APPENDIX E.
ESTIMATION OF SALMON RECOVERY TARGETS

This chapter was drafted in 2010.

APPENDIX E. ESTIMATION OF SALMON RECOVERY TARGETS

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E.1. Introduction

Recovery plans are currently under development for salmon species listed under the Federal Endangered Species Act, including groups of populations in the lower Columbia and Willamette rivers. Recovery plans include descriptions of current status as well as goals for recovery to viable levels where extinction risks are low and numbers are adequate to sustain other resource uses. The breadth, depth, and intensity of strategies and actions included in these recovery plans are based on the "recovery gap" between current and desired status. Effective recovery plans will depend on accurate assessments of the size of this gap.

Population Viability Analysis (PVA) provides a systematic method for estimating the scale of improvement needed to close the recovery gap. 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, Beamesderfer 2001, Beamesderfer et al. 2006, Paulsen et al. 2007).

This report describes a demographic Population Viability Analysis of salmon using a simple stochastic stock-recruitment model to: 1) describe fundamental relationships between risk and demographic parameters, 2) evaluate the effects of key assumptions in the estimation of risk including thresholds and future trends, 3) identify incremental population improvements necessary to reduce extinction risks to levels consistent with recovery, and 4) apply results to representative lower Columbia River coho, spring Chinook, fall Chinook, chum and steelhead populations

E.2. Methods

E.2.1. Analyses

Fundamental relationships between risk and demographic parameters were described with generic sensitivity analyses of the effects of abundance, productivity, and population variability on the frequency of low numbers associated with extinction. These relationships provide general guidance on sustainable and at risk population levels as well as reference values for identifying the risk level from population-specific parameters. These relationships have been reported elsewhere in the form of "conservation curves" by Chilcote (2006) and applied by McElhany et al. (2006). Analyses were conducted for coho and steelhead which represent low (3 years) and high (5 years) average generation times which bracket the range of potential values for lower Columbia River salmon species.

Effects of key assumptions were evaluated with additional sensitivity analysis for representative populations at low, medium, and high risk. Key assumptions included recruitment failure and quasi-extinction thresholds, initial population size, future trend, near-term survival patterns (related to environmental regimes), and contribution of hatchery fish to natural spawning.

Effects of incremental improvements were estimated relative to a variety of current status levels and population parameters intended to represent the range of existing conditions and potential recovery goals. Population-specific gaps and improvements can be identified from these nominal values based on the data available for each population. Incremental improvements were defined based on an "improvement scalar" which is simply a multiplier applied to productivity and equilibrium abundance parameters of the stock-recruitment relationship.

Example applications were based on population values reported for lower Columbia and Willamette populations. Current viability and improvement increments needed to reach benchmark risk levels were identified based on estimated current productivity, equilibrium abundance and inter-annual variance. Population-specific parameters were based on a variety of sources including stock-recruitment patterns from run reconstruction data and inferences from habitat conditions. Population parameters were selected to represent conditions that led to ESA listing in order to provide a standardized reference point for considerations of recovery goals and gaps. Thus, 1999 was used as a reference point for all species because initial listings of most lower Columbia River species occurred in 1999. Results are also presented for a current reference point which reflects reductions in fishing rates for several species since 1999.

E.2.2. Model Description

The model estimates annual spawner numbers over a 100-year period for a prescribed number of iterations. 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 includes optional inputs to apply fishing rates in each year to calculate harvest and fishery effects on population dynamics. Optional inputs are also included for analysis of demographic effects of natural spawning by hatchery fish based on inputs for hatchery releases, release to adult survival, and rates of natural spawning by hatchery fish. 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.

E.2.3. Model Formulation

A full list of model inputs may be found in Table E12-1. Descriptions of derivation and application of model variables and inputs follow.

Conservation risks

This analysis estimates 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. Estimated risks are compared to benchmark values of 60% 25%, 5%, and 1% risk levels identified by the Willamette/Lower Columbia Technical Recovery Team (McElhany et al. 2006) as corresponding to high, moderate, low, and very low extinction risks.

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.

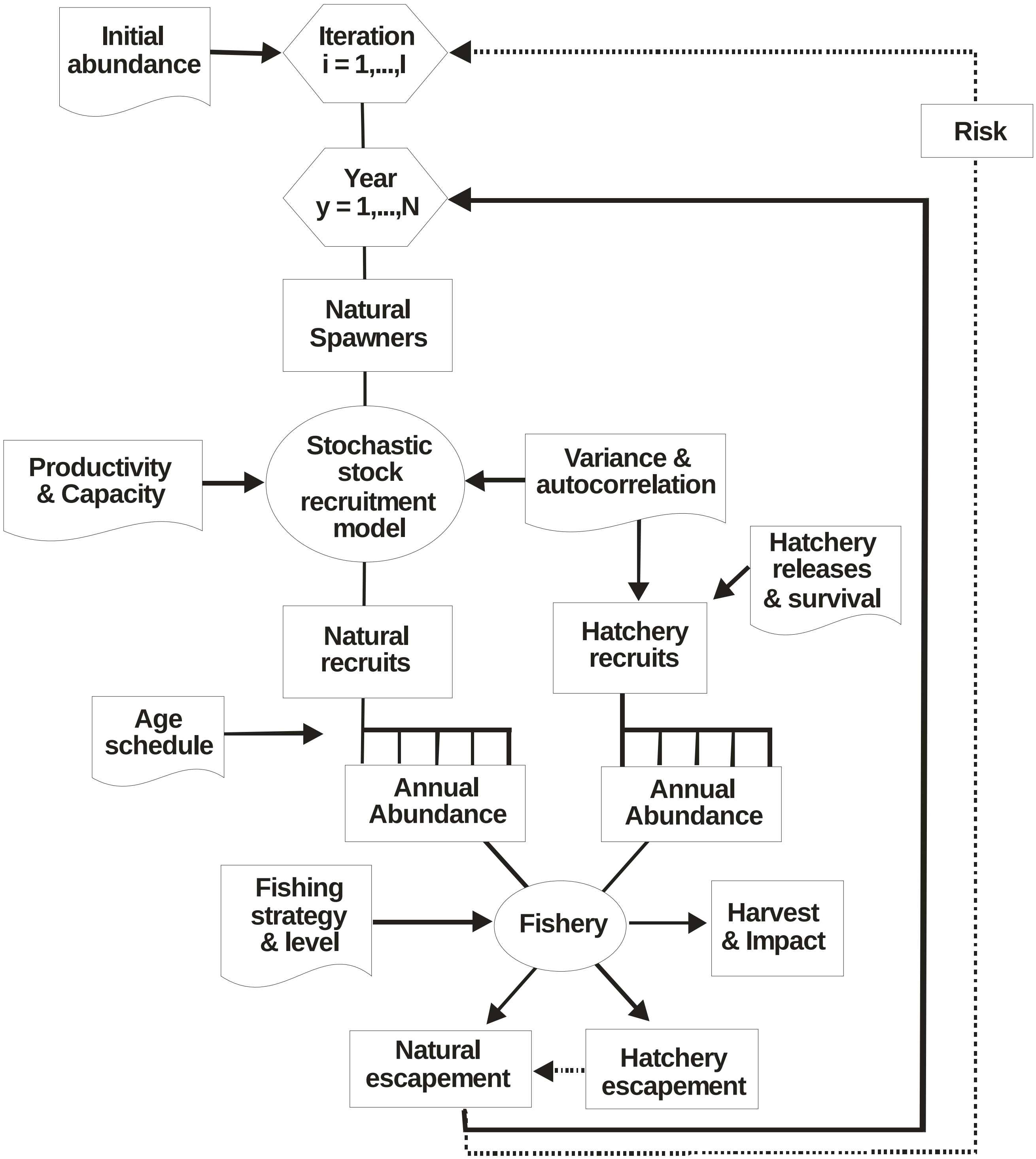

Figure E12-1. Model algorithm.

Table E12-2. Example model input variables and parameters used for generic sensitivity analyses of the effects of abundance, productivity, and population variability on the frequency of low numbers associated with extinction.

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	1, …,8
Equilibrium abundance	N_{eq}	300, 500, 1000, 3000, 10000
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	300
Recruitment stochasticity		
Variance	σ^2	0.5, 1.0, 1.5
Autocorrelation	Ø	0.5
Age schedule	$m_2,\ldots,m_7$	Species-specific (see Table E12-2)
Quasi extinction threshold	QET	50
Critical risk threshold	CRT	300

Generic model sensitivity analysis of the effects of abundance, productivity, and population variability on extinction risk were based on a QET of 50 and a CRT of 300 spawners estimated as a moving average of years in one generation of the species in question. Sensitivity analyses were conducted to examine the effect of different QET and CRT assumptions on projected risks. Generation times were based on the weighted average age of return (3 years for coho; 4 years for spring Chinook, fall Chinook and chum; 6 years for steelhead).

Population-specific estimates of extinction risks and improvement scalars were based on QET values of 50 for all populations and CRT values ranging from 50 to 300 depending on species and the 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 can be based on either hockey stick, Beverton-Holt, or Ricker functional forms.

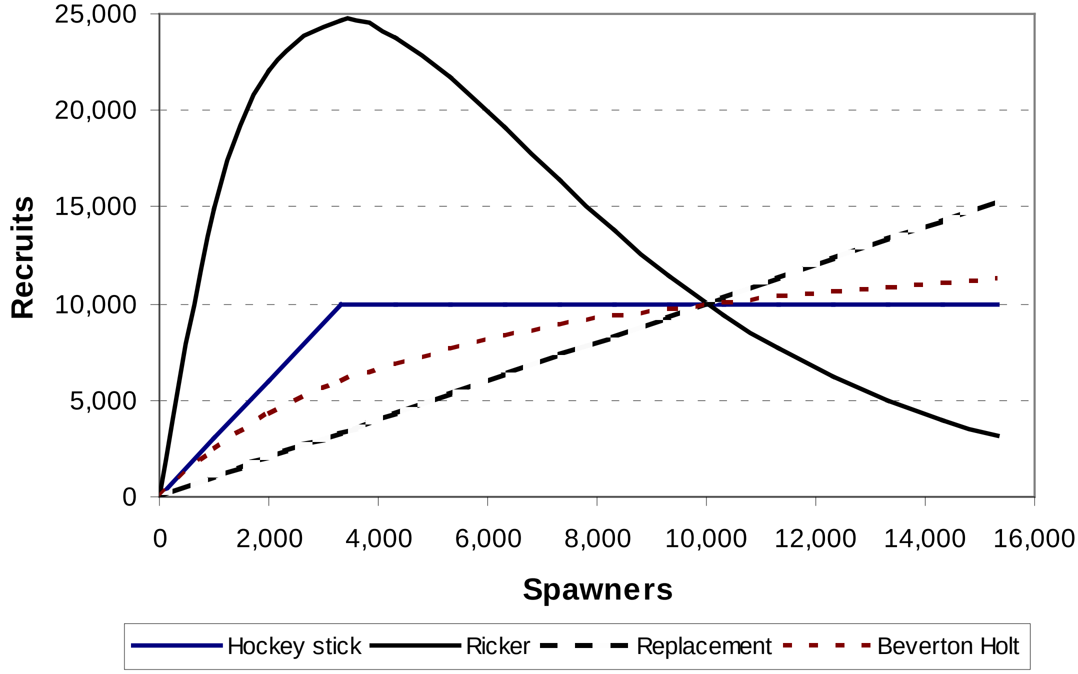

Figure E12- 2. Example stock-recruitment curves based on a productivity parameter of 3 recruits per spawner (maximum observed at low numbers) and an equilibrium population size of 10,000.

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 ~ $N(0, \sigma^2)$.

The Ricker form of the relationship is:

$$R_y = S\, e^{\alpha [1-(S/Neq)] + \varepsilon}$$

where

R_y = recruits,
S_y = spawners,
α = Ricker productivity parameter (maximum recruits per spawner at low abundance),
N_{eq} = parameter for equilibrium abundance,
e = exponent, and
ε = normally-distributed error term.

Generic sensitivity analyses were based on a hockey stick stock-recruitment function and ranges of productivity values that generally encompass normal ranges reported for depleted Pacific Northwest salmon populations (1 to 6 recruits per spawner). A range of equilibrium population sizes was evaluated from 300 to 10,000. The model also included limits on recruitment to prevent unrealistically large or small numbers produced by the log normal distribution function.

Population-specific assessments of risk and improvement scalars were based on the best available data for each population. Population-specific stock-recruitment parameters where used where available. Parameters were based on a hockey stick formulation and the mean RS approach identified by McElhany et al. (2006). This approach defines the equilibrium abundance based on the median pre-harvest recruitment level observed in the historical data time series. The productivity parameter was based on the geometric mean of recruits per spawner for spawning escapements less than the median value in the data set. Pre-harvest stock-recruitment data was used to estimate intrinsic population parameters to account for significant and well documented changes in harvest patterns over time. 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 2005). 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. Where specific population data were lacking, representative values were used consistent with the assumed population status based on other anecdotal information.

Generic sensitivity analyses and population-specific 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. Additional sensitivity analyses were conducted to examine the effect of initial abundance on risks, particularly including near term risks.

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:

$$\sigma_e^2 = \sigma_z^2 (1 - \varnothing^2)$$

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

Generic sensitivity analyses were based on a range of stock-recruitment variances that generally encompass normal ranges reported for Pacific Northwest salmon populations (0.5 to 1.5). Autocorrelation in generic sensitivity analyses was uniformly assumed to be equal to 0.5 based on estimates of this parameter reported in McElhany et al. (2006) and Beamesderfer et al. (2006). Variance and autocorrelation in population-specific risk analyses were based on species values reported by McElhany et al. (2006). All populations of the same species were simulated with the average variance for that species because population-specific estimates were assumed to be more reflective of sampling effects than true differences among populations.

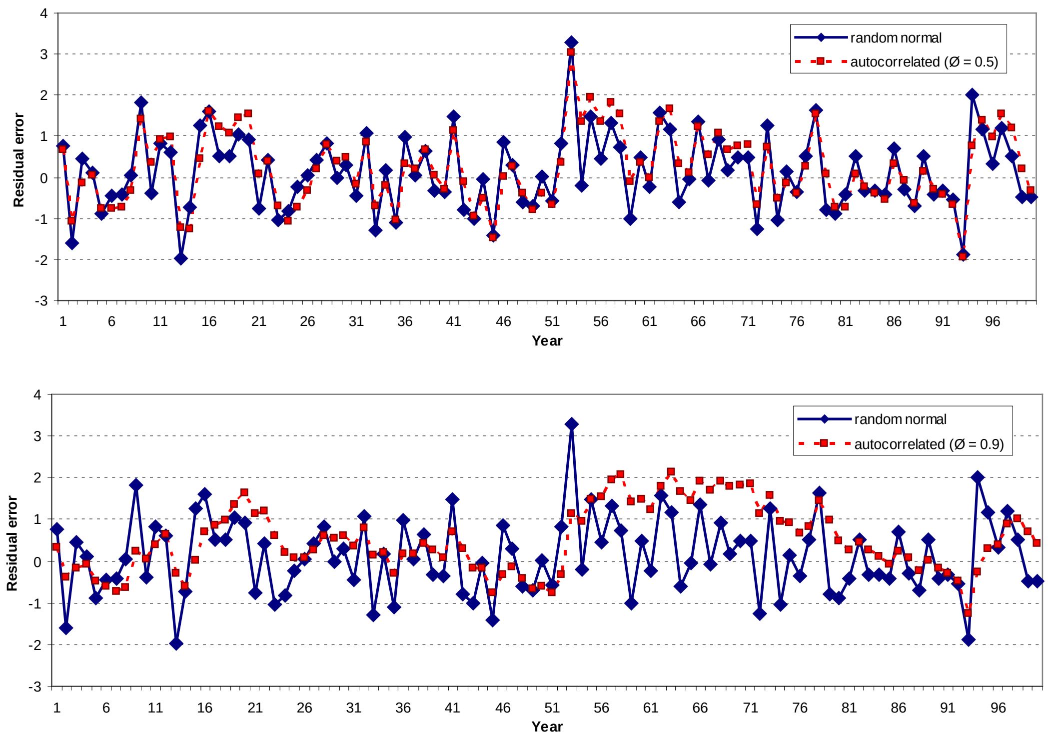

Figure E12-3. Examples of autocorrelation effect on randomly generated error patterns (σ_z^2 = 1).

Depensation & Recruitment Failure Thresholds

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

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

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

where

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

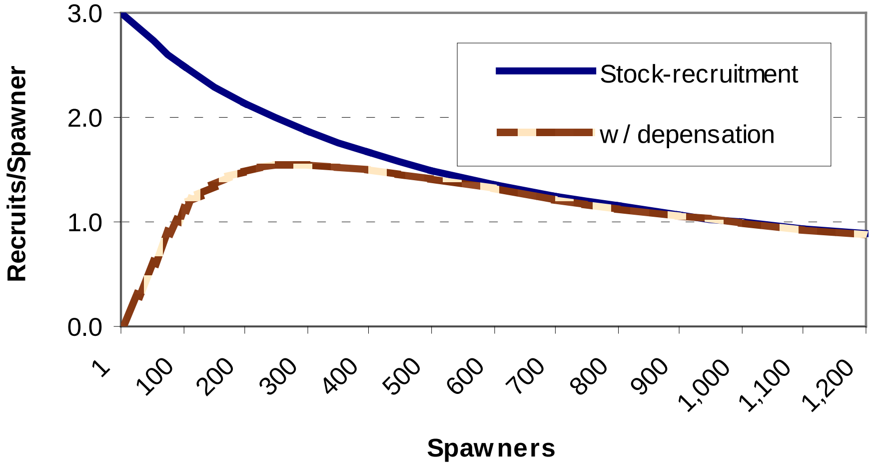

Figure E12-4. Example of depensation function effect on recruits per spawner at low spawner numbers based on a Beverton-Holt function (a = 3.0, Neq =1,000, γ =500).

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

Production Trend

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

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

where

R' = Number of adult recruits after depensation applied, and
t = proportional annual change in productivity.

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

Improvement Scalar

The model includes an optional scalar which is used to estimate the effects of incremental improvements in realized recruitment on quasi-extinction risks:

$$R^* = R'' (1 + C/100)$$

where

- C = Improvement scalar (%), and
- R* = Number of adult recruits after application of the improvement scalar.

Note that application of an improvement scalar results in a proportion increase in equilibrium population size and productivity at spawner numbers less than the equilibrium value (Figure E12-5).

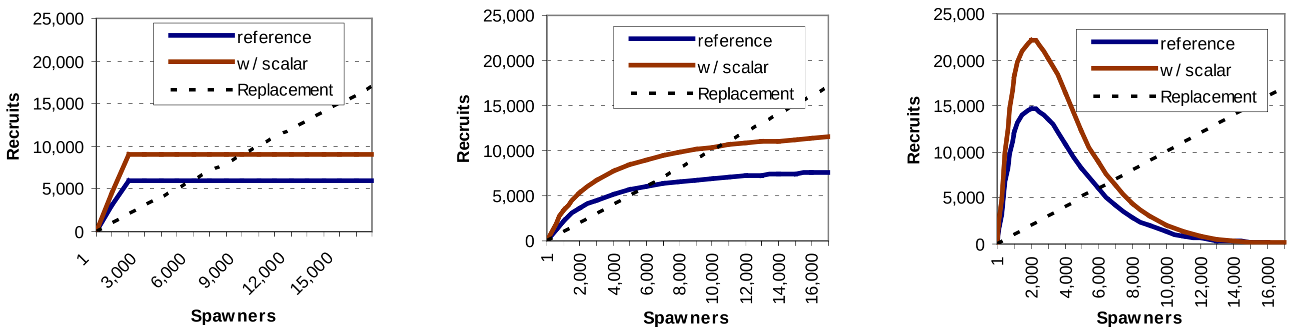

Figure E12-5. Example of effects of improvement scalar (50%) on hockey stock, Beverton Holt, and Ricker stock-recruitment relationships based on an equilibrium abundance of 6,000 and a productivity parameter of 3 recruits per spawner.

Sensitivity analyses evaluated the effects of improvement scalars ranging from 0.9 (a net decrease) to 1.8 (a net increase). This range was selected based on inspection of model results to produce quasi-extinction risks equivalent to a low risk of extinction for most combinations of population parameters and species. Population-specific improvement scalars were defined to represent increments needed to reach prescribed risk levels (1%, 5%, 25%) relative to a baseline at the time of the original ESA listing.

Annual Abundance

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

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

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

where

- N_{xy} = Number of mature naturally-produced adults of age x destined to return to freshwater in year y, and
- m_x = Proportion of adult cohort produced by brood year spawners that returns to freshwater in year x

Species-specific age schedules were based on unpublished WDFW data for fall Chinook (1980-2004 lower river tule returns) and average values estimated for other species in McElhany et al. (2006). McElhany et al. (2006) numbers were revised to include jack proportions for coho (age 2) based on Clackamas and Sandy River data and spring Chinook (age 3) based on McKenzie, Clackamas, and Sandy River data. Jacks were included to reflect their genetic contributions to effective population sizes.

Table E12-3. Average spawner age composition based on escapement data available for Willamette and lower Columbia salmon populations (McElhany et al. 2006 and WDFW unpublished).

Species	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Generation (yrs)
Coho	0	0.05	0.95	0	0	0	0	3
Spring Chinook	0	0	0.05	0.54	0.40	0.01	0	4
Fall Chinook	0	0.06	0.42	0.46	0.06	0.00	0	4
Chum	0	0	0.41	0.57	0.02	0	0	4
Steelhead	0	0	0.01	0.45	0.42	0.11	0.01	5

Hatchery Fish

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

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

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

where

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

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

Fisheries & Harvest

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

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

where

IN_y = fishery impact in number of naturally-produced fish,
fN_y = fishery impact mortality rate on naturally produced fish including harvested catch and catch-release mortality where applicable,
IH_y = Fishery impact in number of hatchery-produced fish, and
fH_y = fishery impact mortality rate including harvested catch and other mortality where applicable.

Generic sensitivity and population-specific assumed that fishery impacts were implicit in stock-recruitment parameter estimates. Estimates of population-specific risks and improvement scalars were based on pre-harvest stock-recruitment parameters calculated using fishery harvest rates representative of conditions leading up to the time of the original ESA listings of most lower Columbia River salmon and steelhead (1998-1999). Corresponding rates were 50% for coho, 50% for spring Chinook, 65% for fall Chinook, 50% for late fall Chinook, 5% for chum, and 10% for steelhead. Rates include ocean and freshwater fisheries and represent management practices in years prior to listing (intended to reflect conditions that led to status at the time of listing). Note that conservation measures implemented since listing have further reduced fishing rates from historical levels.

Spawning Escapement

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

$$S_y = SN_y + SH_y$$

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

$$SH_y = (H_{.y} - IH_y)\, q\, \tau$$

where

SN_y = Naturally-produced spawners in year y,
SH_y = Hatchery-produced natural spawners in year y,
q = proportion of hatchery escapement that spawns naturally, and
τ = spawning success of a naturally-spawning hatchery fish relative to that of a naturally-produced spawner.

The model also tracks the proportion of natural influence by hatchery fish (pNI):

$$pNI_y = SH_y / S_y$$

Note that the relative fitness of a hatchery spawner is applied only to first generation hatchery spawners and continuing hatchery fitness effects in subsequent generations are to be represented in model applications by changes in stock-recruitment parameters.

E.3. Results

E.3.1. Model Behavior

A series of simple simulations illustrates fish population and fishery dynamics as reflected in the simulation model. In a deterministic simulation, spawner numbers change from initial values to reach a stable equilibrium (Figure E12-6).

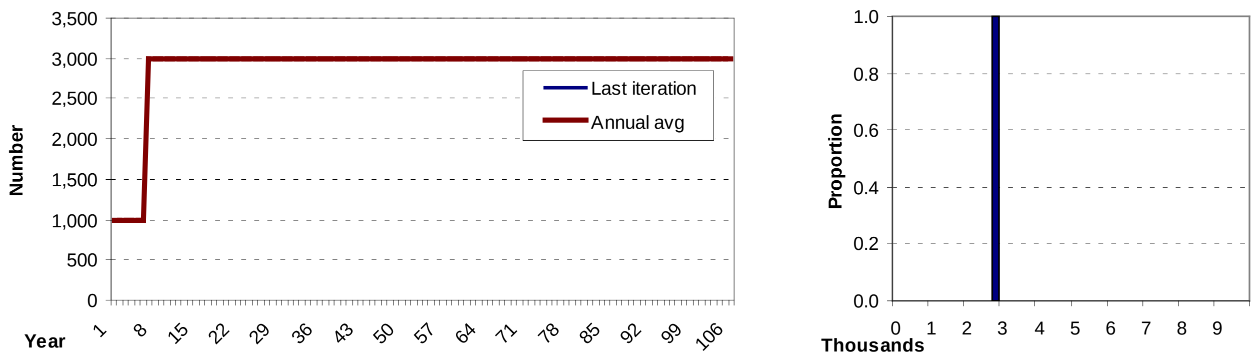

Figure E12-6. Example results of a deterministic 100-year simulation based on a hockey stick stock-recruitment function, an initial population size of 1,000, an equilibrium population size of 3,000, and an intrinsic productivity of 3 recruits per spawner (coho). Years 1-6 in the plot refer to initial values used to seed the future simulation.

Patterns of annual fluctuation in fish numbers and harvest begin to resemble more typical real world patterns when random variation is introduced to the simulation (Figure E12-7). The assumed log-normal distribution of the stock-recruitment variance is reflected in a skewed frequency distribution of spawners as well as an annual average spawner number (3,800 in this example) which is greater than the specified model input equilibrium abundance value (3,000) which represents a median value. This highlights the need for careful derivation of stock-recruitment parameters intended to represent any given population to include error-distribution related corrections in parameters as identified by Hilborn (1985).

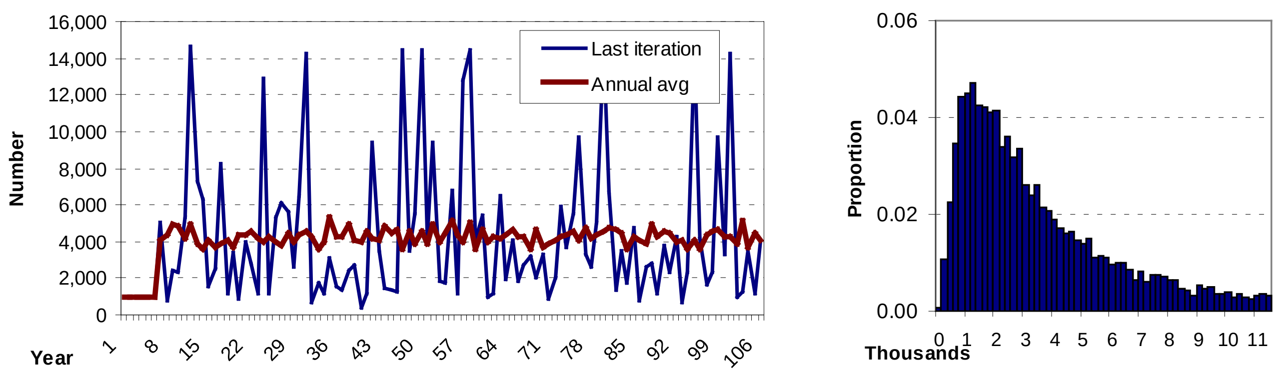

Figure E12-7. Example results of a stochastic 100-year simulation for coho (100 iterations) based on a hockey stick stock-recruitment function, an initial population size of 1,000, an equilibrium population size of 3,000, an intrinsic productivity of 3 recruits per spawner, and a variance of 1.0. Years 1-6 in the plot refer to initial values used to seed the future simulation.

Introduction of autocorrelation into the random recruitment function alters the pattern of variability. At the same net variance, the autocorrelation results in less local variation from year to year and sequences of better or poorer than average survival conditions like those typically observed in time series data.

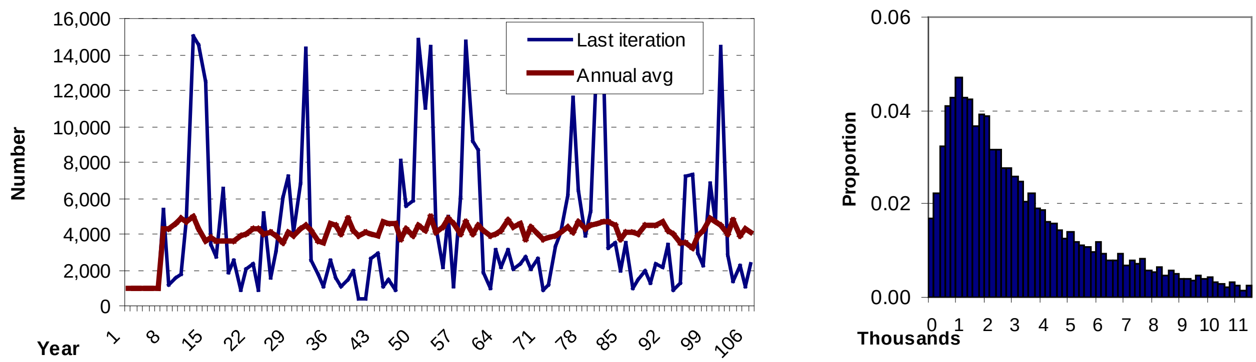

Figure E12-8. Example results of a stochastic 100-year simulation for coho (100 iterations) based on a hockey stick stock-recruitment function, an initial population size of 1,000, an equilibrium population size of 3,000, an intrinsic productivity of 3 recruits per spawner, a variance of 1.0, and an autocorrelation of 0.5. Years 1-6 in the plot refer to initial values used to seed the future simulation.

E.3.2. Quasi-extinction and Critical Risk Levels

Low run size risks are closely related to population size, productivity, and inter-annual variability. Risks increase with decreasing population size and productivity, and increase with increasing variability (Figure E12-9 - Figure E12-10). Differences among species are apparent due to different generation times upon which risks were estimated and corresponding age distributions. Risks are greater for any given combination of parameters for species with short generation times and narrow age distributions (e.g. coho with an average generation time of 3 years) than for species with long generation times and wide age distributions (e.g. winter steelhead with an average generation time of 5 years). Actual risks and differences among species will depend on the normal range of parameters among populations of each species (different species may be characterized by different parameter ranges).

This generic sensitivity analyses highlights population sizes and productivities that almost universally result in high or low quasi-extinction risks. For instance, equilibrium population sizes of 300 or less result in high (>25%) or very high (>60%) quasi-extinction risks at productivities of under 3 recruits per spawner and autocorrelated variances of 1.0 or greater for both coho and steelhead life history patterns. The modeling also suggests that even the most robust life history pattern (steelhead) may be subject to moderate quasi-extinction risks at equilibrium population sizes of 300 or less even when variability is low and productivity is moderate or high (>3 recruits per spawner). Quasi-extinction risks increase rapidly at average productivities of less than 2 recruits per spawner for all species, population sizes, and variances.

The CRT provides a more conservative risk benchmark than the lower QET. Equilibrium abundances of less than 1,000 typically result in high or very high CRT probabilities regardless of productivity at moderate to high levels of variability. CRT probabilities increased rapidly at productivities under 2 recruits per spawner, regardless of equilibrium abundance, variability or generation length.

Conversely, population sizes of over 3,000 are relatively robust at productivities exceeding 2 recruits per spawner even where variance is high. Similarly, high productivities of 5 recruits per spawner or greater typically result in very low to moderate quasi-extinction risks except at combinations of low population size and high variability.

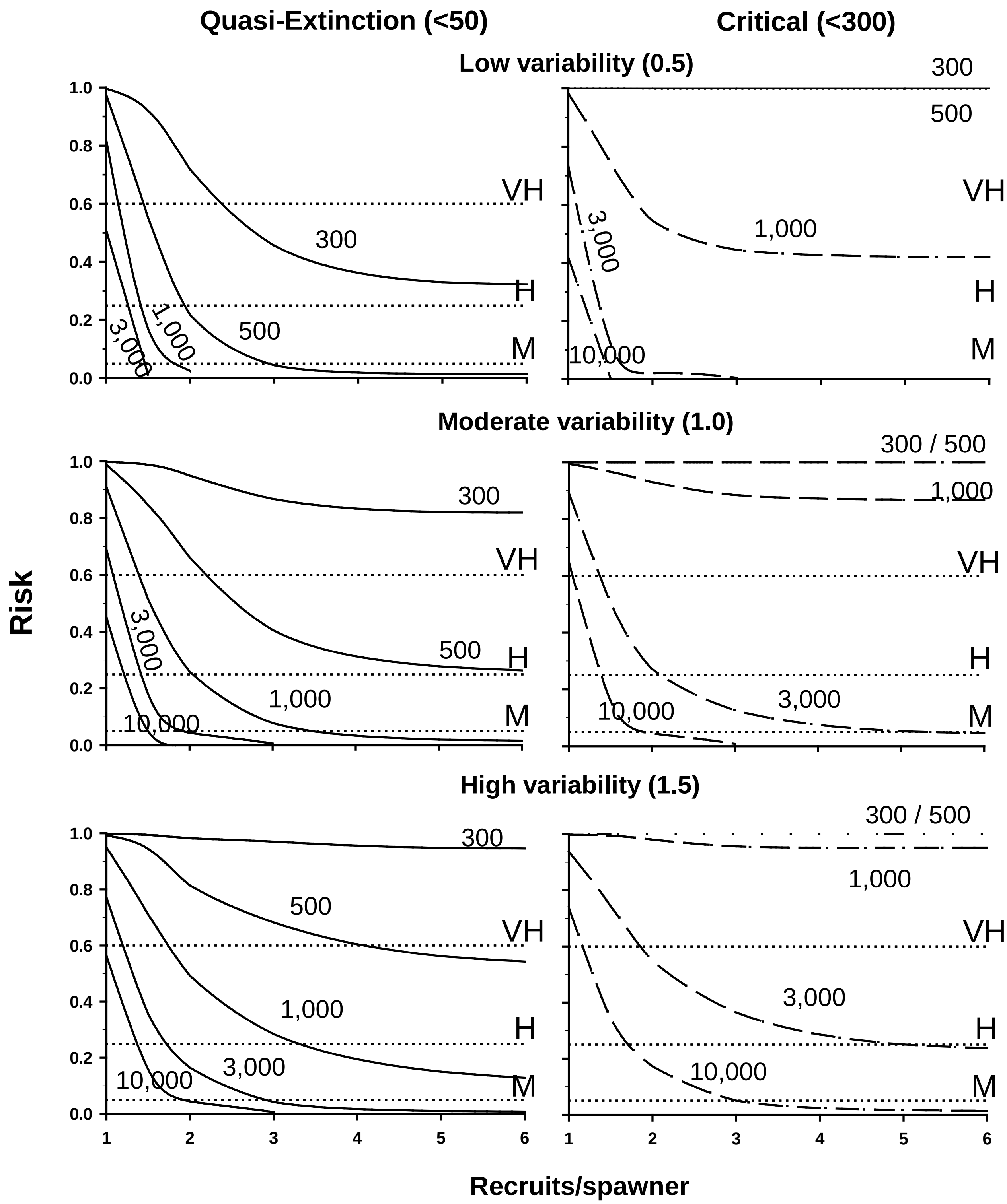

Figure E12-9. Sensitivity of quasi-extinction and conservation concern risks of a hypothetical coho population to productivity (recruits per spawner), equilibrium abundance, and inter-annual variability based a hockey-stick stock-recruitment function and stochastic viability analysis (iteration frequency of average abundance of less than 50 or 300 spawners in one generation). Extinction risk are labeled as VH = very high, H = high, and M = moderate.

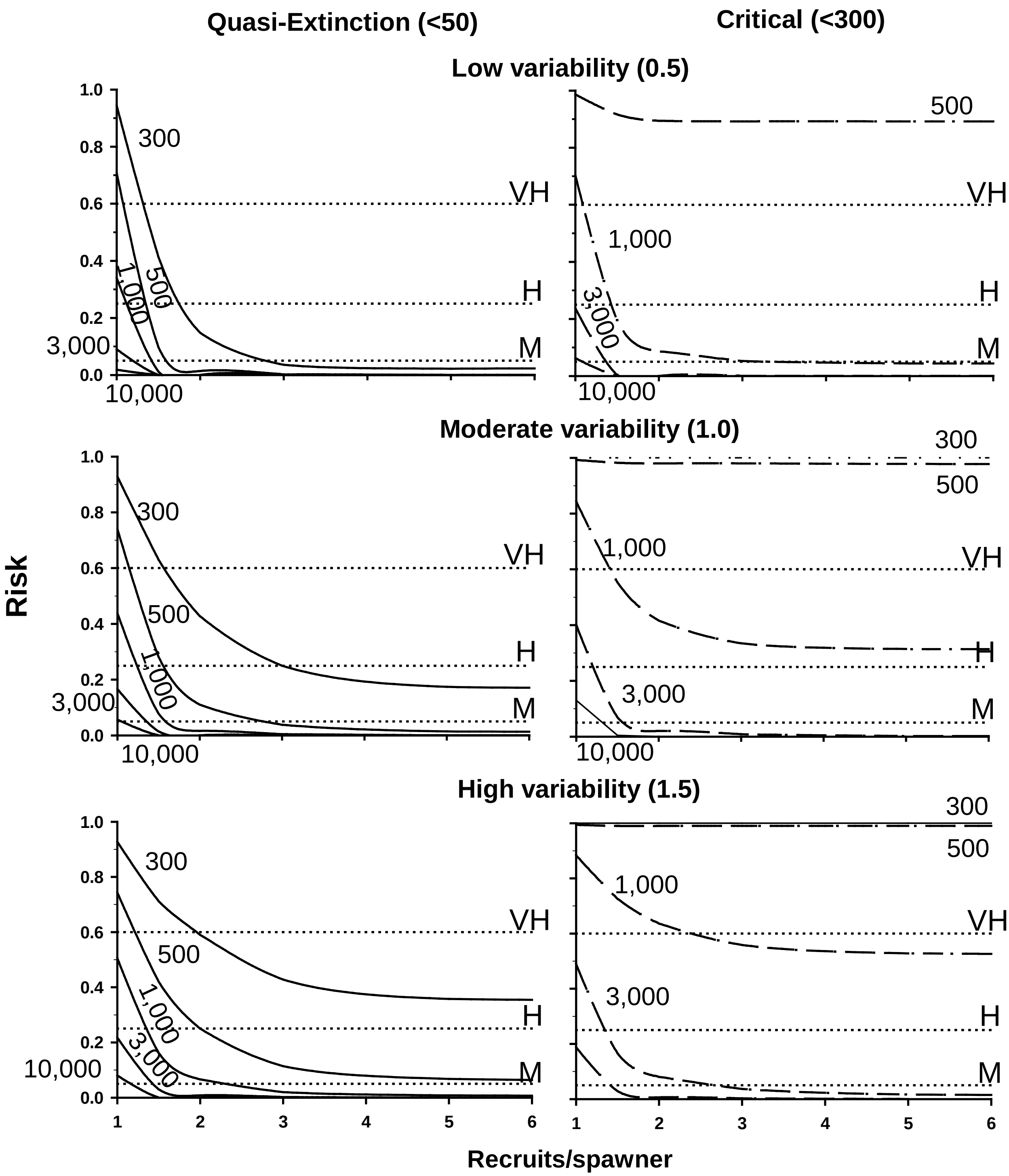

Figure E12-10. Sensitivity of quasi-extinction and conservation concern risks of a hypothetical steelhead population to productivity (recruits per spawner), equilibrium abundance, and inter-annual variability based a hockey-stick stock-recruitment function and stochastic viability analysis (iteration frequency of average abundance of less than 50 or 300 spawners in one generation). Extinction risk are labeled as VH = very high, H = high, and M = moderate.

E.3.3. Effects of alternative parameters

Risk Threshold

Model estimates of risks were extremely sensitive to assumed measurement threshold values (quasi-extinction or critical). Effects were pronounced even for relatively productive (p = 6.0), stable (σ^2 = 0.5) steelhead life histories, except when equilibrium population size is very much greater than the measurement threshold. Selection of a measurement threshold determined the difference between determinations of low and high risk levels for most combinations of abundance, productivity, and variance. Even relatively modest differences in thresholds of 100 to 300 resulted in very different depictions of risk except at the bounds of abundance, productivity, and variance parameters examined.

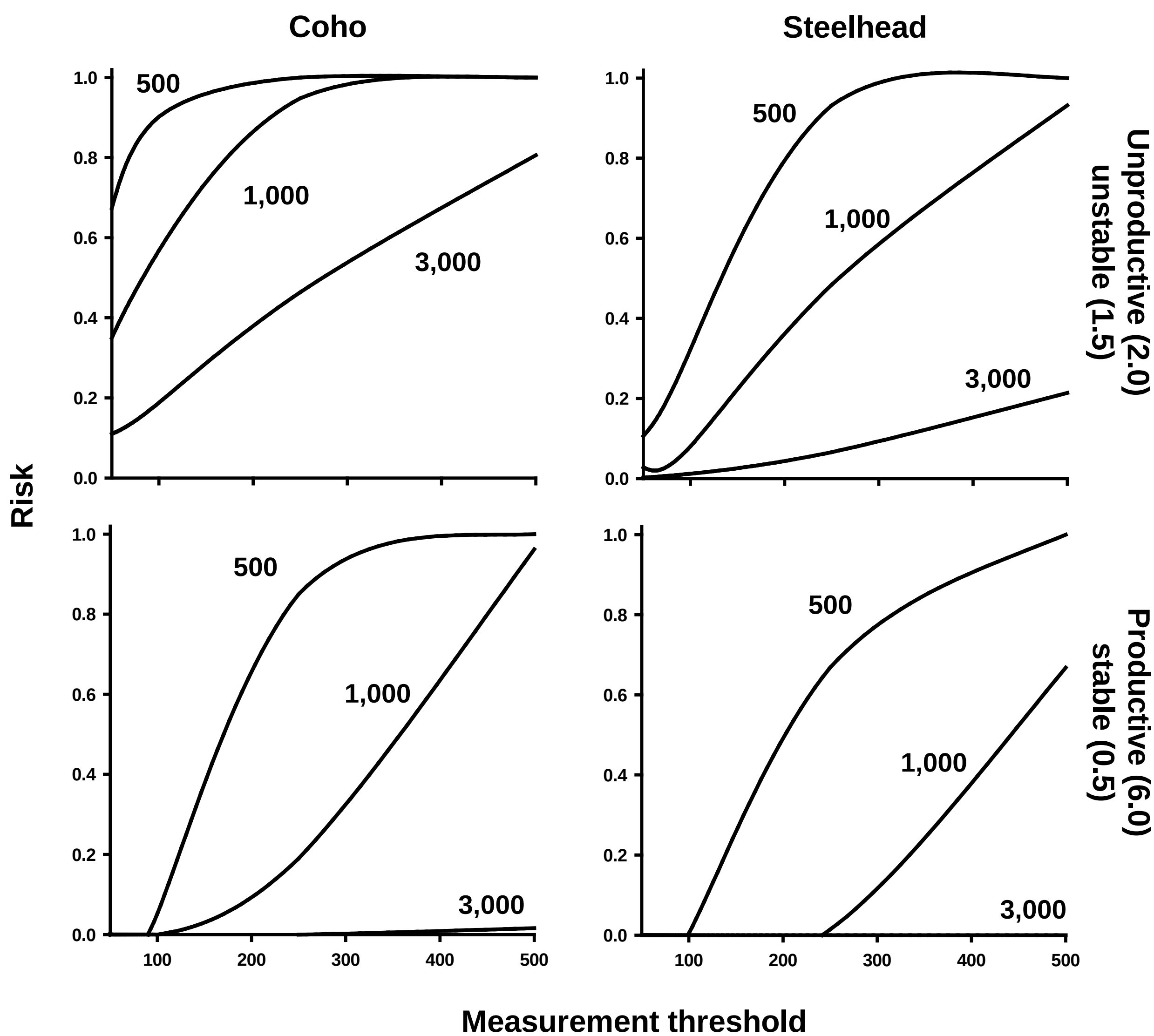

Figure E12-11. Sensitivity of measured risks of example coho and steelhead populations to threshold values (quasi-extinction or critical thresholds) for a range of population sizes between 500 and 3,000.

Recruitment Failure Threshold

Model estimates of risks were not particularly sensitive to assumed recruitment failure thresholds of 10 to 100 (Figure E12-12). Effects were most pronounced for relatively small (500), unproductive (p = 2.0), and unstable (σ^2 = 1.5) populations. Sensitivity increased as risk threshold decreased and as the RFT increased above 50 spawners. Differences between RFTs of 10 and 50 were minor for all combinations of population parameters examined.

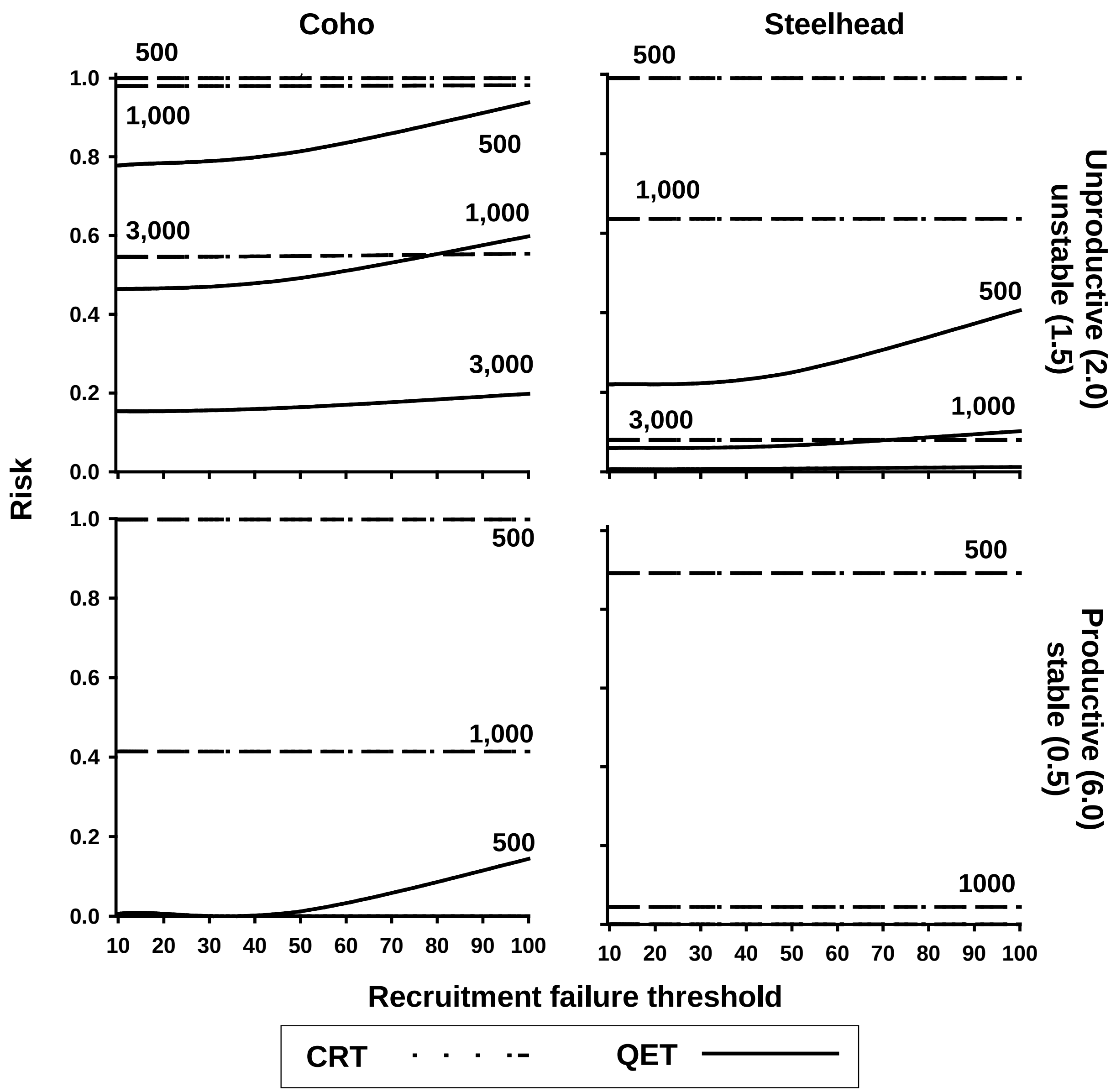

Figure E12-12. Sensitivity of QET (50) and CRT (300) risks of example coho and steelhead populations to recruitment failure thresholds for a range of population sizes and productivities.

Initial Population Size

Risks are sensitive to small initial starting sizes under some combinations of parameters but insensitive under others. Sensitivity is highest at very small initial numbers (<200), higher risk thresholds (300 vs. 50), low productivity, high variability, and a large disparity between initial numbers and the equilibrium population size (Figure E12-13). Where initial numbers are very small, probabilities of falling below critical risk thresholds are very high in the first few generations of the simulation, regardless of the equilibrium population size or average productivity. Effects of initial numbers decline considerably in the 100-year simulations as the initial population size approaches and exceeds the critical risk threshold.

Sensitivity to initial numbers is low for at population sizes because risks are high regardless of starting numbers.

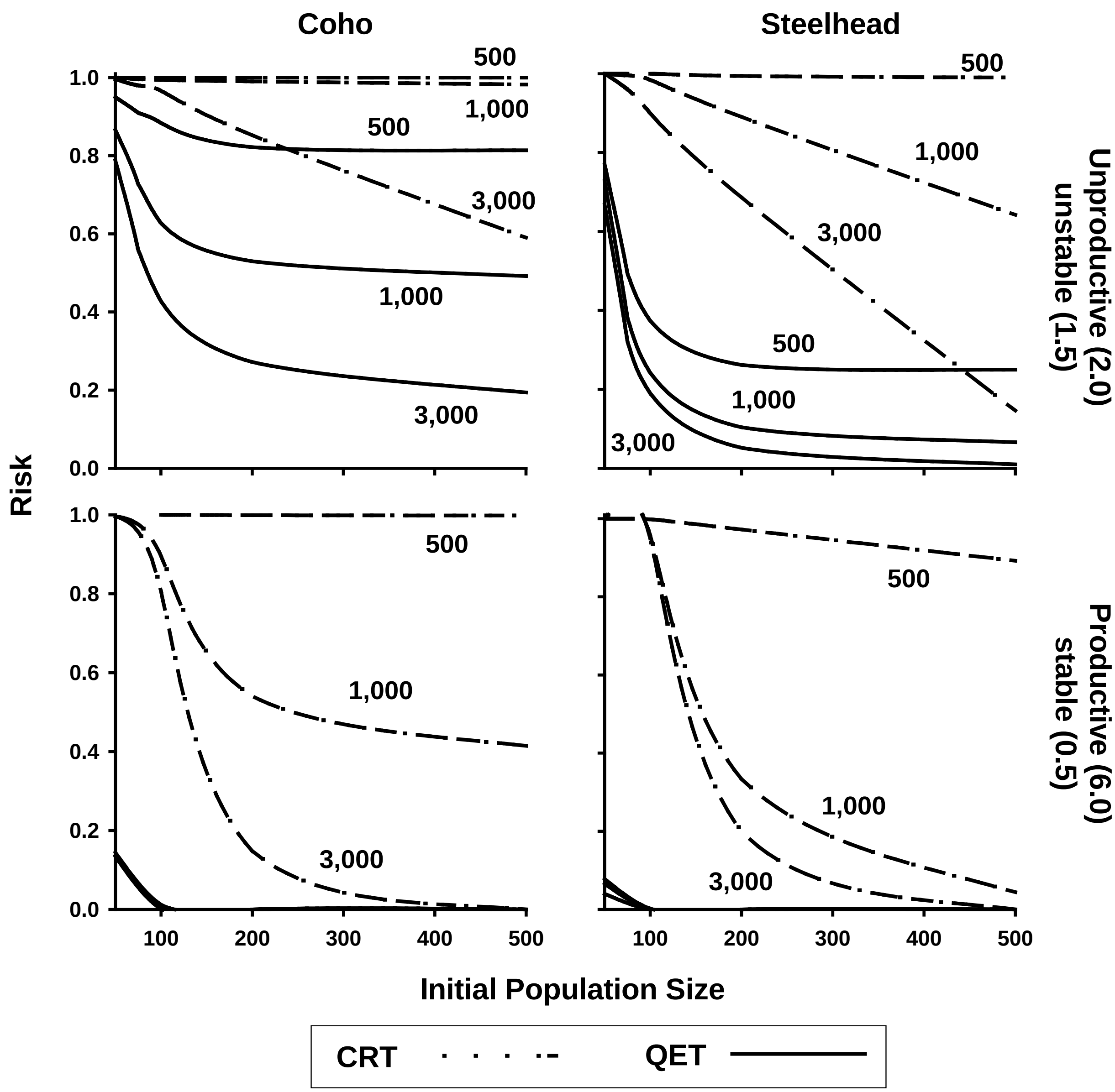

Figure E12-13. Sensitivity of QET (50) and CRT (300) risks of example coho and steelhead populations to initial population size for a range of population sizes and productivities.

Future Production Trend

Risks were generally not very sensitive to small trends in productivity over the 100 year simulations (up to a -20% net change which is equivalent to -0.22%/year). Risks were moderately sensitive to stronger trends, particularly for unproductive highly variable populations. Coho life history was more sensitive than steelhead life history for comparable combinations of population parameters.

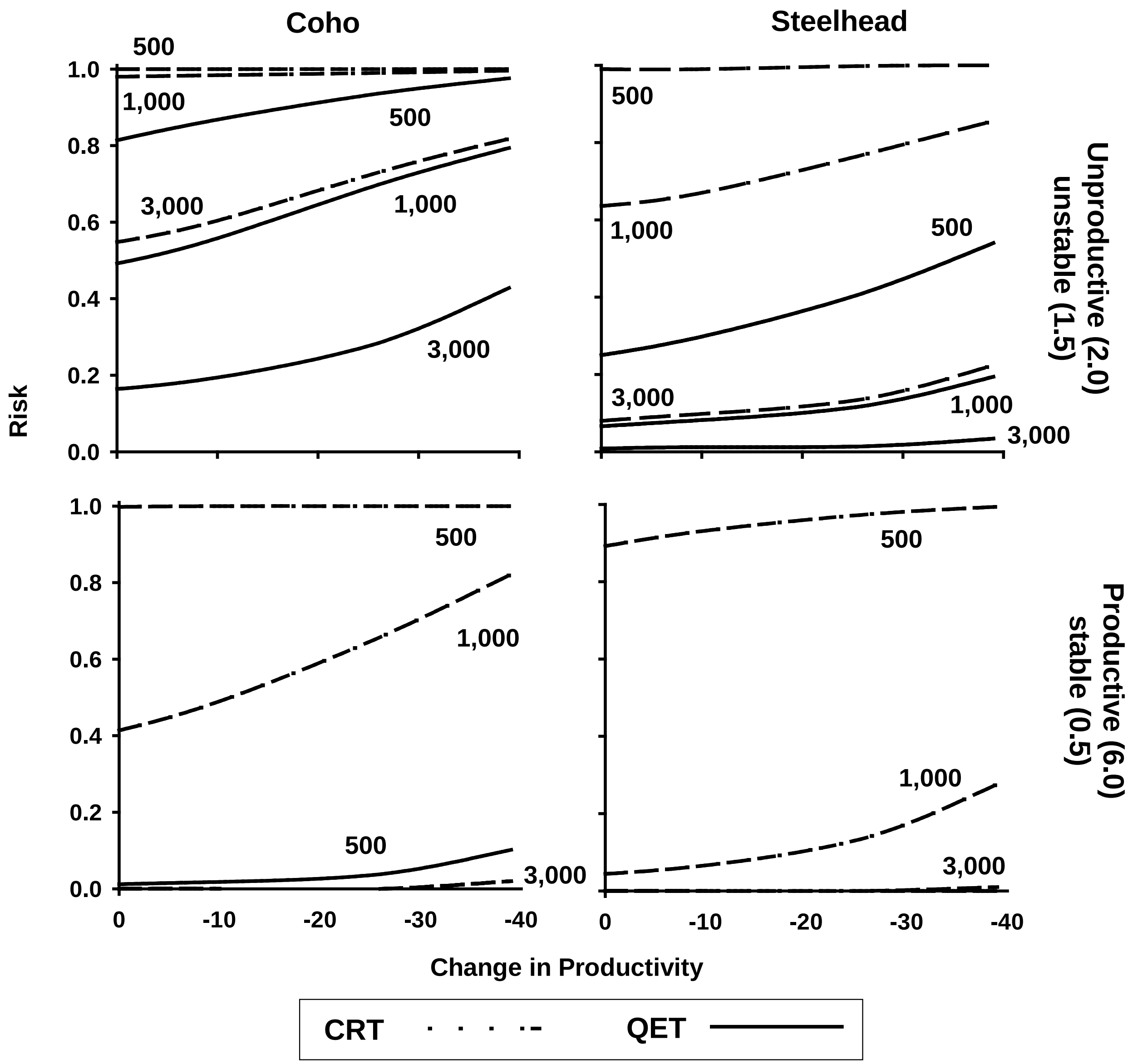

Figure E12-14. Sensitivity of quasi-extinction risks of example coho and steelhead populations to trends in future production for a range of population sizes between 500 and 3,000. The trend is represented as a net percentage change over 100 years.

Autocorrelated Variance

Both critical and quasi-extinction risks were sensitive to the degree of autocorrelation in the stock-recruitment variance (Figure E12-15). Increasing autocorrelation generally increased risks as compounding effects of successive low values reduced populations to low levels. Risks begin to decline at very high levels of autocorrelation as annual values tend to stabilize at a local level (Figure E12-3). Sensitivity to autocorrelation is greatest at low current production levels and population sizes. Risks are less sensitive to autocorrelation as productivity and population size increase. Coho life history was more sensitive than steelhead life history for comparable combinations of population parameters.

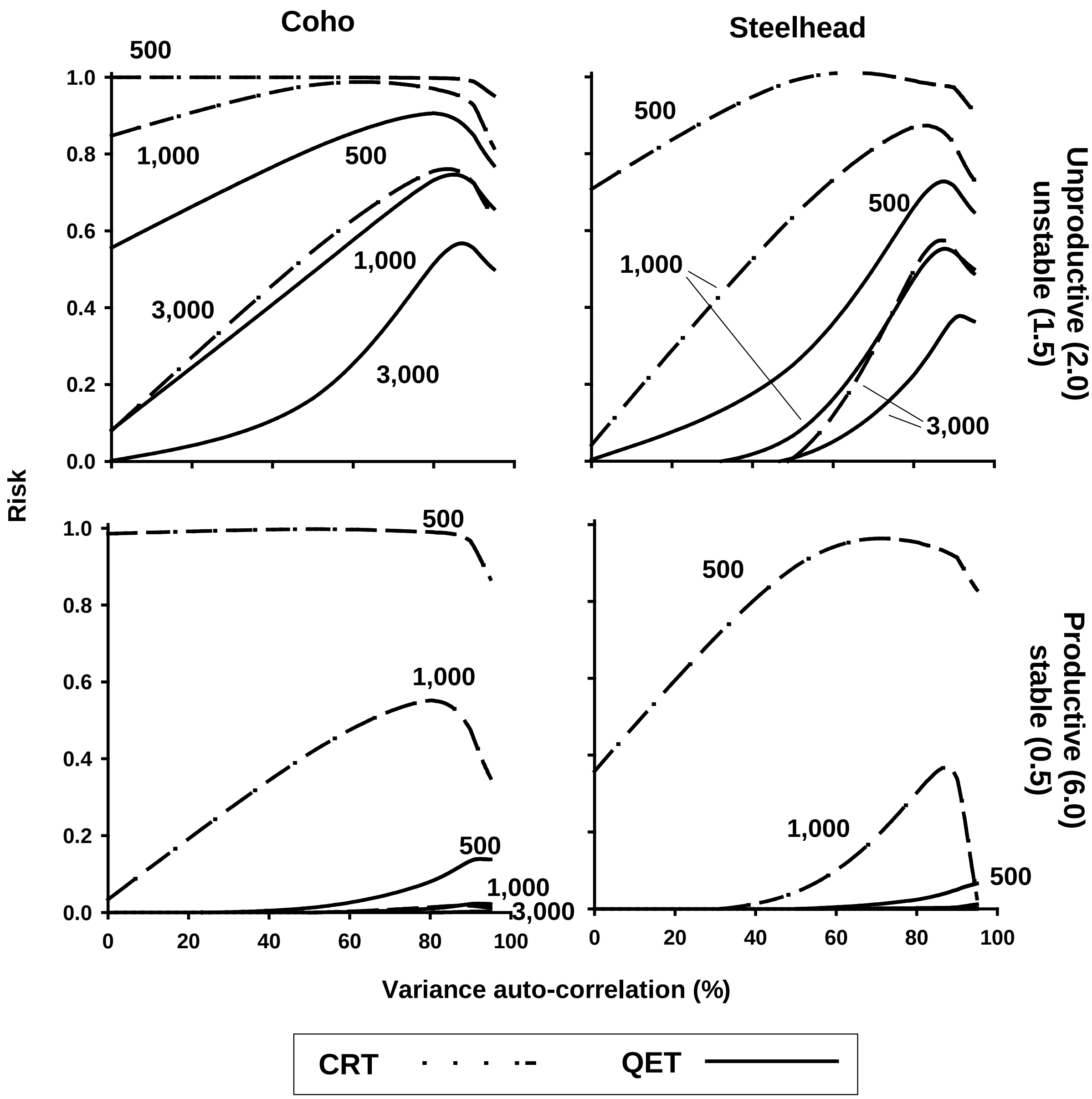

Figure E12-15. Sensitivity of quasi-extinction risks of example coho and steelhead populations to autocorrelation in stock-recruitment variance for a range of population sizes between 500 and 3,000.

E.3.4. Improvement Scalars

Interpretations of improvement scalars are best demonstrated with a simple example. Consider the case of a moderate-sized coho population (N_{eq} = 1,000) of moderate productivity (p = 4.0) subject to moderate inter-annual variability (σ^2 = 1.0) (Figure E12-16E). The critical risk (probability of the generation average number falling below 300) for this combination of parameters is projected to be 90% which is equivalent to a very high risk according to categories identified by the Willamette/Lower Columbia Technical Recovery Team. In this case, an 85% improvement in net productivity would be necessary to reduce the critical risk from 60% to 25% (moderate risk). A 195% improvement would be necessary to reduce the critical risk to 5% (low risk). At least a 300% improvement would be necessary to reduce the critical risk from to 1% (very low risk).

Population size, productivity, and variance all have a substantial impact on the scale of improvements needed to reduce risks to any given level (Figure E12-16 to Figure E12-19). Populations with low abundance, low productivity, and high variability will obviously require much greater improvements in net productivity to reach low levels of risk than populations of high abundance, high productivity, and low variability. For example, while an ten-fold improvement is needed to reach a low (5%) risk level for a moderately productive and variable but small (N_{eq} = 500) coho population, only a 70% improvement would be needed to reach a low risk level when the population size is 3,000 (Figure E12-16E).

Species differences in sensitivity to improvement scalars resulted from different generation times and corresponding age distributions. Thus, greater improvements were generally needed to restore a hypothetical coho population (Figure E12-16 and Figure E12-18) to a given level for any combination of population parameters than for a steelhead population (Figure E12-17 and Figure E12-19). Spring Chinook, fall Chinook, and chum results would be intermediate between these two species. Of course, different species might be characterized by different ranges of abundance, productivity, and variability and so gross generalizations regarding the relative resilience of different life schedules need to be viewed with caution.

Increasingly larger improvement increments are needed to gain marginal improvements in risk as risk levels are reduced. Thus, relatively modest productivity improvements can have a significant effect on risk but much larger improvements can be required to move from low to very low risk levels.

Substantially smaller increments would be required if goals were based on quasi-extinction risks (50 in these simulations) than on the greater critical risk threshold (300). Risks of falling below the lower threshold are substantially less for any given combination on parameters.

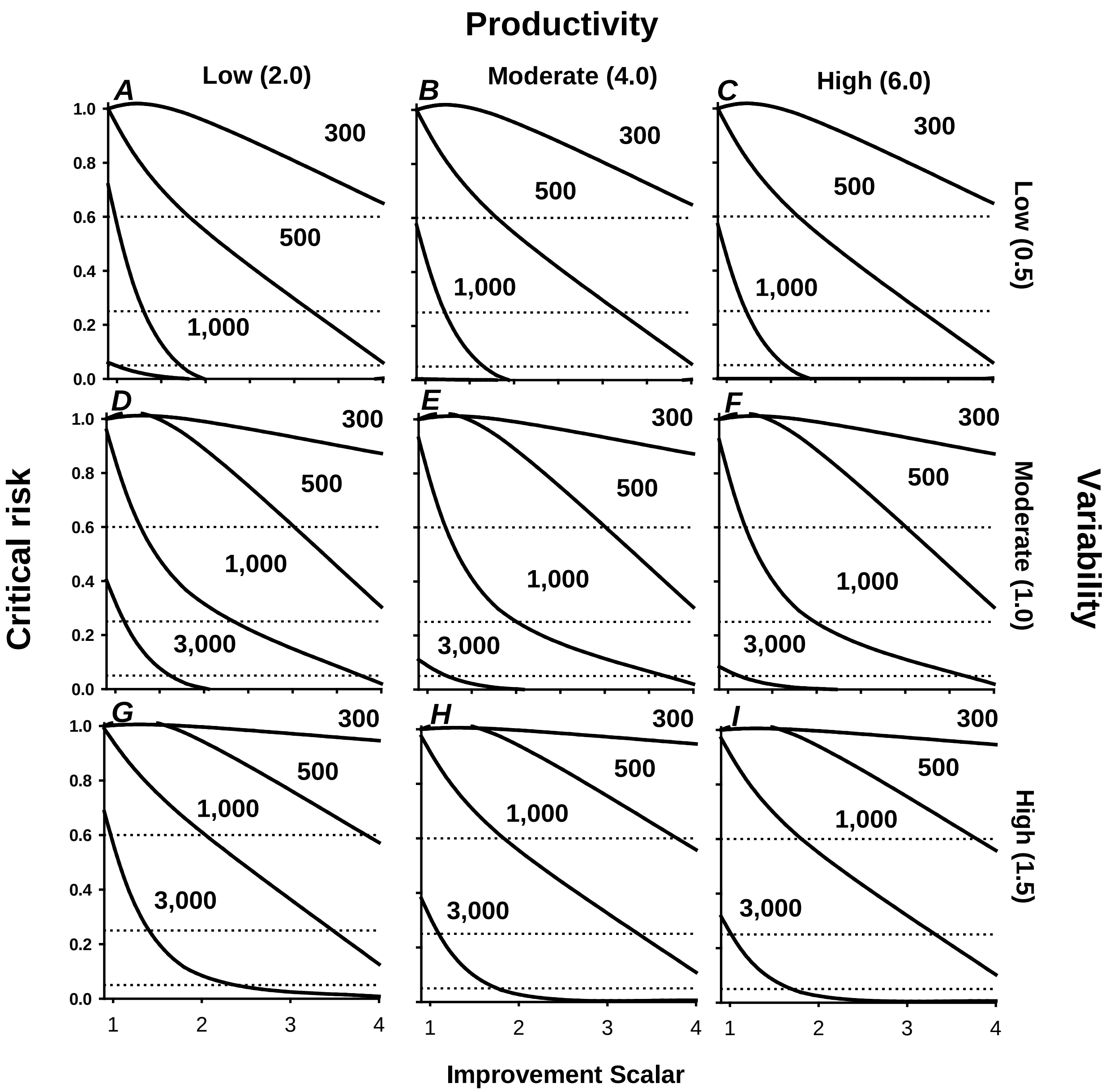

Figure E12-16. Sensitivity of critical risks (CRT = 300) of a hypothetical coho population to improvement scalars for various combination of productivity (recruits per spawner), equilibrium abundance, and inter-annual variability. Benchmark risks corresponding to very high (>60%), high (>25%), and moderate (>5%) extinction risks are indicated.

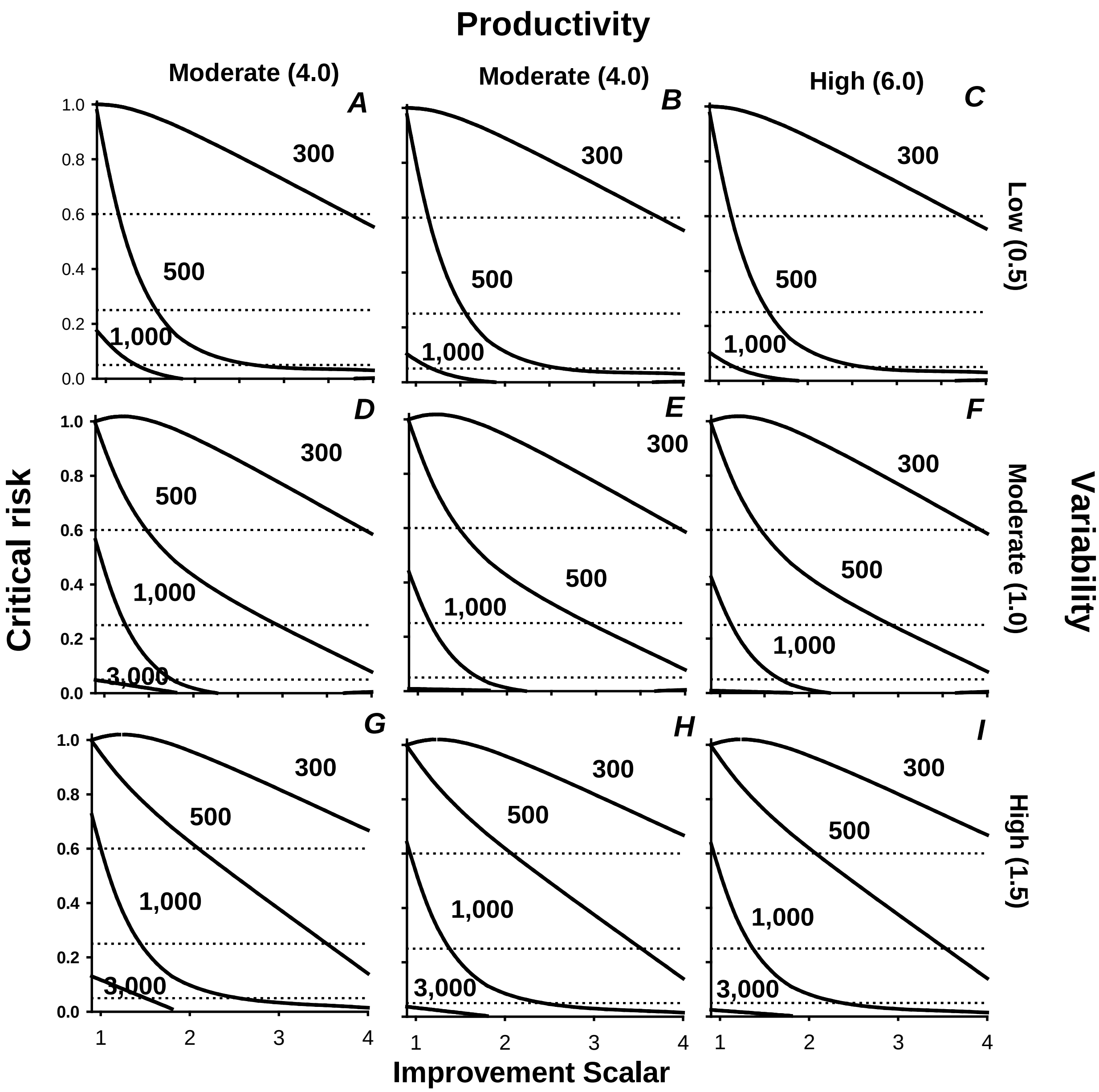

Figure E12-17. Sensitivity of critical risks (CRT = 300) of a hypothetical steelhead population to improvement scalars for various combination of productivity (recruits per spawner), equilibrium abundance, and inter-annual variability. Benchmark risks corresponding to very high (>60%), high (>25%), and moderate (>5%) extinction risks are indicated.

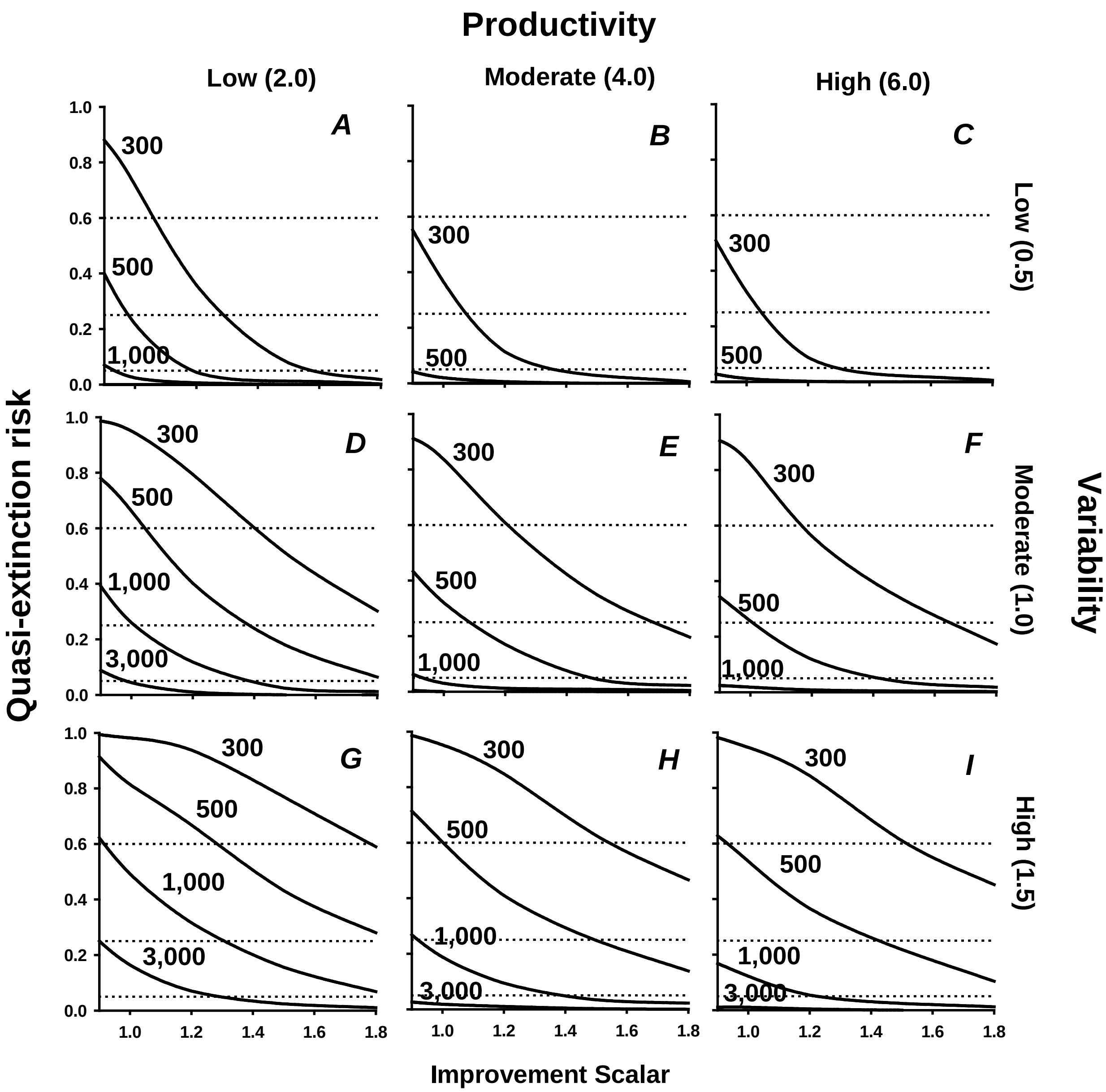

Figure E12-18. Sensitivity of quasi-extinction risks (QET = 50) of a hypothetical coho population to improvement scalars for various combination of productivity (recruits per spawner), equilibrium abundance, and inter-annual variability. Benchmark risks corresponding to very high (>60%), high (>25%), and moderate (>5%) extinction risks are indicated.

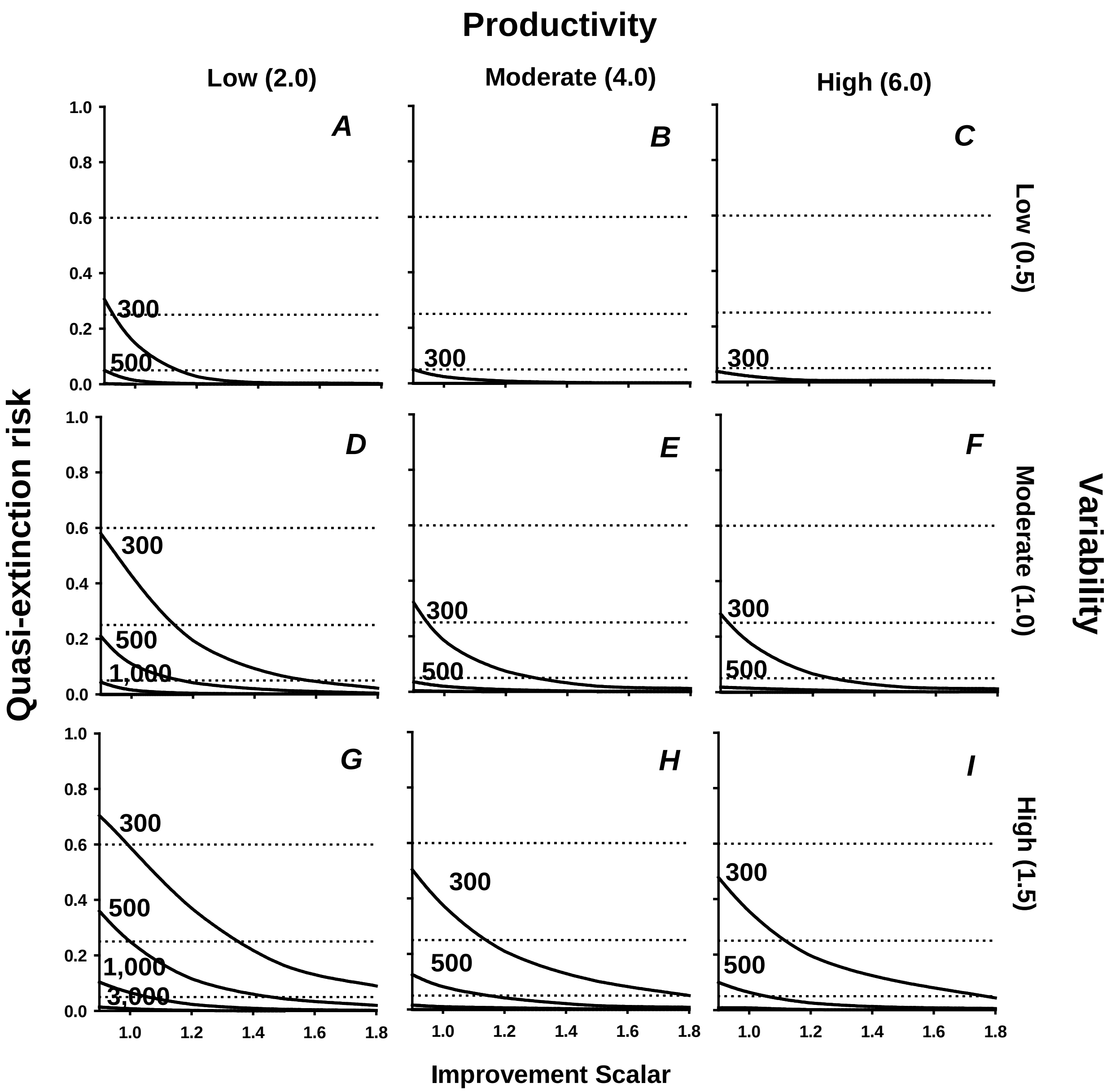

Figure E12-19. Sensitivity of quasi-extinction risks (QET = 50) of a hypothetical steelhead population to improvement scalars for various combination of productivity (recruits per spawner), equilibrium abundance, and inter-annual variability. Benchmark risks corresponding to very high (>60%), high (>25%), and moderate (> 5%) extinction risks are indicated.

E.3.5. Current Population Risks

Risks estimated with this PVA analysis are summarized for Oregon and Washington lower Columbia and Willamette populations in Table E12-3 and in Attachment tables. Attachment tables report quasi-extinction and critical risks. Attachment tables also include estimates based on current fishing rates and fishing rates prevalent at the time of initial listing of many lower Columbia River ESUs (1998-1999). Representative risk levels discussed below are critical risks reference period corresponding to listing of most species during the late 1990s.

Coho run reconstructions are available for the Clackamas and Sandy Rivers (ODFW, unpublished). Parameters for other lower Columbia coho populations in Oregon were inferred from habitat analyses.

EDT analyses are available for Washington coho populations (WDFW unpublished)[1]. The majority of Oregon and Washington coho populations were estimated to be at moderate to very high risk of falling below critical thresholds. Only the Clackamas coho population appeared to be at a low demographic risk of falling below the critical threshold. The Lower Cowlitz population was projected to be at moderate risk.

Spring Chinook run reconstructions are available for Sandy, Clackamas, and McKenzie populations (ODFW, unpublished). EDT analyses are available for Washington populations (WDFW unpublished). Adult and juvenile data is also available in Washington from reintroduction efforts in the Upper Cowlitz but this data was not incorporated into this analysis due to the experimental nature of the reintroduction. Based on the available data, only the Clackamas population was projected to be at low risk (<5%) of falling below the critical threshold. The Sandy and McKenzie populations were projected to be at moderate risk. All Washington populations were projected to be at very high risk.

Fall Chinook data is widely available for Washington populations based on EDT inferences from habitat conditions. Stock-recruitment data is available for Oregon's Clatskanie (tule) and Sandy (late) populations. Population parameters for other Oregon populations were inferred from recent spawner numbers relative to other populations where data exists. The two late fall Chinook populations (Lewis and Sandy) were projected to be at low or very low risk of falling below critical thresholds. The Lower Cowlitz and Coweeman populations were estimated to be at low demographic risk. Risks for other populations were moderate to very high.

Limited data is available for chum. Spawner surveys indicate that most historical populations are extirpated or at very low levels. Significant populations occur only in the Grays and lower Gorge.

Steelhead data was available for almost all Oregon and Washington populations based on run reconstructions or EDT analysis. Eight of the 29 winter and summer steelhead populations were projected to be at low or very low risk. The remaining populations were at moderate to very high levels of risk.

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[1] EDT values were decremented to reflect assumed effects of hatchery-origin natural spawners on productivity. Decrement values considered the proportion of hatchery origin spawners and source of the hatchery broodstock.

Table E12-4. Critical population risks based on population viability analysis of abundance and productivity (reference period corresponding to listing of most species during the late 1990s).

	Population	State	Coho	Chinook			Chum	Steelhead	
				Spring	Fall	Late Fall		Winter	Summer
Coast	Grays/Chinook	WA	VH	--	VH	--	VL	VL[3]	--
	Eloch/Skam	WA	VH	--	VH	--	VH	VL[3]	--
	Mill/Ab/Germ	WA	VH	--	VH	--	VH	L[3]	--
	Youngs	OR	VH	--	VH	--	VH	--[3]	--
	Big Creek	OR	VH	--	VH	--	VH	--[3]	--
	Clatskanie	OR	VH	--	VH	--	VH	--[3]	--
	Scappoose	OR	VH	--	VH	--	VH	--[3]	--
Cascade	Lower Cowlitz	WA	VH	VH	M	--	VH	H	--
	Coweeman	WA	VH	--	H	--	--	H	--
	N. F. Toutle	WA	VH	XX[1]	XX[1]	--	--	VH	--
	S. F. Toutle	WA	VH	VH	VH			M	
	Upper Cowlitz	WA	VH	XX[1]	VH	--	--	VH	--
	Cispus	WA	VH	VH	--	--	--	VH	--
	Tilton	WA	VH	VH	--	--	--	VH	--
	Kalama	WA	VH	VH	VH	--	VH	H	L
	N.F. Lewis	WA	VH	VH	XX[1]	VL	--	VH	VH
	E.F. Lewis	WA	VH	--	VH	--	VH	M	VH
	Salmon	WA	VH	--	VH	--	VH	VH	--
	Washougal	WA	VH	--	VH	--	VH	H	M
	Clackamas	OR	H	M[2]	VH	--	VH	L	--
	Sandy	OR	VH	H	VH	H	VH	VH	--
Gorge	L. Gorge	OR/WA	VH	--	VH	--	VL	H	--
	U. Gorge	WA	VH	--	VH	--	VH	H	VL
	White Salmon	WA	XX[1]	VH	VH		--	--	--
	Hood	OR	VH	VH	VH	--	--	M	VH
Willamette	Molalla	OR	--	VH	--	--	--	M	--
	N. Santiam	OR	--	VH	--	--	--	L	--
	S. Santiam	OR	--	VH	--	--	--	L	--
	Calapooia	OR	--	VH	--	--	--	M	--
	McKenzie	OR	--	M	--	--	--	--	--
	Middle Fork	OR	--	VH	--	--	--	--	--

[1] *Included in another population*
[2] *Clackamas spring Chinook are part of the Willamette ESU.*
[3] *Not listed.*

E.3.6. Lower Columbia & Willamette Population Recovery Targets

Incremental improvements in productivity projected to restore lower Columbia salmonid populations to moderate, low, and very low levels of risk are summarized in the attachments. Note that productivity increments are proportional increases in recruits per spawner for any given spawner number. This is equivalent to increasing both the productivity and capacity parameters in the stock-recruitment function. Improvement scalars are reported relative to both current and listing baseline periods. Significant reductions in risk were apparent for many populations due to reduced fishery impacts between the listing baseline and current conditions. Impact rate limits have been reduced from 65% to 50% for tule Fall Chinook, 50% to 25% for spring Chinook, and 50% to 25% for coho. Effects of other conservation measures implemented since listing are not reflected in risk projections because benefits have not yet translated into measurable increases in fish population parameters used to describe current fish status in these simulations.

Improvement scalars required to reach moderate (<25%), low (<5%), and very low (<1%) risks are plotted in Figure E12-20 relative to current population risk for lower Columbia River populations where status information is adequate to estimate or infer risks. Increments for any given risk level vary depending on species and population productivity and capacity. Incremental improvements exceeding 1000% were not calculated and are considered undefined for very high risk populations. Current and projected population numbers are plotted in Figure E12-21 relative to risks for each species. Median spawner numbers corresponding to any given risk level vary depending on species and population productivity and capacity (Table E12-4). Coho generally require the largest numbers to reach any given risk while steelhead require the smallest numbers to reach any given risk. For instance, low risks (<5%) are generally achieved for coho at median population sizes of 1,100 to 5,000. Low risks are generally achieved for steelhead at population sizes of 300 to 2,100. This reflects the shorter generation time and higher annual variability of coho relative to steelhead. Chinook and chum are generally intermediate between coho and steelhead. Ranges of spawner numbers corresponding to any given level of risk overlap due to the effects of variable productivity.

Table E12-5. Spawner numbers needed to achieve a given risk level by species.

	Risk (median)			Risk (range)		
Species	**Moderate**	**Low**	**Very low**	**Moderate**	**Low**	**Very low**
Coho	1,100	2,000	2,300	700-3,000	1,100-5,000	1,600-7,000
Spring Chinook	1,100	1,500	2,100	700-1,200	900-1,800	1,300-2,300
Fall Chinook	500	1,100	1,900	400-2,300	700-3,600	1,000-6,000
Chum	900	1,300	1,800	700-1,100	1,100-1,600	1,500-2,000
Steelhead	400	500	700	200-1,400	300-2,100	300-2,900

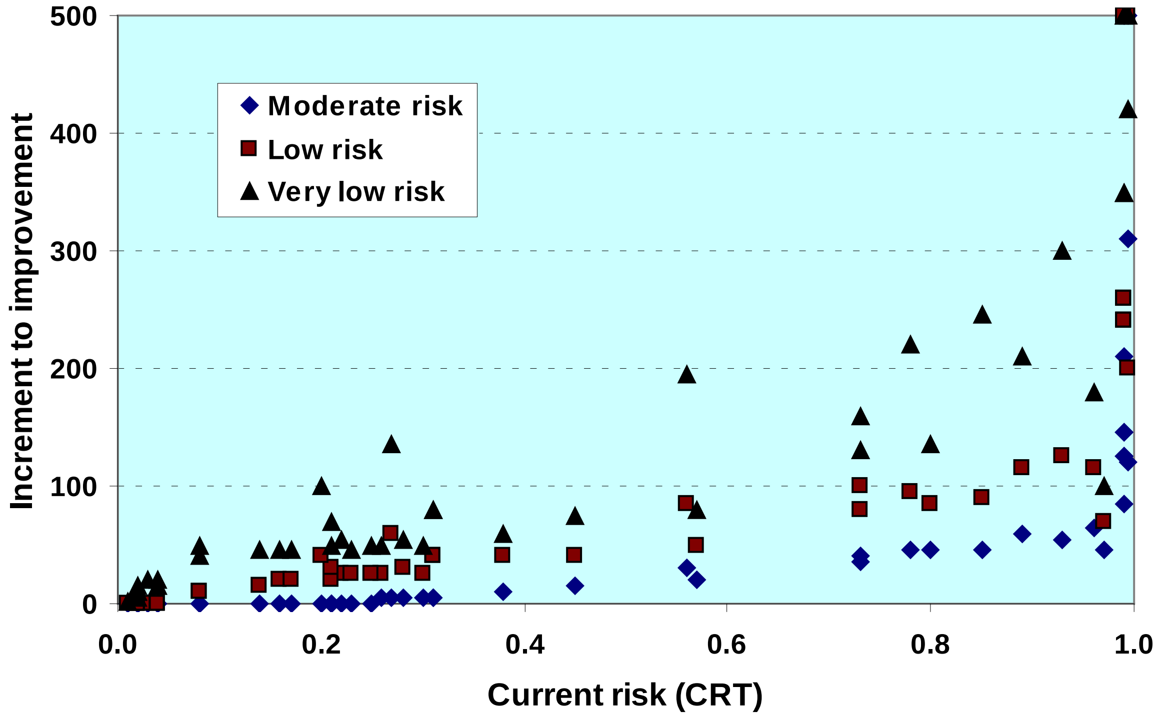

Figure E12-20. Improvement increments required to reduce risk for lower Columbia River salmonid populations relative to current risk levels. Increments are defined as percentage improvements in productivity relative to the current level (e.g. 100% represents an improvement scalar of 2.0).

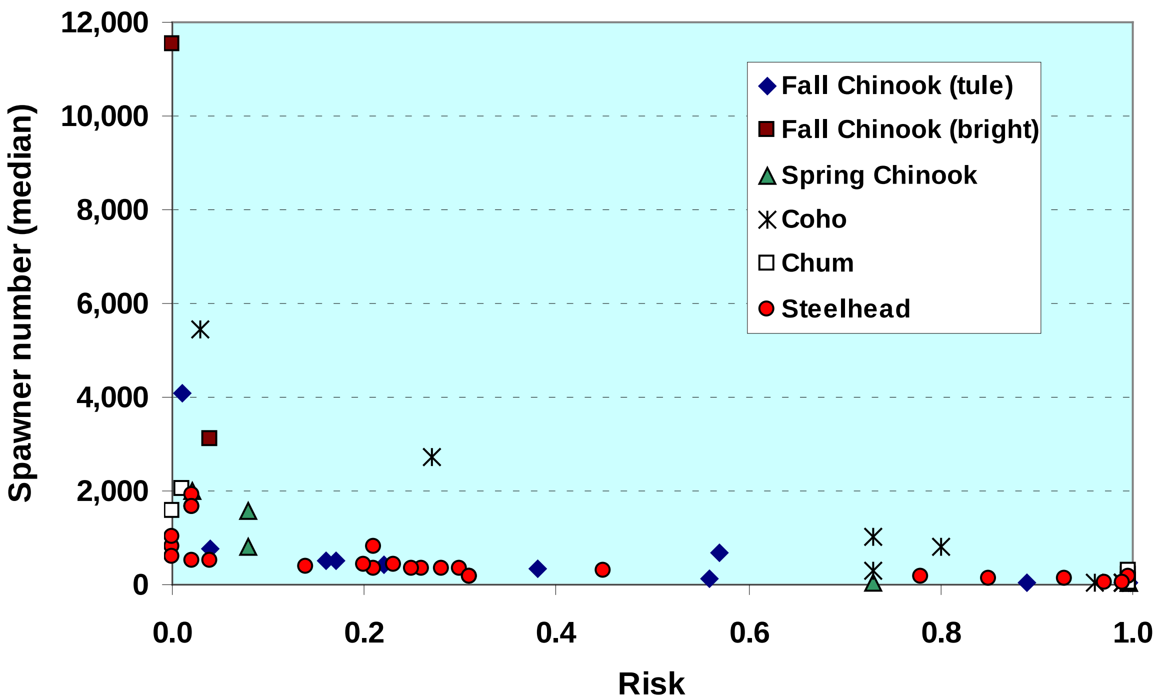

Figure E12-21. Current abundance relative to current risk levels for lower Columbia River salmonids populations.

E.4. Discussion

Population Viability Analyses like those described in this report provide an explicit quantitative basis for estimating risk levels associated with combinations of population parameters. Analyses of generic population values demonstrate the high quasi-extinction risks (>25%) associated with combinations of small equilibrium population sizes (300 or less), low productivities (<5 recruits per spawner at low to intermediate spawner densities, and high, autocorrelated variances in annual recruits per spawner (1.0 or greater). Conversely, quasi-extinction risks are typically low or very low at equilibrium population sizes of 3,000 or greater and inherent productivities of 5 recruits per spawner. Quasi-extinction risks can be estimated for intermediate combinations of population parameters from values detailed in this report.

Analyses were useful for quantifying the level of improvement needed to reduce risk to specified levels. Improvement increments necessary to restore depleted population to high levels of viability obviously depend on current population parameters and associated risk levels. Analyses suggest that moderate improvements in production of 20-80% can be expected to reduce quasi-extinction risks to low levels at moderate population values for abundance, productivity, and variation. However, substantially greater levels of improvement will be necessary to restore populations subject to the combined effects of low numbers, low productivity, and high variability.

Sensitivity analyses illustrate the importance of benchmark threshold levels to the calculation to risk levels. The basis for identification of key quasi-extinction and other levels of conservation concern is quite limited. Other PVA's published to date have used a wide range of values. Choices of different values can lead to very different conclusions. Application of the PVA approach must be considered in light of this significant limitation. This limitation in the application and interpretation of the PVA approach also highlights the value of a multilayered approach to status assessments that also considers qualitative factors such as spatial structure and diversity, as well as empirical data on population trends and responses to recovery measures.

Results of these analyses indicate that a number of salmon and steelhead populations in Oregon and Washington lower Columbia and Willamette river subbasins are demographically viable at current levels and not at significant risk of extinction. Noteworthy examples include Clackamas coho; Clackamas spring Chinook; Lower Cowlitz, and Coweeman fall Chinook; Lewis and Sandy late fall Chinook; Grays/Chinook and lower Gorge chum; Coastal, Clackamas, and upper Willamette winter steelhead;. However, analyses also identified significant extinction risks among many populations in each ESU and the need for substantive improvements to reduce risks to viable levels. Analyses also highlighted significant differences in population parameters and viability related to the life history strategy of each species. These differences mean that the same population levels which might pose significant risk for one species might be entirely viable for another.

This analysis generally depicts more favorable status assessments for some populations than has been published by the WLC/TRT. WLC/TRT assessments based on qualitative or subjective evaluations have typically assessed most lower Columbia River populations to be at high or very high risk of extinction. The most robust populations were thought to be at moderate risk. Our analysis suggests that several populations of each species may be at low to very low risk of extinction based on population demographics. Assigned risks depend heavily on assumptions regarding quasi-extinction levels for which there is little empirical information. This assessment used a moderate recruitment failure and quasi-extinction threshold value of 50 which was based largely on genetics theory. Model sensitivity analyses indicate that much higher risks would be assigned for existing populations at failure threshold values of 100-300 spawners. However, failure thresholds in the 100-300 spawner range are not supported by available time series data. A number of lower Columbia River populations have fallen below these levels during an extended recent period of poor ocean productivity but subsequently have rebounded. Many salmon populations have been observed to persist at low levels for extended periods.

Demographic PVA analyses are based on abundance and productivity and do not directly consider characteristics such as spatial structure and diversity which have also been related to population viability (McElhany et al. 2000). However, abundance and productivity levels implicitly consider the effects of spatial structure and diversity because all four viable salmonid parameters are closely related and it is unlikely that high levels of abundance or productivity can be achieved or sustained without comparably high levels of spatial structure and diversity. We also note that spatial structure and diversity effects of factors such as the influence of hatchery fish and changing climate patterns can be manifested in increasing population variability which directly affect risks estimated using PVA.

Analyses consider independent populations although in reality the historical salmon population structures included a significant metapopulation structure consisting of a complex of interdependent populations and population segments. Thus analysis of independent populations is pessimistic relative to the historical population structure but may be appropriate under current conditions where many populations have been isolated by the erosion of significant metapopulation structure. To this extent, the simulations implicitly capture spatial structure effects associated with the loss of metapopulation structure. However, results would not accurately reflect risks to dependent populations, some of which may be sustainable as satellites to a proximate anchor population.

Improvement scalars were estimated in this analysis based on an assumption of no decreasing or increasing trend in future conditions. Long term effects of climate change and increasing development could result in a long term declining trends in salmon productivity which would warrant even greater levels of effort to implement offsetting improvements needed to reach desired levels of population viability. Conversely, significant recovery actions implemented to date, particularly in hatchery and habitat arenas, could require a number of years before their full effects are realized. In either case, sensitivity analyses of risks to future trends included in this report can inform these considerations.

This analysis did not explicitly consider the effects of measurement error in population parameters on apparent risks. For instance, improvement scalars were not defined to offset potential measurement errors which might have caused population potential to be overestimated. All population parameters are estimated using the best available data to provide the most likely estimates of actual status. In fact, estimates of annual population variability include effects of both process and measurement error. The result is implicit consideration of measurement errors in risk calculations and overestimates of actual risk levels and the scale of improvements necessary to reduce risks to viable levels. Definition of risk levels and recovery increments to offset the potential effects on measurement error would have significant implications to recovery planning. First, populations would need to be recovered to levels higher than necessary in order to prove that to prove viability. This will place a potentially costly burden on activities that affect salmon and may represent unrealistic or unattainable goals where measurement error is significant. Conversely, recovery goals for some populations might be achieved by improving assessment methods to reduce measurement error. Thus, some populations could be “recovered” with no substantive improvement in actual viability. Explicit rather than implicit consideration of actual status and measurement error effects is recommended.

Estimates of risks and improvement increments included in this analysis did not explicitly incorporate harvestability goals. Many recovery plans seek to restore salmon populations to levels which provide for beneficial uses in the form of a harvestable surplus. Salmon populations are entirely capable of providing significant and sustainable harvests in many or most years without risk as long as spawning escapement needs are met and the impacts of other factors are limited to ensure population productivity and resilience. Thus, fishery impacts can be considered a risk factor at low population levels but a benefit of a restored population. Restoration of populations to sustainable, fishable levels will typically require greater reductions in nonfishing impacts that would restoration to sustainable unfished levels. The balance of fishing and nonfishing goals is ultimately a policy issue.

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ATTACHMENT

Table E12-6. Current population parameters and risk levels for modeling recovery increments of lower Columbia coho populations.

Population	State	Data type[a]	N_{eq}[b]	R/S[c]	R/S′[d]	[σ^2][e]	lag[f]	CRT[g]	Risk (1999 reference)[h] QET[i]	CRT[j]	cat.[k]
Coast											
Grays/Chinook	W	2	800	2.0	--	1.0	0.3	200	>99%	>99%	VH
Eloch/Skam	W	2	1,400	2.2	--	1.0	0.3	200	96%	>99%	VH
Mill/Ab/Germ	W	2	400	2.6	--	1.0	0.3	200	>99%	>99%	VH
Youngs	O	3	1,100	--	1.0	1.0	0.3	100	>99%	>99%	VH
Big Creek	O	3	700	--	1.5	1.0	0.3	100	>99%	>99%	VH
Clatskanie	O	3	1,200	--	3.0	1.0	0.3	200	51%	97%	VH
Scappoose	O	3	1,200	--	3.0	1.0	0.3	200	51%	97%	VH
Cascade											
Lower Cowlitz	W	2	5,100	3.7	--	1.0	0.3	300	46%	90%	VH
Coweeman	W	2	900	2.7	--	1.0	0.3	100	99%	>99%	VH
Toutle (NF & SF)	W	2	3,200	2.7	--	1.0	0.3	300	96%	>99%	VH
Upper Cowlitz	W	3	na	na	na	--	--	300	na	na	VH
Cispus	W	3	na	na	na	--	--	300	na	na	VH
Tilton	W	3	na	na	na	--	--	200	na	na	VH
Kalama	W	2	200	3.0	--	1.0	0.3	200	>99%	>99%	VH
NF Lewis (lower)	W	2	1,900	3.6	--	1.0	0.3	300	63%	>99%	VH
EF Lewis	W	2	400	1.8	--	1.0	0.3	200	>99%	>99%	VH
Salmon	W	2	600	1.8	--	1.0	0.3	100	>99%	>99%	VH
Washougal	W	2	300	1.6	--	1.0	0.3	200	>99%	>99%	VH
Clackamas	O	1	8,000	--	3.0	1.0	0.4	300	7%	29%	H
Sandy	O	1	4,000	--	3.5	1.0	0.6	300	27%	71%	VH
Gorge											
L Gorge	W/O	3	500	--	1	1.0	0.3	100	>99%	>99%	VH
U Gorge	W	2	500	--	1	1.0	0.3	100	>99%	>99%	VH
U Gorge	O	3	500	--	1	1.0	0.3	100	>99%	>99%	VH

[a] 1 = stock- recruitment from adult spawner data (modeled as a hockey stick function), 2 = Ecosystem Diagnosis and Treatment Model inference from habitat conditions (Beverton-Holt), 3= assumed based on limited data and representative species ranges (modeled as a hockey stick function).
[b] Pre-harvest equilibrium abundance parameter.
[c] Pre-harvest population productivity parameter (maximum value at low spawner numbers from Beverton-Holt function).
[d] Pre-harvest population productivity parameter (geometric mean recruits per spawner at broods less than equilibrium from Hockey-stick function).
[e] Stock-recruitment variance parameter.
[f] Autocorrelation in stock-recruitment variance based on species values derived by McElhany et al. 2006.
[g] Critical risk threshold identified for population based on basin size.
[h] Probabilities of falling below threshold values under fishing rates prevalent prior to ESA listings (coho 50%,spring Chinook 50%, tule fall Chinook 65%, bright fall Chinook 50%, chum 5%, steelhead 10%).
[i] QET is projected quasi-extinction risk based on a geometric mean population size of less than 50 spawners in one generation.
[j] CRT is projected critical risk based on a geometric mean population size of less than the specified number of spawners in one generation.
[k] Risk categories based on critical risk threshold probability from population viability analysis included in this report (VH = very high risk of >60%, H = high risk of 26-60%. M = moderate risk of 5-25%, L = low risk of 1-5%, VL = very low risk of <1%).
[l] Probabilities of falling below threshold values under fishing rates currently prevalent (coho 25%,spring Chinook 25%, tule fall Chinook 50%, bright fall Chinook 50%, chum 5%, steelhead 10%).
na = not available

Table E12-7. Improvements required to reduce risk for lower Columbia coho populations.

			1999 reference[a]						
		Risk	Increment to achieve[c]			Spawners @[d]			
Population	**St.**	**cat.**[e]	**M**	**L**	**VL**	**Ref**	**M**	**L**	**VL**
Coast									
Grays/Chinook	W	VH	215%	370%	840%	<50	1,360	2,450	5,780
Eloch/Skam	W	VH	110%	170%	260%	<50	1,510	2,390	3,690
Mill/Ab/Germ	W	VH	520%	>1000%	>1000%	<50	1,750	na	na
Youngs	O	VH	790%	>1000%	>1000%	<50	1200	na	na
Big Creek	O	VH	340%	520%	850%	<50	670	1,120	1,860
Clatskanie	O	VH	95%	180%	305%	260	1,100	1,600	2,400
Scappoose	O	VH	95%	180%	305%	260	1,100	1,600	2,400
Cascade									
Lower Cowlitz	W	H	55%	100%	150%	530	2,330	3,720	5,300
Coweeman	W	VH	105%	170%	255%	<50	700	1,200	1,770
Toutle (NF & SF)	W	VH	115%	180%	270%	<50	2,380	3,780	5,950
Upper Cowlitz	W	VH	na	na	na	na	na	na	na
Cispus	W	VH	na	na	na	na	na	na	na
Tilton	W	VH	na	na	na	na	na	na	na
Kalama	W	VH	>1000%	>1000%	>1000%	<50	na	na	na
NF Lewis (lower)	W	VH	115%	200%	310%	190	1,840	2,910	4,280
EF Lewis	W	VH	520%	>1000%	>1000%	<50	2,170	na	na
Salmon	W	VH	155%	235%	350%	<50	800	1,340	2,130
Washougal	W	VH	>1000%	>1000%	>1000%	<50	na	na	na
Clackamas	OR	H	5%	40%	75%	2,720	3,020	4,700	6,400
Sandy	OR	VH	60%	140%	250%	1,280	2,820	4,610	6,720
Gorge									
L Gorge	W/O	VH	280%	430%	695%	<50	720	1,170	1,900
U Gorge	W	VH	280%	430%	695%	<50	720	1,170	1,900
U Gorge	O	VH	280%	430%	695%	<50	720	1,170	1,900

[a] Relative to base period prevalent prior to ESA listings (fishing rates: coho 50%,spring Chinook 50%, tule fall Chinook 65%, bright fall Chinook 50%, chum 5%, steelhead 10%).
[b] Relative to current (fishing rates: coho 25%,spring Chinook 25%, tule fall Chinook 50%, bright fall Chinook 50%, chum 5%, steelhead 10%).
[c] Improvement increments in recruits per spawner (at all spawner numbers) needed to achieve prescribed risk level based on critical risk threshold probability (e.g. 100% = 2 times current).
[d] Projected median abundance at prescribed risk level. Reference value is projected equilibrium based on critical risk threshold probability.
[e] Risk categories based on critical risk threshold probability from population viability analysis included in this report (VH = very high risk of >60%, H = high risk of 26-60%. M = moderate risk of 5-25%, L = low risk of 1-5%, VL = very low risk of <1%). Risk as assumed to be very high for populations where current numbers and population productivity were very small.
na = To be determined and likely very large (>1000%). Typically the case where numbers are very low or unknown.

Table E12-8. Current population parameters and risk levels for modeling recovery increments for lower Columbia and Willamette river spring Chinook populations.

Population	State	Data type[a]	N_{eq}[b]	R/S[c]	R/S′[d]	$[\sigma^2]$[e]	lag[f]	CRT[g]	Risk (1999 reference)[h] QET[i]	CRT[j]	cat.[k]
Cascade Spring											
Cowlitz	W	3	na	na	na	--	--	150	na	na	VH
Cispus	W	3	na	na	na	--	--	150	na	na	VH
Tilton	W	3	na	na	na	--	--	150	na	na	VH
Toutle	W	3	na	na	na	--	--	150	na	na	VH
Kalama	W	2	400	0.9	--	0.9	0.4	150	>99%	>99%	VH
Lewis NF (lower)	W	3	na	na	na	--	--	150	na	na	VH
Sandy	O	3	1,000	--	3.5	0.9	0.4	150	5%	47%	H
Gorge Spring											
White Salmon	W	3	na	na	na	--	--	50	na	na	VH
Hood	O	2	na	na	na	--	--	150	na	na	VH
Willamette Spring											
Clackamas	O	1	2,400	--	5.3	0.9	0.4	250	<1%	9%	M
Molalla	O	3	<100	na	na	--	--	150	>99%	>99%	VH
N. Santiam	O	3	<100	na	na	--	--	150	>99%	>99%	VH
S. Santiam	O	3	<100	na	na	--	--	250	>99%	>99%	VH
Calapooia	O	3	na	na	na	--	--	150	na	na	VH
McKenzie	O	1	2,000	--	2.4	0.9	0.4	250	14%	57%	H
Middle Fork	O	3	<100	na	na	--	--	250	>99%	>99%	VH

see Table E12-5 footnotes

Table E12-9. Improvements required to reduce risk for lower Columbia and Willamette river spring Chinook populations.

Population	St.	Risk cat.[e]	Increment to achieve[c] M	L	VL	Spawners @[d] Ref	M	L	VL
Cascade Spring									
Cowlitz	W	VH	na	na	na	na	na	na	na
Cispus	W	VH	na	na	na	na	na	na	na
Tilton	W	VH	na	na	na	na	na	na	na
Toutle	W	VH	na	na	na	na	na	na	na
Kalama	W	VH	na	na	na	na	na	na	na
Lewis NF (lower)	W	VH	na	na	na	na	na	na	na
Sandy	O	H	20%	70%	135%	500	620	920	1,270
Gorge Spring									
White Salmon	W	VH	na	na	na	na	na	na	na
Hood	O	VH	na	na	na	<50	na	na	na
Willamette Spring									
Clackamas	O	M	--	15%	55%	1,300	1,120	1,540	2,070
Molalla	O	VH	na	na	na	<50	na	na	na
N. Santiam	O	VH	na	na	na	<50	na	na	na
S. Santiam	O	VH	na	na	na	<50	na	na	na
Calapooia	O	VH	na	na	na	na	na	na	na
McKenzie	O	H	25%	65%	130%	800	1,200	1,720	2,480
Middle Fork	O	VH	na	na	na	<50	na	na	na

see Table E12-6 footnotes

Table E12-10. Model parameters and risk levels for lower Columbia River fall Chinook populations.

Population	State	Data type[a]	N_{eq}[b]	R/S[c]	R/S′[d]	$[\sigma^2]$[e]	lag[f]	CRT[g]	Risk (1999 reference)[h] QET[i]	CRT[j]	cat.[k]
Coast Fall											
Grays/Chinook	W	2	300	1.9	--	0.9	0.4	50	>99%	>99%	VH
Eloch/Skam	W	2	1,300	1.9	--	0.9	0.4	50	>99%	>99%	VH
Mill/Aber/Germ	W	2	1,000	2.2	--	0.9	0.4	50	>99%	>99%	VH
Youngs Bay	O	3	200	--	3	0.9	0.4	50	>99%	>99%	VH
Big Creek	O	3	200	--	3	0.9	0.4	50	>99%	>99%	VH
Clatskanie	O	3	350	--	4	0.9	0.4	50	94%	94%	VH
Scappoose	O	3	200	--	3	0.9	0.4	50	>99%	>99%	VH
Cascade Fall											
Lower Cowlitz	W	2	8,200	3.0	--	0.9	0.4	250	51%	79%	VH
Upper Cowlitz	W	2	na	na	na	--	--	250	na	na	VH
Toutle	W	2	2,400	1.6	--	0.9	0.4	150	>99%	>99%	VH
Coweeman	W	2	1,700	3.2	--	0.9	0.4	50	73%	73%	VH
Kalama	W	2	1,000	2.0	--	0.9	0.4	50	>99%	>99%	VH
Lewis	W	2	800	1.7	--	0.9	0.4	50	>99%	>99%	VH
Salmon	W	3	<100	na	na	--	--	50	>99%	>99%	VH
Washougal	W	2	1,100	1.9	--	0.9	0.4	50	>99%	>99%	VH
Clackamas	O	3	<100	na	na	--	--	150	>99%	>99%	VH
Sandy	O	3	<100	na	na	--	--	150	>99%	>99%	VH
Cascade L Fall											
Lewis NF	W	2	21,400	17.0	--	0.9	0.4	250	<1%	<1%	VL
Sandy	O	1	6,500	--	2.7	0.9	0.4	150	29%	46%	H
Gorge Fall											
L. Gorge	W/O	3	500	--	1	0.9	0.4	150	>99%	>99%	VH
U. Gorge	W/O	3	500	--	1	0.9	0.4	150	>99%	>99%	VH
White Salmon	W	3	<100	na	na	--	--	50	>99%	>99%	VH
Hood	O	3	<100	na	na	--	--	50	>99%	>99%	VH

see Table E12-5 footnotes

Table E12-11. Improvements required to reduce risk for lower Columbia River fall Chinook populations.

Population	St.	Risk cat. [e]	Increment to achieve[c] M	Increment to achieve[c] L	Increment to achieve[c] VL	Spawners @[d] Ref	Spawners @[d] M	Spawners @[d] L	Spawners @[d] VL
Coast Fall									
Grays/Chinook	W	VH	275%	900%	>1000%	<50	420	2,040	
Eloch/Skam	W	VH	100%	150%	200%	<50	880	1,540	2,170
Mill/Aber/Germ	W	VH	95%	155%	220%	50	430	870	1,280
Youngs Bay	O	VH	240%	570%	>1000%	<50	230	520	
Big Creek	O	VH	240%	570%	>1000%	<50	230	520	
Clatskanie	O	VH	90%	195%	385%	<50	230	400	660
Scappoose	O	VH	240%	570%	>1000%	<50	230	520	
Cascade Fall									
Lower Cowlitz	W	VH	40%	70%	100%	490	2,300	3,630	4,900
Upper Cowlitz	W	VH	na	na	na	na	na	na	Na
Toutle	W	VH	145%	225%	330%	<50	1,520	3,410	5,950
Coweeman	W	VH	35%	65%	100%	100	460	740	1,040
Kalama	W	VH	110%	175%	250%	<50	460	950	1,560
Lewis	W	VH	145%	225%	400%	<50	490	1,130	2,520
Salmon	W	VH	na	na	na	<50	na	na	na
Washougal	W	VH	110%	170%	230%	<50	520	1,020	1,550
Clackamas	O	VH	na	na	na	<50	na	na	na
Sandy	O	VH	na	na	na	<50	na	na	na
Cascade L Fall									
Lewis NF	W	VL	--	--	--	7,260	1,600	2,380	3,510
Sandy	O	H	15%	40%	65%	1,170	1,940	2,910	3,850
Gorge Fall									
L. Gorge	W/O	VH	590%	>1000%	>1000%	<50	1,170		
U. Gorge	W/O	VH	590%	>1000%	>1000%	<50	1,170		
White Salmon	W	VH	na	na	na	<50	na	na	na
Hood	O	VH	na	na	na	<50	na	na	na

see Table E12-6 footnotes

Table E12-12. Current population parameters and risk levels for modeling recovery increments for lower Columbia River chum populations.

Population	State	Data type[a]	N_{eq}[b]	R/S[c]	R/S′[d]	$[\sigma^2]$[e]	lag[f]	CRT[g]	Risk (1999 reference)[h] QET[i]	CRT[j]	cat.[k]
Coast											
Grays/Chinook	W	2	1,600	2.5	--	0.8	0.4	100	<1%	<1%	VL
Eloch/Skam	W	3	<200	na	na	--	--	200	>99%	>99%	VH
Mill/Ab/Germ	W	3	<100	na	na	--	--	100	>99%	>99%	VH
Youngs	O	3	<50	na	na	--	--	200	>99%	>99%	VH
Big Creek	O	3	<50	na	na	--	--	200	>99%	>99%	VH
Clatskanie	O	3	<50	na	na	--	--	100	>99%	>99%	VH
Scappoose	O	3	<50	na	na	--	--	100	>99%	>99%	VH
Cascade											
Cowlitz	W	3	<300	na	na	--	--	300	>99%	>99%	VH
Kalama	W	3	<100	na	na	--	--	200	>99%	>99%	VH
Lewis (lower)	W	3	<100	na	na	--	--	300	>99%	>99%	VH
Salmon	W	3	<100	na	na	--	--	100	>99%	>99%	VH
Washougal	W	3	<100	na	na	--	--	200	>99%	>99%	VH
Clackamas	O	3	<50	na	na	--	--	100	>99%	>99%	VH
Sandy	O	3	<50	na	na	--	--	100	>99%	>99%	VH
Gorge											
Lower Gorge	W/O	3	2,000	2.5	--	0.8	0.4	200	<1%	1%	VL
Upper Gorge	W/O	3	<50	na	na	--	--	100	>99%	>99%	VH

see Table E12-5 footnotes

Table E12-13. Improvements required to reduce risk for lower Columbia River chum populations.

Population	St.	Risk cat.[e]	Increment to achieve[c] M	L	VL	Ref	Spawners @[d] M	L	VL
Coast									
Grays/Chinook	W	VL	--	--	--	1,570	690	1,120	1,470
Eloch/Skam	W	VH	na	na	na	<200	na	na	na
Mill/Ab/Germ	W	VH	na	na	na	<100	na	na	na
Youngs	O	VH	na	na	na	<50	na	na	na
Big Creek	O	VH	na	na	na	<50	na	na	na
Clatskanie	O	VH	na	na	na	<50	na	na	na
Scappoose	O	VH	na	na	na	<50	na	na	na
Cascade									
Cowlitz	W	VH	na	na	na	<300	na	na	na
Kalama	W	VH	na	na	na	<100	na	na	na
Lewis (lower)	W	VH	na	na	na	<100	na	na	na
Salmon	W	VH	na	na	na	<100	na	na	na
Washougal	W	VH	na	na	na	<100	na	na	na
Clackamas	O	VH	na	na	na	<50	na	na	na
Sandy	O	VH	na	na	na	<50	na	na	na
Gorge									
Lower Gorge	W/O	VL	--	--	--	2,040	1,080	1,550	2,040
Upper Gorge	W/O	VH	na	na	na	<50	na	na	na

see Table E12-6 footnotes

Table E12-14. Current population parameters and risk levels for modeling recovery increments for lower Columbia and Willamette river steelhead populations.

Population	State	Data type[a]	N_{eq}[b]	R/S[c]	R/S′[d]	$[\sigma^2]$[e]	lag[f]	CRT[g]	Risk (1999 reference)[h] QET[i]	CRT[j]	cat.[k]
Coast Winter											
Grays/Chinook[1]	W	2	900	4.6	--	0.4	0.6	100	<1%	<1%	VL
Eloch/Skam[1]	W	2	700	7.2	--	0.4	0.6	100	<1%	<1%	VL
Mill/Ab/Germ[1]	W	2	550	5	--	0.4	0.6	100	<1%	2%	L
Cascade Winter											
Lower Cowlitz	W	2	400	2.0	--	0.4	0.6	100	8%	30%	H
Coweeman	W	2	400	2.8	--	0.4	0.6	100	4%	26%	H
N. F. Toutle	W	2	200	2.0	--	0.4	0.6	100	60%	93%	VH
S. F. Toutle	W	2	400	3.0	--	0.4	0.6	100	3%	21%	M
Upper Cowlitz	W	2	na	na		--	--	na	na	na	VH
Cispus	W	2	na	na		--	--	na	na	na	VH
Tilton	W	2	na	na		--	--	na	na	na	VH
Kalama	W	2	400	2.9	--	0.4	0.6	100	4%	28%	H
N.F. Lewis (lower)	W	2	300	2.7	--	0.4	0.6	200	54%	>99%	VH
E.F. Lewis	W	2	400	2.8	--	0.4	0.6	100	4%	25%	M
Salmon	W	2	40	1.5	--	0.4	0.6	50	>99%	>99%	VH
Washougal	W	2	300	2.5	--	0.4	0.6	100	10%	45%	H
Clackamas	O	1	2,000	--	3	0.8	0.6	200	<1%	2%	L
Sandy	O	1	1,800	--	0.8	0.4	0.6	200	92%	97%	VH
Cascade Summer											
Kalama	W	2	600	3.1	--	0.4	0.6	100	<1%	4%	L
N.F. Lewis	W	2	200	1.8	--	0.4	0.6	100	54%	84%	VH
E.F. Lewis	W	2	200	1.7	--	0.4	0.6	100	85%	99%	VH
Washougal	W	2	400	3.5	--	0.4	0.6	100	1%	14%	M
Gorge Winter											
L. Gorge	W/ O	3	200	--	2	0.5	0.6	50	31%	31%	H
U. Gorge	W/O	3	200	--	2	0.5	0.6	50	31%	31%	H
Hood	O	1	530	--	1.4	0.4	0.6	100	10%	23%	M
Gorge Summer											
Wind	W	2	1,500	4.5	--	0.4	0.6	100	<1%	<1%	VL
Hood	O	1	200	--	2.1	0.4	0.6	100	18%	78%	VH
Willamette Winter											
Molalla	O	3	900	--	2	0.6	0.6	200	2%	21%	M
N. Santiam	O	1	2,000	--	1.6	0.6	0.6	100	<1%	2%	L
S. Santiam	O	1	2,000	--	1.6	0.6	0.6	100	<1%	2%	L
Calapooia	O	3	500	--	2.1	0.9	0.7	50	20%	20%	M

see Table E12-5 footnotes

Table E12-15. Improvements required to reduce risk for lower Columbia and Willamette river steelhead populations.

			1999 reference[a]						
		Risk	Increment to achieve[c]			Spawners @[d]			
Population	**St.**	**cat.**[e]	**M**	**L**	**VL**	**Ref**	**M**	**L**	**VL**
Coast Winter									
Grays/Chinook[1]	W	VL	--	--	--	800	360	490	630
Eloch/Skam[1]	W	VL	--	--	--	600	320	410	550
Mill/Ab/Germ[1]	W	L	--	--	15%	490	330	420	590
Cascade Winter									
Lower Cowlitz	W	H	5%	25%	50%	350	400	540	730
Coweeman	W	H	5%	25%	50%	340	360	470	610
N. F. Toutle	W	VH	55%	125%	300%	120	350	590	1,200
S. F. Toutle	W	M	--	20%	50%	340	--	450	610
Upper Cowlitz	W	VH	na	na	na	na	na	na	na
Cispus	W	VH	na	na	na	na	na	na	na
Tilton	W	VH	na	na	na	na	na	na	na
Kalama	W	H	5%	30%	55%	320	340	470	590
N.F. Lewis (lower)	W	VH	>1000%	>1000%	>1000%	150			
E.F. Lewis	W	M	--	25%	50%	340	340	470	610
Salmon	W	VH	na	na	na	na	na	na	na
Washougal	W	H	15%	40%	75%	280	350	480	640
Clackamas	O	L	--	--	10%	1,920	1,100	1,600	2,160
Sandy	O	VH	45%	70%	100%	400	1,350	2,140	2,880
Cascade Summer									
Kalama	W	L	--	--	20%	510	350	500	660
N.F. Lewis	W	VH	45%	90%	245%	140	360	560	1,230
E.F. Lewis	W	VH	85%	>1000%	>1000%	<50	390		
Washougal	W	M	--	15%	45%	370	330	450	600
Gorge Winter									
L. Gorge	W/ O	H	5%	40%	80%	170	180	260	340
U. Gorge	W/O	H	5%	40%	80%	170	180	260	340
Hood	O	M	--	25%	45%	410	410	590	690
Gorge Summer									
Wind	W	VL	--	--	--	1,040	400	550	750
Hood	O	VH	45%	95%	220%	180	280	380	610
Willamette Winter									
Molalla	O	M	--	30%	70%	810	780	1080	1,440
N. Santiam	O	L	--	--	10%	1,680	900	1,480	1,890
S. Santiam	O	L	--	--	10%	1,680	900	1,480	1,890
Calapooia	O	M	--	40%	100%	430	400	670	990

see Table E12-6 footnotes

Notes on population assumptions

1. Lower Columbia River coho population parameters assumed based on Anlauf et al. estimates of winter carrying capacity based on habitat conditions. Minimum estimates based on their assumed 0.6% survival adults. Productivity based on parr/km values relative to known populations (Clackamas). Youngs & Big Creek productivities were decremented to account for high hatchery influence. Decrement in productivity proportional to half of hatchery fraction. Current fishery impacts on Youngs & Big Creek assumed to be 70% and 50% respectively owing to proximity of select area terminal fishery (90% & 70% historically).
2. Clackamas coho – reduced productivity to account for effects of poor habitat in lower basin. (Empirical productivity estimates based on upper basin only.)
3. Sandy R coho. Used population-specific variance (McElhany) & lag (Chilcote) to represent greater than average variability in that population. Calibrated productivity for risk.
4. L Gorge coho assumed values based on WA EDT plus additional capacity for limited OR streams. Productivity assumed to be low due to large incidence of hatchery fish (% unknown but assumed on the order of 80%. U gorge assumed to be the same.
5. Upper Cowlitz: Cispus, Tilton, U. Cowlitz production assumed to be zero at baseline. Reintroduction efforts are ongoing. Success of reintroduction efforts will depend in part on collection efficiencies at dams.
6. Upper Lewis: No production currently above dams.
7. Hood: Assumed coho values represent very low population size & productivity consistent with current viability assessment. Also consistent with observed numbers at Powerdale Dam.
8. Upper Willamette coho: based on 2001-2006 falls counts of 1,300-7,900 adults per year and moderate productivity assumed from observed resilience of population in recent years.
9. Clatskanie fall Chinook calibrated SR parameters to match Chilcote risk.
10. Sandy bright fall Chinook used pop specific variance (lower than species avg).
11. Sandy spring Chinook. Poor stock-recruitment fit to entire time series. Used approximate meanRS values.
12. McKenzie CHS. Assumed low-moderate productivity comparable to meanRS estimate due to low contrast and poor SR fit.
13. Lower Gorge chum based on survey average including mainstem spawners. EDT data is available for tributary spawning component. Productivity assumed equal to other significant population (Grays)
14. Upper Gorge Chinook based on average spawning escapements, expanded to ocean recruits, but assuming significant hatchery contributions. Note upper gorge pop includes OR & WA streams. White Salmon is White salmon only.
15. Washougal chum population includes mainstem I-205 spawners.
16. Clackamas steelhead: decremented productivity to account for assumed poor habitat productivity for portion of population in the lower basin. Also used actual variance.
17. Sandy winter steelhead: used preharvest RpS was < 1.0.
18. Molalla winter steelhead based on observed values in recent time period because of questionable model fits.
19. Santiam winter steelhead generally based on meanRS data & fits
20. Calapooia winter steelhead based on mean RS & pop-specific variance due to poor data fits.
21. Willamette winter steelhead productivities based on meanRS method because hockey stick fits produced unrealistically productivity high values.