Density dependence, hatchery releases and environmental conditions explain annual variation in productivity of Skagit River wild steelhead

Casey P. Ruff[1], Joseph H. Anderson[2], and Eric Beamer[1]

[1]Skagit River System Cooperative

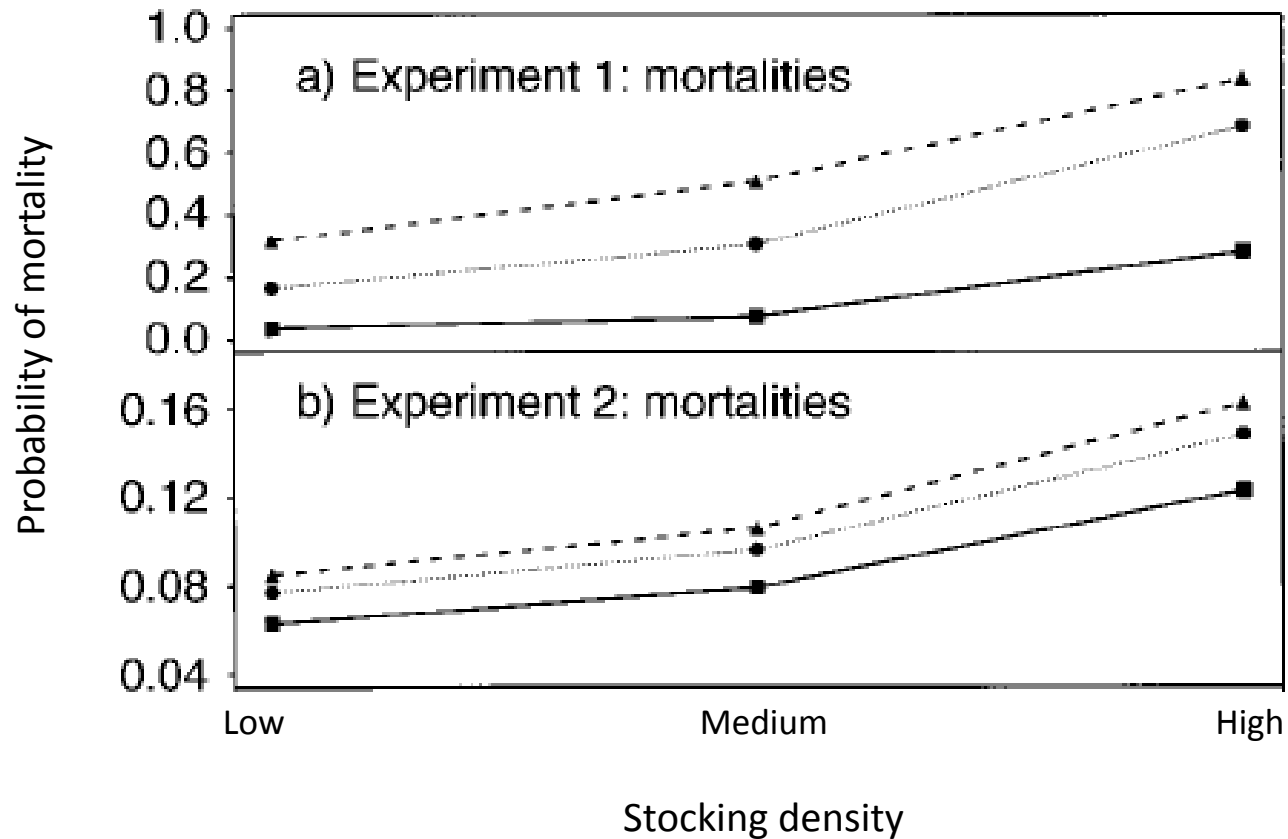*[2]Washington Department of Fish and Wildlife*

Pacific Coast Steelhead Management Conference
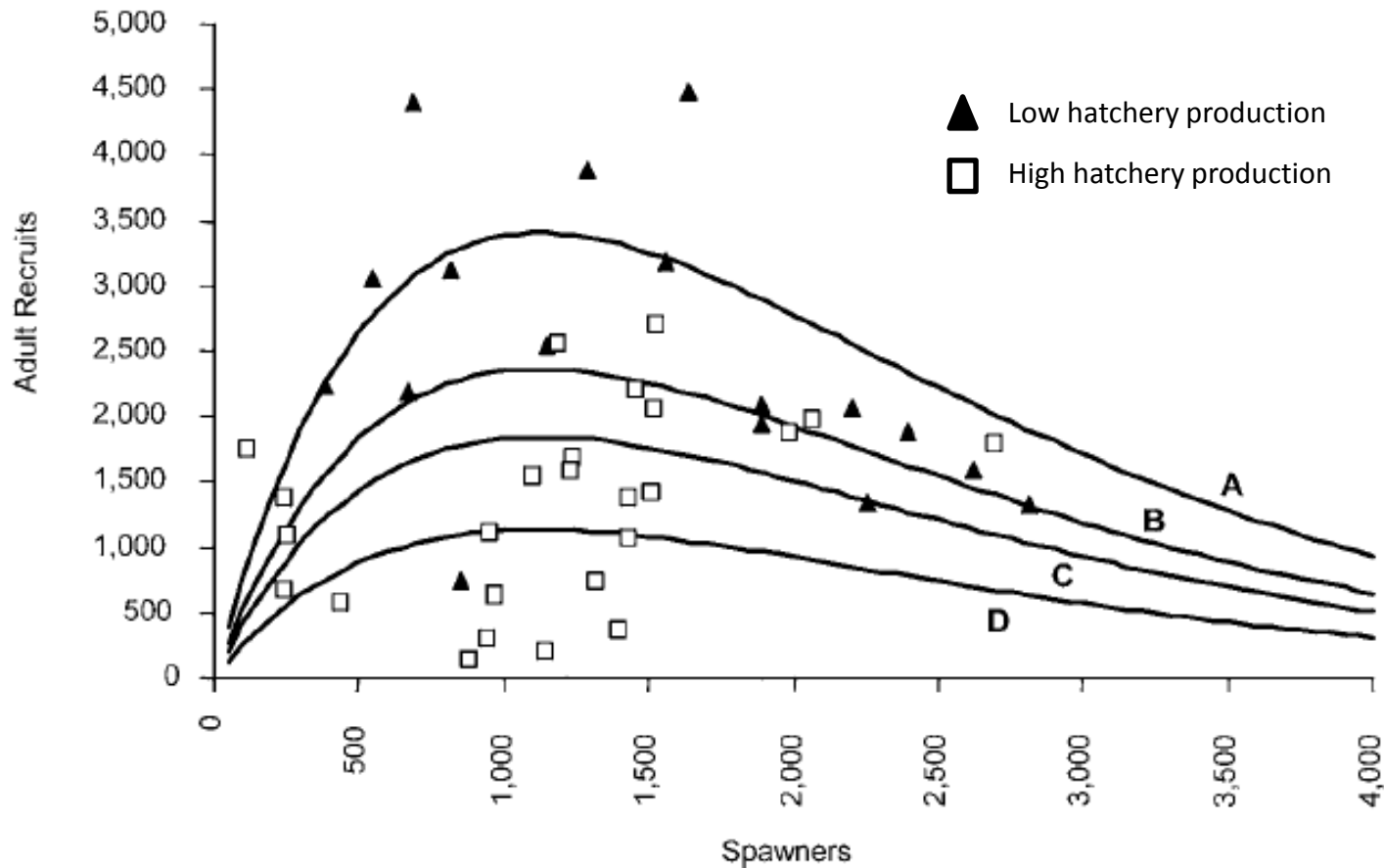
Skamania Lodge WA

March 20, 2014

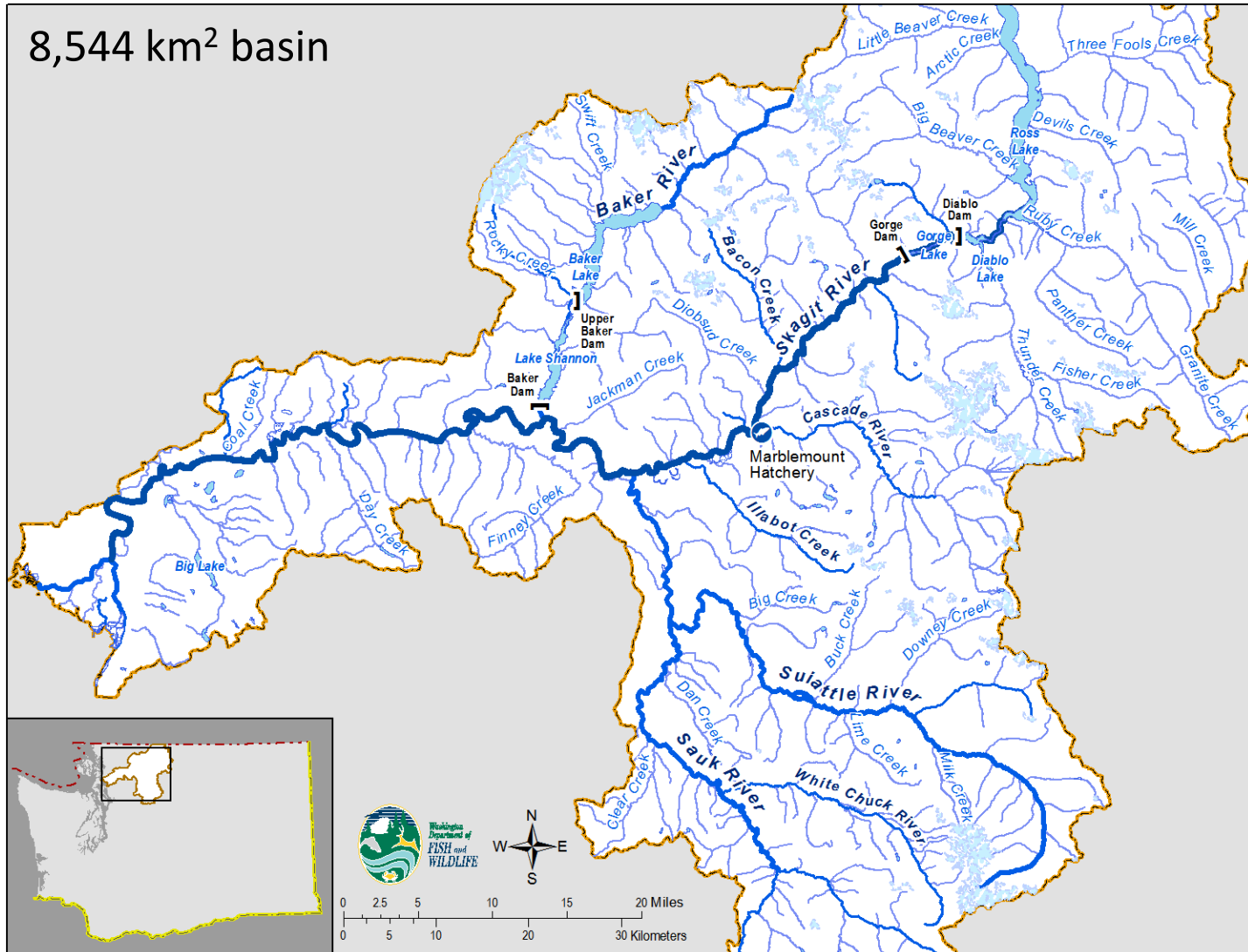# Density dependence in steelhead

Evidence from experimental streams

Keeley 2000 *Ecology*

Density dependence in steelhead

Evidence from natural populations

Kostow and Zhou 2006 *TAFS*

Skagit River basin

Map: Dale Gombert

Skagit River wild steelhead

Research questions

1. Is there evidence for density dependent productivity of wild Skagit River steelhead?

2. Is there any relationship between wild Skagit River steelhead productivity and river discharge or marine conditions?

3. Is there any relationship between wild Skagit River steelhead productivity and releases of hatchery steelhead?

# Methods: run reconstruction

1. Terminal run size

   - Spawners = escapement in generation t

   - Recruits = escapement + catch in generation $t + 1$

2. Age data 1981 - 2013

   - N = 3616 scale samples collected from wild adults

   - Assume complete cohort with age 4 – 6

   - N = 20 return years with ≥ 47 scale samples

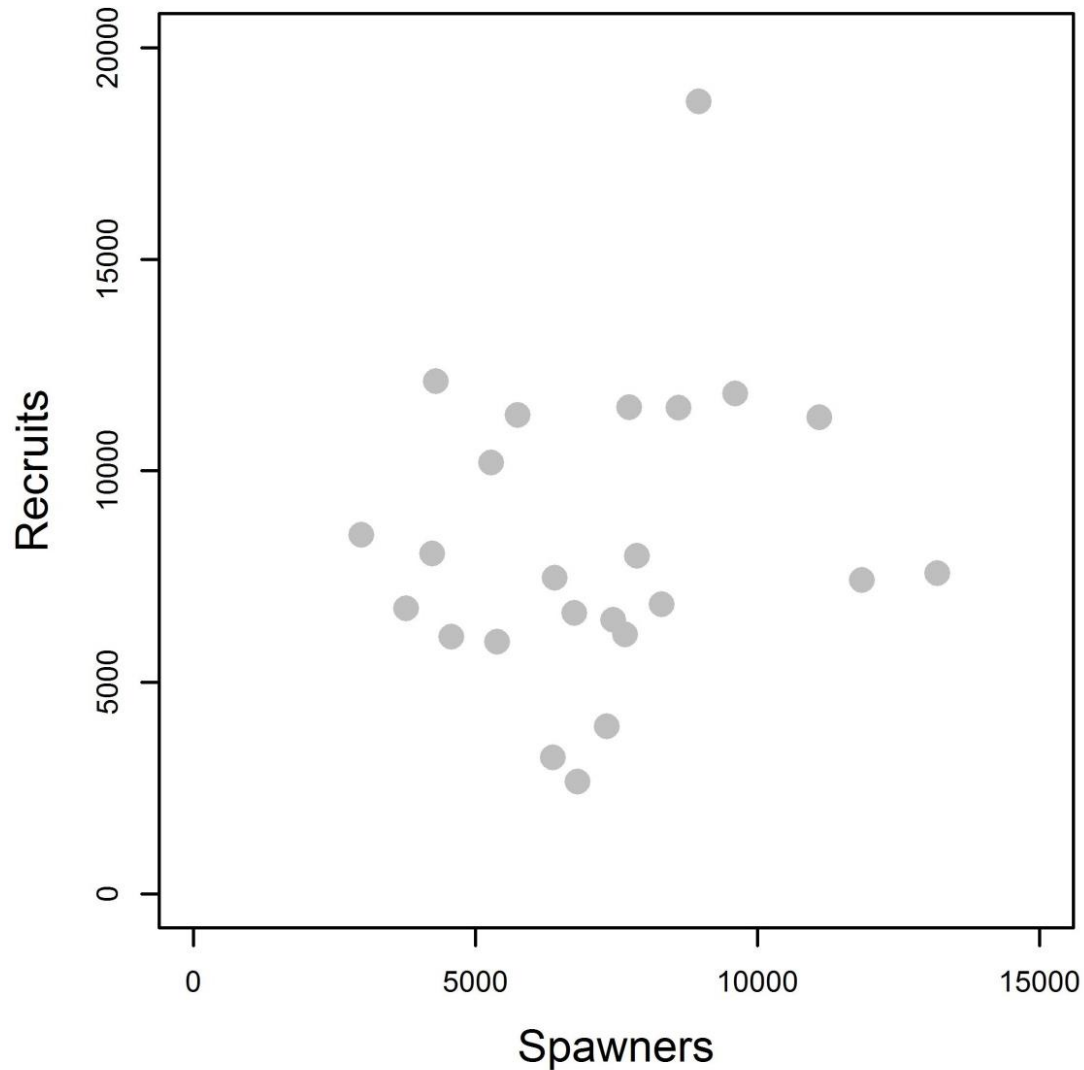   - N = 13 return years, use age structure averaged across return years

3. General recruits/spawner for 24 complete brood years: 1978 – 1989 & 1994 – 2007
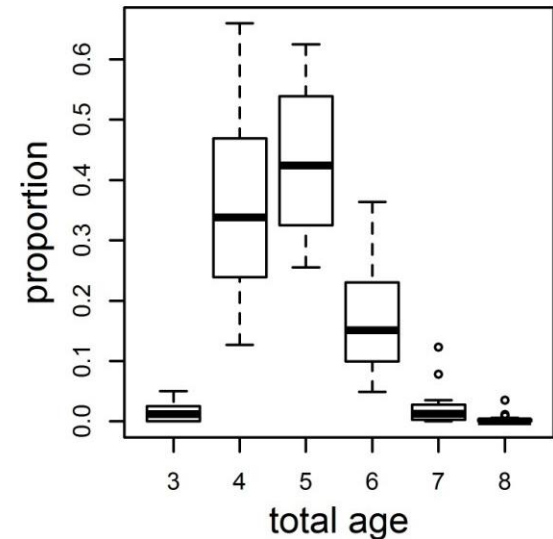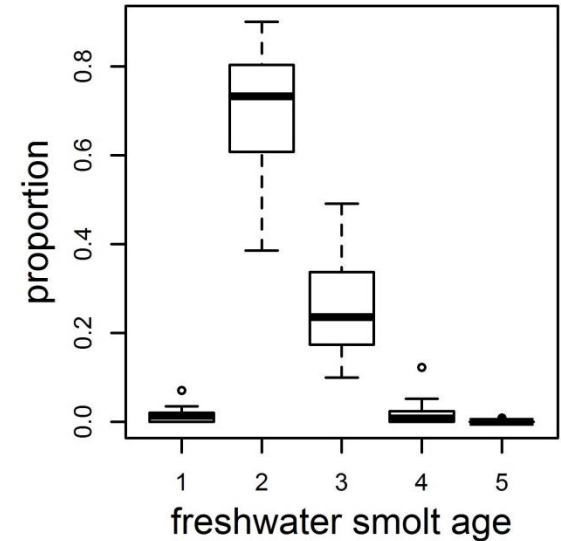
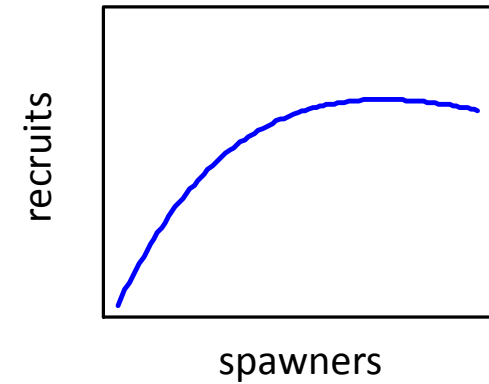# Skagit River steelhead productivity
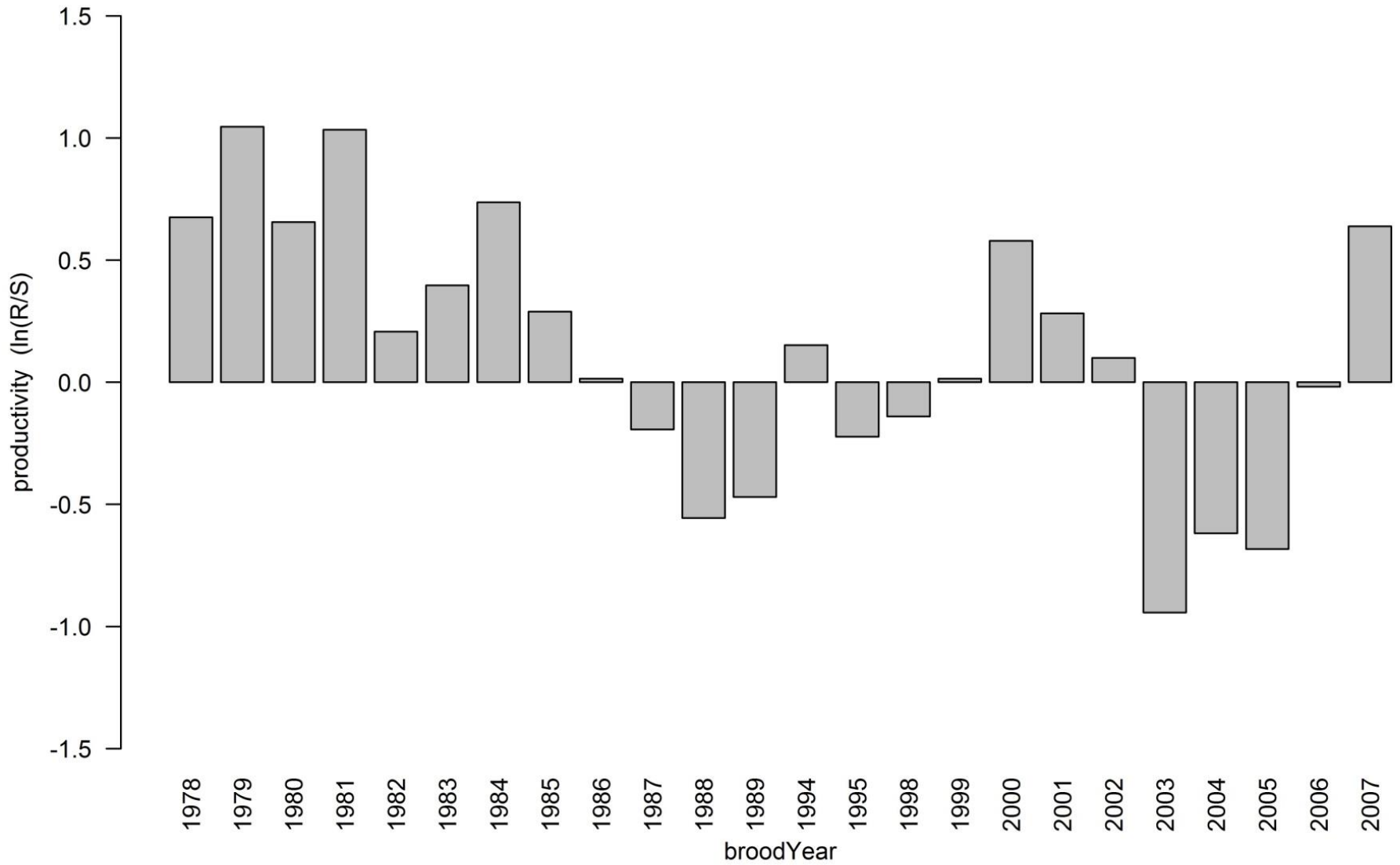
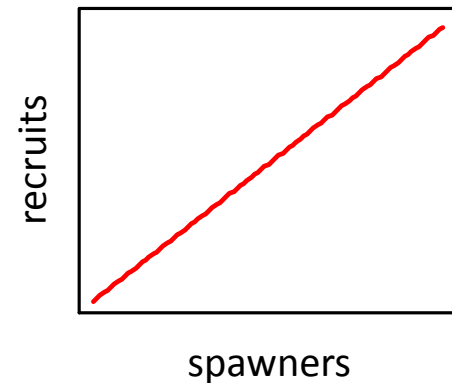# Skagit River steelhead spawner-recruit

Ricker density dependent model
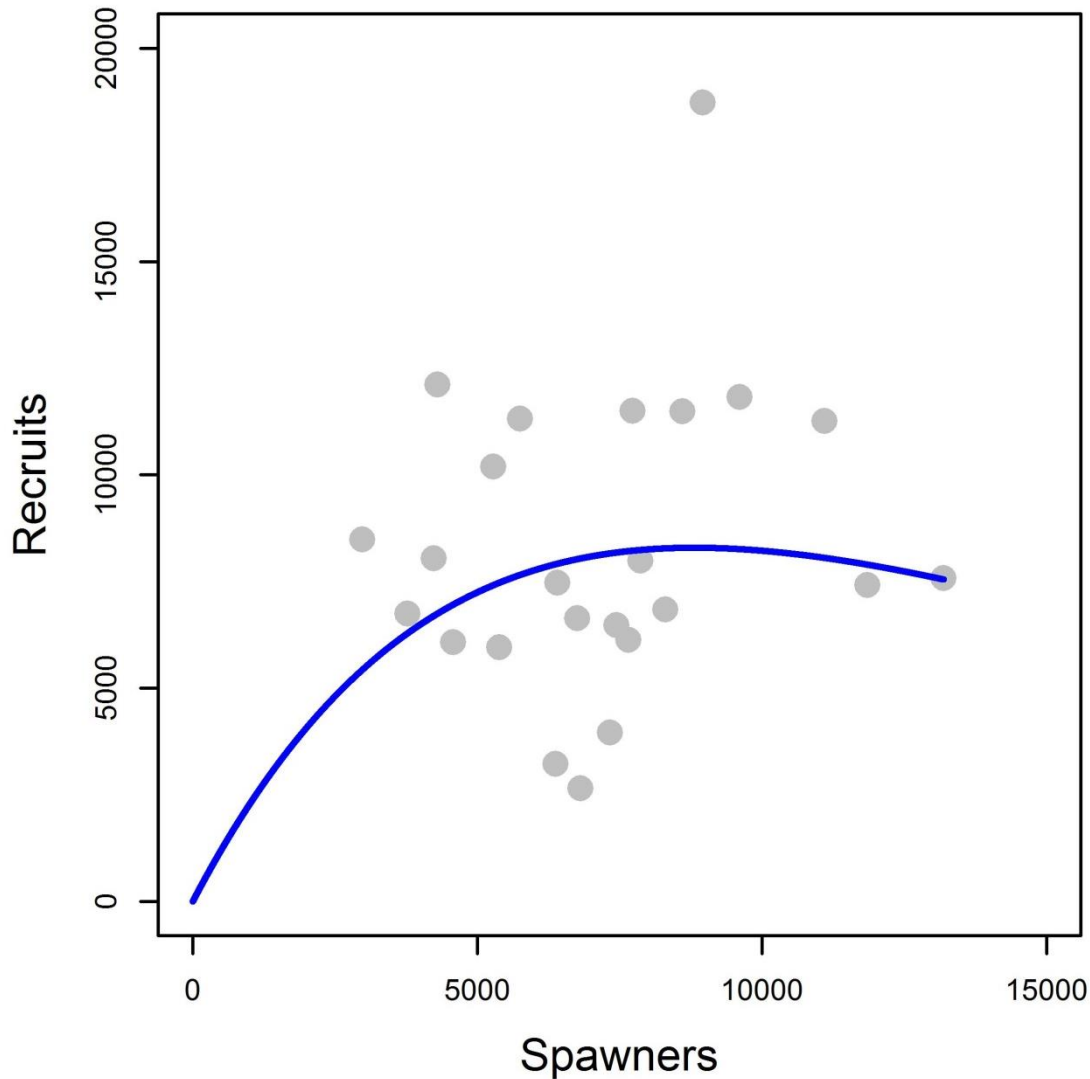
$$log\left(\frac{R}{S}\right) = b_0 - b_1 S$$

Density independent model

$$log\left(\frac{R}{S}\right) = b_0$$
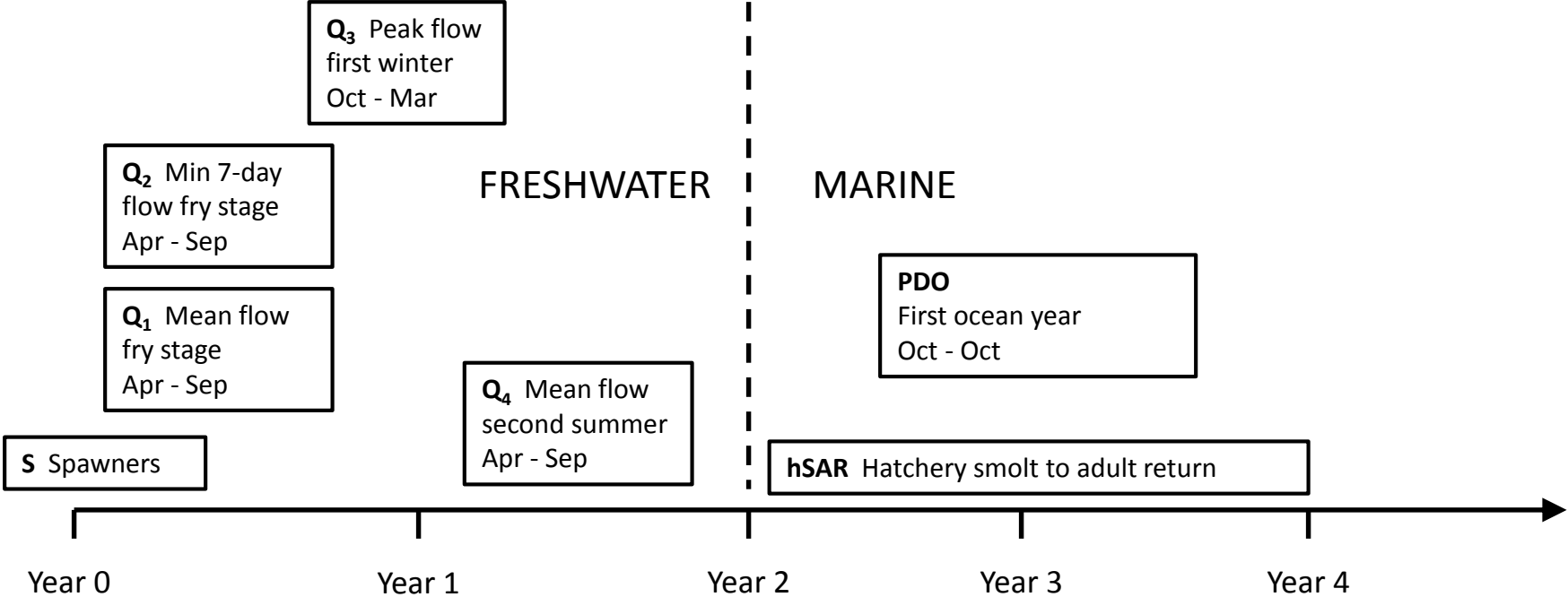
Skagit River steelhead spawner-recruit

Compare models

1. Akaike Information Criterion

Model	AICc
Density dependent Ricker	36.7
Density independent	42.2

2. Partial F-test for nested models

Density dependence term:
F = 8.85, p = 0.00699

Predictors for productivity model

Hatchery predictors

Hypothesize that ecological interactions amongst wild and hatchery juveniles:

- Increase in years when more hatchery fish are released
- Increase when hatchery releases distributed evenly amongst many sites
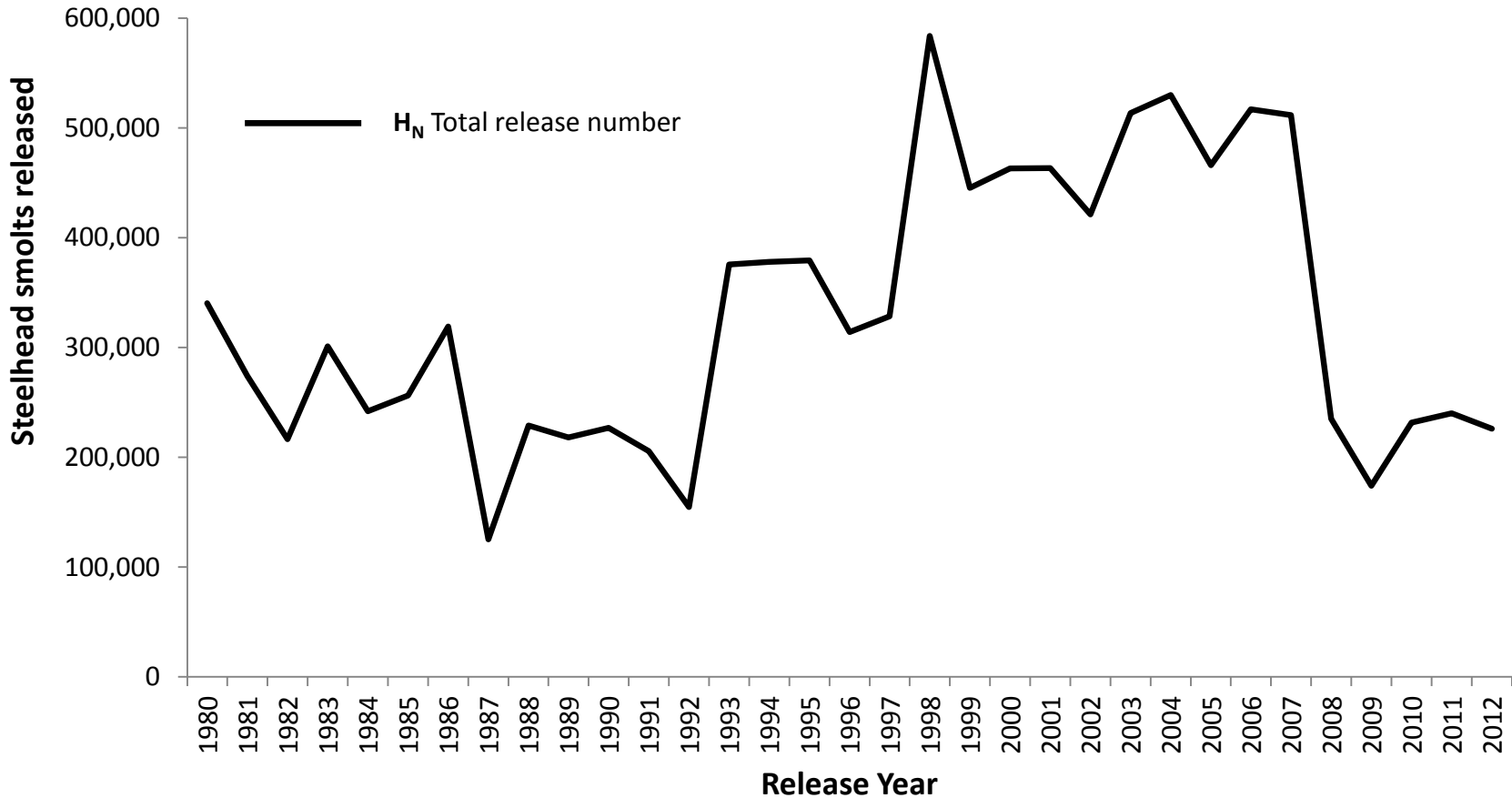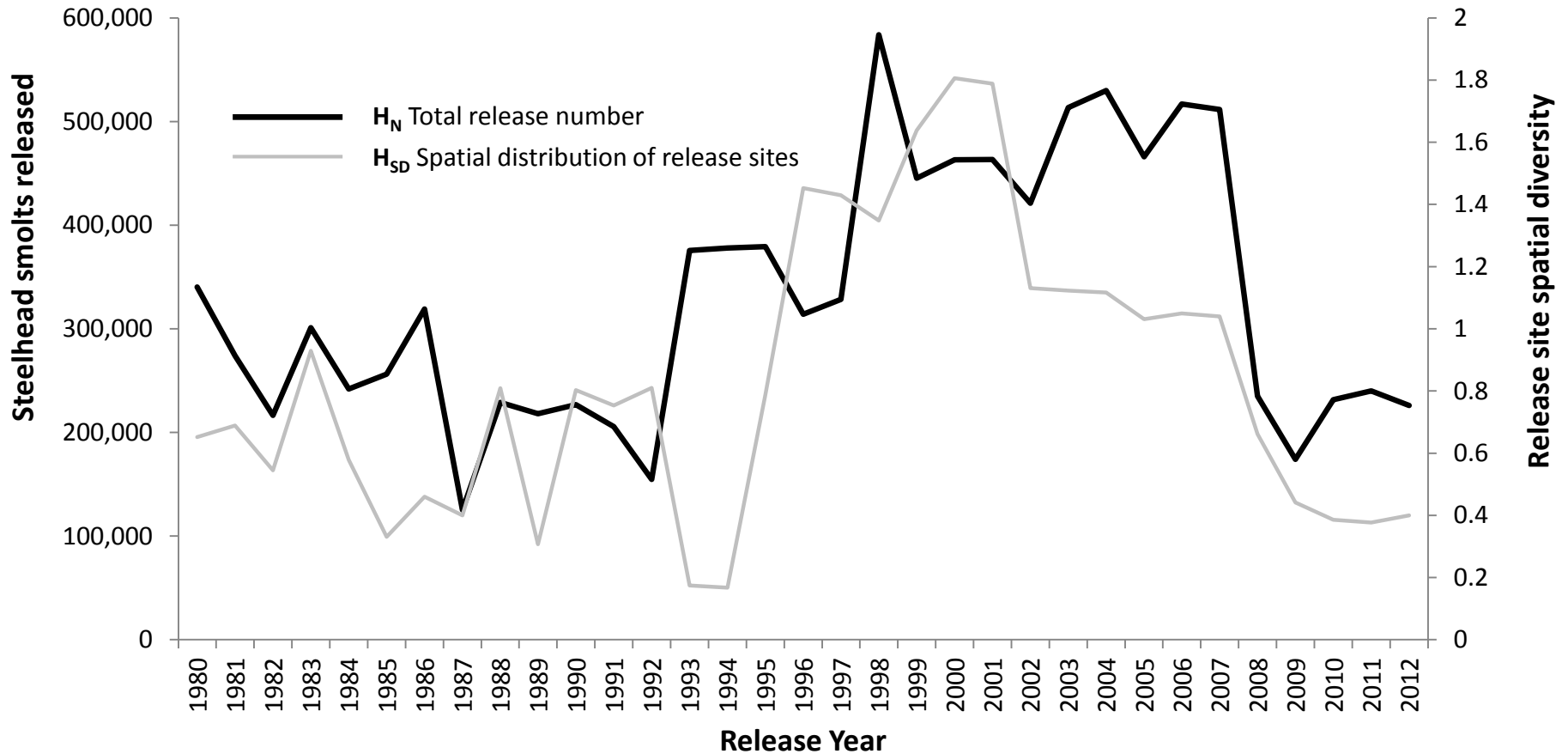
Hatchery predictors

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Model selection

$$log\left(\frac{R}{S}\right) = b_0 + b_1 S + b_2 Q_1 + b_3 Q_2 + b_4 Q_3 + b_5 Q_4 + b_6 PDO + b_7 hSAR + b_8 H_N + b_9 H_{SD} + \varepsilon$$

1. Standardize predictors to mean = 0 and SD = 1

2. Evaluate models containing all possible combinations of predictors: 2^9 = 512

3. To compare models

   - Rank according to AICc

   - Akaike weights: probability that model is best of those evaluated

4. To compare predictors

   - Sum Akaike weights for all models containing that predictor

   - Average parameter estimates according to Akaike weights

Following:
Buhle 2009 *Biological Conservation*
Burnham and Anderson 1998

Model comparison

Model rank	Model	ΔAICc	Akaike weight	R^2
1	$S + H_N + PDO + Q_3$	0	0.171	0.70
2	$S + H_N + PDO + Q_3 + Q_1$	1.11	0.098	0.72
3	$S + H_N + PDO + Q_1$	1.37	0.086	0.69
4	$S + H_N + PDO$	1.65	0.075	0.65
5	$S + H_N + PDO + Q_3 + Q_4$	2.32	0.054	0.71
6	$S + H_N + PDO + Q_3 + Q_1 + Q_4$	3.42	0.031	0.73
7	$S + H_N + PDO + Q_3 + H_{SD}$	3.52	0.030	0.70
8	$S + H_N + Q_3$	3.68	0.027	0.62
9	$S + H_N + PDO + Q_1 + Q_4$	3.70	0.027	0.69
10	$S + H_N + Q_1 + Q_3$	3.78	0.026	0.65

Comparison of predictors

| Symbol	Predictor	Weight	Estimate	SE
S	Spawners	1.00	-0.36	0.079
H_N	Total hatchery release	0.96	-0.26	0.083
PDO	Pacific Decadal Oscillation	0.85	0.18	0.073
Q_3	Peak flow first winter	0.63	-0.14	0.068
Q_1	Mean flow fry stage	0.42	0.11	0.069
Q_4	Mean flow second summer	0.14	0.072	0.067
hSAR	Hatchery SAR	0.14	0.056	0.11
H_{SD}	Hatchery spatial distribution	0.13	0.018	0.11
Q_2	Minimum 7-day flow fry stage	0.12	-0.0089	0.082

Density dependence

For a population at a fraction of its historic abundance, in a basin as large and complex as the Skagit?
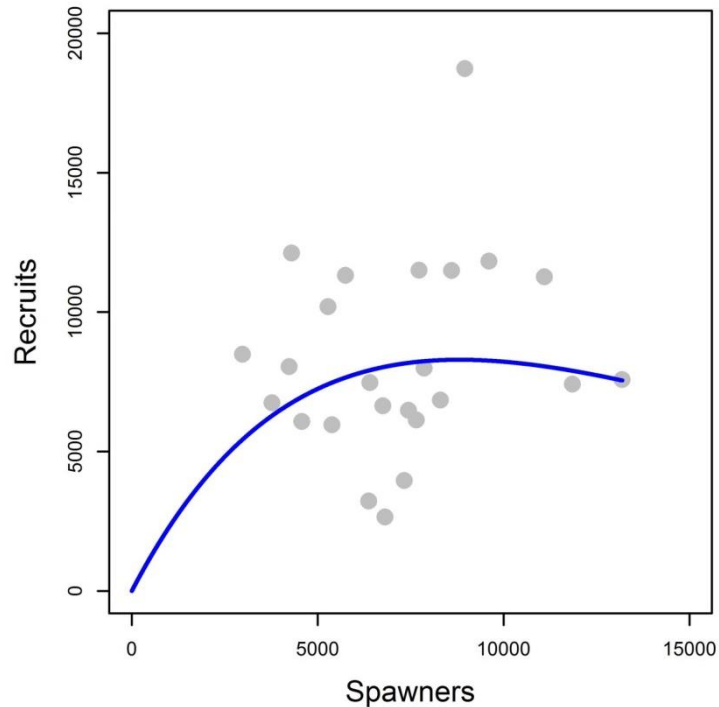
1. Redd based abundance estimates may underestimate true abundance
   - Survey 182 km (66%) mainstem
   - Survey 41 km (13%) tributary
   - Unavoidable assumptions regarding habitat utilized by steelhead

2. Evidence for density dependence in threatened, low abundance Chinook salmon populations
   - Walters 2013 *Ecology Freshwater Fish*

3. Density dependent processes may operate at small spatial scales
   - Einum 2005 *Oecologia*
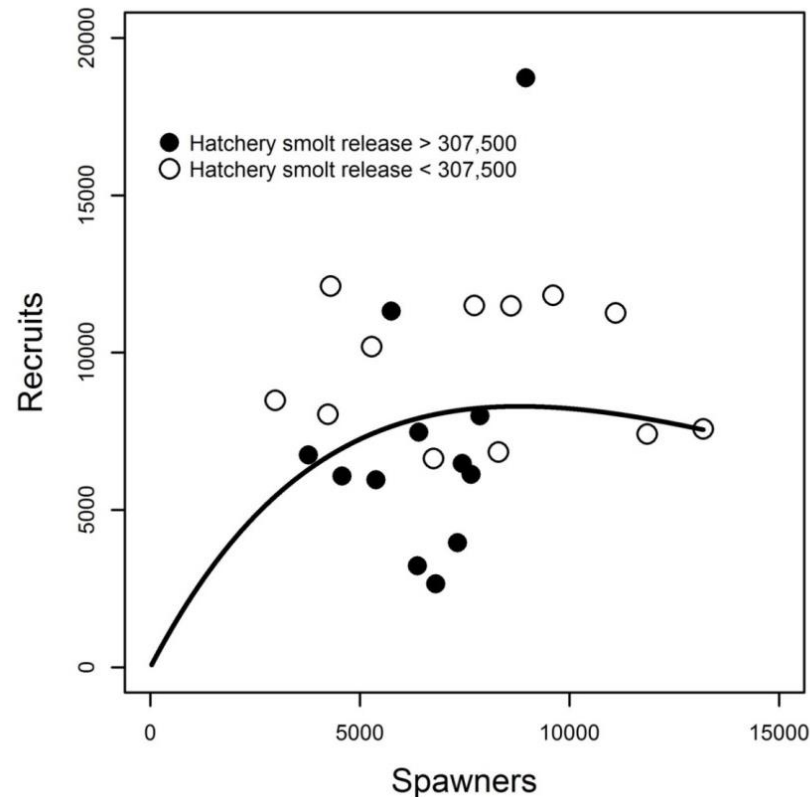   - Einum 2008 *J Animal Ecology*

Hatchery releases
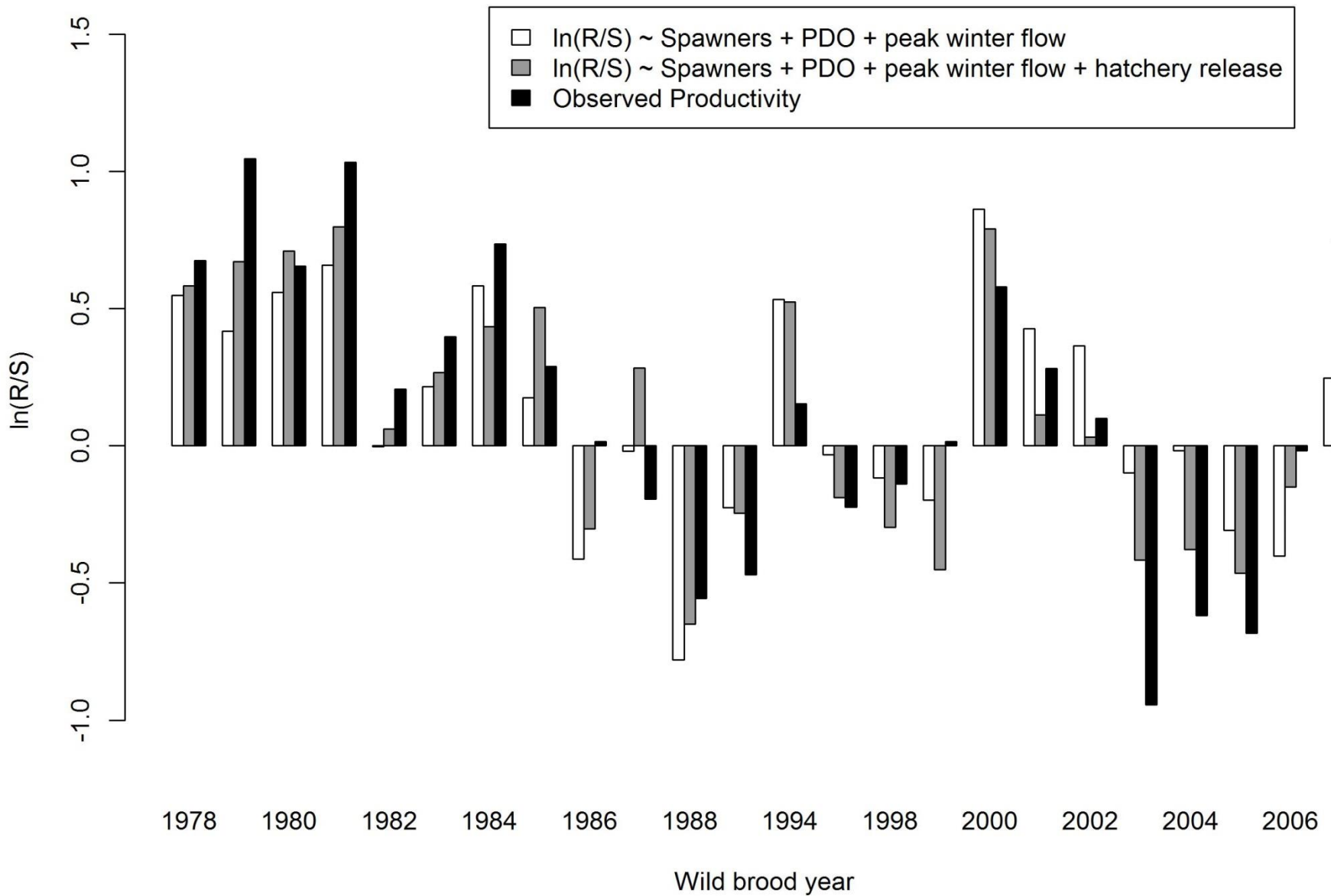
Hatchery releases

Model provides evidence for correlation, but not necessarily causation

- Hatchery releases serially autocorrelated: extended periods of high and low hatchery production

- Low survival during periods of high hatchery production could be related to factors not in model

Mechanism of potential interaction?

Smolt trap data indicate overlap in time and space
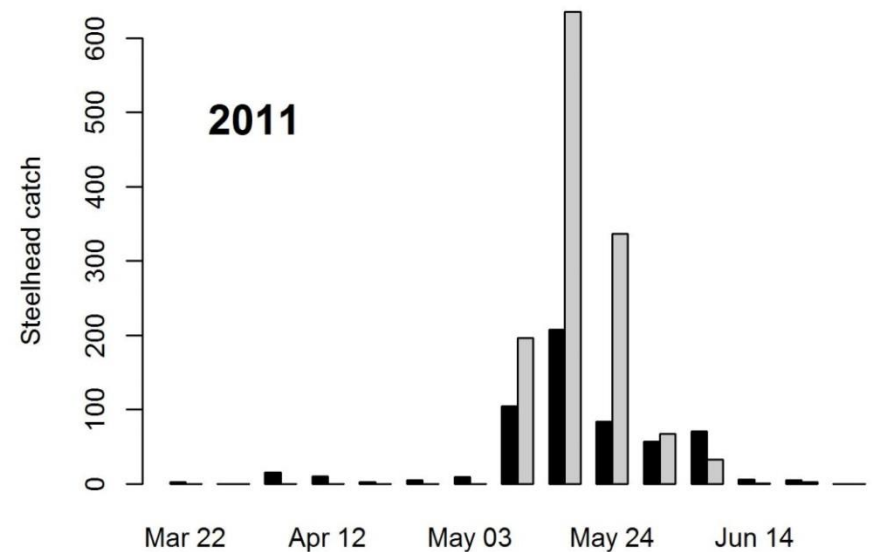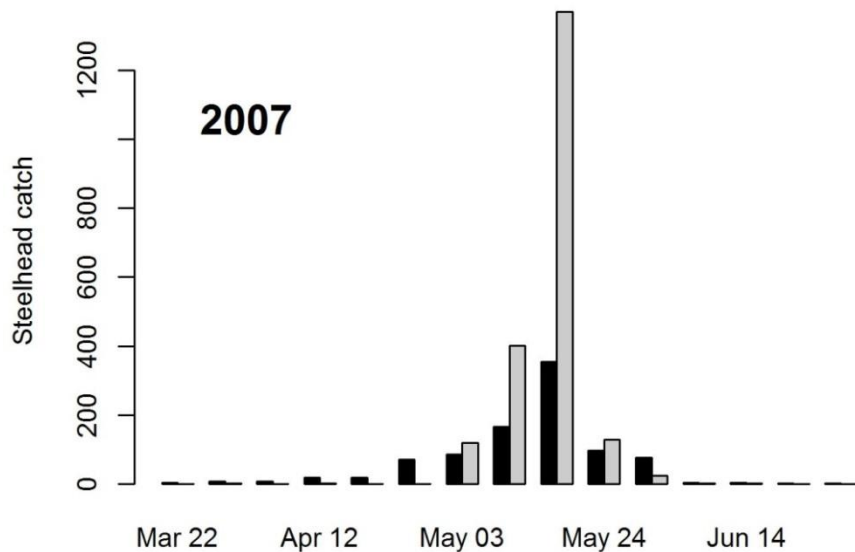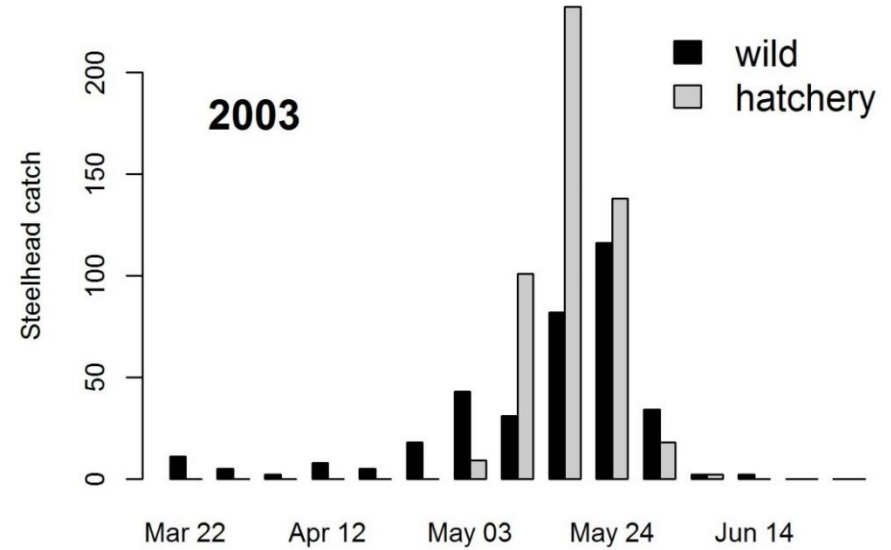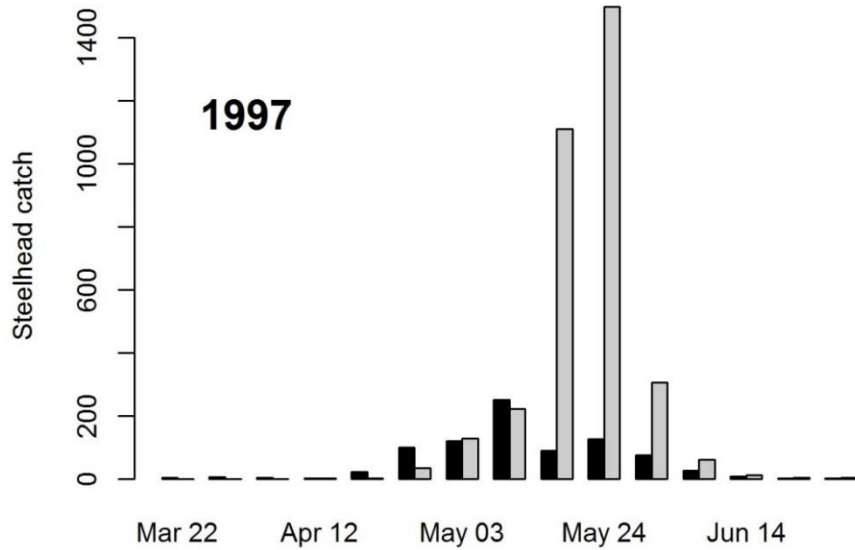
Summary

- Stock-recruit model suggests productivity of wild Skagit River steelhead steelhead governed by density dependent processes

- Model predictions suggest winter flow conditions for parr and PDO are most important environmental variables related to steelhead productivity

- Total number of hatchery fish released negatively associated with wild steelhead productivity

- **Future work:** employ simulations to predict population trajectory given different management scenarios of habitat restoration, harvest and hatchery operations

Acknowledgements