Sacramento River Fall Chinook Workgroup Progress Report

June 5, 2024 – STT version

Prepared for:

SSC of Pacific Fishery Management Council

Prepared by:

Sacramento River Fall Chinook Workgroup and
Pacific Fishery Management Council Staff

Workgroup (WG) Terms of Reference

Develop potential improvements to Sacramento River fall Chinook (SRFC) assessment and management for Pacific Fishery Management Council (Council, PFMC) consideration that would:

a. Evaluate management measures currently in use, which includes:
   i. Reference points
   ii. Conservation objective
   iii. Harvest Control Rule
   iv. Also, consider the effect of environmental variables on the stability and accuracy of the management measures listed above.

F_{MSY} and S_{MSY}/escapement target

b. Provide the Council with a work plan/timeline to
   i. develop alternative management measures as needed, that includes analysis of biological risks and fishery related benefits, and
   ii. design new, or update existing, abundance forecast methods and harvest models that may incorporate age-structure information, as is done for Klamath River fall Chinook.

c. Provide the Council with new or updated management measures, abundance forecast methods, and harvest models, as appropriate and supported by the available data.

- Inputs informing F_{MSY}=0.78 proxy from PFMC (2011)

Table C-1. Independent estimates of F_{MSY} used in the development of the Chinook F_{MSY} proxy.

Run	Location	Brood years	α	F_{MSY}	Source
Fall	Hoh River	1968-1982	23.57	0.90	Cooney (1984)
Fall	Queets River	1968-1982	18.27	0.87	Cooney (1984)
Fall	Quillayute River	1968-1982	17.71	0.87	Cooney (1984)
Fall	Columbia River	1947-1959	7.40	0.72	Chapman et al. (1982), from Reisenbichler (1987)
Spring	Columbia River	1957-1972	8.70	0.76	Chapman et al. (1982), from Reisenbichler (1987)
Summer	Columbia River	1979-1995	8.60	0.75	CTC (1999)
Fall	Columbia River bright	1964-1991	16.75	0.86	Langness and Reidinger (2003)
Fall	North Lewis River	1964-1991	8.93	0.76	CTC (1999)
Fall	Deschutes River	1977-1998	4.85	0.62	Sharma et al. (2010)
Fall	Nehalem River	1967-1991	6.54	0.69	CTC (1999)
Fall	Siletz River	1973-1991	12.10	0.81	CTC (1999)
Fall	Siuslaw River	1965-1991	4.84	0.62	CTC (1999)
Spring	Umpqua River	1946-1977	7.20	0.72	ODFW (Pers. Comm.), from Reisenbichler (1987)
Spring	Rogue River	1960-1979	11.80	0.81	ODFW (Pers. Comm.), from Reisenbichler (1987)
Fall	Klamath River	1979-2000	7.19	0.72	STT (2005)
Fall	Shasta River	1955-1978	9.70	0.78	Reisenbichler (1986)
Fall	South Fork Eel River	1963-1972	11.80	0.81	Reisenbichler (1986)
Fall	Upper Sacramento River	1967-1979	10.40	0.79	Reisenbichler (1986)
Fall	Feather River	1955-1966	13.20	0.83	Reisenbichler (1986)
Fall	San Joaquin River	1955-1976	16.40	0.86	Reisenbichler (1986)
				0.78	mean

- More recent work
  - ODFW (2014) estimated F_{MSY}=0.54 for Rogue River Fall Chinook
    - Endorsed by STT and SSC
  - KRFC WG (2024) fit updated spawner-recruit analysis for Klamath River Fall Chinook
    - alpha=4.7 (no survival covariate, those results not reported) implies F_{MSY}=0.61
  - Other examples might turn up in literature review

4.1 F_{MSY}

The WG discussed five options for updating F_{MSY}.

(page 13)

- **Update proxy** to a value more representative of SRFC
- **Spawner-recruit analysis based on abundance surrogate for natural area escapement**
- **Spawner-recruit analysis based on cohort reconstruction for natural area escapement**
- **Tributary-specific F_{MSY} values,** but there is limited data available and hard to implement
- **Year-specific F_{MSY} values,** but WG recommends against pursuing further

S_{MSY}/conservation objective: 122K-180K adults returning to hatchery and natural areas combined

-upper bound based on sum of hatchery goals and historical mean escapements that can't be reproduced

-lower bound "interim" reduction for Upper Sac, tied to RBDD problems

- Literature review -- November 2022 methodology review
  - SSC report: https://www.pcouncil.org/documents/2022/11/d-2-a-supplemental-ssc-report-1-4.pdf/
  - STT report: https://www.pcouncil.org/documents/2022/11/d-2-a-supplemental-stt-report-1-2.pdf/

photo: USBR

4.2 S_{MSY}
4.4 Conservation Objective

The WG discussed 10 options for updating S_{MSY}.
all of which could also apply to conservation objective

(page 16, page 19)

- **Eliminate 'interim' lower bound**
- **Update status quo approach** based on mean escapement
- **Direct derivation from a spawner-recruit relationship** (either natural-area only or total)
- **Indirect derivation from spawner-juvenile production relationship**
- **Proxy based on escapement maximizing production,** easier to implement but foregoes some yield
- **Proxy based on escapement optimizing production,** policy would need to identify desired fraction of potential production

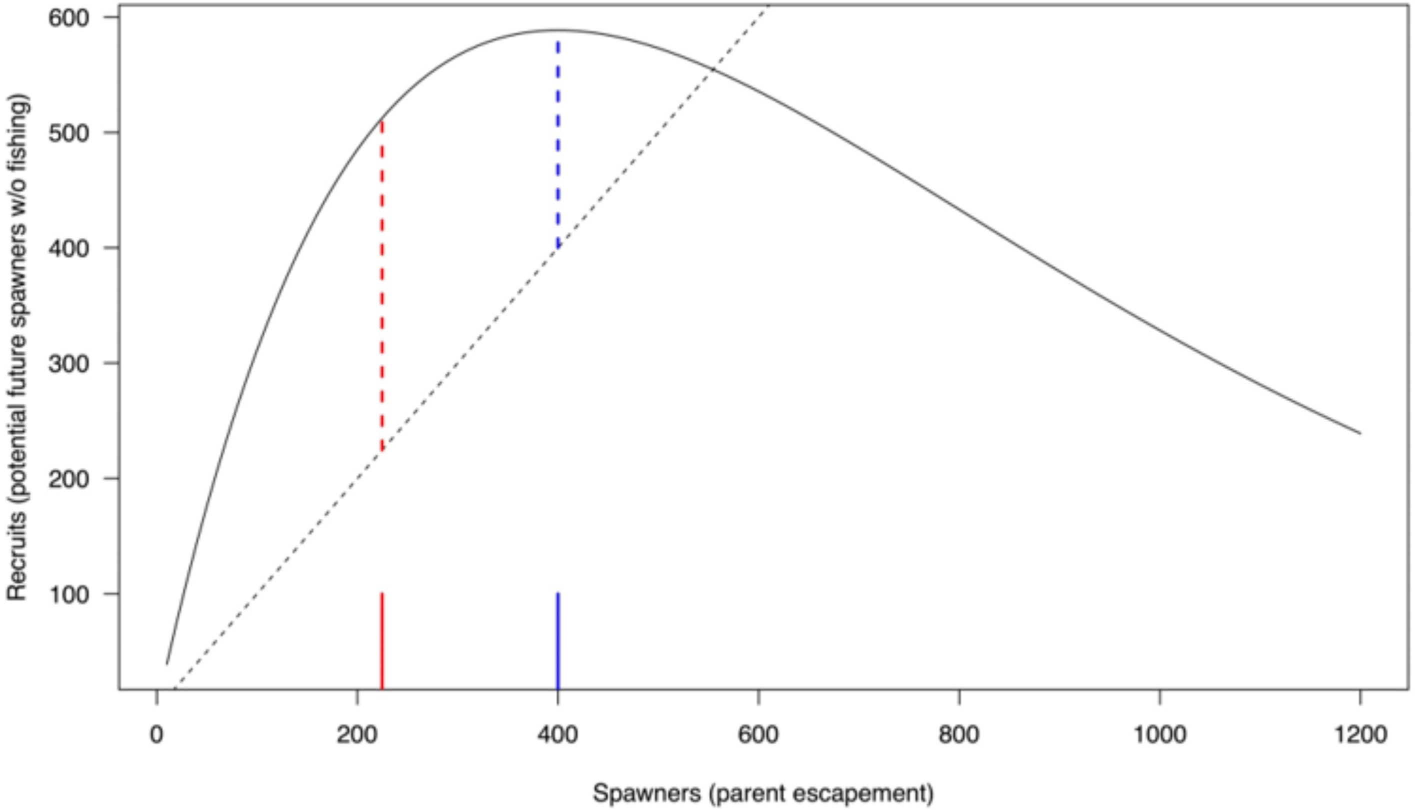


Figure A2. *Target escapement levels maximizing production or sustainable yield for a Ricker spawner-recruit relationship. The dotted line is the 1:1 line where spawners and recruits are equal. The solid blue line denotes the escapement maximizing production (S_{MP}) and the height of the dashed blue line denotes the expected yield from targeting escapement equal to S_{MP}. The solid red line denotes the escapement maximizing sustainable yield (S_{MSY}) and the height of the dashed red line denotes the yield expected from targeting escapement equal to S_{MSY} (maximum sustainable yield, MSY).*

<u>MSY calculation assumes:</u>

Spawners only source of recruits

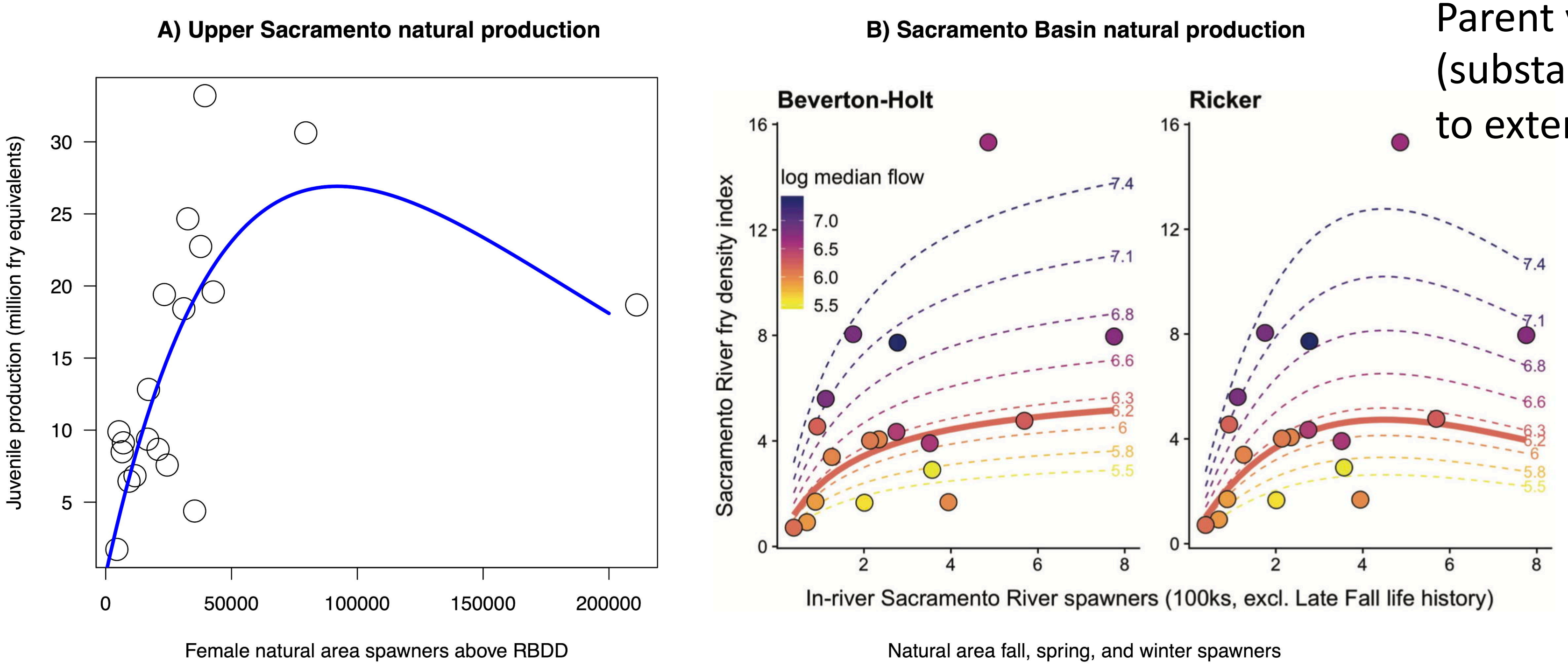
Recruits only source of harvest

Unfished recruits only source of spawners

Some published SRFC spawner-recruit relationships

- Based on juvenile production vs natural-area escapement

Parent years 2002-2020 (should be straight-forward to update)



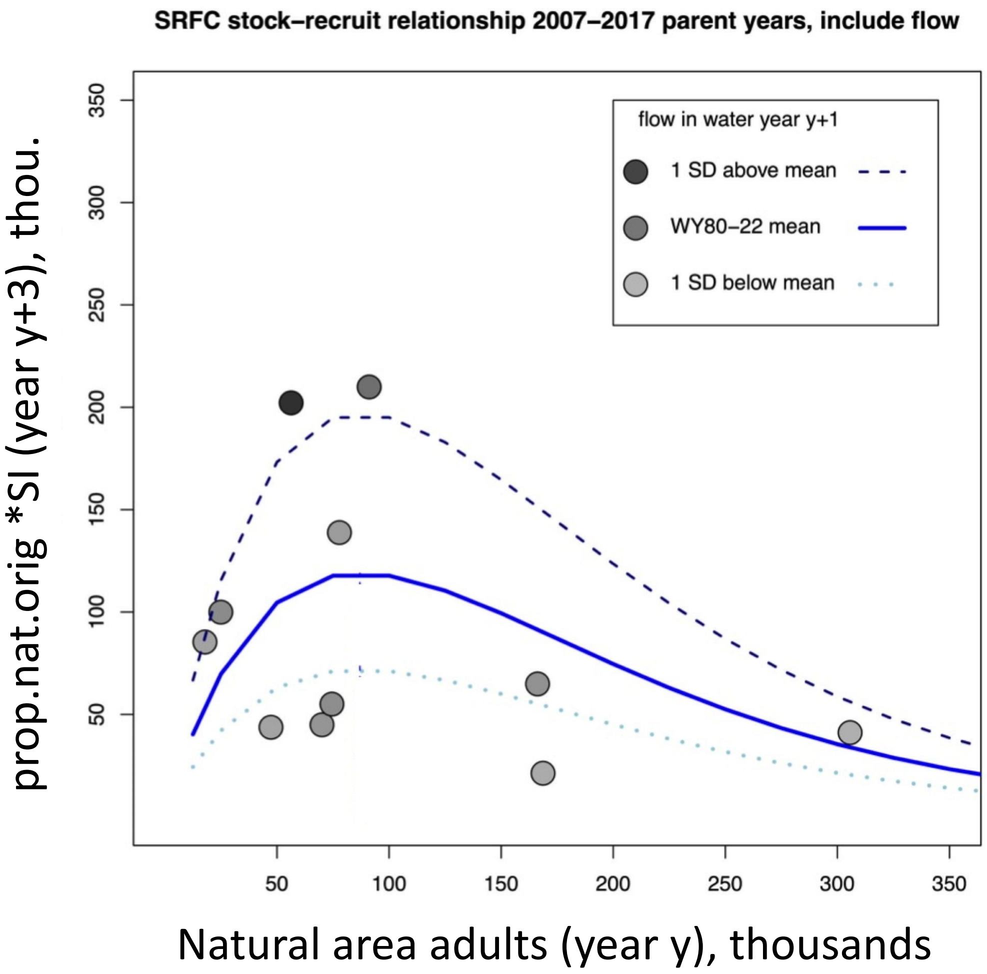
Parent years 1998-2015 (substantial work required to extend index)

Figure 3 Juvenile production in natural areas as a function of escapement for fall Chinook above Red Bluff Diversion Dam (**A**) or fall-, spring-, and winter-run Chinook Salmon throughout the Sacramento Basin (**B**). Panel (**B**) also incorporates an effect of flow as described in Munsch et al. (2020) but note that the peak production is estimated to occur at the same escapement regardless of flow.

- Satterthwaite (2023) and Munsch et al. (2020)

Some SRFC spawner-recruit relationships

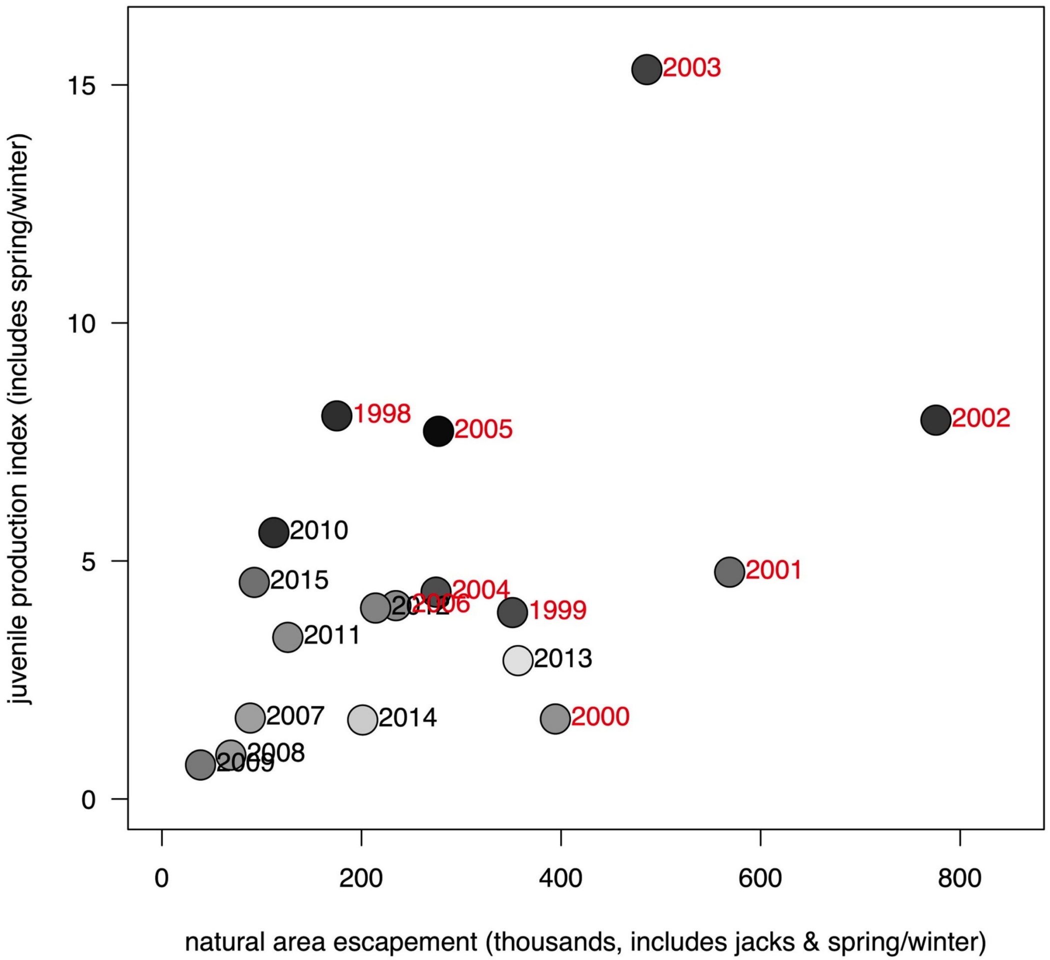
- Based on index for unfished natural-origin escapement vs natural-area escapement



Parent years 2007-2017
11 data points for 3 parameters
(updating further depends on processing of inland CWT recoveries, may be compromised by unmarked fry releases in recent and future years unless new genetic sampling schemes are implemented)

- Satterthwaite (unpublished)

Limitations of years suited to SRFC cohort reconstructions or natural-origin SI calculations

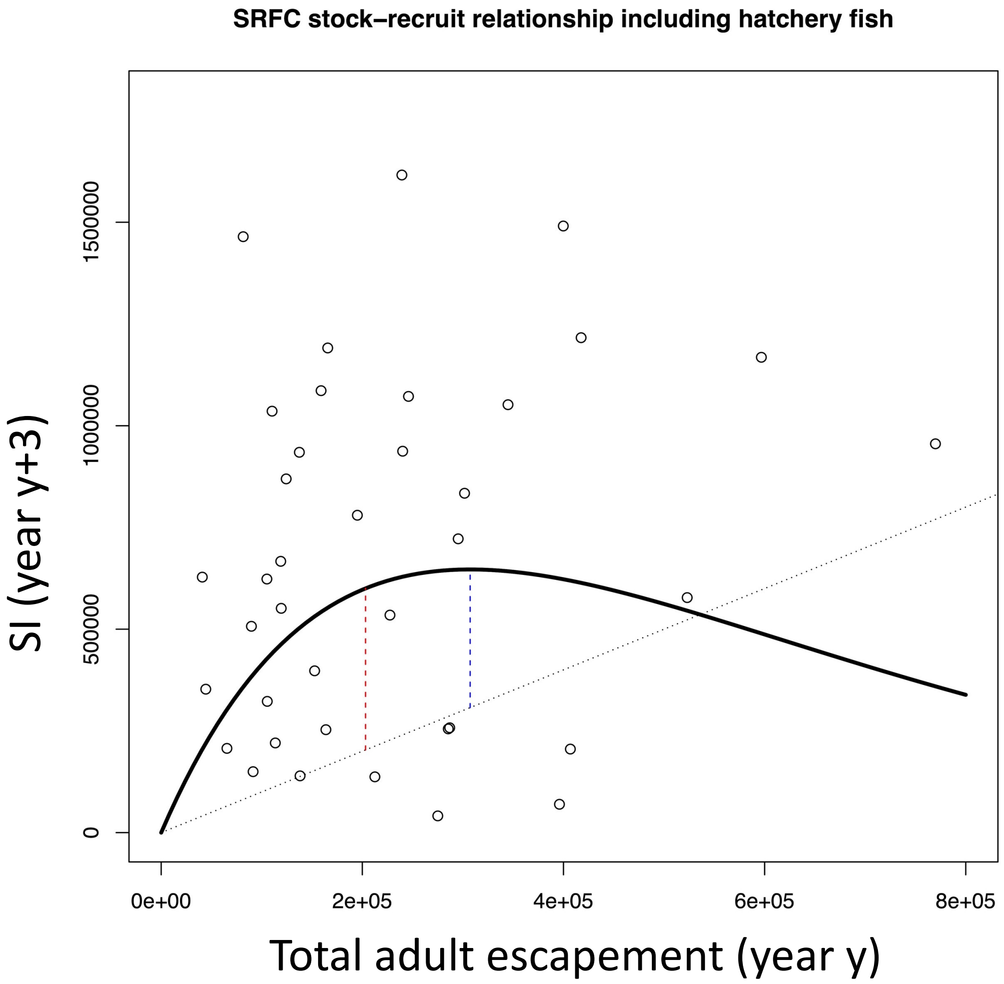


- Parent years in red lack suitable data for cohort reconstruction

- Unmarked fry releases may compromise ability to reconstruct natural cohorts going forward unless new genetic sampling programs are implemented at the required scale

Some SRFC spawner-recruit relationships

- Including spawners returning to hatcheries



Parent years 1984-2020
Easy to update

Consistent units, but little reason to expect a strong functional relationship

- Satterthwaite (extra unpublished, not even seen by WG)

4.2 S_{MSY} (continued)
4.4 Conservation Objective

The WG discussed 10 options for updating S_{MSY}.
all of which could also apply to conservation objective

(page 16, page 19)

Proxy based on level of inland harvest opportunity

Proxy based on habitat

Accounting for San Joaquin Fall and/or Sacramento Late-Fall

Year-specific metrics based on expected conditions for upcoming cohort, but WG recommends against pursuing further

Workgroup (WG) Terms of Reference

Develop potential improvements to Sacramento River fall Chinook (SRFC) assessment and management for Pacific Fishery Management Council (Council, PFMC) consideration that would:

a. Evaluate management measures currently in use, which includes:
   i. Reference points
   ii. Conservation objective
   iii. Harvest Control Rule
   iv. Also, consider the effect of environmental variables on the stability and accuracy of the management measures listed above.

b. Provide the Council with a work plan/timeline to
   i. develop alternative management measures as needed, that includes analysis of biological risks and fishery related benefits, and
   ii. design new, or update existing, abundance forecast methods and harvest models that may incorporate age-structure information, as is done for Klamath River fall Chinook.

c. Provide the Council with new or updated management measures, abundance forecast methods, and harvest models, as appropriate and supported by the available data.

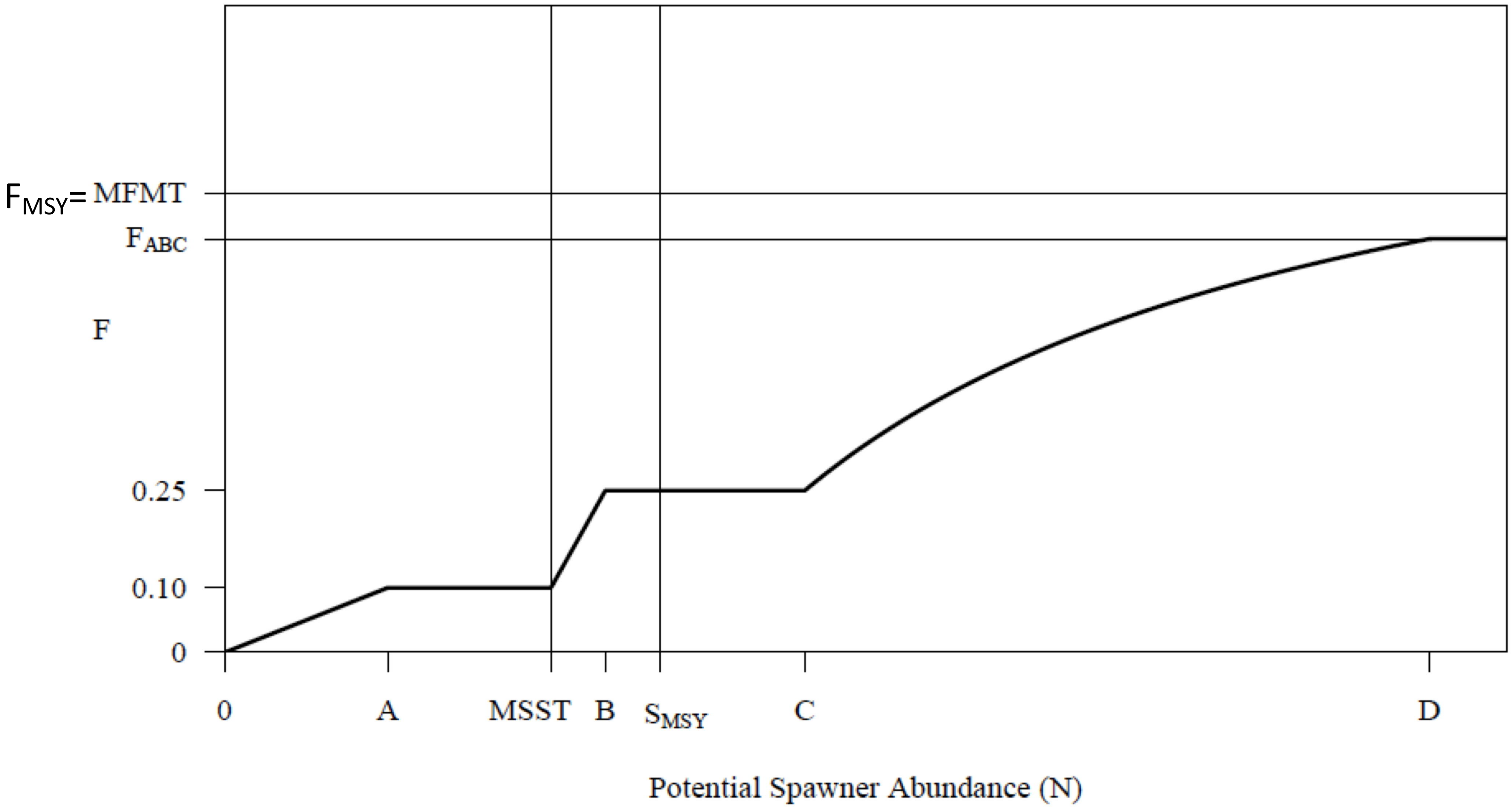


FIGURE 3-1. Control rule for Sacramento River and Klamath River fall Chinook. Abundance is pre-fishery ocean abundance in spawner equivalent units, and F is the exploitation rate. Reference points in the control rule are defined in the text.

https://www.pcouncil.org/documents/2022/12/pacific-coast-salmon-fmp.pdf/#page=41

3.4 Environmental Variables and their Implications for Management Measures

Environmental factors and biological responses

(page 11)

- Currently use the stoplight tables to show influence of environmental factors on salmon at varying life stages
- Strength of correlations change over time which poses challenges
- Environmental variables may have cumulative effects on populations and recruitment
- Year-specific escapement targets would rely on future environmental conditions

4.5 Harvest Control Rule

Updating the harvest control rule would require little time, but analyzing costs and benefits could be more involved.

The WG discussed four approaches.

(page 20)

Update reference points, without changing basic shape

Alternative escapement targets, ex. Year-specific escapements or something other than S_{MSY}

Alternative forms, ex. Eliminating or simplifying *de minimis,* matrix approach informed by risk tables

Uncertainty buffers to account for forecasting and harvest planning model errors

Workgroup (WG) Terms of Reference

Develop potential improvements to Sacramento River fall Chinook (SRFC) assessment and manager
for Pacific Fishery Management Council (Council, PFMC) consideration that would:

a. Evaluate management measures currently in use, which includes:
   i. Reference points
   ii. Conservation objective
   iii. Harvest Control Rule
   iv. Also, consider the effect of environmental variables on the stability and accuracy of the management measures listed above.
b. Provide the Council with a work plan/timeline to
   i. develop alternative management measures as needed, that includes analysis of biological risks and fishery related benefits, and
   ii. design new, or update existing, abundance forecast methods and harvest models that may incorporate age-structure information, as is done for Klamath River fall Chinook.
c. Provide the Council with new or updated management measures, abundance forecast methods, and harvest models, as appropriate and supported by the available data.

6.1 Abundance and Harvest Estimation

(page 22)

- Consider a KRFC-style cohort reconstruction
- Preliminary SRFC cohort-reconstructions are underway, for limited set of years
- Ability to use full cohort reconstruction would depend on recovering enough tags from hatchery fish and age info on natural fish
- Consider an approach similar to SRWC (i.e. hatchery component only)

5.2 Preseason Abundance Forecast (SI Forecast)

(page 21)

- Tendency to over-forecast when abundance is low
- Over-forecasted postseason estimate in 7 out of last 10 years (now 8/11)
- Changes in maturation rates would affect jack:adult ratios, a key driver of forecast method

5.3 Harvest Planning Model (SHM)

(page 22)

Under-predicted postseason estimate of SRFC exploitation rate in 10 of the last 10 years

Planned in-season caps are expected to reduce amount of under-prediction of SRFC harvest

Caps would be sensitive to forecast error for SRFC and co-occurring stocks.

6.3 Harvest Planning Model

The WG agreed it does not have sufficient expertise to lead development of an alternative SHM

(page 25)

- Need to coordinate any changes with harvest models used for other CA stocks
- Challenges with new management measures implemented for California Coastal Chinook protection
- Potential alternatives for changes in reference points could affect the units used or basis for new models (hatchery /natural)

Errata in E.1.a SRWG Report 1

- p. 8 description of F_{MSY} proxy should say brood years as early as 1946, not 1947
- p.9, first line of last paragraph should say "then-recent" (i.e., what was recent in 1984) not "than-recent"
- p. 29, 4th row has the wrong (private) hyperlink, the entry for "Timeline" there should be the same as the 2nd row on p. 31
- p. 40, second sentence of last full paragraph should say "decreases with increasing density" not "increases with increasing density"

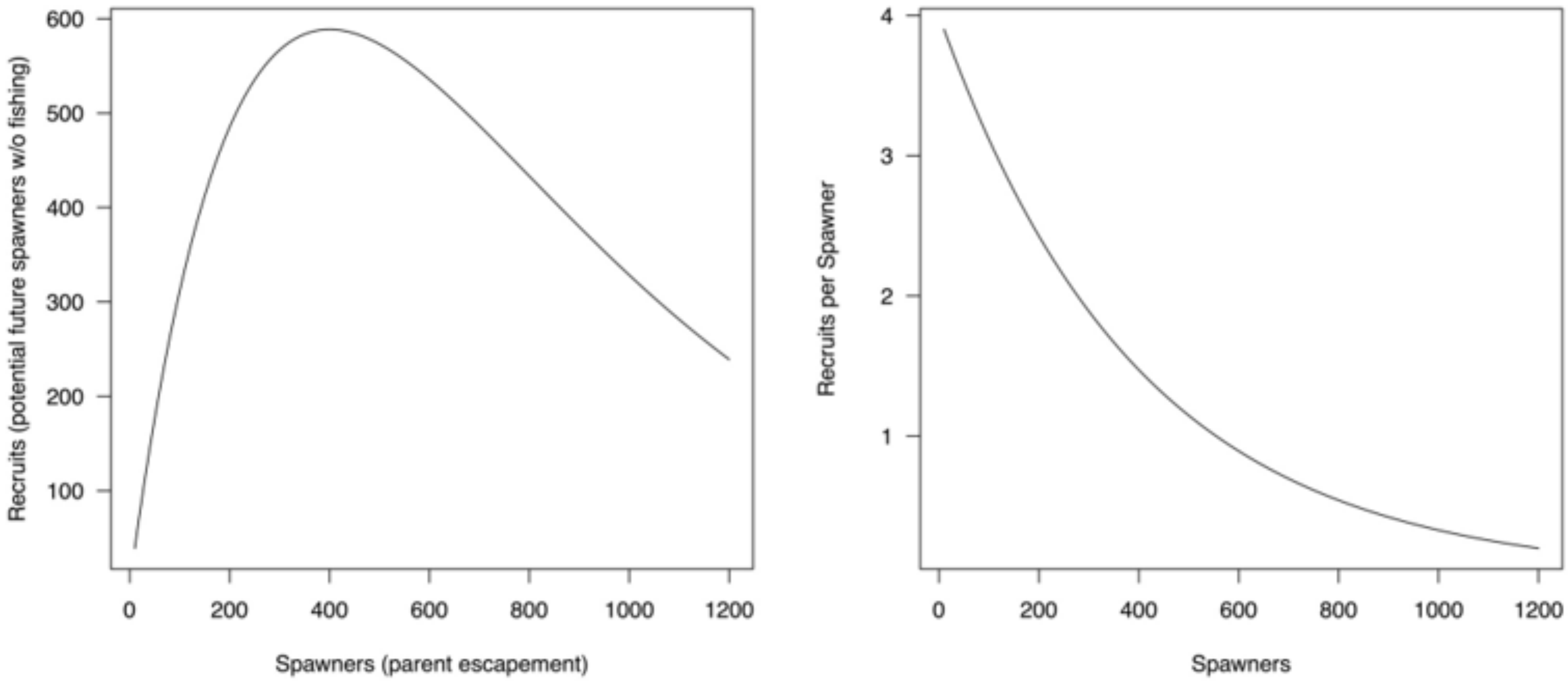


Figure A1. *Ricker spawner-recruit relationship at the population (a) or per spawner (b) level. The solid curve denotes the number of recruits (y-axis) predicted to be produced at any level of parent escapement (x-axis). The plotted curve is not driven by data for any stock and the values used for α and β were chosen arbitrarily for illustrative purposes.*

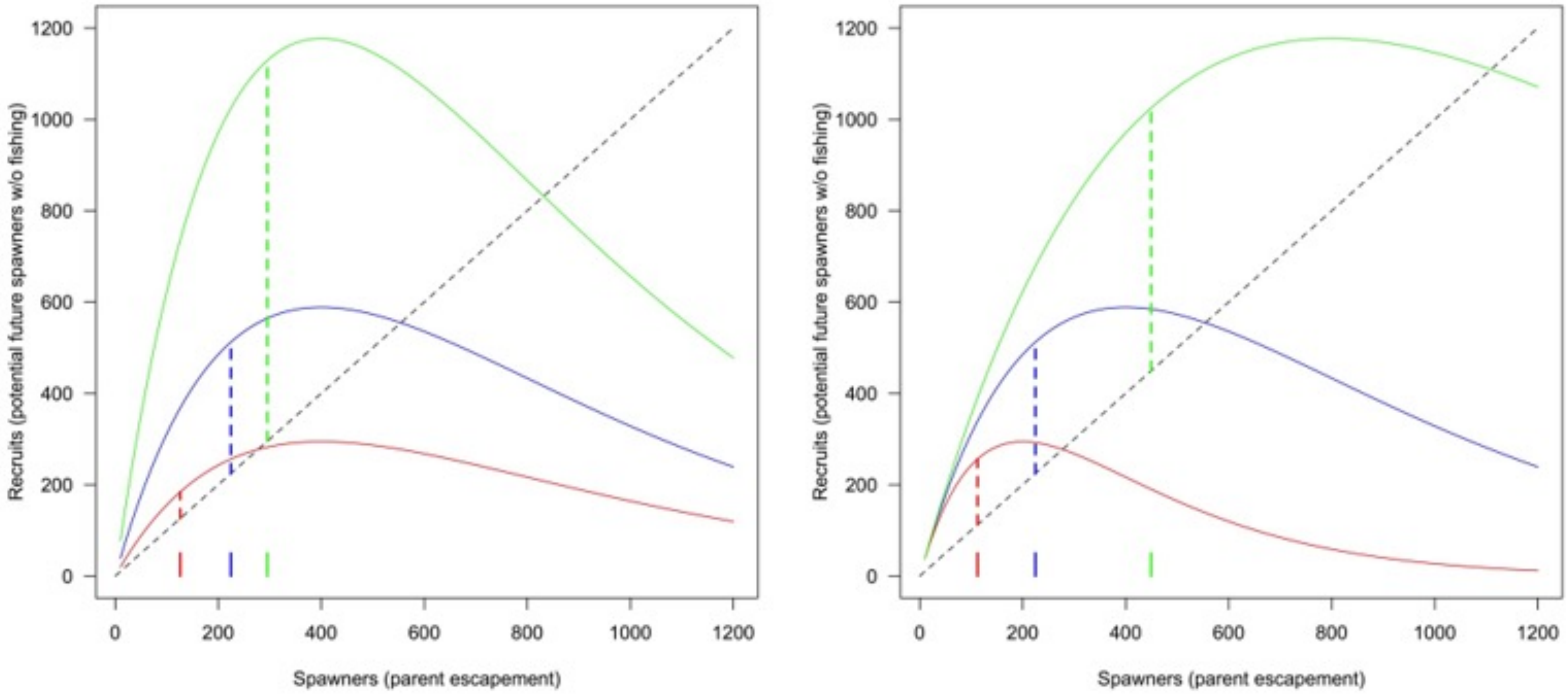
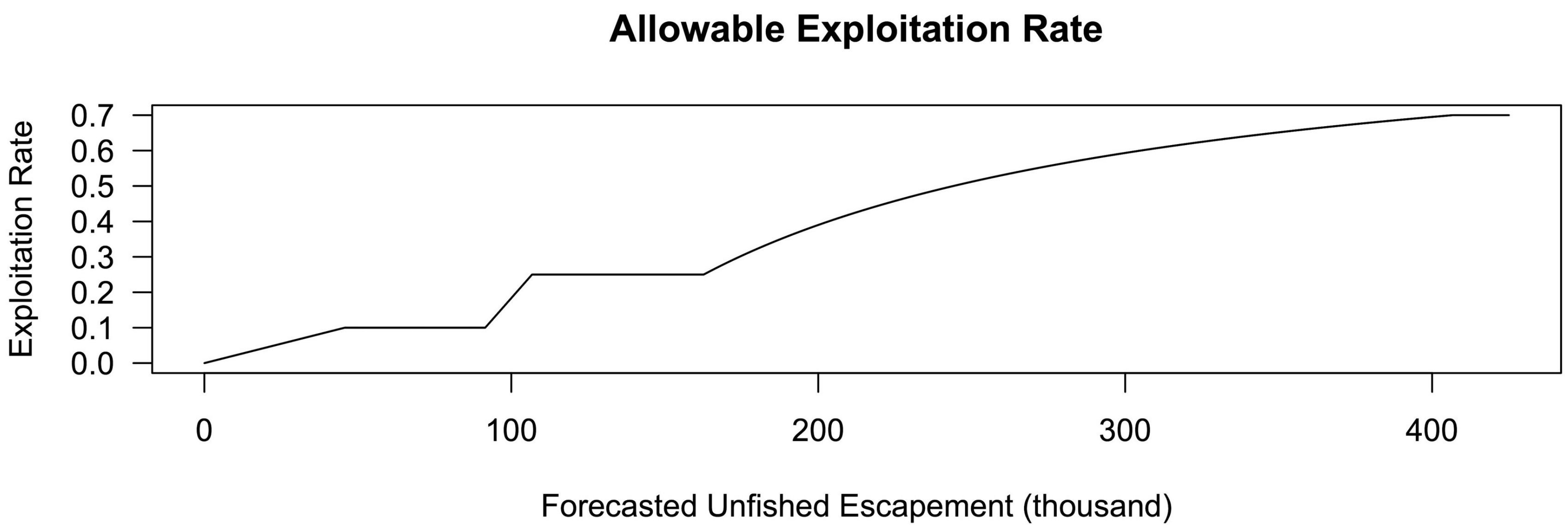
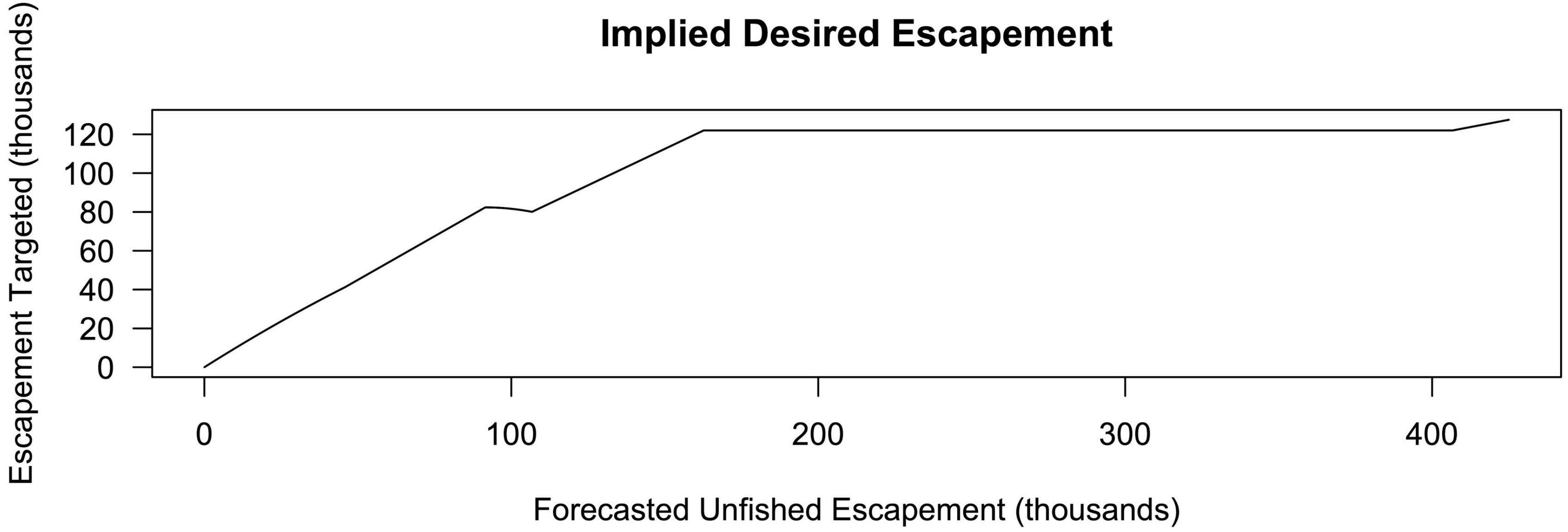


***Figure A3**. Effects of changing per capita productivity (α, left panel) or capacity/strength of density dependence (β, right panel) for a Ricker spawner-recruit relationship. In the left panel, the red curve has the lowest value for α and the green curve has the highest. In the right panel, the green curve has the lowest value for β and the red curve has the highest.*


Allowable Exploitation Rate
Exploitation Rate
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
100
200
300
400
Forecasted Unfished Escapement (thousand)


Implied Desired Escapement
Escapement Targeted (thousands)
0
20
40
60
80
100
120
0
100
200
300
400
Forecasted Unfished Escapement (thousands)

Potential approach to uncertainty buffers

- Satterthwaite and Shelton (2023) described a framework similar to the P*/sigma used for groundfish and coastal pelagic species, based on the historical distribution of forecast errors
- Evaluated retrospective effects that could have resulted from application of various buffers in management years 2014-2021

Table 3
Management outcomes for 2014–202~~0~~1 based on management actually implemented, as well as modified outcomes expected based on alternative scenarios for applying a bias correction and/or uncertainty buffer.

Scenario	Mean ann. SRFC harvest	Years overfished	Years rebuilding	Years Esc<S_{MSY}	Years Esc<MSST
Status quo	197,313	3	0	5	2
Bias adjustment only, P * =0.5	186,469	2	1	4	2
Bias adjustment, P * =0.45 buffer	179,193	1	1	3	2
Bias adjustment, P * =0.40 buffer	170,790	1	1	3	1
Bias adjustment, P * =0.33 buffer	156,871	0	0	3	1
Bias adjustment, P * =0.25 buffer	143,060	0	0	2	1
Bias adjustment, P * =0.10 buffer	116,909	0	0	2	1
Assume unbiased, P * =0.45 buffer	193,336	2	1	5	2
Assume unbiased, P * =0.40 buffer	187,306	2	1	4	2
Assume unbiased, P * =0.33 buffer	175,637	1	1	3	1
Assume unbiased, P * =0.25 buffer	157,860	0	0	3	1
Assume unbiased, P * =0.10 buffer	127,638	0	0	2	1

Some forecasting options

- Winship et al. (2015) explored a range of SI forecast models, the comparison could be updated with more recent data

Table 2. Alternative models for forecasting the Sacramento Index (SI) as a function of the number of jacks the previous 2 years and the environment the previous year.

Model	Formula	Error structure	Model selection	Selected terms (X_i)
1	$SI_t = \beta_0 + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2)$	None	
2	$SI_t = \beta_1 J_{t-1} + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2 J_{t-1})$	None	
3	$SI_t = \beta_1 J_{t-1} + \beta_2 J_{t-2} + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2 J_{t-1})$	None	
4[a,b]	$SI_t = f_{1(3)}(t) J_{t-1} + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2 J_{t-1})$	None	
5	$SI_t = \beta_1 J_{t-1} + \sum_i \beta_i X_i + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2 J_{t-1})$	AIC_c	J_{t-2}, $J_{t-1} \times E_{j,t-1}$
6	$\log SI_t = \beta_0 + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2)$	None	
7	$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2)$	None	
8[c]	$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \epsilon_t$	$\epsilon_t = \rho\epsilon_{t-1} + \nu_t$, $\nu_t \sim N(0, \sigma^2)$	None	
9	$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \beta_2 \log J_{t-2} + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2)$	None	
10[a]	$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + f_{1(2)}(t) + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2)$	None	
11	$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \Sigma_i \beta_i X_i + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2)$	AIC_c	$\log J_{t-2}$, $E_{j,t-1}$
12[a]	$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \Sigma_i X_i + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2)$	AIC_c	$\beta_2 \log J_{t-2}$, $f_{j(2)}(E_{j,t-1})$
13[d]	$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \beta_2 \log J_{t-2} + \Sigma_i \beta_i E_{i,t-1} + \epsilon_t$	$\epsilon_t \sim N(0, \sigma^2)$	None	

Note: Model 2 is the model used in fishery management to forecast the SI. Model variables, parameters, and terms are defined as follows: J_t, jacks in year t; $E_{i,t}$, environmental variable i in year t; β_i, model intercept (β_0) and coefficients; $f_{i(n)}(X_i)$, smooth function of variable X_i with cubic spline basis and maximum n degrees of freedom; ϵ_t, SI residual for year t; ρ, first-order temporal autocorrelation in SI residuals; ν_t, stochastic error for year t; and σ^2, error variance. "Selected terms", symbolized by X_i in the "Formula" column, are terms whose inclusion in the corresponding model was subject to model selection.

[a]Generalized additive model fit with "mgcv" package (Wood 2006) for R (R Core Team 2013).

[b]Varying coefficient model (Wood 2006).

[c]First-order autoregressive error structure fit with "arima" function in R (R Core Team 2013).

[d]Partial least squares regression model fit with "pls" package (Mevik and Wehrens 2007) for R (R Core Team 2013); data were centered and scaled.

- Leeman et al. (2023) describe an approach for automated variable selection and model averaging
- Indicator-based forecasts could build off existing CCIEA work