Estimating the effects of instream flows on the productivity of Chinook salmon

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FRAMEWORK FOR ANALYSES

Background literature

Su Z, Peterman RL. 2012. Performance of a Bayesian state-space model of semelparous species for stock-recruitment data subject to measurement error. *Ecological Modelling* 224: 76-89

Fleischman SJ, Catalano MJ, Clark RA, Bernard DR. 2013. An age-structured state-space stock–recruit model for Pacific salmon (Oncorhynchus spp.) *Can J Fish Aquat Sci* 70: 401-414

Scheuerell MD, Ruff CP, Anderson JH, Beamer EM. *In revision*. Estimating density-dependent population dynamics in a variable environment with imperfect data. *J Applied Ecology*

Spawner-recruit model

Ricker model

$$\ln(R_t) = \ln(S_t) + \ln(a) - bS_t + w_t$$

$$w_t \sim N(\phi w_{t-1}, Q)$$ (Autocorrelated process errors)

Spawner-recruit model

Ricker model

$$\ln(R_t) = \ln(S_t) + \ln(a) - bS_t + cF_t + w_t$$

$$w_t \sim N(\phi w_{t-1}, Q)$$

Flow effects on productivity

Creating recruits from spawners

Year	Spawners	Recruits	Age 3	Age 4	Age 5
1	S_1 →	R_1			
2	S_2 →	R_2			
3	S_3 →	R_3			
4	S_4 →	R_4			
5	S_5 →	R_5			
6					
7					
8					

Projecting recruits-by-age

Recruits-by-age model

Recruits-by-age = Total recruits * prop-by-age

$N_{a,t} = R_{t-a} p_{a,t-a}$

Projecting recruits-by-age

Year	Spawners	Recruits	Age 3	Age 4	Age 5
1	S_1	R_1			
2			$p_{3,1}$		
3				$p_{4,1}$	
4			$N_{4,3}$		$p_{5,1}$
5				$N_{5,4}$	
6					$N_{6,5}$
7					
8					

Projecting recruits-by-age

Year	Spawners	Recruits	Age 3	Age 4	Age 5
1	S_1	R_1			
2	S_2	R_2			
3	S_3	R_3			
4	S_4	R_4	$N_{4,3}$		
5	S_5	R_5	$N_{5,3}$	$N_{5,4}$	
6			$N_{6,3}$	$N_{6,4}$	$N_{6,5}$
7			$N_{7,3}$	$N_{7,4}$	$N_{7,5}$
8			$N_{8,3}$	$N_{8,4}$	$N_{8,5}$

Observation model for spawners

Spawners

$S_t = N_t - H_t$

True spawners are difference between returns and harvest*

Observed spawners

$\ln(E_t) \sim N(\ln(S_t), \sigma_S)$

Measured escapement is estimate of true spawners

*ignoring upstream mortality

Observation model for age comp

Age composition

$O_{a,t}$ ≡ number of fish observed in age class *a* in year *t*

$$D_t = \sum_a O_{a,t}$$ ← Total fish aged in year *t*

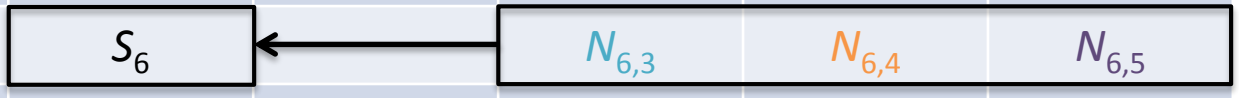
$N_{a,t}$ ≡ number of fish predicted in age class *a* in year *t*

$$p_{a,t} = \frac{N_{a,t}}{\sum_a N_{a,t}}$$ ← Predicted prop. of fish in age class *a* in year *t*

$$\mathbf{O}_t \sim \text{Multinomial}\left(\boldsymbol{\pi}_t, D_t\right)$$

Feedback between *R* & *S*

Year	Spawners	Recruits	Age 3	Age 4	Age 5
1	S_1	R_1			
2	S_2	R_2			
3	S_3	R_3			
4	S_4	R_4	$N_{4,3}$		
5	S_5	R_5	$N_{5,3}$	$N_{5,4}$	
6	S_6		$N_{6,3}$	$N_{6,4}$	$N_{6,5}$
7			$N_{7,3}$	$N_{7,4}$	$N_{7,5}$
8			$N_{8,3}$	$N_{8,4}$	$N_{8,5}$



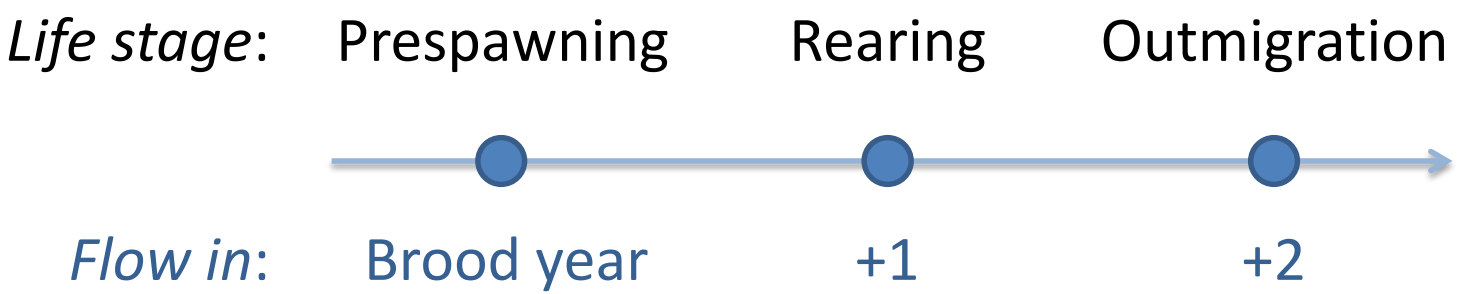
Applying the model to data

- All data pooled for the entire watershed
  1) Escapement estimates
  2) Harvest estimates from terminal fishery
  3) Age composition
- Flow covariates summarized at Salem
- Chinook salmon: 17 years (1999-2015)
- Steelhead: 45 years (1971-2015)*

*Many years missing

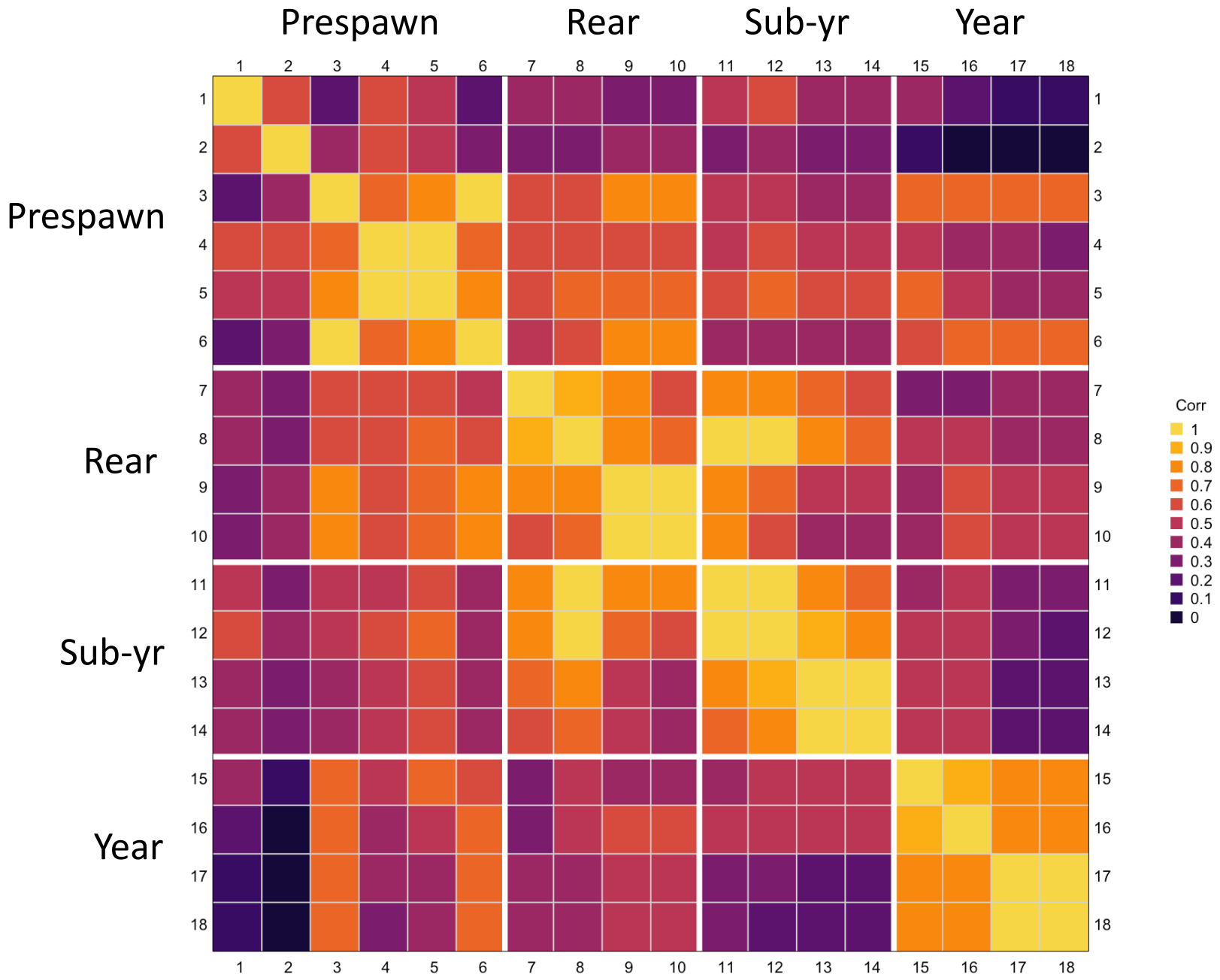
FLOW COVARIATES

Lagging presumed flow effects



Examples of lagged flow effects

Life stage	Description	Time period	Time lag
Prespawn	Min of 7-day mean	Nov-Mar	brood yr
Prespawn	Median of 7-day mean	Nov-Mar	brood yr
Prespawn	Max of 7-day mean	Nov-Mar	brood yr
Rearing	Min of 7-day mean	Jul-Sep	brood yr + 1
⋮	⋮	⋮	⋮
1+ smolt	Min of 7-day mean	Apr-Jun	brood yr + 1
⋮	⋮	⋮	⋮
2+ smolt	Min of 7-day mean	Feb-Apr	brood yr + 2

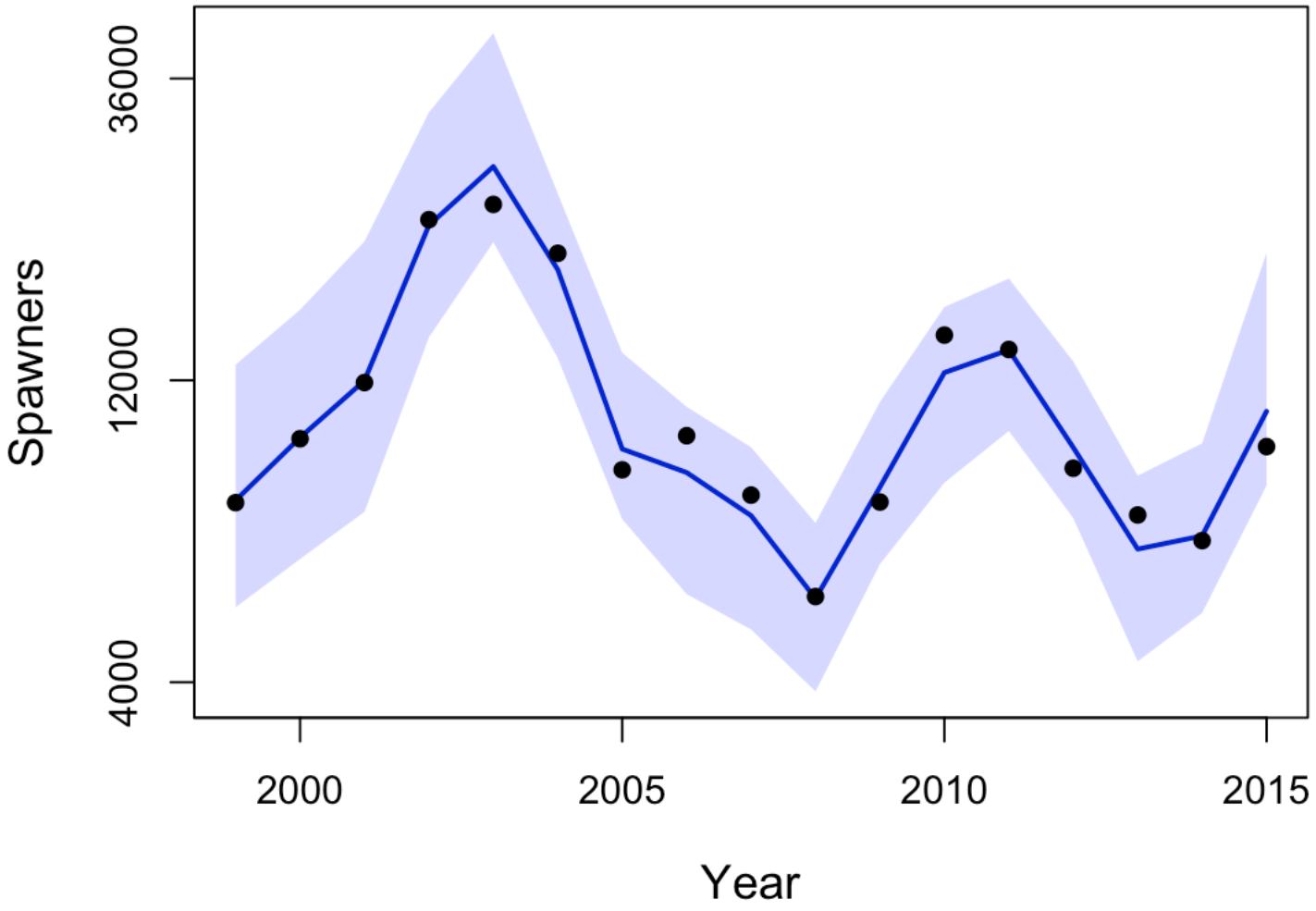

Prespawn
Rear
Sub-yr
Year
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Corr
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

RESULTS

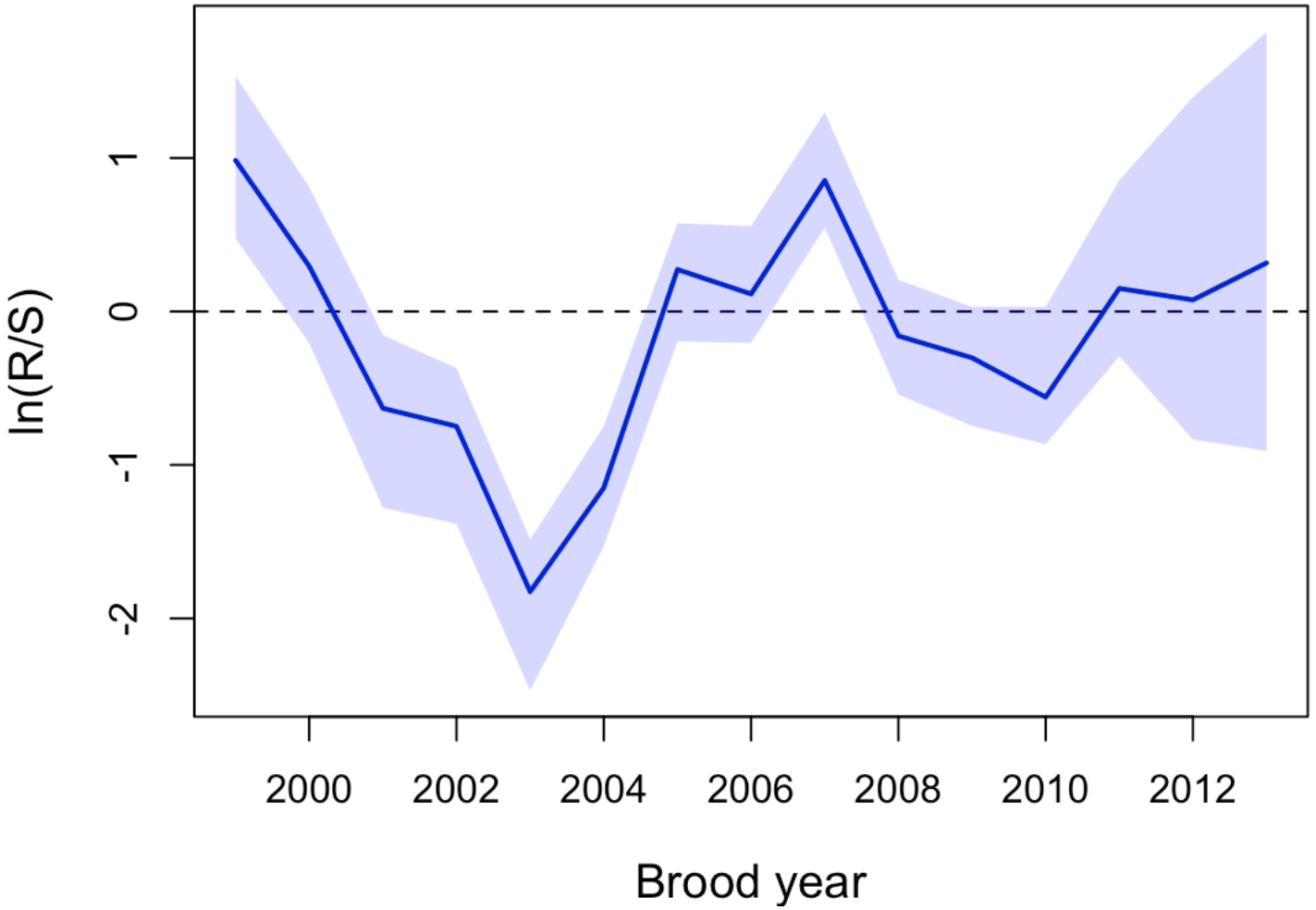
Model selection results

Life stage	Description	Time period	Time lag
Prespawn	Min of 7-day mean	Nov-Mar	brood yr
Prespawn	Median of 7-day mean	Nov-Mar	brood yr
Prespawn	Max of 7-day mean	Nov-Mar	brood yr
Rearing	Min of 7-day mean	Jul-Sep	brood yr + 1
⋮	⋮	⋮	⋮
1+ smolt	Min of 7-day mean	Apr-Jun	brood yr + 1
⋮	⋮	⋮	⋮
2+ smolt	**Min of 7-day mean**	**Feb-Apr**	**brood yr + 2**

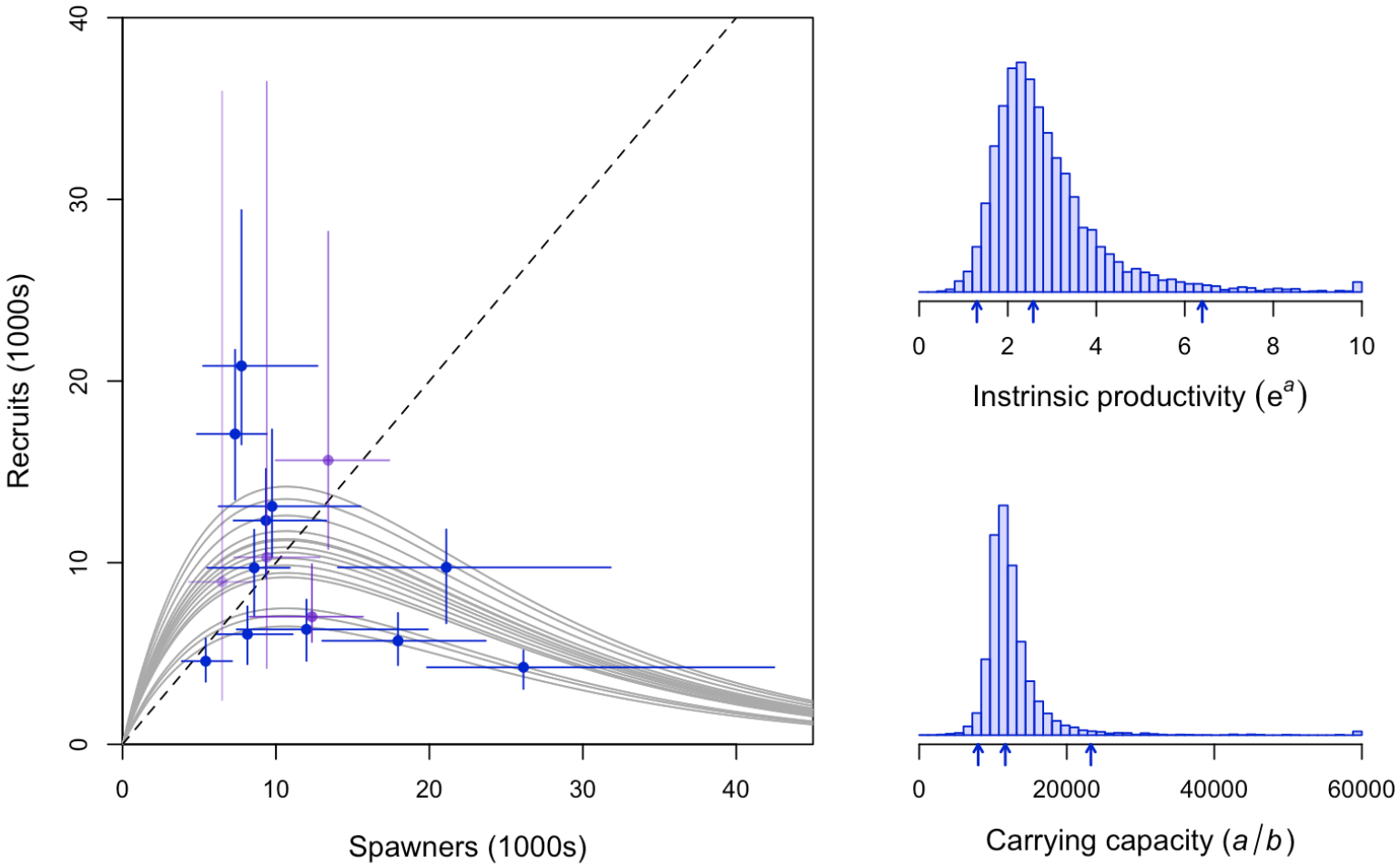
Time series of estimated spawners



Time series of estimated *R/S*

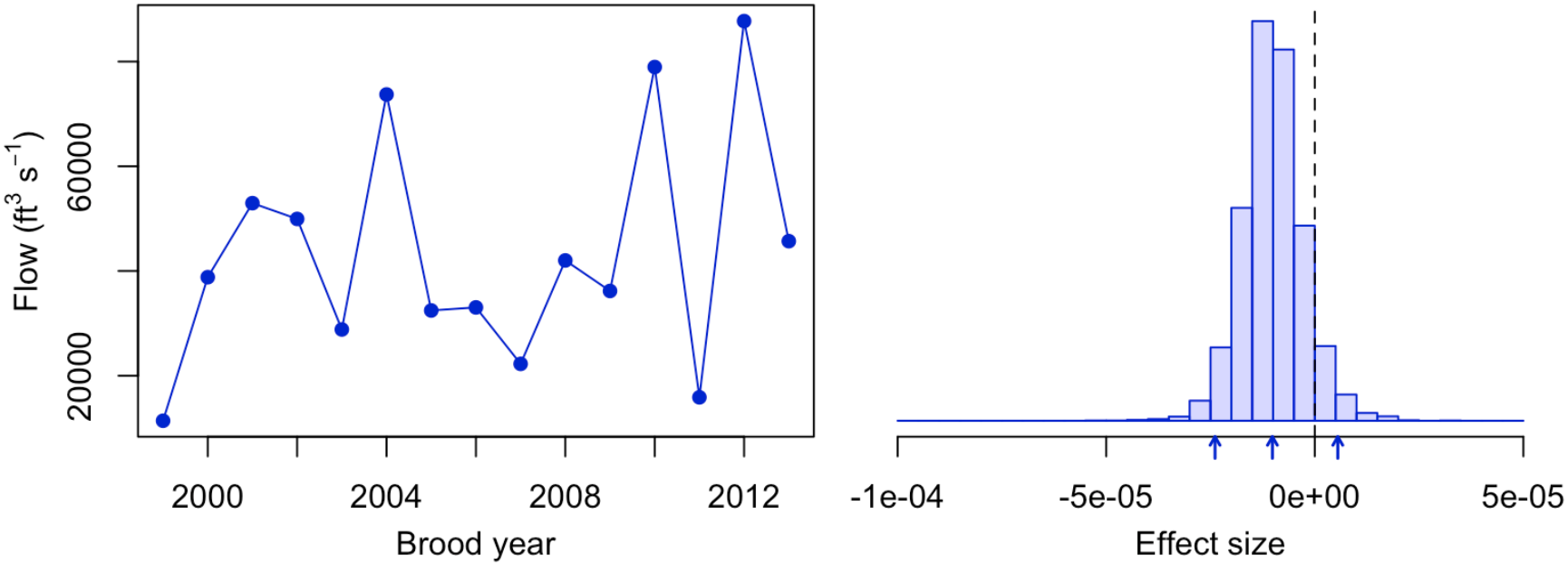


Spawner-Recruit relationships



Example: Range in spring flows

Period of yearling outmigration



1 SD increase in flow

⬇

~25% decrease in R/S

Caveats

- Does not account for hatchery-born fish that spawn in wild, which means:
  - Underestimate of number of spawners
  - Overestimate of recruitment/spawner
- Relatively short time series (17 years)

In summary

- Some evidence for flow effects, but…
- LOTS of uncertainty in:
  - Data
  - Models
  - Parameters

Next steps

- Refine list of flow covariates
- Try to fit model with fewer years to allow for temperature effects
- Evaluate potential effects of reservoir simulations

QUESTIONS?