SRFC Abundance Estimation and Forecasting, Harvest Models

SRFC Workgroup 1/31/24

will.satterthwaite@noaa.gov

- Abundance Estimation (retrospective)
- Abundance Forecasting (preseason)
- Harvest Modeling

- Abundance Estimation (retrospective)
- Abundance Forecasting (preseason)
- Harvest Modeling

Sacramento Index (SI)

https://repository.library.noaa.gov/view/noaa/4449

- Annual index of abundance of "adult" SRFC, hatchery+natural
  - SI= Escapement + River Harvest + Ocean Harvest

Relatively straightforward,
but how to screen out jacks, non-fall run?

Landed (and directed) harvest only,
except special case GSI & coho-only
How do we know which unmarked fish are adult SRFC?

- Approximates potential escapement in absence of fishing, but…
  - Doesn't account for natural mortality or most non-landed mortality
  - Doesn't account for maturation
  - Blurs cohort boundaries
- Contrast with KRFC-style cohort reconstruction

Cohort reconstructions for KRFC (&SRWC, etc.)

- Reconstruct hatchery-origin cohorts using CWT data
  - Assume natural mortality rates after age-2
  - Estimate maturation rates, impact rates, and abundance-at-age

R_5 River run size at age 5 – sum of sample-expanded tags in hatchery, natural spawning, river harvest

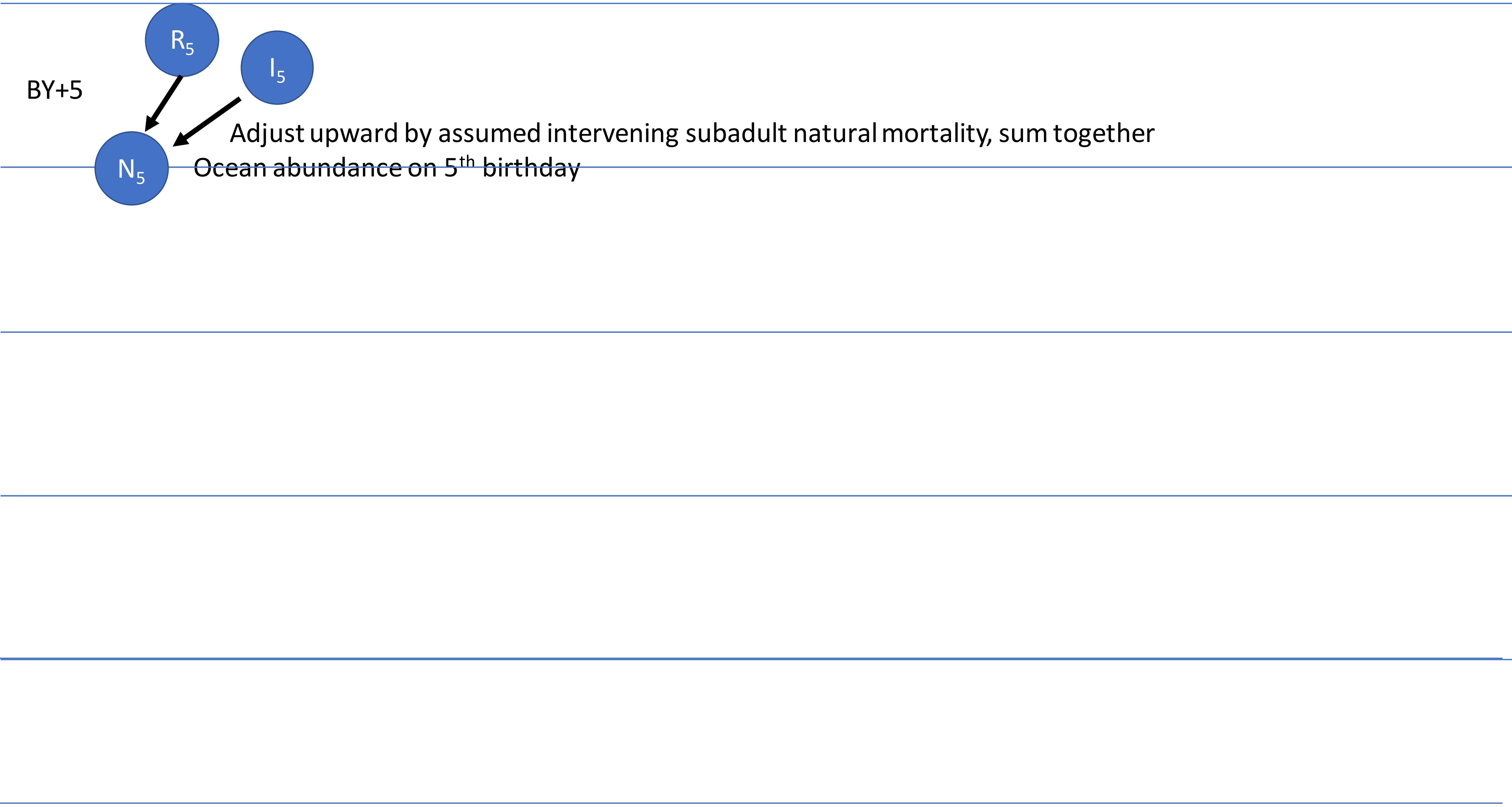
BY+5

R_5

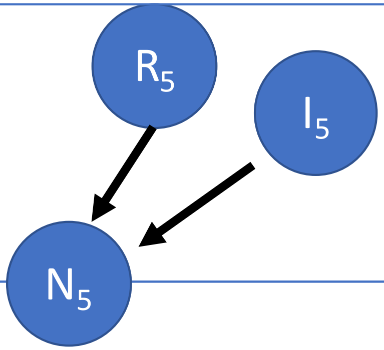
I_5

BY+5

Ocean fishery impacts at age 5 (recovered tags expanded for sampling, release mortality, dropoff mortality)

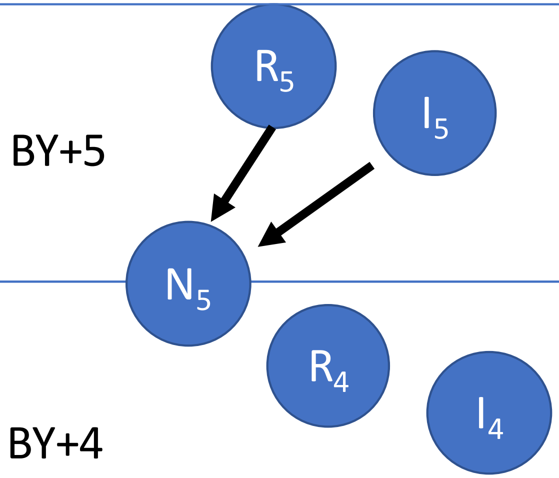

BY+5
R5
I5
N5
Adjust upward by assumed intervening subadult natural mortality, sum together
Ocean abundance on 5th birthday

BY+5

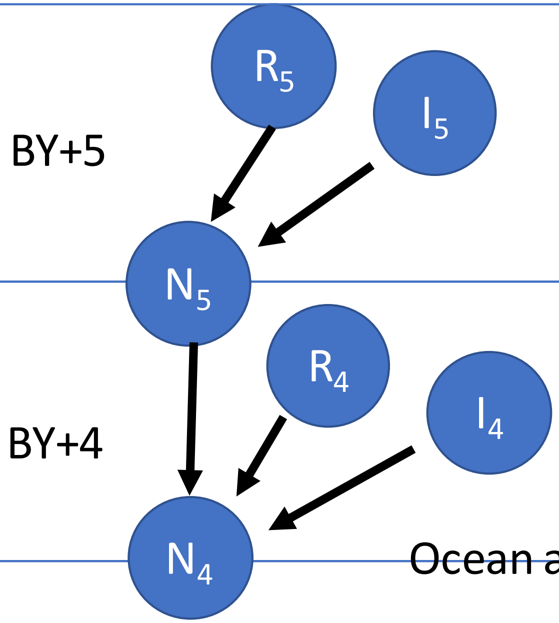


Age 5 maturation rate = 1.0 (assumed)

Age 5 ocean fishery impact rate = I_5/N_5

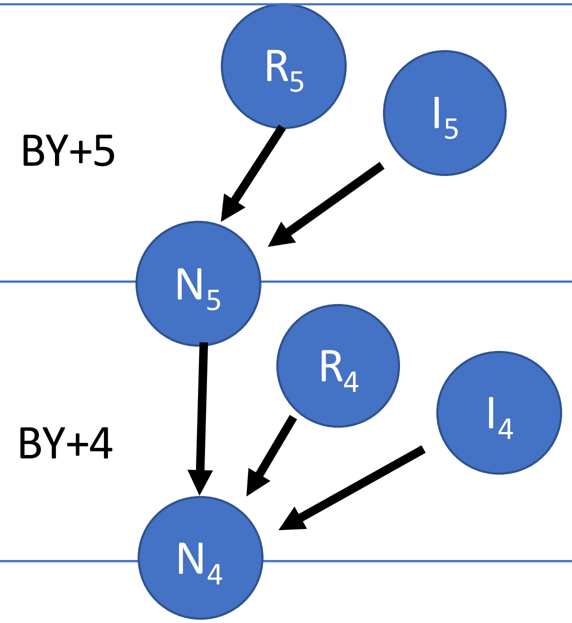


River run size and ocean impacts estimated like before



Then adjust all for assumed subadult natural mortality and sum

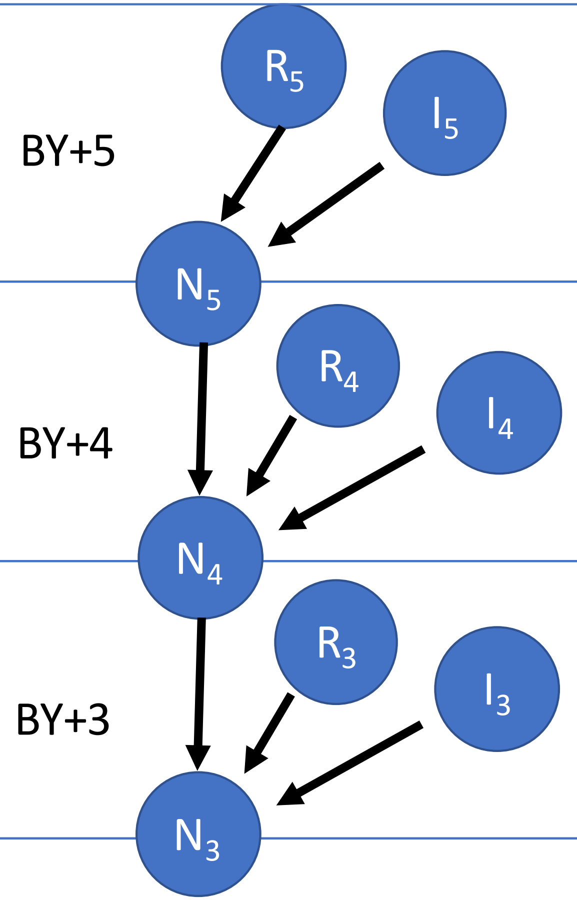
Ocean abundance on 4th birthday



Age 4 maturation rate = $R_4/(N_4 - I_4)$ (roughly)

actually use final-month N incorporating natural mortality, rather than starting month N

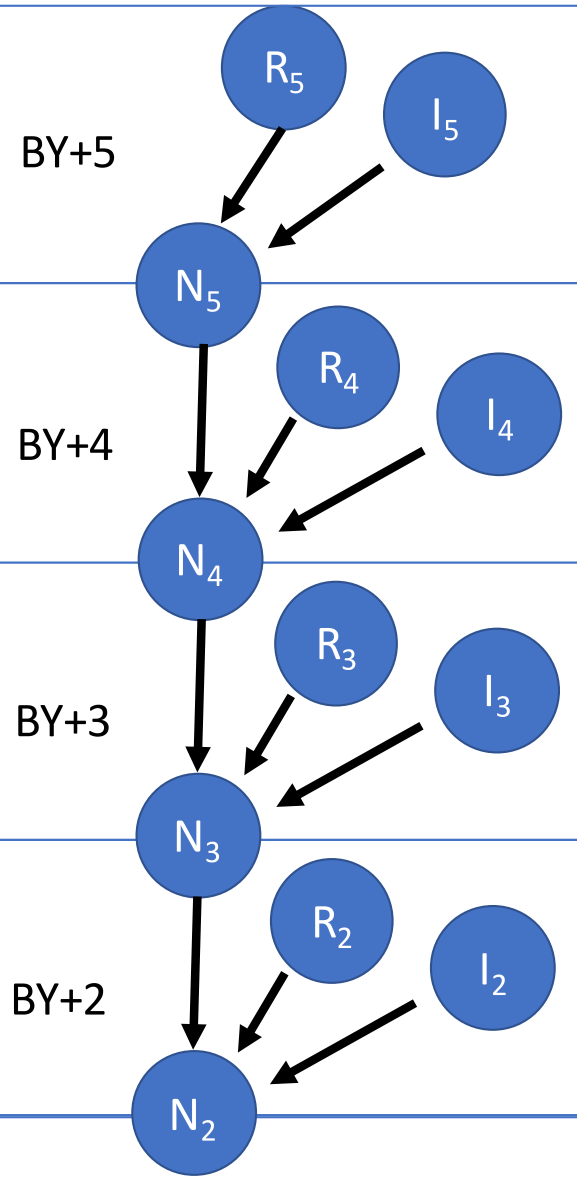
Age 4 ocean fishery impact rate = I_4/N_4



Age 3 maturation rate = $R_3/(N_3\text{-}I_3)$ (roughly)

actually use final-month N incorporating natural mortality, rather than starting month N

Age 3 ocean fishery impact rate = I_3/N_3



Age 2 maturation rate = $R_2/(N_2-I_2)$ (roughly)

actually use final-month N incorporating natural mortality, rather than starting month N

Age 2 ocean fishery impact rate = I_2/N_2


R5
I5
BY+5
N5
R4
I4
BY+4
N4
R3
I3
BY+3
N3
R2
I2
BY+2
N2
Ocean abundance on 2nd birthday


BY+5
R5
I5
N5
BY+4
R4
I4
N4
BY+3
R3
I3
N3
BY+2
R2
I2
N2
BY+1
Nreleased
Count of tagged fish released = Nreleased
BY
Parents returned to spawn


BY+5
R5
I5
N5
BY+4
R4
I4
N4
BY+3
R3
I3
N3
BY+2
R2
I2
N2
Early life survival= N2/Nreleased
BY+1
Nreleased
BY

Cohort reconstructions for KRFC (&SRWC, etc.)

- Reconstruct hatchery-origin cohorts using CWT data
  - Assume natural mortality rates after age-2
  - Estimate maturation rates, impact rates, and abundance-at-age
- "Borrow" age-specific per capita fishery impacts from hatchery-origin cohorts and assume they apply to natural-origin
- Reconstruct natural-origin cohorts using escapement-at-age (based on scales and subtracting off expanded hatchery tags)
  - Borrow fishery impacts
  - Estimate maturation rates and abundance-at-age

Cohort's potential total escapement in absence of fishing

$N_{3,BY,H+N}$*(1-mort)*$mat_{3,combo}$ + (age-3 spawners from cohort)

$N_{3,BY,H+N}$*(1-mort)*(1-$mat_{3,combo}$)*(1-mort)*$mat_{4,combo}$ + (age-4)

$N_{3,BY,H+N}$*(1-mort)*(1-$mat_{3,c}$)*(1-mort)*(1-$mat_{4,c}$)*(1-mort)*$mat_{5,c}$ + … (age-5)

(and so on for older ages, if desired)

Cohort's potential natural-area escapement in absence of fishing

$N_{3,BY,NO}$*(1-mort)*$mat_{3,nat}$*(1-$stray_{nat}$) +

$N_{3,BY,HO}$*(1-mort)*$mat_{3,hat}$*($stray_{hat}$) + (age-3 spawners from cohort)

$N_{3,BY,NO}$*(1-mort)*(1-$mat_{3,nat}$)*(1-mort)*$mat_{4,nat}$*(1-$stray_{nat}$) +

$N_{3,BY,HO}$*(1-mort)*(1-$mat_{3,hat}$)*(1-mort)*$mat_{4,hat}$*($stray_{hat}$)+ (age-4)

+ …

(and so on for older ages, if desired)

Run year's potential total escapement in absence of fishing

$N_{3,RY-3}$*(1-mort)*(mat_3) + (age-3 spawners from RY-3 cohort)

$N_{4,RY-4}$*(1-mort)*mat_4 + (age-4 spawners from RY-4 cohort)

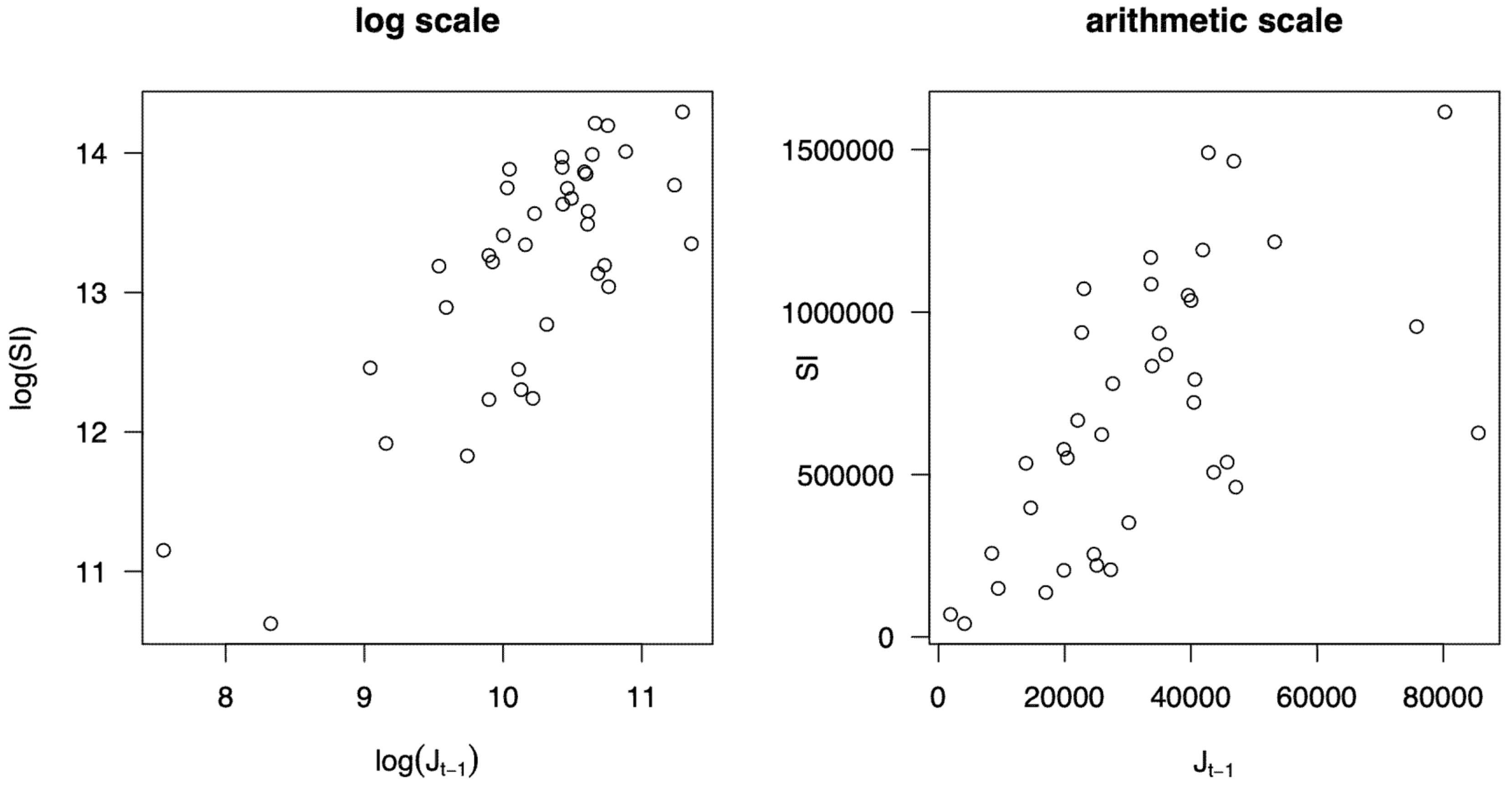
$N_{5,RY-5}$*(1-mort)*mat_5 + … (age-5 spawners from RY-4 cohort)

(and so on for older ages, if desired)

- Abundance Estimation (retrospective)
- Abundance Forecasting (preseason)
- Harvest Modeling

How the SI forecast works

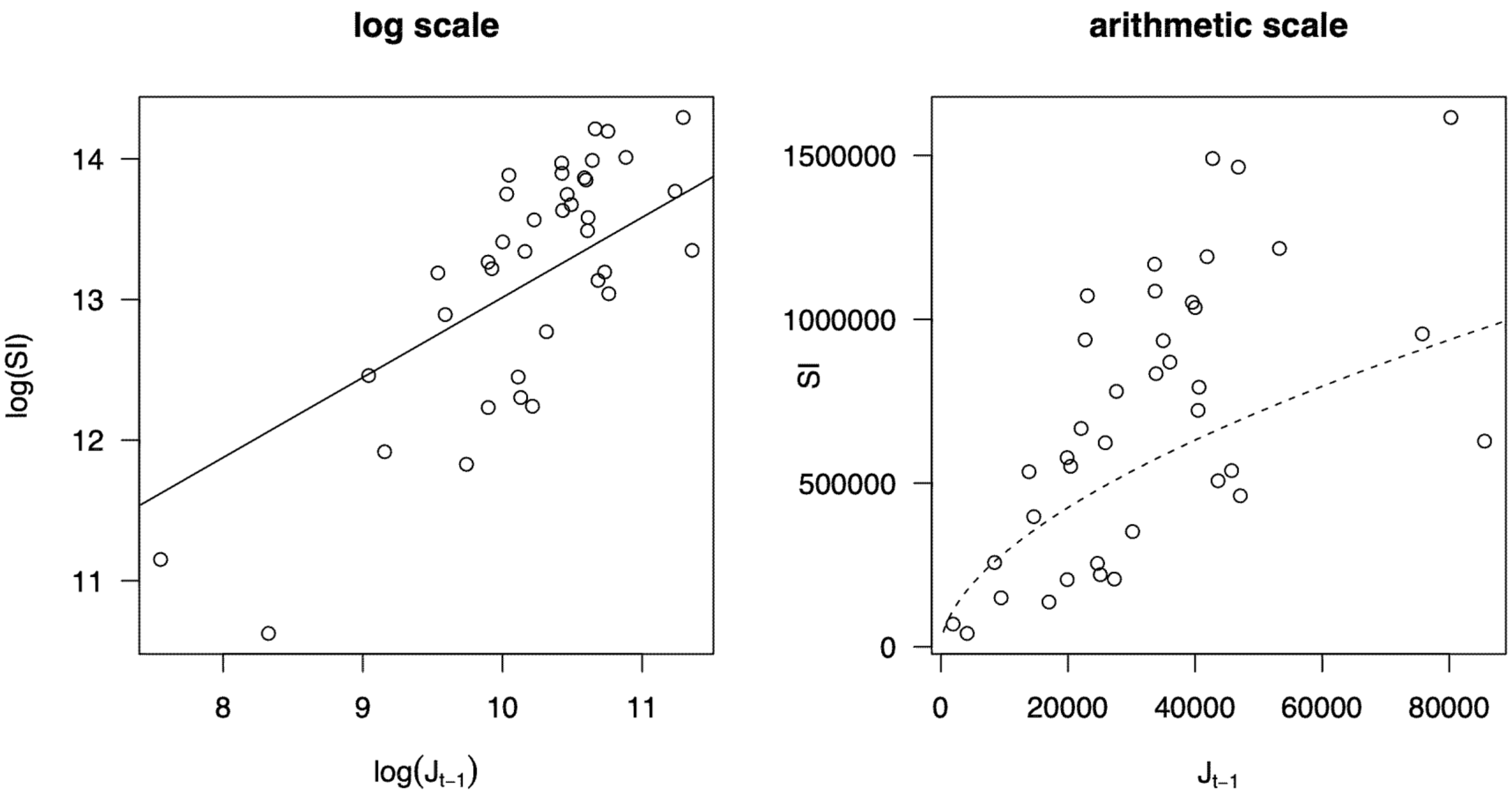
Jack escapement last year as predictor of this year's pre-fishing abundance



$$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \rho\varepsilon_{t-1}$$

How the SI forecast works

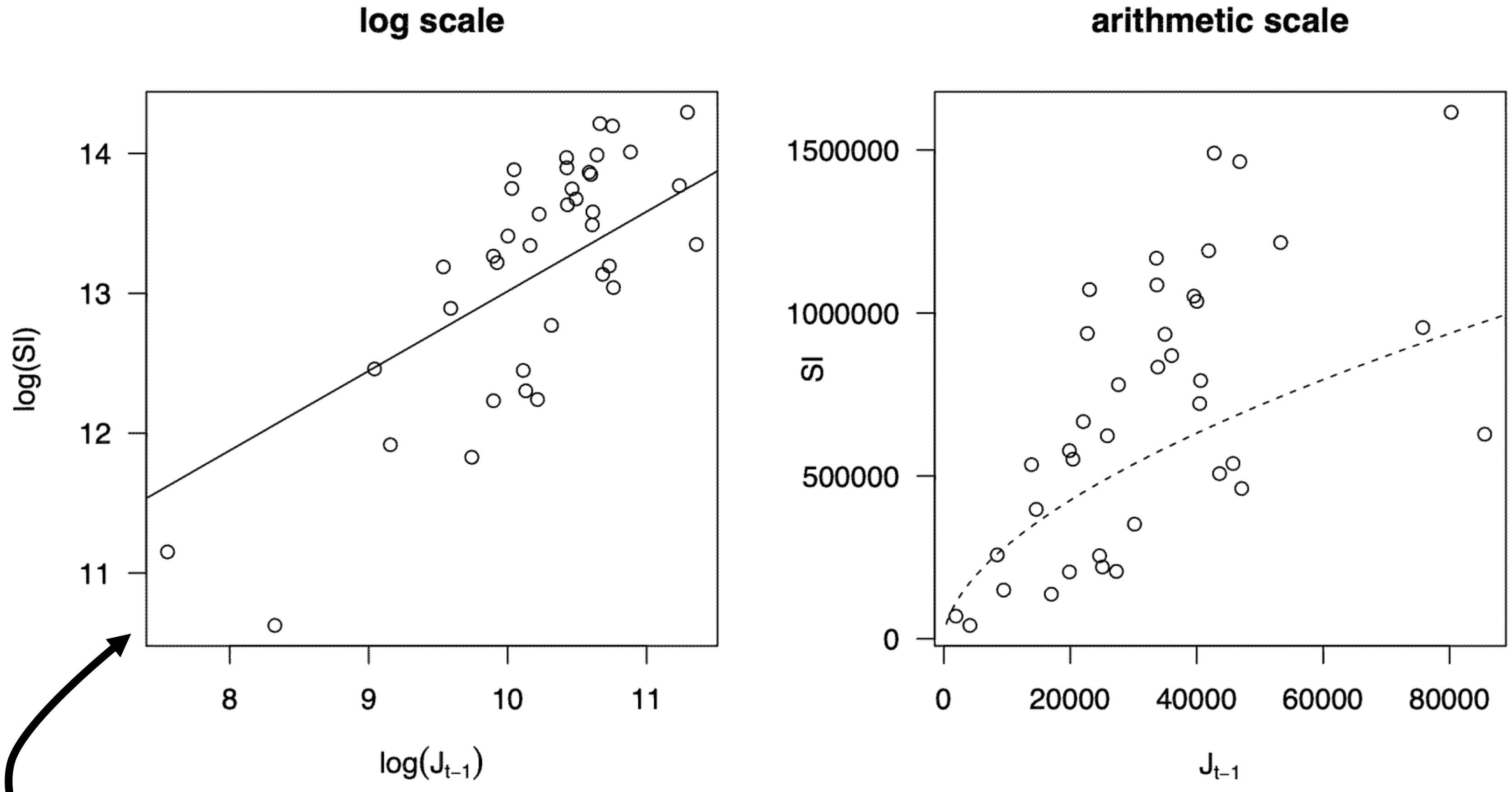
Jack escapement last year as predictor of this year's pre-fishing abundance



$$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \rho\varepsilon_{t-1}$$

How the SI forecast works

Jack escapement last year as predictor of this year's pre-fishing abundance

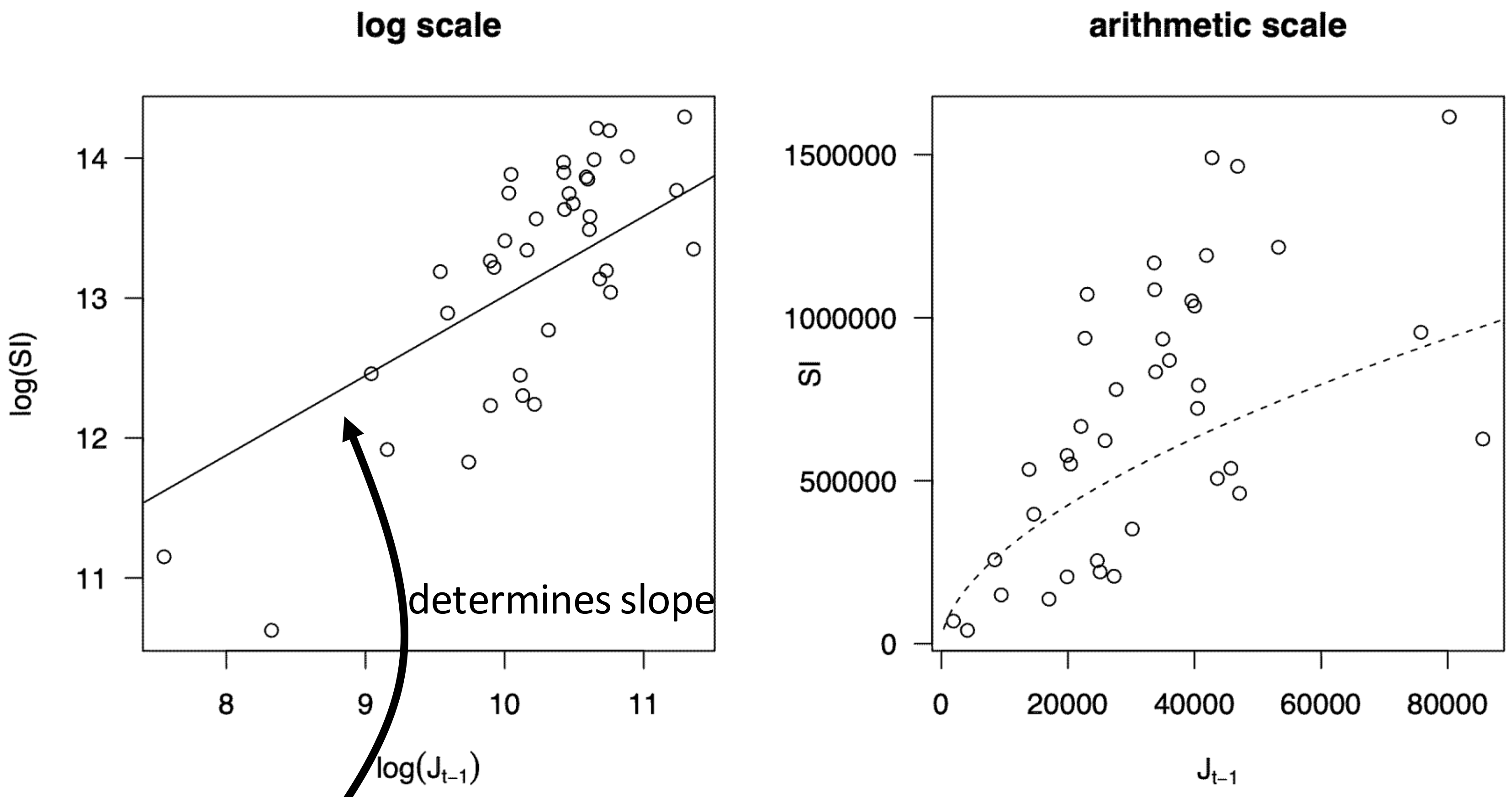


sets intercept (not shown directly)

$$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \rho \varepsilon_{t-1}$$

How the SI forecast works

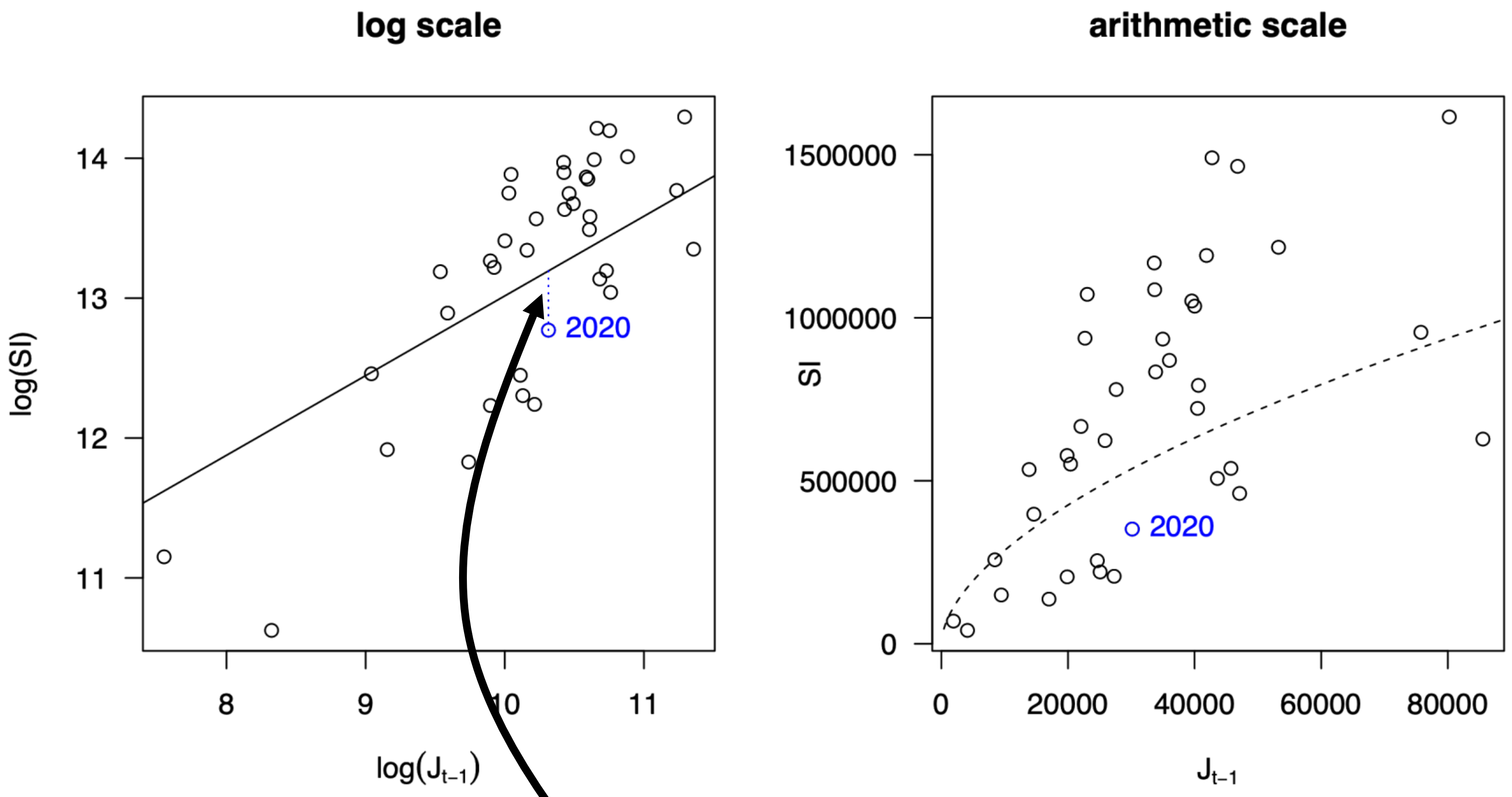
Jack escapement last year as predictor of this year's pre-fishing abundance



$$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \rho\varepsilon_{t-1}$$

How the SI forecast works

Jack escapement last year as predictor of this year's pre-fishing abundance

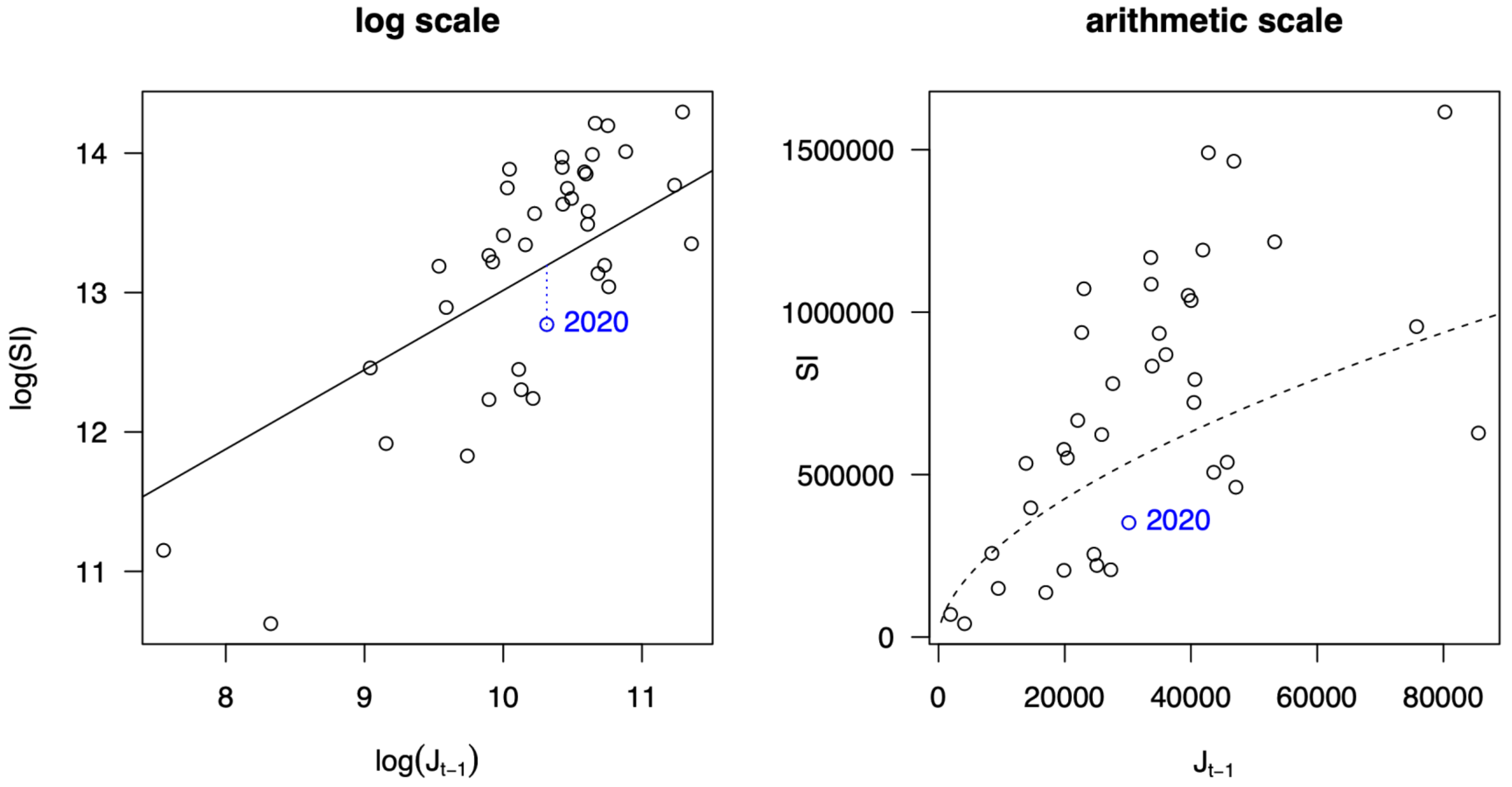


divergence from line (not forecast!) last year

$$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \rho \varepsilon_{t-1}$$

How the SI forecast works

Jack escapement last year as predictor of this year's pre-fishing abundance



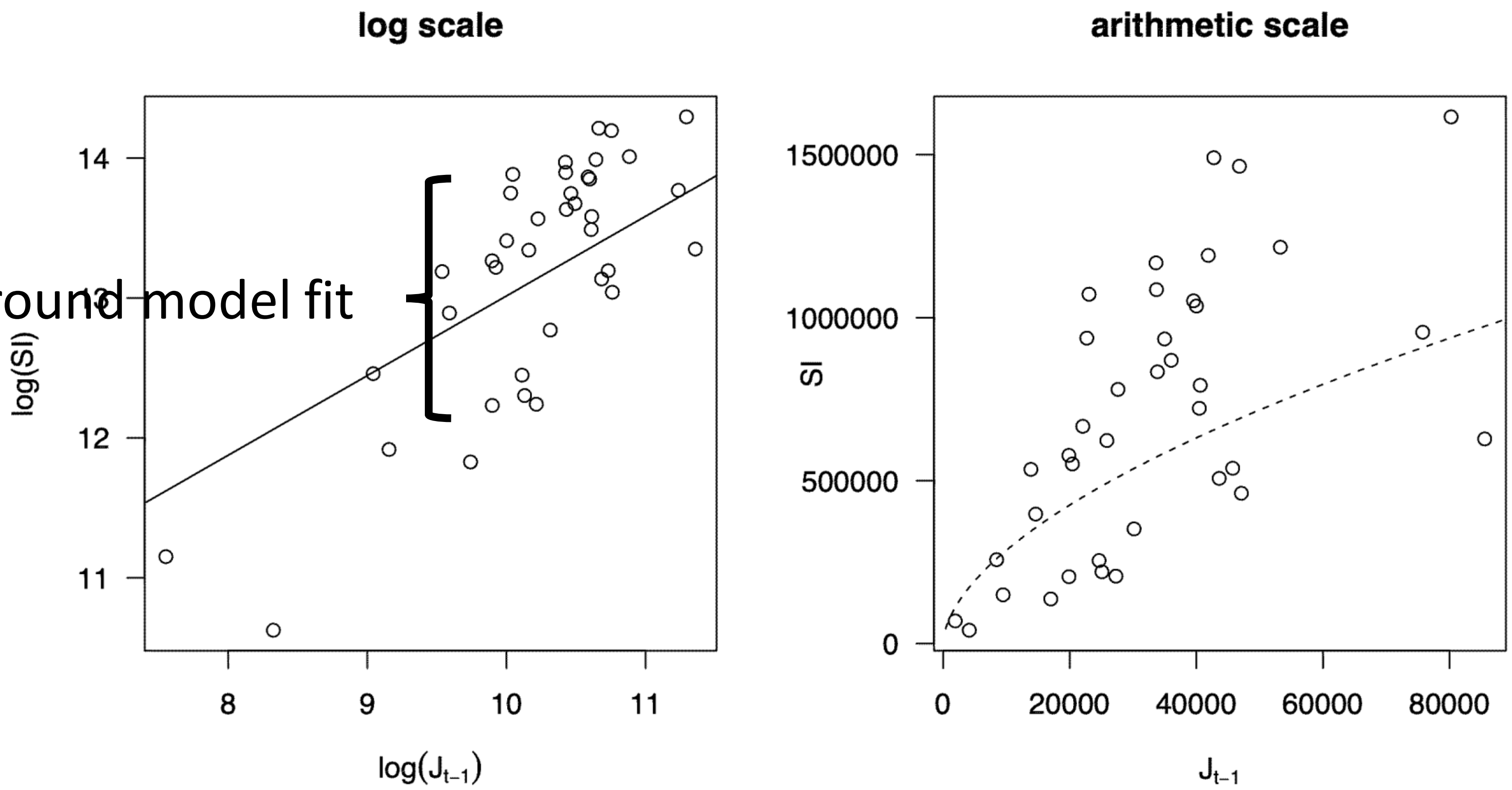
how temporally autocorrelated deviations from line are

$$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \rho \varepsilon_{t-1}$$

How the SI forecast works

Jack escapement last year as predictor of this year's pre-fishing abundance

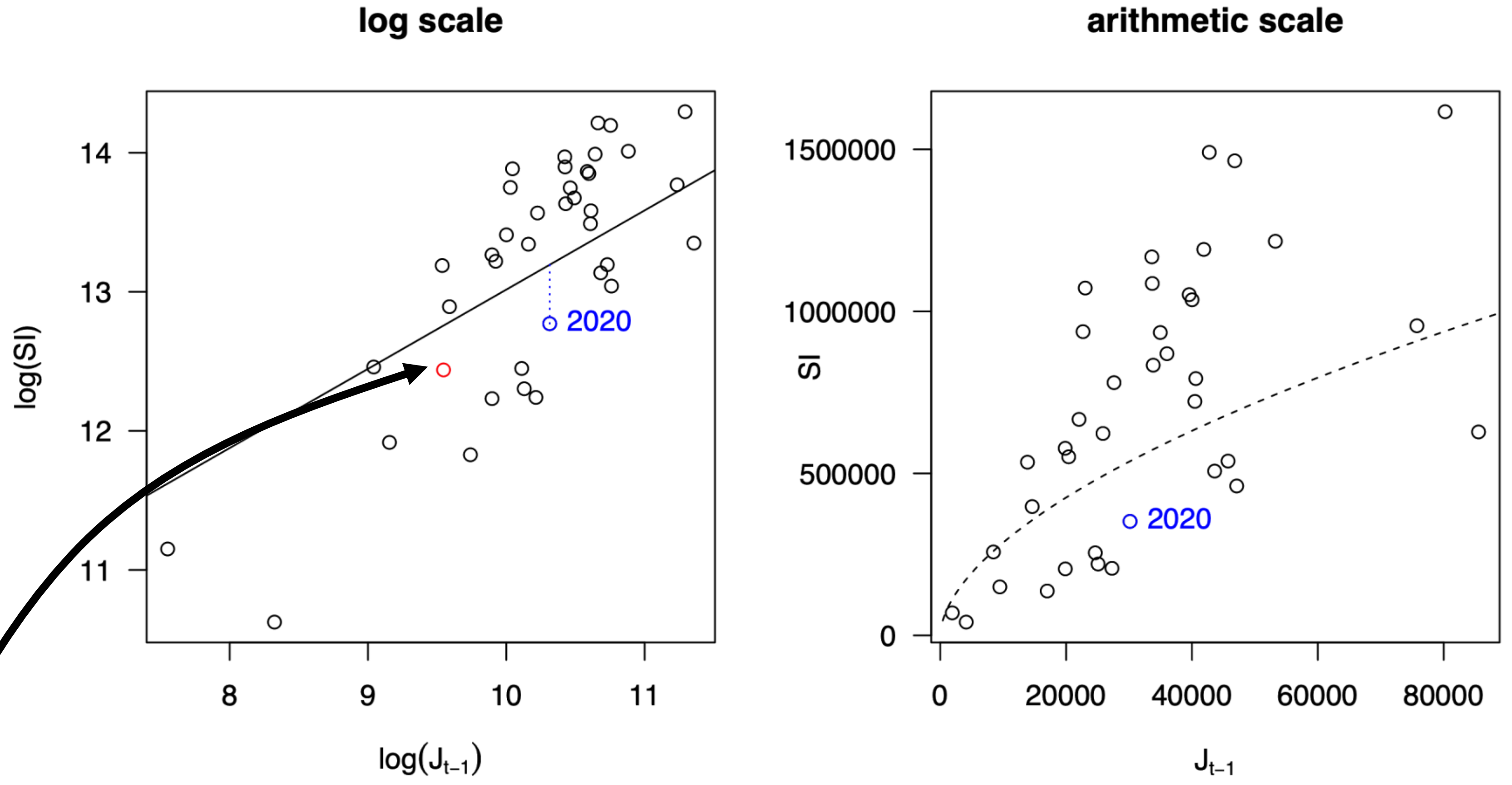
σ: scatter around model fit



$$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \rho \varepsilon_{t-1}$$

How the SI forecast works

Jack escapement last year as predictor of this year's pre-fishing abundance



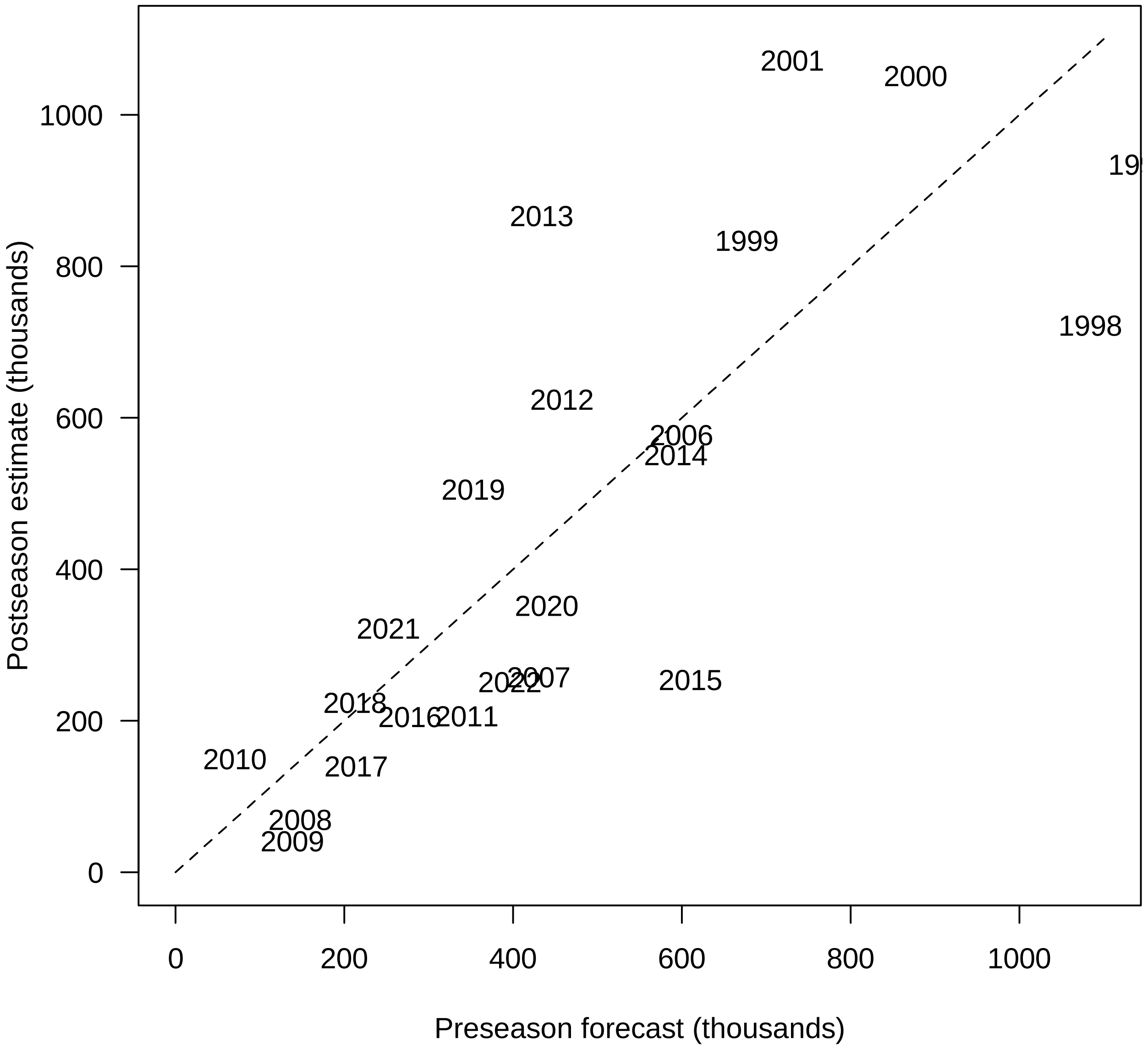
used for 2021 forecast (but there was another step to put it on arithmetic scale)

$$\log SI_t = \beta_0 + \beta_1 \log J_{t-1} + \rho \varepsilon_{t-1}$$

Final step in SI forecast

- Through 2022: $SI_t = e^{logSI_t + \frac{1}{2}\sigma^2}$
  - The $+\frac{1}{2}\sigma^2$ was to preserve the mean when going from logarithmic to arithmetic scales
- Starting in 2023: $SI_t = e^{logSI_t}$
  - This preserves the median
  - Lots of math, SSC and STT concurred that preserving median was preferable, see https://www.pcouncil.org/documents/2022/10/d-2-attachment-1-methodology-review-materials-electronic-only.pdf#page=31/ for details

SI forecast performance (current method applied retrospectively)



Alternative SI forecast methods considered

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

Winship et al. 2015, dx.doi.org/10.1139/cjfas-2014-0247

KRFC forecasting approach

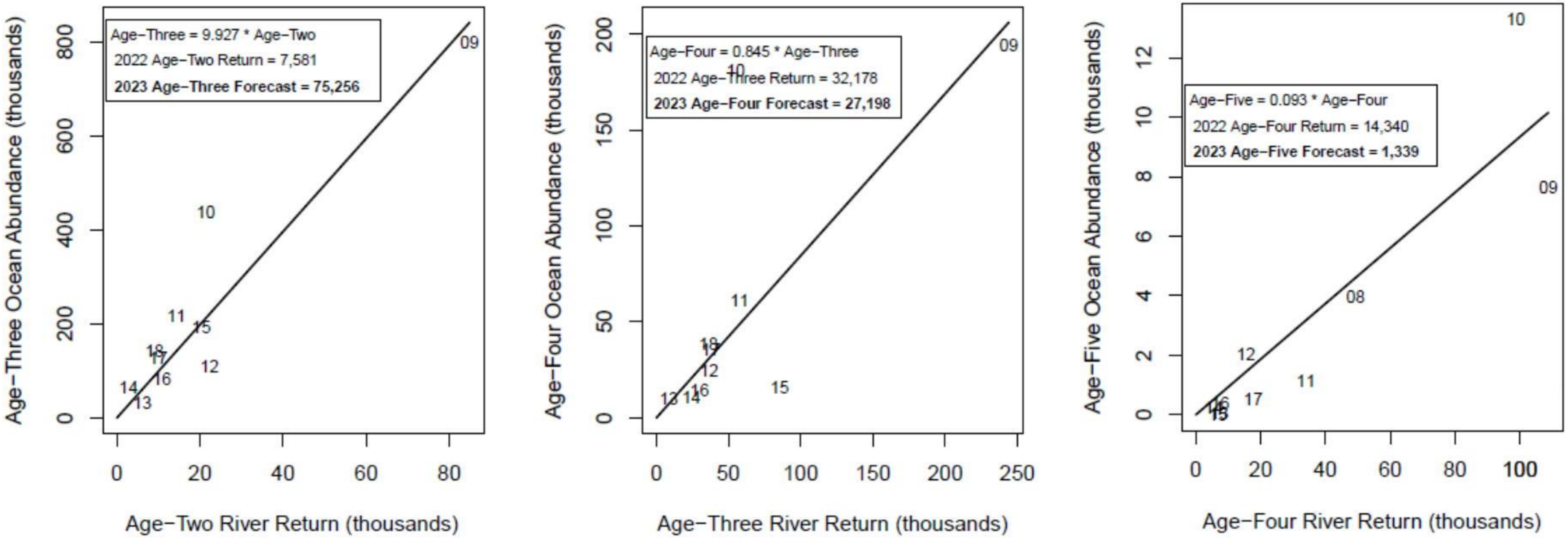


FIGURE II-3. Regression estimators for Klamath River fall Chinook ocean abundance (September 1) based on that year's river return of same cohort. Numbers in plots denote brood years.

- Based on evidence for changing maturation rates through time, KRFC forecast now uses data from 10 most recent cohorts only

- Abundance Estimation (retrospective)
- Abundance Forecasting (preseason)
- Harvest Modeling

Sacramento Harvest Model (SHM)

- Predicts harvest/impacts for each area-month-sector stratum

Mohr and O'Farrell 2014 https://repository.library.noaa.gov/view/noaa/4648/

Sacramento Harvest Model (SHM)

- Predicts harvest/impacts for each area-month-sector stratum
- For quota (Q^k) fisheries (historically rare in SRFC areas), predicted harvest = Q^k*p for that area-month-sector where p = proportion of catch that is SFC
  - harvest rate = harvest/SI
  - Requires prediction of p and forecast of SI

Mohr and O'Farrell 2014 https://repository.library.noaa.gov/view/noaa/4648/

Modeling proportion of catch that is SRFC (p)

$$p = \text{average}\{\tilde{p}\}, \tag{13}$$

where the average is taken over the period 1983–forward, and $\tilde{p}$ is a given year's proportion of SRFC in the harvest adjusted for each stock unit's current year ocean abundance forecast, A_g^*, relative to its estimated ocean abundance at the time, A_g:

$$\tilde{p} = \frac{H_{o,S}\left(A_S^*/A_S\right)}{\sum_g H_{o,g}\left(A_g^*/A_g\right)}, \tag{14}$$

where $H_{o,g}$ is the harvest of stock unit g, and the sum is over $g = S, K, V, N$. A_S^* is the forecast SI and A_K^* is the aggregate-age ocean abundance forecast for Klamath River fall Chinook. The A_S^* and A_K^* forecasts and the time series of $\{A_S\}$ and $\{A_K\}$ estimates are provided in PFMC (2013a). Forecasts of A_V^* and A_N^* and the time series of $\{A_V\}$ and $\{A_N\}$ estimates are produced and maintained by the California Department of Fish and Wildlife, Ocean Salmon Project, as part of the annual stock assessment process.

Sacramento Harvest Model (SHM)

- Predicts harvest/impacts for each area-month-sector stratum
- For quota (Q^k) fisheries (historically rare in SRFC areas), predicted harvest = Q^k*p for that area-month-sector where p = proportion of catch that is SFC
  - harvest rate = harvest/SI
  - Requires prediction of *p* and forecast of SI
- For days-open fisheries, predicted harvest rate = harvest rate per unit effort (β^{hf}) * effort (*f*)
  - Effort (*f*) = effort per day open (β^{fD}) * Days open (D^k)
  - Requires prediction/estimate of both β terms

Mohr and O'Farrell 2014 https://repository.library.noaa.gov/view/noaa/4648/

Modeling harvest rate per unit effort (β^{hf})

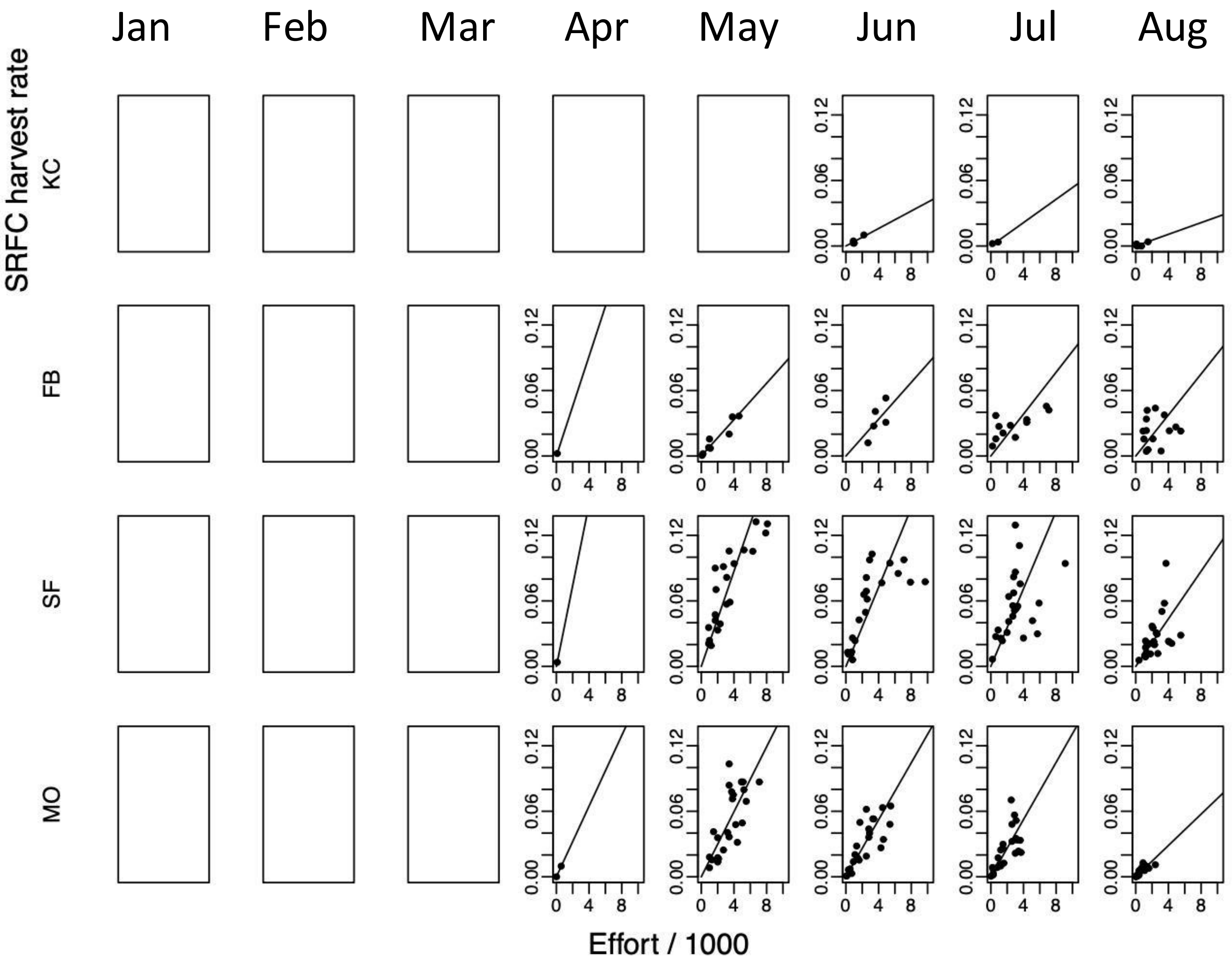


Figure 5. Commercial sector SRFC harvest rates plotted as a function of fishing effort by management area and month. Effort estimates are in units of vessel days. Line slope is estimated average harvest rate per unit of effort.

Modeling effort per day open (β^{fD})

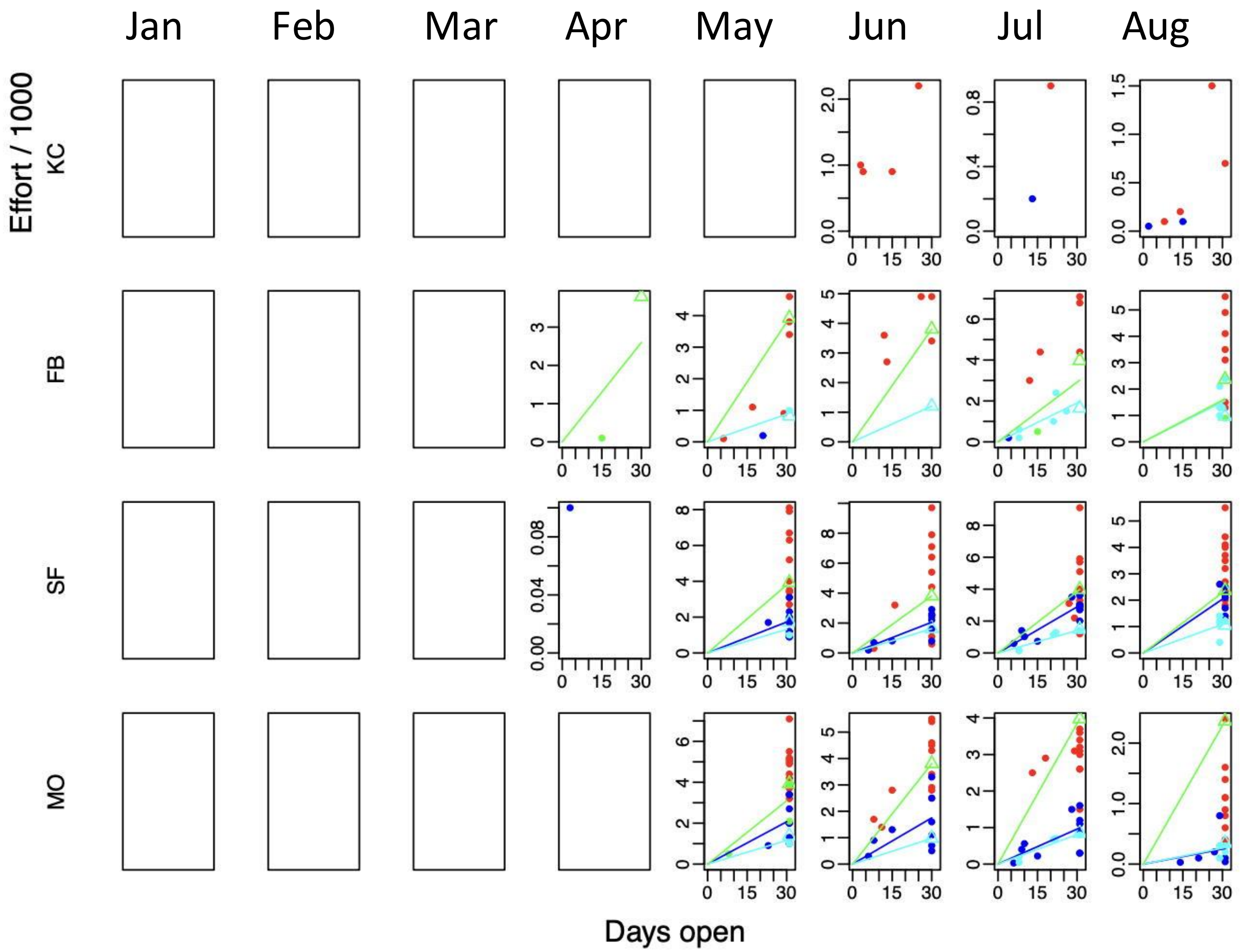


Figure 3. Commercial sector fishing effort plotted as a function of days open to fishing by management area and month. Effort is in vessel day units. See text for description of symbols, lines, and color coding.

Sacramento Harvest Model (SHM)

- Predicts harvest/impacts for each area-month-sector stratum
- For quota (Q^k) fisheries (historically rare in SRFC areas), predicted harvest = Q^k*p for that area-month-sector where p = proportion of catch that is SFC
  - harvest rate = harvest/SI
  - Requires prediction of *p* and forecast of SI
- For days-open fisheries, predicted harvest rate = harvest rate per unit effort (β^{hf}) * effort (*f*)
  - Effort (*f*) = effort per day open (β^{fD}) * Days open (D^k)
  - Requires prediction/estimate of both β terms
- *For non-retention fisheries, similar calculations but discounted by release mortality (s)*
- *Overall harvest/impact rate prediction is obtained by summing across strata*

Mohr and O'Farrell 2014 https://repository.library.noaa.gov/view/noaa/4648/

Potential areas of improvement

- Better estimation of age and origin of unmarked fish
- Account for age structure within the “adult” class
- Account for nonlanded mortality, natural mortality
- Model escapement by origin and/or location
- Abundance forecast refinements
- Harvest model refinements
- Need for increased attention to modeling quota fisheries?
  - New California Coastal Chinook standard will introduce caps, not strictly quotas
- Account for uncertainty in forecast, harvest projections