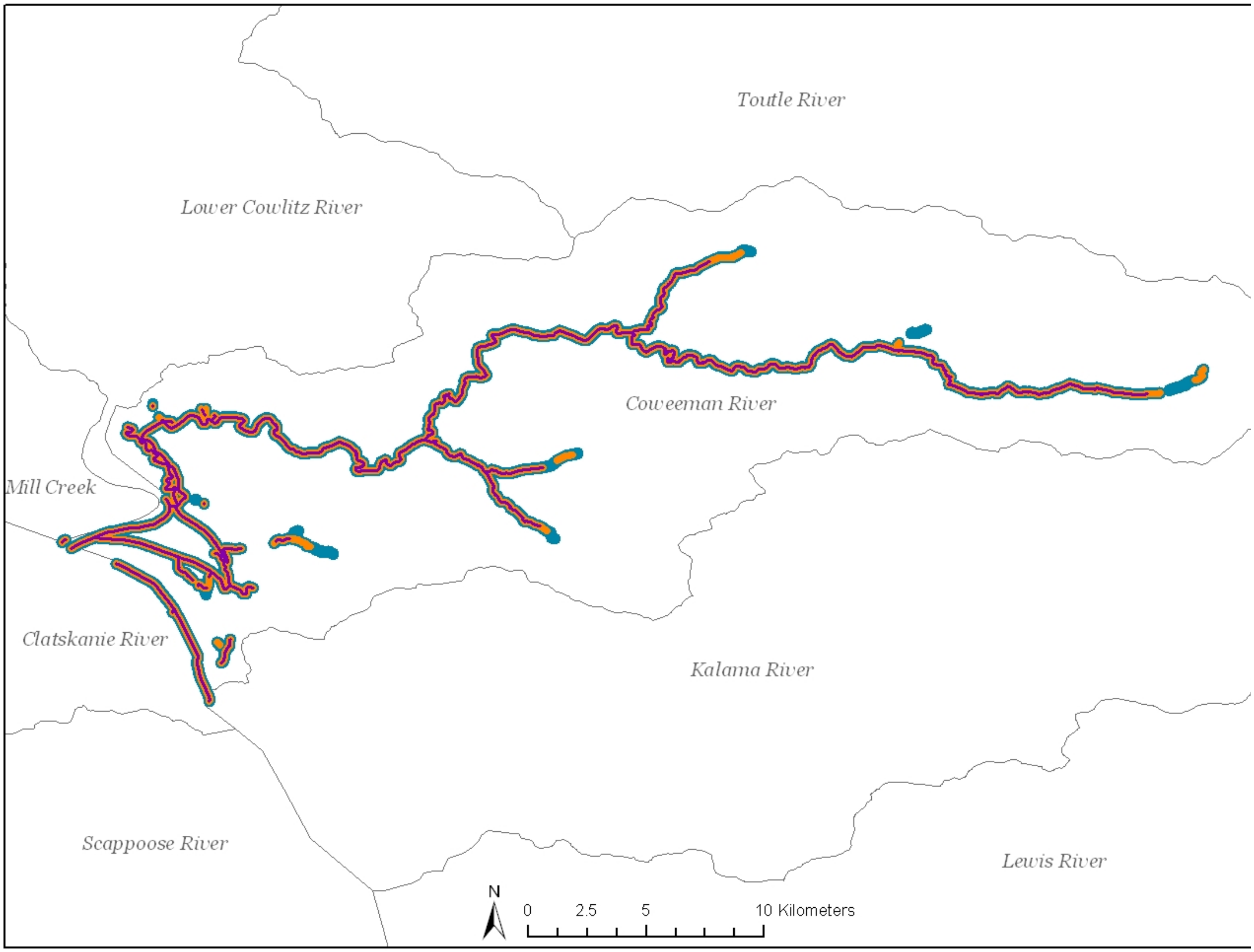


Figure A19. Coweeman spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

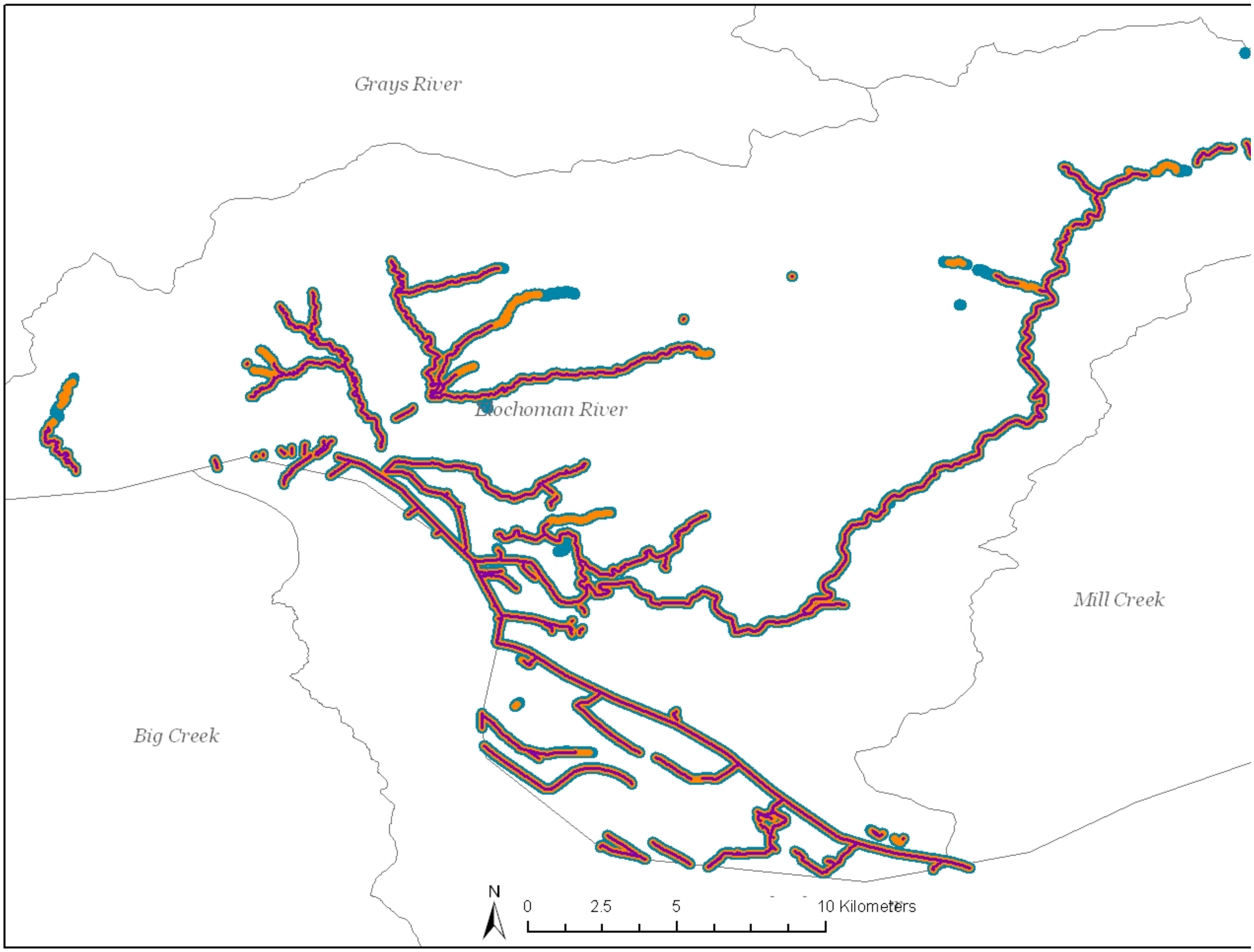


Figure A20. Elochoman spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

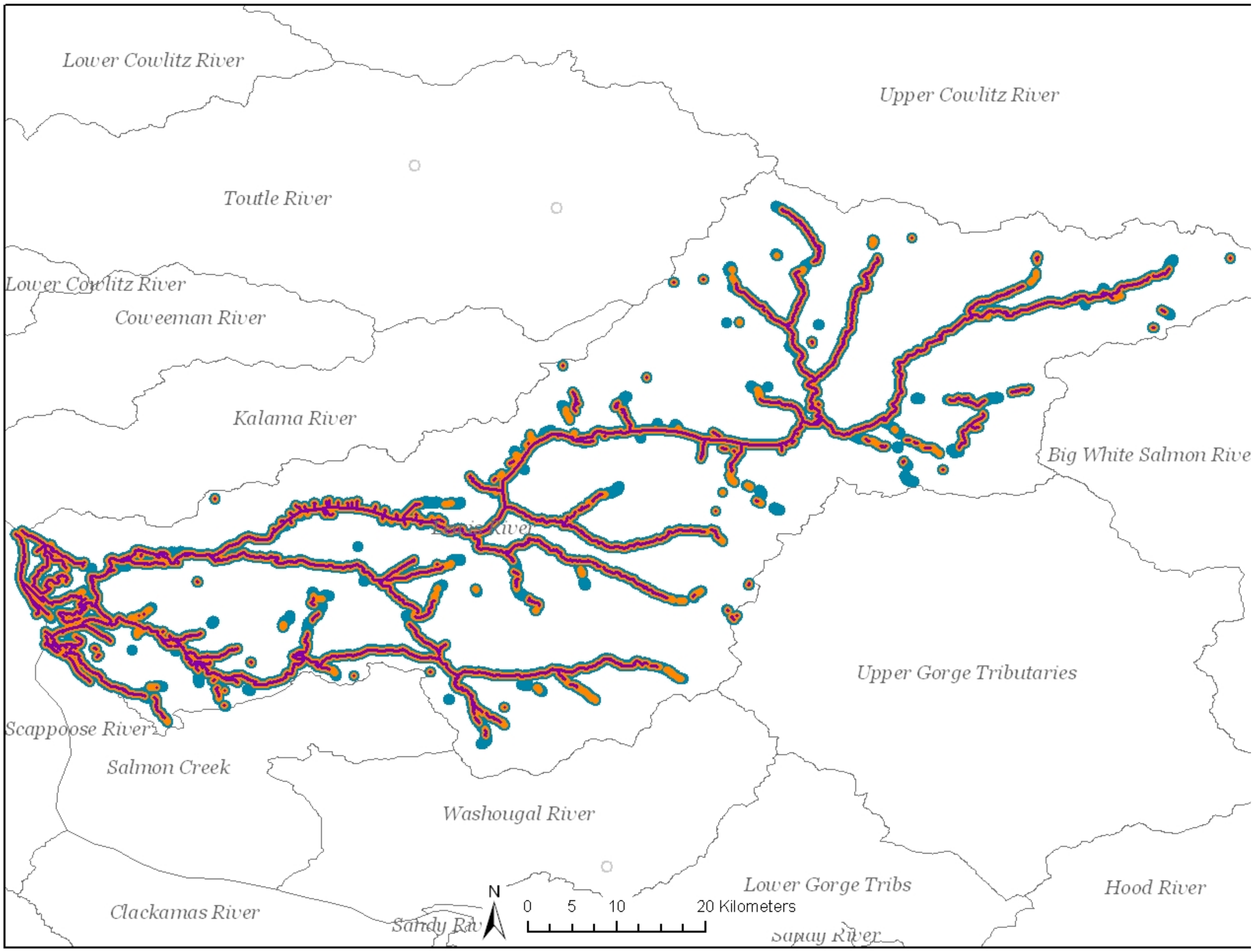


Figure A21. Lewis spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

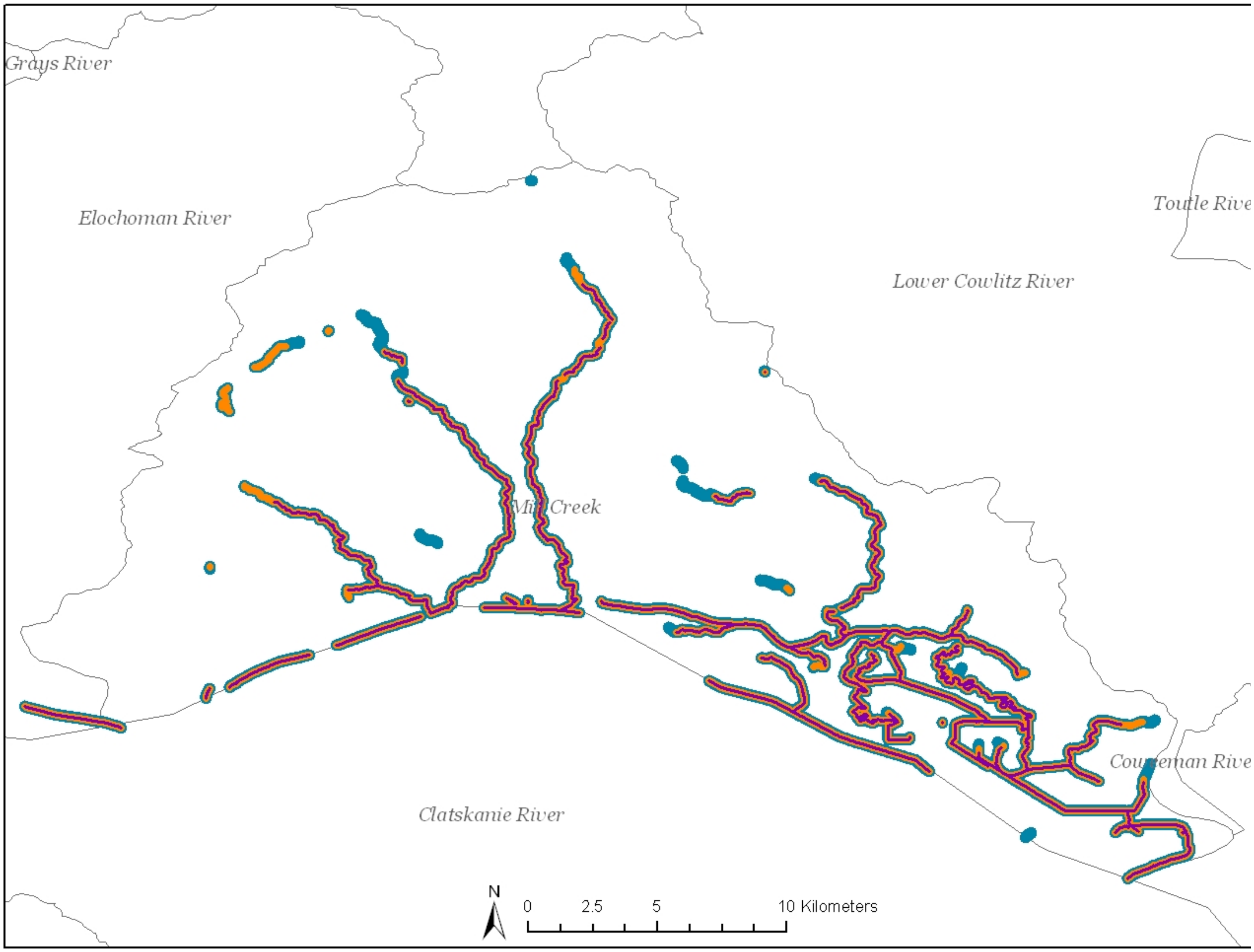


Figure A22. Mill/Abernathy/Germany spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

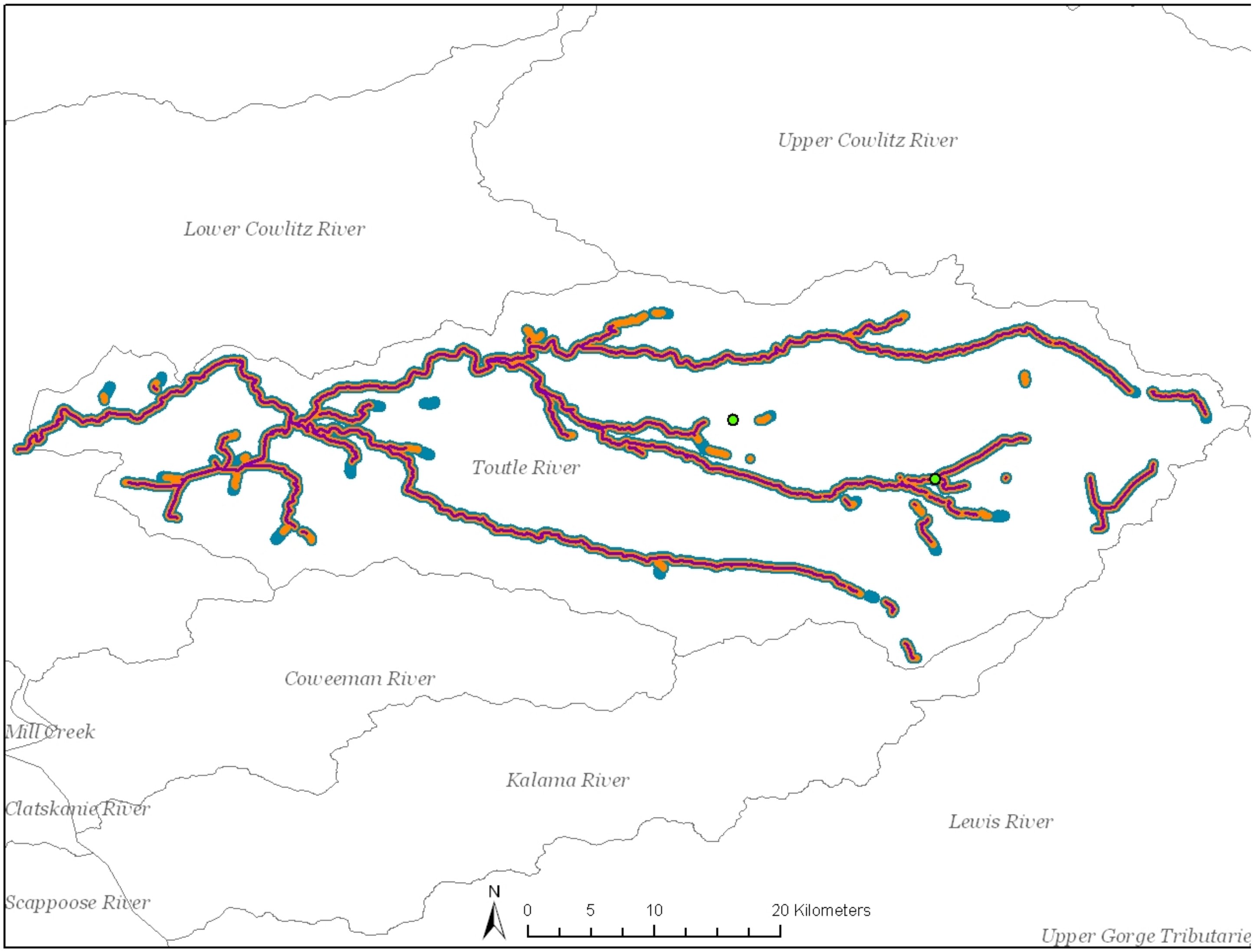


Figure A23. Toutle spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

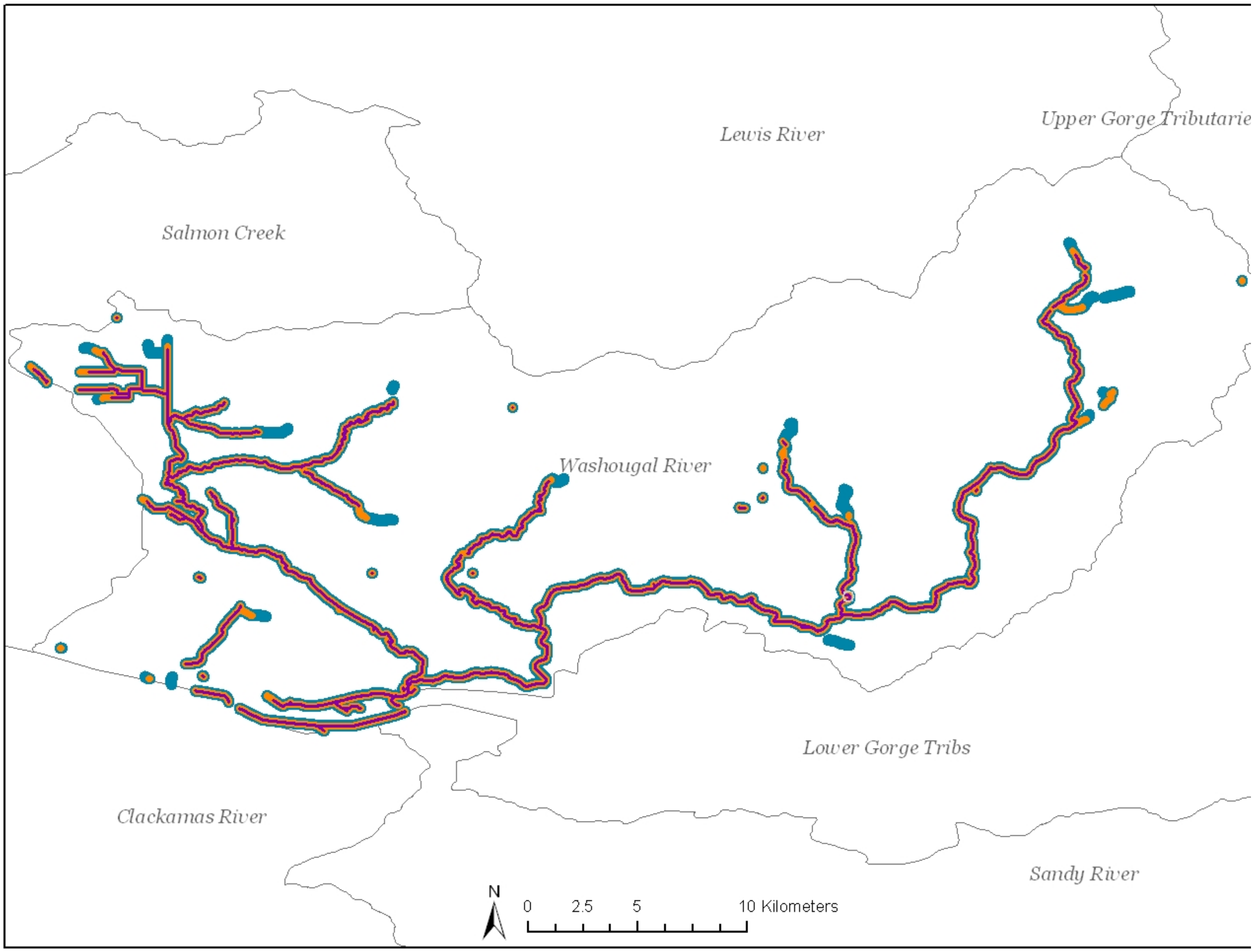


Figure A24. Washougal spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

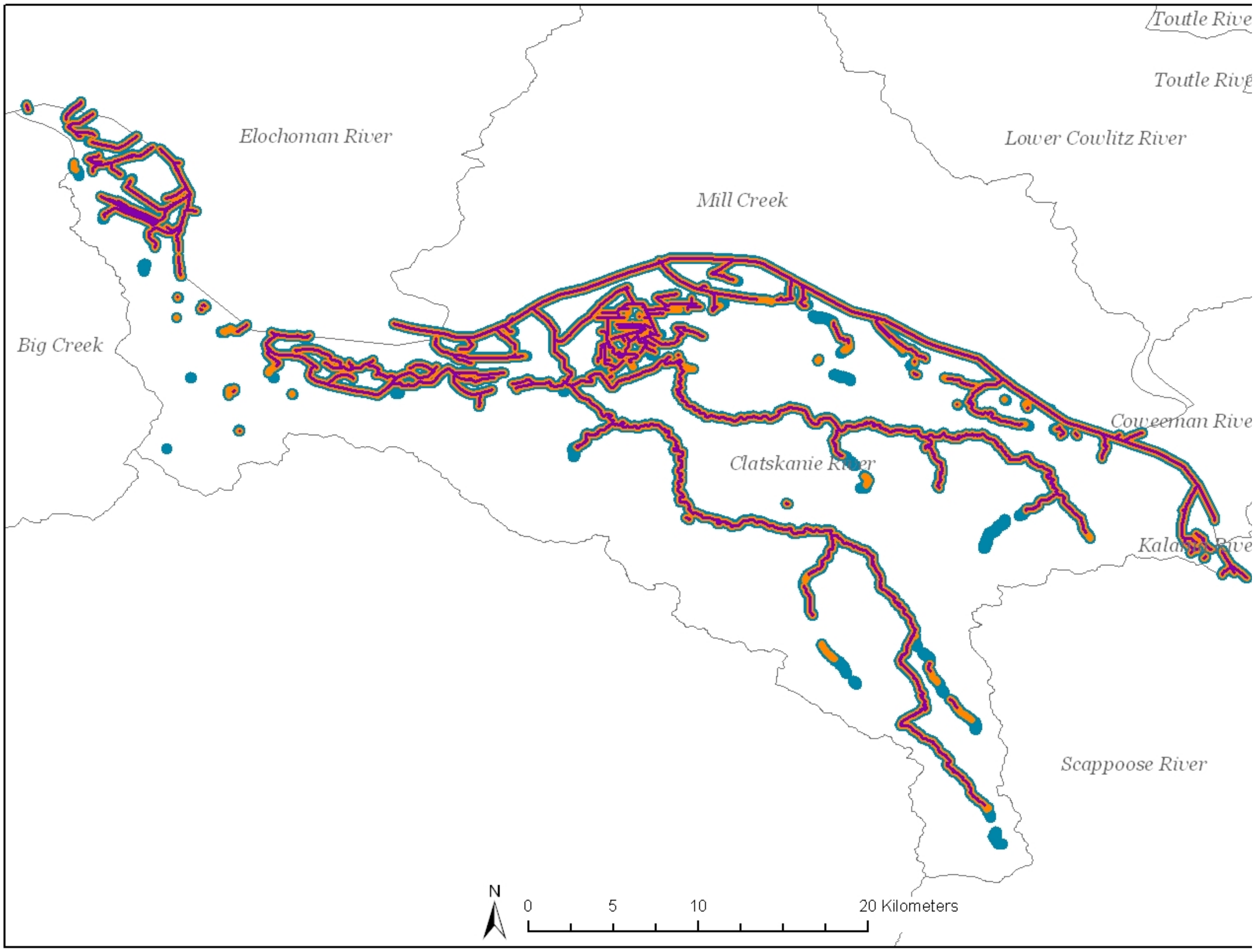


Figure A25. Clatskanie spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

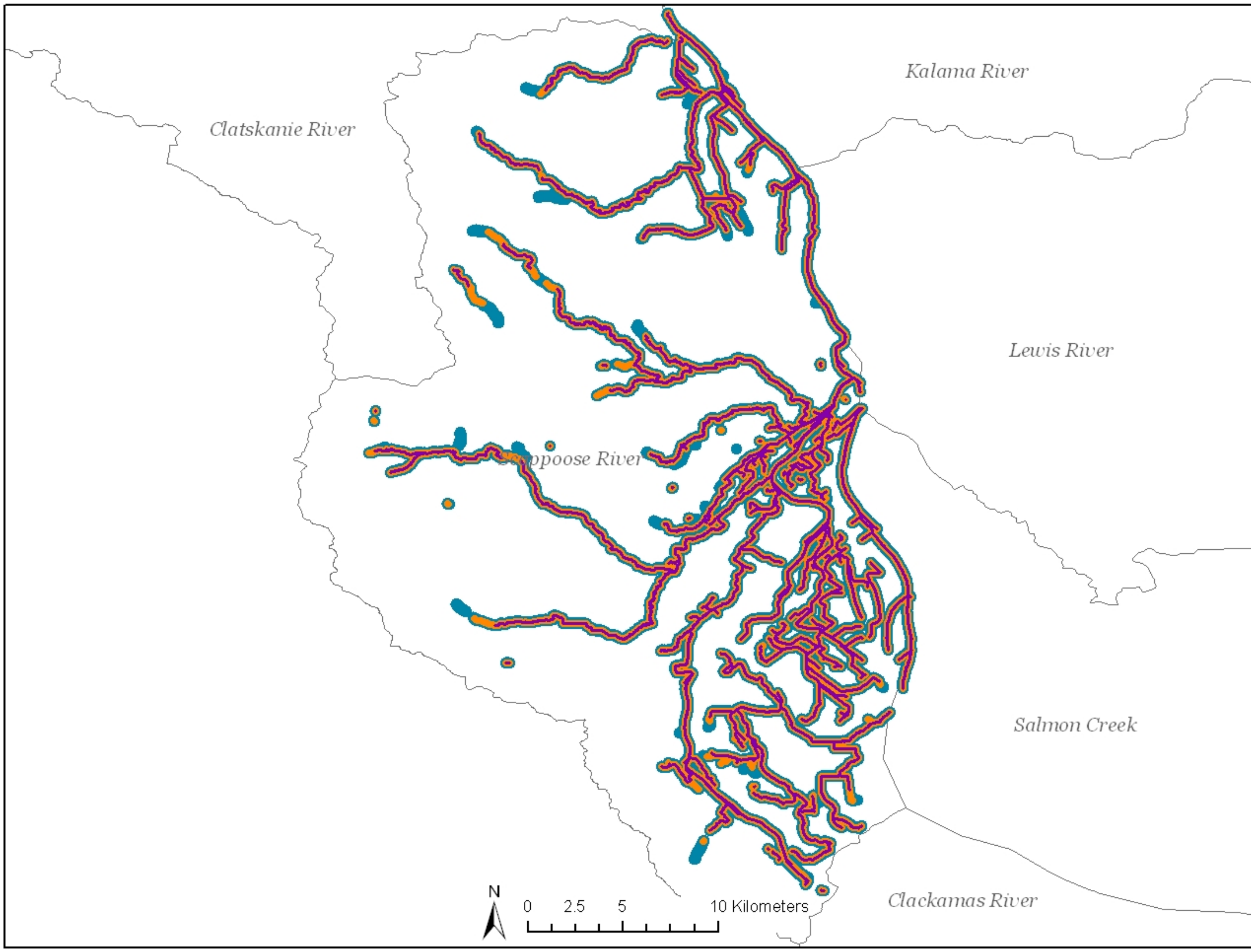


Figure A26. Scappoose spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

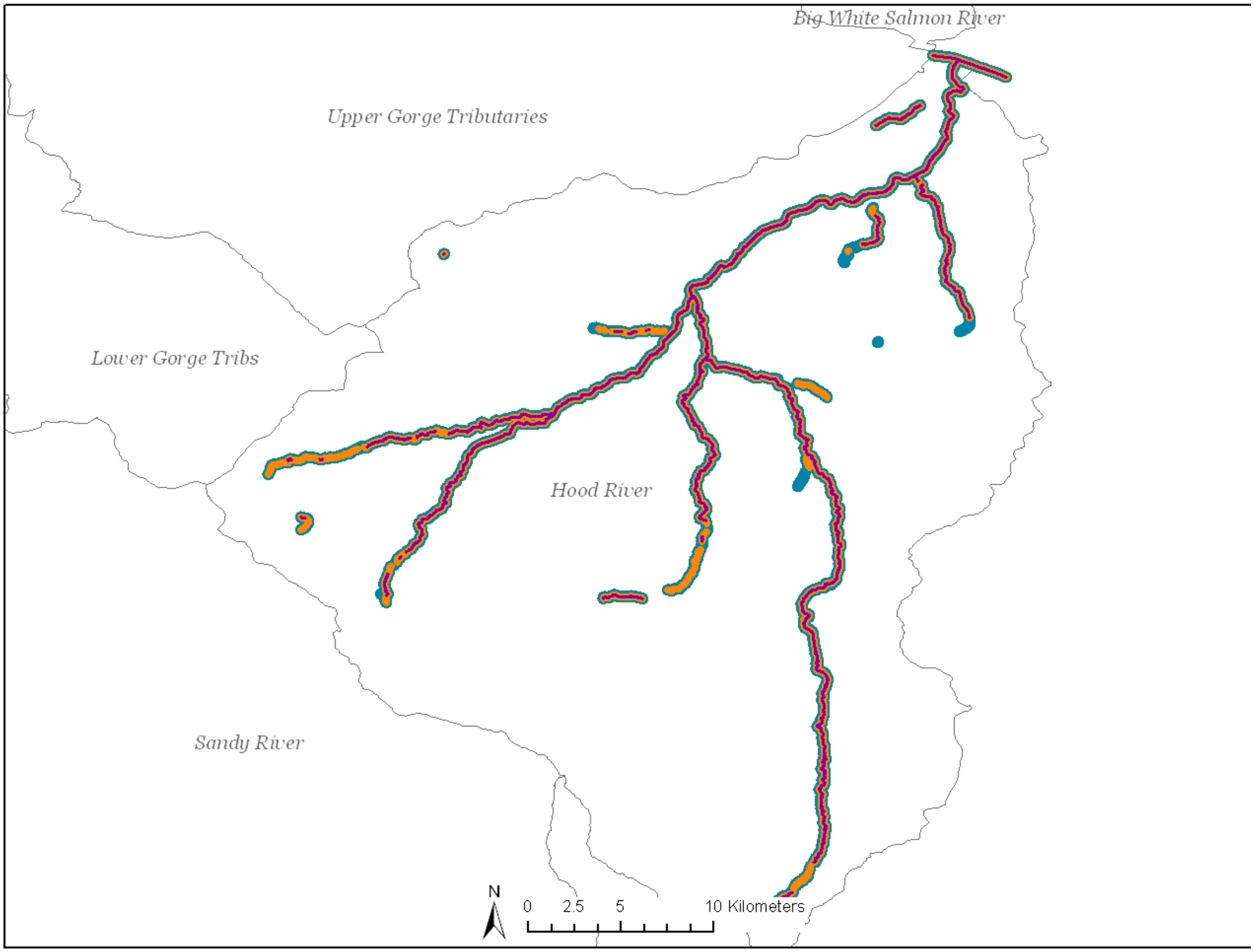


Figure A27. Hood spawning distribution, with likelihood threshold of 0.4 (thick blue), 0.5 (orange), or 0.6 (thin magenta).

Habitat Appendix B. Translating Freshwater Habitat Restoration Actions from Recovery Plans into Recovery Scenarios

Here, we illustrate the approach we took to translating restoration actions called for in recovery plans into a scenario that we could model. In Appendix C, we reproduce the portions of tables from the Washington recovery plan (LCFRB 2004) and the April draft of the Oregon recovery plan (ODFW 2009) that we used to create the "recovery scenario" for our modeling. Target tule Chinook populations in Washington were the Lewis, Washougal, Elochoman, Mill/Germany/Abernathy, Coweeman, and Toutle, and target populations in Oregon were the Clatskanie, Scappoose, and Hood.

Locations. We modeled actions only on reaches identified by recovery plans, or on reaches within subwatersheds identified. For Washington populations, we limited selection to locations listed as 1st Priority locations (generally "Tier 1" or "Tier 2" reaches or "Group A" subwatersheds). For Oregon, we limited selection to reaches identified on maps provided by ODFW. Locations from recovery plans were spatially crosswalked to reaches used in modeling (stream dataset created by NetStream).

Translation. We exemplify our translation approach for Washington populations in Figure B1 for the East Fork Lewis. There, text highlighted in yellow indicates relevant pieces from the recovery plan that we modeled. Text highlighted in orange indicates that we either could not model that feature or that it did not apply to fall Chinook salmon. **Blue text** to the right of each numbered "measure" indicates the freshwater habitat restoration action which we felt best matched that measure, and is how we modeled each. For example, we would model "Restore floodplain function and channel migration processes…" and "Create/restore off-channel and side-channel habitat" as *floodplain reconnection*. Within each measure in the recovery plan, we highlight the aspect which we believe our modeling applies to; there are numerous aspects which we could not model. See Table 4 of the main document for a description of how each restoration action was modeled. Table B1 shows exactly how we interpreted the recovery plan into our modeling scenario. For Oregon, we used a similar approach (see Figures B2-B7 and Tables B2-B4). However, it was sometimes possible to link multiple actions that we could model to a single measure. For these reaches, we apportioned all types equally.

In our recovery scenarios, multiple types of actions could occur simultaneously on the same reach. We only modeled actions that specified that benefits should be expected for "fall Chinook" or "All Species". We omitted measures/actions that targeted only other species. Furthermore, actions were only modeled on reaches that fell within the spatial extent of spawning distributions. We modeled the effect of restoration actions through time (in 4 time steps; see Appendix B for a full explanation). For each time step, reaches were randomly selected for each applicable type of restoration. Each subsequent time step included actions selected for that time step as well as those from all previous time steps (i.e., cumulatively).

Final reach-level restoration actions we modeled as part of the recovery scenario are provided in Appendix D. Each tab in the spreadsheet holds data for one population, so named. Values in columns D-I indicate priority level from the recovery plans (1=1st, which is what we modeled, and 2=2nd, which we did not model) and values in columns K-P indicate the time step during which each first-priority action was modeled in the recovery scenario.

Other assumptions. We assumed that each reach selected for restoration was completely restored to its full potential, and along its entire length (both banks). See Appendix E for a description of when actions were assumed to become effective at improving fish responses.

REFERENCES

LCFRB (Lower Columbia Fish Recovery Board). 2004. Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan. http://www.lcfrb.gen.wa.us/December%20Final%20%20Plans/lower_columbia_salmon_recovery_a.htm.

ODFW (Oregon Department of Fish and Wildlife). 2009. Lower Columbia River Conservation and Recovery Plan for Oregon Populations of Salmon and Steelhead. DRAFT April 24, 2009. http://www.dfw.state.or.us/fish/CRP/lower_columbia_plan.asp.

Figure B1. East Fork Lewis (WA). Table 16, excerpted from the recovery plan (LCFRB 2004).

#1 – Protect stream corridor structure and function — **Riparian protection**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect floodplain function and channel migration processes B. Protect riparian function C. Protect access to habitats D. Protect instream flows through management of water withdrawals E. Protect channel structure and stability F. Protect water quality G. Protect the natural stream flow regime	Potentially addresses many limiting factors	Potentially addresses many limiting factors	All Species	There currently are productive habitats for steelhead in the upper basin, especially in the portion of the basin upstream of Sunset Falls within National Forest. Significant degradation of stream corridor habitat has occurred over the years in the private, mixed-use lands in the lower and middle basin. This area has historically been utilized for timber harvest, agriculture, mining, and rural residential uses and is experiencing increasing development pressure. Preventing further degradation of stream channel structure, riparian function, and floodplain function will be an important component of recovery.

Priority Locations

1st- Tier 1 or 2 reaches with functional riparian conditions according to the IWA
Reaches: EF Lewis 19B, 19C & 20
2nd- Tier 1 or 2 reaches in mixed-use lands at risk of further degradation
Reaches: EF Lewis 1, 3-13; McCormick Creek; Lockwood Creek; Mill Creek; LW Rock Creek
3rd- All remaining reaches

#2 – Protect hillslope processes — **Upland reforestation**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Manage forest practices to minimize impacts to sediment supply processes, runoff regime, and water quality B. Manage agricultural practices to minimize impacts to sediment supply processes, runoff regime, and water quality C. Manage growth and development to minimize impacts to sediment supply, runoff regime, and water quality	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to sediment supply, water quality, and runoff processes	All species	There currently are functioning runoff and sediment supply processes in portions of the headwaters and the Rock Creek basin. Most of the remainder of the basin is moderately impaired with respect to sediment supply. Mixed-use lands are mostly impaired with respect to runoff due to lack of forest cover and impervious surfaces. Preventing additional degradation will be important for habitat recovery.

Priority Locations

1st- Functional subwatersheds contributing to Tier 1 or 2 reaches (functional for sediment *or* flow according to the IWA – local rating)
Subwatersheds: 50612, 50502, 50508, 50202, 50101, 50401, 50301,50402, 50403, 50405
2nd- All other functional subwatersheds plus Moderately Impaired subwatersheds contributing to Tier 1 or 2 reaches
Subwatersheds: 50201, 50203, 50302, 50404, 50501, 50503, 50505, 50506, 50507, 50509, 50602, 50603, 50604, 50605, 50607, 50608, 50609, 50611, 50613, 50614, 50615, 50616
3rd- All other Moderately Impaired subwatersheds plus Impaired subwatersheds contributing to Tier 1 or 2 reaches
Subwatersheds: 50601, 50606, 50610

#3 - Restore floodplain function and channel migration processes in the mainstem and major tributaries — **Floodplain reconnection**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Set back, breach, or remove artificial confinement structures	• Bed and bank erosion • Altered habitat unit composition • Restricted channel migration • Disrupted hyporheic processes • Reduced flood flow dampening • Altered nutrient exchange processes • Channel incision • Loss of off-channel and/or side-channel habitat • Blockages to off-channel habitats	• Floodplain filling • Channel straightening • Artificial confinement	All species	Much of the lower mainstem has been subject to artificial channel confinement associated with mining, residential development, and agriculture. Restoring floodplain function and channel migration processes will lead to improvements in riparian and channel habitats. Selective breaching, setting back, or removing confining structures would help to restore floodplain and CMZ function as well as facilitate the creation of off-channel and side channel habitats. There are challenges with implementation due to private lands, existing infrastructure already in place, potential flood risk to property, and large expense.

Priority Locations

1st- Tier 1 reaches with hydro-modifications (obtained from EDT ratings)
Reaches: EF Lewis 4, 5, 6, 8 & 19A; Rock Creek 3
2nd- Tier 2 reaches with hydro-modifications
Reaches: EF Lewis 1, 3, 19B & 20; Lewis 1 tidal; Lockwood Creek; LW Rock Creek
3rd- Other reaches with hydro-modifications
Reaches: EF Lewis 2; Brezee Creek; Dean Creek; Green Fork; Manley Creek; Mason Creek

#4- Restore degraded hillslope processes on forest, agricultural, and developed lands **Decommission roads**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Upgrade or remove problem forest roads B. Reforest heavily cut areas not recovering naturally C. Employ agricultural Best Management Practices with respect to contaminant use, erosion, and runoff D. Reduce watershed imperviousness E. Reduce effective stormwater runoff from developed areas	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to water quality and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest, road building, agriculture, and development. These processes must be addressed for reach-level habitat recovery to be successful.
Priority Locations				
1st- Moderately impaired or impaired subwatersheds contributing to Tier 1 reaches (mod. impaired or impaired for sediment *or* flow according to IWA – local rating) Subwatersheds: 50201, 50203, 50302, 50404, 50501, 50503, 50505, 50506, 50507, 50509, 50603, 50604, 50605, 50613, 50614, 50615, 50616, 50502, 50508, 50202, 50101, 50401, 50301, 50405 2nd- Moderately impaired or impaired subwatersheds contributing to Tier 2 reaches Subwatersheds: 50612, 50611, 50608, 50607, 50602, 50609 3rd- Moderately impaired or impaired subwatersheds contributing to other reaches Subwatersheds: 50601, 50606, 50610				

#5 - Restore riparian conditions throughout the basin **Riparian planting**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore the natural riparian plant community B. Exclude livestock from riparian areas C. Eradicate invasive plant species from riparian areas	• Reduced stream canopy cover • Altered stream temperature regime • Reduced bank/soil stability • Reduced wood recruitment • Lack of stable instream woody debris • Exotic and/or invasive species • Bacteria	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to agriculture and residential development	All species	Riparian areas have been degraded by a host of land-uses including timber harvest, road building, mining, agriculture, and development. Although most riparian areas are now protected, natural recovery is limited in many areas by existing land use. The increasing abundance of exotic and invasive species is also a concern. Riparian restoration projects are relatively inexpensive and are often supported by landowners. There is a high potential benefit due to the many limiting factors that are addressed.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#6 – Restore degraded water quality with emphasis on temperature impairments **Riparian planting**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Exclude livestock from riparian areas B. Increase riparian shading C. Decrease channel width-to-depth ratios D. Reduce delivery of chemical contaminants to streams E. Address leaking septic systems	• Bacteria • Altered stream temperature regime • Chemical contaminants	• Timber harvest – riparian harvests • Riparian grazing • Leaking septic systems • Clearing of vegetation due to rural development and agriculture • Chemical contaminants from agricultural and developed lands	• All species	There are known temperature impairments throughout the basin. There are also known fecal coliform bacteria impairments, although bacteria is more of a human health concern than a fish health concern. Degraded riparian areas and cattle access to streams are contributing factors to both temperature and bacteria. Excluding livestock from riparian areas is particularly important along some of the heavily grazed tributaries. Leaking septic systems may be contributing to bacteria levels in areas with concentrated rural residential development. The degree of impact of agricultural pollutants is unknown and needs further assessment.
Priority Locations				
1st- Tier 1 or 2 reaches with 303(d) listings (2002-2004 draft list) Reaches: EF Lewis 8 (temperature and bacteria); EF Lewis 15, 16, 19A, 19B & 20 (temperature); EF Lewis 3, 11-13 (bacteria); Lockwood Creek (bacteria); LW Rock Creek (bacteria); McCormick Creek (bacteria); Rock Creek 4 (bacteria) 2nd- Other reaches with 303(d) listings Reaches: EF Lewis 2 (bacteria); Brezee Creek (bacteria) 3rd- All remaining reaches				

#7 – Provide for adequate instream flows during critical periods

Could not model

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect instream flows through water rights closures and enforcement B. Restore instream flows through acquisition of existing water rights C. Restore instream flows through implementation of water conservation measures	• Stream flow – Maintain or improve flows during low-flow Summer months	• Water withdrawals	All species	Expanding growth has increased pressures for ground and surface water withdrawals. It is crucial that withdrawals are managed carefully to minimize impacts on aquatic resources. Instream flow management strategies for the EF Lewis Basin have been identified as part of Watershed Planning for WRIA 27 (LCFRB 2004). Strategies include water rights closures, setting of minimum flows, and drought management policies. This measure applies to instream flows associated with water withdrawals and diversions, generally a concern only during low flow periods. Hillslope processes also affect low flows but these issues are addressed in separate measures.
Priority Locations				
Entire Basin				

#8 – Restore access to habitat blocked by artificial barriers

Does not apply to Chinook

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers	• Blockages to channel habitats • Blockages to off-channel habitats	• Dams, culverts, in-stream structures	coho, winter steelhead, summer steelhead	As many as 30 miles of potentially accessible habitat are blocked by culverts or other barriers. The blocked habitat is believed to be marginal in the majority of cases and no individual barriers in themselves account for a significant portion of blocked miles (there are 23 barriers total). Passage restoration projects should focus only on cases where it can be demonstrated that there is good potential benefit and reasonable project costs.
Priority Locations				
1st- Culverts on McCormick, Brezee Creek & tribs, Mason Creek, Gee Creek (not in EF basin proper) 2nd- Other small tributaries with blockages				

#9 - Restore channel structure and stability

Instream placements

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Place stable woody debris in streams to enhance cover, pool formation, bank stability, and sediment sorting B. Structurally modify channel morphology to create suitable habitat C. Restore natural rates of erosion and mass wasting within river corridors	• Lack of stable instream woody debris • Altered habitat unit composition • Reduced bank/soil stability • Excessive fine sediment • Excessive turbidity • Embedded substrates	• None (symptom-focused restoration strategy)	All species	Channel structure and stability have been compromised by altered sediment and flow regimes, degraded riparian conditions, stream-adjacent gravel mining/processing, and confinement. Large wood installation projects could benefit habitat conditions in many areas although watershed processes contributing to wood deficiencies should be considered and addressed prior to placing wood in streams. Other structural enhancements to stream channels may be warranted in some places, particularly in reaches that have been simplified through channel straightening and confinement or that has experienced avulsions into streamside gravel processing ponds.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

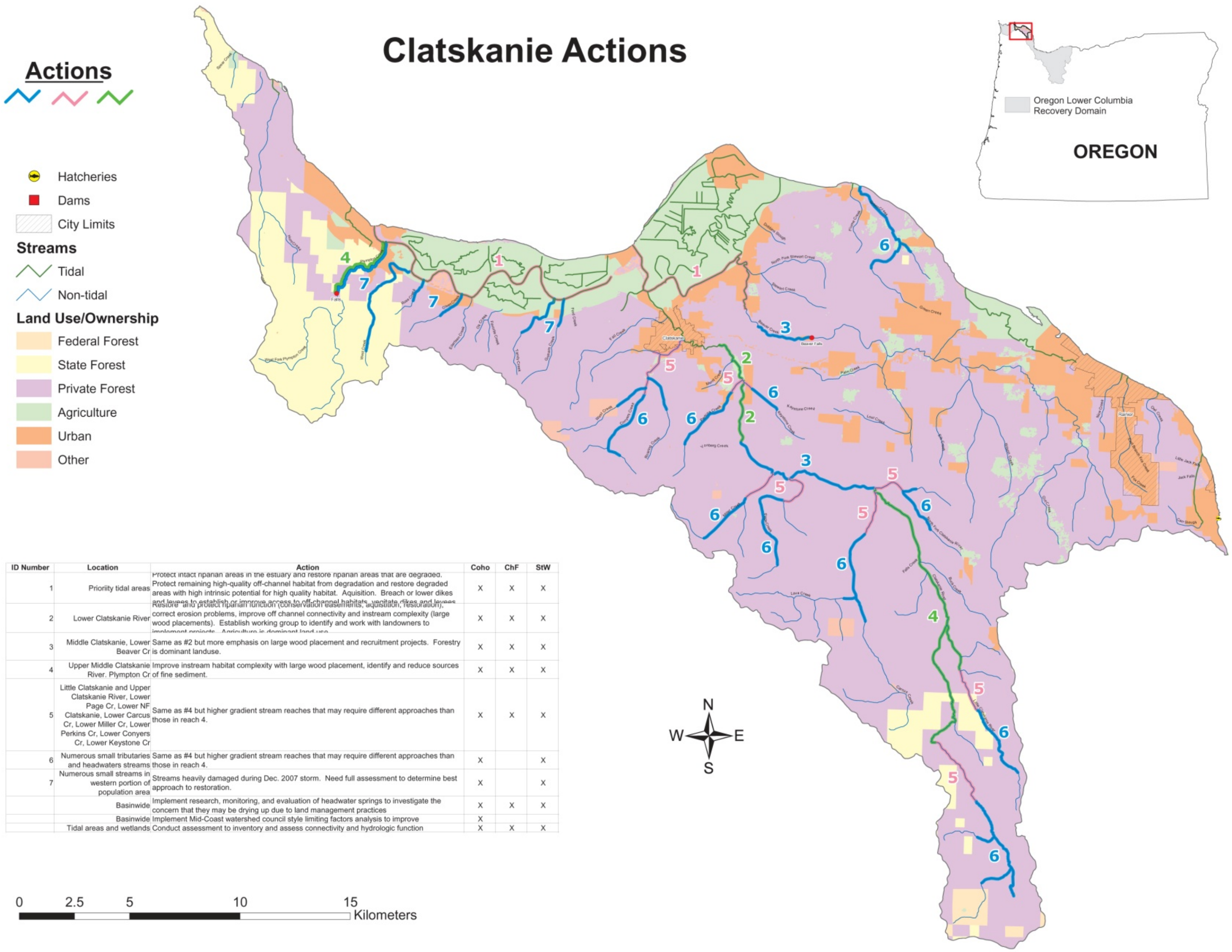
#10 – Create/restore off-channel and side-channel habitat

Does not apply to Chinook

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore historical off-channel and side-channel habitats where they have been eliminated B. Create new channel or off-channel habitats (i.e. spawning channels)	• Loss of off-channel and/or side-channel habitat	• Floodplain filling • Channel straightening • Artificial confinement	chum coho	There has been significant loss of off-channel and side-channel habitats, especially along the lower mainstem that has been extensively channelized. This has severely limited chum spawning habitat and coho overwintering habitat. Targeted restoration or creation of habitats would increase available habitat where full floodplain and CMZ restoration is not possible.
Priority Locations				
1st- Lower Mainstem EF Lewis 2nd- Other reaches that may have potential for off-channel and side-channel habitat restoration or creation				

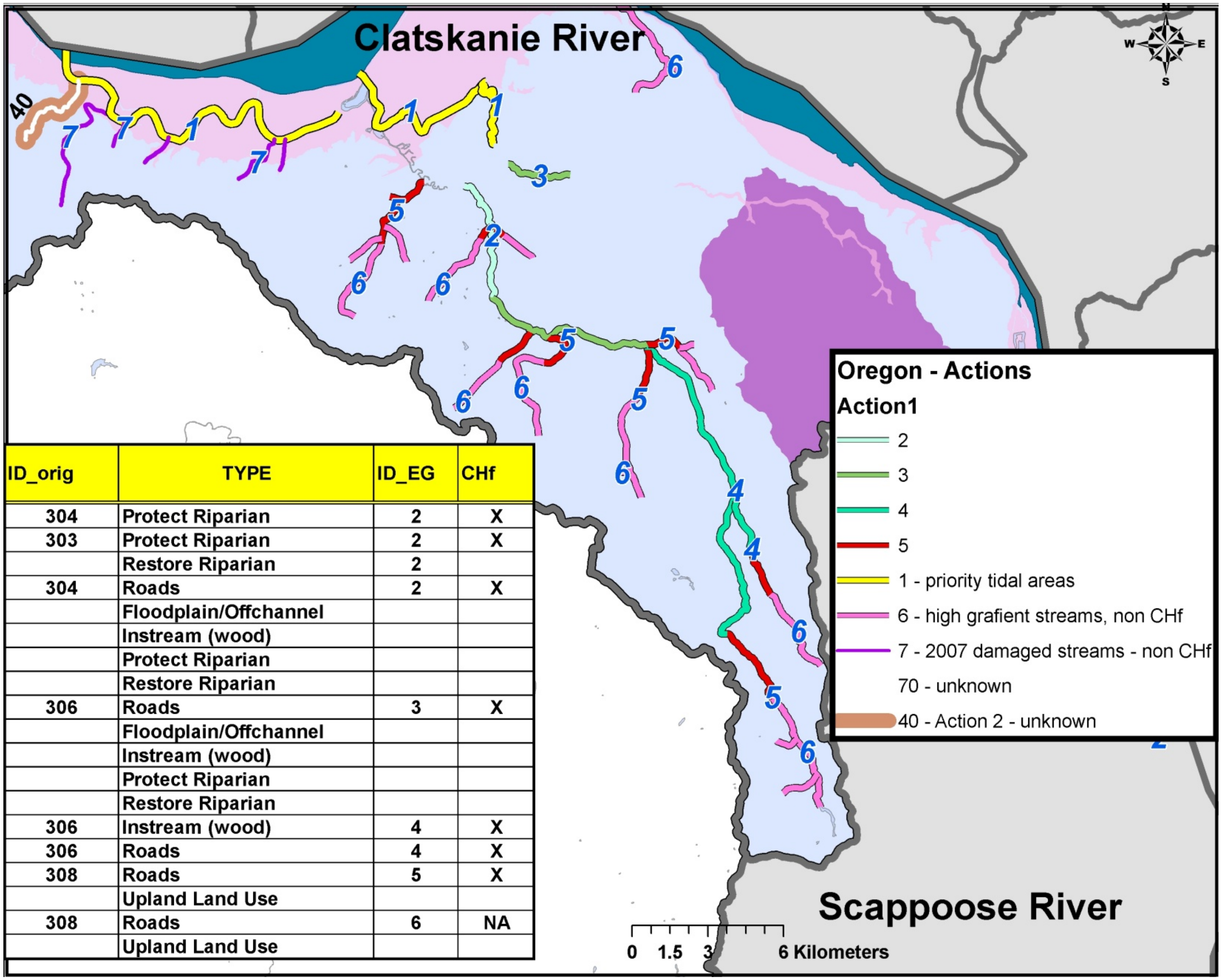
Table B1. The lookup table we used for assigning what types of restoration actions would occur on which reach in the East Fork Lewis tule fall Chinook recovery scenario. Measure number, submeasures, EDT Reach, Subwatersheds, and Priority refer to Table 16 in LCFRB (2004). Modeled Actions indicates how we interpreted the submeasures in our modeled scenario; for this project, we modeled only the first type of action listed, for transparency. We also modeled only reaches with Priority=1. Note that we could not model measure 7, and parts of measure 6, and that measures 8 and 10 were not modeled because they did not apply to fall Chinook. As well, some of these actions may occur in reaches not used by tule (i.e., outside of the spawning distribution extent), and therefore had no effect.

Measure	Submeasures	Modeled Actions	EDT Reach	Subwatersheds	Priority
1	Protect floodplain function and channel migration Protect riparian function Protect access to habitats Protect channel structure and stability	Riparian protection; Floodplain reconnection	EF Lewis 19B, 19C, 20		1
			EF Lewis 3-13, McCormick Creek, Lockwood Creek, Mill Creek, LW Rock Creek		2
2	Manage forest practices Manage ag practices Manage growth and development	Upland reforestation; Deommission roads		50101, 50202, 50301, 50401-3, 50405, 50502, 50508, 50612	1
				50201 , 50203, 50302, 50404, 50501, 50503, 50505, 50506-7, 50509, 50602-5, 50607-11, 50611,	2
3	modify or remove artificial channel confinement structures	Floodplain reconnection	EF Lewis 4-6, 8, 19A, Rock Creek		1
			EF Lewis 1, 3, 19B, 20, Lewis 1tidal, Lockwood Creek. LW Rock Creek		2
4	Upgrade or remove problem forest roads Reforest heavily cut areas that aren't recovering Employ agriculture best management (contaminant use), erosion and runoff Reduce watershed imperviousness	Deommission roads; Upland reforestation		50101, 50201-3, 50301-2, 50401, 50404-5, 50501-3, 50505-9, 50603-5, 50613-16	1
	Reduce effective stormwater runoff from develeoped areas			50602, 50607-9, 50611-12	2
5	Restore the natural riparian plant community Exclude livestock from riparian Eradicate invasive plants	Riparian planting	EF Lewis 4-10, 12-13, 15, 17-18, 19A, Rock Creek 1-4		1
			EF Lewis 1, 3, 11, 16, 19B, 19C, Lewis 1tidal, Little Cr, Lockwood Cr, LW Rock Cr, McCormick Cr, Mill Cr, Slide		2
6	Increase riparian shading	Riparian planting	EF Lewis 8, 15-16, 19A, 19B, 20		1
	<other submeasures we could not model>				
7		could not model			
8	restore access to isolated habitats blocked by culverts, dams or other barriers	Barrier removal (does not apply to fall Chinook)	McCormick Creek Brezee Creek Brezee Creek Tribs Mason Creek Gee Creek		1
			Other small tribs with blocks		2
9	Place woody debris in streams Sturcturally modify channel morphology to create habitat Restore natural rates of erosion and mass wasting within river corridors	Instream placements	EF Lewis 4-10, 12-13, 15, 17-18, 19A, Rock Creek 1-4		1
			EF Lewis 1, 3, 11, 16, 19B, 19C, Lewis 1tidal, Little Cr, Lockwood Cr, LW Rock Cr, McCormick Cr, Mill Cr, Slide		2
10	restore historical off-channel and sidechannel habitats	Floodplain reconnection (does not apply to fall Chinook)	EF Lewis 4-10		1
	create new channels or spawning channels		others with potential		2



ID Number	Location	Action	Coho	ChF	StW
1	Prioriity tidal areas	Protect intact riparian areas in the estuary and restore riparian areas that are degraded. Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high quality habitat. Aquisition. Breach or lower dikes and levees to establish or improve access to off-channel habitats, vegitate dikes and levees	X	X	X
2	Lower Clatskanie River	Restore and protect riparian function (conservation easements, aquisition, restoration), correct erosion problems, improve off channel connectivity and instream complexity (large wood placements). Establish working group to identify and work with landowners to implement projects. Agriculture is dominant land use.	X	X	X
3	Middle Clatskanie, Lower Beaver Cr	Same as #2 but more emphasis on large wood placement and recruitment projects. Forestry is dominant landuse.	X	X	X
4	Upper Middle Clatskanie River. Plympton Cr	Improve instream habitat complexity with large wood placement, identify and reduce sources of fine sediment.	X	X	X
5	Little Clatskanie and Upper Clatskanie River, Lower Page Cr, Lower NF Clatskanie, Lower Carcus Cr, Lower Miller Cr, Lower Perkins Cr, Lower Conyers Cr, Lower Keystone Cr	Same as #4 but higher gradient stream reaches that may require different approaches than those in reach 4.	X	X	X
6	Numerous small tributaries and headwaters streams	Same as #4 but higher gradient stream reaches that may require different approaches than those in reach 4.	X		X
7	Numerous small streams in western portion of population area	Streams heavily damaged during Dec. 2007 storm. Need full assessment to determine best approach to restoration.	X		X
	Basinwide	Implement research, monitoring, and evaluation of headwater springs to investigate the concern that they may be drying up due to land management practices	X	X	X
	Basinwide	Implement Mid-Coast watershed council style limiting factors analysis to improve	X		
	Tidal areas and wetlands	Conduct assessment to inventory and assess connectivity and hydrologic function	X	X	X

Figure B2. Map provided by ODFW showing locations and types of suggested restoration actions from the recovery plan for Clatskanie River salmonids (Chf = fall Chinook).

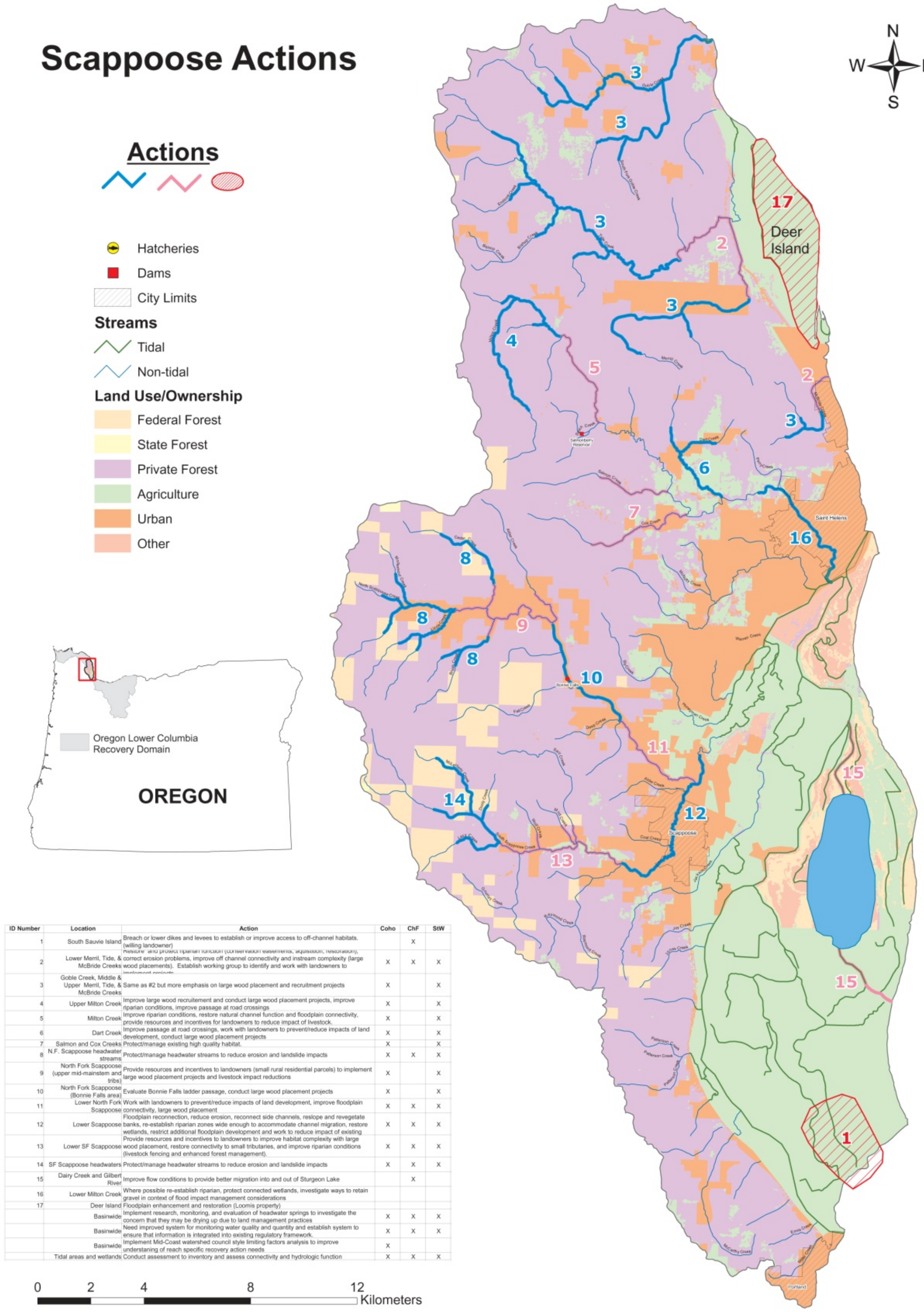


ID_orig	TYPE	ID_EG	CHf
304	Protect Riparian	2	X
303	Protect Riparian	2	X
	Restore Riparian	2	
304	Roads	2	X
	Floodplain/Offchannel		
	Instream (wood)		
	Protect Riparian		
	Restore Riparian		
306	Roads	3	X
	Floodplain/Offchannel		
	Instream (wood)		
	Protect Riparian		
	Restore Riparian		
306	Instream (wood)	4	X
306	Roads	4	X
308	Roads	5	X
	Upland Land Use		
308	Roads	6	NA
	Upland Land Use		

Figure B3. Map showing locations where each type of restoration action could occur for Clatskanie River tule fall Chinook salmon (derived from Figure B2) specifically for tules and actions we could model. The inset is a condensed version of Table B2.

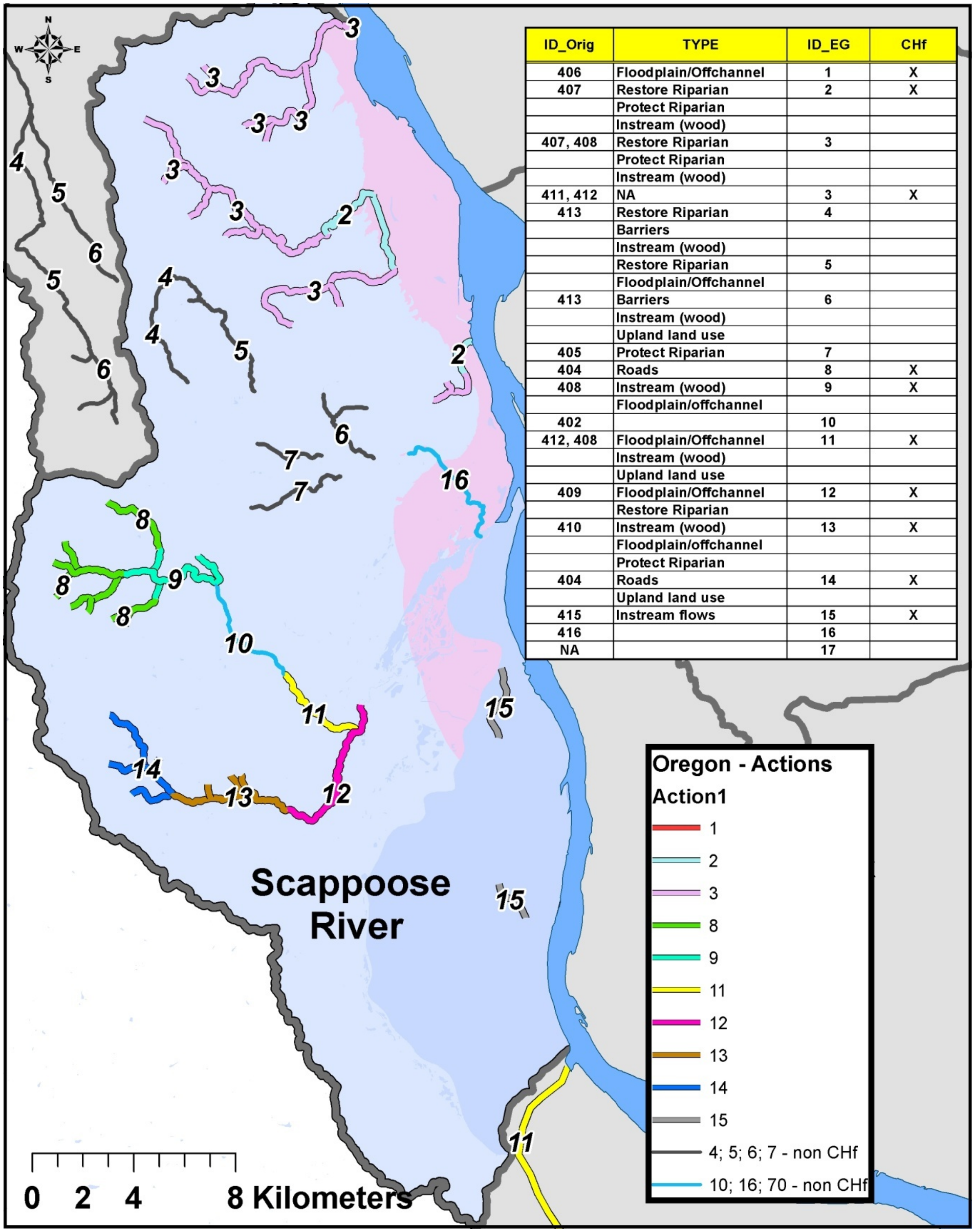
Table B2. Crosswalk approach for how we modeled actions (TYPE) suggested by the recovery plan (Actions-Submeasure). Note that information in this table was provided by ODFW, and is an updated version of Table 7-10 that will occur in the final recovery plan. Actions shown are only those affecting Clatskanie River fall Chinook salmon.

ID_orig	TYPE	Reach	ActionStreams	Actions - Submeasure
305	**Floodplain/Offchannel**	**1**	priority tidal areas	Protect intact riparian areas in the estuary and restore riparian areas that are degraded.
	Restore Riparian	**1**		Protect remaining high-quality off-channel habitat from degradation and restore degraded
	Barriers	**1**		areas with high intrinsic potential for high quality habitat. Aquisition. Breach or lower dikes
				and levees to establish or improve access to off-channel habitats, vegitate dikes and levees.
304	**Protect Riparian**	**2**	Middle Clatskanie,	Protect remaining high-quality off-channel habitat from degradation and restore degraded areas
		2	Lower Beaver Cr	areas with high intrinsic potential for high quality habitat.
303	**Protect Riparian**	**2**	Middle Clatskanie,	Protect intact riparian areas and restore riparian areas that are degraded.
	Restore Riparian	**2**	Lower Beaver Cr	(conservation easements, aquistition, restoration)
304	**Roads**	**2**	Lower Clatskanie River	Restore and protect riparian function (conservation easements, aquistition, restoration),
	Floodplain/Offchannel	**2**		correct erosion problems, improve off channel connectivity and instream complexity (large
	Instream (wood)	**2**		wood placements). Establish working group to identify and work with landowners to
	Protect Riparian	**2**		implement projects. Agriculture is dominant land use.
	Restore Riparian	**2**		
306	**Roads**	**3**	Middle Clatskanie,	Same as #2 but more emphasis on large wood placement and recruitment projects. Forestry
	Floodplain/Offchannel	**3**	Lower Beaver Cr	is dominant landuse.
	Instream (wood)	**3**		
	Protect Riparian	**3**		
	Restore Riparian	**3**		
306	**Instream (wood)**	**4**	Upper Middle Clatskanie	Improve instream habitat complexity with large wood placement,
		4	Plympton Cr	
306	**Roads**	**4**	Upper Middle Clatskanie	identify and reduce sources of fine sediment.
		4	Plympton Cr	
308	**Roads**	**5**	Little Clatskanie	identify and reduce sources of fine sediment.
	Upland Land Use	**5**	Upper Clatskanie	Same as #4 but higher gradient stream reaches that may require different approaches than
		5	Lower Page Cr.	those in reach 4
		5	Lower NF Clatskanie	
		5	Lower Carcus Cr.	
		5	Lower Miller Cr.	
		5	Lower Perkins Cr.	
		5	Lower Conyers Cr.	
		5	Lower Keystone Cr.	



ID Number	Location	Action	Coho	ChF	StW
1	South Sauvie Island	Breach or lower dikes and levees to establish or improve access to off-channel habitats. (willing landowner)		X	
2	Lower Merril, Tide, & McBride Creeks	Restore and protect riparian function (conservation easements, aquisition, restoration), correct erosion problems, improve off channel connectivity and instream complexity (large wood placements). Establish working group to identify and work with landowners to implement projects	X	X	X
3	Goble Creek, Middle & Upper Merril, Tide, & McBride Creeks	Same as #2 but more emphasis on large wood placement and recruitment projects	X		X
4	Upper Milton Creek	Improve large wood recruitement and conduct large wood placement projects, improve riparian conditions, improve passage at road crossings	X		X
5	Milton Creek	Improve riparian conditions, restore natural channel function and floodplain connectivity, provide resources and incentives for landowners to reduce impact of livestock.	X		X
6	Dart Creek	Improve passage at road crossings, work with landowners to prevent/reduce impacts of land development, conduct large wood placement projects	X		X
7	Salmon and Cox Creeks	Protect/manage existing high quality habitat.	X		X
8	N.F. Scappoose headwater streams	Protect/manage headwater streams to reduce erosion and landslide impacts	X	X	X
9	North Fork Scappoose (upper mid-mainstem and tribs)	Provide resources and incentives to landowners (small rural residential parcels) to implement large wood placement projects and livestock impact reductions	X		X
10	North Fork Scappoose (Bonnie Falls area)	Evaluate Bonnie Falls ladder passage, conduct large wood placement projects	X		X
11	Lower North Fork Scappoose	Work with landowners to prevent/reduce impacts of land development, improve floodplain connectivity, large wood placement	X	X	X
12	Lower Scappoose	Floodplain reconnection, reduce erosion, reconnect side channels, reslope and revegetate banks, re-establish riparian zones wide enough to accommodate channel migration, restore wetlands, restrict additional floodplain development and work to reduce impact of existing	X	X	X
13	Lower SF Scappoose	Provide resources and incentives to landowners to improve habitat complexity with large wood placement, restore connectivity to small tributaries, and improve riparian conditions (livestock fencing and enhanced forest management).	X	X	X
14	SF Scappoose headwaters	Protect/manage headwater streams to reduce erosion and landslide impacts	X	X	X
15	Dairy Creek and Gilbert River	Improve flow conditions to provide better migration into and out of Sturgeon Lake		X	
16	Lower Milton Creek	Where possible re-establish riparian, protect connected wetlands, investigate ways to retain gravel in context of flood impact management considerations			
17	Deer Island	Floodplain enhancement and restoration (Loomis property)			
	Basinwide	Implement research, monitoring, and evaluation of headwater springs to investigate the concern that they may be drying up due to land management practices	X	X	X
	Basinwide	Need improved system for monitoring water quality and quantity and establish system to ensure that information is integrated into existing regulatory framework.	X	X	X
	Basinwide	Implement Mid-Coast watershed council style limiting factors analysis to improve understaning of reach specific recovery action needs	X		
	Tidal areas and wetlands	Conduct assessment to inventory and assess connectivity and hydrologic function	X	X	X

Figure B4. Map provided by ODFW showing locations and types of suggested restoration actions from the recovery plan for Scappoose River salmonids (Chf = fall Chinook).

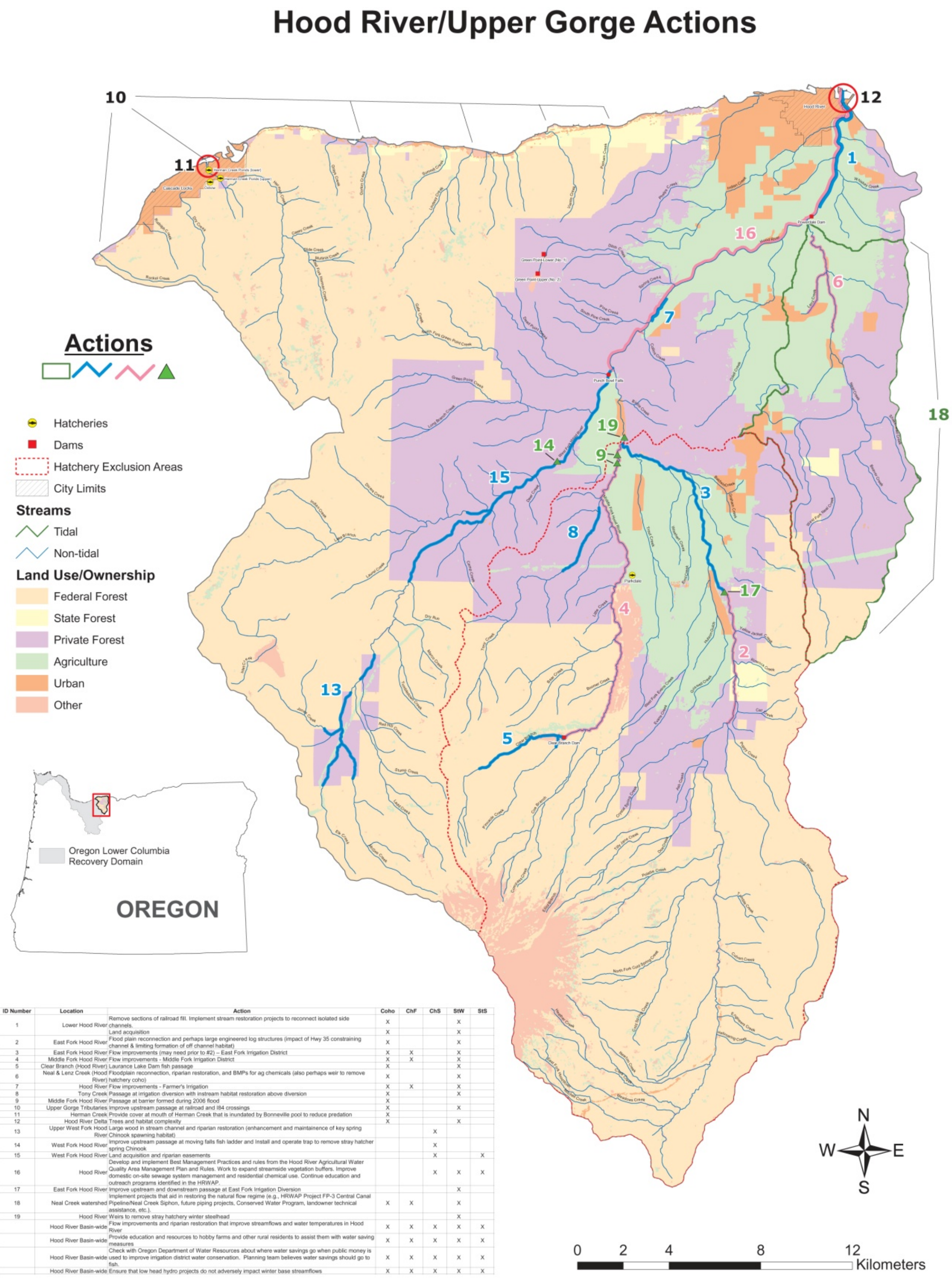


ID_Orig	TYPE	ID_EG	CHf
406	Floodplain/Offchannel	1	X
407	Restore Riparian	2	X
	Protect Riparian		
	Instream (wood)		
407, 408	Restore Riparian	3	
	Protect Riparian		
	Instream (wood)		
411, 412	NA	3	X
413	Restore Riparian	4	
	Barriers		
	Instream (wood)		
	Restore Riparian	5	
	Floodplain/Offchannel		
413	Barriers	6	
	Instream (wood)		
	Upland land use		
405	Protect Riparian	7	
404	Roads	8	X
408	Instream (wood)	9	X
	Floodplain/offchannel		
402		10	
412, 408	Floodplain/Offchannel	11	X
	Instream (wood)		
	Upland land use		
409	Floodplain/Offchannel	12	X
	Restore Riparian		
410	Instream (wood)	13	X
	Floodplain/offchannel		
	Protect Riparian		
404	Roads	14	X
	Upland land use		
415	Instream flows	15	X
416		16	
NA		17	

Figure B5. Map showing locations where each type of restoration action could occur for Scappoose River tule fall Chinook salmon (derived from Figure B4) specifically for tules and actions we could model. The inset is a condensed version of Table B3.

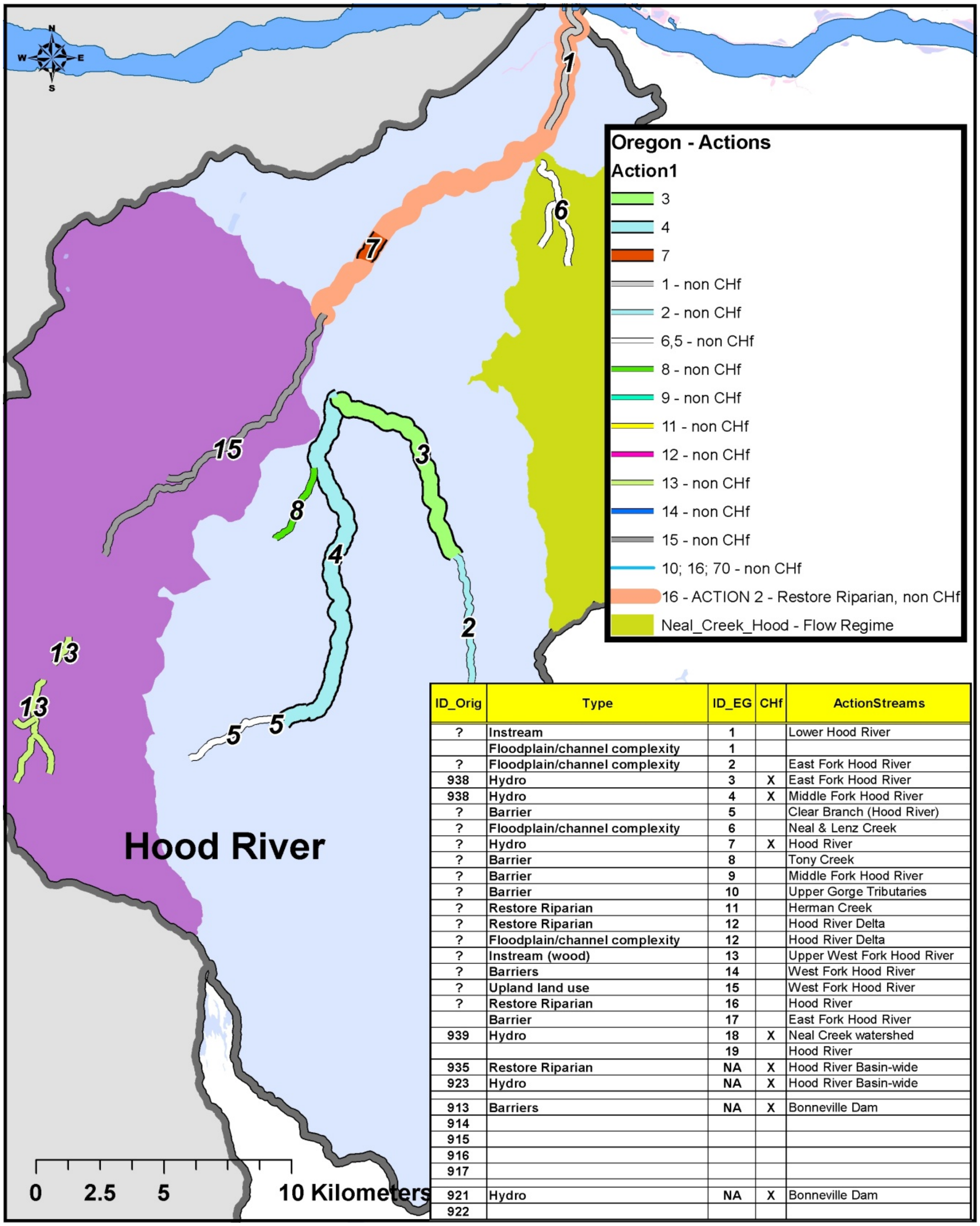
Table B3. Crosswalk approach for how we modeled actions (TYPE) suggested by the recovery plan (Actions-Submeasure). Note that information in this table was provided by ODFW, and is an updated version of Table 7-11 that will occur in the final recovery plan. Actions shown are only those affecting Scappoose River fall Chinook salmon.

ID_Orig	TYPE	Reach	ActionStreams	Actions - Submeasure
406	**Floodplain/Offchannel**	**1**	South Sauvie Island	Breach or lower dikes and levees to establish or improve access to off-channel habitats.
407	**Restore Riparian**	**2**	Lower Merril	Restore and protect riparian function (conservation easements, aquistition, restoration),
	Protect Riparian	**2**	Tide creek	correct erosion problems, improve off channel connectivity and instream complexity (large
	Instream (wood)	**2**	McBride creek	wood placements). Establish working group to identify and work with landowners to
				implement projects.
404	**Roads**	**8**	N.F. Scappoose headwater streams	Protect/manage headwater streams to reduce erosion and landslide impacts
408	**Instream (wood)**	**9**	North Fork Scappoose	Provide resources and incentives to landowners (small rural residential parcels) to implement
	Floodplain/offchannel	**9**	(upper mid-mainstem and tribs)	large wood placement projects and livestock impact reductions
412, 408	**Floodplain/Offchannel**	**11**	Lower North Fork Scappoose	Work with landowners to prevent/reduce impacts of land development, improve floodplain
	Instream (wood)	**11**		connectivity, large wood placement
	Upland land use	**11**		
409	**Floodplain/Offchannel**	**12**	Lower Scappoose	Floodplain reconnection, reduce erosion, reconnect side channels, reslope and revegetate
	Restore Riparian	**12**		banks, re-establish riparian zones wide enough to accommodate channel migration, restore
				wetlands, restrict additional floodplain development and work to reduce impact of existing
410	**Instream (wood)**	**13**	Lower SF Scappoose	Provide resources and incentives to landowners to improve habitat complexity with large
	Floodplain/offchannel	**13**		wood placement, restore connectivity to small tributaries, and improve riparian conditions
	Protect Riparian	**13**		(livestock fencing and enhanced forest management).
404	**Roads**	**14**	SF Scappoose headwaters	Protect/manage headwater streams to reduce erosion and landslide impacts
	Upland land use	**14**		
415	**Instream flows**	**15**	Dairy Creek	Improve flow conditions to provide better migration into and out of Sturgeon Lake
		15	Gilbert River	



ID Number	Location	Action	Coho	ChF	ChS	StW	StS
1	Lower Hood River	Remove sections of railroad fill. Implement stream restoration projects to reconnect isolated side channels.	X			X	
		Land acquisition	X			X	
2	East Fork Hood River	Flood plain reconnection and perhaps large engineered log structures (impact of Hwy 35 constraining channel & limiting formation of off channel habitat)	X			X	
3	East Fork Hood River	Flow improvements (may need prior to #2) – East Fork Irrigation District	X	X		X	
4	Middle Fork Hood River	Flow improvements - Middle Fork Irrigation District	X	X		X	
5	Clear Branch (Hood River)	Laurance Lake Dam fish passage	X			X	
6	Neal & Lenz Creek (Hood River)	Floodplain reconnection, riparian restoration, and BMPs for ag chemicals (also perhaps weir to remove hatchery coho)	X			X	
7	Hood River	Flow improvements - Farmer's Irrigation	X	X		X	
8	Tony Creek	Passage at irrigation diversion with instream habitat restoration above diversion	X			X	
9	Middle Fork Hood River	Passage at barrier formed during 2006 flood	X				
10	Upper Gorge Tributaries	Improve upstream passage at railroad and I84 crossings	X			X	
11	Herman Creek	Provide cover at mouth of Herman Creek that is inundated by Bonneville pool to reduce predation	X				
12	Hood River Delta	Trees and habitat complexity	X			X	
13	Upper West Fork Hood River	Large wood in stream channel and riparian restoration (enhancement and maintainence of key spring Chinook spawning habitat)			X		
14	West Fork Hood River	Improve upstream passage at moving falls fish ladder and Install and operate trap to remove stray hatcher spring Chinook			X		
15	West Fork Hood River	Land acquisition and riparian easements			X		X
16	Hood River	Develop and implement Best Management Practices and rules from the Hood River Agricultural Water Quality Area Management Plan and Rules. Work to expand streamside vegetation buffers. Improve domestic on-site sewage system management and residential chemical use. Continue education and outreach programs identified in the HRWAP.			X	X	X
17	East Fork Hood River	Improve upstream and downstream passage at East Fork Irrigation Diversion				X	
18	Neal Creek watershed	Implement projects that aid in restoring the natural flow regime (e.g., HRWAP Project FP-3 Central Canal Pipeline/Neal Creek Siphon, future piping projects, Conserved Water Program, landowner technical assistance, etc.).	X	X		X	
19	Hood River	Weirs to remove stray hatchery winter steelhead				X	
	Hood River Basin-wide	Flow improvements and riparian restoration that improve streamflows and water temperatures in Hood River	X	X	X	X	X
	Hood River Basin-wide	Provide education and resources to hobby farms and other rural residents to assist them with water saving measures	X	X	X	X	X
	Hood River Basin-wide	Check with Oregon Department of Water Resources about where water savings go when public money is used to improve irrigation district water conservation. Planning team believes water savings should go to fish.	X	X	X	X	X
	Hood River Basin-wide	Ensure that low head hydro projects do not adversely impact winter base streamflows	X	X	X	X	X

Figure B6. Map provided by ODFW showing locations and types of suggested restoration actions from the recovery plan for Hood River salmonids (Chf = fall Chinook).



ID_Orig	Type	ID_EG	CHf	ActionStreams
?	Instream	1		Lower Hood River
	Floodplain/channel complexity	1		
?	Floodplain/channel complexity	2		East Fork Hood River
938	Hydro	3	X	East Fork Hood River
938	Hydro	4	X	Middle Fork Hood River
?	Barrier	5		Clear Branch (Hood River)
?	Floodplain/channel complexity	6		Neal & Lenz Creek
?	Hydro	7	X	Hood River
?	Barrier	8		Tony Creek
?	Barrier	9		Middle Fork Hood River
?	Barrier	10		Upper Gorge Tributaries
?	Restore Riparian	11		Herman Creek
?	Restore Riparian	12		Hood River Delta
?	Floodplain/channel complexity	12		Hood River Delta
?	Instream (wood)	13		Upper West Fork Hood River
?	Barriers	14		West Fork Hood River
?	Upland land use	15		West Fork Hood River
?	Restore Riparian	16		Hood River
	Barrier	17		East Fork Hood River
939	Hydro	18	X	Neal Creek watershed
		19		Hood River
935	Restore Riparian	NA	X	Hood River Basin-wide
923	Hydro	NA	X	Hood River Basin-wide
913	Barriers	NA	X	Bonneville Dam
914				
915				
916				
917				
921	Hydro	NA	X	Bonneville Dam
922				

Figure B7. Map showing locations where each type of restoration action could occur for Hood River tule fall Chinook salmon (derived from Figure B6) specifically for tules and actions we could model. The inset is a condensed version of Table B4.

Table B4. Crosswalk approach for how we modeled actions (TYPE) suggested by the recovery plan (Actions-Submeasure). Note that information in this table was provided by ODFW, and is an updated version of Table 7-11 that will occur in the final recovery plan. Actions shown are only those affecting Hood River fall Chinook salmon.

ID_Orig	Type	Reach	ActionStreams	Actions-Submeasure
938	**Hydro**	**3**	East Fork Hood River	Flow improvements (may need prior to #2) –East Fork Irrigation D
938	**Hydro**	**4**	Middle Fork Hood River	Flow improvements - Middle Fork Irrigation District
?	**Hydro**	**7**	Hood River	Flow improvements - Farmer's Irrigation
939	**Hydro**	**18**	Neal Creek watershed	Implement projects that aid in restoring the natural flow regime
935	**Restore Riparian**	**NA**	Hood River Basin-wide	Restore riparian areas to improve flows and water temperatures ir
923	**Hydro**	**NA**		Ensure that low head projects do not adversely impact winter base
				Flow improvements and riparian restoration that improve streamflc Hood R.
913	**Barriers**	**NA**	Bonneville Dam	Operational and structural improvements, multiple Columbia River
914		**NA**		
915		**NA**		
916		**NA**		
917		**NA**		
921	**Hydro**	**NA**	Bonneville Dam	implement water quality measures to enhance survival and maint
922		**NA**		and rearing habitat, restore hydrologic regimes and floodplain con

Habitat Appendix C. Excerpts from Recovery Plans affecting tule Chinook salmon.

Figures C1-C6 were excerpted from LCFRB (2004), and Figures C7-C9 were excerpted from ODFW (2009).

REFERENCES

LCFRB (Lower Columbia Fish Recovery Board). 2004. Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan. http://www.lcfrb.gen.wa.us/December%20Final%20%20Plans/lower_columbia_salmon_recovery_a.htm.

ODFW (Oregon Department of Fish and Wildlife). 2009. Lower Columbia River Conservation and Recovery Plan for Oregon Populations of Salmon and Steelhead. DRAFT April 24, 2009. http://www.dfw.state.or.us/fish/CRP/lower_columbia_plan.asp.

Figure C1a. East Fork Lewis (WA).

Table 16, excerpted from the recovery plan (LCFRB 2004).

#1 – Protect stream corridor structure and function

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect floodplain function and channel migration processes B. Protect riparian function C. Protect access to habitats D. Protect instream flows through management of water withdrawals E. Protect channel structure and stability F. Protect water quality G. Protect the natural stream flow regime	Potentially addresses many limiting factors	Potentially addresses many limiting factors	All Species	There currently are productive habitats for steelhead in the upper basin, especially in the portion of the basin upstream of Sunset Falls within National Forest. Significant degradation of stream corridor habitat has occurred over the years in the private, mixed-use lands in the lower and middle basin. This area has historically been utilized for timber harvest, agriculture, mining, and rural residential uses and is experiencing increasing development pressure. Preventing further degradation of stream channel structure, riparian function, and floodplain function will be an important component of recovery.
Priority Locations				
1st- Tier 1 or 2 reaches with functional riparian conditions according to the IWA Reaches: EF Lewis 19B, 19C & 20 2nd- Tier 1 or 2 reaches in mixed-use lands at risk of further degradation Reaches: EF Lewis 1, 3-13; McCormick Creek; Lockwood Creek; Mill Creek; LW Rock Creek 3rd- All remaining reaches				

#2 – Protect hillslope processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Manage forest practices to minimize impacts to sediment supply processes, runoff regime, and water quality B. Manage agricultural practices to minimize impacts to sediment supply processes, runoff regime, and water quality C. Manage growth and development to minimize impacts to sediment supply, runoff regime, and water quality	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to sediment supply, water quality, and runoff processes	All species	There currently are functioning runoff and sediment supply processes in portions of the headwaters and the Rock Creek basin. Most of the remainder of the basin is moderately impaired with respect to sediment supply. Mixed-use lands are mostly impaired with respect to runoff due to lack of forest cover and impervious surfaces. Preventing additional degradation will be important for habitat recovery.
Priority Locations				
1st- Functional subwatersheds contributing to Tier 1 or 2 reaches (functional for sediment *or* flow according to the IWA – local rating) Subwatersheds: 50612, 50502, 50508, 50202, 50101, 50401, 50301,50402, 50403, 50405 2nd- All other functional subwatersheds plus Moderately Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 50201, 50203, 50302, 50404, 50501, 50503, 50505, 50506, 50507, 50509, 50602, 50603, 50604, 50605, 50607, 50608, 50609, 50611, 50613, 50614, 50615, 50616 3rd- All other Moderately Impaired subwatersheds plus Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 50601, 50606, 50610				

#3 - Restore floodplain function and channel migration processes in the mainstem and major tributaries

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Set back, breach, or remove artificial confinement structures	• Bed and bank erosion • Altered habitat unit composition • Restricted channel migration • Disrupted hyporheic processes • Reduced flood flow dampening • Altered nutrient exchange processes • Channel incision • Loss of off-channel and/or side-channel habitat • Blockages to off-channel habitats	• Floodplain filling • Channel straightening • Artificial confinement	All species	Much of the lower mainstem has been subject to artificial channel confinement associated with mining, residential development, and agriculture. Restoring floodplain function and channel migration processes will lead to improvements in riparian and channel habitats. Selective breaching, setting back, or removing confining structures would help to restore floodplain and CMZ function as well as facilitate the creation of off-channel and side channel habitats. There are challenges with implementation due to private lands, existing infrastructure already in place, potential flood risk to property, and large expense.
Priority Locations				
1st- Tier 1 reaches with hydro-modifications (obtained from EDT ratings) Reaches: EF Lewis 4, 5, 6, 8 & 19A; Rock Creek 3 2nd- Tier 2 reaches with hydro-modifications Reaches: EF Lewis 1, 3, 19B & 20; Lewis 1 tidal; Lockwood Creek; LW Rock Creek 3rd- Other reaches with hydro-modifications Reaches: EF Lewis 2; Brezee Creek; Dean Creek; Green Fork; Manley Creek; Mason Creek				

#4- Restore degraded hillslope processes on forest, agricultural, and developed lands

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Upgrade or remove problem forest roads B. Reforest heavily cut areas not recovering naturally C. Employ agricultural Best Management Practices with respect to contaminant use, erosion, and runoff D. Reduce watershed imperviousness E. Reduce effective stormwater runoff from developed areas	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to water quality and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest, road building, agriculture, and development. These processes must be addressed for reach-level habitat recovery to be successful.
Priority Locations				
1st- Moderately impaired or impaired subwatersheds contributing to Tier 1 reaches (mod. impaired or impaired for sediment *or* flow according to IWA – local rating) Subwatersheds: 50201, 50203, 50302, 50404, 50501, 50503, 50505, 50506, 50507, 50509, 50603, 50604, 50605, 50613, 50614, 50615, 50616, 50502, 50508, 50202, 50101, 50401, 50301, 50405 2nd- Moderately impaired or impaired subwatersheds contributing to Tier 2 reaches Subwatersheds: 50612, 50611, 50608, 50607, 50602, 50609 3rd- Moderately impaired or impaired subwatersheds contributing to other reaches Subwatersheds: 50601, 50606, 50610				

#5 - Restore riparian conditions throughout the basin

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore the natural riparian plant community B. Exclude livestock from riparian areas C. Eradicate invasive plant species from riparian areas	• Reduced stream canopy cover • Altered stream temperature regime • Reduced bank/soil stability • Reduced wood recruitment • Lack of stable instream woody debris • Exotic and/or invasive species • Bacteria	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to agriculture and residential development	All species	Riparian areas have been degraded by a host of land-uses including timber harvest, road building, mining, agriculture, and development. Although most riparian areas are now protected, natural recovery is limited in many areas by existing land use. The increasing abundance of exotic and invasive species is also a concern. Riparian restoration projects are relatively inexpensive and are often supported by landowners. There is a high potential benefit due to the many limiting factors that are addressed.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#6 – Restore degraded water quality with emphasis on temperature impairments

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Exclude livestock from riparian areas B. Increase riparian shading C. Decrease channel width-to-depth ratios D. Reduce delivery of chemical contaminants to streams E. Address leaking septic systems	• Bacteria • Altered stream temperature regime • Chemical contaminants	• Timber harvest – riparian harvests • Riparian grazing • Leaking septic systems • Clearing of vegetation due to rural development and agriculture • Chemical contaminants from agricultural and developed lands	• All species	There are known temperature impairments throughout the basin. There are also known fecal coliform bacteria impairments, although bacteria is more of a human health concern than a fish health concern. Degraded riparian areas and cattle access to streams are contributing factors to both temperature and bacteria. Excluding livestock from riparian areas is particularly important along some of the heavily grazed tributaries. Leaking septic systems may be contributing to bacteria levels in areas with concentrated rural residential development. The degree of impact of agricultural pollutants is unknown and needs further assessment.
Priority Locations				
1st- Tier 1 or 2 reaches with 303(d) listings (2002-2004 draft list) Reaches: EF Lewis 8 (temperature and bacteria); EF Lewis 15, 16, 19A, 19B & 20 (temperature); EF Lewis 3, 11-13 (bacteria); Lockwood Creek (bacteria); LW Rock Creek (bacteria); McCormick Creek (bacteria); Rock Creek 4 (bacteria) 2nd- Other reaches with 303(d) listings Reaches: EF Lewis 2 (bacteria); Brezee Creek (bacteria) 3rd- All remaining reaches				

#7 – Provide for adequate instream flows during critical periods

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect instream flows through water rights closures and enforcement B. Restore instream flows through acquisition of existing water rights C. Restore instream flows through implementation of water conservation measures	• Stream flow – Maintain or improve flows during low-flow Summer months	• Water withdrawals	All species	Expanding growth has increased pressures for ground and surface water withdrawals. It is crucial that withdrawals are managed carefully to minimize impacts on aquatic resources. Instream flow management strategies for the EF Lewis Basin have been identified as part of Watershed Planning for WRIA 27 (LCFRB 2004). Strategies include water rights closures, setting of minimum flows, and drought management policies. This measure applies to instream flows associated with water withdrawals and diversions, generally a concern only during low flow periods. Hillslope processes also affect low flows but these issues are addressed in separate measures.
Priority Locations				
Entire Basin				

#8 – Restore access to habitat blocked by artificial barriers

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers	• Blockages to channel habitats • Blockages to off-channel habitats	• Dams, culverts, in-stream structures	coho, winter steelhead, summer steelhead	As many as 30 miles of potentially accessible habitat are blocked by culverts or other barriers. The blocked habitat is believed to be marginal in the majority of cases and no individual barriers in themselves account for a significant portion of blocked miles (there are 23 barriers total). Passage restoration projects should focus only on cases where it can be demonstrated that there is good potential benefit and reasonable project costs.
Priority Locations				
1st- Culverts on McCormick, Brezee Creek & tribs, Mason Creek, Gee Creek (not in EF basin proper) 2nd- Other small tributaries with blockages				

#9 - Restore channel structure and stability

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Place stable woody debris in streams to enhance cover, pool formation, bank stability, and sediment sorting B. Structurally modify channel morphology to create suitable habitat C. Restore natural rates of erosion and mass wasting within river corridors	• Lack of stable instream woody debris • Altered habitat unit composition • Reduced bank/soil stability • Excessive fine sediment • Excessive turbidity • Embedded substrates	• None (symptom-focused restoration strategy)	All species	Channel structure and stability have been compromised by altered sediment and flow regimes, degraded riparian conditions, stream-adjacent gravel mining/processing, and confinement. Large wood installation projects could benefit habitat conditions in many areas although watershed processes contributing to wood deficiencies should be considered and addressed prior to placing wood in streams. Other structural enhancements to stream channels may be warranted in some places, particularly in reaches that have been simplified through channel straightening and confinement or that has experienced avulsions into streamside gravel processing ponds.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#10 – Create/restore off-channel and side-channel habitat

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore historical off-channel and side-channel habitats where they have been eliminated B. Create new channel or off-channel habitats (i.e. spawning channels)	• Loss of off-channel and/or side-channel habitat	• Floodplain filling • Channel straightening • Artificial confinement	chum coho	There has been significant loss of off-channel and side-channel habitats, especially along the lower mainstem that has been extensively channelized. This has severely limited chum spawning habitat and coho overwintering habitat. Targeted restoration or creation of habitats would increase available habitat where full floodplain and CMZ restoration is not possible.
Priority Locations				
1st- Lower Mainstem EF Lewis 2nd- Other reaches that may have potential for off-channel and side-channel habitat restoration or creation				

Figure C1b. Lower North Fork Lewis (Cedar Creek) (WA).

Excerpted from the recovery plan (LCFRB 2004).

Table 16. Prioritized measures for the Lower North Fork Lewis Basin.

#1 – Protect stream corridor structure and function

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect floodplain function and channel migration processes B. Protect riparian function C. Protect access to habitats D. Protect instream flows through management of water withdrawals E. Protect channel structure and stability F. Protect water quality G. Protect the natural stream flow regime	Potentially addresses many limiting factors	Potentially addresses many limiting factors	All Species	The mainstem Lewis below Merwin Dam has been heavily altered due to adjacent land uses including agriculture, residential development, transportation corridors, and industry. The mainstem is heavily channelized in many areas. The flow regime has been altered through hydro-regulation. Tributary streams, in particular Cedar Creek, have been altered by agriculture, rural residential development, and past riparian timber harvest. Preventing further degradation of stream channel structure, riparian function, and floodplain function will be an important component of recovery.
Priority Locations				
1st- Tier 1 or 2 reaches in mixed-use lands at risk of further degradation Reaches: Lewis 3-7; Cedar Creek 1a, 1b, 3, 4 2nd- All remaining reaches				

#2 – Protect hillslope processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Manage forest practices to minimize impacts to sediment supply processes, runoff regime, and water quality B. Manage agricultural practices to minimize impacts to sediment supply processes, runoff regime, and water quality C. Manage growth and development to minimize impacts to sediment supply processes, runoff regime, and water quality	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to sediment supply, water quality, and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest and road building, particularly in the upper Cedar Creek Basin. Lowland hillslope processes have been impacted by agriculture and development. Limiting additional degradation will be necessary to prevent further habitat impairment.
Priority Locations				
1st- Functional subwatersheds contributing to Tier 1 or 2 reaches (functional for sediment *or* flow according to the IWA – local rating) Subwatersheds: 60401 2nd- All other functional subwatersheds plus Moderately Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 60502, 60503, 60504, 60403, 60402, 60404, 60406, 60405 3rd- All other Moderately Impaired subwatersheds plus Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 40602, 60501				

#3 – Manage regulated stream flows to provide for critical components of the natural flow regime

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Provide adequate flows for specific life stage requirements (i.e. fry to smolt rearing for fall chinook) B. Address geomorphic effects of hydro-regulation (i.e. channel-forming flows, spawning gravel recruitment)	• Alterations to the temporal pattern of stream flow • Altered stream temperature regime • Disrupted sediment transport processes • Lack of channel-forming flows	• Hydropower operations – changes to flow regime, sediment transport, and stream temperature	All species	Hydro-regulation on the Lewis River has altered the natural stream flow regime below Merwin Dam. In general, summer, fall, and winter flows have increased, spring flows have decreased, and flood (pulse) flows have decreased in frequency and magnitude. To support fish and their habitat, hydro-regulation will need to provide adequate flows for habitat formation, fish migration, water quality, floodplain connectivity, habitat capacity, and sediment transport below Merwin Dam.
Priority Locations				
Lower mainstem Lewis (Lewis 1-tidal to Lewis 7)				

#4 - Restore floodplain function and channel migration processes in the mainstem and major tributaries

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Set back, breach, or remove artificial confinement structures	• Bed and bank erosion • Altered habitat unit composition • Restricted channel migration • Disrupted hyporheic processes • Reduced flood flow dampening • Altered nutrient exchange processes • Channel incision • Loss of off-channel and/or side-channel habitat • Blockages to off-channel habitats	• Floodplain filling • Channel straightening • Artificial confinement	Chum, fall chinook, coho	There has been significant degradation of floodplain connectivity and constriction of channel migration zones along the mainstem below Merwin Dam. Selective breaching, setting back, or removing confining structures would help to restore floodplain and CMZ function as well as facilitate the creation of off-channel and side channel habitats. There are feasibility issues with implementation due to private lands, existing infrastructure already in place, potential flood risk to property, and large expense.
Priority Locations				
1st- Tier 1 reaches with hydro-modifications (obtained from EDT ratings) Reaches: Lewis 3-4 2nd- Tier 2 reaches with hydro-modifications Reaches: Lewis 5; Cedar Creek 3 3rd- Other reaches with hydro-modifications Reaches: Lewis 1-tidal, 2-tidal_A, 2-tidal_B; Robinson Cr; Ross Cr; Johnson Cr; Cedar Creek 6; Chelatchie Cr 2				

#5 – Restore access to habitat blocked by artificial barriers

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers	• Blockages to channel habitats • Blockages to off-channel habitats	• Dams, culverts, in-stream structures	All species	As many as 16 miles of potentially accessible habitat are blocked by culverts or other barriers. The blocked habitat is believed to be marginal in the majority of cases and no individual barriers in themselves account for a significant portion of blocked miles. Passage restoration projects should focus only on cases where it can be demonstrated that there is good potential benefit and reasonable project costs.
Priority Locations				
1st- Colvin Creek; Bitter Creek 2nd- Other small tributaries with blockages				

#6 – Create/restore off-channel and side-channel habitat

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore historical off-channel and side-channel habitats where they have been eliminated B. Create new channel or off-channel habitats (i.e. spawning channels)	• Loss of off-channel and/or side-channel habitat	• Floodplain filling • Channel straightening • Artificial confinement	chum coho	There has been significant loss of off-channel and side-channel habitats, especially along the lower mainstem that has been extensively channelized. This has severely limited chum spawning habitat and coho overwintering habitat. Targeted restoration or creation of habitats would increase available habitat where full floodplain and CMZ restoration is not possible.
Priority Locations				
1st- Mainstem Lewis and Cedar Creek Reaches: Lewis 1-tidal to Lewis 5; Cedar Creek 3-5 2nd- Other reaches that may have potential for off-channel and side-channel habitat restoration or creation				

#7- Restore degraded hillslope processes on forest, agricultural, and developed lands

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Upgrade or remove problem forest roads B. Reforest heavily cut areas not recovering naturally C. Employ agricultural Best Management Practices with respect to contaminant use, erosion, and runoff D. Reduce watershed imperviousness E. Reduce effective stormwater runoff from developed areas	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to water quality and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest, road building, agriculture, and development. These processes must be addressed for reach-level habitat recovery to be successful.
Priority Locations				
1st- Moderately impaired or impaired subwatersheds contributing to Tier 1 reaches (mod. impaired or impaired for sediment *or* flow according to IWA – local rating) Subwatersheds: 60502, 60503, 60504, 60403, 60402, 60404, 60406, 60405, 60401 2nd- Moderately impaired or impaired subwatersheds contributing to other reaches Subwatersheds: 40602, 60501				

#8 - Restore riparian conditions throughout the basin

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore the natural riparian plant community B. Exclude livestock from riparian areas C. Eradicate invasive plant species from riparian areas	• Reduced stream canopy cover • Altered stream temperature regime • Reduced bank/soil stability • Reduced wood recruitment • Lack of stable instream woody debris • Exotic and/or invasive species • Bacteria	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to agriculture and residential development	All species	There is a high potential benefit due to the many limiting factors that are addressed. Riparian impairment is related to most land-uses and is a concern throughout the basin. The increasing abundance of exotic and invasive species is of particular concern. Riparian restoration projects are relatively inexpensive and are often supported by landowners.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#9 – Restore degraded water quality with emphasis on temperature impairments

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Exclude livestock from riparian areas B. Increase riparian shading C. Decrease channel width-to-depth ratios D. Reduce delivery of chemical contaminants to streams E. Address leaking septic systems	• Altered stream temperature regime • Bacteria • Chemical contaminants	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to rural development and agriculture • Leaking septic systems • Chemical contaminants from agricultural and developed lands	• All species	There are several stream segments that are known as having concerns for temperature impairment (WDOE 2004). Fecal coliform bacteria, while more of a human health concern than a fish health concern, is also an issue in the basin. Cedar Creek is listed on the 2002-2004 draft 303(d) list for fecal coliform bacteria impairment. Excluding livestock from riparian areas is particularly important in the heavily grazed lowland areas. Leaking septic systems may be contributing to bacteria levels in areas with concentrated rural residential development. The degree of impact of agricultural pollutants is unknown and needs further assessment.
Priority Locations				
1st- Tier 1 or 2 reaches with 303(d) listings (2002-2004 draft list) Reaches: Cedar Creek 1b (bacteria) 2nd- All remaining reaches				

#10 – Provide for adequate instream flows during critical periods

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect instream flows through water rights closures and enforcement B. Restore instream flows through acquisition of existing water rights C. Restore instream flows through implementation of water conservation measures	• Stream flow – maintain or improve flows during low-flow Summer months	• Water withdrawals	All species	Instream flow management strategies for the Lower NF Lewis Basin have been identified as part of Watershed Planning for WRIA 27 (LCFRB 2004). Strategies include water rights closures, setting of minimum flows, and drought management policies. This measure applies to instream flows associated with water withdrawals and diversions, generally a concern only during low flow periods. Hydropower regulation and hillslope processes also affect low flows but these issues are addressed in separate measures.
Priority Locations				
Entire Basin				

#11 - Restore channel structure and stability

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Place stable woody debris in streams to enhance cover, pool formation, bank stability, and sediment sorting B. Structurally modify channel morphology to create suitable habitat C. Restore natural rates of erosion and mass wasting within river corridors	• Lack of stable instream woody debris • Altered habitat unit composition • Reduced bank/soil stability • Excessive fine sediment • Excessive turbidity • Embedded substrates	• None (symptom-focused restoration strategy)	All species	Large wood installation projects could benefit habitat conditions in many areas although watershed processes contributing to wood deficiencies should be considered and addressed prior to placing wood in streams. Other structural enhancements to stream channels may be warranted in some places, especially in lowland alluvial reaches that have been simplified through channel straightening and confinement.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#12 – Limit intensive recreational use during critical periods

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Limit intensive recreational use of stream channels during adult holding and spawning periods	• Harassment	• Harassment	Chum, fall chinook, coho	The Lower NF Lewis River between Woodland, WA and Merwin Dam is heavily used for recreational purposes. There is harassment potential that was identified through the EDT analysis, but the specific degree of the harassment threat needs to be further evaluated.
Priority Locations				
Lower NF Lewis mainstem between Woodland, WA and Merwin Dam				

Figure C2. Washougal River (WA).

Excerpted from the recovery plan (LCFRB 2004).

Table 16. Prioritized measures for the Washougal Subbasin

#1 – Protect stream corridor structure and function

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect floodplain function and channel migration processes B. Protect riparian function C. Protect access to habitats D. Protect instream flows through management of water withdrawals E. Protect channel structure and stability F. Protect water quality G. Protect the natural stream flow regime	Potentially addresses many limiting factors	Potentially addresses many limiting factors	All Species	Important productive habitats for steelhead that are currently in good condition are located in the upper mainstem Washougal and in the West Fork Washougal basin. These reaches are supported by relatively functional watershed sediment, flow, and riparian processes. The lower mainstem reaches provide critically important habitat that has been heavily impacted by adjacent land-uses and channel modifications. Preventing additional habitat degradation in this area is necessary for population persistence.
Priority Locations				
1st- Tier 1 or 2 reaches with functional riparian conditions Reaches: Washougal 16-19 2nd- Tier 1 or 2 reaches in mixed-use lands at risk of further degradation Reaches: Washougal 1 tidal, 2 tidal, 3 – 9; WF Washougal 1; Little Washougal 1, 1B, 2 - 4 3rd- Remaining Tier 1 and 2 reaches				

#2 – Protect hillslope processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Manage forest practices to minimize impacts to sediment supply processes, runoff regime, and water quality B. Manage agricultural practices to minimize impacts to sediment supply processes, runoff regime, and water quality C. Manage growth and development to minimize impacts to sediment supply processes, runoff regime, and water quality	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to sediment supply, water quality, and runoff processes	All species	There currently are relatively functional hillslope sediment and hydrology processes in portions of the headwaters and the West Fork Washougal basin. In other areas, hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest, road building, and fires. Limiting additional degradation will be necessary to prevent further habitat impairment.
Priority Locations				
1st- Functional subwatersheds contributing to Tier 1 or 2 reaches (functional for sediment *or* flow according to the IWA – local rating) Subwatersheds: 60304, 60204, 60102, 60103, 60101, 60202, 60302, 60503, 60301, 60608, 60607, 60603, 60602 2nd- All other functional subwatersheds plus Moderately Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: All remaining subwatersheds				

#3- Restore degraded hillslope processes on forest, agricultural, and developed lands

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Upgrade or remove problem forest roads B. Reforest heavily cut areas not recovering naturally C. Employ agricultural Best Management Practices with respect to contaminant use, erosion, and runoff D. Reduce watershed imperviousness E. Reduce effective stormwater runoff from developed areas	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to water quality and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded as a result of past intensive timber harvest, road building, agriculture, residential development, and urbanization. These processes must be addressed for reach-level habitat recovery to be successful.
Priority Locations				
1st- Moderately impaired or impaired subwatersheds contributing to Tier 1 reaches (mod. impaired or impaired for sediment *or* flow according to IWA – local rating) Subwatersheds: All subwatersheds except 60304, 60204, 60102				

#4 - Restore riparian conditions throughout the basin

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore the natural riparian plant community B. Exclude livestock from riparian areas C. Eradicate invasive plant species from riparian areas	• Reduced stream canopy cover • Altered stream temperature regime • Reduced bank/soil stability • Reduced wood recruitment • Lack of stable instream woody debris • Exotic and/or invasive species • Bacteria	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to agriculture and residential development	All species	Riparian areas have been degraded throughout the basin and recovery of riparian vegetation is necessary in both forest and mixed-use areas. Much of this recovery is expected to occur passively on forest lands due to legal protections of riparian buffers. Active measures, such as hardwood-to-conifer conversion, may be necessary in some areas. The increasing abundance of exotic and invasive species is of particular concern. Riparian restoration projects are relatively inexpensive and are often supported by landowners.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#5 – Restore degraded water quality with emphasis on temperature impairments

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Exclude livestock from riparian areas B. Increase riparian shading C. Decrease channel width-to-depth ratios D. Reduce delivery of chemical contaminants to streams E. Address leaking septic systems	• Bacteria • Altered stream temperature regime • Chemical contaminants	• Timber harvest – riparian harvests • Riparian grazing • Leaking septic systems • Clearing of vegetation due to rural development and agriculture • Chemical contaminants from agricultural and developed lands	All species	There are several stream segments listed on the 2002-2004 draft 303(d) list for temperature and dissolved oxygen impairment. There are also a few reaches listed for fecal coliform bacteria impairment, which is more of a human health concern than a fish health concern. Reach Washougal 8 is listed for bacteria impairment. Most of the water quality impaired stream segments are located in the Lacamas Creek basin. Reduced riparian canopy cover is a contributor to temperature impairment. Livestock grazing and leaking septic systems are likely responsible for elevated bacteria levels. The degree of impact of agricultural pollutants is unknown and needs further assessment.
Priority Locations				
1st- Tier 1 or 2 reaches with 303(d) listings (2002-2004 draft list) Reaches: Washougal 8 (bacteria) 2nd- Other reaches with 303(d) listings Reaches: Lacamas Cr (temperature, bacteria, dissolved oxygen); Matney Cr (temperature, bacteria); Shanghai Cr (temperature); Fifth Plain Cr (temperature, dissolved oxygen) – Matney, Shanghai, and Fifth Plain are located within the Lacamas Creek Basin 3rd- All remaining reaches				

#6 – Provide for adequate instream flows during critical periods

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect instream flows through water rights closures and enforcement B. Restore instream flows through acquisition of existing water rights C. Restore instream flows through implementation of water conservation measures	• Stream flow – maintain or improve flows during low-flow Summer months	• Water withdrawals	All species	Expanding growth has increased pressures for ground and surface water withdrawals. It is important that withdrawals are managed carefully to minimize impacts on aquatic resources. Of particular concern are municipal withdrawals from Jones and Boulder Creeks. There are also concerns with illegal withdrawals occurring throughout the basin. This measure applies to instream flows associated with water withdrawals and diversions, generally a concern only during low flow periods. Hillslope processes also affect low flows but these issues are addressed in separate measures.
Priority Locations				
1st- Little Washougal Basin (municipal withdrawals from Jones and Boulder Creeks) 2nd- Lacamas Basin 3rd- Remainder of Basin				

#7 – Restore access to habitat blocked by artificial barriers

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers	• Blockages to channel habitats • Blockages to off-channel habitats	• Dams, culverts, in-stream structures	Steelhead	A dam on Wildboy Creek blocks at least 1.7 miles of potential habitat. There are several other known blockages on small tributaries, including blockages associated with water intake facilities on Jones and Boulder Creeks. Passage restoration projects should focus only on cases where it can be demonstrated that there is good potential benefit and reasonable project costs.
Priority Locations				
1st- Wildboy Creek (Wildboy Creek Dam) 2nd- Other small tributaries with blockages				

#8 - Restore floodplain function and channel migration processes in the mainstem and major tributaries

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Set back, breach, or remove artificial confinement structures	• Bed and bank erosion • Altered habitat unit composition • Restricted channel migration • Disrupted hyporheic processes • Reduced flood flow dampening • Altered nutrient exchange processes • Channel incision • Loss of off-channel and/or side-channel habitat • Blockages to off-channel habitats	• Floodplain filling • Channel straightening • Artificial confinement	All species	There has been degradation of floodplain connectivity and constriction of channel migration zones along the lower mainstem downstream of the WF Washougal, especially in and around the town of Washougal. Significant degradation has also occurred on the lower and middle Little Washougal River. Selective breaching, setting back, or removing confining structures would help to restore floodplain and CMZ function as well as facilitate the creation of off-channel and side channel habitats. There are feasibility issues with implementation due to private lands, existing infrastructure already in place, potential flood risk to property, and large expense.
Priority Locations				
1st- Tier 1 reaches with hydro-modifications (obtained from EDT ratings) Reaches: Washougal 1-tidal, 2-tidal, 3-4; WF Washougal 1B 2nd- Tier 2 reaches with hydro-modifications Reaches: Washougal 5-7; Little Washougal 1, 1B, 2, 2B 3rd- Other reaches with hydro-modifications Reaches: Washougal 10A; Deer Cr; Dougan Cr; Dougan Cr 1B; RB trib 1A-1C, 2; LB tribA; Lacamas Creek				

#9 - Restore channel structure and stability

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Place stable woody debris in streams to enhance cover, pool formation, bank stability, and sediment sorting B. Structurally modify channel morphology to create suitable habitat C. Restore natural rates of erosion and mass wasting within river corridors	• Lack of stable instream woody debris • Altered habitat unit composition • Reduced bank/soil stability • Excessive fine sediment • Excessive turbidity • Embedded substrates	• None (symptom-focused restoration strategy)	All species	Channel structure and stability have been degraded by past riparian timber harvest, splash dam logging, removal of LWD from channels, and channel confinement. Large wood installation projects could benefit habitat conditions in many areas although watershed processes contributing to wood deficiencies should be considered and addressed prior to placing wood in streams. Other structural enhancements to stream channels may be warranted in some places, especially in lowland alluvial reaches that have been simplified through channel straightening and confinement.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#10 – Create/restore off-channel and side-channel habitat

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore historical off-channel and side-channel habitats where they have been eliminated B. Create new channel or off-channel habitats (i.e. spawning channels)	• Loss of off-channel and/or side-channel habitat	• Floodplain filling • Channel straightening • Artificial confinement	chum, coho	There has been significant loss of off-channel and side-channel habitats, especially along the lower mainstem that has been extensively channelized. This has severely limited chum spawning habitat and coho overwintering habitat. Targeted restoration or creation of habitats would increase available habitat where full floodplain and CMZ restoration is not possible.
Priority Locations				
1st- Lower mainstem Washougal 2nd- Other reaches that may have potential for off-channel and side-channel habitat restoration or creation				

Figure C3. Coweeman River (WA).

Excerpted from the recovery plan (LCFRB 2004).

Table 16. Prioritized measures for the Coweeman Basin.

#1 – Protect stream corridor structure and function

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect floodplain function and channel migration processes B. Protect riparian function C. Protect access to habitats D. Protect instream flows through management of water withdrawals E. Protect channel structure and stability F. Protect water quality G. Protect the natural stream flow regime	Potentially addresses many limiting factors	Potentially addresses many threats related to limiting factors	All Species	Reach Coweeman 3 and 4 are low gradient, alluvial reaches that contain important potential chum and fall Chinook habitat. Providing adequate protections to these reaches is important given the proximity to the expanding Longview/Kelso urban area. Other Tier 1 and Tier 2 reaches in mixed-use areas are also at risk of continuing development pressure. Preventing further degradation of stream channel structure, riparian function, and floodplain function will be an important component of recovery.
Priority Locations				
1st- Tier 1 and 2 reaches with functional riparian conditions according to the IWA assessment Reaches: Coweeman 21-22 2nd- Tier 1 or 2 reaches in mixed-use lands at risk of further degradation Reaches: Coweeman 1-tidal; Coweeman 2-12; Goble Creek 1 3rd- Remaining Tier 1 and 2 reaches 4th- All remaining reaches				

#2 – Protect hillslope processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Manage forest practices to minimize impacts to sediment supply processes, runoff regime, and water quality B. Manage agricultural practices to minimize impacts to sediment supply processes, runoff regime, and water quality C. Manage growth and development to minimize impacts to sediment supply processes, runoff regime, and water quality	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to sediment supply, water quality, and runoff processes	All species	There currently are functional hillslope sediment processes in the Upper Baird and Upper Mulholland Creek basins. In other areas, hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest and road building. Agriculture and development have impacted sediment and flow processes in portions of the lower basin. Urban development impacts the lower mainstem subwatershed (80402). Limiting additional degradation will be necessary to prevent further habitat impairment.
Priority Locations				
1st- Functional subwatersheds contributing to Tier 1 or 2 reaches (functional for sediment *or* flow according to the IWA – local rating) Subwatersheds: upper Baird (80304) & upper Mulholland (80306) 2nd- All other functional subwatersheds plus Moderately Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 80403, 80401, 80405, 80404, 80301, 80302, 80303, 80307, 80305 3rd- All other Moderately Impaired subwatersheds plus Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 80402, 80407, 80406				

#3- Restore degraded hillslope processes on forest, agricultural, and developed lands

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Upgrade or remove problem forest roads B. Reforest heavily cut areas not recovering naturally C. Employ agricultural Best Management Practices with respect to contaminant use, erosion, and runoff D. Reduce watershed imperviousness E. Reduce effective stormwater runoff from developed areas	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to water quality and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest, road building, agriculture, and development. These processes must be addressed for reach-level habitat recovery to be successful.
Priority Locations				
1st- Moderately impaired or impaired subwatersheds contributing to Tier 1 reaches (mod. impaired or impaired for sediment *or* flow according to IWA – local rating) Subwatersheds: 80403, 80401, 80405, 80404, 80301, 80302, 80303, 80307, 80305, 80304, 80306 2nd- Moderately impaired or impaired subwatersheds contributing to Tier 2 reaches Subwatersheds: 80402 3rd- Moderately impaired or impaired subwatersheds contributing to other reaches Subwatersheds: 80406, 80407				

#4 - **Restore floodplain function and channel migration processes in the mainstem and major tributaries**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Set back, breach, or remove artificial confinement structures	• Bed and bank erosion • Altered habitat unit composition • Restricted channel migration • Disrupted hyporheic processes • Reduced flood flow dampening • Altered nutrient exchange processes • Channel incision • Loss of off-channel and/or side-channel habitat • Blockages to off-channel habitats	• Floodplain filling • Channel straightening • Artificial confinement	chum, fall Chinook, coho	Significant degradation of floodplain function and channel migration processes have occurred over the years in the lower mainstem (Coweeman 1 tidal – 4). This area has historically been utilized for agriculture and is experiencing increasing development pressure as nearby population centers expand. There are feasibility issues with implementation of floodplain restoration initiatives due to private lands, existing infrastructure already in place, potential flood risk to property, and large expense.
Priority Locations				
1st- Tier 1 reaches with hydro-modifications (obtained from EDT ratings) Reaches: Coweeman 4, 10, 11 & 14 2nd- Tier 2 reaches with hydro-modifications Reaches: Coweeman 1-tidal; Coweeman 2, 9, 13, 15; Canyon 1; Goble Creek 1 3rd- Other reaches with hydro-modifications Reaches: Goble Creek 3; North Fork Goble Cr; Turner Creek; LBtrib (26.0071)				

#5 - **Restore riparian conditions throughout the basin**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore the natural riparian plant community B. Exclude livestock from riparian areas C. Eradicate invasive plant species from riparian areas	• Reduced stream canopy cover • Altered stream temperature regime • Reduced bank/soil stability • Reduced wood recruitment • Lack of stable instream woody debris • Exotic and/or invasive species • Bacteria	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to agriculture and residential development	All species	Recovery of riparian vegetation is necessary throughout the basin in both forest and mixed-use areas. Much of this recovery is expected to occur passively on forest lands due to protection requirements for riparian buffers. Active measures, such as hardwood-to-conifer conversion, may be necessary in some areas. The increasing abundance of exotic and invasive species is of particular concern. Riparian restoration projects are relatively inexpensive and are often supported by landowners.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#6 – **Restore access to habitat blocked by artificial barriers**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers	• Blockages to channel habitats • Blockages to off-channel habitats	• Dams, culverts, in-stream structures	All species	As many as 9 miles of potential anadromous habitat are blocked by artificial obstructions, mostly on small tributary streams. No individual barriers account for a large share of the blocked habitat. The extent of potential habitat above these barriers is not well known but is expected to be minimal. Passage restoration projects should focus only on cases where it can be demonstrated that there is good potential benefit and reasonable project costs.
Priority Locations				
Several blocking culverts on small tributary streams				

#7 - **Restore channel structure and stability**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Place stable woody debris in streams to enhance cover, pool formation, bank stability, and sediment sorting B. Structurally modify channel morphology to create suitable habitat C. Restore natural rates of erosion and mass wasting within river corridors	• Lack of stable instream woody debris • Altered habitat unit composition • Reduced bank/soil stability • Excessive fine sediment • Excessive turbidity • Embedded substrates	• None (symptom-focused restoration strategy)	All species	Large wood installation projects could benefit habitat conditions in many areas although watershed processes contributing to wood deficiencies should be considered and addressed prior to placing wood in streams. Other structural enhancements to stream channels may be warranted in some places, especially in lowland alluvial reaches that have been simplified through channel straightening and confinement.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#8 – Restore degraded water quality with emphasis on temperature impairments

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Exclude livestock from riparian areas B. Increase riparian shading C. Decrease channel width-to-depth ratios D. Reduce delivery of chemical contaminants to streams E. Address leaking septic systems	• Bacteria • Altered stream temperature regime • Chemical contaminants	• Timber harvest – riparian harvests • Riparian grazing • Leaking septic systems • Clearing of vegetation due to rural development and agriculture • Chemical contaminants from agricultural and developed lands	• All species	Several stream segments are listed on the draft 2002-2004 303(d) list (WDOE 2004) for stream temperature impairment. A few other segments are included as a concern for temperature impairment. Temperature impairment is believed to be related primarily to degraded riparian conditions.
Priority Locations				
1st- Tier 1 or 2 reaches with 303(d) listings (2002-2004 draft list) Reaches: Coweeman 5, 6, 10-12 (temperature); Canyon 1-2 (temperature); Baird Creek 1 (temperature); Goble Creek1 (temperature) 2nd- Other reaches with 303(d) listings Reaches: Mulholland Creek 1 (temperature); Turner Creek (temperature); RB trib3 (temperature) 3rd- All remaining reaches				

#9 – Provide for adequate instream flows during critical periods

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect instream flows through water rights closures and enforcement B. Restore instream flows through acquisition of existing water rights C. Restore instream flows through implementation of water conservation measures	• Stream flow – maintain or improve flows during low-flow Summer months	• Water withdrawals	All species	Instream flow management strategies for the Coweeman Basin have been identified as part of Watershed Planning for WRIA 26 (LCFRB 2004). Strategies include water rights closures, setting of minimum flows, and drought management policies. This measure applies to instream flows associated with water withdrawals and diversions, generally a concern only during low flow periods. Hillslope processes also affect low flows but these issues are addressed in separate measures.
Priority Locations				
Entire Basin				

#10 – Create/restore off-channel and side-channel habitat

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore historical off-channel and side-channel habitats where they have been eliminated B. Create new channel or off-channel habitats (i.e. spawning channels)	• Loss of off-channel and/or side-channel habitat	• Floodplain filling • Channel straightening • Artificial confinement	chum coho	There has been some loss of off-channel and side-channel habitats, especially along the lower mainstem below the canyon. This has limited chum spawning habitat and coho overwintering habitat. Targeted restoration or creation of habitats would increase available habitat where full floodplain and CMZ restoration is not possible.
Priority Locations				
1st- Lower mainstem downstream of the canyon Reaches: Coweeman 1-tidal; Coweeman 2-4 2nd- Other reaches that may have potential for off-channel and side-channel habitat restoration or creation				

Figure C4. Toutle River (WA).

Excerpted from the recovery plan (LCFRB 2004).

Table 17. Prioritized measures for the Toutle River Basin.

#1 – Protect stream corridor structure and function

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect floodplain function and channel migration processes B. Protect riparian function C. Protect access to habitats D. Protect instream flows through management of water withdrawals E. Protect channel structure and stability F. Protect water quality G. Protect the natural stream flow regime	Potentially addresses many limiting factors	Potentially addresses many threats related to limiting factors	All Species	The mainstem Toutle, lower NF Toutle, and lower SF Toutle were heavily dredged, rip rapped and confined shortly following the 1980 Mount St. Helens eruption, seriously compromising floodplain function (Wade 2000). The upper SF Toutle and upper NF Toutle (above the SRS) contain functioning floodplains and remain heavily aggraded with eruption sediments. The upper Green River (upstream of the hatchery) also contains functioning floodplains. Riparian areas were severely impacted by the eruption and subsequent timber harvests. Protecting floodplains, channel migration processes, and riparian areas from further degradation will be an important component of recovery.
Priority Locations				
1st- Tier 1 or 2 reaches in mixed-use lands at risk of further degradation Reaches: Toutle 1-9; SF Toutle 1-2; NF Toutle 1-2; Stankey Cr; Wyant Cr 1 2nd- Remaining Tier 1 and 2 reaches 3rd- All remaining reaches				

#2 – Protect hillslope processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Manage forest practices to minimize impacts to sediment supply processes, runoff regime, and water quality B. Manage growth and development to minimize impacts to sediment supply processes, runoff regime, and water quality	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Development – impacts to sediment supply, water quality, and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to forest denudation related to the 1980 eruption of Mount St. Helens and subsequent intensive timber harvest and road building, particularly on private commercial timberlands. Limiting additional degradation will be necessary to prevent further habitat impairment.
Priority Locations				
1st- Functional subwatersheds contributing to Tier 1 or 2 reaches (functional for sediment *or* flow according to the IWA – local rating) Subwatersheds: 40101, 30201, 30204, 30104, 30102 2nd- All other functional subwatersheds plus Moderately Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: All other subwatersheds except 50403, 50202, 40302 & 40203 3rd- All other Moderately Impaired subwatersheds plus Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 50403, 50202, 40302 & 40203				

#3 – Address fish passage and sediment issues at the Sediment Retention Structure on the NF Toutle

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers B. Reduce persistent sediment contribution from the SRS	• Blockages to channel habitats • Excessive fine sediment • Excessive turbidity • Embedded substrates	•Dams, culverts, in-stream structures	All species	As many as 50 miles of habitat are blocked by the Sediment Retention Structure on the NF Toutle. Fish are currently transported around this structure. The structure is also a source of persistent sediment to the lower river.
Priority Locations				
1st- Sediment Retention Structure on the NF Toutle				

#4 - Restore floodplain function and channel migration processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Set back, breach, or remove artificial confinement structures	• Bed and bank erosion • Altered habitat unit composition • Restricted channel migration • Disrupted hyporheic processes • Reduced flood flow dampening • Altered nutrient exchange processes • Channel incision • Loss of off-channel and/or side-channel habitat • Blockages to off-channel habitats	• Floodplain filling • Channel straightening • Artificial confinement	All species	Portions of the mainstem Toutle, lower NF Toutle, lower SF Toutle, and Green River all suffer from channel confinement and bank hardening in some areas. There is significant potential for restoration of floodplain function and channel migration processes that could improve flow conditions and create key habitat types. Selective breaching, setting back, or removing confining structures would help to restore floodplain and CMZ function as well as facilitate the creation of off-channel and side channel habitats. There are challenges with implementation due to private lands, existing infrastructure already in place, potential flood risk to property, and large expense.
Priority Locations				
1st- Tier 1 reaches with hydro-modifications (obtained from EDT ratings) Reaches: Toutle 1; NF Toutle 2 & 10; SF Toutle 2 & 3; Green River 6 2nd- Tier 2 reaches with hydro-modifications Reaches: Toutle 2; NF Toutle 9 & 11; SF Toutle 6; Green River 7-9; Brownell Creek 2 3rd- Other reaches with hydro-modifications Reaches: NF Toutle 3; Silver Lake 1; Sucker Cr; RB trib5				

#5- Restore degraded hillslope processes on forest, agricultural, and developed lands

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Upgrade or remove problem forest roads B. Reforest heavily cut areas not recovering naturally	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Rural residential and small scale agriculture – impacts to water quality and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to the 1980 Mount St. Helens eruption and subsequent intensive timber harvest and road building. Rural residential development and small-scale agricultural operations contribute to degraded hillslope processes in the lower basin. Hillslope processes must be addressed for reach-level habitat recovery to be successful.
Priority Locations				
1st- Moderately impaired or impaired subwatersheds contributing to Tier 1 reaches (mod. impaired or impaired for sediment *or* flow according to IWA – local rating) Subwatersheds: All subwatersheds in the basin				

#6 - Restore riparian conditions throughout the basin

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore the natural riparian plant community B. Exclude livestock from riparian areas C. Eradicate invasive plant species from riparian areas	• Reduced stream canopy cover • Altered stream temperature regime • Reduced bank/soil stability • Reduced wood recruitment • Lack of stable instream woody debris • Exotic and/or invasive species • Bacteria	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to agriculture and residential development	All species	Riparian areas were severely degraded from mudflows from the 1980 Mount St. Helens eruption and subsequent timber harvest. Riparian impairment is a concern throughout the basin. There is a high potential benefit of riparian restoration due to the many limiting factors that are addressed. The increasing abundance of exotic and invasive species in riparian areas is a particular concern. Riparian restoration projects are relatively inexpensive and are often supported by landowners.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#7 - Restore channel structure and stability

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Place stable woody debris in streams to enhance cover, pool formation, bank stability, and sediment sorting B. Structurally modify channel morphology to create suitable habitat C. Restore natural rates of erosion and mass wasting within river corridors	• Lack of stable instream woody debris • Altered habitat unit composition • Reduced bank/soil stability • Excessive fine sediment • Excessive turbidity • Embedded substrates	• None (symptom-focused restoration strategy)	All species	Channel structure and stability was severely compromised due to mudflows associated with the 1980 eruption. Channels remain highly aggraded and unstable. Much of the large wood was transported through the system or buried in sediments during or shortly after the eruption. As channels naturally become more stable, large wood installation projects may be appropriate. Care should be taken to acknowledge that structural enhancements may not succeed if channels are too unstable or if artificial confinement structures are inhibiting natural flow processes.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#8 – Restore degraded water quality with emphasis on temperature impairments

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Increase riparian shading B. Decrease channel width-to-depth ratios	• Altered stream temperature regime	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to rural development and agriculture	• All species	There are a few stream segments on the draft 2002-2004 303(d) list for temperature impairment and one stream segment included as a concern for temperature impairment. Despite the few listed segments, elevated stream temperature is believed to be a concern throughout the basin due to high channel width-to-depths and lack of riparian cover. High suspended sediment levels are also a concern but are related primarily to high sediment loads and unstable channels due to the 1980 eruption.
Priority Locations				
1st- Reaches with 303(d) listings Reaches: Harrington Creek; Hoffstadt Cr 2; Shultz Creek 2 2nd- All remaining reaches				

#9 – Provide for adequate instream flows during critical periods

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect instream flows through water rights closures and enforcement B. Restore instream flows through acquisition of existing water rights C. Restore instream flows through implementation of water conservation measures	• Stream flow – maintain or improve Summer low-flows	• Water withdrawals	All species	Instream flow management strategies for the Toutle Basin have been identified as part of Watershed Planning for WRIA 26 (LCFRB 2004). Strategies include water rights closures, setting of minimum flows, and drought management policies. This measure applies to instream flows associated with water withdrawals and diversions, generally a concern only during low flow periods. Hillslope processes also affect low flows but these issues are addressed in separate measures.
Priority Locations				
Entire Basin				

#10 – Restore access to habitat blocked by artificial barriers

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers	• Blockages to channel habitats • Blockages to off-channel habitats	• Dams, culverts, in-stream structures	All species	Culverts or other barriers block as much as 23 miles of anadromous habitat; the blocked habitat is believed to be marginal in most cases. Passage restoration projects should focus on cases where it can be demonstrated that there is good potential benefit and reasonable project costs. Passage issues at the SRS on the NF Toutle are addressed in a separate measure.
Priority Locations				
1st- Several small tributaries with blockages				

#11 – Create/restore off-channel and side-channel habitat

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore historical off-channel and side-channel habitats where they have been eliminated B. Create new channel or off-channel habitats (i.e. spawning channels)	• Loss of off-channel and/or side-channel habitat	• Floodplain filling • Channel straightening • Artificial confinement	chum coho	There was significant loss of off-channel and side-channel habitats due to mudflows associated with the 1980 eruption. Sediment loading and subsequent channel braiding may set the stage for the creation of quality side channel and off-channel habitats as stream channels slowly stabilize and fines are transported out of the system. Dredging and levee construction following the eruption will limit side-channel and off-channel creation in places. Creating habitats may be warranted in some areas, especially targeted for chum spawning; however, processes limiting habitat creation and maintenance (i.e. instability, confinement) must be addressed for them to be successful.
Priority Locations				
1st- Lower mainstem Toutle, lower NF Toutle, lower SF Toutle 2nd- Other reaches that may have potential for off-channel and side-channel habitat restoration or creation				

Figure C5. Elochoman River (WA).

Excerpted from the recovery plan (LCFRB 2004).

Table 18. Prioritized measures for the Elochoman/Skamokawa Watershed.

#1 – Protect stream corridor structure and function

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect floodplain function and channel migration processes B. Protect riparian function C. Protect access to habitats D. Protect instream flows through management of water withdrawals E. Protect channel structure and stability F. Protect water quality G. Protect the natural stream flow regime	Potentially addresses many limiting factors	Potentially addresses many limiting factors	All Species	Streams in upper elevations have been heavily impacted by past riparian timber harvests and splash-dam logging. Stream channel conditions within the broad agricultural valley in the middle and lower Skamokawa and Wilson Creek have been heavily impacted by agricultural practices. Reaches in agricultural areas along the lower and middle Elochoman have also received significant alteration. Preventing further degradation of stream channel structure, riparian function, and floodplain function will be an important component of recovery.
Priority Locations				
1st- Tier 1 or 2 reaches in mixed-use lands (agriculture, rural residential) at risk of further degradation Reaches: Skamokawa 4-8; LF Skamokawa 2; Falk 1-2; Wilson 1-4; Elochoman 3-7; Duck 1, 3, 4, 6; Clear Cr 1,3 2nd- Remaining Tier 1 and 2 reaches				

#2 – Protect hillslope processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Manage forest practices to minimize impacts to sediment supply processes, runoff regime, and water quality B. Manage agricultural practices to minimize impacts to sediment supply processes, runoff regime, and water quality C. Manage growth and development to minimize impacts to sediment supply processes, runoff regime, and water quality	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to sediment supply, water quality, and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest and road building. Lowland hillslope processes have been impacted by agriculture. Limiting additional degradation will be necessary to prevent further habitat impairment.
Priority Locations				
1st- Functional subwatersheds contributing to Tier 1 or 2 reaches (functional for sediment *or* flow according to IWA – local rating) Subwatersheds: 60306 2nd- All other functional subwatersheds plus Moderately Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 60303, 60302, 60301, 60101, 60102, 60103, 60307, 60202, 60201, 60204, 60203 3rd- All other Moderately Impaired subwatersheds plus Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 60304, 60308, 60401, 60305 4th- All remaining subwatersheds Subwatersheds: 60402				

#3- Restore degraded hillslope processes on forest and agricultural lands with an emphasis on sediment supply processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Upgrade or remove problem forest roads B. Reforest heavily cut areas not recovering naturally C. Employ agricultural Best Management Practices with respect to contaminant use, erosion, and runoff	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest and road building. According to EDT, the sediment impact to egg incubation is the greatest limiting factor for all species in the Elochoman and Skamokawa Basins. Sediment supply processes must be addressed for reach-level habitat recovery to be successful.
Priority Locations				
1st- Moderately impaired or impaired subwatersheds contributing to Tier 1 reaches (mod. Impaired or impaired for sediment *or* flow according to IWA – local rating) Subwatersheds: 60303, 60302, 60301, 60101, 60102, 60103, 60307, 60202, 60201, 60204, 60203, 60306 2nd- Moderately impaired or impaired subwatersheds contributing to other reaches Subwatersheds: 60304, 60308, 60305, 60401				

#4 - Restore floodplain function and channel migration processes in lowland mixed-use areas along the major streams

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Set back, breach, or remove artificial confinement structures	• Bed and bank erosion • Altered habitat unit composition • Restricted channel migration • Disrupted hyporheic processes • Reduced flood flow dampening • Altered nutrient exchange processes • Channel incision • Loss of off-channel and/or side-channel habitat • Blockages to off-channel habitats	• Floodplain filling • Channel straightening • Artificial confinement	Chum, fall chinook, coho	There has been significant degradation of floodplain connectivity and constriction of channel migration zones in the agricultural valleys of the Elochoman, Skamokawa, and Wilson Creek. Removal of confining structures would restore floodplain and CMZ function as well as facilitate the creation of off-channel and side channel habitats. There are feasibility issues with implementation due to private lands, existing infrastructure already in place, potential flood risk to property, and large expense.
Priority Locations				
1st- Tier 1 reaches in mixed-use areas with hydro-modifications (obtained from EDT ratings) Reaches: Elochoman 3-4, 6-7; Skamokawa 5-6; Clear 3; Duck 1; Wilson 3 2nd- Tier 2 reaches in mixed-use areas with hydro-modifications Reaches: Elochoman 8, 12; Skamokawa 7; Wilson 1, 2, 4; Beaver 2 3rd- Other reaches with hydro-modifications Reaches: Alger 1-2; Beaver 1, 6; Brooks 1; Elochoman 1-2; Kelly 2; Nelson 1; NF Eloch 2-4; Risk 4; Skamokawa 1-4; West Valley 1; WF Skamokawa 1-2; Wilson 5-6				

#5 - Restore riparian conditions throughout the basin

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore the natural riparian plant community B. Exclude livestock from riparian areas C. Eradicate invasive plant species from riparian areas	• Reduced stream canopy cover • Altered stream temperature regime • Reduced bank/soil stability • Reduced wood recruitment • Lack of stable instream woody debris • Exotic and/or invasive species • Bacteria	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to agriculture and residential development	All species	There is a high potential benefit due to the many limiting factors that are addressed. Riparian impairment is related to most land-uses and is a concern throughout the basin. The increasing abundance of exotic and invasive species is of particular concern. Riparian restoration projects are relatively inexpensive and are often supported by landowners.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#6 – Restore degraded water quality with emphasis on temperature impairments

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Exclude livestock from riparian areas B. Increase riparian shading C. Decrease channel width-to-depth ratios D. Reduce delivery of chemical contaminants to streams E. Address leaking septic systems	• Altered stream temperature regime • Bacteria • Chemical contaminants	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to rural development and agriculture • Leaking septic systems • Chemical contaminants from agricultural and developed lands	All species	There are known impairments to stream temperature and fecal coliform bacteria in the basin. Bacteria is more of a human health concern than a fish health concern. Excluding livestock from riparian areas is particularly important in the heavily grazed lowland areas. Leaking septic systems may be contributing to bacteria levels in some areas. The degree of impact of agricultural pollutants is unknown and needs further assessment.
Priority Locations				
1st- Tier 1 or 2 reaches with 303(d) listings (2002-2004 draft list) Reaches: Elochoman 3-4 (temperature); Skamokawa 5 (temperature); Wilson 1-2 (temperature) 2nd- Other reaches with 303(d) listings Reaches: Skamokawa 3 (temperature) 3rd- All remaining reaches				

#7 – Create/restore off-channel and side-channel habitat

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore historical off-channel and side-channel habitats where they have been eliminated B. Create new channel or off-channel habitats (i.e. spawning channels)	• Loss of off-channel and/or side-channel habitat	• Floodplain filling • Channel straightening • Artificial confinement	chum coho	There has been significant loss of off-channel and side-channel habitats, especially along lowland portions of the large streams that are now in agricultural uses. This has severely limited chum spawning habitat and coho overwintering habitat. Targeted restoration or creation of habitats would increase available habitat where full floodplain and CMZ restoration is not possible.
Priority Locations				
Lower basin alluvial reaches (lower Skamokawa Creek; lower WF Skamokawa; Wilson Creek; lower and middle Elochoman)				

#8 – Restore access to habitat blocked by artificial barriers

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers	• Blockages to channel habitats • Blockages to off-channel habitats	• Dams, culverts, in-stream structures	All species	As many as 10 miles of potentially accessible habitat are blocked by culverts or other barriers (approximately 8 barriers total). The blocked habitat is believed to be marginal in most cases. The water intake dam for the hatchery on Beaver Creek is believed to be a partial barrier. Passage restoration projects should focus on cases where it can be demonstrated that there is good potential benefit and reasonable project costs.
Priority Locations				
1st- Beaver Creek 2nd- Other small tributaries with blockages				

#9 - Restore channel structure and stability

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Place stable woody debris in streams to enhance cover, pool formation, bank stability, and sediment sorting B. Structurally modify channel morphology to create suitable habitat C. Restore natural rates of erosion and mass wasting within river corridors	• Lack of stable instream woody debris • Altered habitat unit composition • Reduced bank/soil stability • Excessive fine sediment • Excessive turbidity • Embedded substrates	• None (symptom-focused restoration strategy)	All species	Large wood installation projects could benefit habitat conditions in many areas although watershed processes contributing to wood deficiencies should be considered and addressed prior to placing wood in streams. Other structural enhancements to stream channels may be warranted in some places, especially in lowland alluvial reaches that have been simplified through channel straightening and confinement. Most areas of bank instability are located in the agricultural middle valley of the Skamokawa River and Wilson Creeks. Bio-engineered approaches that rely on structural as well as vegetative measures are the most appropriate. These projects have a high risk of failure if causative factors are not adequately addressed.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#10 – Provide for adequate instream flows during critical periods

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect instream flows through water rights closures and enforcement B. Restore instream flows through acquisition of existing water rights C. Restore instream flows through implementation of water conservation measures	• Stream flow – maintain or improve flows in tributaries during low-flow Summer months	• Water withdrawals	All species	Instream flow management strategies for the Elochoman Subbasin have been identified as part of Watershed Planning for WRIA 25 (LCFRB 2004). Strategies include water rights closures, setting of minimum flows, and drought management policies. This measure applies to instream flows associated with water withdrawals and diversions, generally a concern only during low flow periods. Hillslope processes also affect low flows but these issues are addressed in separate measures.
Priority Locations				
Entire Basin				

Figure C6. Mill/Germany/Abernathy Creeks (WA).

Excerpted from the recovery plan (LCFRB 2004).

Table 17. Prioritized measures for the M-A-G Watershed.

#1 – Protect stream corridor structure and function

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect floodplain function and channel migration processes B. Protect riparian function C. Protect access to habitats D. Protect instream flows through management of water withdrawals E. Protect channel structure and stability F. Protect water quality G. Protect the natural stream flow regime	Potentially addresses many limiting factors	Potentially addresses many limiting factors	All Species	The lower mainstems of Mill, Abernathy, and Germany Creek have been altered by adjacent land uses including agriculture, rural residential development, and transportation corridors. Preventing further degradation of stream channel structure, riparian function, and floodplain function will be an important component of recovery.
Priority Locations				
1st- Tier 1 or 2 reaches with functional riparian conditions (IWA) (reach Mill 8) 2nd- Tier 1 or 2 reaches in mixed-use lands at risk of further degradation (reaches: Mill1-3; SF Mill 1; Abernathy 1-8; Germany 2-6 3rd- Remaining Tier 1 and 2 reaches 4th- All remaining reaches				

#2 – Protect hillslope processes

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Manage forest practices to minimize impacts to sediment supply processes, runoff regime, and water quality B. Manage agricultural practices to minimize impacts to sediment supply processes, runoff regime, and water quality C. Manage growth and development to minimize impacts to sediment supply processes, runoff regime, and water quality	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes • Development – impacts to sediment supply, water quality, and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest and road building. Lowland hillslope processes have been impacted by agriculture and rural residential development. Limiting additional degradation will be necessary to prevent further habitat impairment.
Priority Locations				
1st- Functional subwatersheds contributing to Tier 1 or 2 reaches (functional for sediment *or* flow according to IWA – local rating) Subwatersheds: 50502 2nd- All other functional subwatersheds plus Moderately Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 50501, 50503, 50402, 50403, 50401, 50301, 50302 3rd- All other Moderately Impaired subwatersheds plus Impaired subwatersheds contributing to Tier 1 or 2 reaches Subwatersheds: 50202, 50201, 50103 4th- All remaining subwatersheds Subwatersheds: 50101, 50104, 50102				

#3- Restore degraded hillslope processes on forest, agricultural, and developed lands

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Upgrade or remove problem forest roads B. Reforest heavily cut areas not recovering naturally C. Employ agricultural Best Management Practices with respect to contaminant use, erosion, and runoff	• Excessive fine sediment • Excessive turbidity • Embedded substrates • Stream flow – altered magnitude, duration, or rate of change of flows • Water quality impairment	• Timber harvest – impacts to sediment supply, water quality, and runoff processes • Forest roads – impacts to sediment supply, water quality, and runoff processes • Agricultural practices – impacts to sediment supply, water quality, and runoff processes	All species	Hillslope runoff and sediment delivery processes have been degraded due to past intensive timber harvest, road building, agriculture, and rural residential development. These processes must be addressed for reach-level habitat recovery to be successful.
Priority Locations				
1st- Moderately impaired or impaired subwatersheds contributing to Tier 1 reaches (mod. Impaired or impaired for sediment *or* flow according to IWA – local rating) Subwatersheds: 50501, 50502, 50402, 50503, 50403, 50401, 50301, 50302 2nd- Moderately impaired or impaired subwatersheds contributing to other reaches Subwatersheds: 50202, 50201, 50103, 50104, 50101, 50102				

#4 - **Restore floodplain function and channel migration processes along the lower mainstems and major tributaries**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Set back, breach, or remove artificial confinement structures	• Bed and bank erosion • Altered habitat unit composition • Restricted channel migration • Disrupted hyporheic processes • Reduced flood flow dampening • Altered nutrient exchange processes • Channel incision • Loss of off-channel and/or side-channel habitat • Blockages to off-channel habitats	• Floodplain filling • Channel straightening • Artificial confinement	Chum, fall chinook, coho	There has been degradation of floodplain connectivity and constriction of channel migration zones along the lower mainstems of Mill, Abernathy, and Germany Creeks and in the lower reaches of major tributaries. Selective breaching, setting back, or removing confining structures would help to restore floodplain and CMZ function as well as facilitate the creation of off-channel and side channel habitats. There are feasibility issues with implementation due to private lands, existing infrastructure already in place, potential flood risk to property, and large expense.
Priority Locations				
1st- Tier 1 reaches with hydro-modifications (obtained from EDT ratings) Reaches: Mill 2; Abernathy 1, 2, 4, 5, & 8; Germany 2, 6, 12, 13, & 15 2nd- Tier 2 reaches with hydro-modifications Reaches: Mill 1 & 3; Abernathy 7 & 9; Germany 4 3rd- Other reaches with hydro-modifications Reaches: Mill 10; Weist 1-2; Ordway 1; Midway 1; Germany 1, 11, & 16; several small unnamed tributaries				

#5 - **Restore riparian conditions throughout the basin**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore the natural riparian plant community B. Exclude livestock from riparian areas C. Eradicate invasive plant species from riparian areas	• Reduced stream canopy cover • Altered stream temperature regime • Reduced bank/soil stability • Reduced wood recruitment • Lack of stable instream woody debris • Exotic and/or invasive species	• Timber harvest – riparian harvests • Riparian grazing • Clearing of vegetation due to agriculture and residential development	All species	There is a high potential benefit due to the many limiting factors that are addressed. Riparian impairment is related to most land-uses and is a concern throughout the basin. The increasing abundance of exotic and invasive species is of particular concern. Riparian restoration projects are relatively inexpensive and are often supported by landowners.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#6 – **Restore degraded water quality with emphasis on temperature impairments**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Exclude livestock from riparian areas B. Increase riparian shading C. Decrease channel width-to-depth ratios D. Reduce delivery of chemical contaminants to streams E. Address leaking septic systems	• Bacteria • Altered stream temperature regime • Chemical contaminants	• Timber harvest – riparian harvests • Riparian grazing • Leaking septic systems • Clearing of vegetation due to rural development and agriculture • Chemical contaminants from agricultural lands	• All species	There are known impairments to stream temperature throughout the basin, related primarily to degraded riparian canopy cover. Livestock grazing may be contributing to temperature as well as bacteria impairment in some areas. Bacteria is more of a human health concern than a fish health concern. The impact of leaking septic systems may also be a concern and should be further evaluated. The degree of impact of agricultural pollutants is unknown and needs further assessment. The Longview Ditches, in the southeastern portion of the basin near Longview suffer from a number of water quality impairments.
Priority Locations				
1st- Tier 1 or 2 reaches with 303(d) listings (2002-2004 Draft list) Reaches: Abernathy 2-5 & 8 (temperature); Germany 3, 4, & 10 (temperature) 2nd- Other reaches with 303(d) listings Reaches: Coal Creek (temperature); Longview Ditches (bacteria and dissolved oxygen) 3rd- All remaining reaches				

#7 – **Create/restore off-channel and side-channel habitat**

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore historical off-channel and side-channel habitats where they have been eliminated B. Create new channel or off-channel habitats (i.e. spawning channels)	• Loss of off-channel and/or side-channel habitat	• Floodplain filling • Channel straightening • Artificial confinement	chum coho	There has been significant loss of off-channel and side-channel habitats, especially along the lower mainstems of Mill, Abernathy, and Germany Creeks that are located in agricultural or rural residential areas. This has severely limited chum spawning habitat and coho overwintering habitat. Targeted restoration or creation of habitats would increase available habitat where full floodplain and CMZ restoration is not possible.
Priority Locations				
1st- Lower mainstems of Mill, Abernathy, and Germany Creeks and lower portions of major tributaries 2nd- Other reaches that may have potential for off-channel and side-channel habitat restoration or creation				

#8 - Restore channel structure and stability

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Place stable woody debris in streams to enhance cover, pool formation, bank stability, and sediment sorting B. Structurally modify channel morphology to create suitable habitat C. Restore natural rates of erosion and mass wasting within river corridors	• Lack of stable instream woody debris • Altered habitat unit composition • Reduced bank/soil stability • Excessive fine sediment • Excessive turbidity • Embedded substrates	• None (symptom-focused restoration strategy)	All species	Large wood installation projects could benefit habitat conditions in many areas although watershed processes contributing to wood deficiencies should be considered and addressed prior to placing wood in streams. Other structural enhancements to stream channels may be warranted in some places, especially in lowland alluvial reaches that have been simplified through channel straightening and confinement.
Priority Locations				
1st- Tier 1 reaches 2nd- Tier 2 reaches 3rd- Tier 3 reaches 4th- Tier 4 reaches				

#9 – Provide for adequate instream flows during critical periods

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Protect instream flows through water rights closures and enforcement B. Restore instream flows through acquisition of existing water rights C. Restore instream flows through implementation of water conservation measures	• Stream flow – maintain or improve flows during low-flow Summer months	• Water withdrawals	All species	Instream flow management strategies for the Mill/Abernathy/Germany Basin have been identified as part of Watershed Planning for WRIA 25 (LCFRB 2004). Strategies include water rights closures, setting of minimum flows, and drought management policies. This measure applies to instream flows associated with water withdrawals and diversions, generally a concern only during low flow periods. Hillslope processes also affect low flows but these issues are addressed in separate measures.
Priority Locations				
Entire Basin				

#10 – Restore access to habitat blocked by artificial barriers

Submeasures	Factors Addressed	Threats Addressed	Target Species	Discussion
A. Restore access to isolated habitats blocked by culverts, dams, or other barriers	• Blockages to channel habitats • Blockages to off-channel habitats	• Dams, culverts, in-stream structures	All species	As many as 5 miles of potentially accessible habitat are blocked by culverts or other barriers. The blocked habitat is believed to be marginal in the majority of cases and no individual barriers in themselves account for a significant portion of blocked miles. Passage restoration projects should focus only on cases where it can be demonstrated that there is good potential benefit and reasonable project costs.
Priority Locations				
1st- Tributaries to Mill Creek and Coal Creek 2nd- Other small tributaries with blockages				

Figure C7. Clatskanie River (OR).

Table 7-10. Strategies and actions needed to address the current key and secondary threats and limiting factors to the recovery of Clatskanie salmon and steelhead populations. Bold text indicates the actions that address key threats and limiting factors. Excerpted from the April draft recovery plan (ODFW 2009).

Threat Category: Land/Water Management						
Limiting Factors: Degraded physical habitat quality due to increased fine sediment (7a) and Impaired habitat complexity/diversity, including access to off-channel habitat (8a); Degraded water quality (9a); Altered hydrology and degraded uplands due to land use practices (10f) Strategies: Protect natural ecological processes; Restore floodplain connectivity/function, riparian condition, channel structure/complexity, upland processes						
303	**Protect intact riparian areas and restore riparian areas that are degraded (conservation easements, acquisition, restoration).**	Priority tidal areas; lower Clatskanie	X	X	X	X
		Middle Clatskanie; lower Beaver Cr.	X		X	X
304	**Protect remaining high-quality off-channel habitat from degradation, restore degraded areas with high intrinsic potential for high quality habitat, and improve connectivity.**	Priority tidal areas; lower Clatskanie;	X	X	X	X
		Middle Clatskanie R; lower Beaver Creek	X		X	X
305	**Breach or lower dikes and levees to establish or improve access to off-channel habitats; vegetate dikes and levees.**	Priority tidal areas	X	X	X	X
306	**Restore instream habitat complexity with large wood placements.**	Lower & upper Clatskanie R.; Plympton Cr; lower Page Cr; lower NF Clatskanie, lower Carcus Cr, lower Miller Cr, lower Perkins Cr, lower Conyers Cr, lower Keystone Cr	X	X	X	X
		Middle Clatskanie R; lower Beaver Cr	X		X	X
307	**Establish working group to identify priority areas for riparian and instream habitat enhancement, and work with landowners to implement projects.**	Lower Clatskanie River	X	X	X	X
		Middle Clatskanie River; lower Beaver Creek	X		X	X
308	**Identify and reduce sources of fine sediment.**	Up. Middle Clatskanie R; Plympton Cr; Little Clatskanie R; upper Clatskanie R; lower Page Cr; lower NF Clatskanie; lower Carcus Cr; lower Miller Cr; lower Perkins Cr; lower Conyers Cr; lower Keystone Cr;	X	X	X	X
		Numerous small tributaries and headwaters streams	X	X		X
309	**Conduct full assessment of streams that were heavily damaged during Dec. 2007 storm to determine best approach to restoration.**	Numerous small streams in western portion of population area	X			X
310	**Implement Mid-Coast watershed council style limiting factors analysis to improve understanding of reach specific recovery action needs.**	Population-wide	X			
311	**Conduct assessment to inventory and assess connectivity and hydrologic function.**	Tidal areas and wetlands	X		X	X
Limiting Factor: Altered hydrology due to upslope land use practices (10f) Strategies: Restore and maintain hydrologic regimes; restore degraded upland processes						
312	Implement research, monitoring, and evaluation of headwater springs to investigate the concern that they may be drying up due to land management practices.	Population-wide	X	X	X	X

Figure C8. Scappoose River (OR).

Table 7-11. Strategies and actions needed to address the current key and secondary threats and limiting factors to the recovery of Scappoose salmon and steelhead populations. Bold text indicates the actions that address key threats and limiting factors. Excerpted from the April draft recovery plan (ODFW 2009).

Threat Category: Land/Water Management						
Limiting Factor: Impaired habitat access (2d) Strategy: Restore passage and connectivity to habitats blocked/impaired by artificial barriers						
402	**Evaluate Bonnie Falls ladder passage, conduct large wood placement projects.**	North Fork Scappoose (Bonnie Falls area)	X			X
403	**Improve passage at road crossing.**			X		
Limiting Factor: Degraded physical habitat quality due to fine sediment (7a) Strategy: Restore degraded upland processes						
404	Protect/manage headwater streams to reduce erosion and landslide impacts.	NF Scappoose headwater streams; SF Scappoose headwaters	X	X	X	X
Limiting Factors: Degraded physical habitat quality due to impaired habitat complexity/diversity, including access to off-channel habitat (8a); Degraded water quality (9a); Altered hydrology and degraded uplands due to land use practices (10f) Strategies: Protect natural ecological processes; Restore floodplain connectivity/function, riparian condition, channel structure/complexity, upland processes						
405	**Protect/manage existing high quality habitat.**	Salmon and Cox Creeks	X			X
406	**Breach/lower dikes and levees to establish or improve access to off-channel habitats (willing landowner).**	South Sauvie Island			X	
407	**Protect/restore riparian function (conservation easements, acquisition, restoration) and improve large wood recruitment.**	Lower Merril, Tide & McBride Creeks; lower Scappoose; lower SF Scappoose	X	X	X	X
		Mid/upper Merril, Tide & McBride Creeks; Goble Cr; upper Milton Cr	X			X
		Lower/middle Milton Creek	X	X		X
408	**Restore instream habitat complexity, including large wood placement.**	Lower Merri, Tide & McBride Creeks; NF Scappoose (upper mid-mainstem and tribs); lower NF Scappoose; lower SF Scappoose	X	X	X	X
		Goble Creek, mid/upper Merril, Tide, & McBride Creeks; upper Milton Cr; Dart Cr	X			X
		Lower/middle Milton Creek	X	X		X
409	**Improve degraded floodplains, restore off channel connectivity and correct erosion problems; reconnect side channels.**	Lower Merril, Tide & McBride Creeks; lower NF Scapoose; lower Scappoose; Deer Island (Loomis property)	X	X	X	X
		Milton Creek	X	X		X
		Mid/upper Merril, Tide & McBride Creeks; Goble Cr;	X			X

410	Restore connectivity to small tributaries.	Lower SF Scappoose	X	X	X	X
411	Establish working group to identify habitat enhancement projects.	Lower Merril, Tide & McBride Creeks	X	X	X	X
412	Work with landowners to implement projects to prevent/reduce impacts from development and land management. Provide resources and incentives.	Lower Merril, Tide & McBride Creeks; lower NF Scappoose; lower Scappoose; lower SF Scappoose	X	X	X	X
		Mid/upper Merril, Tide & McBride Creeks; Goble Cr; NF Scappoose (upper mid-mainstem and tribs); Dart Cr	X			X
413	Improve passage at road crossings.	Upper Milton Creek; Dart Cr	X			X
414	Protect/restore wetlands	Lower Scappoose; lower Milton Cr	X	X	X	X
415	Improve flow conditions to provide better migration into and out of Sturgeon Lake.	Dairy Creek and Gilbert River			X	
416	Investigate ways to retain gravel in context of flood impact management considerations.	Lower Milton Creek	X	X		X
417	Implement Mid-Coast watershed council style limiting factors analysis to improve understanding of reach specific recovery action needs.	Basin-wide	X			
418	Conduct assessment to inventory and assess connectivity and hydrologic function.	Tidal areas and wetlands	X	X	X	X
419	Improve system for monitoring water quality and quantity and ensure that information is integrated into existing regulatory framework.	Basin-wide	X		X	X
Limiting Factor: Altered hydrology due to upslope land use practices (10f) Strategies: Restore and maintain hydrologic regimes; restore degraded upland processes						
420	Implement research, monitoring, and evaluation of headwater springs to investigate the concern that they may be drying up due to land management practices.	Basin-wide	X	X	X	X

Figure C9. Hood River (OR).

Table 7-12. Strategies and actions needed to address the current key and secondary threats and limiting factors to the recovery of Hood River salmon and steelhead populations. Bold text indicates the actions that address key threats and limiting factors. Excerpted from the April draft recovery plan (ODFW 2009).

Threat Category: Land/Water Management							
Limiting Factor: Impaired habitat access (2g) Strategy: Restore passage /connectivity to habitats blocked or impaired by artificial barriers							
924	Provide access to habitat above passage barrier.	Laurance Lake Dam on Clear Branch (Hood River)	X			X	
Limiting Factor: Degraded physical habitat quality due to: Increased fine sediment (7a) and Impaired habitat complexity/diversity, including access to off-channel habitat (8a) Strategies: Protect/conserve natural ecological processes; Restore floodplain connectivity/function, passage/connectivity, riparian condition, channel structure/complexity, degraded upland processes							
925	**Remove sections of railroad fill.**	Lower Hood River	X			X	
926	**Implement stream restoration projects to reconnect side channels.**	Lower Hood River	X			X	
927	**Restore floodplain connectivity and function.**	East Fork Hood River; Neal Cr; Lenz Cr;	X			X	
928	**Protect/restore riparian function (conservation easements, acquisition, restoration.)**	Lower Hood River; Neal Cr; Lenz Cr; Hood River Delta	X			X	
		West Fork Hood River			X		X
		Upper West Fork Hood River			X		
929	**Restore channel structure and complexity.**	East Fork Hood River; Hood River Delta	X			X	
930	Provide passage at irrigation diversions, road and railroad crossings, other barriers, and investigate feasibility of modifying barriers formed by 2006 flood.	Tony Creek, Upper Gorge tributaries, Middle Fork Hood	X			X	
		East Fork Hood River				X	
931	Restore instream habitat complexity, including large wood placement.	Tony Cr. (above diversion); Hood River Delta	X			X	
		Upper West Fork Hood River			X		
932	Develop and implement Best Management Practices and rules from the Hood River Agricultural Water Quality Area Management Plan and Rules.	Hood River			X	X	X
933	Work to expand streamside vegetation buffers.	Hood River			X	X	X
934	Continue education and outreach programs identified in the HRWAP.	Hood River			X	X	X

Limiting Factor: Degraded water quality due to elevated water temperatures (9a) and toxins from agricultural chemicals (9b) **Strategy: Restore degraded water quality and riparian condition**							
935	**Restore riparian areas to improve flows and water temperatures in Hood River.**	Hood River Basin-wide	X	X	X	X	X
936	**Implement BMPs for ag chemicals.**	Neal & Lenz Creek	X			X	
937	Improve domestic on-site sewage system management and residential chemical use.	Hood River			X	X	X
Limiting Factors: Altered hydrology due to irrigation withdrawals (10c); degraded upslope land uses (10f) **Strategies: Restore and maintain hydrologic regimes; Restore degraded upland processes**							
938	**Identify and implement flow improvements within East Fork, Middle Fork and Farmers Irrigation Districts.**	East Fork Hood River; Middle Fork Hood River, Hood River	X	X		X	
939	**Implement projects that aid in restoring the natural flow regime (e.g., HRWAP Project FP-3 Central Canal Pipeline/Neal Creek Siphon, future piping projects, Conserved Water Program, landowner technical assistance, etc.).**	Neal Creek Watershed	X	X		X	
940	**Provide education and resources to hobby farms and other rural residents to assist them with water saving measures.**	Hood River Basin-wide	X	X	X	X	X
941	**Work with OWRD and others to keep water saved through publically-funded water conservation efforts instream for fish.**	Hood River Basin-wide	X	X	X	X	X

Habitat Appendix D – Reach Level Scenario Translation – Excel sheet available from Aimee.Fullerton@noaa.gov

Appendix E. Modeling Time Lags in Recovery Scenarios

To estimate when expected benefits to freshwater restoration actions might occur, we conducted a two-step process. First, we projected time lags associated with each type of restoration action, based on literature, reports, or expert opinion (Table E1). Total time lags included both how long it takes to get a project implemented, and the time to which we might expect to see ecological benefits to improved habitat.

Using the entire range of a total lag estimate (e.g., from 10 to 50 yrs), we divided the proportion of projects likely to occur in each of 7 time steps (Table E2). For faster modeling, and because we can only estimate time lags with low precision, we lumped these proportions into 4 time steps: <5 years, 5-25 years, 25-50 years, and >50 years (Table E3). The final project allocations for the recovery scenario for each population of tule Chinook salmon are listed in tables E4-E12.

REFERENCES

Blair, G.R., L.C. Lestelle, and L.E. Mobrand. 2004. Characterizing actions with the EDT Scenario Builder: a "how-to guide". Mobrand Biometrics, Inc.

Roni, P., K. Hanson, and T. Beechie. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management 28:856-890.

Table E1. Estimated time lags (years) associated with restoration actions. We do not report on time needed for planning, designing, and obtaining funding for projects, nor on project longevity here, thus these estimates should be considered conservative.

Restoration Action	Habitat Target	Permits [1]	Physical Work [2]	Imple-mentation (all pieces) [3]	Habitat Response [3,4]	Fish Response [3,4]	Ecological Benefit [5]	Estimated Total Lag
Barrier	Access	0.25-1	0.3 (0.1-3.0; n=58)	2-3	0	0-8	NA	0.5-12
Instream	Wood, gravel, complexity	0.25-1	1.3 (0.2-4.3; n=49)	3	0	0-8	0-25	0.5-25
Floodplain	Off-channel habitat	1-2	NA	1-5	0-10	0-10	10-50	10-50
Road	Sediment	0	0.2 (0.1-0.5; n=46)	NA	1	NA	10-50	10-50
Riparian A (active)	Shade Wood	0	1.1 (0.2-4.0; n=39)	1	5-15 50-150	NA	10-25 50-100	10-150
Riparian P (protection)	Shade Wood	0	0.3 (0.3-0.8; n=3)	1	5-15 50-150	NA	10-25 50-100	10-150
Upland	Sediment	0	0.8 (0.5-4.1; n=12)	NA	10-150	NA	10-100	10-150

Actions:
Barrier = providing passage via removal or improvement of anthropogenic barriers such as culverts
Instream = instream placements such as large wood, log jams, or gravel or channel re-configuring
Floodplain = improving connections between main channel and floodplain, including off-channel habitats
Road = decommissioning or improving roads to reduce sediment input
Riparian (active) = riparian restoration including planting and invasive species removal
Riparian (protection) = passive protection including land purchases, easements, and fencing out livestock
Upland = best management practices that improve land cover to reduce runoff and sediment into streams

Sources:
[1]Patricia Olson, Washington Department of Ecology; includes Washington state and local ordinances but does not assess Oregon state or Federal regulations.
[2]NWFSC Restoration Database (queried 9/09); values are medians of non-zero years between project start and end dates with 10^{th} and 90^{th} percentiles in parentheses; usually implemented alongside other project types so these may be overestimates for individual types.
[3]Eli Asher, Habitat Program Manager, Lower Columbia Fish Recovery Board.
[4]Roni et al. 2008, NAJFM 28:856–890.
[5]Blair et al. 2004. Estimates effectiveness, presumably both habitat and fish response.

Table E2. Distribution of simulated restoration actions across time steps (projects are uniformly distributed throughout the range of times, where each year is weighted equally). Values are the proportion of total projects modeled during that time step.

Restoration Action	Estimated Total Lag*	0-5 years	5-10 years	10-25 years	25-50 years	50-75 years	75-100 years	100-150 years
Barrier	0.5-12	0.5	0.5					
Instream	0.5-25	0.2	0.2	0.6				
Floodplain	10-50			0.4	0.6			
Road	10-50			0.4	0.6			
Riparian A	10-150			0.1	0.2	0.2	0.2	0.3
Riparian P	10-150			0.1	0.2	0.2	0.2	0.3
Upland	10-150			0.1	0.2	0.2	0.2	0.3

* From Table B1

Table E3. Condensed time steps (from Table B2) for faster simulation.

Restoration Action	Estimated Total Lag	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	0.5-12	0.5	0.5		
Instream	0.5-25	0.2	0.8		
Floodplain	10-50		0.4	0.6	
Road	10-50		0.4	0.6	
Riparian A	10-150		0.1	0.2	0.7
Riparian P	10-150		0.1	0.2	0.7
Upland	10-150		0.1	0.2	0.7

Table E4. Length of habitat treated per time step for the Lewis River (WA), translated from proportions in Table 3).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier*	NA				
Instream	24.9	5.0	19.9	0.0	0.0
Floodplain	16.5	0.0	6.6	9.9	0.0
Road	24.9	0.0	10.0	14.9	0.0
Riparian A	24.9	0.0	2.5	5.0	17.4
Riparian P	0.0	0.0	0.0	0.0	0.0
Upland	0.0	0.0	0.0	0.0	0.0

* total refers to number of barriers, rather than to length treated

Table E5. Length of habitat treated per time step for the Clatskanie River (OR).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	??				
Instream	17.1	3.4	13.7	0.0	0.0
Floodplain	42.7	0.0	17.1	25.6	0.0
Road	42.5	0.0	17.0	25.5	0.0
Riparian A	25.8	0.0	2.6	5.2	18.1
Riparian P	17.1	0.0	1.7	3.4	12.0
Upland	8.5	0.0	0.9	1.7	6.0

Table E6. Length of habitat treated per time step for the Washougal River (WA).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	NA				
Instream	15.7	3.1	12.6	0.0	0.0
Floodplain	9.6	0.0	3.9	5.8	0.0
Road	34.1	0.0	13.6	20.5	0.0
Riparian A	15.7	0.0	1.6	3.1	11.0
Riparian P	0.0	0.0	0.0	0.0	0.0
Upland	8.2	0.0	0.8	1.6	5.7

Table E7. Length of habitat treated per time step for the Coweeman River (WA).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	NA				
Instream	12.3	2.5	9.8	0.0	0.0
Floodplain	4.1	0.0	1.7	2.5	0.0
Road	50.5	0.0	20.2	30.3	0.0
Riparian A	27.1	0.0	2.7	5.4	18.9
Riparian P	3.0	0.0	0.3	0.6	2.1
Upland	1.0	0.0	0.1	0.2	0.7

Table E8. Length of habitat treated per time step for the Toutle River (WA).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	NA				
Instream	72.3	14.5	57.8	0.0	0.0
Floodplain	18.0	0.0	7.2	10.8	0.0
Road	156.1	0.0	62.5	93.7	0.0
Riparian A	78.1	0.0	7.8	15.6	54.7
Riparian P	38.3	0.0	3.8	7.7	26.8
Upland	19.3	0.0	1.9	3.9	13.5

Table E9. Length of habitat treated per time step for the Mill/Germany/Abernathy Creek complex (WA).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	NA				
Instream	14.6	2.9	11.6	0.0	0.0
Floodplain	10.9	0.0	4.3	6.5	0.0
Road	31.7	0.0	12.7	19.0	0.0
Riparian A	18.9	0.0	1.9	3.8	13.3
Riparian P	0.0	0.0	0.0	0.0	0.0
Upland	7.3	0.0	0.7	1.5	5.1

Table E10. Length of habitat treated per time step for the Elochoman River (WA).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	NA				
Instream	11.4	2.3	9.1	0.0	0.0
Floodplain	9.9	0.0	4.0	5.9	0.0
Road	27.9	0.0	11.1	16.7	0.0
Riparian A	11.4	0.0	1.1	2.3	8.0
Riparian P	11.1	0.0	1.1	2.2	7.7
Upland	0.0	0.0	0.0	0.0	0.0

Table E11. Length of habitat treated per time step for the Scappoose River (OR).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	??				
Instream	28.6	5.7	22.9	0.0	0.0
Floodplain	23.1	0.0	9.2	13.9	0.0
Road	4.0	0.0	1.6	2.4	0.0
Riparian A	26.9	0.0	2.7	5.4	18.8
Riparian P	24.4	0.0	2.4	4.9	17.1
Upland	4.4	0.0	0.4	0.9	3.1

Table E12. Length of habitat treated per time step for the Hood River (OR).

Restoration Action	Total Km treated	0-5 years	5-25 years	25-50 years	50-150 years
Barrier	??				
Instream	0.0				
Floodplain	0.0				
Road	0.0				
Riparian A	(ALL)				
Riparian P	0.0				
Upland	0.0				

Habitat Appendix F. Comments on Spawning Distributions

Here, we reproduce the comments provided on the spawning distributions that we used as spatial extents for model summaries in this analysis. We will use these comments as a basis for planned revisions to spawning distributions for the next iteration of modeled predictions.

Washington Populations

Comments provided by Dan Rawding and Steve VanderPloeg, Washington Dept. Fish & Wildlife

General - The distribution model is based on the uppermost observed distribution, in some cases from multiple years, with the intent of developing a sampling frame. In reality spawning distribution is variable. Therefore, the model probably slightly over-predicts average distribution.

Coweeman. Pretty accurate for upper limit of distribution. In some years, probably with low flow there is no spawning in the mainstem above Browns Creek or any tributaries.

Washougal. Mainstem and Lacamas distributions are accurate. Limited info suggest very limited spawning in Little Washougal. The NF Washougal is wrong. There is a natural waterfall at the downstream end of Skamania Hatchery (lat/long = -122.216151, 45.620489; NAD 83). Therefore, the distribution should be truncated at this point, probably at the end of the first EDT reach in the NF (some maps also refer to the NF as the WF). There is also a complete barrier falls (source: Streamnet) on Hoffstadt Cr (off NF Toutle at -122.411612, 46.331717; NAD 83) and a complete barrier falls (source: Streamnet) on Coldwater Cr (-122.26898, 46.288256; NAD 83).

Mill/Abernathy/Germany. The model predicts the uppermost observed point in Mill and SF Mill very accurately, and it slightly over predicts Germany, and under predicts Abernathy. Based on the median or mean upper distribution from 2005-09, the model is over-predicting observed spawning distribution.

Lewis. East Fork Lewis mainstem looks good but there is probably limited current spawning in Mason Creek and Rock Creek due to degraded habitat. Predicted Cedar Creek distribution may be a little long. Chelatchie Creek is reasonable but we really don't survey this stream. (note from A. Fullerton – I have surveyed the lower extent of Chelatchie in 2006 and it was primarily beaver ponds).

Toutle. We have very limited data in this system. The Army Corps of Engineers constructed a sediment retention structure (SRS) on the NF Toutle just above the confluence of the Green River. This structure has done its job and stores huge amounts of sediment above the SRS, and provides a very high suspended sediment load in the water. The magnitudes can be accessed from USGS water quality summaries. However, the high sediment loads are likely to severely negatively impact incubation and juvenile survival rates for salmon. Also due to the current low returns Chinook salmon are not likely to ascend as far above the SRS in the mainstem and tributaries. There is poor habitat in Studebaker Creek, and it is unlikely that there are fish in this stream. Green River looks reasonable. Outlet Creek drains Silver Lake, and currently the model predicts spawning in the lake (not possible). There may be some spawning in the lowest EDT reach of Outlet Creek.

Elochoman. This population should include both the Elochoman River and Skamokawa Creek (the map we reviewed does not include Skamokawa Creek). I believe we only have one survey for the upper limit in the Elochoman River, and the distribution appeared to be stopped by a low water barrier below the West Fork. However, if this is passable in some years, distributions in the lower West Fork and confluence of North Fork and East Fork are reasonable.

Oregon Populations

Comments provided by Erin Gilbert and Jeff Rodgers, Oregon Dept. Fish & Wildlife
Background – we applied the Rawding et al. (2009) logistic regression model to streams generated by NetMap for these populations. We then compared the resulting distributions with two other datalayers: (1) spatially-explicit restoration action priorities proposed as part of the recovery plan, and (2) fall Chinook distribution generated for Oregon state (referred to as NRIMP below).
General Comments– It is clear that the spatial locations of the restoration actions from recovery plans should not be used, or used with caveats, for comparisons with the

Rawding distribution. The action locations were derived from opinions of resource managers and there was little QA/QC. The same applies to attributing actions to different species. I notice that some of the actions you are displaying in your maps are not for Fall Chinook (ex: Scappoose action 3). You can identify the actions specific to Fall Chinook using the tables in the Actions maps. Other actions specific to CHF (ex: Scappoose action 8) really seem too high up in the basin so it seems like the actions may not necessarily overlay with spawning and rearing distribution. Scappoose action 8 deals with erosion so it seems like a downstream cumulative impact on CHF.
Of greater concern are the differences with NRIMP distribution. It would be nice if I could say with confidence that NRIMP distribution is accurate and up to date but that is not necessarily the case. That means we have to look at potential "inaccuracy" in both the modeled and NRIMP layers. I've seen differences for other species between NRIMP and the distribution defined by CLAMS modeled streams. One data source that may help are the Chinook surveys just started by the spawning project here at the lab. They have only just completed their first year but those surveys will hopefully inform both NRIMP distribution and efforts such as this.

Clatskanie. Pending (under review).
Scappoose. Pending (under review).
Hood. Pending (under review).

Attachment 2 -- Life History of Tule Fall Chinook Salmon in Lower Columbia River Tributaries with Estimates of Juvenile Survival, Intrinsic Productivity, and Capacity

From Life Cycle Studies, by Dan Rawding, Tom Cooney, and Cameron Sharpe

Working Draft

10 February 2010

Executive Summary

- Fish in/out (life cycle) monitoring for Tule fall Chinook salmon in the lower Columbia River occurred for 4 to 5 brood years in Mill, Abernathy, and Germany (MAG) creeks and in the Coweeman River.
- The juvenile Tule outmigration data from these streams suggests at least two different life history strategies: 1) fry migrant strategy, where fish emigrate shortly after emergence at less than 40mm before early May, and 2) subyearling migrant strategy, where after a period of little movement a secondary migration peaks in early July when mean fish lengths are above 80mm.
- The limited LCR dataset suggest that watersheds with a smaller drainage area and shorter streams produce a higher percentage of fry migrants compared to watersheds with larger drainage areas and longer streams.
- Analysis suggests that egg to fry survival was highly variable ranging from over 44% to less than 1%. During 2006, when peak flows were double those seen in other years in MAG streams, survival was the lowest recorded (< 3% on all streams) suggesting that floods may be a major source of mortality during the incubation period. Overall, mean egg to fry survival was 17.5% and 21.3% for all years and the non-flood years, respectively.
- Multiple spawner-recruit models indicated intrinsic productivity (survival) from the egg to fry stages in non-flood years was ~16%. Estimates of survival for non-flood years were 18%, 24%, 25%, 26%, and 28% for the hockey stick (HS), logistic hockey stick (LHS), Ricker (R), continuous smoothed hockey stick (CSHS), and Beverton-Holt (BH) models, respectively when a single outlier was removed.
- Theoretical estimates of maximum seeding extrapolated from juvenile production estimates can be used to standardize estimates of stock production relationships for salmonid populations. Estimates of maximum seeding levels are related to standard measures of fish population production potential used in setting

escapement policies or evaluating production potential (e.g., production at MSY spawning escapements, expected equilibrium production at unfished equilibrium, etc.). Maximum seeding for Chinook fry in the HS and R models is achieved when escapement was 4.0 and 12.3 females per square mile of effective drainage area.

- The estimated capacity ranged from a high of 10,100 fry per square mile of drainage area using the BH model to a low of 7,300 using CSHS model. Estimates of subyearling capacity from four data points ranged from 610 to 729 subyearlings per square mile of drainage area depending on the type of analysis.
- Our empirical estimates of seeding levels, egg to fry survival, spawning and subyearling rearing capacity compared favorably with estimates based on a NOAA model. The only exception is NOAA-based spawner capacity estimates, which were two or more times greater than previous estimates, which suggests that spawning capacity is not limited in these basins.
- Due to the limited dataset, these estimates of LCR Tule fall Chinook Salmon survival, capacity, and seeding levels should be interpreted cautiously. Estimates of maximum seeding were reported as a comparison to Fullerton's habitat capacity estimates and previous spawner-recruit analysis to estimate Recovery Exploitation Rates (RER) to assess the "reasonableness" of our estimates. Our maximum seeding estimates are very imprecise due to the few monitoring locations. Additional years and locations for fish in/out monitoring in the LCR are recommended to better define freshwater productivity for this race of Chinook salmon.

Table of Contents

List of Tables

List of Figures

Introduction

Tule fall Chinook are an ecologically, genetically, and economically important species in the lower Columbia River and there is a remarkable lack of understanding of their early life history, especially with regard to productivity parameters. Fish in/out monitoring for Tule Fall Chinook salmon occurred for brood years 2003 through 2007 in Mill, Abernathy, and Germany creeks and in the Coweeman River for brood years 2004 through 2007 (Figures 1 and 2). Mill, Abernathy and Germany Creeks are part of the WDFW Intensively Monitored Watershed (IMW) system in Washington and the Coweeman is part of the WDFW Statewide Monitoring Framework for fish in/fish out monitoring in the state. The Coweeman River population has been a stock of concern and adult and juvenile monitoring has been funded by the Southern Fund of the Pacific Salmon Commission, Mitchell Act, and the State of Washington. The purpose of this analysis is to summarize the available data from fish in/out (life cycle modeling) studies in the Lower Columbia River (LCR) area to provide estimates of survival, intrinsic productivity, seeding, and capacity for Tule fall Chinook Salmon populations.

Fall Chinook Salmon are native to the Lower Columbia River (LCR) ESU. Two races of fall Chinook are generally recognized: Tule and Bright. Compared to the Tule populations, bright populations have different migration patterns, a more protracted and later adult entry into freshwater, broader and later spawn timing, and an older age structure (Myers et al. 2006). Bright fall Chinook are found primarily in the NF Lewis River, with an additional Bright population in the Sandy River. Brights have been observed in the EF Lewis and Cowlitz Rivers but they are believed not to be self-sustaining. No Tule fall Chinook were believed to be historically present in the NF Lewis because no fall Chinook were observed in the 1940's during spawning ground surveys conducted during the typical Tule spawning time. In recent years, a Tule population has been observed spawning in the NF Lewis in September and October before the later spawning Brights. This Tule population is composed of natural and hatchery origin spawners. However, it is unclear if this Tule population is self-sustaining and what its impact on the native Bright population might be.

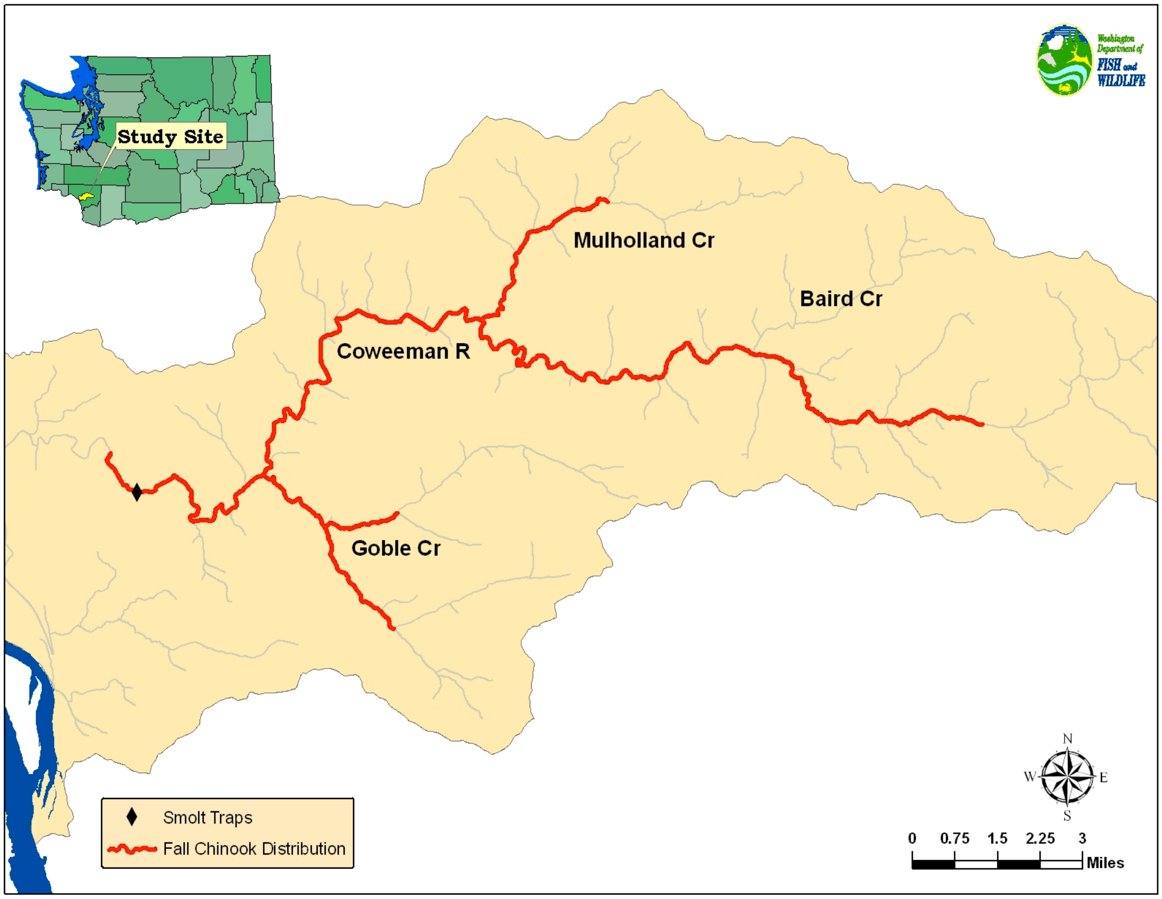


Figure 15. The Tule fall Chinook Salmon spawning distribution and the location of the smolt trap site in the Coweeman River.

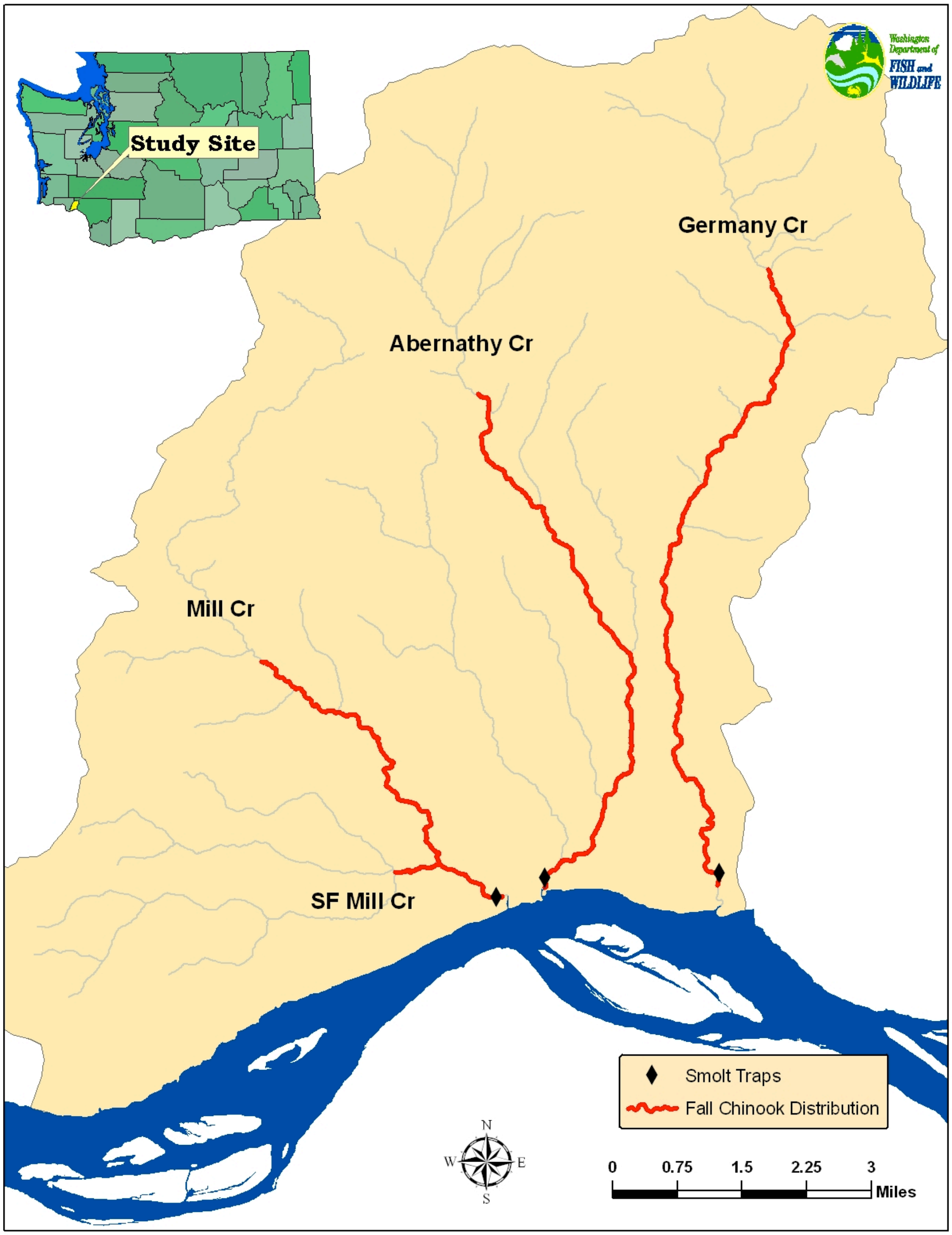


Figure 2. The Tule fall Chinook Salmon spawning distribution in Mill, Abernathy, and Germany Creeks and the location of the smolt trap sites.

Tule fall Chinook are native to the remaining LCR watersheds. Tule Chinook salmon hatcheries have been operated for more than 100 years. WDFW, USFWS, and ODFW have operated Tule Chinook salmon hatcheries funded by the Mitchell Act program since the 1950's. The primary purpose of the Tule hatchery program has been to replace lost production from the construction and operation of hydroelectric facilities along the Columbia River. This mitigation has been used to sustain ocean and freshwater fisheries. Recently, there have been modifications to Tule hatchery programs to assist in salmon recovery where appropriate. Hatchery fall Chinook salmon releases are provided in Table1.

The proportion of hatchery spawners in specific Tule populations has been determined by expansion of CWT recoveries. However, since a small percentage of hatchery Tules are CWT and sampling rates are low in streams without hatcheries, there is high uncertainty in the estimates of proportion of hatchery spawners. The recent mass marking of all LCR hatchery production has allowed for more precise estimates of the proportion of hatchery origin spawners. Based on CWT expansion the proportion of hatchery spawners in Washington Tule populations ranged from 3% to over 67%, depending on the number of juveniles release, their survival, and straying rates. WDFW currently operates weirs in the Grays, Elochoman, Green, and Kalama River to manage the proportion of hatchery spawners, identified based on mass marking (clipped adipose fin). WDFW has proposed to expand the program to the Washougal River, with initiation of weir operations in 2010.

In addition, introduced fall Chinook stocks are also observed straying into natural Tule spawning areas in the Lower Columbia, including a Rogue River stock, released from Oregon tributaries near Youngs Bay, and Upriver Bright stock released from Bonneville and Little White Salmon Hatcheries. The Upriver Bright stock appears to have established natural spawning populations in the mainstem Columbia below Bonneville Dam, Wind River, White Salmon River, and Little White Salmon River. It is unclear if these introduced populations affect native Tule populations. The Rogue stock is primarily observed in most downstream Oregon and Washington tributaries to the Lower

Table 19. 2009 fall Chinook subyearling releases below Bonneville Dam. Note that releases in Tanner Creek, Youngs Bay, and Klaskanine are not Tule releases.

Release Site	Release Period Begin	End	Number Released	Fish per Pound	Stock	Comment
Big Creek Hatchery	05/11/2009	05/20/2009	5,666,218	76.0	Big Creek	97.9% AD; 4% CWT (09-01-99)
Tanner Creek	07/30/2009	07/30/2009	2,075,794	45.2	URB	99.4% AD; 55160 CWT (09-02-21)
Tanner Creek	05/15/2009	05/15/2009	2,493,052	105.6	Tule	99.2% AD; 6.8% CWT (09-01-98)
Youngs Bay	07/02/2009	07/02/2009	702,659	17.3	Rogue R	99.9% LV; 3.6% CWT (09-02-16)
S Fk Klaskanine River	07/21/2009	07/21/2009	714,118	32.8	Rogue R	99.9% AD/LV; 3.9% CWT (09-02-43)
Cowlitz River	06/04/2009	06/30/2009	5,104,829	65.7	Cowlitz	4353372 AD Only; 201933 AD/CWT (63-42-79); 549524 Unmarked
Deep River Net Pens	06/01/2009	06/01/2009	700,000	78.0	Elochoman	641477 AD Only; 54670 AD/CWT (63-47-72); 3853 Unmarked
Fallert Creek	07/04/2009	07/04/2009	498,612	79.0	Kalama	402980 AD Only; 90046 AD/CWT (63-47-74); 5586 Unmarked
Kalama River	06/04/2009	06/19/2009	2,070,841	79.4	Kalama	2045859 AD Only; 24982 Unmarked
Kalama River	06/19/2009	07/08/2009	2,957,203	75.1	Kalama	2846940 AD Only; 91476 AD/CWT (63-47-75); 18787 Unmarked
Klaskanine Hatchery	06/09/2009	06/14/2009	3,422,931	77.4	LWS-URB	15% AD Only; 16.1% AD/CWT (63-48-43 -74 -79); 68.9% Unmarked
Youngs Bay	06/01/2009	06/01/2009	25,000	45.0	Rogue R	Unmarked; Rel by Astoria HS STEP
Skipanon River	06/01/2009	06/01/2009	15,324	30.0	Big Creek	100% AD; Rel by Warrenton HS STEP
Washougal River	07/01/2009	07/15/2009	3,000,000	80.0	Washougal R	97% AD Only; 3% AD/CWT
Chinook River	06/01/2009	06/30/2009	20,000	100.0	Chinook R.	100% AD; COOP = Sea Resources

Columbia. In Washington, the weirs installed in the Grays and Elochoman Rivers are being used to reduce the percentage of Rogue stock reaching natural spawning areas.

Life History

Freshwater Adults. Sexually mature Tules return to the mouth of the Columbia River from late July through early October, with the peak occurring during August and September. Entry into Lower Columbia tributaries is flow dependent and occurs from August through October, peaking in September. Spawning occurs from early September to early November with a peak from late September to early October (Figure 3). It appears that Mill Creek and adjacent streams have a slightly earlier spawning time, while the EF Lewis timing is later. Entry timing is not precisely known but the average timing on the Elochoman River in 2002 suggested that average time from entry to carcass recovery was ~14 days. Therefore, assuming ~ three days from peak spawning activity to death, entry timing may be approximated from the spawning time graphs by subtracting about 11 days.

In order to estimate sex ratios and age structure, biological data from stream surveys in the EF Lewis and Coweeman Rivers were summarized. These populations were chosen because they have low hatchery influence, and it is possible to determine age and sex ratios for the natural origin component that are minimally confounded by the presence of hatchery fish. This is not possible in other streams with moderate to high hatchery influence because the origin of individual fish is unknown (only a small portion of the hatchery production can be identified with a CWT). Our ability to unambiguously assign individual fish to hatchery or wild origin is improving with the mass marking of all Tule hatchery production and all returns will be marked by 2012.

Age and sex ratio data is based on recovered carcasses. Since carcasses recoveries can be biased toward larger fish (Zhou 2002), the age structure may be biased toward older fish and this is

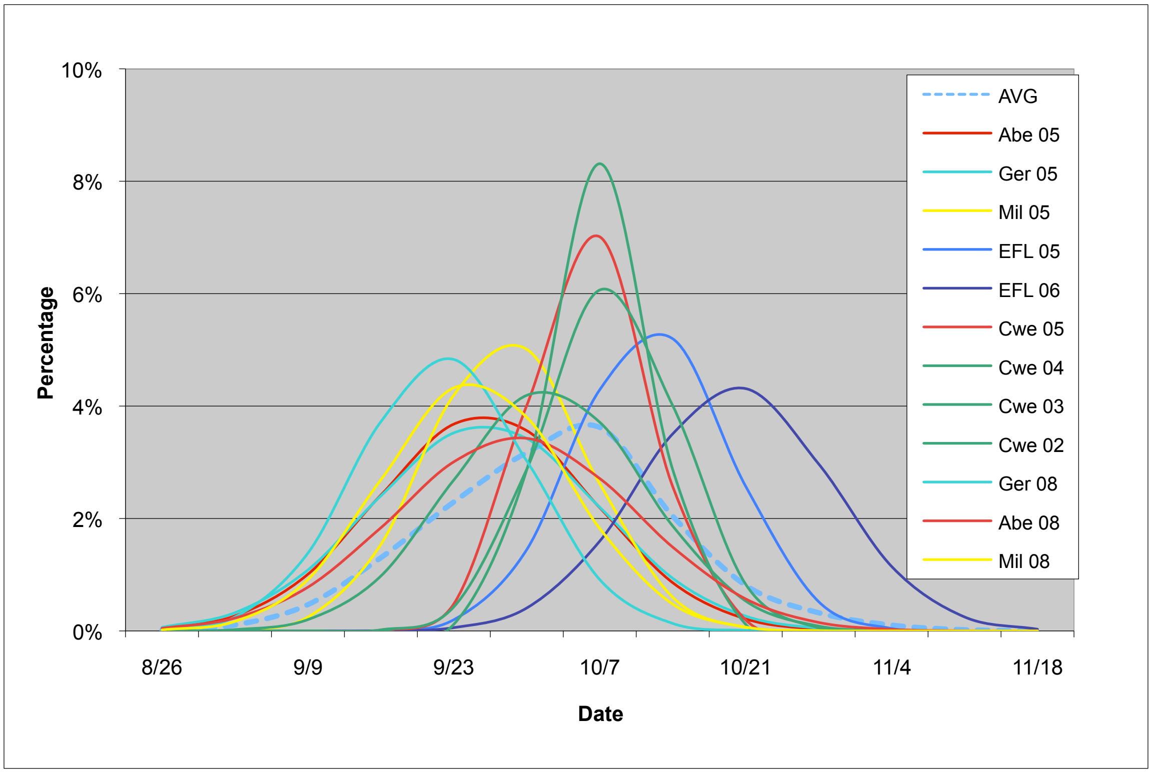


Figure 3. Natural spawning time in selected and representative Tule subbasins (Abernathy: Abe; Germany: Ger; Mil: Mil; East Fork Lewis: EFL; Coweeman: Cwe).

especially true for males. It is likely that jacks are underestimated in carcass recoveries because they are more difficult to see and are probably removed from spawning grounds by a broader size range of scavengers. The percentage of females for the EF Lewis data set was 48% over the 26 years period of record and 52% for the Coweeman data set over the 19 years of data collection (Figures 4 and 5).

The mean proportion of Chinook salmon by age and sex is shown for EF Lewis and Coweeman fall Chinook based on stream surveys and scale readings (Figure 4). Patterns are similar for Coweeman and EF Lewis populations. Males make up a higher proportion of the age 2 and 3 spawners, while females comprise more age 4 and older spawners. Fecundity for natural origin Chinook is unknown. However, limited hatchery sampling at Elochoman, Kalama, and Washougal facilities in the late 1990’s suggests the mean fecundity is 4606, 5157, 5509, and 5801 for age 3, 4, 5, and 6 females, respectively.

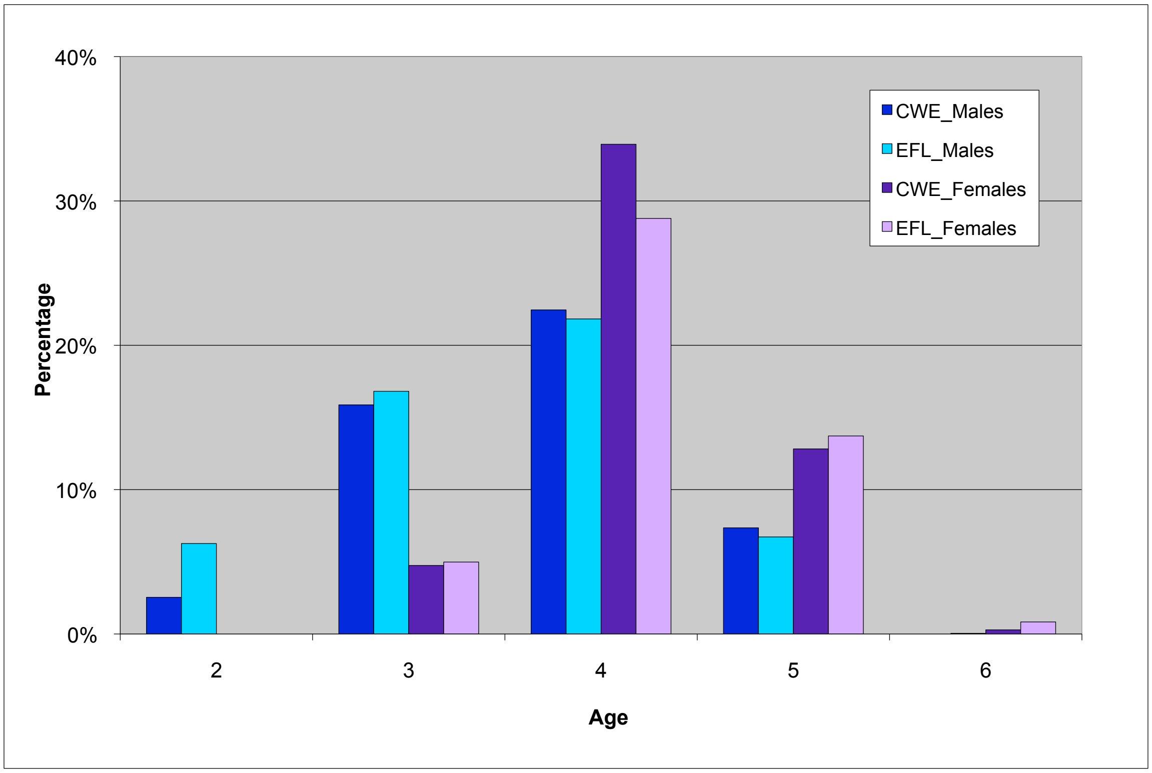


Figure 4. Mean proportion of Chinook salmon by age and sex from stream surveys, 1983 –2008 on the EF Lewis (EFL) and Coweeman (CWE) Rivers.

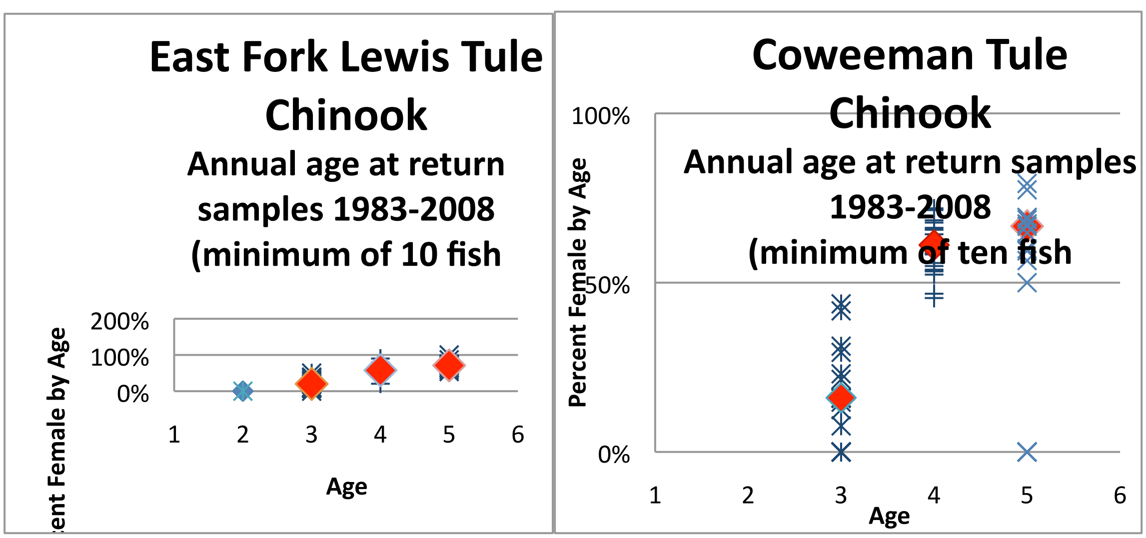


Figure 5. Proportion female by age derived from carcass sampling from stream surveys (1983 –2008) on the EF Lewis and Coweeman Rivers. Diamonds: median estimates by age.

The relative proportion females by age showed similar patterns across both populations. All age 2 fish sampled in both locations were males. The median proportion female for age 3 returns was approximately 20% in both locations. The proportion of females for age 4 returns was approximately 60% for both population sample sets. Age 5 returns had a slightly higher median proportion of females (67 and 71% for East Fork Lewis and Coweeman, respectively).

The relative contribution of a spawner in terms of redds or eggs can be calculated from the proportion female by age and fecundity data described above (Table 2). Age 2 returns are virtually 100% male. Assuming 1 redd is laid down per female, the number of redds contributed per spawner by age 3 fish is 30% of the contribution per spawner for age 4 fish. Age 5 fish contribute redds at a rate 16% higher than that of age 4 fish. Including an adjustment for relative fecundity by age increases the relative gap in redd construction among ages.

Freshwater Juveniles. Incubation occurs throughout the winter and emergence occurs from mid-winter to early spring. It is believed that peak flows and sedimentation are the major sources of incubation mortality. WDFW has limited trap data for juvenile Chinook outmigrants. Potential data sets include Mill, Abernathy, and Germany Creeks (2005-09), Coweeman (2005-08), and Grays (2008-09). Data obtained from these projects includes abundance, timing, and lengths. The Mill, Abernathy, and Germany Creek data has been summarized for 2008 Chinook migrants. In 2008, these creeks exhibited a consistent pattern: migration occurred from February through June, with the majority occurring in March and April. The mean size of the migrants was slightly less than 40mm. In May and June there was a very small migration of larger fish possibly peaking in late June, with a mean size near 60mm. Unfortunately, there was no trapping after the end of June but electrofishing for tagging and genetic sampling of coho and steelhead parr in the summer yielded few Chinook juveniles. Therefore, we assume these streams produce mostly Chinook salmon fry, which are less than 40mm. It should be noted that winter or spring freshets can transport many juvenile fall Chinook downstream in a short

Table 20. Relative contributions of spawners as a function of age at return. Expressed as redds per spawner and eggs/spawner. Proportion female by age are averages of estimates for Coweeman and EF Lewis River. Relative contribution rates are expressed as a ratio to age 4 spawners. Carcass data did not include sufficient numbers of age 6 fish to allow an estimate of relative proportion female, age 6 proportions assumed equal to age 5.

Age	Prop. Female	Relative Redd Potential	Fecundity	Eggs per Spawner	Relative Contribution
2	0%	0	--	--	--
3	18%	0.3	4,606	829	0.27
4	59%	1	5,157	3,062	1
5	69%	1.16	5,509	3,801	1.25
6	69%	1.16	5,801	4,003	1.32

period of time thereby altering the outmigrant timing for fry. A similar pattern was observed in Gnat Creek in the late 1950's (Myers et al. 2006, page 25).

Coweeman outmigration patterns were different than those observed in MAG in 2008. The Coweeman Chinook outmigration pattern is bimodal with peaks occurring in near wk 13, just like MAG, with a large secondary peak occurring near week 26 with a few fish trickling out throughout the fall. Approximately 42% of Coweeman outmigrant migrate before week 20, and they average less than 40mm during this time. This outmigrant data is suggestive of two main juvenile migration patterns for Tule in the LCR. The first pattern is a fry migration pattern. These fish migrate after limited rearing and at less than 40mm and before statistical week 20. This pattern occurs in all streams. The second pattern is a subyearling pattern where migration builds to a peak during the summer (usually early July) and continues at low levels through fall. These fish average over 80mm at the peak of the migration.

In the MAG streams the majority of fall Chinook spawning occurs within 4 miles of the trap (Figure 2) and the average drainages area for each of these three streams is less than 30 square miles. In the Coweeman drainage, the majority of spawning occurs from 3 to 22 miles above the trap (Figure 1), with a high percentage of spawning greater than 10 miles above the trap. In addition, the Coweeman drainage area is ~ 120 square miles above the trap site.

There are at least three reasonable hypotheses regarding the observed life histories in the MAG and Coweeman watersheds that could be applied to the remaining Tule populations in the lower Columbia where empirical data is lacking. While these hypotheses are based primarily on the outmigration timing patterns observed in the MAG and Coweeman River systems, they also reflect results from studies of Chinook life history patterns on the Oregon coast (Reimers, 1973, Bottom et al. 2005), British Columbia (Healy, 1980; Levy and Northcote, 1982) and Puget Sound (Greene and Beechie, 2004). The first general hypothesis assumes that the distance between spawning locations and the lower reaches of a river influences the relative proportion of fry versus subyearling outmigrants from upstream reaches. Virtually all the fry produced from natural spawning in relatively short river systems (e.g., Mill Creek, Germany Creek, Abernathy Creek, Gnat Creek) emigrate out of natal upstream habitats in March and April as fry. It is likely these fish rear for an extended period in lower mainstem and adjacent estuary habitats until they reach sufficient size to move out into the open estuary. Our second general hypothesis applies to larger river systems represented by the outmigrant timing data from the Coweeman River. In those systems the proportion of fry migrants may be influenced by watershed size and the distance spawning occurs from the mouth of the Columbia River, reflecting a potential rearing capacity limitation. In this hypothesis, larger rivers at least historically had more of the type of habitat that supports rearing/subyearling production. Our third general hypothesis is that the proportion of Tule fry migrants for a particular population is based on the quantity and quality of rearing habitat between spawning areas and the tidally influenced lower river/estuarine habitat (Cooney and Holzer, 2010).

The purpose of this document is to summarize the available data from fish in/out (life cycle modeling) studies in the Lower Columbia River (LCR) area to provide estimates of survival, intrinsic productivity, seeding, and capacity for Tule fall Chinook Salmon populations.

Methods

Juvenile Abundance Estimates. Juvenile outmigrant estimates were based on the trap efficiency method whereby catch in rotary screw traps was expanded by stratified estimates of trap efficiency with strata based on time, flow, or both, depending on watershed and year. Detailed procedures for trapping in Mill, Abernathy, and Germany creeks are available in Seiler et al. (2005), and for the Coweeman River in Sharpe and Glaser (2007), Sharpe and Glaser (2007) and Sharpe et al. (2009). Smolt trapping in Mill, Abernathy, and Germany creeks was continuous throughout the migration season (February through June) in all years. Smolt trapping in the Coweeman did not start until late March in 2005 and 2006 (corresponding to brood years 2004 and 2005), and direct estimates of the fry component of the migrant cohort were not available for those years. In 2007 and 2008 smolt trapping was initiated in the Coweeman River prior to the commencement of Chinook salmon outmigration in early February. We derived an estimate of the likely fry component in 2005 and 2006 in the Coweeman using the average proportion of fry migrants in years when trapping was comprehensive (2007 and 2008).

As mentioned above, the juvenile Tule outmigration data suggests at least two different life history strategies. The first is a fry migrant strategy, where fish emigrate shortly after emergence (Healey 1991). In the Coweeman and other watersheds these fish migrate at less than ~ 40mm, and usually before statistical week 19. After a period of low abundance a secondary migration of subyearlings peaks almost 8 weeks later when mean fish lengths are above 80mm. The limited dataset in the LCR suggest that watersheds with a smaller drainage area and shorter streams produce a higher percentage of fry migrants compared to watersheds with larger drainage areas and longer streams. Therefore, for this analysis we assumed that all migrants from Mill, Abernathy, and Germany Creeks were fry (Figure 6) and we classified Coweeman migrants as fry if they migrated before week 19 and subyearlings from week 19 onward (Figures 7 and 8).

Fry were defined as fish that emigrated before June with a mean size less than 40mm. Subyearlings were classified as juveniles from weeks where the mean size exceeded 40mm, with migration occurring after May. To estimate fry abundance from subyearling data in the Coweeman River, it was assumed that the survival between fry and subyearlings was 25% based on the number of weeks between the fry and subyearling migrations and an average weekly mortality rate derived from the literature for a Puget Sound chinook modeling study (Cooney and Holzer, 2010).

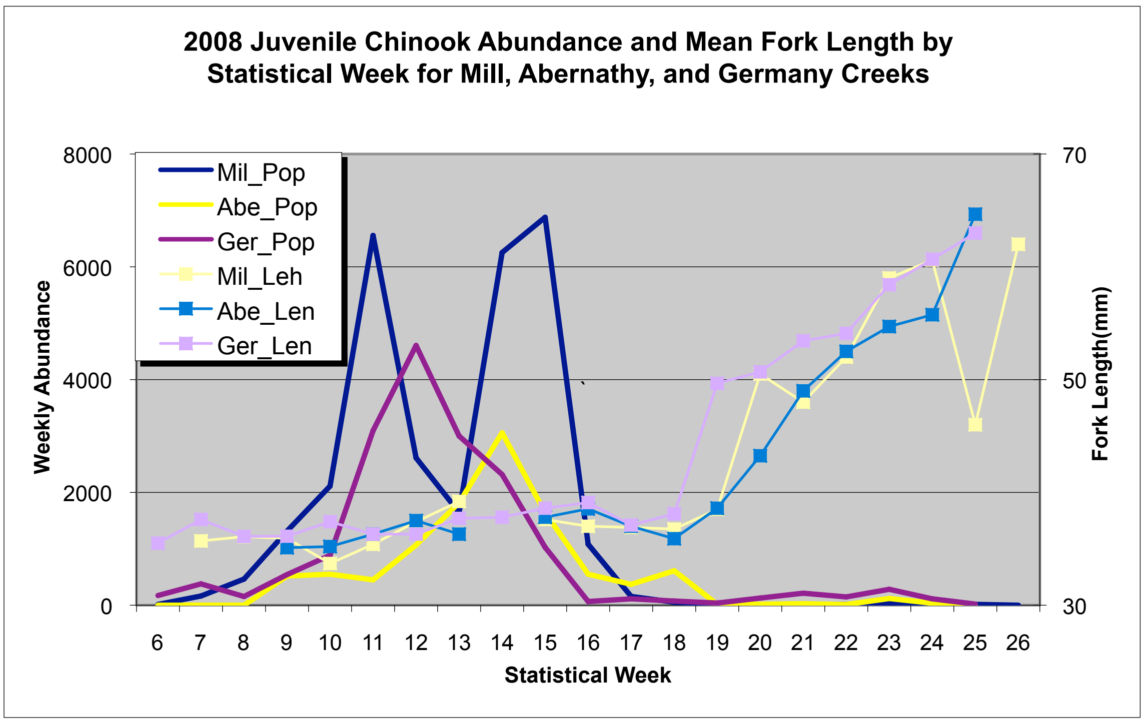


Figure 6. Mill, Abernathy, and Germany (MAG) outmigration data, 2008.

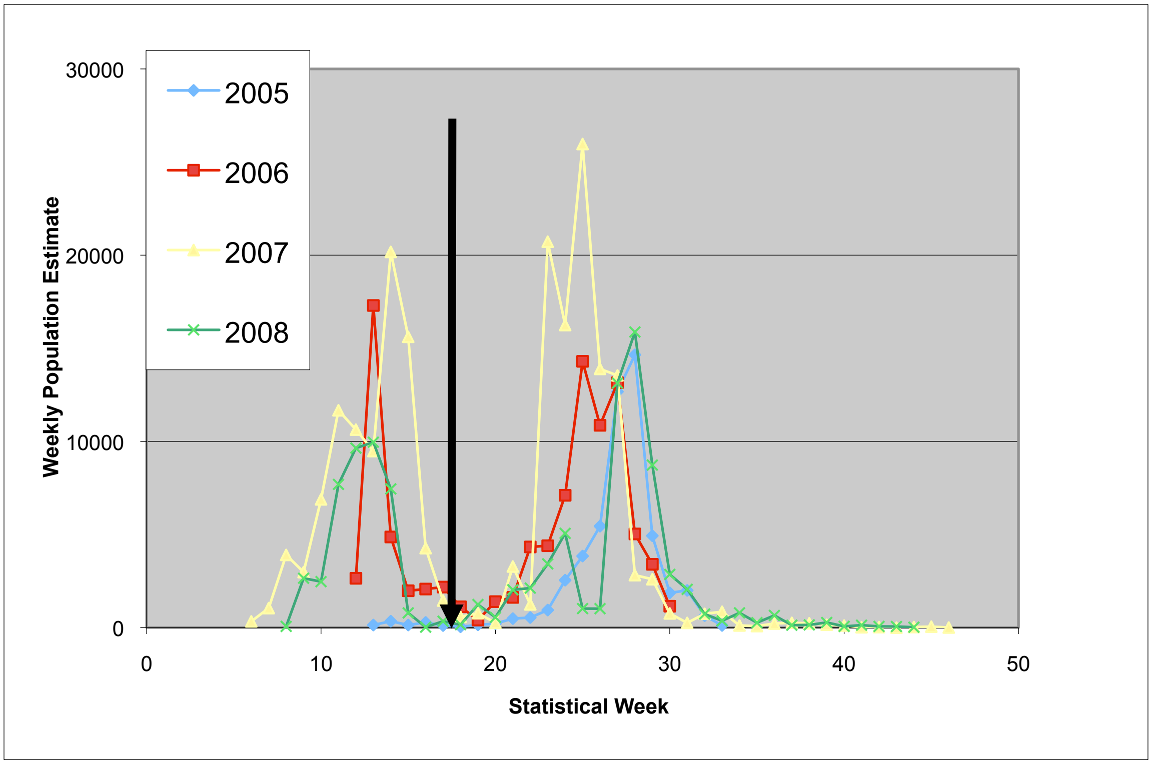


Figure 7. Coweeman Chinook outmigrant data 2005-08. The arrow indicates assumed temporal threshold between fry and subyearling smolt migrants.

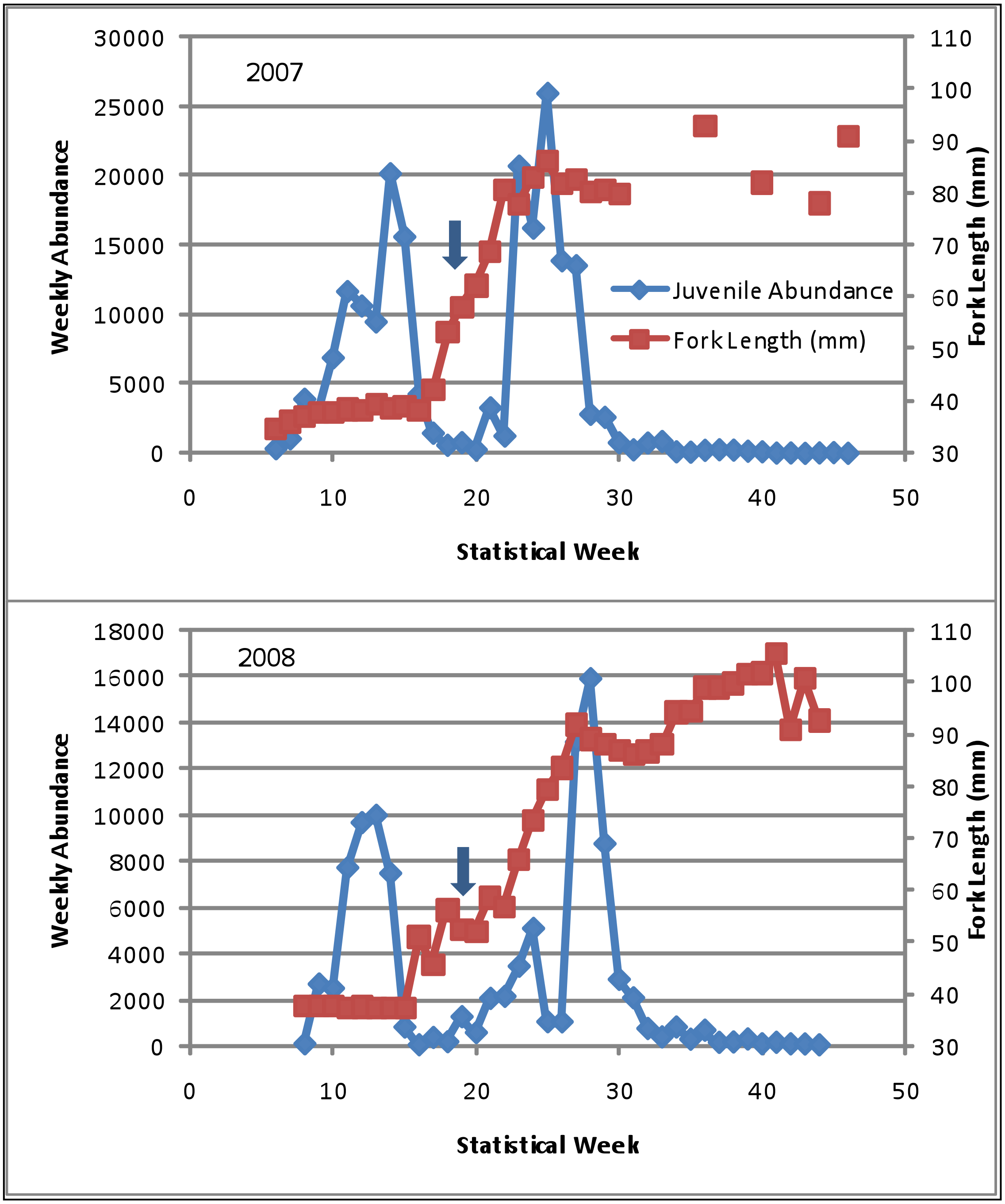


Figure 8. Estimates of abundance and mean fork length by statistical week for the juvenile Chinook outmigration on the Coweeman River in 2007 and 2008. Arrows indicate statistical week 19.

Adult Abundance Estimates. The methodology used to estimate the adult population for the creeks in 2005 and 2007 is found in Rawding et al. (2006) and Glaser et al. (2009). These same methods were used to obtain preliminary mark-recapture or AUC estimates of adult abundance in the creeks for the remaining years in MAG and the Coweeman River. Age and sex ratios were estimated from carcass recoveries (Bob Woodard, WDFW unpublished), and fecundity by age was estimated from LCR hatcheries (Howard Fuss, WDFW, unpublished).

Peak Flow Estimates. Annual peak flow estimates were obtained from the Germany Creek stream gauge because that instrument appeared to more consistently estimate peak flow than the other IMW gauges. Peak flow estimates in the Coweeman were obtained directly from a Washington Department of Ecology gauge in the lower watershed near the smolt trap location but were limited to 2006 though 2008. Adult, juvenile, and flow data used in the analysis can be found in Table 3.

Data Analysis. The first goal for this analysis was to estimate the mean egg to fry survival for each creek and river. Stream gauge peak flow estimates in Germany Creek suggested that 2006 peak flows were approximately twice the flows from other years. Therefore, survival was computed for all years and the non-flood years for IMW streams, and for all years on the Coweeman because there was no operating gauge or there were missed estimates of flow near the peak runoff.

The second goal was to use spawner-recruit analysis to estimate intrinsic productivity, escapement levels that maximize fry production, and carrying capacity of the watersheds for fry. Given the short time series (4 years for each dataset), data was transformed into eggs and fry per square mile of drainage area (Parken et al. 2006), and a single spawner-recruit function was fit to the combined data. Common spawner-recruit models for salmon were investigated including the Ricker (R), Beverton-Holt (BH), hockey stick (HS), logistic hockey stick (LHS), and the continuous smooth hockey stick (CSHS)

Table 3. Summary data from LCR fish in/out studies. Yellow indicates peak flow was not estimated due to missing data, beige indicates peak flow estimate appears close. Purple indicates mark-recapture estimate of adult escapement, and pink indicates an AUC estimate of escapement based on average residence time. Survival is the estimated fry survival adjusted for the Coweeman data by assuming 25% fry-subyearling survival. Light blue indicates very low survival corresponding with flood events. Age Eggs is an estimate of eggs based on actual annual age data. This is not been filled out so fecundity is the average (5,207 eggs/female) from WDFW (Unpublished).

Watershed	Brood Year	Peak CFS	Adults	Females	Mean Eggs	Fry	Subyearling	Survival
Germany Creek	2004	723	3,417	1,842	9,590,186	2,882,618	NA	30.06%
	2005	895	667	421	2,190,107	139,193	NA	6.36%
	2006	1,590	263	228	1,186,849	1,300	NA	0.11%
	2007	710	31	16	80,709	17,127	NA	21.22%
	2008	779	444	168	874,300	NA	NA	NA
Abernathy Creek	2004	746	533	330	1,717,408	529,521	NA	30.83%
	2005	429	738	470	2,445,397	98,156	NA	4.01%
	2006	404	102	56	289,699	3,973	NA	1.37%
	2007	622	32	27	138,853	29,465	NA	21.22%
	2008	550	85	43	221,298	NA	NA	NA
Mill Creek	2004	134	194	107	559,682	246,475	NA	44.04%
	2005	136	524	330	1,715,841	411,211	NA	23.97%
	2006	453	349	194	1,010,610	23,080	NA	2.28%
	2007	765	182	105	544,726	29,536	NA	5.42%
	2008	512	206	89	465,643	NA	NA	NA
Coweeman River	2004	NA	1,503	837	4,358,259	38,511	52,488	5.70%
	2005	NA	853	460	2,394,965	53,556	72,077	14.27%
	2006	2,410	566	356	1,851,757	89,045	105,321	27.56%
	2007	2,410	251	134	700,156	41,258	62,862	41.81%
	2008	2,140	NA	NA	NA	NA	NA	NA

(Hilborn and Walters 1992, Barrowman and Myers 2000, and Froese 2008). Drainage area estimates are from CBIAC (1967) and scaled to anadromous area by WDFW staff based on professional judgment.

The third goal was to estimate the subyearling capacity of the Coweeman River. However, the data was limited to four years. The average of the four years of subyearling data was used to estimate the average abundance of subyearlings. Spawner-recruit analysis was also used. The results of the spawner-recruit analysis for this portion of the data should be viewed with caution because of the few data points.

Our estimates of productivity, fry, and subyearling capacity, and seedling levels that maximized fry production were compared with available data to assess the "reasonableness' of our estimates.

The observed spawner-recruit data was fit to the models using maximum likelihood estimation (MLE) and assuming lognormal error (Hilborn and Waters 1992) using the following:

$$R = (\alpha S/(1+\alpha S/K)) * e^{\varepsilon t} \quad (1)$$

$$R = \alpha S e^{-\beta S} * e^{\varepsilon t} \quad (2)$$

$$R = (\alpha S \text{ if } \alpha S < K) * e^{\varepsilon t} \text{ or}, \quad (3)$$

$$(K \text{ if } \alpha S > K) * e^{\varepsilon t}$$

$$R = K(1-e^{-\alpha S/K}) * e^{\varepsilon t} \quad (4)$$

for the BH, R, HS, and CHS models, respectively, where:

R = the number of recruits measured as juveniles (fry or subyearlings)
S = the number of spawners, females, or eggs
α = the intrinsic productivity of the stock,
β = the escapement that produces the maximum number of juvenile (R models),
K = the carrying capacity (BH, HS, CSHS),
S* = the number of spawners needed to seed habitat (S* = K/α in HS model),
ε_t = a normal distributed random variable ($N(0,\sigma^2)$)

A non-linear search over α, β, and σ was used to minimize the negative log-likelihood and estimate the parameters. Parameter confidence intervals were estimated using a likelihood profile generated over all values that provided likelihood within a specified range of the negative log-likelihood (Hudson 1971). For each parameter the confidence interval was estimated using a chi-squared distribution with one degree of freedom (Hilborn et al. 1999).

Results

Preliminary analysis suggests that egg to fry survival was highly variable ranging from over 44% to less than 1% (Table 3). During 2006, when peak flows were double those seen in other other years, survival was the lowest recorded (< 3%). Overall, mean egg to fry survival was 17.5% and 21.3% for all years and the non-flood year, respectively.

The five spawner-recruit models fit the data equally well. Since, the goal of this analysis was to estimate ***average*** egg to fry survival the flood year data in IMW streams was treated as an outlier and not included. While this approach arguably results in a better estimate of the expected survival rate for average years, stochastic modeling designed to evaluate the potential future risks to LC tule populations should also incorporate probability of a flood event and the associated reduced egg to fry survival. Spawner-recruit analysis with the remaining data suggested that average survival was ~16% for all data. However, this result was influenced by the 2004 Germany Creek escapement of 1842 females, which is almost four times larger than the next highest escapement per square mile of drainage area (Table 3). For the sake of this analysis this point was considered an outlier, and not used in the analysis. Estimates of intrinsic survival were 18%, 24%, 25%, 26%, and 28% for the HS, LHS, R, CSHS, and BH models, respectively. A graphical display of spawner-recruit analysis is found in Figure 9.

Theoretical estimates of maximum seeding extrapolated from juvenile production estimates can be used to standardize estimates of stock production relationships for salmonid populations. Estimates of maximum seeding levels are related to standard measures of fish population production potential used in setting escapement policies or evaluating production potential (e.g., production at MSY spawning escapements, expected equilibrium production at unfished equilibrium, etc.). These data suggest that maximum seeding based on adult escapement is between 7.1 and 20.9 adults per square

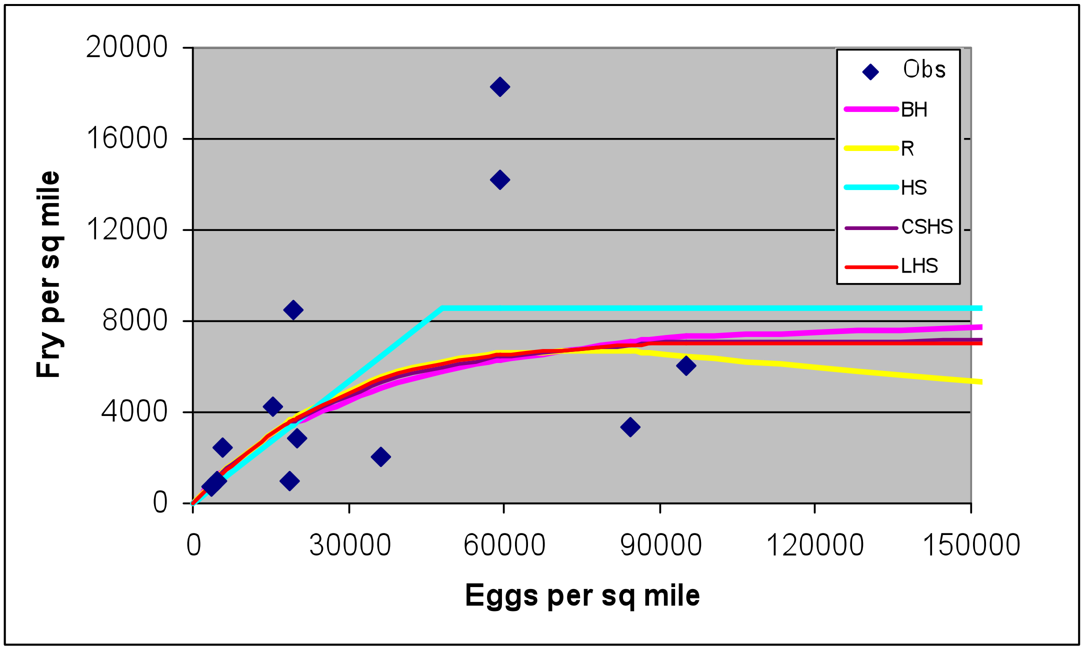


Figure 9. Fit of different spawner-recruit relationships to estimate egg and fry production per square mile of drainage area from Lower Columbia River tributaries. Intrinsic productivity is well defined compared to capacity.

mile of drainage area or 4.0 to 12.3 females per square mile (Table 4). This equates to 169 to 606 adults in the MAG creeks and 853 to 2509 adults in the Coweeman River using the hockey stick and Ricker models, respectively. Maximum seeding of females and adults were calculated for other tributaries of concern (Table 5).

These same spawner-recruit data were used to estimate fry capacity using BH, HS, LHS, and CSHS models. Since the CSHS and LHS provided essentially the same estimates (Figure 9), only the CSHS were reported. Results of this analysis suggest that the capacity of studied watersheds ranged from a high of 10,100 fry per square mile of drainage area using the BH model to a low of 7,300 using CSHS (Table 6). Estimates of fry capacity were also calculated for other watersheds of concern.

Estimates of survival were well defined compared to fry capacity (Figures 10). For example, 95% CI for survival from the CSHS ranged from 12% to 68%, with a ML

Table 4. Estimates of eggs, females, and adults per square mile for maximum seeding based on Ricker and Hockey Stick (HS) curves.

Parameter	Eggs/mi^2	females/mi^2	Adults/mi^2	Females Coweeman	(Adults) Mill	Abernathy	Germany
Maximum Productivity (Ricker B)	72,984	12.3	20.9	1,481 (2,509)	358 (606)	358 (606)	284 (481)
Maximum Productivity (HS - S*)	47,940	4.0	7.1	479 (853)	116 (206)	116 (206)	92 (163)

Table 5. Estimates of females and adults per square mile for study populations and other Columbia Tule populations of concern for full seeding based on Ricker and Hockey Stick (HS) curves.

Watershed	R Seeding (Females/mi^2 =12.3)	HS Seeding (Females/mi^2 =4.0)	R Seeding (Adults/mi^2 =20.9)	HS Seeding (Adults/mi^2 =7.1)	LCTCWG 2008 R	LCTCWG 2008 HS
Grays	308	100	523	178	359	NA
Elochoman Skamokawa	1,242	404	2,111	717		
MAG	996	324	1,693	575		
SF Toutle/Green	2,866	932	4,870	1,654		
Coweeman	1,476	480	2508	852	1,475	536
Cedar	677	220	1,150	391		
EF Lewis	861	280	1,463	497	1,309	663
Washougal	861	280	1,463	497		

Table 6. Estimates of fry carrying capacity for LCR Tule populations for Beverton-Holt (BH), Continuous Smoothed Hockey Stick (CSHS) and Hockey Stick (HS) models.

Watershed	Effective Drainage Area in square miles	BH capacity (Fry/mi2= 10,135)	CSHS capacity (Fry/mi2= 7,325)	HS capacity (Fry/mi2= 8,534)
Grays	25	253375	183125	213350
Skamokawa	35	354725	256375	298690
Elochoman	66	668910	483450	563244
Mill	29	293915	212425	247486
Abernathy	29	293915	212425	247486
Germany	23	233105	168475	196282
MAG	81	820935	593325	691254
Toutle	484	4905340	3545300	4130456
SF Toutle/ Green	233	2361455	1706725	1988422
Coweeman	120	1216200	879000	1024080
Cedar	55	557425	402875	469370
EF Lewis	70	709450	512750	597380
Washougal	70	709450	512750	597380

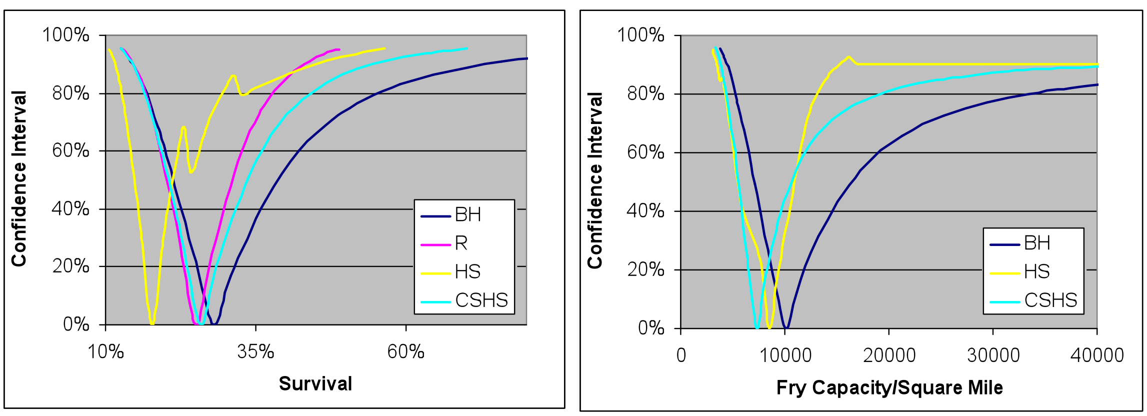


Figure 10. Funnel graph of egg to fry survival and fry capacity and associated confidence intervals based on likelihood profiles from the spawner recruit analysis. The jagged line for the hockey stick (HS) model is caused by local minima.

estimate of 26%. More precise estimates were obtained from the HS and R models. The survival estimate from the BH model was imprecise and ranged from 12% to 99%.

The precision of fry capacity estimates are provided Figure 10. In all cases the upper 95% CI for fry capacity was undefined (infinity). The subyearling capacity based on the average of the four years of subyearling estimates was 610 (SD 190) subyearlings per square mile of drainage area. Subyearling capacity was estimated from spawner-recruit analysis (Figure 11). Initial attempts to run the BH model, yielded an unrealistic egg to subyearling estimate of survival of over 200%. Therefore, egg to subyearling survival was fixed at the estimate from the CSHS model. The capacity estimates for subyearlings per mile ranged from 629 to 729 subyearlings per mile using the HS and BH models (Figure 12).

Our estimates were compared with other available information. LCTCWG (2008) completed a spawner-recruit analysis for Grays, Coweeman, and EF Lewis Tule populations using the R, BH, and HS models, and a composite Tule hatchery CWT group to estimate marine survival and harvest. The estimates from that report included the adult escapement needed to produce maximum production (B) and adult seeding (S*), which are slightly different than adult escapement to produce maximum fry production and

seeding from this report. For the Coweeman River, LCTCWG (2008) estimated B and

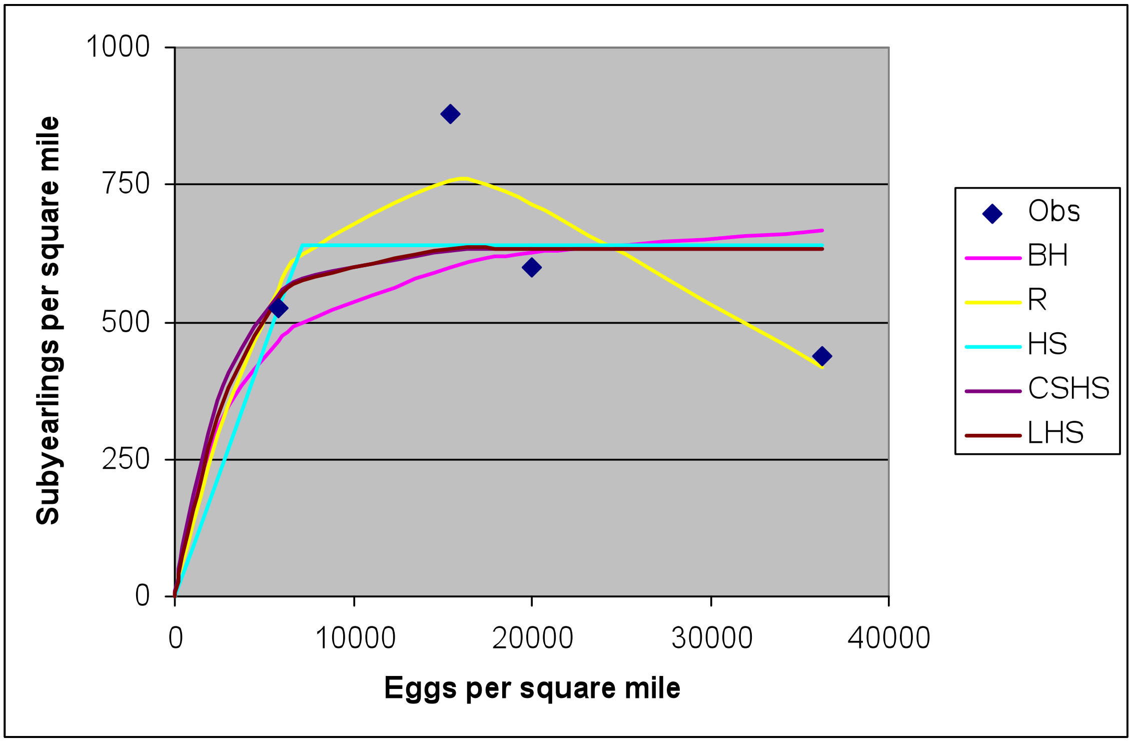


Figure 11. Fit of different spawner-recruit relationships to estimate egg and subyearling production per sq mile of drainage area from Lower Columbia River tributaries. Due to few data points intrinsic productivity and capacity are poorly defined.

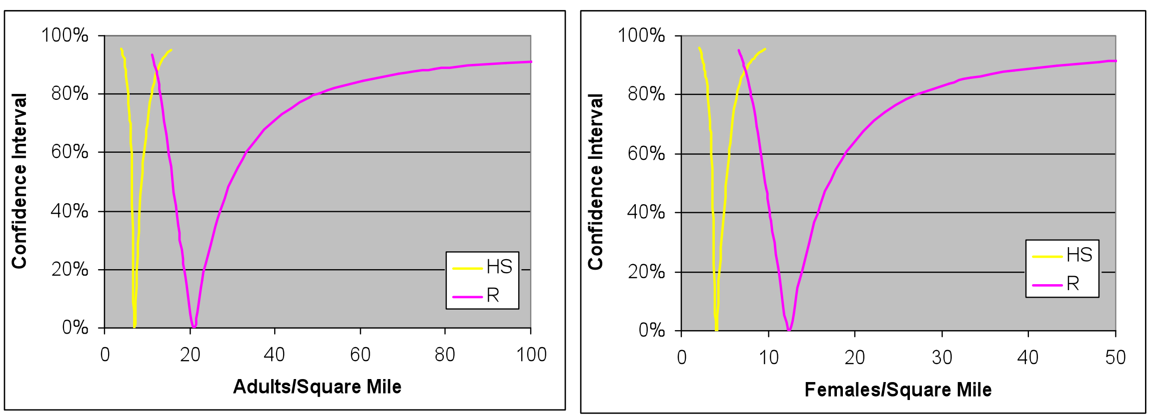


Figure 12. Funnel graph of adult and female seeding levels to maximize fry production based on S* from the hockey stick and B from the Ricker models, and associated confidence intervals based on likelihood profiles from the spawner recruit analysis.

S* for maximum seeding were 1475 and 536, respectively (Table 4). In this analysis, B was 2508 and S* was 852. Only B was estimated from the LCTCWG report for the Grays River population and it was 359, which is less than our estimate from this analysis of 523. For the EF Lewis population, discrepancies were similar; B and S* from the LCTCWG report were 1309 and 663 respectively, compared 1464 and 497 from this analysis. In general, seeding estimates from the fry model were higher than the spawner-recruit analysis on the Coweeman and closer on the Grays and EF Lewis Rivers.

Fullerton et al. (2009) provided estimates of egg to fry survival, along with subyearling and spawning capacity for selected LCR Tule populations. These estimates were based on the application of a model predicting survival based on fine sediment, spawning and subyearling rearing capacities based on stream characteristics and empirical adult spawning and subyearling rearing densities through out the Pacific Northwest. Fullerton et al. (2009) only calculated survival estimates for the EF Lewis and EF Lewis and Cedar Creek combined. These estimates were ~ 16% and 21%, respectively, and agree with our generic LCR estimate of 18% - 28% egg to fry survival from the different spawner-recruit models.

Our estimates of subyearling density at capacity were only available for the Coweeman River. We expanded these densities to other watersheds. As mentioned above, it appears that smaller creeks that support Tules (Mill, Abernathy, Germany, and Gnat) do not produce significant subyearlings. Fullerton's estimates for these small creeks are higher than our observation of few subyearlings but lower applying our generic Coweeman multiplier. Fullerton's estimate are similar to the ours for larger rivers (Table 7). The only exception is for the Toutle River: we estimate capacity for SF Toutle and Green Rivers only because the NF/mainstem Toutle River sediment load still has severe negative impacts for juvenile Chinook salmon due to sediment from the eruption of Mt. St. Helens and the discharge of sediment from the Sediment Retention Structure (SRS) on the NF Toutle River (Mark Johnson, WDFW pers. Comm.). Excluding the NF/mainstem Toutle River reduced our subyearling capacity estimate by almost 50%.

LCTCWG (2008) estimated spawning capacity for the Coweeman and EF Lewis Rivers (Table 8). Their estimates of spawner capacity in the Coweeman were 6306 and 3591 using the BH and HS models, respectively. Fullerton's spawner capacity estimate was 7121. The EF Lewis River spawner capacity estimates from the BH and HS models were 3539 and 2521, respectively, well below Fullerton's corresponding estimates of 7121 and

8548 (Table 8). In this limited capacity, Fullerton's estimates tend to be higher than the empirical data. This could occur if there is an abundance of spawning habitat but spawning habitat is not the most limiting factor for Tule fall Chinook salmon.

Table 7. Estimates of subyearling capacity for LCR Tule populations for Beverton-Holt (BH) model, Hockey Stick (HS) model, and from Fullerton et al. (2009).

Watershed	BH capacity (Subyearlings/ mi2= 729)	HS capacity (Subyearlings/ mi2= 629)	Fullerton et al. 2009
Grays	18225	15725	
Skamokawa	25515	22015	
Elochoman	48114	41514	21333
MAG	59049	50949	21703
Toutle	352836	304436	291213
SF Toutle/ Green	169857	146557	
Coweeman	87480	75480	57568
Cedar	40095	34595	
EF Lewis	51030	44030	47766
Washougal	51030	44030	61596

Table 8. Estimates of spawner capacity for LCR Tule populations for Beverton-Holt (BH) model, Hockey Stick (HS) model from LCTCWG and from Fullerton et al. (2009).

Watershed	LCTCWG 2008 BH	LCTCWG 2008 HS	Fullerton et al. 2009
Coweeman	6306	3591	7121
EF Lewis	3539	2521	8548

Discussion

This spawner stock and recruitment (SSR) analysis used 13 data points from four different LCR tributaries for egg to fry analysis. The time series was not long enough for individual spawner-recruit analysis for the fry. Hierarchical modeling was considered but given the few data points this was not pursued (Liermann et al. in press). Since peak flow during incubation is a primary factor in explaining wild Chinook salmon return rates (Greene et al. 2005), the addition of the environmental variable to the spawner-recruit function was considered (Hilborn and Walters 1992) but was not pursued because of limited data and lack of peak flow estimates for all basins for the entire period. Therefore, spawners and recruits were standardized into a single common metric of fish per square mile of drainage area (Parken et al. 2006) for analysis. In addition, three of the four data sets were from relatively short tributaries that exhibited almost 100% outmigration as fry while one (the Coweeman River) had a substantial subyearling outmigrant component.

Other issues of concern for SSR include: 1) the effect of measurement error on SSR, 2) time series bias, and 3) lack of contrast. Walters and Ludwig (1981) indicated that as the coefficient of variation (CV) approaches 20% the true spawner-recruit-relationship (SRR) may be transformed into one that shows little relation between spawners and recruits. Our CV although not reported in this analysis were generally less than 20% and for some adult mark-recapture estimates the CV were less than 10%. These suggest that measurement error was sufficiently low. Time series biased should be minimized because spawners and recruits are measured in different units including eggs, females, or adults for spawners and fry or subyearlings for recruits. Furthermore, there is not likely to be autocorrelation in this type of time series (Bradford et al. 2000). Finally, there is some indication of lack of contrast in the data series because there are fewer high levels of escapement. However, this is manifest in the lack of precision in seeding levels and juvenile capacity estimates.

Our approach to the sparse data available for spawner-recruit analysis, less than 4 points for each of the 4 populations, was to standardize data per unit of area. We chose square miles of drainage area because it was convenient and drainage area has been used for other standardizations (Parken et al. 2006). We did not test transformation of the data due to its sparseness. In future analysis, we recommend that transformations of drainage area, such as a log transformation, be examined for better fit.

LCR Tule populations have varying degrees of hatchery influence. Based on CWT expansions the proportion of hatchery spawners in the Coweeman River was generally less than 20% and often approached zero. In contrast, the proportion of hatchery spawners exceeded 50% in the IMW streams. If the relative reproductive success of hatchery Tules is reduced compared to wild Tules as observed in studies of other salmonids (Chilcote et al. 1986, Araki and Blouin 2007), our estimates of survival, seeding levels, and capacity may be biased compared to natural populations with less hatchery influence such as has been observed for other species (Chilcote 2003, Kostow and Zhou 2007, Buhle et al. 2009).

The approach we used to combine the data sets converted the subyearling outmigrants to fry assuming a constant survival rate. As a result, the fry per spawner data for the Coweeman River reflected the combined impact of potential capacity limitations at the egg, fry and subyearling stages while the data sets for the other three rivers only reflected the impact of egg and egg to fry components. This analysis demonstrated higher uncertainty in fry capacity and seeding estimate compared to the survival estimates, and that consistently higher escapement and additional years of data are needed to better define fry capacity and seeding levels for maximum production.

The survival estimate from the data was lower than the estimate from the spawner-recruit analysis suggesting that there may be evidence of density dependence in egg to fry survival, which is similar to other salmonids (Barrowman et al. 2003). It should be noted that the egg to fry survival in this report is expected to be lower than incubation survival, (i.e. survival of eggs to emergence). Few alevins or fry with visible yolk were captured, implying that fry outmigrants had reared for some period of time, possibly on the order of 2 to 4 weeks, and had therefore experienced some level of mortality since emergence.

A total of four data points, all in the Coweeman River, were available to estimate subyearling capacity. As expected there is great uncertainty in the resulting spawner-recruit analysis, and this analysis needs to be supplemented with other subyearling capacity data. With the two different life history strategies (fry and subyearling) in the Coweeman River, one hypothesis is that the fry would fill subyearling habitat up to its capacity, and all other fry would emigrate due to the lack of habitat or due to high flows after emergence. The 2004 and 2005 escapement in the Coweeman were over 1500 and 800 adults, representing the highest two highest escapements in the 4-year data series. However, the fry outmigration estimates in these years were extrapolated, not direct estimates (trapping was initiated late in the fry outmigration time window). The Coweeman River fry production estimates for these years were generated by applying the average proportion of the subyearling estimate from the 2006 and 2007 brood years. Therefore any density dependent increase in the proportion of fry outmigrants would not be detected.

Due to the sparseness of the data, there was no "best" model using AIC or other model selection criteria for the egg to fry spawner-recruit analysis. The model with the poorest fit was the HS, and the best fit was the R. The BH model has been criticized for over-estimating productivity (Myers et al. 1999; Barrowman and Myers 2000; Barrowman et al; 2003). Given this, the CSHS or R models may be the most appropriate for this Tule Chinook modeling project. However, the dome shape of the R model causes difficulty in risk assessments because as spawner abundance approaches infinity, the fry estimate approaches zero. Therefore, the average productivity and capacity parameters resulting from fitting the continuous smoothed hockey stick are a good starting point in the life cycle modeling. We reiterate that subyearling capacity estimates needed to be supplemented with inferences drawn from fall Chinook data from outside the LCR area.

In this report separate analyses were conducted for fry and subyearling stages. However, a more realistic approach may be to model Chinook juvenile life history patterns and trajectories in LCR tributaries and especially the estuary using, for example, state-dependent life history theory (Satterthwaite et al. 2009). This may require additional funding and a more fully integrated approach to monitoring between state and federal partners. However, this approach is likely to provide greater insight into life history modeling, which is likely to remain the key tool in LCR salmonid risk assessments and all-H analyses.

Caution should be used in the application of these results because of the above assumptions and concerns. If these types of viability analyses are important, the LCR salmon recovery domain should follow the Willamette-Lower Columbia Technical Recovery Team (WLC-TRT) recommendation of intensive adult and outmigrant monitoring for at least one primary population per strata, and possibly the selection of representative watersheds based on size, hatchery influence, and habitat condition. These may require relatively intensive monitoring of more than the minimum of three primary populations recommended by the WLC-TRT. However, the certainty from these risk analyses should be greatly improved with the additional data.

Acknowledgements

The authors thank Pat Hanratty for sharing unpublished juvenile data and summarizing it for this analysis. In addition, we thank Bryce Glaser, and Todd Hillson for preliminary escapement estimates for the Coweeman River, and all IMW watersheds in 2004, 2006, and 2007. Steve VanderPloeg provided the maps, and Bob Woodard and Michelle Groesbeck summarized adult age and sex data. Anne Marshall deserves a special mention as she located Howard Fuss's ten-year old data files to provide the fecundity data used in this analysis.

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Attachment 3 – Estuary rearing capacity estimates

Lower Columbia Tule Chinook Populations: Estimating Intertidal Rearing Capacities and Survival Rates

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February 9, 2010 DRAFT

Introduction

Lower Columbia 'tule' fall Chinook salmon are classified as 'ocean' type, migrating to the ocean during their first year of life (e.g., Myers et al., 1998). Tule chinook populations are associated with relatively short tributary rivers entering the Columbia River mainstem. Studies of ocean type Chinook in similar geographic settings in British Columbia, Puget Sound and the Oregon coast indicate that a substantial portion of fry production may migrate downstream from natal spawning reaches shortly after emergence (e.g., Healy,1980, Reimers, 1973, Carl & Healy, 1984, Lister and Genoe, 1970, Levings et al., 1986, Bottom et al., 2005). In general, each of these studies highlights the importance of lower tributary and mainstem intertidal habitats as rearing areas for emigrating chinook juveniles. A number of different patterns of use and mechanisms to 'explain' the relative proportions of fry production moving downstream into these areas from spawning reaches are suggested in these studies. We developed a relatively simple model of fry rearing capacity as a function of marsh type habitats and applied it to each of the Lower Columbia River primary populations. We also developed a crude estimate of historical intertidal fry rearing capacity to provide a context for evaluating potential contributions to achieving recovery plan objectives for each population.

We framed our analysis around the following questions:

- What patterns of fry and subyearling smolt emigration occur in Lower Columbia tule populations?
- What basic assumptions regarding emigration timing, rearing capacities and rearing stage survival are available for use in modeling Lower Columbia tule populations?

For each of the lower Columbia River tributaries associated with primary tule fall chinook populations;

- How much habitat is available to support fry to pre-smolt rearing in the intertidally influenced lower tributary and the adjacent downstream mainstem Columbia River?
- How much rearing habitat was historically available to each population?

Background

Mechanisms driving the emigration of fry from natal spawning areas downstream to intertidal rearing habitats are not well understood. At least three different mechanisms have been suggested for northwest ocean type chinook populations. Results summarized in Healy (1980) and Carl and Healy (1984) suggested that emigration rates for fry rearing were influenced by distance from the intertidal or estuarine rearing areas based on emigrant trapping at three different locations ranging up the Nanaimo River, a relatively short drainage emptying into an extensive estuarine area along the inner coast of Vancouver Island. Almost all the fry produced from the lower sections emigrated relatively soon after emergence down into rearing areas in the transition zone to seawater for extended rearing. Roughly half of the production from middle sections of the river migrated to the upper estuary, the rest reared in freshwater and emigrated in the summer. A substantial proportion of the fry produced in the upper most sections of the system remained in upper tributary habitats for extended rearing. Some studies have suggested a genetic linkage to propensity to migrate downstream soon after emergence. Others have suggested that a tendency towards early migration to the estuary might be linked to particular spawning habitats.

Juvenile Outmigration Patterns

The Washington Department of Fish and Wildlife (WFDW) has monitored the outmigration of fall Chinook juveniles from three lower Columbia tributaries in recent years (e.g., Sharpe et al., 2009). Traps Screw traps are located in tributary mainstems below most spawning areas in Coweeman River, Grays River, Germany Creek, Mill Creek and Abernathy Creek. The juvenile outmigration from the Coweeman River occurs primarily in two peaks – a major pulse of 40-50 mm fry leave the system in March and early April. A second mode in the outmigration occurs centered on early July and is comprised of pre-smolts 70-90mm in length. Virtually all of the juvenile outmigrants from Germany, Mill and Abernathy Creeks pass the smolt traps prior to the middle of April. The spawning reaches in these three systems are a relatively short distance upstream from intertidal compared to the Coweeman River.

We used the results from the WDFW trapping studies to reconstruct the relative proportions of fry that migrate downstream into intertidal reaches relatively soon after emergence (Rawding, Cooney and Sharpe, 2010). Based on the WDFW outmigrant trapping results and information from studies on ocean type chinook populations in other northwest regions, we assume that the outmigration patterns for individual Lower Columbia tule populations are variations on two basic themes (figures 1 & 2). Virtually all of the naturally produced juveniles in the three relatively short systems that comprise the Germany/Mill/Abernathy population migrate to intertidal reaches as fry in March and April. In the longer systems, a portion migrates downstream as fry in the early spring, the bulk of the remaining juveniles rear through early summer and emigrate downstream in late June/early July. In the Coweeman River, approximately 15% of the estimated number of fry available to migrate in early April emigrate to intertidal reaches, the remaining 85% remain in freshwater through early summer. Quantitative estimates of the relative proportions migrating as fry versus as presmolts are only available for the WDFW study streams.

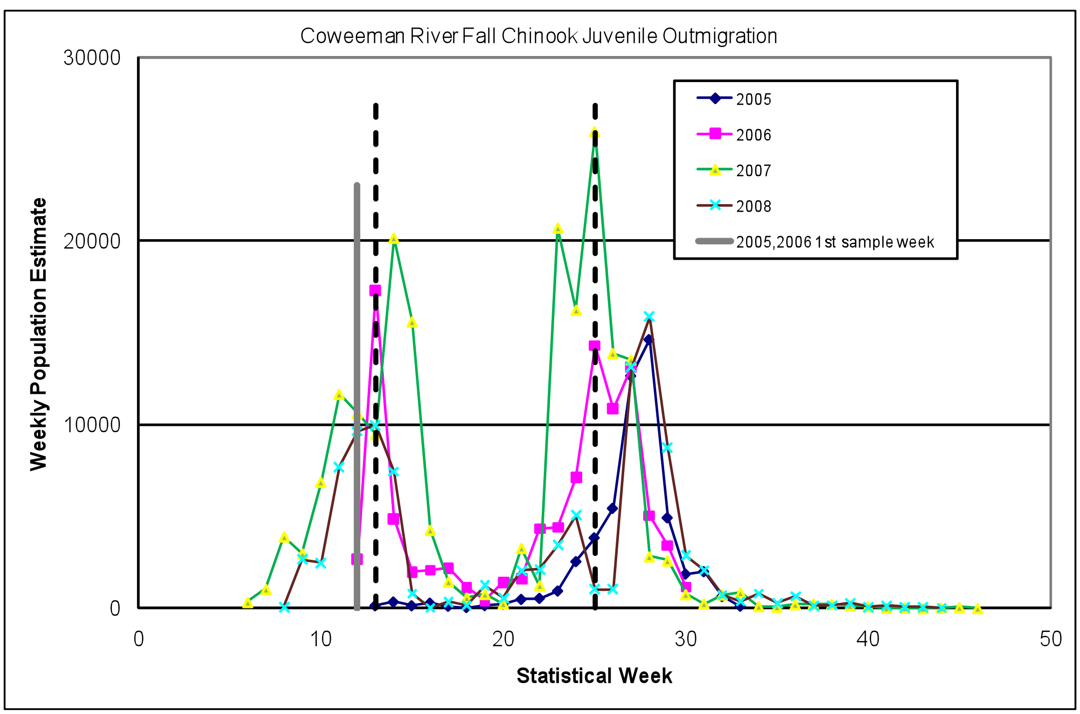


Figure 16. Juvenile outmigrants counted at lower river trap. Dashed lines indicate first weeks in April, July .

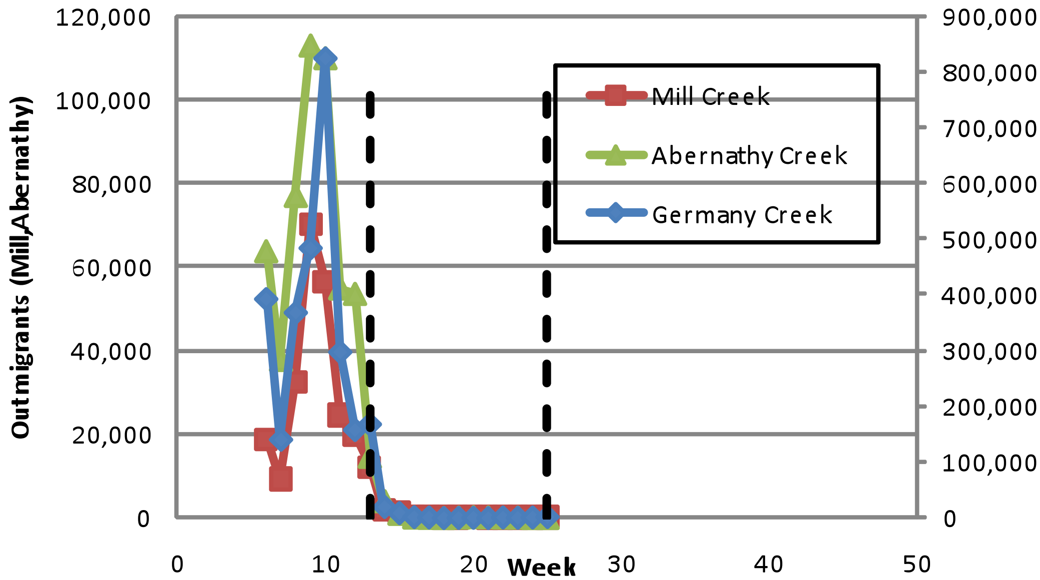
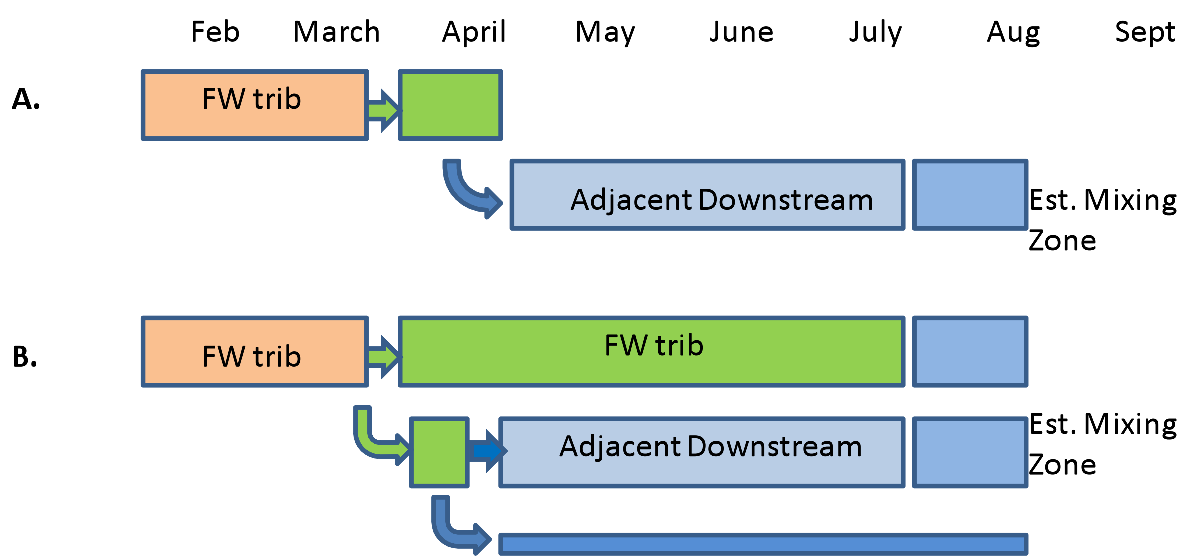


Figure 17 Juvenile outmigrants counted at lower river trap. Dashed lines indicate first weeks in April, July

The migration patterns observed in the Lower Columbia studies could be explained by any of the three general hypotheses (proportion of fry migrating to intertidal a function of distance from spawning reaches, genetic mechanism, or link to spawning in particular reaches. Given the potential implications for restoration planning, life cycle modeling should incorporate sensitivity analyses to these alternative mechanisms.



<u>Juvenile Survival Estimates</u>

The derivation of egg to fry stage survival estimates developed for use in modeling lower Columbia River tule chinook populations are described in Rawding et al. 2010 and Fullerton et al. 2010.

Fry to Presmolt Survival Rates

No direct estimates of juvenile rearing life stage survivals are available for Lower Columbia River tule populations. Greene and Beechie (2004) compiled a set of habitat specific life stage survival rate estimates based on a review of published estimates for ocean type chinook stocks. We estimated average residence times for fry juvenile outmigrants and subyearling outmigrants in natal tributary and intertidal habitats and applied the synthesized tributary weekly mortality rate. (Greene and Beechie 2004: Table 2). Greene and Beechie (2004) concluded that mortality rates likely differed among rearing habitats in freshwater tributaries, delta channels and nearshore shoreline habitats. They speculated that mortality rates on rearing juveniles were the lowest in delta habitats, higher in nearshore shoreline areas and intermediate in natal freshwater habitats. Given the lack of specific data on fry to presmolt survival rates for lower Columbia River tule type chinook stocks, we assumed that the weekly rate was the same in natal tributary rearing habitats and intertidal rearing habitats. The weekly mortality (.138) is expressed as a mortality coefficient In an exponential equation. We assumed that fry following each of the two basic migration/rearing patterns (fry remaining in freshwater natal tributary reaches vs. fry emigrating downstream and rearing in intertidal reaches) reared for an average of 10 weeks before migrating relatively quickly to the lower Columbia mixing zone (salt water influenced). The estimated survival rate in the absence of density dependent effects for the subyearling JOM pathway was $S = \exp(-.138 \times 10) = 0.25$. The survival to the mixing zone for the fry JOM was also 0.25, assuming 2 weeks in the natal tributary habitat followed by 8 weeks rearing in intertidal reaches (0.76×0.33).

Presmolt to Ocean Survival Rates:

No direct estimates of residence time in the estuarine mixing zone are available for lower Columbia tule chinook juveniles. We developed the following assumption set based on inferences from studies in other systems, genetic analysis of juvenile samples from lower Columbia reaches and PIT tag studies of subyearling migrants originating from hatcheries in the Upper Columbia River detected passing Bonneville Dam.

Studies in other Northwest river systems indicate that juvenile ocean type chinook shift from nearshore estuarine/marsh channel type habitats to schooling in deeper waters after reaching a length of 80-90 mm. Downstream movement towards the ocean accelerates when this size threshold is reached. Detections of tagged subyearling juvenile chinook migrating downstream after passing through Bonneville Dam indicate a relatively rapid transit to the brackish water mixing zone in the lower Columbia River. We assumed that presmolts transitioning from either natal tributary or intertidal rearing habitats moved relatively quickly down the mainstem Columbia River to the estuarine mixing zone and were subjected to the same weekly mortality rate as applied to fry to presmolt rearing (transition survival = $\exp\{-.138*1 \text{ week}\} = 0.76$.

Based on acoustic tagging, juvenile subyearling chinook begin entering the nearshore ocean/Columbia River plume after two weeks to a month residence in the mixing zone. Temporal patterns in the relative contribution of West Cascades stock to the aggregate juvenile chinook population occupying the mixing zone also supports a relatively rapid movement into nearshore ocean waters in mid to late summer. Based on the loss rates from acoustic tagging studies for similar sized subyearling migrants originating above Bonnneville Dam, we assumed that survival from the mixing zone to the plume is 0.70 (reference?? Slides from D. Teal).

Methods

We developed a simple spatial model of fry rearing capacity as a function of available habitat based largely on work done on the Skagit system in Puget Sound. We applied estimates of capacity per unit (m2) of marsh type habitats taken from the Skagit analyses to GIS based habitat maps for each primary Lower Columbia tule population. Two general assumptions framed the analysis:

Fry rearing capacity is a function of available tributary margin and wetlands marsh type habitat. The relative value of available rearing habitat to a particular population decreases with distance downstream from natal spawning areas.

The analysis was organized into a series of steps:

1. Estimate the amount of accessible bank margin and wetlands habitat in 1 km increments downstream from the terminus of freshwater spawning/rearing habitat for each system.
2. Apply estimates of deep (2 m depth or greater) tidal channel area per unit of wetlands habitat estimated from Skagit field studies.
3. Calculate an estimate of rearing capacity for each 1 km increment by multiplying the amount of deep channel habitat by the average maximum rearing density from Skagit study.
4. Accumulate an estimate of total available fry rearing habitat for each population after incorporating a measure of Connectivity (weighting by distance downstream) based on Skagit field studies.
5. Generate a preliminary estimate of historical capacity assuming loss of a minimum of 50% from pre-settlement conditions.

We were not able to develop a submodel of potential rearing capacities for application to presmolts entering the lower Columbia mixing zone for this analysis. Modeling capacity interactions in this zone requires information and/assumptions about additional considerations including the relationship of larger, schooling presmolts and habitat capacity over a relatively short period of time (residence time in days or weeks), interactions among presmolts produced from all lower Columbia tule populations, and interactions with hatchery releases from a broad range of programs.

Mapping current Marsh habitats

Tidal model

Juvenile fall chinook use intertidal marsh areas in the lower reaches of tributaries and along the mainstem Lower Columbia River for rearing for extensive periods during the spring and summer. In order to estimate rearing capacity in intertidal reaches,, it was first necessary to delineate the tidal zone within lower Columbia River fall Chinook tributaries. In general, tidal cycles influence the surface elevation of the Columbia River mainstem from the mouth upstream to Bonneville Dam. In fact, the effects can be quite dramatic and frequently initiate flow reversals during the highest tides at least as far upstream as river kilometer 83. For our purposes, we were most interested in the areas of mean tidal maxima during the times rearing juvenile fall Chinook were present (spring through at least mid-summer).

River level fluctuations are measured by tidal stations managed by NOAA's Center for Operational Oceanographic Products and Services (CO-OPS). We collected all available data for Columbia River sites between Bonneville Dam and Astoria, Oregon. In total, six locations were summarized by month and the elevation of the Columbia River for the average of the higher high water height of each tidal day (MHHW). We used the June value as an approximation of the maximum extent of tidal inundation because it coincides with the presence of juvenile fall Chinook originating from Lower Columbia River populations and the highest spring tides.

From this data, it was necessary to estimate a series of continuous values along the length of the river. There is a strong relationship between the station's distance from the mouth of the Columbia River and the elevation of the MHHW (fig. 1). By applying a regression model we were able to calculate a MHHW height for each river kilometer from the mouth upstream to Bonneville Dam. The MHHW values attributed to each 1km river segment were then converted to a Euclidean allocation grid which was then subtracted from a mosaic generated using USGS digital elevation model (DEM) results. All negative values from this raster calculation correspond to the inundated area as represented by the DEM and mean June MHHW heights. Prior to analysis, we adjusted all input datasets to a common vertical datum (NAVD 1988).

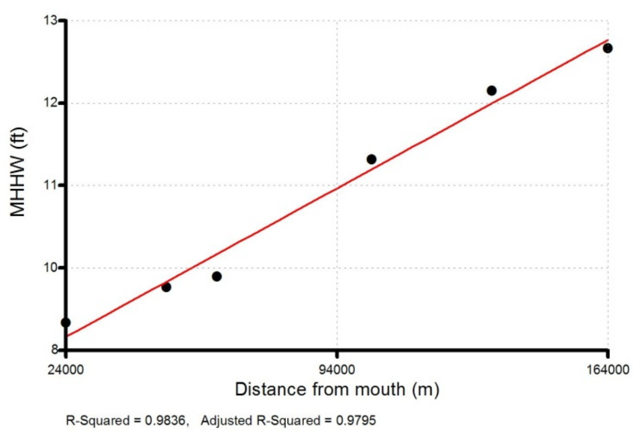


Figure 18

GIS application

The area of tidal inundation became the foundation for the tributary and associated downstream fall Chinook rearing zones. We assigned each population with a series of reaches starting with the main tributary estuary. The first zone included all areas upstream from the mainstem confluence. Progressing downstream from this point, we split the tidally inundated areas into one kilometer sectors that were further subdivided by the centerline of mainstem flow. Each discrete zone was then attributed with its appropriate river kilometer and bank side.

NWI maps

We utilized the National Wetland Inventory (NWI) from the United States Fish and Wildlife Service (USFWS) as the basis for quantifying wetland habitats within the intertidal zone. The NWI spatial layers for Washington and Oregon were obtained and clipped to the subbasins within the Lower Columbia River subbasins. We then used the NWI classification scheme to determine which wetland types would be likely used by rearing fall Chinook juveniles. Estuary/marine, freshwater emergent, and freshwater forested wetlands were considered the most preferred habitat types within saltwater tidal, freshwater tidal, and nontidal water regimes. Additionally, we selected for temporarily, seasonally, semipermanently, intermittently, and regularly flooded wetland types (Figure 3). Once the dataset was queried for these attributes, the selection set was converted to a new spatial theme and clipped to the tidally inundated zonal theme. From the resulting dataset we were able to summarize the quantity of wetlands by type and the one kilometer zones associated with each fall Chinook tributary population.

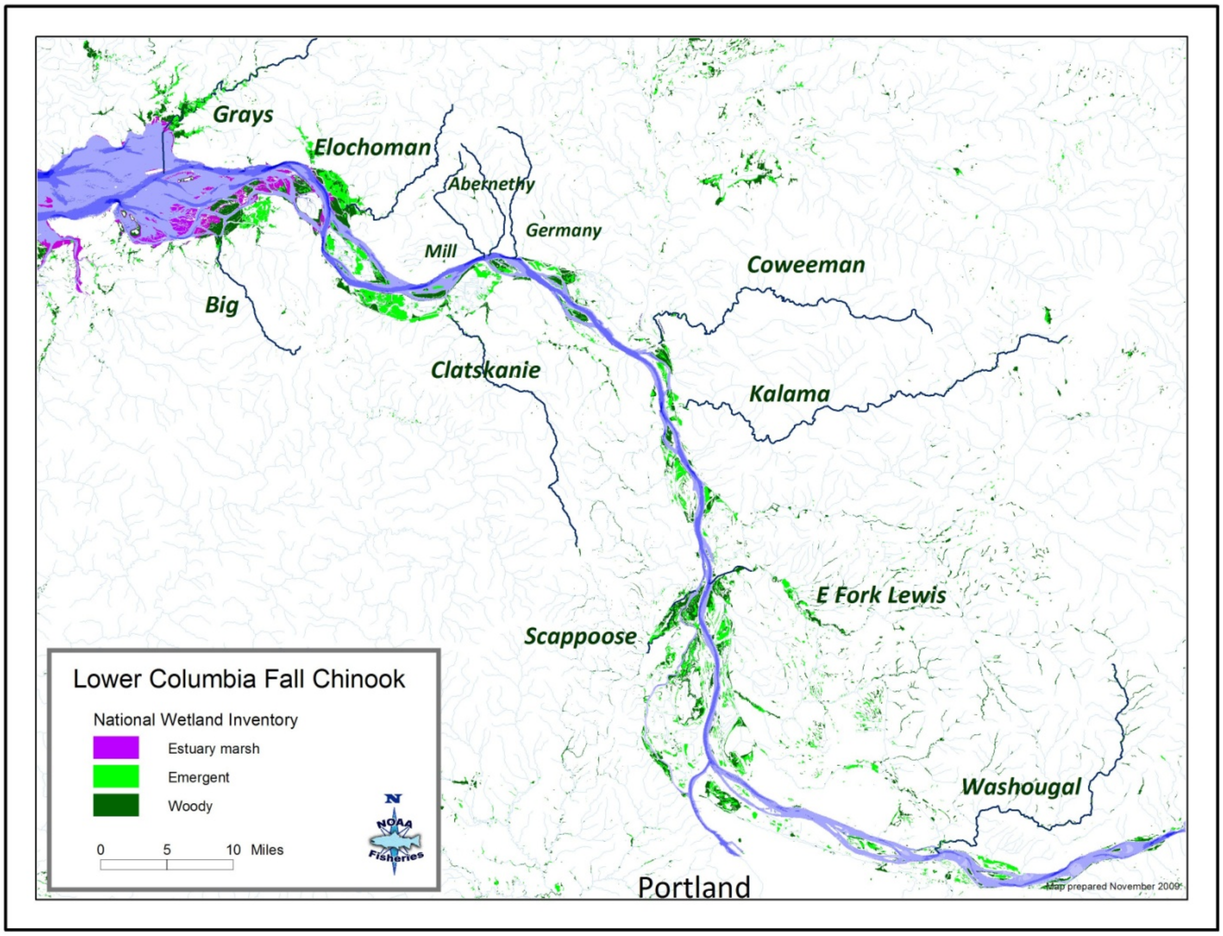


Figure 19. Current Lower Columbia wetland areas based on NWI spatial mapping GIS layers.

Rearing habitat per unit wetlands

Relatively small (40-50 mm) subyearling chinook juveniles emigrating into intertidal wetlands habitats use deeper channel habitats for refuge during non-feeding hours. Population models developed for Puget Sound chinook have assumed that the volume of deep channel habitat associated with intertidal wetlands is a measure of rearing capacity. We applied the results of field studies in the Skagit basin to population specific estimates of available wetlands to estimate the capacity for fry rearing for each of the Lower Columbia tule chinook populations designated as Primary in the current recovery planning drafts.

Beamer et al. (2005) analyzed infrared orthophotos of a subsample of marsh habitats in the Skagit delta to determine potential relationships between channel surface area and marsh surface area. Regressions of channel area on marsh area differed when samples from the North and South Fork Skagit delta were analyzed separately (see appendix DIII in Beamer et al 2005). Estimates for marsh areas outside of either the North or South Fork delta sections clustered more closely with the South Fork. We applied the fitted relationship developed from the South Fork

Skagit River to estimate the amount of intertidal channel habitat associated with Lower Columbia tule populations.

Emergent wetlands: Channel area = .006 X (hectares of wetlands)^1.48

The Skagit River juvenile studies confirmed that some proportion of fry emigrating downstream from up-river spawning areas transit through the Skagit delta and enter pocket estuaries – defined as wetlands that result from small tributaries or general runoff into margins away from main tributary (e.g., along Puget sound shoreline but not directly associated with major tributaries. Beamer et al. 2005 developed a separate regression relating the amount of channel area to total marsh area for pocket estuaries. We incorporated this relationship into our assessment of marsh type habitats currently accessible along the mainstem Columbia River.

Pocket marsh habitats: Channel area = .0614 X (wetlands hectares)

Analyses of the field sampling data from the Skagit delta indicated that chinook densities during the spring and early summer rearing phase were influenced by channel depth and average water velocity (Beamer et al., 2005 appendix DII). Beamer et al. 2005 concluded that fry densities were low in habitats shallower than 0.2 m or where average water velocities exceeded 0.2 m per sec. The Skagit delta habitat surveys indicated that for channels up to 100 m in width, approximately 20% of the channel habitat would exceed 0.2 m depth while having an average water velocity below 0.2 m per second. We applied the 20% estimate in our analysis of potential intertidal rearing habitat for Lower Columbia tule chinook populations.

Densities

Beamer et al. (2005) estimated that the average Skagit delta juvenile rearing density at capacity was 1.31fish/m3 of rearing habitat (appendix DVII of Beamer et al. 2005). We assumed that this estimate applied per unit channel rearing habitat to the Lower Columbia tule population. We also assumed it represents the maximum expected out put of 80-90 mm early summer pre smolt migrants from this habitat.

Connectivity

B eamer et al. 2005 concluded that the effective capacity of a unit of habitat dropped off as a function of distance and channel complexity (number of alternative pathways from natal areas) in the Skagit delta. A model that included a capacity index (1/distance) provided the best fit to relative density data collected from different sections of the delta. Given the relatively simple linear main channel structure associated with current intertidal habitats for Lower Columbia tule Chinook populations, we limited the connectivity function to distance downstream from natal spawning. We applied two variations of the Skagit connectivity model : (1/distance) to 1 km reaches downstream of the confluence of each primary tributary, alternative calculate weight as (1/(0.5*distance downstream).

Accumulating at population level

We generated a range of estimates of total potential channel habitat for Lower Columbia tule chinook populations using a systematic approach. We analyzed the populations targeted for restoration to high or very high viability in recovery planning – the primary populations (note: we did not attempt to model downstream rearing habitats associated with the Hood River population). We generated a range of estimates by applying alternative inputs for two factors: the channel to wetlands area conversion and the relative discount for distance downstream from the lower end of tributaries. We report the point estimate for one set of assumptions (Skagit

delta channel to wetlands area ratio applied down tributary confluence with Columbia mainstem, pocket estuary relationship in mainstem Columbia; connectivity factor of 1/ distance downstream of natal tributary confluence) along with the range of capacity estimates across the remaining combinations of marsh channel habitat ratios and connectivity assumptions). Option 2: applied emergent wetlands channel estimate across all of the habitats associated with each population.
Note: we are evaluating an alternative approach to expand the analysis to incorporate alternative downstream dispersion mechanisms, use of downstream Lower Columbia marsh habitats by multiple populations, etc.

Estimating historical marsh habitat capacities

Lewis river plan supporting document (Cramer et al) reference to loss of at least 50%
1983 CREST report (Thomas 1983), historical vs. current for mainstem Columbia up through the embayment Elochoman empties into.
Personal communication from C. Simenstad (sp??) that more detailed assessment of current vs. historical extending up river to Bonn Dam is underway, expected in about a year.
Note: we are working generating estimates of extant marsh habitats that are cut off by diking in relation to each Lower Columbia tule population.

Results

East Fork Lewis River

The East Fork Lewis River supports a tule chinook population designated for primary status by recovery planners (targeted for restoration to high viability). Chinook spawning in the East Fork extends upstream from the confluence of a side tributary (Mason Creek) just upstream of the town of La Center. WDFW spawning survey records indicate that virtually all spawning occurs in mainstem East Fork habitats. The starting point for our estimates of potential intertidal rearing habitats in the Lewis River was the confluence with Mason Creek. We estimated the total amount of marsh habitat currently available under spring flow conditions in the 8.6 km accessible from the 8.6 km reach of the mainstem East Fork Lewis River extending downstream to the confluence with the main Lewis River. We continued the analysis downstream from that confluence, summing the estimated current marsh habitat associated with each 1 km increment of distance down the mainstem Lewis River to the confluence with the Columbia River. We continued accumulating estimates of current marsh habitat in 1 km increments downstream an additional 12 km. We ended the Lewis River rearing capacity assessment at the downstream end of Martin Island, the last increment of current marsh habitat before the confluence of

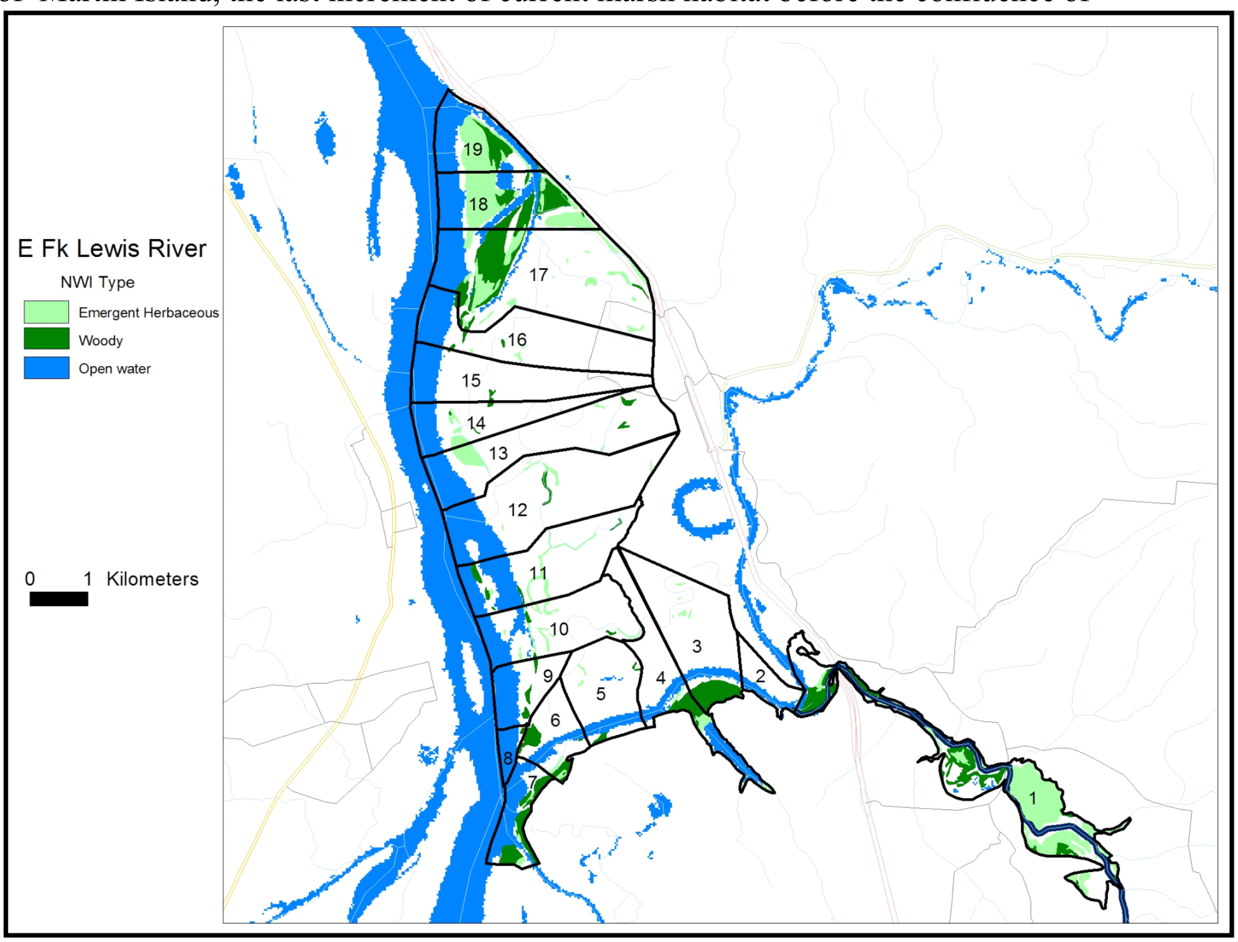


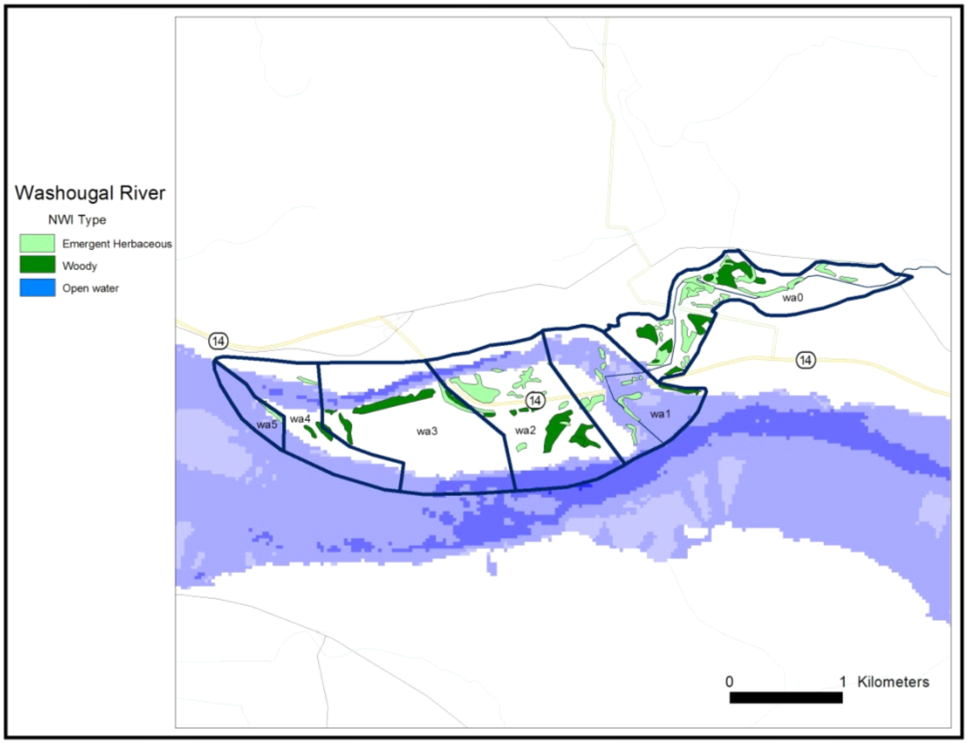
Figure 20. East Fork Lewis River. Currently accessable marsh habitats and relative downstream distances.

the next river supporting tule chinook production (the Kalama River). The amount of channel habitat in each zone was estimated by applying the empirically based regression relationships derived from sampling in the Skagit River estuary (Beamer et al. 2005). Option A assumes that the relationship derived from pocket estuary samples applies to all zones. Option B applies the relationship derived from habitats sampled in the Skagit River delta to lower tributary sections. The pocket estuary relationship was used for mainstem Columbia River sections. Two different connectivity weightings were applied: connectivity = 1/distance from natal tributary (relationship derived from empirical data for the Skagit River) and a variation where the discount was set at half the Skagit rate (1/distance x 0.5).

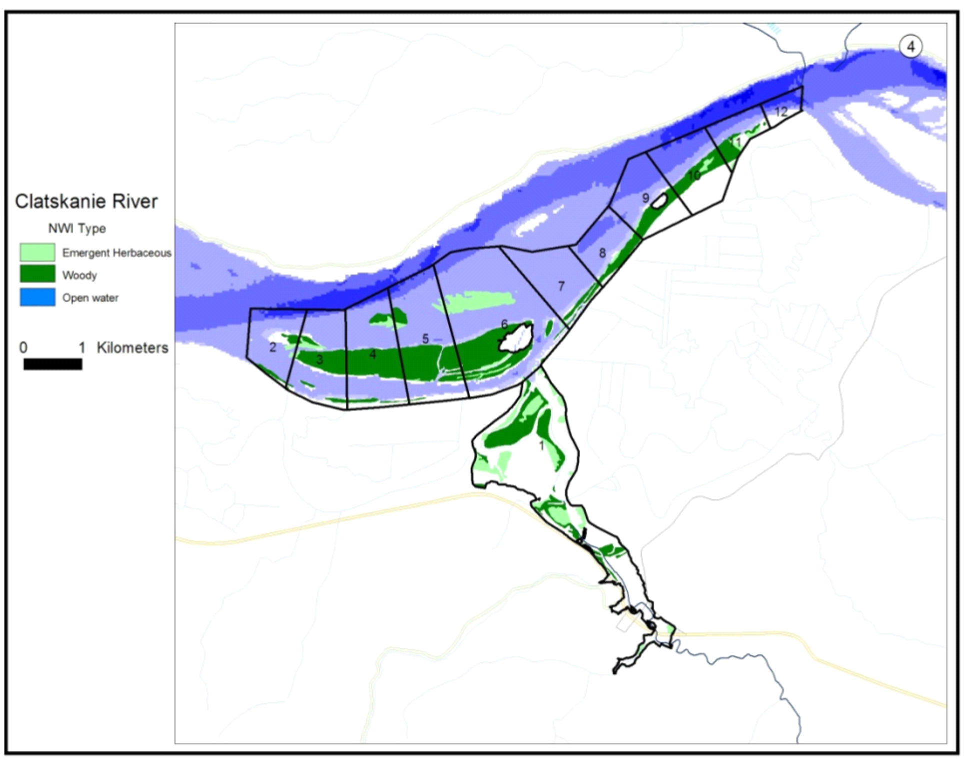
Table 21. Lewis River intertidal rearing capacity analysis. Channel habitat estimates: Skagit pocket estuary relationship (Option A), Skagit delta relationship applied to lower tributary reaches (Option B). Rearing capacity = channel habitat X 0.20 proportion gt 2 m deep X 20,000 m2/hectare channel X 1.31 presmolts/m2.

			Marsh Habitat (Hectares)					Marsh Channel Habitat				Marsh Channel Habitat	
Zone	Reach kms	Distance	Emergent Herbaceous	Wooded	Total		Connectivity = 1/distance	Option A	Option B		Connectivity = 1/(0.5 * distance)	Option A	Option B
1*	8.6	0	127.1	56.8	183.9		1.00	11.38	**13.48**		1.00	11.38	13.48
2	1	2	0.0	0.0	0.0		0.50	-	**-**		1.00	-	-
3	1	3	2.5	29.0	31.5		0.33	0.65	**0.99**		0.67	1.30	0.99
4	1	4	10.0	14.3	24.3		0.25	0.38	**0.67**		0.50	0.75	0.67
5	1	5	1.7	3.2	5.0		0.20	0.06	**0.06**		0.40	0.12	0.06
6	1	6	4.6	16.0	20.7		0.17	0.21	**0.53**		0.33	0.43	0.53
7	1	7	4.1	30.2	34.3		0.14	0.30	**1.12**		0.29	0.61	1.12
8	1	8	0.0	1.3	1.3		0.13	0.01	**0.01**		0.25	0.02	0.01
9	1	9	0.0	5.2	5.2		0.11	0.04	**0.01**		0.22	0.07	0.02
10	1	10	12.2	2.6	14.8		0.10	0.09	**0.03**		0.20	0.18	0.06
11	1	11	13.5	7.1	20.6		0.09	0.12	**0.05**		0.18	0.23	0.10
12	1	12	5.6	3.5	9.1		0.08	0.05	**0.01**		0.17	0.09	0.03
13	1	13	16.2	3.4	19.6		0.08	0.09	**0.04**		0.15	0.19	0.08
14	1	14	8.8	1.6	10.4		0.07	0.05	**0.01**		0.14	0.09	0.03
15	1	15	0.0	1.7	1.8		0.07	0.01	**0.00**		0.13	0.01	0.00
16	1	16	2.0	4.3	6.3		0.06	0.02	**0.01**		0.13	0.05	0.01
17	1	17	51.1	62.3	113.4		0.06	0.41	**0.39**		0.12	0.83	0.78
18	1	18	77.8	43.1	120.9		0.06	0.42	**0.40**		0.11	0.83	0.80
19	1	19	46.7	17.1	63.7		0.05	0.21	**0.15**		0.11	0.42	0.30
						Total:		14.50	**17.97**			17.61	19.07
						Rearing capacity @ 5,240/h		75,960	**94,178**			92,266	99,927

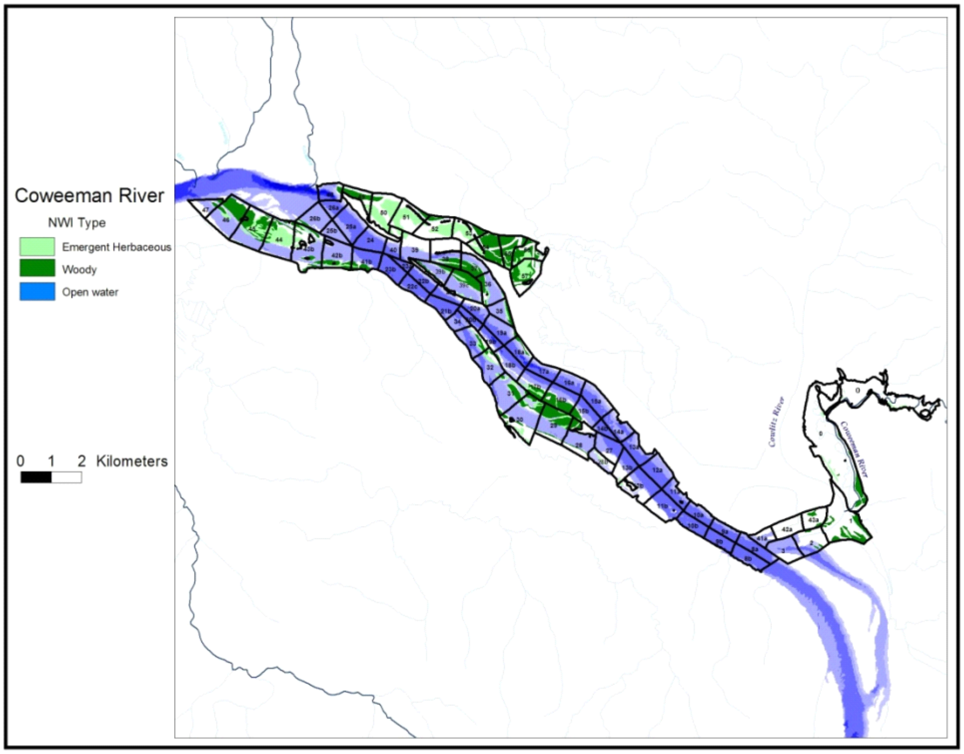
Washougal River



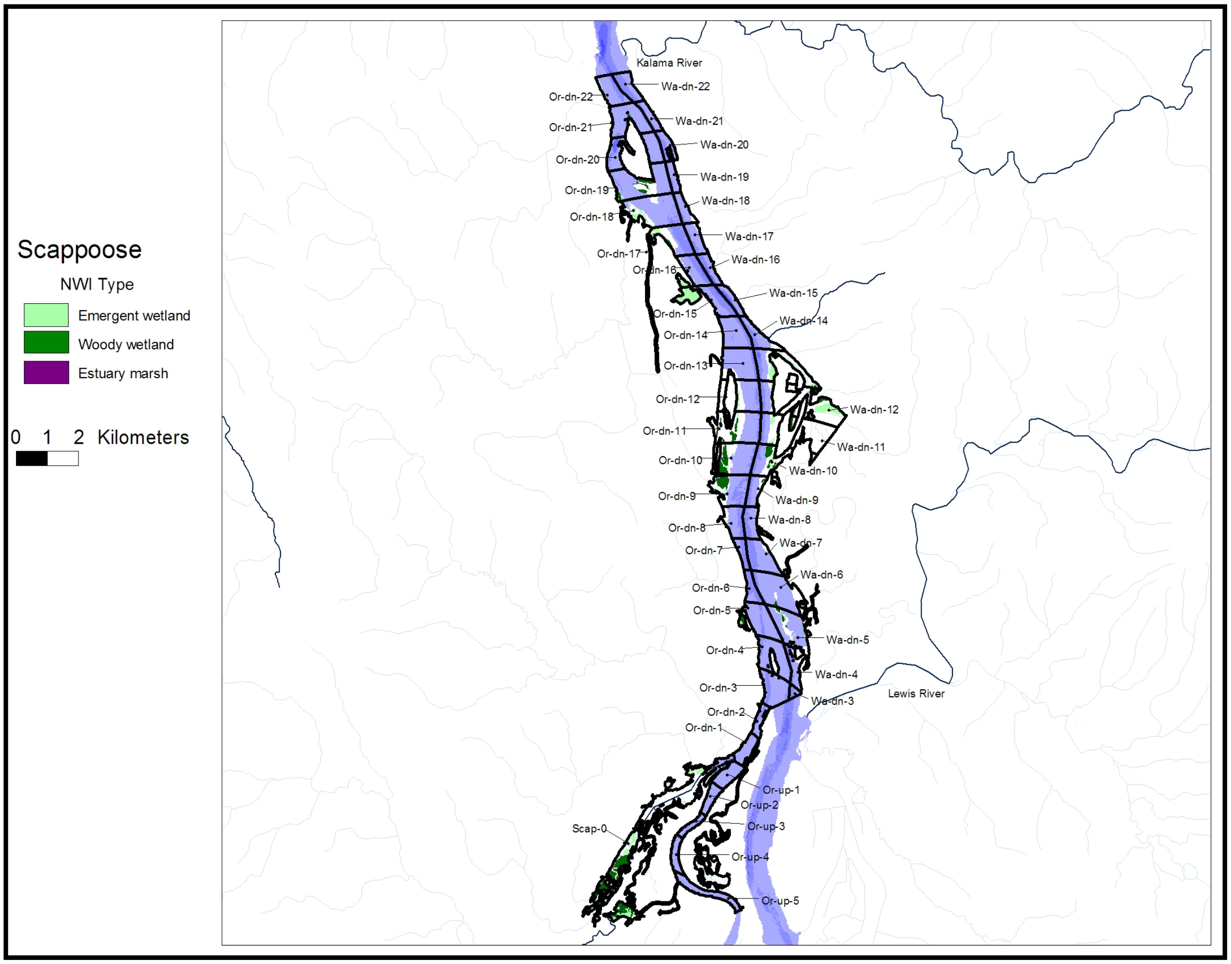
Claskanine River



Coweeman River

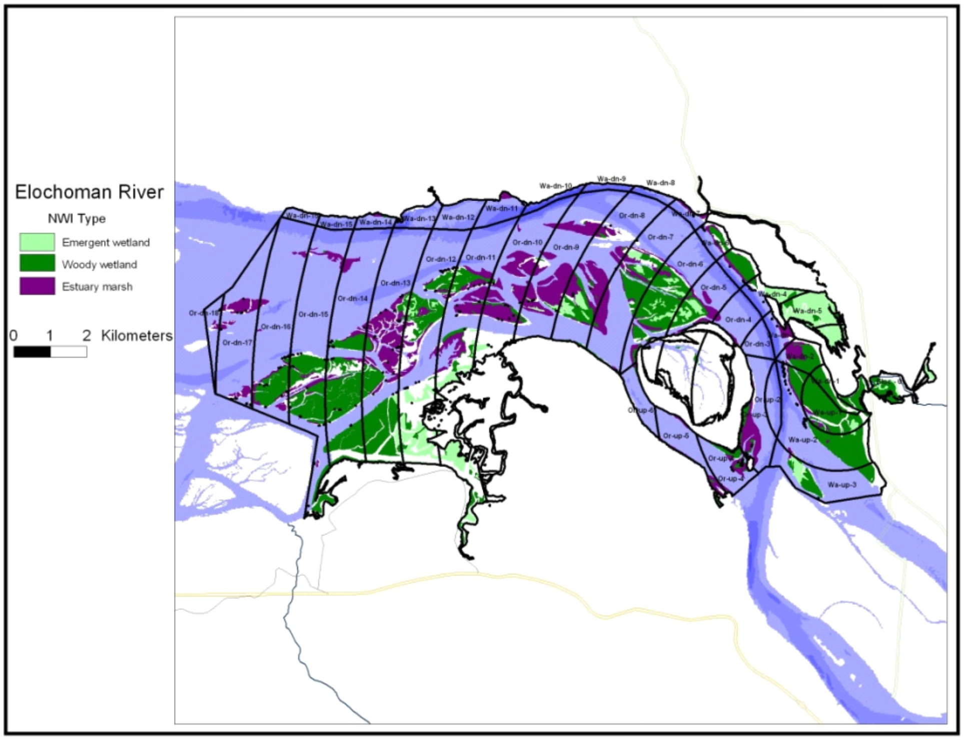


Scappoose River



Germany,Mill and Abernathy Creeks

Elochoman River



Summary

We used the methods described above to generate estimates of the potential capacity for fry to presmolt rearing associated with the lower tributary mainstems and the adjacent Columbia River habitats for each seven of the eight primary populations in the Cascade and Coastal strata (Table).

Population	Rearing Capacity Estimates *Minimum*	**Standard**	*Maximum*
East Fork Lewis	*75,960*	***94,178***	*99,927*
Coweeman	*42,824*	***52,950***	*62,550*
Washougal	*5,350*	***7,923***	*17,793*
Claskanine	*51,348*	***58,230***	*145,392*
Germ/Mill/Aber	*104,900*	***104,900***	*174,545*
Eloch/Skam	*224,460*	***224,460***	*348,515*
Scappoose	*57,114*	***64,386***	*76,293*
	-	**-**	-

Acknowledgements

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Attachment 4 -- Hatchery parameters

This section of the report describes how we parameterized the effects of alternative hatchery scenarios in the SLAM model. We focused on three scenarios: no hatcheries (historical), baseline (hatchery release and broodstock protocols typical of the decades preceding ESA listing in 1998), and a recovery scenario. The recovery scenario was based upon the actions described in both Oregon's draft Lower Columbia River recovery plan and Washington's Conservation and Sustainable Fisheries Plan.

The recovery actions related to hatcheries are generally related to the following types of activities: reductions in releases, changes in hatchery operations including greater use of wild fish for broodstock, reducing straying of hatchery fish to natural spawning areas, and improved monitoring including mass marking of hatchery fish. As we describe below, our analysis focused primarily on the how proposed hatchery recovery actions would impact the number and proportion of hatchery fish on natural spawning grounds (pHOS).

Fall Chinook release scenarios: Current and recovery

Our assumptions about baseline and recovery scenario fall Chinook releases are summarized in Table 22.

Table 22 – Summary of baseline and recovery scenario Lower Columbia River fall Chinook releases. Current releases are drawn largely from existing Hatchery Genetic and Management Plans (HGMPs -- http://wdfw.wa.gov/hat/hgmp/) and future releases are based on information from WDFW and ODFW.

Strata	Population	Category	Baseline release (M)	Recovery release (M)
Coastal	Grays/Chinook (WA)	C	0	0
	Elochoman/Skamokawa (WA)	P	2	0
	Mill/Germany/Abernathy (WA)	P	0	0
	Youngs Bay (OR)	S	1.45	1.45
	Big Creek (OR)	S	5.7	5.7
	Clatskanie (OR)	P	0	0
	Scappoose (OR)	P	0	0
Cascade	Lower Cowlitz (WA)	C	5	5
	Upper Cowlitz (WA)	S	0	0
	Toutle (WA)	P	2.5	1.4
	Coweeman (WA)	P	0	0
	Kalama (WA)(includes	C	5	5.0

	Fallert Ck)			
	Lewis [tule] (WA)	P	0	0
	Salmon (WA)	S	0	0
	Washougal (WA)	P	4.0	0.9
	Sandy (OR)	S	0	0
	Clackamas (OR)	C	0	0
Gorge				
	Lower Gorge (WA & OR)	C	0	0
	Upper Gorge (WA & OR)	S	0	0
	White Salmon (WA)	C	0	0
	Hood (OR)	P	0	0
	Spring Creek	NA	6.1	6.1
	Spring Creek	NA	4.6	4.6
	Little White Salmon	C/S	1.7	1.7
	Little White Salmon	C/S	4.5	4.5
	Total		42.55	34.85

Baseline pHOS was based on estimates for the most recent 5 years of spawning ground data available for each primary population. For the Coweeman, Grays, Lewis, Cowlitz, Kalama, Washougal , Elochoman, and Germany/Abernathy/Mill (GAM) populations these were obtained from the Table 12 of the 2008 Technical Advisory Committee report (attached), and generally corresponded to return years 2001-2005. For the Clatskanie data were obtained from Mark Chilcote (ODFW). No data were available for the Scappose or Toutle populations, so these populations were assumed to have the same number of hatchery strays as the nearby Clatskanie and Cowlitz populations, respectively. For the baseline scenarios, the mean, minimum and maximum numbers of hatchery strays to the spawning areas were assumed to be the same as the observed values for the most recent 5 years of data for each population.

For the recovery scenario, the predicted number of hatchery origin spawners on the natural spawning grounds was determined using a two step process. First, we used coded wire tag (CWT) recovery information obtained from the Regional Mark Processing Center database (http://www.rmpc.org) to determine the origin of hatchery origin salmon recovered in each population. For the most part, hatchery fish tended to be recovered in populations in the same stratum in which they were released (Table 23). Next, we used the proposed reductions in Lower Columbia River fall Chinook salmon releases (Table 22) to predict the reduction in the average number of hatchery strays to a population as a result of reduced releases (Table 25). For populations that the WDFW conservation plan proposes to use weirs to control straying (Washougal, Toutle, Grays), strays were limited to the specific percentage of the natural population proposed in the "HSRG solutions" for those population or 5%, whichever was larger (Table 24).

Table 23 – Summary of coded wire tag recoveries on spawning grounds in Lower Columbia tule Chinook salmon population waterseds since 2001.

Population	Source	# tags since	Proportion

		2001	
Elochoman	Elochoman	252	0.73
	Big Creek	79	0.23
	Greys R	1	0.00
	Blind SL	3	0.01
	Deep River	6	0.02
	Klaskanine	1	0.00
	Tongue Point	2	0.01
G/M/A	Big Creek	105	0.41
	Elochoman	148	0.58
	Kalama R	1	0.00
	Snake R	1	0.00
	Youngs Bay	2	0.01
Grays	Deep R	37	0.77
	Youngs Bay	11	0.23
Coweeman	Kalama	5	0.63
	Fallert Cr	2	0.25
	Elocohman	1	0.13
EF Lewis	Washougal	7	0.64
	Kalama	2	0.18
	Fallert Cr	1	0.09
	Gobar Cr	1	0.09
Toutle	Kalama	3	0.38
	Fallert Cr	2	0.25
	Youngs Bay	2	0.25
	Green R	1	0.13
Washougal	Washougal	89	0.98
	Fallert Cr	1	0.01
	Tanner Cr	1	0.01

Table 24 –Summary of current (2001 – 2005) average proportion hatchery spawners (pHOS), proportionate natural influence (PNI) under the WDFW conservation plan, pHOS target under the conservation plan, and method of pHOS control.

Population	current pHOS (average 2001 - 2005)	PNI target	pHOS target	method of pHOS control
Greys/Chinook (WA)	22%	NA	<0.05	weir
Elochoman/Skamokawa (WA)	69%	NA	<0.05	passive
Mill/Germany/Abernathy (WA)	77%	NA	<0.05	passive

Youngs Bay (OR)	high	NA	?	?
Big Creek (OR)	high	NA	?	?
Clatskanie (OR)	90%	NA	<0.05	passive
Scappoose (OR)	high	Na		passive
Lower Cowlitz (WA)	41%	0.50	<0.1	?
Toutle (WA)	41%	0.67	<0.1	weir
Coweeman (WA)	18%	NA		passive
Kalama (WA)	93%	0.50	<0.1	weir
Lewis [tule] (WA)	25%	NA	<0.05	passive
Salmon (WA)	high	NA	?	passive
Washougal (WA)	61%	0.67	0.05	weir
Sandy (OR)	high	NA	?	passive
Clackamas (OR)	high	NA	?	passive
Lower Gorge (WA & OR)		NA	?	passive
Upper Gorge (WA & OR)		NA	?	passive
White Salmon (WA)		NA	?	passive
Hood (OR)		N	?	passive

Table 25 –Summary of hatchery origin spawners for current conditions and predicted under the conservation plan scenario.

Population	average natural origin spawners last five years	natural spawners average last five years	hatchery origin spawners last five years	hatchery origin spawners - recovery plan
Greys/Chinook (WA)	207	264	57	57
Elochoman/Skamokawa (WA)	509	1,665	1,155	309
Mill/Germany/Abernathy (WA)	487	2,118	1,631	692
Youngs Bay (OR)				
Big Creek (OR)				
Clatskanie (OR)	18	179.4	161	126
Scappoose (OR)			treat same as Clatskanie	
Lower Cowlitz (WA)	1451	2,460	1,009	
Upper Cowlitz (WA)			0	
Toutle (WA)	3,441	5,832	2,391	10% of NOR - weir
Coweeman (WA)	583	711	128	84
Kalama (WA)	454	6,674	6,220	
Lewis [tule] (WA)	830	1,110	280	183
Salmon (WA)				
Washougal (WA)	1500	3,846	2,346	5% of NOR - weir
Sandy (OR)				
Clackamas (OR)				

Lower Gorge (WA & OR)
Upper Gorge (WA & OR)
White Salmon (WA)
Hood (OR)

Fitness reductions due to the presence of hatchery fish

In some scenarios, the presence of hatchery spawners was assumed to lead to a reduction in population fitness. This reduction was modeled using a modification of the empirical approach developed by Mark Chilcote and described in the Oregon recovery plan. The "Chilcote approach" uses an empirically observed relationship between pHOS and estimated natural population productivity Table 26 to predict changes in a population's productivity as a function of changes in pHOS (Figure 21).

The fitted relationships developed by Chilcote expressed productivity in terms of ln(alpha), the estimated productivity at the origin in a Beverton Holt or Ricker stock recruit function. The version SLAM used in the tule Chinook life cycling modeling project incorporates density dependence into the spawning and the fry to juvenile outmigrant life stages expressed in terms of linear hockey stock relationships. In a hockey stock relationship, the estimated productivity per spawner is a constant for parent spawner densities up to the point where capacity is reached. In a Beverton-Holt or a Ricker function, productivity per spawner decreases as a function of increasing spawner density. It would therefore be inappropriate to use the relationship developed for ln(alpha) to directly describe relationship between pHOS and a hockey stick productivity function.

One approach for expressing a Beverton Holt or Ricker stock recruit alpha in a manner that directly relates to the slope parameter in a corresponding hockey stock curve is to calculate the so called steepness parameter – the expected productivity at 20% of equilibrium spawner level. Assuming a Beverton Holt curve, that productivity can be calculated algebraically after re-arraigning terms as P20 = Alpha/(1+0.2*(Alpha-1)), and the resulting slope of the relationship between survival and pHOS is then 0.70.

We used this relationship to make early stage survival a function of pHOS. Specifically, the egg-to-fry, fry-to-upper tidal, and upper-tidal to mixing zone survival rates were each decremented by the cube root of the total P20 survival decrement based on the pHOS value for the population the preceding year.

Table 26 – Fall Chinook population used to develop relationship between the proportion hatchery origin spawners in a population (Ph) and average population productivity (Ln(alpha). Population productivity was estimated using either a Ricker or Beverton-Holt spawner recruitment function, with environmental co-variates. The best supported function was chosen on the basis of AIC values. Further details are available from Mark Chilcote (mark.chilcote@noaa.gov).

Population	Species	start	end	h type	Ph	Ln(alpha)
Elk	Chinook Fall	1981	2000	2	0.515	1.231
Coquille	Chinook Fall	1981	2000	1	0.000	1.667
Coos	Chinook Fall	1981	2000	1	0.000	3.275
Siuslaw	Chinook Fall	1981	2000	1	0.000	2.950
Alsea	Chinook Fall	1981	2000	1	0.000	2.063
Salmon	Chinook Fall	1987	2000	3	0.439	1.082
Siletz	Chinook Fall	1981	2000	1	0.000	1.783
Nestucca	Chinook Fall	1981	2000	1	0.000	2.072
Tillamook	Chinook Fall	1981	2000	1	0.000	2.211
Wilson	Chinook Fall	1981	2000	1	0.000	2.289
Kilchis	Chinook Fall	1981	2000	1	0.000	3.333
Nehalem	Chinook Fall	1981	2000	1	0.000	1.768
Clatskanie	Chinook Fall	1981	2000	1	0.900	-0.112
Sandy	Chinook LFall	1981	2000	1	0.240	1.939
Willapa	Chinook Fall	1981	2000	3	0.805	1.206
Grays Harbor	Chinook Fall	1981	2000	3	0.281	1.823
Queets	Chinook Fall	1981	2000	3	0.084	1.855
Hoh	Chinook Fall	1981	2000	1	0.004	2.268
Quillayute	Chinook Fall	1981	2000	3	0.006	2.191
Grays Harbor	Chinook Fall	1981	2000	3	0.281	1.823
Queets	Chinook Fall	1981	2000	3	0.084	1.850
Hoh	Chinook Fall	1981	2000	1	0.004	2.268
Quillayute	Chinook Fall	1981	2000	3	0.006	2.191

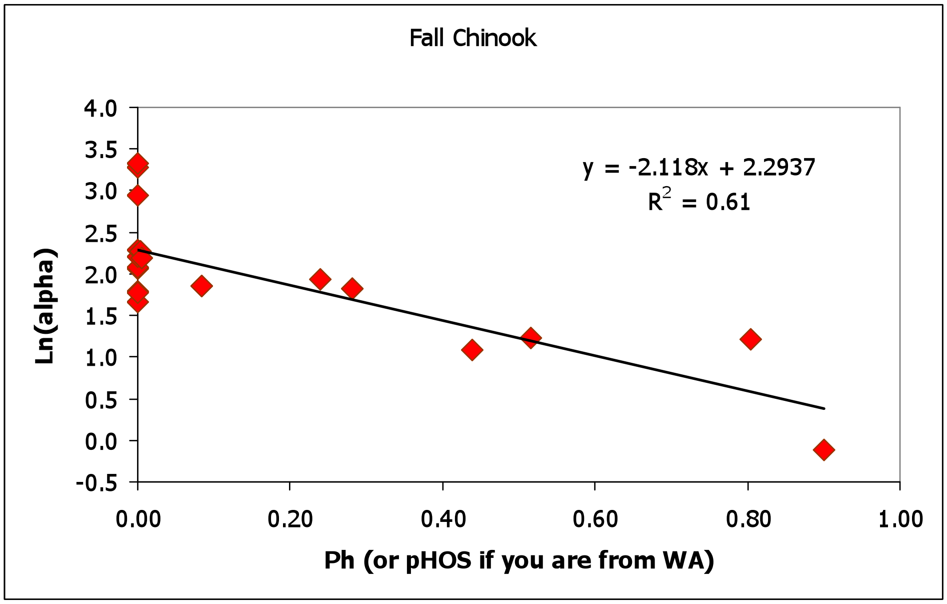

Figure 21 –Relationship between natural population productivity and proportion hatchery spawners, based on the data in Table 26.

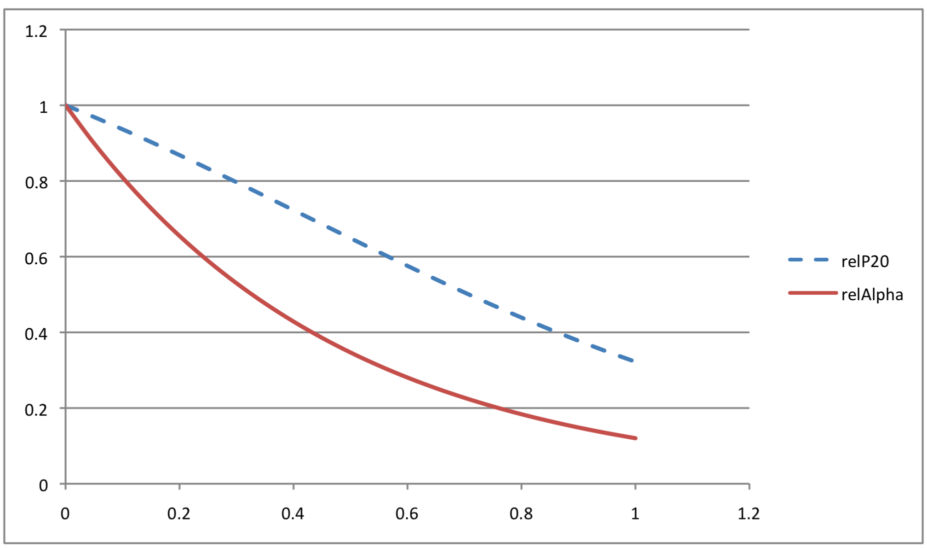

Figure 22 – The dashed relP20 curve describes the relationship used between pHOS and early life-stage survival used in some of the SLAM modeling scenarios. The solid relApha curve illustrates the same relationship when regression of alpha productivity versus pHOS illustrated in Figure 21 is converted to relative survival directly.

The modeling of the effects of pHOS on population fitness merits some discussion. The relationship between pHOS and natural population productivity described in Figure 21 is based on fitting recruit/spawner models using data from an ~20 year period for 23 fall Chinook salmon populations. The resulting relationship is similar to previous results for steelhead (Chilcote 2003) and unpublished results for coho and spring Chinook salmon

(Mark Chilcote, personal communication). Other negative correlations between pHOS and natural population have also been published for both coho and Chinook salmon (Buhle et al. 2009, Hoekstra et al. 2007).

The causal mechanisms driving these relationships, however, have not been well established and likely differ among populations and over time. In the current version of the SLAM modeling, we are assuming an essentially instantaneous relationship between pHOS and population fitness. Such an assumption may be approximately correct if the primary driver of the pHOS/fitness relationship is ecological interactions between hatchery and wild fish. On the other hand, if the primary driver of the relationship is loss of fitness due to genetic effects, it is not realistic to assume population would respond instantaneously to changes in pHOS.

In considering the modeling results, it is also important to evaluate the possibility that the pHOS/productivity relationship is in some way artifactual in either a statistical or ecological sense. Ecologically, there are plausible mechanisms that could contribute to a negative relationship between pHOS and estimated productivity that do involve changes in the survival rates of any wild fish. For example, if hatchery fish spawn only low quality portions of a watershed high numbers of hatchery fish would result in low estimates of productivity simply because they increase the denominator in a recruit/spawner ratio. Under such a scenario a reduction in pHOS would result in increase in estimated natural population productivity, but would not result in any increase in the abundance of natural origin fish. Statistically, in order to estimate population productivity, it is necessary to count the number of natural 'recruits' to use in the numerator in a recruits/spawner ratio. In practice, this will almost always involve some multiplication of total recruits by an estimate of the proportion of total recruits that are of natural origin. Estimates of productivity are therefore probably not completely independent of estimates of pHOS, which could create an artificial relationship between pHOS and natural population productivity.

The issues described above mean that the model results that assume a fitness increase due to reductions in pHOS should be used with some caution. However, on balance we believe the available data suggests that the presence of hatchery fish does lead to reductions in population productivity, and reducing pHOS is likely to produce increases in natural population productivity. The magnitude of these increases and the time frame over which they will accrue remains highly uncertain, however.

In addition to using the relationship described in Figure 22, we also considered the possibility of using the quantitative genetic model described by Ford (2002) to model the effects of alternative hatchery strategies on population fitness. This was the model used by the HSRG in their assessment of hatchery programs. For this round of modeling, however, we elected not to include the Ford/HSRG model of hatchery effects, for two primary reasons. First, the model is not currently incorporated into SLAM. Second, in practice, for most of the tule populations the HSRG approaches assumed that past hatchery practices resulting in a 50% decline in fitness from historical conditions and that hatchery reform would therefore result in a maximum productivity increase of 50%

(actual increases could be lower). In practice, this is quite similar to the degree of survival decrease modeling using the relationship in Figure 22, so the two approaches as implemented will have similar effects.

Cumulative effects of multiple hatchery releases

In addition to modeling the effects of the presence of hatchery origin spawners, we also evaluated whether there was any support for modeling natural fish survival in the mixing zone, estuary or ocean as a function of hatchery releases. Based on an analysis of recruit/spawner relationship in the Coweeman, EF Lewis and Grays populations (the three population considered to have the most reliable data -- (Ford et al. 2007)) no evidence of an effect of hatchery releases on natural population productivity was detected (see Attachment XX - A preliminary examination of run-size forecasting for Lower Columbia River Tule Chinook salmon). We therefore concluded that although such effects may in fact exist, we did not have sufficient information to model them based on the available data.

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29 October 2012

Attachment 5 -- A preliminary examination of run-size forecasting for Lower Columbia River Tule Chinook salmon, by Mark Scheuerell

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Introduction

I was asked to investigate the possibility of developing a short-term forecast of adult returns for populations of Tule Chinook salmon from the Lower Columbia River (LCR), that were composed primarily of wild fish (i.e. East Fork Lewis, Grays, and Coweeman Rivers). In particular, there was interest in whether the incorporation of ocean-climate indicators would improve forecasts.

As a first pass, I applied a new technique for forecasting adult returns that I have been developing based on time-varying proportions of jacks. For these analyses, I used data for the aggregate returns of lower river hatchery (LRH) fish provided by Peter Dygert. These data covered complete returns for brood years 1962-2002. I used brood years 1962-1991 (n = 30 years) as a model "fitting" portion of the dataset. I reserved brood years 1992-2002 for comparison with model forecasts, although the forecasts can be compared over any set of desired years. I also made a forecast of total returns for the 2003 brood year even though it is not yet complete.

The first approach requires good estimates of age-composition because adult returns must be assigned the correct brood year. In the case of the wild populations of LCR Tules, however, regional biologists expressed several concerns over the accuracy of age-composition estimates for wild populations. Thus, I subsequently explored the feasibility of using a modified Ricker model to estimate recruits from spawners, with the assumption being that errors in aging would be "smoothed" over at longer time scales, effectively integrating the errors across brood years. For these analyses, I used data provided by the LCR TRT (Paul MacElhany & Norma Jean Sands, NOAA Fisheries Service). These data covered complete returns for brood years 1977-

2002. I used brood years 1977-1996 (n = 20 years) as a model "fitting" portion of the dataset. I reserved brood years 1997-2002 for comparison with model forecasts

Models

Part I – time-varying jack proportions

The first approach I used derives from the observation that the proportion of jacks from a given brood year is indicative of the total return of all adults from that brood year. In mathematical terms, I define

(1) $$N_{TOTAL,t} = \sum_{i=1}^{a} N_{i,t} \ ,$$

such that $N_{TOTAL,t}$ is the total number of adults returning from brood year t, and $N_{i,t}$ is the number of adults from brood year t that returned after i years at sea (i.e. 1 = jacks; a = maximum ocean age). Next, I define the proportion of jacks (p_t) as simply the number of jacks divided by the sum of adult returns

(2) $$p_t = \frac{N_{1,t}}{N_{TOTAL,t}} \ .$$

Next, some simple algebra leads to

(3) $$N_{TOTAL,t} = \frac{N_{1,t}}{p_t} \ .$$

Thus, if we knew *a priori* what the proportion of jacks was for a given brood year, we could count the number of jacks and calculate exactly the total expected return. Unfortunately, we do not know p until all fish have returned and we calculate it post-hoc via Eqn. (2). If, however, we had a reasonable predictor of p, we could use that to make a forecast of the total adult return from brood year t (after counting returning jacks in year t+1).

Here I model the observed number of jacks ($N_{1,t}$) in a given brood year as a stochastic binomial process based on the forecasted proportion of jacks in that brood year (p_t) and the forecasted total number of returning adults from the brood year ($N_{\mathrm{TOTAL},t}$), such that

(4) $$N_{1,t} \sim Bin(p_t, N_{TOTAL,t}).$$

Because we wish to constrain p on the interval [0,1], I used the logit transform (π = logit[p]). The logit-transformed proportion of jacks in year t is then modeled as a stationary time series using either a first-order auto-regressive (Eqn. 5a), moving-average (Eqn. 5b), or combined (Eqn. 5c) process.

(5a) $$\pi_t = c + \phi p_{t-1} + \varepsilon_t .$$

(5b) $$\pi_t = c + \theta \varepsilon_{t-1} + \varepsilon_t .$$

(5c) $$\pi_t = c + \phi p_{t-1} + \theta \varepsilon_{t-1} + \varepsilon_t .$$

For the forecasting part of the model, however, we do not know the actual total number of adult returns for year t+1 ($N_{TOTAL,t+1}$), but it is the primary number of interest. Therefore, I treat it as an unknown parameter

(6) $$N_{1,t+1} \sim Bin(p_t, \hat{N}_{TOTAL,t+1}).$$

I conducted all statistical analyses with WinBUGS to obtain Bayesian posterior estimates of all parameters and credible limits around the run forecasts. I assumed non-informative, uniform priors (i.e. ~Unif[-100,100]) for all parameters except $\hat{N}_{TOTAL,t+1}$, which I assumed was uniform-discrete (i.e. ~UnifD[10^3-10^6,10^2]). Subsequent model selection based on DIC favored a first-order, auto-regressive, moving-average model (ARMA[1,1]) analogous to Eqn 5c.

This approach generates forecasts of adult returns by *brood* year, but total adult returns for a *calendar* year are typically more useful. Thus, in order to obtain forecasts for a calendar year, I first obtained forecasts for subsequent brood years, and then used recent age-composition estimates to essentially distribute those returns into the appropriate calendar year.

Part II – modified Ricker model

The second approach is a standard Ricker model modified to include additional effects of the environment on population productivity. In this case, the number of recruits (R_t) is a non-linear function of the number of spawners (S_t), k environmental covariates (X_k), and stochastic error (ε_t), such that

(7) $$R_t = S_t \exp(a + bS_t + c_1 X_1 + \cdots + c_k X_k + \varepsilon_t)$$, and

(8) $$\varepsilon_t \sim N(m, s^2)$$.

Of interest here is whether this approach offers any promise of accurate forecasts in general, and specifically, whether the inclusion of environmental covariates improves forecasting performance.

I applied Eqn. (7) to each of the 3 populations of wild fish separately, as well as to an aggregate measure of R and S for all populations combined. I also tried a multivariate version of Eqn. (7) in which the response of all 3 populations was modeled simultaneously in hopes of capturing 1-2 important trends common to all 3 populations while also simplifying assumptions about the variance-covariance matrix. I considered 13 different covariates (Table 1) and used model selection methods based on AICc to determine the relative support for each model based on the data.

Table 1. Description and sources for the covariates considered in the forecasting models. Unless otherwise noted, the year of the index corresponds to the year the juvenile fish enter the ocean.

Abbreviation	Description	Source
LRH.s	Smolt-to-adult survival for Lower River Hatchery fish	1
col.flow	Columbia River flow at the Dalles Dam	2
cui.48.mar	Mean monthly Coastal Upwelling Index at 48°N for March	3
cui.48.apr	Mean monthly Coastal Upwelling Index at 48°N for April	3
cui.48.may	Mean monthly Coastal Upwelling Index at 48°N for May	3
cui.48.jun	Mean monthly Coastal Upwelling Index at 48°N for June	3
PDO.fw	Mean Pacific Decadal Oscillation for fall and winter (Sep-Feb)	4
PDO.ss	Mean Pacific Decadal Oscillation for spring and summer (Mar-Aug)	4
ENSO.3.4	Annual El Nino-Southern Oscillation anomaly (5°N-5°S)(170-120°W):	5
NPGO.fw	Mean North Pacific Gyre Oscillation for fall and winter (Sep-Feb)	6
NPGO.ss	Mean North Pacific Gyre Oscillation for spring and summer (Mar-Aug)	6
fall.rel	Total releases of hatchery fall Chinook in the lower Columbia River	7
tot.rel	Total releases of all hatchery salmon in the lower Columbia River	7

Sources:
(1) Mike Ford, NOAA Fisheries
(2) USGS National Water Information System
(3) NOAA Pacific Fisheries Environmental Laboratory
(4) Nate Mantua, UW
(5) NOAA Climate Prediction Center
(6) Emanuele Di Lorenzo, Georgia Institute of Technology
(7) Fish Passage Center

Results

Part I

The fitted series based on brood years 1962-1991 matched the observed values quite well (r = 0.89, Figure 1), with most of the observed values falling within the 95% confidence limits. The forecasted series also provided reasonable estimates of the observed total return (r = 0.77); the lack of fit resulting largely from the particularly low forecast for 1998. Again, nearly all of the observed values fell within the prediction intervals of the forecasted series.

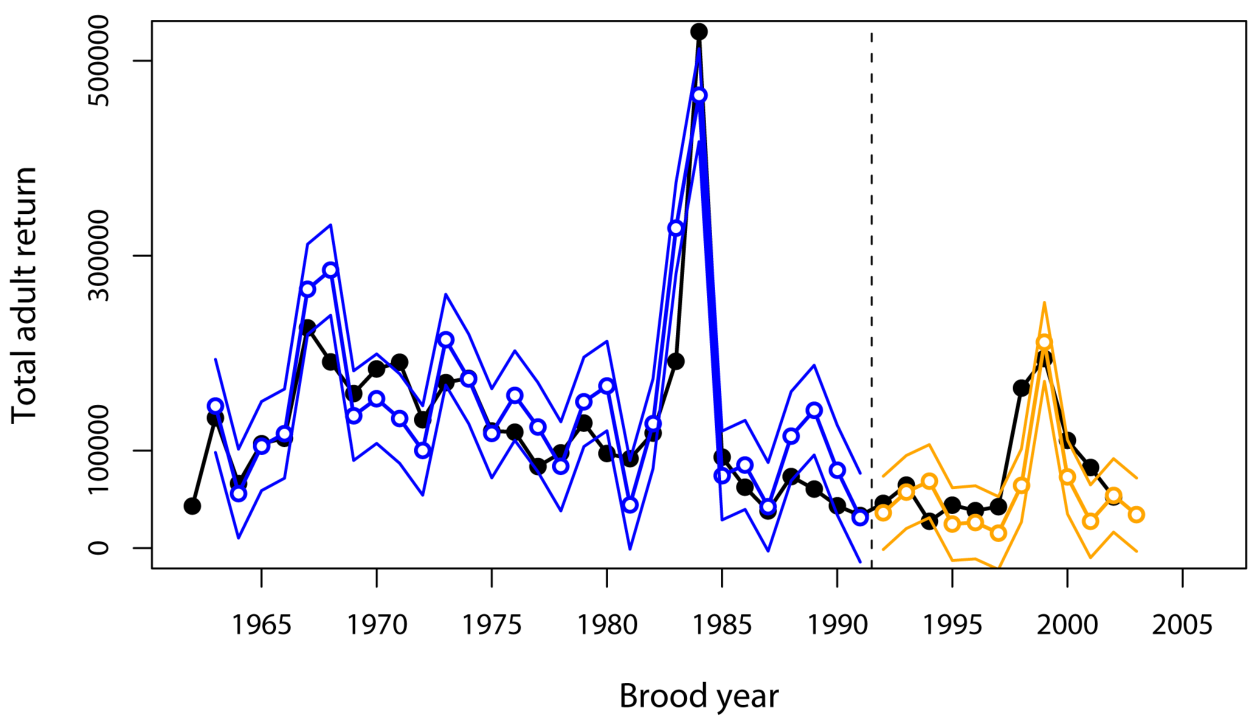

Figure 1. Time series of observed total adult returns for Columbia River LRH tule Chinook salmon from brood years 1962-2002 (solid black points). Model fitted values (blue) and forecasts (orange) are also shown. The thin lines represent the 95% confidence interval for the fitted series (blue) and the 95% prediction interval for the forecast series (orange).

Part II

With the exception of the Coweeman, model fits to the observed data were improved greatly by incorporating additional covariates. These generally included local upwelling effects and large scale patterns in ocean temperature (Table 2).

In the case of the modified Ricker models, the fitted series based on brood years 1977-1996 matched the observed values quite well (r = 0.69 – 0.82), with most of the observed values falling within the 95% confidence limits. In all cases, however, the forecasted series were marginally correlated with the observed returns (r = 0.35 – 0.49, Figure 2).

The general lack of fit for these models becomes even more problematic when productivities are extrapolated to actual adult returns because (i) the point estimates are not very good (i.e. low accuracy) and (ii) the variance around the estimates is high (i.e. low precision). For example, when considering the aggregate return of wild adults by brood year, the prediction intervals span more than an order of magnitude (Table 3).

Table 2. List of covariates included in the most parsimonious model (Eqn. 7) for each of the three wild populations. By default, each model contains an intercept and density-dependent effect of spawners. Also shown is the difference in AIC (Δ) between the indicated "best" model and a model that contains only an intercept and density-dependent effect of spawners (i.e., a standard Ricker model). Models with Δ > 7 are considered to be very well supported by the data.

Population	Predictor variables	Δ
Coweeman	*none*	0.0
EF Lewis	cui.48.jun + NPGO.ss	7.9
Grays	cui.48.apr + cui.48.may + PDO.fw + ENSO.3.4	9.1
Aggregate	cui.48.jun + NPGO.ss	8.5

Table 3. Forecasted adult returns by brood year for aggregate returns of wild tule Chinook salmon to the lower Columbia River.

Brood year	Mean	95% P.I.
1997	8506	(2166, 33400)
1998	4042	(918, 17787)
1999	6149	(1352, 27958)
2000	7050	(1545, 32162)
2001	5172	(1324, 20198)
2002	6871	(1810, 26075)

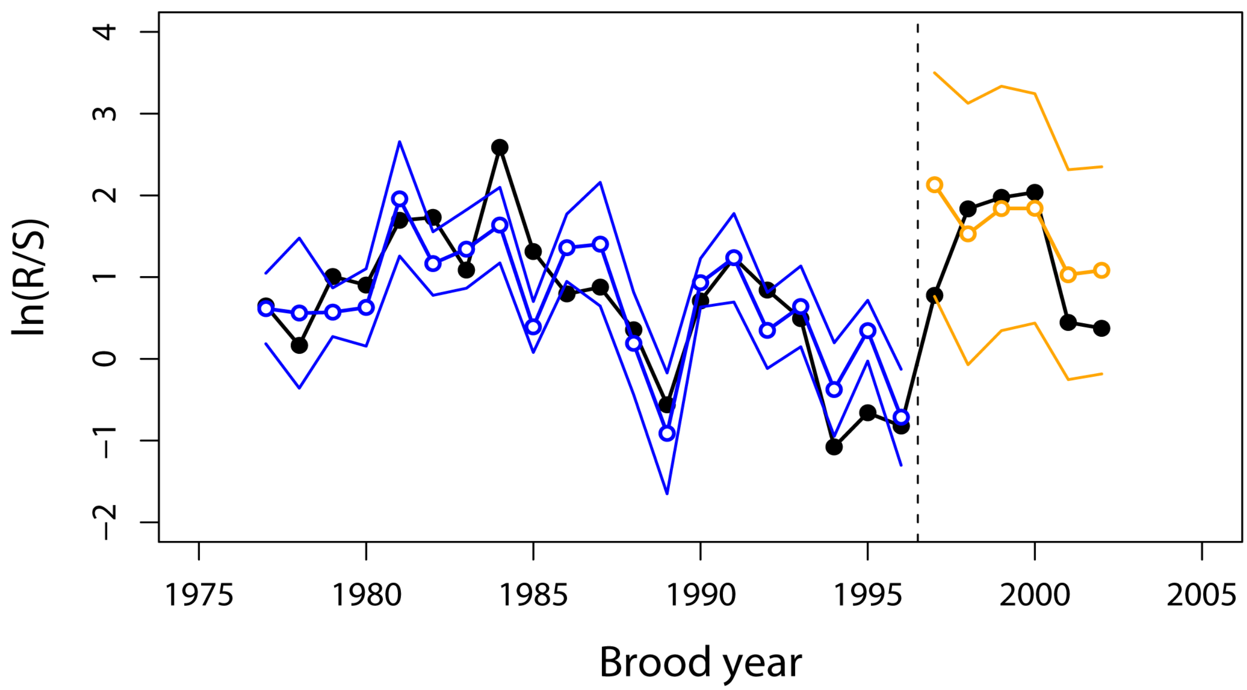

Figure 2. Example time series of observed productivity (ln[R/S]) for aggregate wild Columbia River tule Chinook salmon from brood years 1977-2002 (solid black points). Model fitted values (blue) and forecasts (orange) are also shown. The thin lines represent the 95% confidence interval for the fitted series (blue) and the 95% prediction interval for the forecast series (orange).

Summary

My preliminary investigation suggest that, absent better age-composition data for the wild populations, it will be difficult to obtain forecasts that are meaningful to managers attempting to set harvest limits based on adult run size. For other regions/species where “good” estimates of age-composition exist (e.g., Snake River spring/summer Chinook), the forecasting methods outlined in Part I appear to provide considerable promise in forecasting adult returns. Thus, in particular, I would recommend that more resources be directed at obtaining some basic, but necessary, information on the population demographics of these stocks.