UPDATED F_{MSY} PROXY AND S_{MSY}/S_{MP} RATIO

Sacramento River Fall Chinook Work Group
Contact Author: Will Satterthwaite
will.satterthwaite@noaa.gov

In June 2024, the Sacramento River Fall Chinook (SRFC) Work Group (SRWG) recommended that updating the F_{MSY} proxy[1] used for SRFC should be a high priority, given the very dated nature of the analyses informing the current value (PFMC/NMFS 2011, their Appendix C) and concerns that they did not represent current conditions for SRFC. The Scientific and Statistical Committee (SSC) also recommended updating the reference point with more recent information. In addition, the SRWG proposed one option for indirect derivation of S_{MSY}, and the Salmon Technical Team (STT) supported it, wherein the "typical" ratio between S_{MSY} (the escapement corresponding to maximum sustainable yield) and S_{MP} (the escapement maximizing production[2]) could be identified through a review of spawner-recruit relationships from other stocks. This ratio might be the basis of extrapolating S_{MSY} for SRFC from an estimate of S_{MP} derived from a SRFC-specific spawner-production relationship, noting that the available data for SRFC might allow for estimation of S_{MP} but do not allow for estimating S_{MSY} directly.

These were initially identified as separate tasks, albeit both tasks that could be informed by a review of spawner-recruitment analyses based on recent data for stocks thought to be reasonably representative of SRFC under current conditions. However, mathematically, these recommendations constitute a single task, at least under the assumption that the spawner-recruit relationships for salmon can be described by a Ricker function, as is widely assumed for PFMC-managed salmon and serves as the basis of the current F_{MSY} proxy (PFMC/NMFS 2011, their Appendix C). This is because, for a Ricker applied to a Pacific salmon life history[3], $S_{MSY}/S_{MP}=F_{MSY}$, as shown in Appendix A[4].

[1] F_{MSY} is the exploitation rate corresponding to maximum sustainable yield. "*A stock will be considered subject to overfishing when the postseason estimate of F_t exceeds the MFMT, where the MFMT is generally defined as less than or equal to F_{MSY}*." (PFMC 2024).

[2] This quantity has been identified using a wide range of terms. In the FMP and STT statement, it is referred to as S_{MSP}, for maximum "sustainable" production. However, unlike for yield, the "sustainable" qualifier is not necessary for production because it is the theoretical maximum possible production which holds every year. In contrast, temporary yield above MSY is possible, at the cost of future yield, thus the sustainable qualifier is necessary for MSY versus MY. The SRWG report referred to this quantity as S_{MAX}, but S_{MP} is used here to be more consistent with FMP terminology.

[3] In particular, semelparity (Pacific salmon spawn once and then die) and fishing taking place on recruits after density-dependence has occurred.

[4] This does not seem to be widely appreciated or written down in an easy to cite format, though it can readily be derived from equation T1.7 of Schnute and Kronlund (2002), noting that for a Ricker gamma=0 and S_{MP}=1/beta.

Thus, we addressed these two recommendations simultaneously by reproducing and updating the derivation of the F_{MSY} proxy for application to SRFC. The derivation of the current value is described by PFMC/NMFS (2011, their Appendix C). The proxy value of 0.78 generally used for Chinook stocks without stock-specific estimates is equal to the average of F_{MSY} estimates from 20 stocks using data from as early as brood year 1946 and no more recent than 2000. We first reviewed the set of analyses included in the original derivation and asked whether analyses for any stocks included originally had been updated, whether each analysis that has not been updated (to our knowledge) should still be considered representative, and whether additional analyses had been performed for stocks and datasets that should be considered representative. We then derived various reference points and summary statistics for each analysis still considered representative, and derived resulting F_{MSY} and S_{MSY}/S_{MP} ratio proxies for application to SRFC based on different methods for weighting individual analyses and summarizing central tendencies.

The SRWG's preferred value for application to SRFC is 0.58 based on the mean of estimates for Klamath River Fall Chinook and Rogue River Fall Chinook. Below we describe the derivation of this value, and other values considered and our reasons for choosing our preferred approach.

Identification of Updated or Additional Analyses

Central Valley

This analysis was precipitated by a lack of suitable information to estimate MSY from a spawner-recruit relationship for SRFC, and the same challenges would apply to San Joaquin Fall or Sacramento Late-Fall Chinook. Although a published cohort reconstruction would allow for estimating potential natural-origin escapement in the absence of fishing for Sacramento River Winter Chinook (brood years 2002-2015, Chen et al. 2023), we judged this stock too different in their biology (e.g. outmigration behavior, run timing, age at maturity). Although a cohort reconstruction has been performed for the tagged component of natural-origin Central Valley (Butte Creek) Spring Chinook (brood years 1998-2007, Satterthwaite et al. 2023), the fraction of natural-origin production that was tagged is unknown. These analyses (especially for spring run) covered a limited range of brood years, so we did not attempt to fit spawner-recruit relationships to them.

California Coast

Based on the summary of available data and data gaps in O'Farrell et al. (2023), we are confident that there are not suitable data available to estimate spawner-recruit relationships for any stocks in the California Coastal Chinook Evolutionarily Significant Unit (ESU).

Klamath/Trinity

The derivation of the current F_{MSY} proxy included an analysis for Klamath River Fall Chinook based on brood years 1979-2000, compared to brood years 2001-2017 informing an updated analysis (Klamath River Fall Chinook Work Group 2024). We considered the updated analyses to be more representative of current conditions for this stock and more suitable for use in deriving the proxy. Although the data should exist to estimate a similar relationship for Klamath/Trinity Spring Chinook, complete recovery data for CWT in freshwater do not seem to be available in RMIS, and we suspect fall-run is more representative of SRFC due to more similar life history timing (Liermann et al. 2010).

Southern Oregon / Northern California Coast

Confer and Falcy (2014) performed a spawner-recruit analysis for Rogue River Fall Chinook brood years 1980-2004 and the resultant F_{MSY} estimate was endorsed and recommended for use by both the SSC and STT during the 2014 salmon methodology review[5]. ODFW (2019) fit a spawner-recruit relationship for Rogue River Spring Chinook, but did not report F_{MSY} nor the parameters needed to estimate it, did not include effects of ocean harvest, and lacked direct age data for most of the analysis. Due to these limitations, and a sense that the rigorously reviewed and endorsed fall-run estimate was more applicable to SRFC, we did not pursue the Rogue River Spring Chinook spawner-recruit relationship further. Based on the summary of available data and data gaps in OC and SONCC Status Review Team (2024), we are confident that there are not suitable data to estimate spawner-recruit relationships for any other stocks in the Southern Oregon / Northern California Coast ESU.

Oregon Coast

The derivation of the current proxy included analyses based on brood years 1967-1991 for Nehalem River Fall Chinook, 1973-1991 for Siletz River Fall Chinook, 1965-1991 for Siuslaw River Fall Chinook, and 1946-1977 for Umpqua River Spring Chinook. There are now more recent analyses based on approximate brood years[6] 1986 to 2006 for all of those stocks (ODFW 2014, their Table A-II:11). We considered the updated analyses to be more representative of current conditions for those stocks and more suitable for potential use in deriving the proxy. ODFW (2014, their Table A-II:11) also reports parameters for spawner-recruit relationships fit to another eleven fall Chinook stocks and one spring Chinook stock in Oregon coastal rivers from the Nehalem in the north to the Elk in the south, based on the same set of years. Note that direct estimates of ocean harvest impacts were only available for a subset of the stocks, and ocean impact rates estimated for those proxy stocks were assumed to apply to the escapement data from nearby rivers.

Northern Stocks

Among those Chinook salmon stocks with available information on ocean spatial distributions, all Chinook salmon stocks originating from the Columbia River Basin northward are rarely

[5] The FMP uses the F_{MSY}=0.78 proxy from PFMC/NMFS (2011).

[6] The brood years used in the ODFW (2014) analyses are not explicitly stated, although page 29 refers to the "period used for the abundance and productivity assessment (1986-2011), which would imply the last reasonably complete (age-5 included) brood year would be 2006.

encountered in ocean areas south of Cape Falcon, OR (Weitkamp 2010, Shelton et al. 2019). This contrasts with Central Valley stocks (including SRFC) along with Klamath and Rogue stocks that are mostly encountered in ocean areas south of Cape Falcon (Weitkamp 2010, Bellinger et al. 2015, Shelton et al. 2019) and Oregon Coastal stocks that have either a northerly (e.g. Trask, Salmon) or intermediate (e.g. Rock Creek Spring, Elk River) distribution (Weitkamp 2010, Shelton et al. 2019).

Given that ocean distributions of these northern stocks are very different from SRFC, we did not perform an extensive search for additional spawner-recruit relationships for stocks originating north of the Oregon Coast. However, we note that the FMP includes an F_{MSY} value for one northern stock that was not included in the original F_{MSY} proxy calculation, Grays Harbor Fall Chinook. A value of F_{MSY}=0.63 is specified for that stock, but no direct citation is provided for that F_{MSY} value. The description of the conservation objective for that stock cites QNDNR & WDFW (2014), which provides alpha estimates for the Chehalis and Humptulips substocks that are consistent[7] with this F_{MSY} value based on brood years 1986-2005, but does not directly state an F_{MSY} estimate for the composite stock.

Consideration of Remaining Analyses in Original F_{MSY} Proxy Derivation

We excluded analyses for which the majority of brood years were from before the late 1970s from further consideration. In part, this is because such brood years would pre-date the use of coded-wire tags (Nandor et al. 2010) and so there could be little to no empirical basis to the ocean harvest rates assumed for those brood years. In addition, the late 1970s mark a widely-recognized “regime shift” for Pacific salmon (Mantua and Hare 2002).

After excluding these out-dated analyses, the remaining analyses to potentially carry over for the updated F_{MSY} proxy are Columbia Upriver Summer (brood years 1979-1995, CTC 1999) and Deschutes River Fall Chinook (brood years 1977-1998, Sharma et al. 2010[8]). However, as previously noted, these stocks have a more northerly ocean distribution than SRFC.

Values to Inform Updated F_{MSY} and S_{MSY}/S_{MP} Proxy

Table 1 reports F_{MSY} estimates and other key quantities for the stocks we identified updated analyses for, identified in our search of the literature, or retained from the original F_{MSY} proxy derivation.

[7] Alpha = 5.61 for Chehalis implies F_{MSY} = 0.66 while alpha = 5.16 for Humptulips implies F_{MSY} = 0.63.

[8] This is cited as an “unpublished report” in PFMC/NMFS (2011), and does not appear to be available online, however we were able to acquire a copy by emailing lead author Rishi Sharma directly.

Estimates of alpha or "productivity" were obtained directly from each cited report. In cases where covariates were included through their effects on alpha, we used only the reported alpha value (i.e. assumed a value of zero for the covariates, which were all scaled to have mean zero in the original analyses), and used the beta value when it was directly reported. In some cases, only the inverse of beta (S_{MP} or "capacity") was reported, so we took the inverse of that. For the Oregon Coastal stocks reported in ODFW (2014), the unfished equilibrium population size N_{eq} was reported rather than beta or capacity. Since $N_{eq} = \frac{log\,(\alpha)}{\beta}$ (ODFW 2014, page 145), $\beta = \frac{log\,(\alpha)}{N_{eq}}$.

We then estimated the remaining values as follows: S_{MSY} was estimated from alpha and beta using the algorithm in Scheuerell (2016)[9]. S_{MP} was estimated as 1/beta. R_{MSY} and R_{MP} were determined by evaluating the Ricker recruitment function $R = \alpha S e^{-\beta S}$ at S_{MSY} or S_{MP}, respectively. Then $Y_{MSY}=R_{MSY}-S_{MSY}$, $Y_{MP}=R_{MP}-S_{MP}$, and $F_{MSY}=Y_{MSY}/R_{MSY}$[10].

Note that there are many more estimates available from the Oregon Coastal region than from other regions. Counting all fourteen (fall) or sixteen (fall and spring) Oregon Coastal Chinook stocks equally toward the F_{MSY} proxy could lead to disproportionate influence by stocks from a single geographic region, and one from which fish seem to have a considerably more northerly ocean distribution than SRFC (Weitkamp 2010, Shelton et al. 2019), so to represent this group we calculated the mean F_{MSY} for all fourteen Oregon Coastal fall run stocks, which was 0.66[11].

Updated F_{MSY} and S_{MSY}/S_{MP} Proxy

Given the geographic proximity of the respective rivers and distinct ocean distribution of Rogue, Klamath, and Central Valley Chinook relative to the distributions of stocks from the Elk River north (Weitkamp 2010, Shelton et al. 2019), arguably the most representative stocks for an updated SRFC F_{MSY} proxy and S_{MSY}/S_{MP} ratio would be just the Klamath and Rogue Fall Chinook stocks, which have a mean and median F_{MSY} and S_{MSY}/S_{MP} ratio of 0.58. This is the SRWG's preferred value for application to SRFC or other south-migrating stocks (i.e., stocks originating from south of the Elk River [Oregon]).

[9] In some cases, the results of our S_{MSY} and/or F_{MSY} calculation were similar to, but not identical to, the values reported in the source documents. This may reflect the source documents using an approximate solution (e.g. Hilborn 1985), rounding error in the reported parameter estimates, use of Bayesian posteriors for derived quantities independently of the individual parameter estimates, and/or different treatment of covariates. However, differences were small and since PFMC/NMFS (2011) simply evaluated F_{MSY} based on the alpha value extracted from each cited study, we performed our own calculations based on the reported parameter values for consistency with past practices.

[10] Equivalently, F_{MSY} can be shown to depend only on alpha and can be found through iterative solution of the equation $(1\text{-FMSY})e^{\text{-FMSY}}=1$ (PFMC/NMFS 2011, their Appendix C), which we confirmed to hold exactly for all of our estimates.

[11] The mean value is the same (to two digits) whether or not we included the two spring run stocks, since their F_{MSY} estimates were very close to the overall mean, such that their inclusion versus exclusion was not very influential.

Including the mean of the Oregon Coastal stocks as a third estimate given their intermediate ocean distribution increases the mean and median to 0.61. Including the Columbia Upriver Summer and Deschutes estimates increases the mean to 0.64 and median to 0.62. If all Oregon Coastal fall stocks are included as individual estimates, this increases the mean to 0.66 and median to 0.68, but note that this leads to considerable over-representation of stocks from a limited geographic area and limited similarity to SRFC. We did not consider including the Grays Harbor Fall Chinook value for deriving a proxy applicable to SRFC due to its northern distribution and lack of clarity on exactly how the value was derived, but note that the Grays Harbor Fall Chinook F_{MSY} value of 0.63 is close to the means calculated for the more inclusive sets of stocks described at the start of this paragraph.

The SRWG also discussed the possibility of using just the Klamath River Fall Chinook value, as potentially the single most representative stock based on its geographic proximity. However, the SRWG notes that the Rogue River Fall Chinook estimates are less affected by hatchery-origin fish spawning in natural areas (OC and SONCC Status Review Team 2024) and there is a high degree of similarity in the ocean distributions of Rogue River and Klamath River Chinook (Weitkamp 2010, Bellinger et al. 2015).

The SRWG also wishes to highlight two reasons that, while a considerable improvement on the existing F_{MSY} proxy, the values reported here may nevertheless be an over-estimate of F_{MSY} for SRFC. CA HSRG (2012, p. 21) noted that "the Sacramento Basin habitat (particularly the conditions for downstream migration) for fall Chinook is more highly degraded and SRFC natural spawning areas are probably less productive" than the Klamath River. Similar arguments would likely apply in comparison to the Rogue River, and the differences may be even more acute now than they were in 2012. Second, due to inconsistency among the source documents in which estimates for parameters and derived quantities were reported, we followed the approach of PFMC/NMFS (2011) in basing our F_{MSY} estimate for each stock on the point estimates of alpha and beta reported for that stock (and further note F_{MSY} depends directly only on alpha). However, there is uncertainty in each of these parameters, and F_{MSY} is a concave downward function of alpha. Therefore, the value of the F_{MSY} function evaluated at the mean value of alpha is greater than the mean of the function values evaluated at each alpha value, due to Jensen's inequality. This is illustrated by comparing our point estimate of F_{MSY}=0.56 for Rogue River Fall Chinook based on the point estimate of alpha (the posterior mean[12] for alpha from Confer and Falcy [2014]) to the posterior mean point estimate of 0.54 obtained from the posterior distribution for F_{MSY} itself reported by Confer and Falcy (2014).

It is also important to realize that all of these analyses may over-estimate F_{MSY} since they do not consider the effects of spawner age structure in relating escapement to expected recruitment. For

[12] Confer and Falcy (2014) does not explicitly state that the point estimates are posterior means, but we confirmed that they were via email exchange with Matt Falcy.

a given maturation and natural mortality schedule there is a tradeoff where higher ocean harvest rates lead to younger age structures (Carvalho et al. 2023). Since older fish tend to have higher reproductive output and weigh more (Hixon et al. 2014, Barenche et al. 2018), harvest rates lower than the F_{MSY} values estimated here could have benefits in terms of increased productivity and greater mean weight of catch (Staton et al. 2021) that are not captured by any of the spawner-recruit analyses considered in Table 1. Fostering a more diverse age structure could also have benefits for stability and resilience to environmental stressors (Carvalho et al. 2023).

On the other hand, these analyses do not employ the adjustment to alpha suggested by Hilborn (1985) and discussed in the context of KRFC by the STT (2005) to account for model-estimated process error (see Appendix D for details). This adjustment would have increased F_{MSY} estimates. The choice not to employ the adjustment reflects a mix of precedent (PFMC/NMFS [2011, their Appendix C] seems to have largely used un-adjusted alpha values, although this is not explicitly discussed and for KRFC they appear to have used the adjusted value), pragmatism (the information needed to calculate the adjustment is not available in most reports providing alpha values), and concerns about the suitability of this adjustment (Appendix D).

Table 1. Stocks, regions, brood years, spawner-recruit parameters, and reference point estimates for potential inclusion in an updated F_{MSY} proxy. As noted in the main text, F_{MSY} and S_{MSY}/S_{MP} estimates for each stock are identical, this was further confirmed through calculating each one separately in the code and confirming outputs were identical to at least eight decimal places.

Stock	Region	Brood Years	Citation	alpha	beta	S_{MSY}	S_{MP}	F_{MSY}	S_{MSY}/S_{MP}	R_{MSY}/R_{MP}	Y_{MP}/Y_{MSY}
Rogue F	SONC	1980-2004	Confer & Falcy 2014	3.93	0.0000156	35,655	64,103	0.56	0.56	0.87	0.64
Klamath F	Klamath	2001-2017	KRFC WG 2024	4.7	0.0000274	22,221	36,496	0.61	0.61	0.90	0.77
Col URS	Columbia	1979-1995	CTC 1999	8.60	0.0000620	12,146	16,129	0.75	0.75	0.96	0.94
Deschutes	Columbia	1977-1998	Sharma et al. 2010	4.85	0.000136	4,553	7,372	0.62	0.62	0.91	0.79
Nehalem	OR Coast	1986-2006	ODFW 2014	6.5	0.0000431	16,049	23,176	0.69	0.69	0.94	0.89
Tillamook	OR Coast	1986-2006	ODFW 2014	5.2	0.0000487	13,067	20,528	0.64	0.64	0.92	0.82
Nestucca	OR Coast	1986-2006	ODFW 2014	4.4	0.0000336	17,562	29,766	0.59	0.59	0.89	0.73
Salmon	OR Coast	1986-2006	ODFW 2014	3.9	0.000193	2,874	5,189	0.55	0.55	0.87	0.63
Siletz	OR Coast	1986-2006	ODFW 2014	8.5	0.000110	6,804	9,063	0.75	0.75	0.96	0.94
Yaquina	OR Coast	1986-2006	ODFW 2014	12.8	0.000147	5,586	6,794	0.82	0.82	0.98	0.98
Alsea	OR Coast	1986-2006	ODFW 2014	9.1	0.000168	4,556	5,963	0.76	0.76	0.97	0.95
Siuslaw	OR Coast	1986-2006	ODFW 2014	7.2	0.0000350	20,447	28,563	0.72	0.72	0.95	0.91
So Umpq	OR Coast	1986-2006	ODFW 2014	7.7	0.000120	6,062	8,299	0.73	0.73	0.96	0.93
Coos	OR Coast	1986-2006	ODFW 2014	6.4	0.0000743	9,276	13,466	0.69	0.69	0.94	0.89
Coquille	OR Coast	1986-2006	ODFW 2014	6.0	0.0000466	14,438	21,446	0.67	0.67	0.93	0.87
Floras	OR Coast	1986-2006	ODFW 2014	8.2	0.000602	1,235	1,661	0.74	0.74	0.96	0.94
Sixes	OR Coast	1986-2006	ODFW 2014	4.8	0.000180	3,412	5,550	0.61	0.61	0.90	0.78
Elk	OR Coast	1986-2006	ODFW 2014	2.0	0.000103	3,045	9,670	0.31	0.31	0.62	0.0[13]
No Ump S	OR Coast	1986-2006	ODFW 2014	5.0	0.0000837	7,479	11,948	0.63	0.63	0.91	0.80
So Ump S	OR Coast	1986-2006	ODFW 2014	5.7	0.00158	418	632	0.66	0.66	0.93	0.85

[13] For Elk River Chinook, maximum production is predicted to occur at an escapement higher than the unfished equilibrium, thus there is no available surplus for harvest at maximum production.

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Appendix A: Proof that for a Ricker applied to salmon, $F_{MSY}=S_{MSY}/S_{MP}$

Define:
S = spawners
R = recruits (potential future spawners in the absence of fishing)
Y = yield = R-S (consistent with how this is treated in PFMC harvest models and exploitation rate calculations, "yield" here is the reduction in escapement compared to unfished, not just simply harvest)
F = exploitation rate = $Y/R = Y/(Y+S)$

Ricker spawner-recruit relationship:

$$R = \alpha S e^{-\beta S}$$

Define:

$$a = log\,(\propto)$$

which leads to

$$R = S e^{a-\beta S}$$

Find S_{MP} the escapement that maximizes production (i.e., where the first derivative of R is 0):

$$\frac{dR}{dS} = (1-\beta S)e^{a-\beta S}$$

$$(1-\beta S_{MP})e^{a-\beta S_{MP}} = 0$$

Divide both sides by $e^{a-\beta S_{MP}}$

$$(1-\beta S_{MP}) = 0$$

$$\beta S_{MP} = 1$$

$$S_{MP} = \frac{1}{\beta}$$

Find S_{MSY} the escapement that maximizes yield (i.e., where the first derivative of Y is 0):

$$Y = R - S = S e^{a-\beta S} - S$$

$$\frac{dY}{dS} = (1-\beta S)e^{a-\beta S} - 1$$

$$(1-\beta S_{MSY})e^{a-\beta S_{MSY}} - 1 = 0$$

Note that since $R = S e^{a-\beta S}$, $e^{a-\beta S} = \frac{R}{S} = \frac{Y+S}{S}$

$$(1-\beta S_{MSY})\frac{Y_{MSY}+S_{MSY}}{S_{MSY}} - 1 = 0$$

Add 1 to both sides

$$(1-\beta S_{MSY})\frac{Y_{MSY}+S_{MSY}}{S_{MSY}} = 1$$

Multiply through

$$\frac{Y_{MSY} + S_{MSY}}{S_{MSY}} - \beta S_{MSY} \frac{Y_{MSY} + S_{MSY}}{S_{MSY}} = 1$$

Multiply by $\frac{S_{MSY}}{Y_{MSY}+S_{MSY}}$ on both sides

$$1 - \beta S_{MSY} = \frac{S_{MSY}}{Y_{MSY} + S_{MSY}}$$

Note that since $F = \frac{Y}{S+Y}$, $1 - F = \frac{Y+S}{Y+S} - \frac{Y}{Y+S} = \frac{S}{Y+S}$, so the above equation is equivalent to

$$1 - \beta S_{MSY} = 1 - F_{MSY}$$

Rearrange to get

$$F_{MSY} = \beta S_{MSY}$$

And since, as shown above, $S_{MP} = \frac{1}{\beta}$ and so $\beta = \frac{1}{S_{MP}}$

$$F_{MSY} = \frac{S_{MSY}}{S_{MP}}$$

Appendix B: R Code for Reference Point Estimation

```
library(gsl) #To get Lambert function for exact Smsy calculation per Scheuerell 2016
PeerJ http://dx.doi.org/10.7717/peerj.1623

#read in Ricker parameter estimates by stock -  see Appendix C
dat=read.csv("SRparams.csv")

#set up file to output estimates to
write(c("Stock","alpha","beta","Smsy","Smp","Rmsy","Rmp","Ymsy","Ymp","Fmsy"),file="Re
fPointCalcs.csv",ncolumns=10,sep=",")

stocks=dat$Stock
for (stock.counter in 1:length(stocks))
{
	Stock=stocks[stock.counter]
	alpha=dat$alpha[stock.counter]
	beta=dat$beta[stock.counter]
	lambert_in=exp(1-log(alpha))
	lambert_out=lambert_W0(lambert_in)
	Smsy=(1-lambert_out)/beta
	Smp=1/beta
	Rmsy=alpha*Smsy*exp(-beta*Smsy)
	Rmp=alpha*Smp*exp(-beta*Smp)
	Ymsy=Rmsy-Smsy
	Ymp=Rmp-Smp
	Fmsy=Ymsy/(Ymsy+Smsy)
	write(c(Stock,alpha,beta,Smsy,Smp,Rmsy,Rmp,Ymsy,Ymp,Fmsy),file="RefPointCalcs.c
sv",ncolumns=10,sep=",",append=TRUE)
}
```

Appendix C: CSV file ("SRparams.csv") of alpha and beta estimates

```
Stock,alpha,beta
Rogue,3.93,0.0000156
Klamath,4.7,0.0000274
Columbia,8.5987,0.000062
Deschutes,4.85,0.000135648
Nehalem,6.5,4.31E-05
Tillamook,5.2,4.87E-05
Nestucca,4.4,3.36E-05
Salmon,3.9,0.000192718
Siletz,8.5,0.000110343
Yaquina,12.8,0.000147196
Alsea,9.1,0.000167697
Siuslaw,7.2,3.50E-05
SouthUmpqua,7.7,0.000120496
Coos,6.4,7.43E-05
Coquille,6,4.66E-05
Floras,8.2,0.000601986
Sixes,4.8,0.000180175
Elk,2,0.000103411
NorUmpSpr,5,8.37E-05
SoUmpSpr,5.7,0.001581328
```

Appendix D: Discussion of Hilborn (1985) adjustment to alpha

Hilborn (1985) notes that under the assumption of lognormally-distributed process error (i.e., both spawning escapement and recruitment are observed without error, and any deviation between a single observation and the best-fit model prediction is a random error unrelated to model mis-specification or confounding factors not considered), the Ricker can be expressed as:

$$R = \alpha S^{-\beta S + \epsilon}$$

where ε is a normally distributed random variable with mean 0 and variance σ^2.

Under this formulation, the expectation (arithmetic mean) for recruitment at a particular level of spawning escapement is

$$\bar{R} = \alpha S^{-\beta S} e^{\sigma^2/2} = \alpha e^{\sigma^2/2} S^{-\beta S}$$

Rather than

$$R = \alpha S^{-\beta S}$$

Thus, it could be argued that F_{MSY} should be calculated based on

$$\alpha' = \alpha e^{\sigma^2/2}$$

rather than α.

However, this adjustment assumes that recruits are estimated perfectly, which is unlikely, and thus it will tend to over-correct by conflating process and observation error. Probably more significantly, model mis-specification is likely to be a major source of error that may not follow a lognormal distribution. The expectation or arithmetic mean is only one of many potential measures of central tendency (e.g. median, mode or maximum likelihood estimate, etc.) and there seems to be an increasing tendency to base salmon metrics on medians (e.g., SSC 2022).

Finally, there seem to be some troubling aspects to following the Hilborn (1985) adjustment to its logical endpoint. Holding the median value of productivity (α) constant but increasing the degree of recruitment variability (σ) actually decreases the modal (most likely) value, but the resultant management recommendation would be to use a larger value of α', resulting in a higher F_{MSY} and more intense fishing on an equally productive but more variable stock based on the expectation of occasional very high recruitments, but also a higher risk of low recruitments. Given the risks associated with increasingly variable recruitment, and National Standard 1 Guidance that states "The most important limitation on the specification of OY is that the choice of OY and the conservation and management measures proposed to achieve it must prevent overfishing", it may be prudent to retain α rather than α' as the basis for F_{MSY} calculation even for those studies where sufficient information to calculate α' is provided.

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