

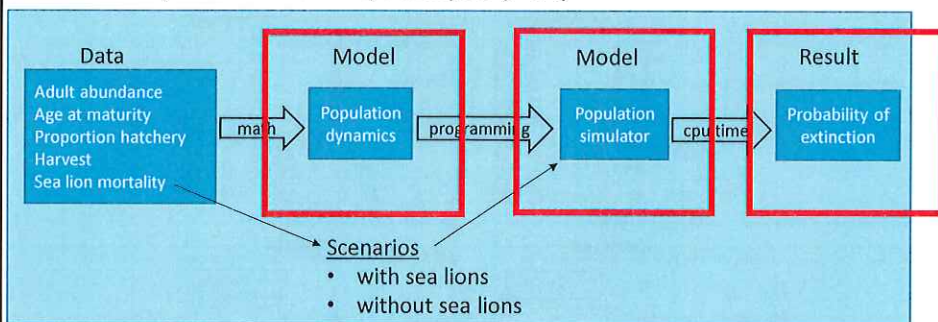
Population Viability of Willamette River Winter Steelhead

An assessment of the effects of sea lions at Willamette Falls

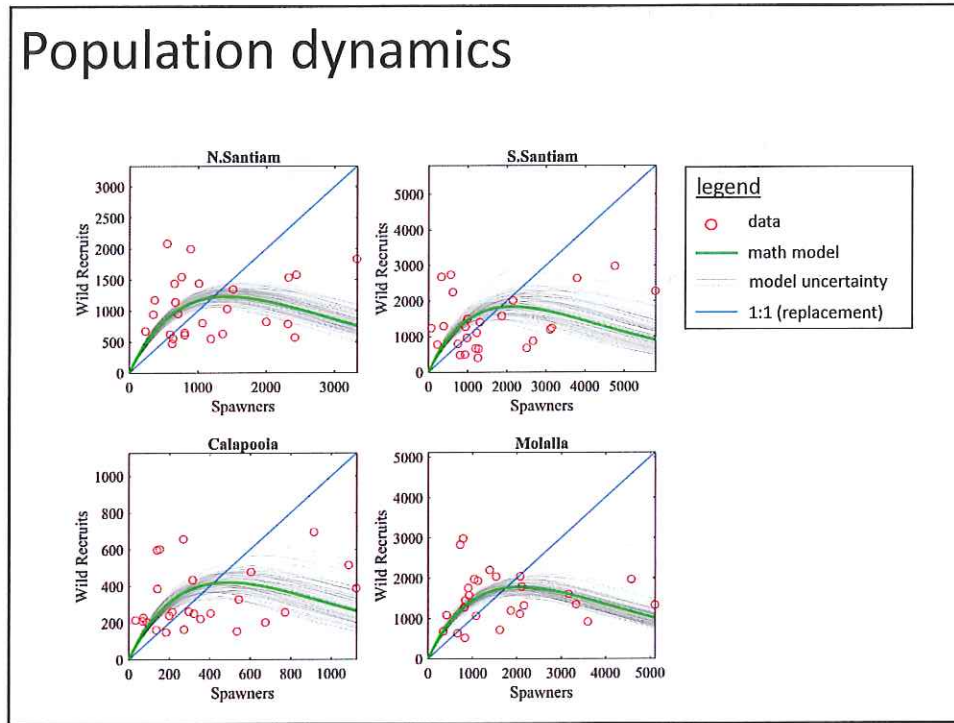
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Goal: Quantify threat of extinction posed by sea lions

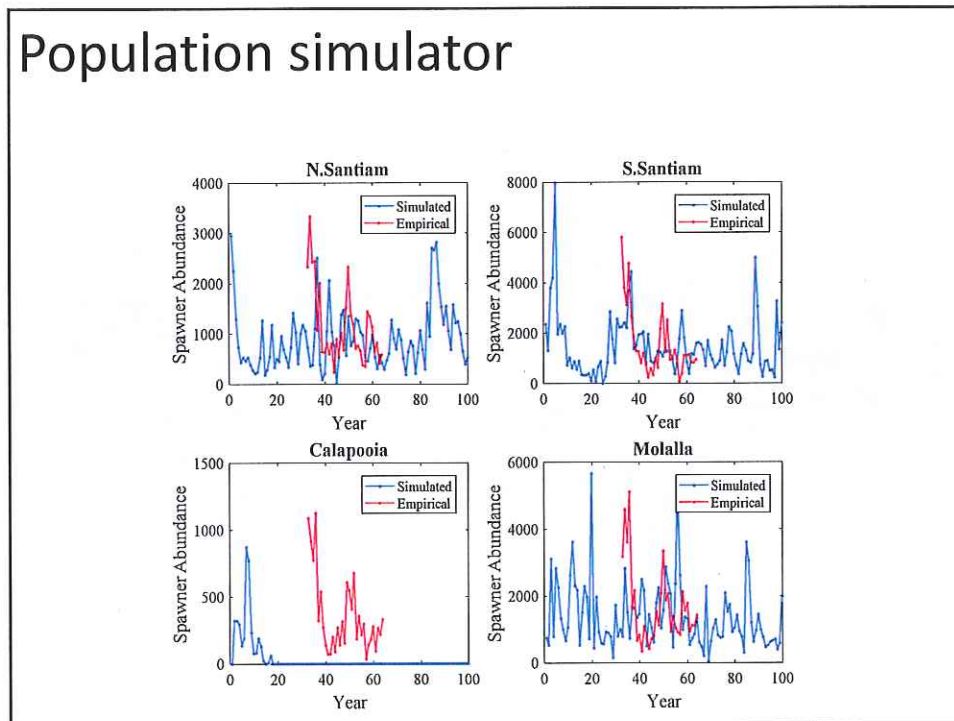
Method: Population Viability Analysis (PVA)



Population dynamics



Population simulator



Probability of extinction

Scenario	Single Population				Three Populations*	
	North Santiam	South Santiam	Molalla	Calapooia	At least 1 goes extinct	
Without Sea Lions	2%	5%	0%	99%	6%	
With Sea Lions	lowest observed predation (2015)	8%	16%	0%	99%	23%
	average predation (2016)	27%	34%	2%	99%	53%
	highest observed predation (2017)	64%	60%	21%	99%	89%

* Excluding Calapooia and assuming independence

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July 7, 2017

Dr. Matthew Falcy

Oregon Department of Fish and Wildlife



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An assessment of the effect of sea lions at Willamette Falls

This document describes methods used to assess the effects of sea lions at Willamette Falls on the viability of four populations of wild winter steelhead. Several data sets were compiled, manipulated, statistically modeled, and ultimately used to project population dynamics through time. An accompanying webpage provides all the data and MATLAB computer code to replicate results: <http://people.oregonstate.edu/~falcym/WillametteSteelhead.html>

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PVA Results

The results of the PVA indicate that sea lions have a large negative effect on the viability of winter steelhead (Table 1). The remainder of this document elaborates how these results were obtained.

Table 1. Probabilities of quasi-extinction over a 100 year period in four populations of Willamette River winter steelhead under four different scenarios. Scenarios with sea lions assume that the predation mortality estimated during that year will continue indefinitely. The lowest predation rate was observed in 2015 and the highest predation rate was observed in 2017.

Scenario	Population			
	N. Santiam	S. Santiam	Calapooia	Molalla
No Sea Lions	0.015	0.048	0.993	0.000
2015 Sea Lions	0.079	0.158	0.998	0.001
Average Sea Lions	0.274	0.335	0.999	0.021
2017 Sea Lions	0.644	0.599	0.999	0.209

Population Viability Analysis



Population viability analysis (PVA) can be broadly defined as the use of quantitative methods to predict the future status of populations under defined conditions or scenarios. Here, a PVA is used to determine the probability of quasi-extinction over a 100 year period. The PVA scenarios perpetuate observed effects of sea lions at Willamette Falls.



Overview of Method

Sea lions feed on adult salmonids attempting to find passage over Willamette Falls. Mortality of adults during their spawning run is considered to have a density independent effect on subsequent survival rates. This is analogous to harvest mortality. Thus, we can usefully employ common fisheries stock assessment models to capture population dynamics.

With a time series of spawner abundance, spawner age compositions, and mortality due to fishing and sea lions, it is possible to compute the adult recruits (progeny) associated with each year's spawner abundance. Density-dependence in these data can be modeled with Ricker or Beverton-Holt type stock-recruitment functions.

Bayesian analysis uniquely permits probabilistic interpretation of parameter estimates, and the Markov chain Monte Carlo methods used to fit Bayesian models conveniently preserves the covariance structure among parameters. Bayesian methods were therefore used to probabilistically describe parameter uncertainty a stock recruitment relationship.

The estimated stock-recruitment relationship with parameter uncertainty and residual autocorrelation is combined with age composition and adult mortality data. This is sufficient information to project population dynamics through time. The PVA program takes 1000 random draws from the parameter posterior distribution of the best stock recruitment model, and then replicates a 100-year time series 100 times. The total number of simulations where spawner abundance falls below a critical threshold across 4 consecutive year is divided by the total number of simulations (100,000). The result of this computation is the probability of quasi-extinction.

Density Dependence



Density dependence occurs when demographic parameters (e.g. birth rate or death rate) depend on the density of individuals in the population. For example, as the density (number) of fish increases, competition can cause survival rate to decrease. The form and magnitude of density dependence is a critical component of population dynamics, extinction risk, and optimal harvest rate.



Abundance of Willamette Winter Steelhead

The North Santiam, South Santiam, Calapooia, and Mollala river systems are used to delineate “populations” of winter steelhead. This delineation is consistent with previous conservation and planning efforts (ODFW 2008). Several sources of information were used to construct time series of spawner abundances in these focal populations.

A counting station on the fishway at Willamette Falls has produced a time series of annual abundances of winter steelhead dating back to 1946. Since Willamette Falls is below the focal populations, additional information is needed to apportion annual counts at the falls into each population.

A radiotelemetry study conducted in 2013 found that 106 out of 170 tagged fish (62%) reached their maximum migration point within one of the four focal populations (Jepson et al. 2014). This is assumed to reflect spawning distribution because fish were rarely observed to wander among river systems (Jepson 2017 personal communication). Thus we conclude that 38% of the winter steelhead that pass Willamette Falls are not members of the focal populations.

Fish are enumerated at the Minto fish facility in the upper North Santiam and at Foster Dam in the upper South Santiam. These “known fate” individuals were therefore subtracted out of the Willamette Falls count (N_{wf}) to obtain the number of fish whose spawning distribution needs to be determined N_{ibd} :

$$N_{ibd} = N_{wf} * 0.62 - N_{minto} - N_{foster}$$

The quantity N_{ibd} is apportioned to the focal populations based on miles of spawning habitat within each population (L_p) multiplied by the observed redd density ($D_{t,p}$). Note that L_p is temporally static quantity (no time subscript), whereas $D_{t,p}$ varies in time and across populations. In the North Santiam and South Santiam populations, only spawning habitat mileage below the counting facilities is used because there is already a known number of fish that go above the facility. Let $D_{t,p=NS}$ be the density of redds in year t within the North Santiam (NS) population. The population abundance that year is

$$N_{t,NS} = N_{ibd,t} \left(\frac{D_{t,NS} * L_{NS}}{\sum_p (D_{t,p} * L_p)} \right) + \text{Minto Count.}$$

Observations of redd density have been made at multiple sites within each population since 1985. However, weather conditions and staff workload can prevent observation of redd density at some sites and years. If a given site generally has a high density of redds, then neglecting the site on a given year could give a false appearance of low redd density within the population relative to the years when observation are made at the site. Across all four populations, there are 30 redd survey sites. The date when most surveys began is 1985. There are 30 sites X 32 years = 960 potential observations of redd



densities in the redd density data set. However there are 478 actual observations. The extent of missing values is therefore an issue that needs to be resolved so that all available data can be used while also minimizing biases associated with missing values from above average or below average sites.

A multiple imputation technique was developed to infer missing redd densities. Redd survey data from all four populations was combined with the Willamette Falls counts, Minto counts and Foster counts, yielding a matrix with 32 years (rows) and 33 locations (columns). Beginning with the first location, the first year with a missing value was identified. All existing redd densities in that location (across years) were linearly regressed on the redd densities in the next location. A prediction for the missing value was generated, and the log likelihood of the associated statistical model was recorded. A new linear regression was established from the next location, and the model prediction and log likelihood were once again recorded. This repeats across all locations, yielding 32 regressions for a single missing value. A final, model averaged prediction for the missing value was obtained as

$$\widehat{D}_{t,p} = \frac{\sum_i \hat{y}_i * w_i}{\sum_i w_i},$$

where \hat{y}_i is the model prediction from location i and w_i are individual model weights. The w_i are calculated

$$w_i = \frac{e^{-0.5BIC_i}}{\sum_i e^{-0.5BIC_i}},$$

where BIC_i is the Bayesian information criterion of regression i ,

$$BIC_i = 2 * nll + k * \log(n),$$

nll is the negative log likelihood, k is the number of estimated parameters (3) and n is the sample size used in the regression.

Imputed values are not used to impute other values. Imputation of data can be problematic because methods such as the one employed here will artificially reduce the variance of the data. However, this is not a problem in this particular application because the purpose is to

Likelihood



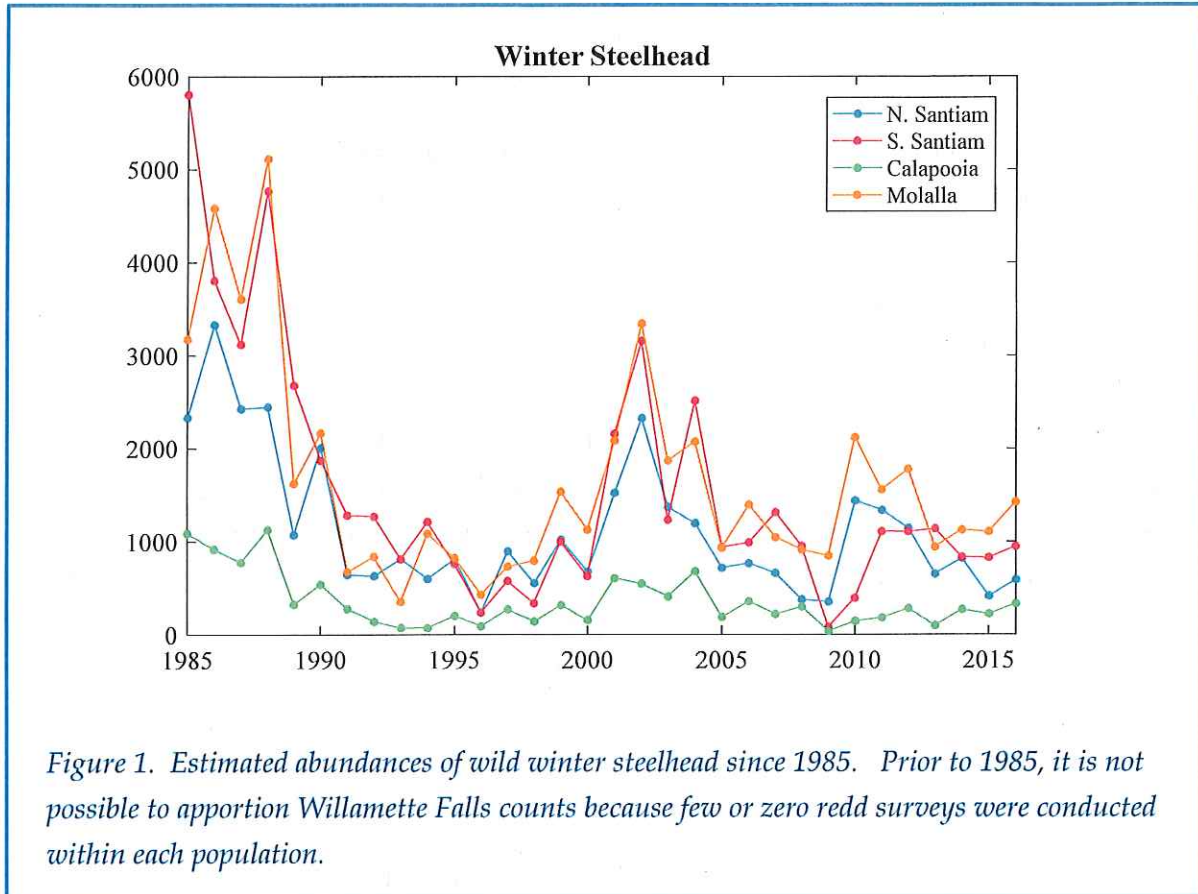
Likelihoods have provided a major theoretical foundation for scientific inference since the work of Ronald Fisher in 1922. Given a probability distribution function, one can find parameter values that maximize the likelihood of observed data. Such parameters are called maximum likelihood estimates, and the likelihood of the observed data given these parameter estimates is a relative measure of the adequacy of the model.

Population Viability of Willamette River Winter Steelhead



merely avoid biasing an average across sites when a particular site has a missing value.

The result of the foregoing methods to apportion Willamette Falls counts of winter steelhead into time series of abundances in the four focal populations is presented in Figure 1.





Mortality from Sea Lions

Sea lion predation on salmonids has been rigorously monitored by Wright et al. (2016) since 2014. The estimated number of winter steelhead killed by sea lions in 2014, 2015, and 2016 is 780, 557, and 915 respectively. Wright et al. (2016) note that the 2016 estimate applied to just the “falls strata” whereas monitoring in 2014 and 2015 included the fall and a “river” stratum just below the falls. Using information from years when both strata were monitored, Wright et al. (2016) find that the mortality in the river stratum is 0.385 of the falls plus river. The 2016 winter steelhead estimate in the falls stratum was expanded to a number reflecting mortality in the falls and river strata: $915/(1-0.385) = 1488$.

However, as noted in the previous section, 38% of winter steelhead at Willamette Falls are not members of the four focal populations. Thus only 62% of the estimated mortality is on fish that pertain to the focal populations:

$$\begin{bmatrix} 780 \\ 557 \\ 1488 \end{bmatrix} * [0.62] = \begin{bmatrix} 486 \\ 347 \\ 927 \end{bmatrix}$$

An additional adjustment is needed because the mortality estimates pertain only to the time of the monitoring project, yet 23%, 30% and 22% of winter steelhead runs of 2014, 2015, and 2016, respectively, pass through the monitoring area before mortality monitoring begins (Figure 2). A loess quadratic polynomial local regression with span 0.4 was used to smooth daily counts of California sea lions (Figure 3, green). An “interaction index” was computed as the sum of the daily products between the loess smooth of California sea lions (CSL) and counts of winter steelhead (StW) at Willamette Falls:

$$Interaction\ Index = \sum_{day=Feb2}^{June1} CSLsmooth_{day} * StW_{day}$$

The leftmost point of the loess smooth was then extended further to the left (Figure 3, black), reflecting the assumption that California sea lions are present at low densities before the monitoring project began. The interaction index was then recomputed beginning November 1. The ratio between these interaction indices is a factor for expanding sea lion mortality to the entire run of winter steelhead. These factors were computed three times, once for each winter steelhead abundance time series in given in Figure 2. Each factor used the 2016 sea lion information.

Population Viability of Willamette River Winter Steelhead

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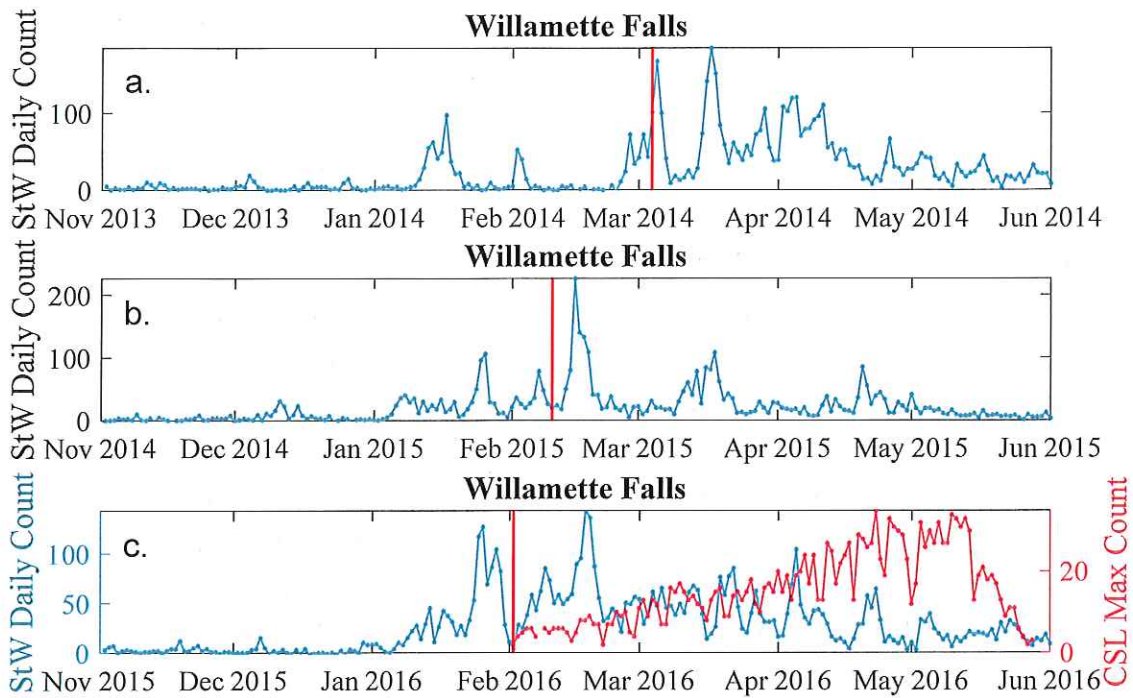


Figure 2. Vertical red bars give the initiation of the California sea lion (CSL) monitoring study relative to the run timing of winter steelhead (StW) at Willamette Falls.

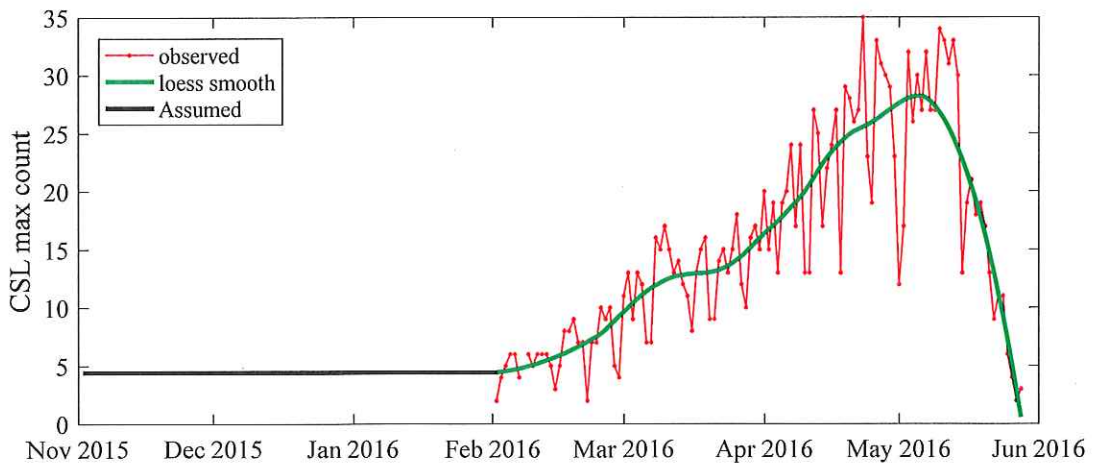


Figure 3. Maximum daily counts of California sea lion (CSL) are identical to Figure 2c.

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The factor values are 1.10, 1.14, and 1.09. Even though 23%, 30% and 22% of the steelhead runs went unmonitored for sea lion mortality, expanding for the unmonitored component of the runs adds just 10%, 14% and 9% because California sea lion abundance is relatively low during this time. The final mortality estimates for year 2014, 2015, and 2016 are: $486 \times 1.10 = 531$, $347 \times 1.14 = 395$, and $927 \times 1.09 = 1016$, respectively.

Wright et al. (2014) note that predation losses of salmonids were generally a few hundred or less at the Falls from the late 1990s through 2003. Starting with 150 salmonid mortalities, we made the same adjustments described above (expand for river stratum, deflate for proportion spawning outside the focal populations, expand by mean of three factors used to correct for early run timing) and then deflated the number again by the mean proportion of all the salmonid mortality during 2014, 2015, and 2016 that are winter steelhead (15%). This computation results in 33 winter steelhead. This amount of mortality was assumed to occur from 1995 through 2003, with linear increase in mortality until the study of 2014, and zero mortality prior to 1995. This time series of mortality is then apportioned to each of the four populations by the relative abundance of fish in each population, as calculated in the previous section. Mortality by California sea lions was 15%, 13% and 24% of the winter steelhead runs in 2014, 2015, and 2016, respectively.

In the spawner-recruit analysis below, the mortality caused by sea lions within each population on year t (denoted M_t) is added into the recruits.



Age Composition of Spawners

Age of spawning fish was determined through scale analysis. There were a total of 784 scales collected from 16 years. The composition of ages on a given year was applied to all populations. When age composition was missing for a given year, the average over all years with age data was used. The matrix of proportions of fish at age = 1,2,3, ..6, on given years (t) is denoted $A_{t,a}$ in the recruitment calculations below.

Angling Mortality

There has not been a directed retention fishery on Willamette River winter steelhead since 1992. Following previous conservation planning efforts (ODFW 2008), harvest rates on winter steelhead in the Willamette River system up through 1992 were assumed to be 21%, then decline to 5% to the present time for incidental mortality in fisheries targeting other stocks. A 2% incidental harvest rate is assumed in the Columbia River for all years. The vector of harvest rates (0.23 through 1993, 0.07 thereafter) is denoted HR_t in the recruitment calculations below.

Proportion of Hatchery-Origin Spawners

Hatchery winter steelhead have not been produced in the Willamette River since the late 1990s. The proportion of hatchery-origin fish spawning in the four focal populations in the 1980s and 1990s has been determined from scale analysis and used in previous conservation planning efforts (ODFW 2008, Appendix B). Specific values for each year and population can be found in the online supplement. Each population's vector of proportions of hatchery-origin spawners in year t is denoted $pHOS_t$ in the recruitment calculations below. This is needed because hatchery-origin fish should not be counted as recruits of the naturally spawning population. The PVA simulates dynamics of naturally spawning fish only.



Spawner-Recruit Analysis

The abundance of naturally produced (“wild”) adult recruits associated with fish spawning on year t is

$$R_{S(t)} = \sum_{a=1}^6 A_{t+a,a} \left(\frac{S_{t+a} * (1 - pHOS_{t+a})}{(1 - HR_{t+a})} + M_{t+a} \right).$$

From here it is possible to fit nonlinear models of the relationship between recruits and spawners. Errors in such models are customarily lognormal, reflecting the multiplicative survival processes that gives rise to uncertainty in the number of recruits.

Bayesian methods were adopted for recruitment modeling for two related reasons. First, Bayesian analysis uniquely yields probabilistic interpretation of parameters. Second, the Markov chain Monte Carlo (MCMC) methods used to fit Bayesian models allow parameter uncertainty to be easily folded into a PVA simulations. JAGS software was used to run the MCMC. JAGS called from MATLAB using matjags.m.

Beverton-Holt models were fitted to these data, but the posterior distribution for the productivity parameters always exactly matched the noninformative priors. These data therefore do not contain sufficient information to reliably identify the Beverton-Holt productivity parameter. A Ricker models were used instead (Table 2). Data from all four populations were combined into a “single” recruitment model. Three such models were constructed that make different assumptions about the across-population independence of parameters (Table 2). Model 1 assumes all parameters, including error variance, are unique in each population. Models 2 and 3 assume that some parameters can be shared across populations. Model 2 assumes there is a single error variance shared by all four populations, but each population has a unique productivity (α) and rate of compensatory density dependence (β). Model 3 assumes that productivity is identical across populations, while the magnitude of compensatory density dependence and error are unique to each population. In all three models, extremely diffuse (noninformative) uniform priors were used for α (Unif(1,200)), β (Unif(0,0.1)), and the standard deviation ϵ (Unif(0,4)).

Table 2. Three Ricker recruitment models fitted to four populations of winter steelhead spawner-recruit data. The models make different assumptions about the number and structure of necessary parameters. WAIC measures relative out-of-sample predictive performance.

ID	Model	# Params	WAIC
1	$R_{t,p} = \alpha_p S_{t,p} e^{-\beta_p S_{t,p}} e^\epsilon, \epsilon \sim N(0, \sigma_p)$	12	224.8
2	$R_{t,p} = \alpha_p S_{t,p} e^{-\beta_p S_{t,p}} e^\epsilon, \epsilon \sim N(0, \sigma)$	9	248.9
3	$R_{t,p} = \alpha S_{t,p} e^{-\beta_p S_{t,p}} e^\epsilon, \epsilon \sim N(0, \sigma_p)$	9	217.6



Four MCMC chains per model were ran. The first 35,000 iterations were discarded as a “burn-in” period, and 10,000 samples per chain were retained after thinning 1:13 samples from the MCMC. Trace plots of the MCMC were visually inspected for signs of mixing and convergence. Extremely good estimates of the Gelman-Rubens diagnostic ($\hat{R} = 1 \mp 0.0001$) were obtained.

Watanabe-Akaike Information Criterion (WAIC) can be used to assess the relative out-of-sample predictive performance of Bayesian models (Gelman, Whang, and Vehtari, 2013). Each iteration of the MCMC yields a draw from the multidimensional posterior distribution. This parameter vector can be used to compute the probability density of each datum in the data set. This produces I-by-S matrix of densities, where I is the number of data points (4 populations X 32 years = 128), and S is the arbitrary number of MCMC samples in the posterior. Armed with this matrix, the computed log pointwise predictive density is

$$lppd = \sum_{i=1}^I \log \left(\frac{1}{S} \sum_{s=1}^S p(y_i | \theta^s) \right).$$

A correction for effective number of parameters to adjust for overfitting is obtained with

$$pwaic = \sum_{i=1}^I V_{s=1}^S (\log p(y_i | \theta^s)),$$

where V is the sample variance. Thus *pwaic* is just the posterior variance (across MCMC iterations) of the log predictive density for each data point, summed over all data points, and

$$WAIC = -2 * (lppd - pwaic).$$

The units of WAIC can be interpreted like the more familiar AIC and DIC. Specifically, smaller values indicate better models. There are 31.4 units separating model Model 2 and Model 3, indicating that there is no empirical support whatsoever for Model 2 (Table 2). There are 7.3 units separating Model 1 and Model 3, indicating that Model 1 is considerably inferior to Model 3. Model 3 is therefore the only model used hereafter. Hilborn and Waters (1992, page 271-272) argued from first principles that productivities (α) should be similar within a species over much of its range. The model selection results presented here support Hilborn and Walters’ (1992) assertion.

The fit of Ricker Model 3 to the spawner-recruit data is given in Figure 4. Uncertainty in Ricker parameters gives rise to multiple potential recruitment functions. Random draws from the MCMC output ensures that parameter values and parameter covariance are obtained in proportion to the associated posterior probability densities.

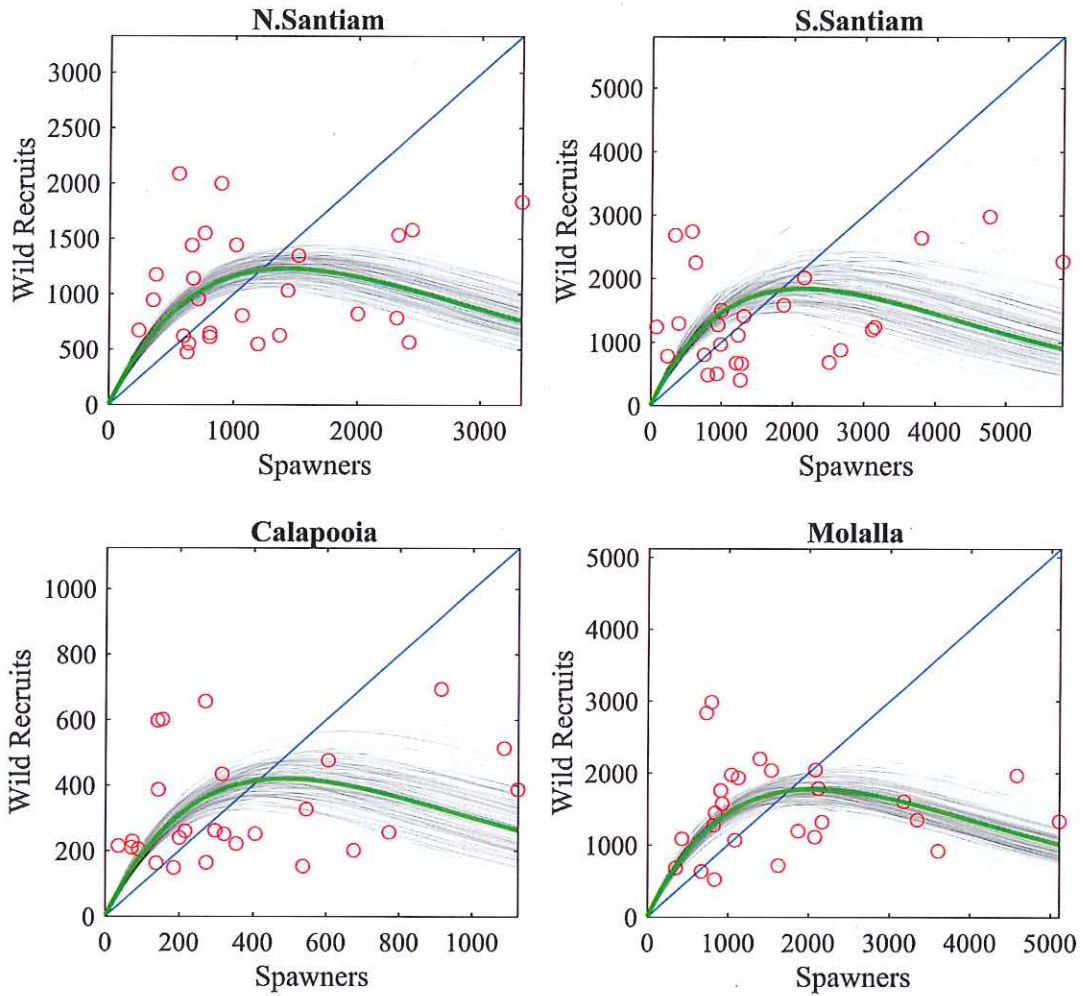


Figure 4. Spawner-recruit data and associated Ricker Model 3 fits. Thick green lines produced from the mean of the parameter posterior distribution. Thin grey lines produced from randomly chosen parameters in the posterior distribution. The blue diagonal line shows the 1:1 relationship between spawners and recruits.



PVA

The population viability analysis (PVA) model use here was also used in a previous assessment of coastal fall Chinook (ODFW 2011). The PVA is a computer model that uses information from the spawner-recruit analysis (see previous section) to project/simulate population abundances into the future. 100,000 repetitions of the 100-year simulation are conducted, and the fraction of these that result in an extinction event yields the probability of extinction. It is important to note that the word “extinction” refers to a population (i.e. “local extinction”, or “extirpation”), not a species.

The PVA was ran under four different scenarios for each population. In the scenario called “No Sea Lions” (Table 1) it is assumed that there is no additional mortality beyond the incidental angling mortality during the adult life stage. This assumption holds for all 100 years in the simulation. The scenario called “2015 Sea Lions” perpetuates the lowest mortality rate observed since 2014 for all 100 years of the PVA simulation. The scenario called “2017 Sea Lions” perpetuates the highest mortality rate observed since 2014 for all 100 years of the PVA simulation.

The Ricker recruitment function that is fitted to each population (Model 3) is the model of intergenerational population dynamics that is used within the PVA to simulate spawner abundances through time. However, in the spawner-recruit analysis, “recruits” are defined as pre-angling and pre-sea lion adults. The very same inland mortality estimates that are used to estimate adult recruits from spawner abundances are also used by the PVA to convert adult recruits back into spawners. Indeed, the analytical steps used to estimate recruits for the spawner-recruit analysis are reversed inside the PVA. The PVA

1. takes a given spawner abundance on year t ,
2. uses the recruitment function to compute adult recruits,
3. recruits are apportioned across years according to random permutations of the age composition data,
4. recruits are summed across ages within a year and then deflated by harvest rate sea lion mortality (if any).

A critically important aspect of all PVAs is the incorporation of stochasticity (“randomness”). Indeed, if stochasticity is neglected, then the steps outlined above would quickly result in static population and extinction risk would be zero. Stochasticity enters the PVA in several ways. First, the spawner-recruit data are ambiguous with respect to the parameters of the recruitment function (Figure 4). Thus, uncertainty in the estimates of recruitment parameters α and β are simulated within the PVA by repeating simulations with 1000 different values of α and β . The 1000 different values of α and β are selected in proportion to the probabilities of different values and their covariance. This is



accomplished by fitting the Ricker spawner-recruit model with MCMC methods in a Bayesian context. Samples of the MCMC are saved, and the PVA randomly selects parameter values out of this pool.

The spawner-recruit data are not fully explained by the Ricker recruitment function, even though parameter uncertainty is acknowledged. In Figure 4, this can be seen as the vertical distances between spawner-recruit “points” and the line(s) representing the recruitment function(s). These “residual” deviations must also be simulated in the PVA. These residuals are lognormally distributed (note that the errors, ε , are exponentiated in the recruitment functions described above) and contain temporal autocorrelation. After the PVA receives a set of values for α and β , the variance of the errors is computed as well as the lag-1 autocorrelation of the errors. A 100-year time series of residual errors is then simulated using:

$$\varepsilon_t = \rho\varepsilon_{t-1} + \sqrt{\sigma^2} \sqrt{1 - \rho^2} z_t,$$

where ρ is the lag-1 autocorrelation of the errors, σ^2 is the variance of the errors, and z_t is a standard normal random deviate (Morris and Doak 2002, p. 139). These simulations are repeated 100 times for each of the 1000 random parameter draws. There are therefore 100*1000=100,000 repetitions of a 100-year time series.

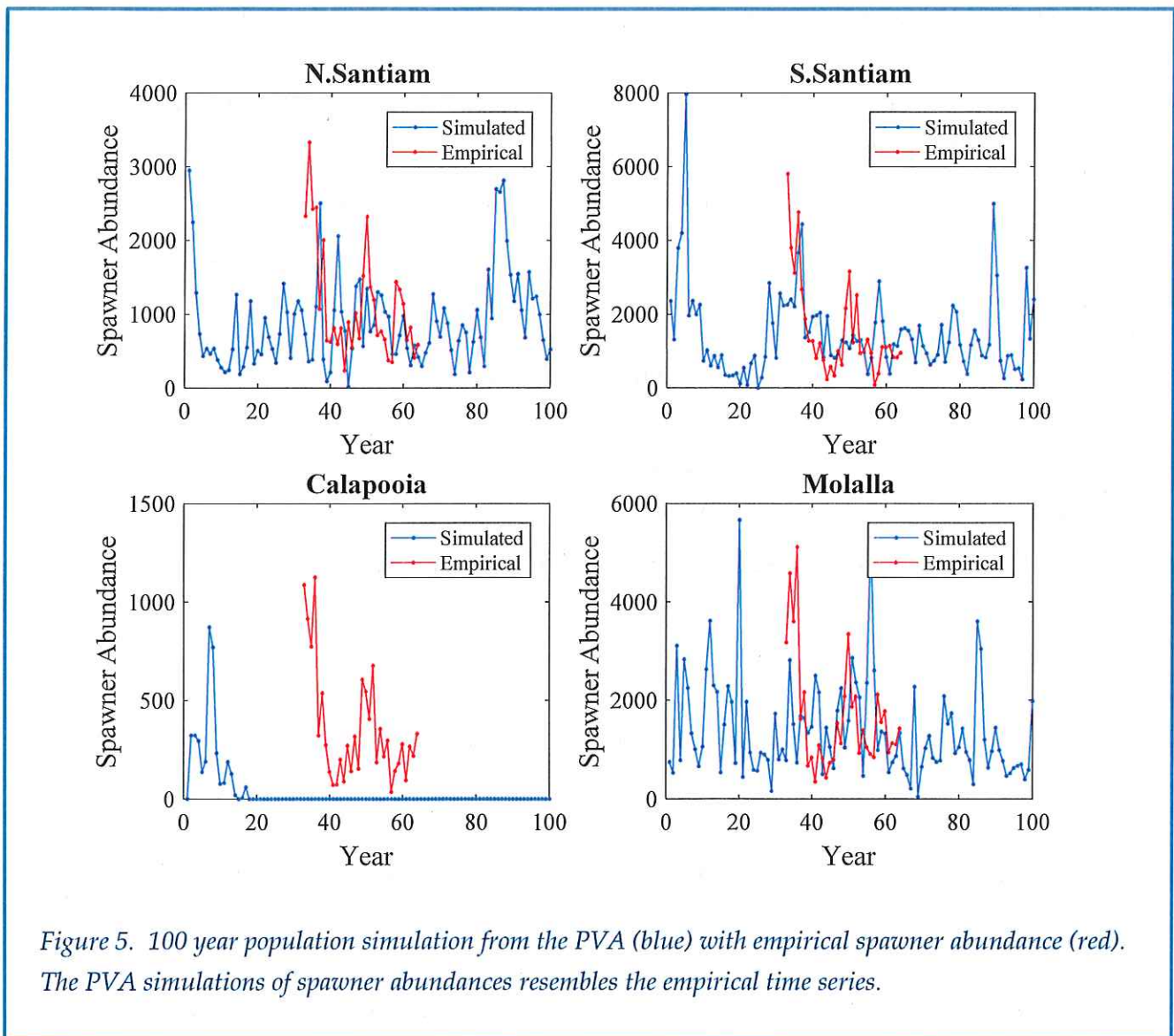
Extinction in the PVA model occurs when spawner abundance for four consecutive years falls below a “quasi-extinction threshold” (QET). A separate process called “reproductive failure threshold” (RFT) is used to zero-out recruitment at critically low spawner abundances. Both of these thresholds are implemented because processes like inbreeding depression, genetic drift, mate finding, and increased per-capita juvenile mortality will drive the population into extinction at critically low abundances. These negative density-dependent processes are very infrequently observed in nature, so they cannot be explicitly modeled. Collectively, both QET and RFT represent the boundary of an “extinction vortex” from which real populations are irrecoverable (Gilpin and Soulé 1984, Courchamp et al. 2008, Jamieson and Allendorf 2012). The specific values used here are RFT=QET=100. The PVA counts the fraction of the 100,000 simulations where adult abundance falls below QET across 4 consecutive years.

The PVA model uses past abundances to infer extinction risk. Thus, the interpretation of the result is couched in the assumption that the conditions that were present when the data were collected will persist for 100 years. The model is not intended to capture effects of global warming, human population growth, or other anticipated future change. Of course, the future will not be like the past. Future food webs are uncertain, as is the adaptive potential of these fish. The purpose of the PVA is not to forecast the future; rather, the PVA is a comparison of two different sea lion scenarios while holding everything else constant across scenarios.

Population Viability of Willamette River Winter Steelhead



The PVA needs to replicate observed patterns of variation in spawner abundance. A crude but effective method to determine if the PVA adequately captures observed population dynamics is to simply plot a randomly selected 100 year time series of simulated abundances and then superimpose the empirically observed/reconstructed abundances (Figure 4). This visual test indicates that the PVA performs well. It simulates abundances that are greater and less than the empirical abundances, the volatility of these deviations seems to match the volatility of the empirical abundances, and the average simulated abundance approximates the average of the empirical abundances.



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Oregon Department of Fish and Wildlife

Date: July 18, 2017

Subject: *Marine Mammal Protection Act: the need for revision to balance the conservation of pinnipeds with the conservation of vulnerable fish species*

Contact: Shaun Clements, PhD, Senior Policy Analyst, Fish Division
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Background

The protections provided by the Marine Mammal Protection Act (MMPA) have allowed pinniped populations to rebound to very healthy levels across the West Coast, USA. As pinniped numbers have increased, a very small proportion of the population has expanded their range into areas where migrating salmon and steelhead are especially vulnerable (e.g., Ballard Locks, WA; Bonneville Dam, Columbia River; Willamette Falls, OR). At these locations, predation by pinnipeds is having a significant negative impact on the health of listed salmon and steelhead stocks, as well as some currently unlisted fish (e.g., sturgeon). Striking an appropriate balance between the recovery of imperiled salmon and steelhead populations and the ongoing conservation of pinnipeds (e.g., sealions) is essential. Without restoring this balance, costly recovery efforts are at high risk of failure and some fish populations may even be lost.

The majority of the iconic wild salmon and steelhead populations in the Columbia River Basin have declined to levels where they are now listed under the Endangered Species Act (ESA) as threatened or endangered. Dams for hydropower and flood control are the primary cause of these declines, but tributary and estuarine habitat degradation, harvest, and hatcheries have also contributed. To address these declines, there has been an unprecedented effort among Northwest states, federal agencies, tribes, and private citizens to protect and recover salmon and steelhead. These efforts equate to hundreds of millions of dollars invested annually and billions over the past decades. The ongoing imperiled status of these fish is not only costing the region millions in direct investments, but also in opportunity costs associated with lost fisheries, restricted power generation, and constraints on land and water use.

The Problem

Although predation by pinnipeds is natural, there are specific circumstances in the Columbia basin where predation has grown to a level where it is significantly out of balance with historic levels, is undermining restoration efforts and cannot be ignored in a comprehensive recovery strategy. A review of predation issues in the Columbia basin¹ confirms this. The authors concluded that by spreading within their historical range, attaining extreme abundances, and exerting severe per-capita effects as a result of predation, pinnipeds are no longer in balance with the system, and instead have similar characteristics to invasive species.

Experience over the past 25 years has proven that current laws are inadequate to address the impact this small proportion of the pinniped population is having on fish runs. Extensive non-lethal hazing has been ineffective and the experiences at Ballard Locks, Bonneville Dam, and Willamette Falls have demonstrated the inevitability of events once pinnipeds locate these areas where salmon, steelhead, and other currently non-listed species (e.g., sturgeon) are particularly vulnerable to predation. At the extreme, pinniped predation led to the functional extinction of a wild steelhead population at Ballard Locks, WA. In Oregon, we are currently observing a similar trajectory for wild Willamette winter steelhead. A decade ago this population had >15000 fish and was being considered for delisting, now it is on the brink of extinction. In 2017, a record low of <1000 fish returned to the Willamette and

pinnipeds in the Willamette river consumed a minimum of 25% of these. If this level of predation continues, there is a 2 in 3 chance some of the Willamette winter steelhead populations will be extinct in the next 100 years. (cite ODFW's PVA)

Current law under the MMPA requires that managers wait until the problem is out of control before being given the authority to take action. Managers are required to spend multiple years collecting data to document individual pinnipeds consuming fish at the problem location, and to prove that this is having a significant impact this is having on the fish population. This data collection is costly and time consuming. While data is being collected, the problem continues to worsen as additional pinnipeds learn to exploit the fish at these locations. This required delay in action, inherent in the current MMPA Section 120 language, ultimately results in a far greater loss of fish from predation and requires the removal of far more pinnipeds to resolve the problem than if proactive actions were allowed at these areas before predators became established.

The solution

The State of Oregon, our management partners, and many other organizations would like to see the MMPA amended in a way that recognizes the lessons learned from Ballard Locks, Bonneville, and Willamette Falls. To prevent further extinction of fish runs and *minimize* the necessary take of pinnipeds, it is important that state and tribal natural resource managers have the necessary tools to restore a balance between abundant and healthy pinniped populations and the endangered and threatened salmon and steelhead populations in the Columbia River and tributaries.

Research, and the professional opinion of experts in pinniped behavior, suggest that early intervention offers the best hope of minimizing pinniped mortality and preventing declines in vulnerable fish stocks. In Oregon and the UK, research has shown that a very small proportion of pinniped populations specialize in feeding on salmon in riversⁱⁱ. This supports the notion that removal of problem animals can aid threatened salmon/steelhead stocks. Indeed, a recent review of selective wildlife removal programs concluded that there is broad support for the ecological basis, and efficacy of, selective wildlife management^{iv}. A study into the effectiveness of current management of California Sea-lions in the Columbia Basin^v concluded that earlier implementation of removal could have substantially reduced the extent of behavioral transmission among sea-lions and, ultimately, resulted in *fewer* pinnipeds being removed and a *lower impact* on salmon/steelhead.

Taking past experience and this body of science into account, the States and Tribal governments need authority to act early at problem locations, *without* first having to conduct years of data collection to identify individual animals and *without* having to first prove there is a significant impact to fish stocks that, left long enough, is inevitable. Oregon and our management partners value sealions and their important role as an apex predator in marine ecosystems. This is not about getting rid of sealions or impairing the health of sealion populations. Instead, this is about identifying certain areas where imperiled fish populations are particularly vulnerable, like dams and falls, and allowing proactive management actions to exclude pinnipeds from expanding into these areas and habituating. This will allow both the MMPA and ESA to be successful, rather than one Act undermining the other, and help restore an appropriate predator/prey balance for these species.

ⁱ **Native invaders – challenges for science, management, policy, and society.** Carey, M. P., et al. (2012). *Frontiers in Ecology and the Environment*, 10: 373–381. doi:10.1890/110060

ⁱⁱ **Do ‘rogue’ seals exist? Implications for seal conservation in the UK.** Graham, J. M., et al. (2011), *Animal Conservation*, 14: 587–598. doi:10.1111/j.1469-1795.2011.00469.x

ⁱⁱⁱ **Assessment of harbor seal predation on adult salmonids in a Pacific Northwest estuary.** Wright, B. E., et al. (2007), *Ecological Applications*, 17: 338-351. Doi: 10.1890/05-1941

^{iv} **Ecology of Problem Individuals and the Efficacy of Selective Wildlife Management.** Swan, G.J.F. et al. *Trends in Ecology & Evolution*, 32, 7, 518-530

^v **Epidemiological models to control the spread of information in marine mammals.** Schakner, Z. A et al., *Proceedings of the Royal Society B* 283:1844 .DOI: 10.1098/rspb.2016.2037

Op-Ed from Chair Finley to the Oregonian

Sometimes fish need our help – this is one of those times

Extinction of our native wildlife is not something Oregonians take lightly. Unfortunately, the fate of one of Oregon's iconic fish, native Willamette winter steelhead, hangs in the balance. Steelhead have returned to the Willamette for millennia but the run has been declining for some time and is listed under the federal Endangered Species Act. This year a record low 512 fish passed the falls to spawn upriver.

The decline has many causes. The 2015 drought and warm ocean compounded the impact of dams, habitat loss, and past harvest and hatchery practices. As a state, we're addressing these issues by restoring habitat, limiting harvest, improving hatchery programs, and providing fish passage at dams. But, there is a relatively new and growing threat that managers have been unable to address: predation by California sea lions at Willamette Falls.

Migrating salmon and steelhead are particularly vulnerable to sea lions as they try to pass natural and man-made barriers like Willamette Falls. In the early 2000's, three or four sea lions waited and fed at Willamette Falls. Today, over 40 congregate there. In 2017, a record 25% of the winter steelhead run was eaten by sea lions at Willamette Falls. A recent analysis by the Oregon Department of Fish and Wildlife shows that if this trend continues, there is nearly 90% probability that at least one Willamette steelhead population will go extinct. In contrast, if sea lions were not feeding at the Falls, that risk would drop to around 5%.

Currently, there is little that states can do about this. California sea lions are protected under the federal Marine Mammal Protection Act (MMPA). When the act was passed in the 1970s, sea lion numbers were at record lows. Today 250-300,000 inhabit the West coast and a small number of males now feed in freshwater areas outside their historical range. The MMPA has worked exceptionally well at recovering sea lions, but lacks the flexibility to balance the conservation of both sea lions and ESA-listed salmon and steelhead. Modest revisions to the MMPA allowing removal of a small number of sea lions would provide emergency relief for steelhead in the Willamette and help prevent future situations like this. Only Congress can do this. When sea lions were in danger, Congress acted. Today, native winter steelhead need the help.

Oregonians have a strong conservation ethic. We've taken tremendous steps to protect our fish and wildlife and will continue to work on all of the challenges facing Willamette steelhead. Sea-lions are not a scapegoat for that hard work as some suggest, but if we fail to address their impact, native steelhead will not last to benefit from these other efforts. Modifying the MMPA will not hurt robust sea lion populations. It will give native winter steelhead a fighting chance. We need to give our trained professionals the tools to balance the conservation of both sea lions and imperiled native fish.

