APPENDIX E. FISHERY RISK ASSESSMENT

This chapter was drafted in 2010.

APPENDIX E. FISHERY RISK ASSESSMENT

Tables

Figures

E.1. Introduction

This report evaluates the effects of different fishing rates for fixed and abundance-based fishing strategies on coho conservation risks. Conservation risks are based the projected incidence of low spawning escapements of key populations under various fishery alternatives. Low escapements can pose significant risk of functional extinction or demographic and genetic effects which threaten to increase future extinction risks. Thus, conservation-based fishing levels protect of weak-stock spawning escapements rather than maximize or optimize sustained yields of the stronger populations.

E.2. Methods

E.2.1. Analyses

Low run size probabilities at different fishing levels were estimated using a Population Viability Analysis (PVA). PVA is a quantitative model-based approach for predicting the likely future status of a population or collection of populations in terms of extinction risk (Burgman et al. 1993, Morris and Doak 2002, Beissinger and McCullough 2002). PVA has been widely applied in conservation biology and is increasingly being adapted for application to salmon status assessments and recovery plans (Emlen 1995, Chilcote 1998a, Chilcote 1998b, Nickelson and Lawson 1998). This approach was previously used to evaluate conservation fishery alternatives for Willamette Spring Chinook (ODFW 2001) and Klamath Fall Chinook (PFMC 2007).

The analysis was conducted using a stochastic, age-structured, stock-recruit population model. Stochastic simulations will involve multiple iterations (e.g. 1,000) of a 100 year time interval at an annual time step. Model inputs include current population size, stock-recruitment parameters, variance and autocorrelation in recruitment, and an adult maturation schedule. The model estimates frequency distributions of annual harvest and spawner numbers (Figure E13-1) based on ocean adult recruits exposed to input fishing levels.

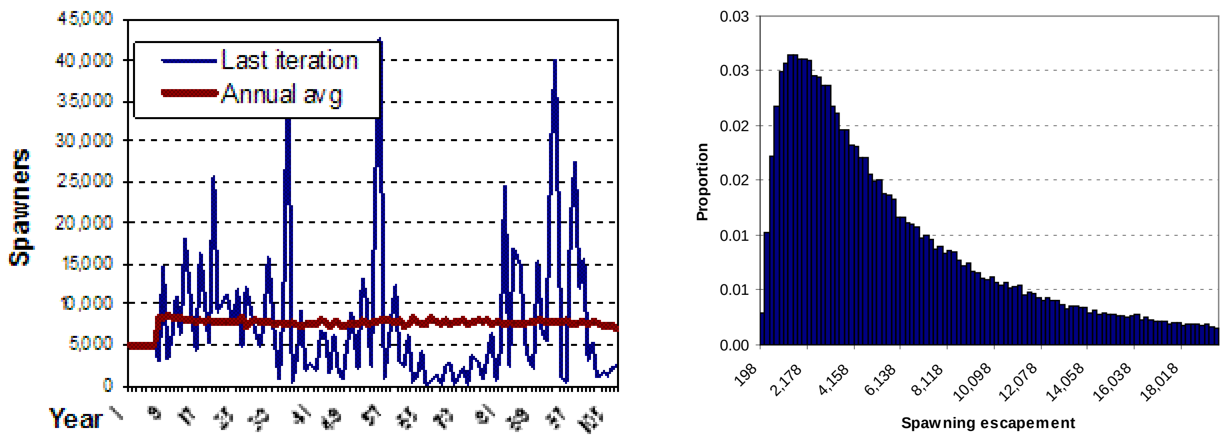

Figure E13-1. Example stochastic simulation results showing annual patterns and frequency distribution of spawning escapements.

Risks were expressed as probabilities of future spawning escapement less than benchmark thresholds. Thresholds were defined for "critical risk" and "quasi-extinction" as per standards consistent with direction by the WLC TRT(McElhany et al. 2006). The quasi-extinction threshold (QET) is defined as a population size where functional extinction might occur. The model assumes a QET of 50 expressed as an average annual population size over a generation at any point in a modeled trajectory. The critical risk threshold (CRT) is defined as a population size below which depensatory demographic and genetic processes increase the threat of falling to lower levels where the risk of extinction becomes significant. It is a population level below which recovery is not assured. The model assumed CRT's of 100, 200, and 300 (moving three-year generational average) for small, medium, and large subbasin populations as per McElhany et al. (2006). To reflect precautionary concerns for risks associated with low spawning escapements, the model also assumed depensatory reductions in productivity at spawning escapements of less than the CRT and recruitment failure in years when spawner numbers fell below 50.

E.2.2. Fishery Alternatives

This analysis is particularly concerned with population-level effects of an abundance-based fishery management strategy developed by Oregon for the management of coho populations within the Oregon Production Index Area. In 2001, the Oregon Fish and Wildlife Commission adopted a state Recovery Plan (ODFW 2001, OAR 635-100-0190 though 0194 and 0135) that included a matrix to determine maximum annual ocean and in-river exploitation rates for wild coho based on marine survival and parent-spawner status. The matrix was developed from a risk assessment on Clackamas River wild coho, but has been applied to all Oregon wild coho populations. This matrix has been used for management of ocean and Columbia River fisheries since 2002. The abundance-based fishing strategy identified by the matrix provides additional conservation when abundance is low and allows for appropriate harvest opportunity to target hatchery fish when abundance is high. An abundance-based approach is currently being used for several Columbia River salmon stocks and under discussion for a number of others (*U.S. v Oregon* Interim Agreement).

Table E13-1. The Oregon Matrix {Source: Appendix 1. Oregon Department of Fish and Wildlife's Endangered Species Management Plan for Lower Columbia Coho Salmon.}

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

The fishery matrix approach determines fishing rates based on seeding levels of the parent brood and relative marine survival rates encountered by offspring of that parent brood. Fishing rates are reduced to *de minimis* levels at low population sizes or poor marine survival rates in order to maximize escapement and avoid compounding critical low numbers from the current cohort. Fishing rates are increased at high seeding levels and high marine survival years when fish are available in excess of habitat seeding capacities. Seeding levels are based on annual escapement survey data. Marine survival is indexed based on proportions of hatchery fish returning as jacks (early returning fish at age 2). Figure E13-2 illustrates recent marine survival patterns for Columbia River and Oregon Production Index hatchery coho.

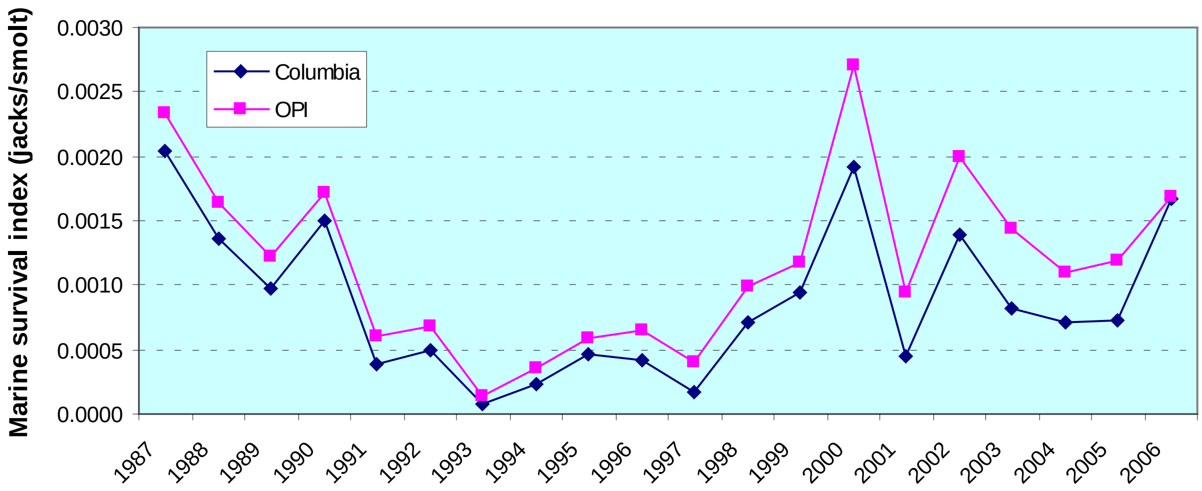

Figure E13-2. Recent 20-year patterns in marine survival index based on hatchery jack returns.

This analysis estimated effects of fishery alternatives including: 1) fixed fishing rates (0%, 5%, 15%, 20%, 30%, 40%, 50%), 2) the Oregon Matrix, 3) Oregon Matrix times 1.5, and 4) a modified matrix (approximately Oregon Matrix times 0.85). The modified matrix was selected to produce equivalent risks to a fixed 15% harvest rate. Fishing rate refers to combined ocean and in-river fishery impacts (harvest and incidental mortality). Fisheries were modeled with variance reflecting differences between target and realized fishing rates due to forecast and catchability uncertainties in any given year. In addition to estimating effects of fishing rates on harvest and spawning escapement, the model also estimated frequencies of occurrence of target and actual fishing rates, and how often each cell of the Oregon matrix was applied.

Table E13-2. Harvest matrix and variations addressed by analyses.

Matrix

	Marine surv Index (jacks/smolt)			
Seeding	Critical	low	med	high
>0.75	0.117	0.214	0.405	0.574
0.5-0.75	0.117	0.214	0.292	0.498
0.2-0.5	0.117	0.214	0.227	0.344
0.1-0.2	0.117	0.163	0.181	0.199
<0.1	0.117	0.117	0.117	0.117

Matrix X 1.5

	Marine surv Index (jacks/smolt)			
Seeding	Critical	low	med	high
>0.75	0.176	0.321	0.608	0.574
0.5-0.75	0.176	0.321	0.438	0.498
0.2-0.5	0.176	0.321	0.341	0.344
0.1-0.2	0.176	0.245	0.272	0.199
<0.1	0.176	0.176	0.176	0.117

Modified Matrix

	Marine surv Index (jacks/smolt)			
Seeding	Critical	low	med	high
>0.75	0.10	0.18	0.35	0.45
0.5-0.75	0.10	0.18	0.25	0.40
0.2-0.5	0.10	0.18	0.20	0.30
0.1-0.2	0.10	0.15	0.15	0.17
<0.1	0.10	0.10	0.10	0.10

E.2.3. Coho Population Parameters

Model analyses considered a range of abundances and productivities representative of the full spectrum of coho populations. Sensitivity analyses of fishery effects were conducted for hypothetical values including a small, unproductive population, and a large productive population. Population values used in sensitivity analyses were assumed to most significant lower Columbia River coho populations. Values do not include marginal populations in areas blocked by hydropower development (e.g. upper Cowlitz and Lewis) or subject to severe habitat degradation (e.g. Salmon Creek). Population-specific analyses were also conducted for a subset of populations representing a range of abundance and productivity values.

Model parameters were based on Lower Columbia coho population data (Figure E13-3). Representative values were based on stock-recruitment population parameters where available from adult cohort run reconstructions of the Sandy and Clackamas (M. Chilcote, unpublished), juvenile cohort run reconstructions of the Tilton, upper Cowlitz, and Cedar Creek (D. Rawding, unpublished), inferences from habitat conditions in Washington using EDT for the Grays, Mill, Abernathy, Germany, Elochoman, Skamokawa, Coweeman, Cowlitz, Toutle, Kalama, lower gorge, and Washougal areas (D. Rawding, unpublished), and inferences from habitat conditions in Oregon using empirical habitat and fish density information for Youngs Bay, Big Creek, Clatskanie, and Scappoose areas (Anluaf et al. 2006).

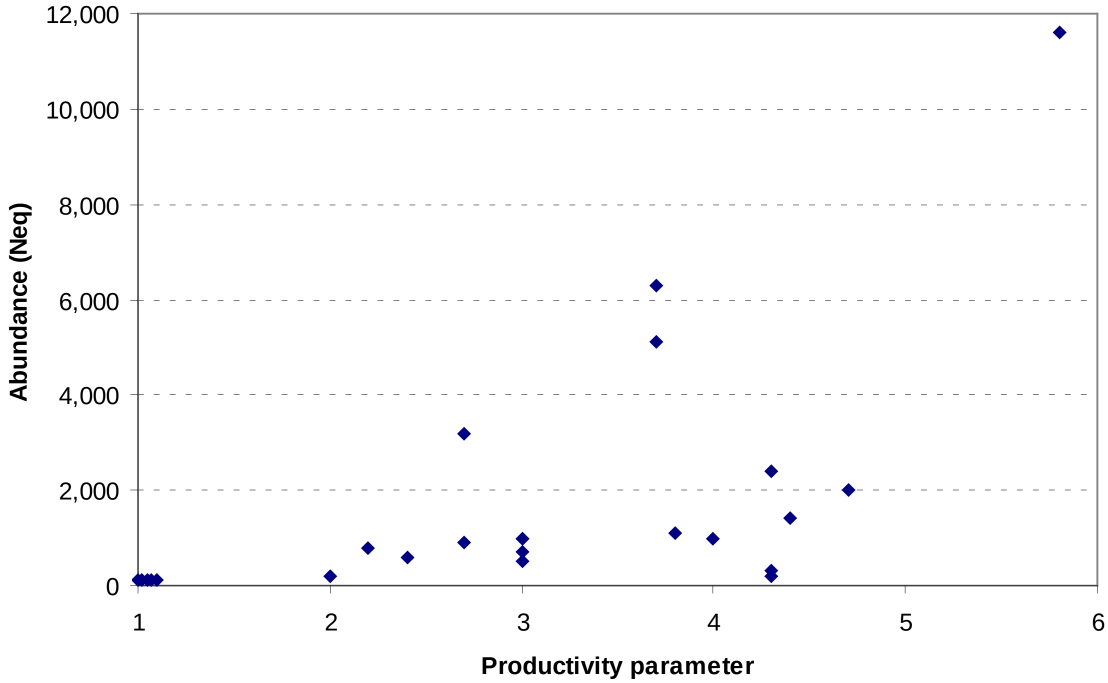

Figure E13-3. Distribution of abundance and productivity parameters identified for 24 lower Columbia River coho populations based on run reconstruction or habitat inferences (Beverton Holt or Hockey stick parameters based on pre-harvest recruitment). ODFW & WDFW unpublished data.

E.2.4. Model Documentation

The model estimated annual spawner numbers over a 100-year period for a prescribed number of iterations (Figure E13-4). The model is initialized with recent population size and subsequent numbers are calculated using a stochastic stock-recruitment function described by input parameters. Recruits are estimated as an ocean adult cohort. Annual numbers of fish from this cohort are apportioned among years based on an input age schedule. The model applied fishing rates in each year to calculate harvest and fishery effects on population dynamics. Risks were expressed based on probabilities of future spawning escapement less than prescribed threshold values. The model is built in Microsoft Excel using Visual Basic. A simple interface page facilitates model use and review of results.

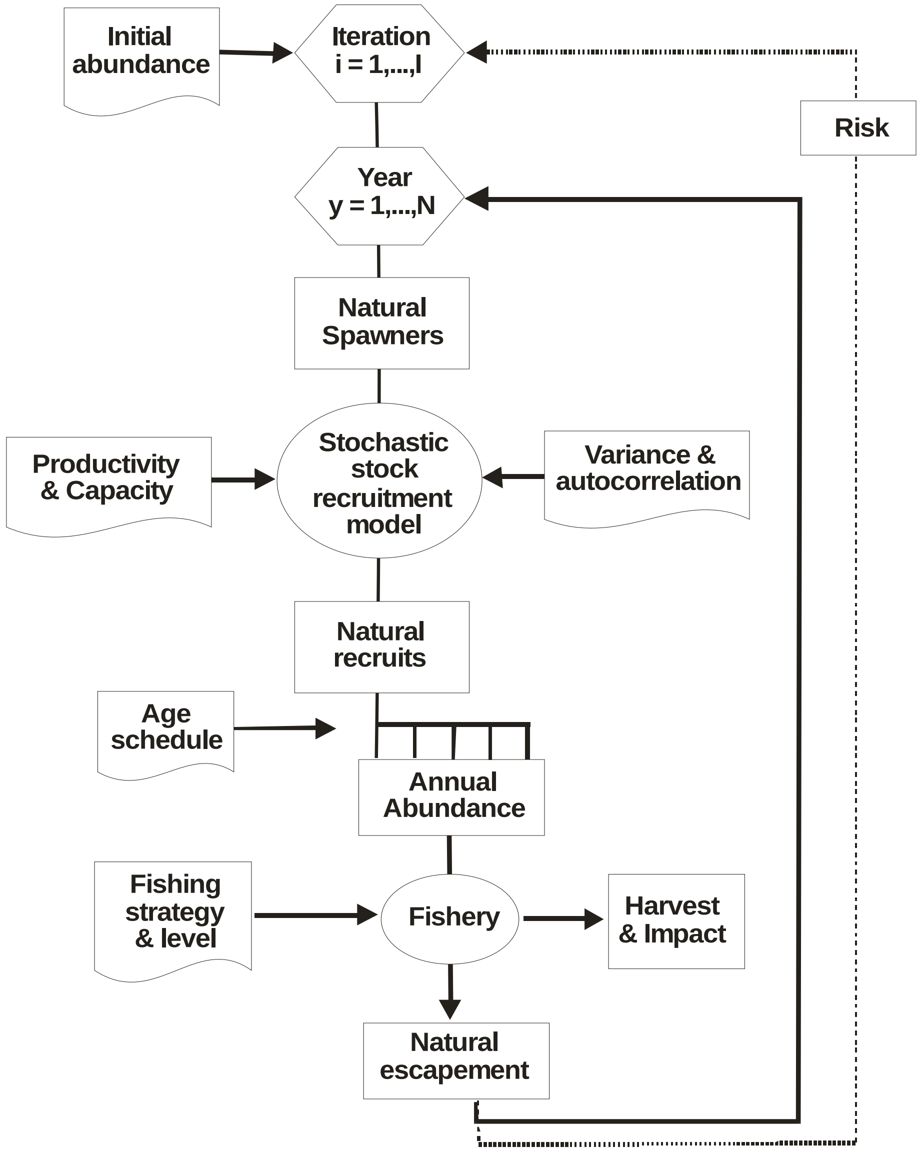

Figure E13-4. Model algorithm.

Table E13-3. Example model input variables and parameters used for generic sensitivity analyses of fishery effects on the risks of low spawner numbers in small, unproductive and large productive coho populations.

Variable or parameter	Notation	Value
Initial abundance	$S_{-5},\ldots,S_0$	All initial years equal to equilibrium abundance
Stock-recruitment		
Function	Option 1	Hockey stick
Productivity	p	3.0, 5.0
Equilibrium abundance	N_{eq}	500, 10,000
Maximum spawner constraint	lim S_y	(10) (N_{eq})
Maximum recruit constraint	lim R_y	(10) (N_{eq})
Recruitment failure threshold	RFT	50
Depensation threshold	RDT	100, 200, 300 (depending on CRT)
Recruitment stochasticity		
Variance	σ^2	1.0
Autocorrelation	Ø	0.3
Age schedule	m_2, m_3	0.05, 0.95
Quasi extinction threshold	QET	50
Critical risk threshold	CRT	100, 200, 300 (depending on basin size)
Fishing strategy	--	Fixed or matrix
Fishing rate	fN_y	fixed @ 0%, 5%, 15%, 20%, 30%, 40%, 50% or matrix
Fishing rate variance	CV	0.5

A full list of model inputs may be found in Table E13-3. Descriptions of derivation and application of model variables and inputs follow.

Conservation risks

This analysis evaluates population viability based quasi-extinction and critical risk thresholds. A quasi-extinction threshold (QET) is defined as a population size where functional extinction occurs due to the effects of small population processes (McElhany et al. 2006). The model assumes that extinction occurs if the average annual population size over a generation (g) falls below this threshold at any point in a modeled trajectory. Quasi-extinction risk is thus estimated as the proportion of all iterations where the moving generational average spawner number falls below the QET at any point in each 100 year simulation.

The analysis also considers risks of falling below a conservation risk threshold (CRT) that is greater than the assumed quasi-extinction level. The CRT level might be considered analogous to a point where a population is threatened with falling to lower levels where the risk of extinction becomes significant. For the purposes of this analysis, CRT is defined as a level where diversity is eroded and population resilience may be lost. CRT may be considered to be the risk of being threatened with becoming endangered with quasi-extinction. Benchmark values of 60% 25%, 5%, and 1% risk levels have been identified by the Willamette/Lower Columbia Technical Recovery Team (McElhany et al. 2006) as corresponding to high, moderate, low, and very low extinction risks.

Population-specific estimates of extinction risks and improvement scalars were based on QET values of 50 for all populations and CRT values ranging from 100 to 300 depending on size of the basin inhabited by a population (McElhany et al. 2006). While there is an extensive amount of literature on the relationships among extinction risk, persistence time, population abundance, and level of variation in demographic parameters, there are no simple generic abundance levels that can be identified as viable (McElhany et al. 2000). Because empirical data on actual extinction and conservation risk levels is lacking, QET and CRT values were based on theoretical numbers identified in the literature based on genetic risks. Effective population sizes between 50 to 500 have been identified as levels which theoretically minimize risks of inbreeding depression and losses of genetic diversity, respectively (Franklin 1980, Soule 1980, Thompson 1991, Allendorf et al. 1997). Effective population size assumes balanced sex ratios and random mating. Benchmark values in this analysis assume approximately equivalent effects of differences between effective and census population sizes, and the multi-year generation structure of salmon (Waples 1990, 2004; Lindley et al. In press). Relatively low QET values are supported by recent observations of salmon rebounds from very low numbers (e.g. Oregon lower Columbia River coho: ODFW 2005 and Washington lower Columbia winter steelhead: D. Rawding, WDFW, unpublished) and apparently-sustainable small population sizes of salmon in other regions (e.g. King Salmon River Chinook population in Alaska: McPherson et al. 2003).

Stock-Recruitment Function

The model stock recruitment function was based on either hockey stick or Beverton-Holt functional forms (Hilborn and Walters 1992) depending on the data available for a specific population (Figure E13-5). Note the hockey stick form is similar to a chevron shape.

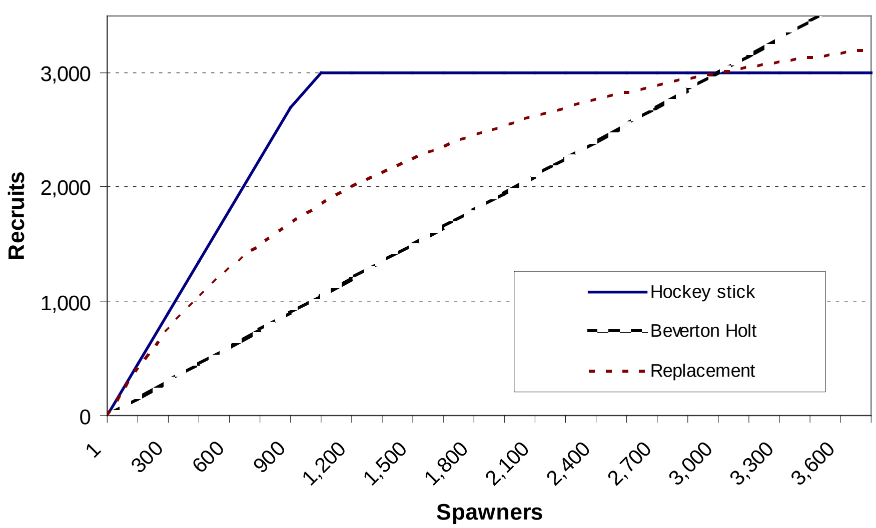

Figure E13-5. Example stock-recruitment curves based on a productivity parameter of 3 recruits per spawner (maximum observed at low numbers) and an equilibrium population size of 10,000.

The Hockey Stick form of the relationship is:

$$R_y = (S_y)(p)(e^{\varepsilon}) \text{ when } (S_y)(p) < N_{eq}$$
$$R_y = (N_{eq})(e^{\varepsilon}) \text{ when } (S_y)(p) \geq N_{eq}$$

where

R_y = recruits,
S_y = spawners,
p = parameter for productivity (average recruits per spawner at spawner numbers under full seeding levels),
N_{eq} = parameter for equilibrium abundance,
e = exponent, and
ε = normally-distributed error term ~ $N(0, \sigma^2)$

The Beverton-Holt form of the relationship is:

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

where

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

Population-specific assessments of risk and improvement scalars were based on the best available data for each population. Parameters based on cohort run reconstructions were used in a hockey stick formulation and the mean RS approach identified by McElhany et al. (2006). Population parameters were inferred from habitat conditions in many cases where population-specific stock recruitment data were unavailable. Habitat inferences were generally based on the Ecosystem Diagnosis and Treatment Model (LCFRB 2004). EDT results are in the form of Beverton-Holt function parameters. Note that MeanRS and Beverton-Holt equilibrium and productivity parameters are related but not directly comparable.

Analyses were based on initial population sizes equal to the average equilibrium abundance as specified with the corresponding stock recruitment parameter (N_{eq}). Equilibrium rather than recent abundance levels were used to provide estimates of representative long term risks and avoid confounding effects of large annual fluctuations in spawner escapements in recent years. For instance, viability estimates based on record low escapements during poor El Niño conditions of the late 1990s would have resulted in different results than would have been calculated from recent high returns associated with a post El Niño transition to more favorable ocean conditions. Sensitivity analyses indicated that long term risks were not strongly related to effects of initial abundance.

Stock-Recruitment Variance

The stochastic simulation model incorporated variability about the stock-recruitment function to describe annual variation in fish numbers and productivity due to the effects of variable freshwater and marine survival patterns (as well as measurement error in stock assessments). This variance is modeled as a lognormal distribution (e^{ε}) where ε is normally distributed with a mean of 0 and a variance of σ_z^2 (Peterman 1981).

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

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

where

- Z_t = autocorrelation residual,
- $\emptyset$ = lag autoregression coefficient,
- ε_t = autocorrelation error, and
- σ_e^2 = autocorrelation error variance.

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

$$\sigma_e^2 = \sigma_z^2\,(1 - \emptyset^2)$$

Model simulations using the autocorrelated residual options were seeded in the first year with a randomly generated value from N(0, σ_z^2). Variance and autocorrelation in population-specific risk analyses were based on species values reported by McElhany et al. (2006). All populations were simulated with the average variance because population-specific estimates were assumed to be more reflective of sampling effects than true differences among populations.

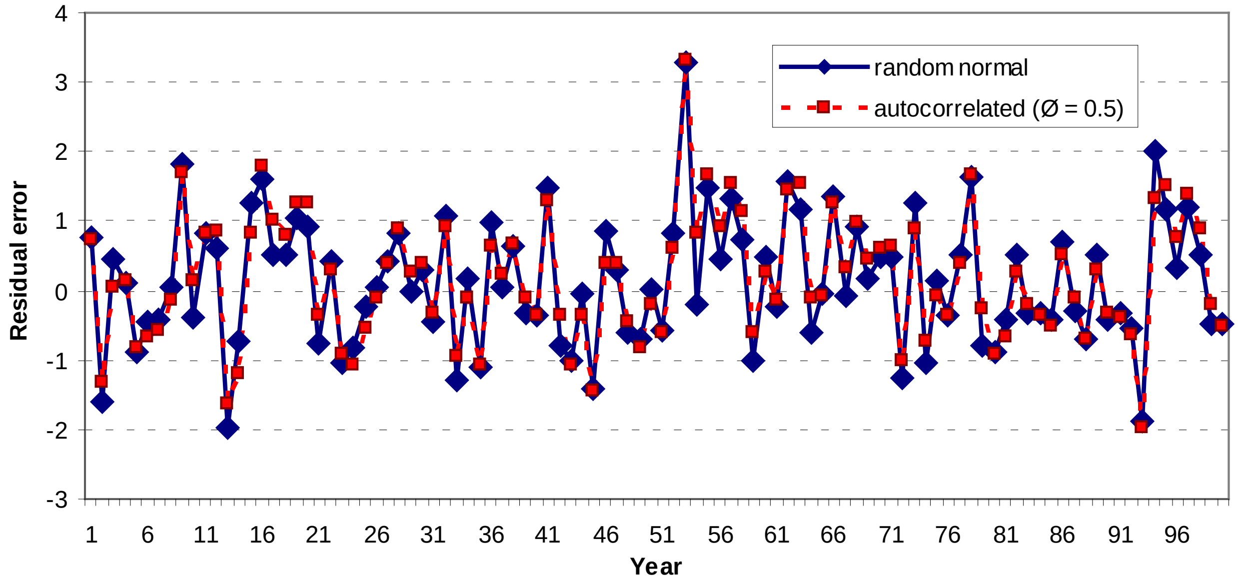

Figure E13-6. Examples of autocorrelation effect on randomly generated error patterns (σ_z^2 = 1, lag = 0.3).

Depensation & Recruitment Failure Thresholds

The model limited recruitment at low spawner numbers consistent with assumed depensatory effects of stock substructure and small population processes. Depensation was achieved by 1) progressively reducing productivity at spawner numbers below a specified recruitment depensation threshold (RDT) and 2) setting recruitment to zero at spawner numbers below a specified recruitment failure threshold (RFT):

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

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

where

R' = Number of adult recruits after depensation applied,
R = Number of adult recruits estimated from stock-recruitment function,
S = spawners, and
γ = Depensation threshold (spawner number).

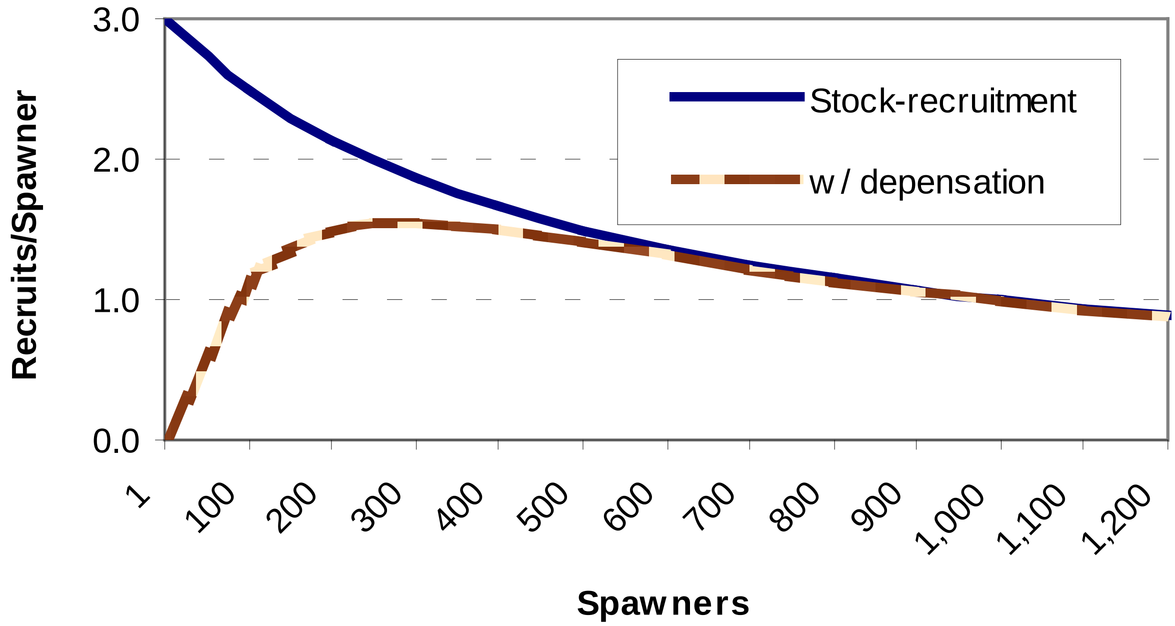

Figure E13-7. Example of depensation function effect on recruits per spawner at low spawner numbers based on a Beverton-Holt function (a = 3.0, Neq =1,000, γ =500).

Annual Abundance

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

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

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

where

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

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

Age schedules were based on average values for Clackamas and Sandy rivers (0.05 age 2, 0.95 age 3).

E.2.5. Fisheries & Harvest

Fishery impact is defined in the model in terms of the adult equivalent number of fish that die as a result of direct and indirect fishery effects:

$$IN_y = N_{.y} fN_y$$

where

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

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

For the purposes of this analysis, ocean and freshwater fishery impacts were modeled as one combined rate.

Fishery Variance

Fishery variance was included to account for the effects of differences between in-season and actual impact rates due to forecast errors and fishery factors. Fishery variance was input as a coefficient of variation and modeled such that absolute errors were proportionately greater for greater target rates. This variance was estimated:

$$fN_y = fN'_y + \varepsilon \qquad \varepsilon \sim N(0, \sigma_e^2)$$
$$\sigma_e = \text{stdev}(fN'_y / fN_y)$$

where

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

$$fN'_y / fN_y \sim N(1, \sigma_e^2)$$

Spawning Escapement

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

$$S_y = (N_{.y} - lN_y)$$

E.3. Results

Low run size risks were affected by fishing levels but the magnitude of effect varied with population size and productivity. Average fishing rates under 20% generally had a small effect on the frequency of escapements falling below quasi-extinction or critical risk thresholds, except for relatively small, unproductive populations (Table E13-4, Table E13-5). The CRT was more sensitive than the QET to the effects of fishing (e.g. spawning escapements were more likely to fall below the CRT than the lower QET).

Risks associated with the abundance-based Oregon Matrix fishing schedule were generally similar to those of a fixed 15% harvest rate for Clackamas, Sandy, and Elochoman/Skamokawa populations. For instance, a 15% rate produced a 9.9% risk while the matrix produces a 10.6% CRT frequency for the Elochoman/Skamokawa population. For the smaller and less resilient Grays population, a fixed 15% rate produced a 16.3% CRT risk whereas the matrix resulted in a 21.5% CRT risk. No difference between the matrix and a fixed 15% rate was projected for the Clackamas population.

The matrix fishing strategy provides for substantially greater harvest opportunities in years of good coho production (Figure E13-8, Figure E13-9). Higher fishing rates in large run years come with limited risk of low spawning escapements because fisheries harvest adults in excess of the available habitat capacity. Because of density-dependent spawning and rearing habits, no demographic benefit accrues from additional spawners beyond a certain level. Also note that while the matrix allows for higher fishing rates in some years, matrix cells with rates exceeding 25% are only occasionally applied (Table E13-6, Table E13-7). Cell frequencies are similar whether based on a large or small population seeding level and marine survival index.

The four specific populations modeled generally include the full spectrum of population sizes and productivities targeted for protection or significant improvements to meet recovery goals. They are not representative of the smallest and least productive coho populations in the ESU. However, low run size risks would be very high in marginal populations potentially represented by the low end sensitivity reference values, regardless of fishery effects. We also note that recovery criteria developed by the WLC TRT are based on an average improvement in populations of each recovery strata but do not require recovery of every population to high levels of viability. Washington's recovery strategy involves concentrating recovery efforts on a subset of the populations for maximum effect (LCFRB 2004).

The low end reference population values used in model sensitivity analysis might be considered to be representative of a population not targeted for significant recovery. The high end reference population values might be considered to be representative of a recovered population capable of sustaining significant annual fishing rates with no risk of small spawning escapements.

Table E13-4. Effects of fishing level on quasi-extinction risks defined as the probability of a 3-year moving average of escapement of less than 50 spawners. (Beverton-Holt productivity and equilibrium abundance parameters are identified in parentheses).

	Fishing level										
	0%	5%	10%	15%	20%	30%	40%	50%	Matrix	Matrix * 1.5	Modified matrix
Sensitivity analysis											
High end reference (5.0 / 10,000)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
Low end reference (3.0 / 500)	0.268	0.347	0.450	0.562	0.686	0.892	0.994	1.000	0.750	0.959	0.638
Populations											
Clackamas (2.5 / 9,900)	0.000	0.000	0.000	0.000	0.004	0.018	0.151	0.579	0.000	0.006	0.000
Sandy (4.1 / 3,600)	0.000	0.000	0.000	0.000	0.000	0.012	0.081	0.428	0.000	0.000	0.000
Elochoman/Skamokawa (4.3 / 2,400)	0.000	0.000	0.000	0.000	0.003	0.018	0.123	0.398	0.000	0.004	0.000
Grays (3.8 / 1,100)	0.010	0.015	0.022	0.036	0.069	0.211	0.530	0.877	0.045	0.152	0.031

Table E13-5. Effects of fishing level on critical population risks defined as the probability of a 3-year moving average of escapement of less than critical risk thresholds (100, 200, or 300 depending on basin size as indicated in parentheses).

	Fishing level										
	0%	5%	10%	15%	20%	30%	40%	50%	Matrix	Matrix * 1.5	Modified matrix
Sensitivity analysis											
High end reference (300)	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.021	0.000	0.000	0.000
Low end reference (100)	0.602	0.677	0.763	0.841	0.903	0.984	1.000	1.000	0.958	1.000	0.919
Populations											
Clackamas (300)	0.005	0.008	0.015	0.023	0.045	0.018	0.465	0.884	0.023	0.062	0.021
Sandy (300)	0.032	0.049	0.068	0.099	0.135	0.338	0.650	0.955	0.115	0.276	0.092
Elochoman/Skamokawa (200)	0.031	0.046	0.062	0.093	0.130	0.314	0.615	0.891	0.106	0.256	0.086
Grays (100)	0.059	0.081	0.110	0.163	0.239	0.464	0.799	0.980	0.215	0.448	0.159

Table E13-6. Projected frequency of occurrence in cells of the Oregon coho fishery matrix based on model simulations (Clackamas population example).

Parental escapement		Marine survival index (based on jacks/hatchery smolt)				
	% of full seeding	critical	low	medium	high	Total
high	>75%	0.080	0.085	0.134	0.032	0.332
medium	50%-75%	0.034	0.037	0.056	0.014	0.141
low	20%-50%	0.080	0.083	0.131	0.032	0.326
very low	10%-20%	0.030	0.033	0.051	0.013	0.127
critical	<10%	0.017	0.019	0.030	0.008	0.075
	Total	0.242	0.258	0.402	0.099	1.000

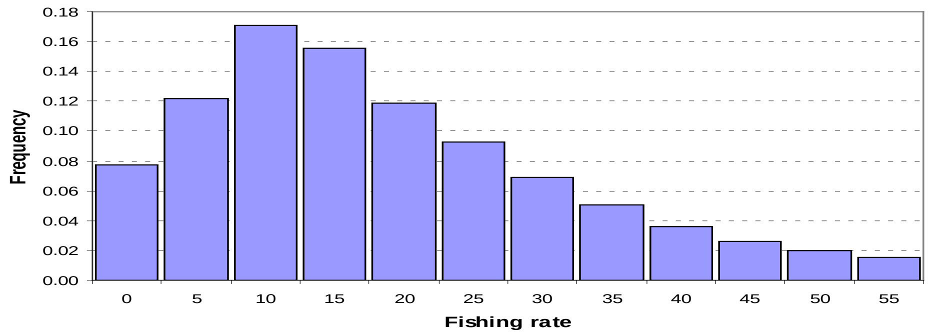

Figure E13-8. Projected distribution of annual fishery impact rates (Clackamas population example) under the Oregon matrix (assuming a 0.5 coefficient of variance between target and fishing rates).

Table E13-7. Projected frequency of occurrence in cells of the Oregon coho fishery matrix based on model simulations (Grays population example).

Parental escapement		Marine survival index (based on jacks/hatchery smolt)				
	% of full seeding	critical	low	medium	high	Total
high	>75%	0.090	0.096	0.151	0.036	0.373
medium	50%-75%	0.036	0.039	0.059	0.015	0.149
low	20%-50%	0.076	0.080	0.127	0.031	0.315
very low	10%-20%	0.024	0.026	0.041	0.010	0.102
critical	<10%	0.014	0.016	0.025	0.006	0.062
	Total	0.242	0.258	0.402	0.099	1.000

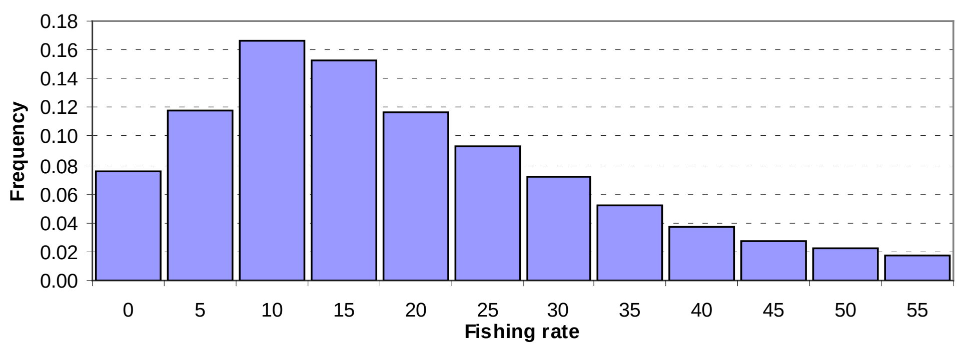

Figure E13-9. Projected distribution of annual fishery impact rates (Grays population example) under the Oregon matrix (assuming a 0.5 coefficient of variance between target and fishing rates).

E.4. Discussion

These analyses confirm that the Oregon harvest matrix is adequate to protect the majority of lower Columbia River coho populations in Oregon and Washington. Small fishery impact rates have little or no effect on conservation risks, even for moderately small populations. Analyses indicate that an abundance-based fishing strategy can be an effective alternative to a fixed recovery fishing rate for meeting conservation and recovery goals while balancing access to large escapements in good survival years. This analysis of fishery effects is based on relative comparisons for a given set of conditions. Relative comparisons of effects are a robust application of this modeling approach.

Fishing rates evaluated in this analysis are typically much less than fishing rates that provide maximum sustained yield. Stock-recruitment relationships for lower Columbia River coho populations generally predicted MSY at equilibrium fishing rates of 40-50% and hatchery stocks can support even higher fishing rates. However, management for these rates on an annual basis does not provide adequate for low run size risks. Harvest rates of 50% or greater implemented on an annual basis clearly posed a significant risk to sustainability. Results also highlight risks of high historical fishing rates that failed to protect weak populations or escapement in years of poor survival. Weak stock harvest strategies implemented since the early 1990s have eliminated high annual harvest rates for coho.

Small changes in risk levels predicted by this analysis (on the order of absolute values of 10% or less) can be considered to be relatively insignificant in comparison with other uncertainties associated with coho status and fishery management. These include the arbitrary nature of threshold values selected for QETs and CRTs, uncertainty in population status of many coho populations, incorporation of both measurement and process errors in simulation variances, and difficulties in estimating actual harvest rates on different components of the coho run. Therefore, results of this population viability analysis should be considered indicative of appropriate fishing strategies rather than absolute estimates of population risk.

Several conservative assumptions provided a precautionary evaluation of risks:

1. Risk was evaluated in terms of quasi-extinction which assumes that functional extinction occurs at numbers greater than actual numerical extinction (50 vs. 1).
2. Risk was also evaluated in terms of a critical risk threshold greater than the QET to represent concerns for the depensatory demographic and genetic effects of small population processes.
3. Depensation was assumed for escapements less than the CRT although the scientific basis for these dynamics is based on theoretical rather than empirical information.
4. The PVA model assumed a Beverton-Holt stock-recruitment function which represents no reduction in recruitment at high escapements. If a Ricker function was more appropriate, fishing risks would have been reduced. However, we generally lack the data needed to distinguish the form of the stock-recruitment relationship at high escapements.
5. Population viability analyses assumed a large stochastic variation ($\sigma = 1.0$) for all populations in the absence of specific empirical data for most populations.
6. Analyses assumed a large fishery implementation error (CV = 0.5) in the absence of long term observed and expected comparisons of the actual population-specific error that can be expected under an abundance-based fishing strategy. This high rate was included to address incomplete synchrony in annual variation among all coho populations.

These analyses are conditional on an assumption of no long term changes in productivity or mortality associated with other human factors. This would be a pessimistic assumption if we believe long term declines in environmental conditions and the failure of significant benefits from habitat, hatchery, or hydropower actions. This would be a conservative assumption if we believe other habitat, hatchery, or hydropower actions are likely to prove beneficial to coho. Absolute estimates of population risks depicted in this exercise do not include future benefits of other recovery actions in the habitat, hatchery, and hydropower sectors. Current recovery plans call for significant improvements in these areas. With effective implementation of other recovery actions, risks associated with fishery strategies are expected to be substantially less than those depicted by this analysis.

Finally, it is noted that application of the results of this risk analysis in annual fishery management will require consideration of timing differences of different population or stock units over the extended duration of the coho run within the Columbia River. The aggregate coho run consists of a mixture of early and late returning hatchery and wild populations (Figure E13-10). Fisheries implemented during different periods will affect different run components. This risk analysis identifies fishery limitations that will minimize fishery effects on the incidence critical low escapements. Accurate estimates of actual fishing rates for comparison to rate limits for each substock component will require some understanding of substock composition during fishery implementation.

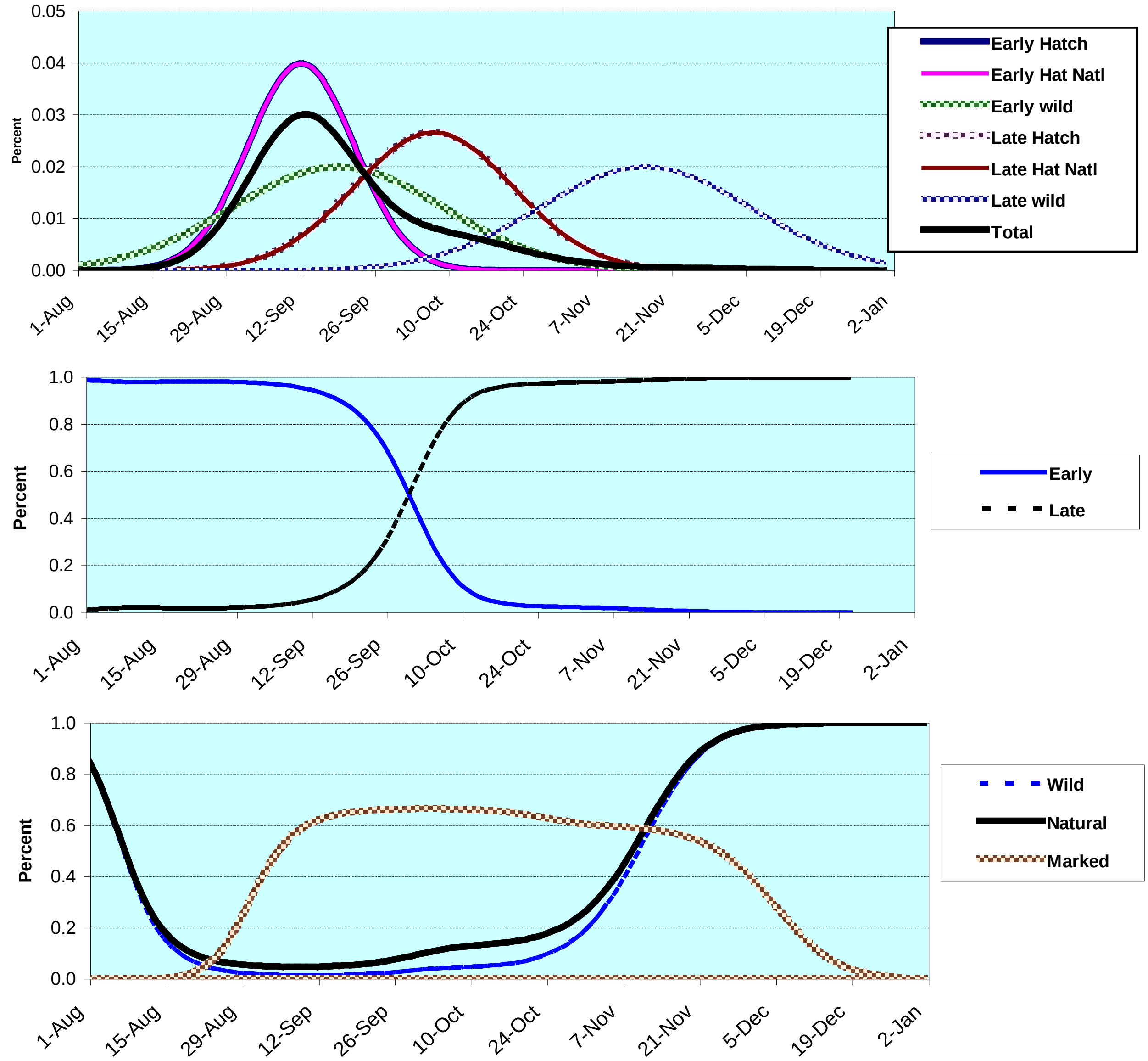

Figure E13-10. Approximate timing of different coho run components in the lower Columbia River and projected effects on wild proportions and mark rates in the aggregate run. Run timing curves are inferred from CWT and mark-rate data in past commercial fishery catches by week, Bonneville Dam Counts, and tributary return patterns. The early portion of the run is replaced by predominately late run fish by the first week of October. Numbers of hatchery fish and mark rates are greatest in the lower Columbia River from mid September through late October. Curves also reflect the belief that a significant portion of the naturally-produced coho present in October are of hatchery origin (late run hatchery stock).

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