Using hierarchical models to estimate management reference points for for coastal steelhead populations in Washington

Thomas Buehrens, WDFW
Dan Rawding, WDFW
Daniel Schindler, UW-SAFS

SAFS SCHOOL OF AQUATIC and FISHERY SCIENCES

Washington Department of FISH AND WILDLIFE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION NOAA U.S. DEPARTMENT OF COMMERCE

Acknowledgements

- Charlie Cochran
- Martin Liermann
- Schindler Lab
- Daniel Schindler
- WDFW ELC Unit
- Mara Zimmerman
- George Pess
- Joe Anderson
- Phil Sandstrom
- Neala Kendall
- Bryce Glaser
- Pat Hanratty
- Jamie Lamperth
- Josh Holowatz
- Thom Johnson
- Randy Cooper
- Clayton Kinsel
- Matt Klungle
- Jan Ohlberger
- John McMillan
- Andre Punt
- Many others…

Photo Credit:
John McMillan

Background

- Management and conservation of steelhead require estimates of Biological Reference Points (BRPs)
  - o (e.g., MSY, productivity, capacity)
  - o Used to manage fisheries, establish escapement goals, harvest rates, viability targets
- WA historical BRP estimates made with limited data
  - o Limited data on juvenile (parr) densities
  - o Estimated habitat quantity
  - o 3-5 years of spawner data for 5 pops
  - o Used to estimate MSY across western WA (Gibbons et al. 1985)
- Opportunity to revisit previous analysis
  - o Abundance time series (juv. + adult) data are now available
  - o Many ESA recovery planning efforts, pop. viability models require these parameters.

Objectives

- Goal: Estimate biological reference points for W. WA populations
  - Make use of new abundance time series data
  - Develop model which can predict parameters for pops w/no data
  - Determine what factors explain among-watershed variation in parameters


Photo credit: Will Atlas

Approach

Classic approach :

Adult to adult spawner-recruit analysis to estimate density-dependent population parameters, separately

Problems:

- No/few data for many pops
- Full life-cycle data includes life-stages with both ***density-dependent*** AND ***density-independent*** survival
    - o Smolt to adult survival-highly variable
    - o Known 'regime shifts' in productivity
    - o Both result in noisy SR analysis

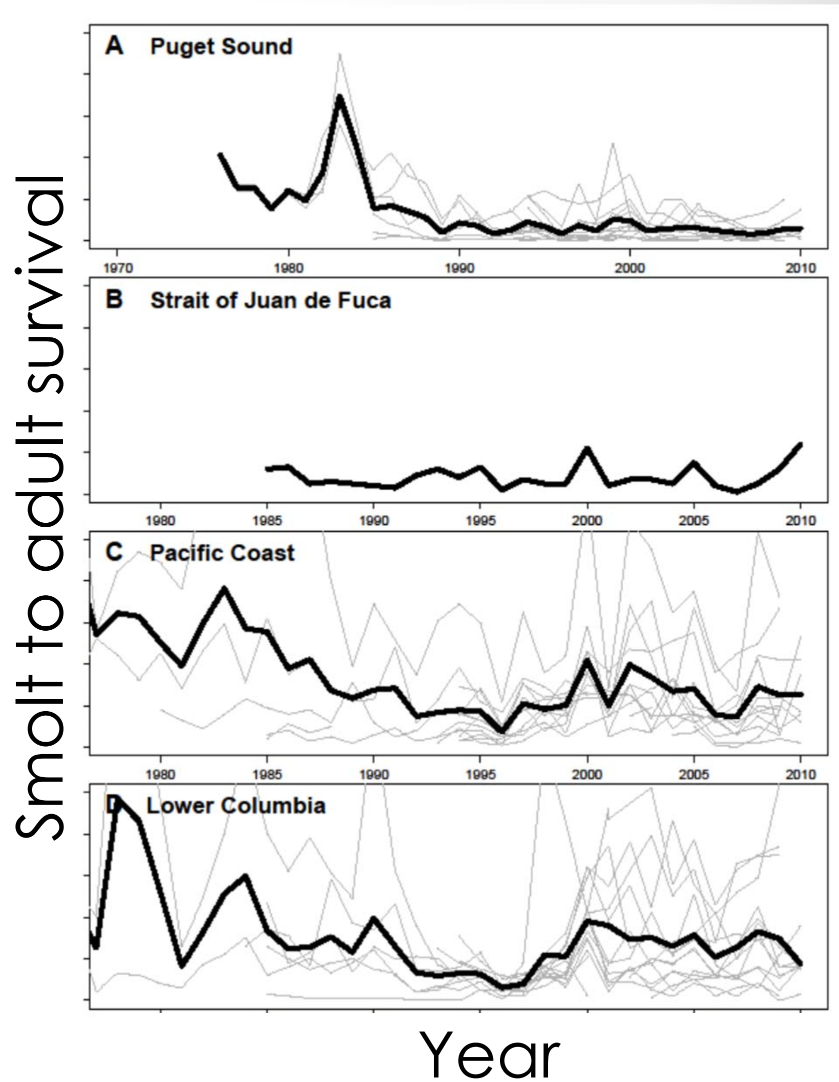


Figure provided by Neala Kendall

Steelhead Life Histories Enable Simplified SR Models

Survival Density **Dependent**

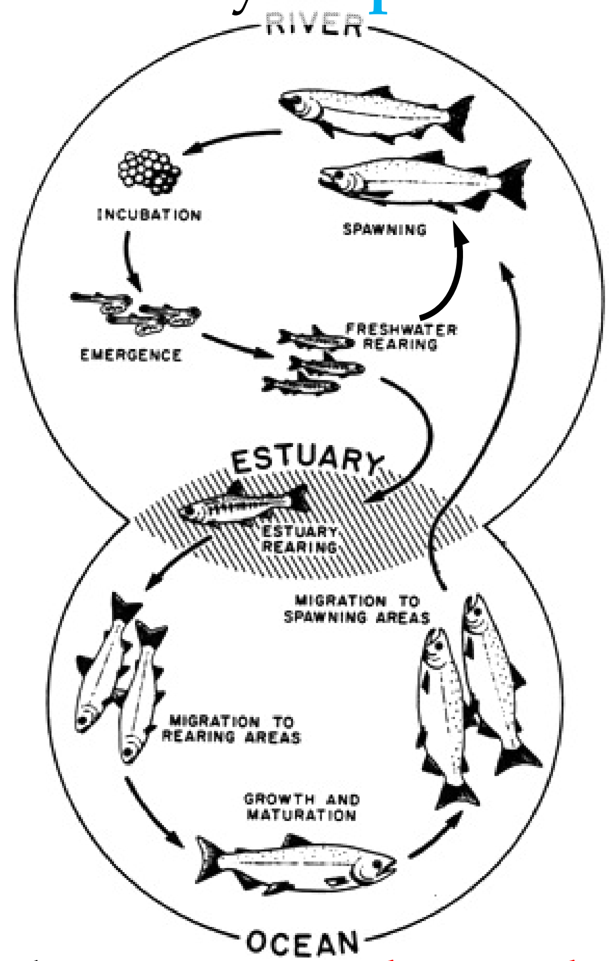
Freshwater

- Rear in natal watershed(1-4 years)
- Resource sharing *within* populations
- Territorial
  - contest (as opposed to scramble competition)

Vs.

Marine

- Rapid movement away from river mouths
- Mixed stock rearing areas
- Resource sharing *among* populations
- Low correlations in abundance among populations



Survival Density **Independent**

Solution: Bayesian spawner smolt-recruit meta-analysis

- Eliminate "noise" in due to variable marine survival

- Incorporate covariates explaining among-population differences due to watershed characteristics
  - Enables meeting assumption of "exchangeability" among pops
  - Empirically identify habitat features important to steelhead production
  - Test of existing habitat-based capacity models

- Make use of very short time series (data limited pops) by modeling all simultaneously

- Tractable for watershed restoration efforts
  - Future SR data points will intrinsically tell us whether restoration is improving population productivity/capacity independent of marine survival shifts
    - existing management reference points are independent of assessment data!

Estimating Habitat Covariates

1. Determine steelhead distribution
   a) Logistic regression to estimate upper steelhead extent

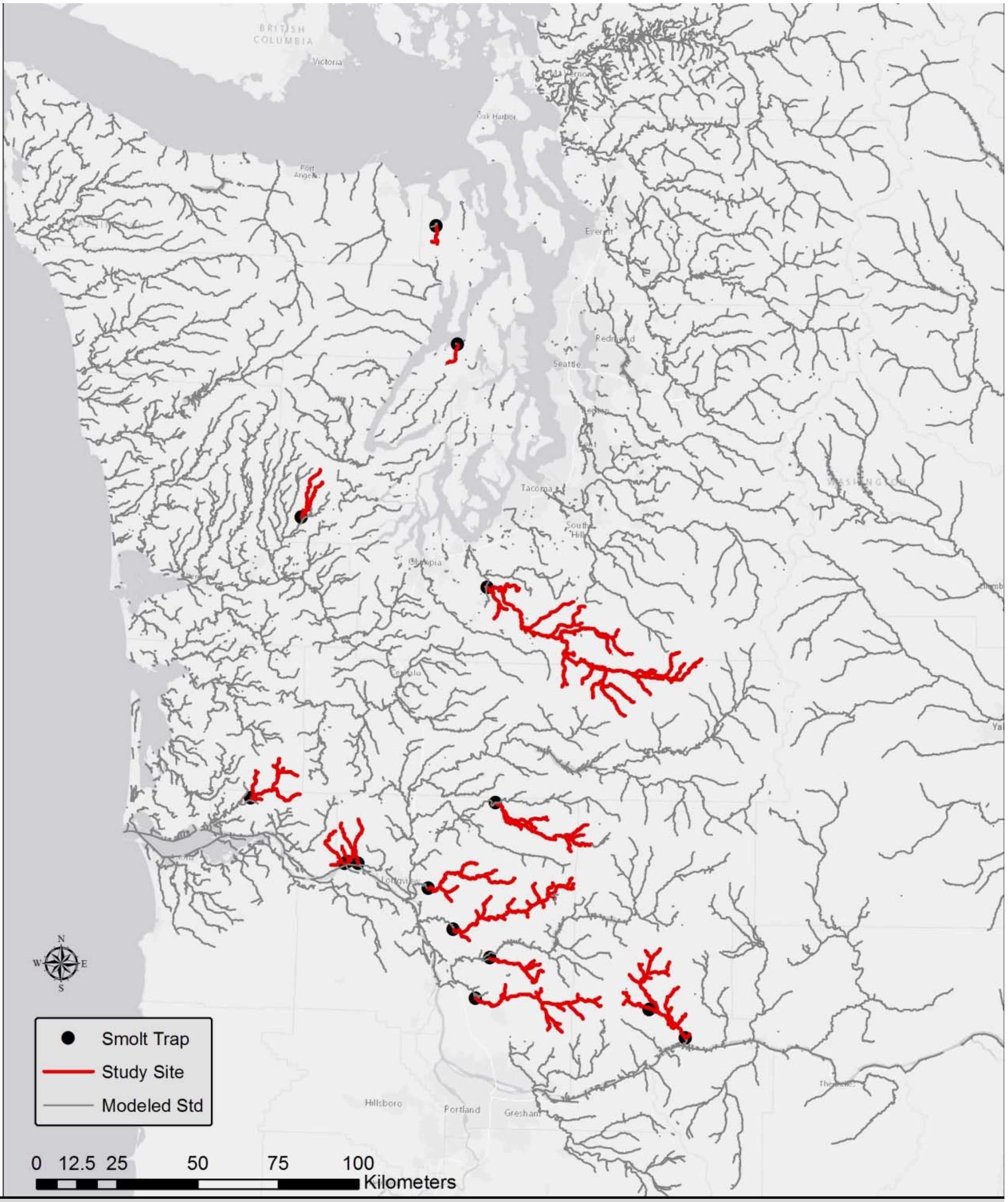
      logit(presence/absence) = mean annual discharge
      + gradient
      + max. downstream gradient

   b) Lower extent defined by tidewater
   c) Truncated modeled distribution for known anadromous barriers

2. Use habitat attributes for reaches with >50% probability of occurrence

Study Sites

- 15 populations
- 164 pairs of spawner and smolt abundance estimates
- GIS Habitat covariates modeled over 100's to 1000's of reaches

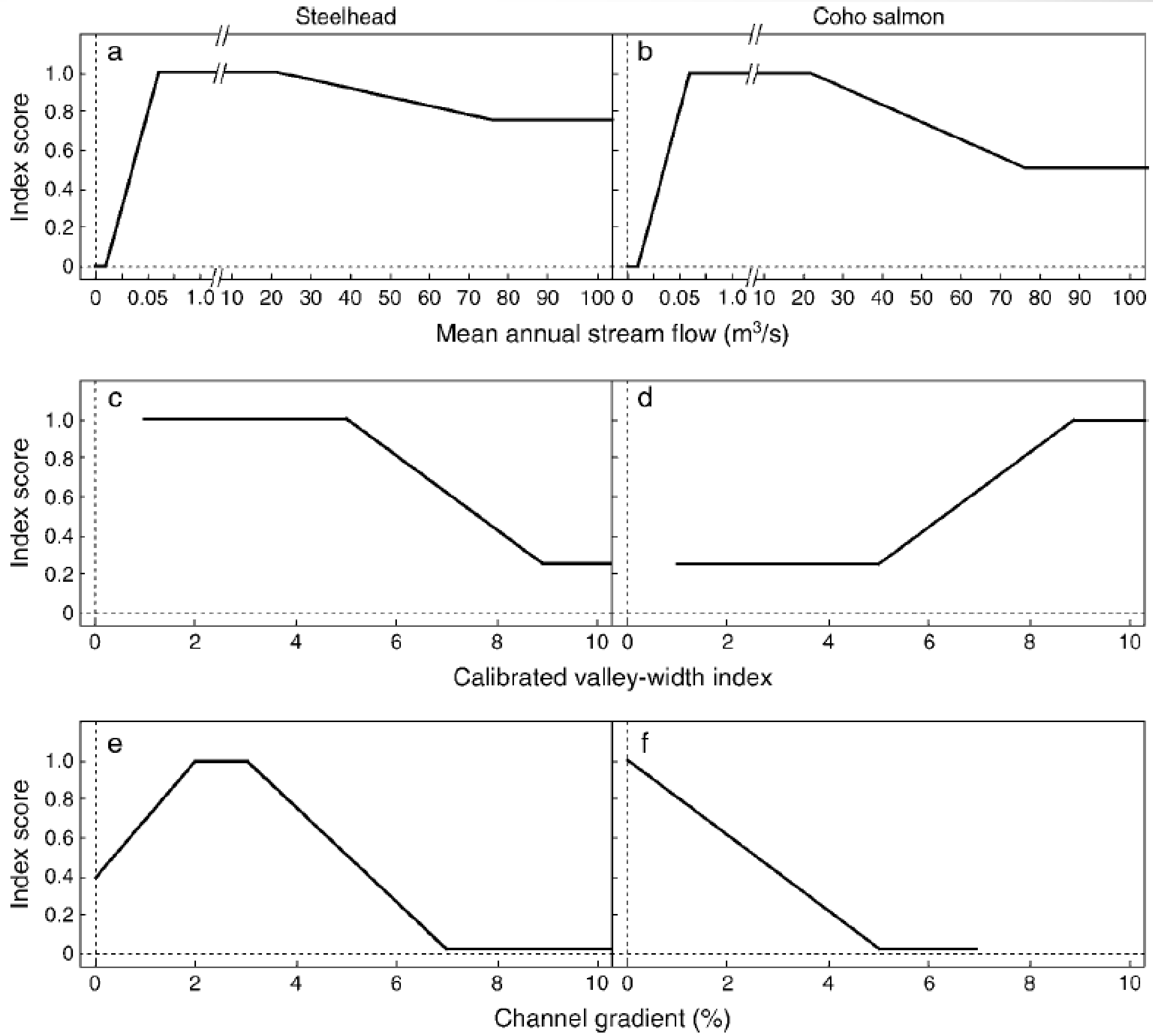


Populations and Habitat Attributes

Population	Modeled Habitat (km)	Burnett IP scores	Surface Area (sq. m)	Discharge (cms)	Watershed Area (sq. km)	Max Elevation (m)	Mean Gradient
BigBeef	9	70	57412	1.0	37	109	1.3%
Snow	9	57	57513	1.1	59	111	1.2%
Wind-Trout	17	100	104128	6.8	74	605	1.6%
Germany	17	133	187656	3.4	59	256	1.4%
Abernathy	22	181	203129	4.4	74	260	1.9%
Mill	22	162	182631	4.3	75	317	2.1%
Bingham	35	228	311150	5.0	81	160	0.5%
Cedar	37	243	397198	6.8	135	304	0.9%
Grays	52	398	743339	20.5	230	315	1.8%
Coweeman	64	519	1033086	17.1	306	438	1.5%
NF Toutle	74	414	1407393	28.6	378	1055	2.7%
Kalama	81	628	1822813	42.4	466	606	2.5%
Wind	88	575	841272	73.4	579	612	1.9%
EF Lewis	88	633	1835920	31.3	424	559	1.7%
Nisqually	166	1068	2930153	46.1	1467	841	0.9%

IP Models

- "Intrinsic potential"
- Scalars are applied to reach-level habitat data
- Sum scores across reaches to get estimate of "capacity" for freshwater
- Extensive use of these models in salmon management, recovery
- ***Scalars based on professional opinion***
- ***Estimates rely on spatial expansions***



(Burnett et al. 2007; Ecol. Apps)

Spawner-Recruit model

Data

R = Smolt Recruits

S = Spawners

Standard Hockey Stick Model

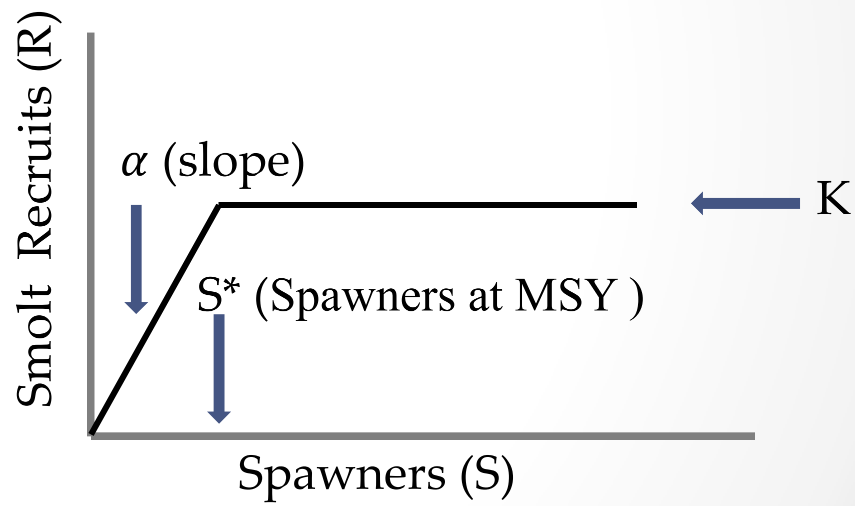
$$R = \min\ (\alpha S, K) = \begin{cases} \alpha S, = \text{if } \alpha S < K \\ K, = \text{if } \alpha S \geq K \end{cases}$$

Parameters

α = Asymptotic recruits per spawner

K = Smolt recruits at carrying capacity

$S^* = \frac{K}{\alpha}$ = Spawners at MSY, full seeding



Modified Model

K = log-linear function of habitat variables

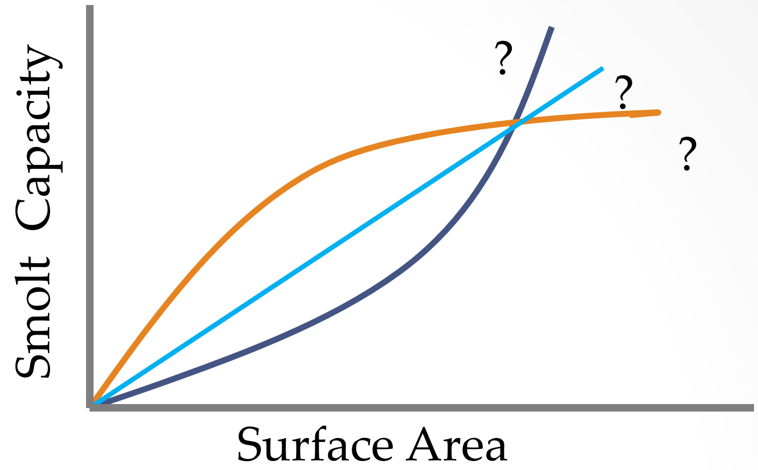
Surface area best explains capacity

Habitat Covariate Model	DIC	ΔDIC
Surface Area (m^2)	224.47	0.0
Burnett et al. (2007) IP scores	226.07	1.6
Watershed Area (km^2)	226.91	2.4
Discharge (m^3s^{-1})	229.75	5.3
Accessible Habitat Length (km)	230.85	6.4

- DIC suggested stream surface area was a better explained variability in capacity than other habitat covariates

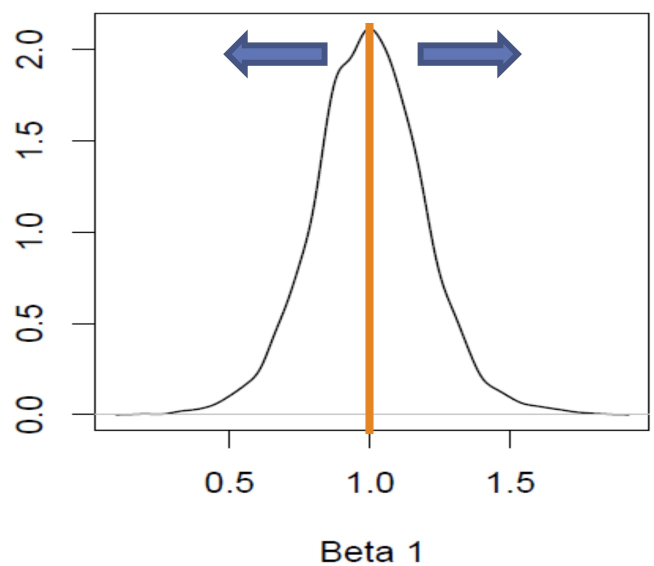
Is capacity-surface area relationship linear?

$$K = slope * surface\ area^{\beta_1} * error\ term$$

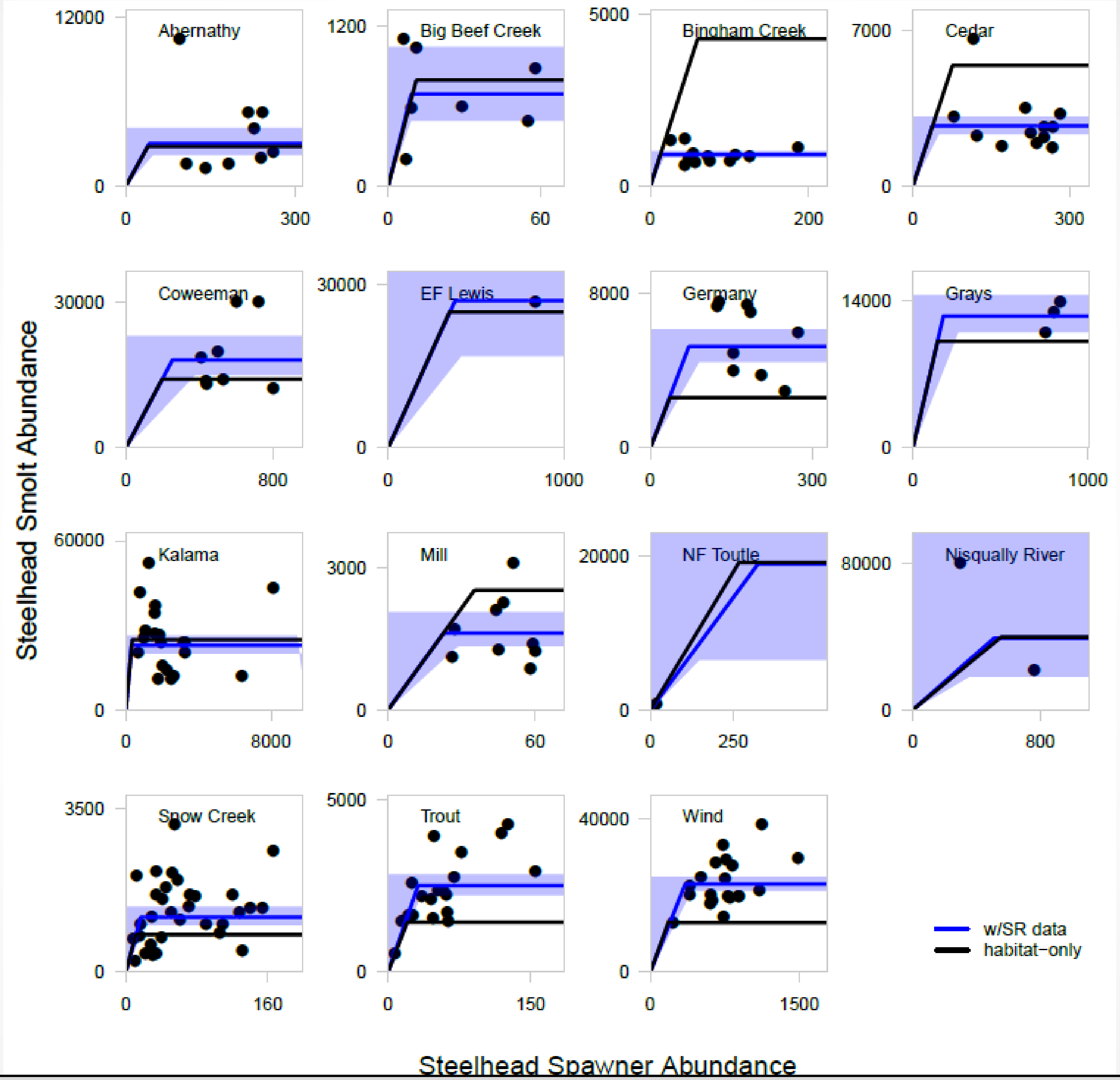


- Answer: Yes; no evidence of non-linearity in the capacity-surface area relationship

- Not necessarily true for very large watersheds where steelhead juveniles are relegated to edges

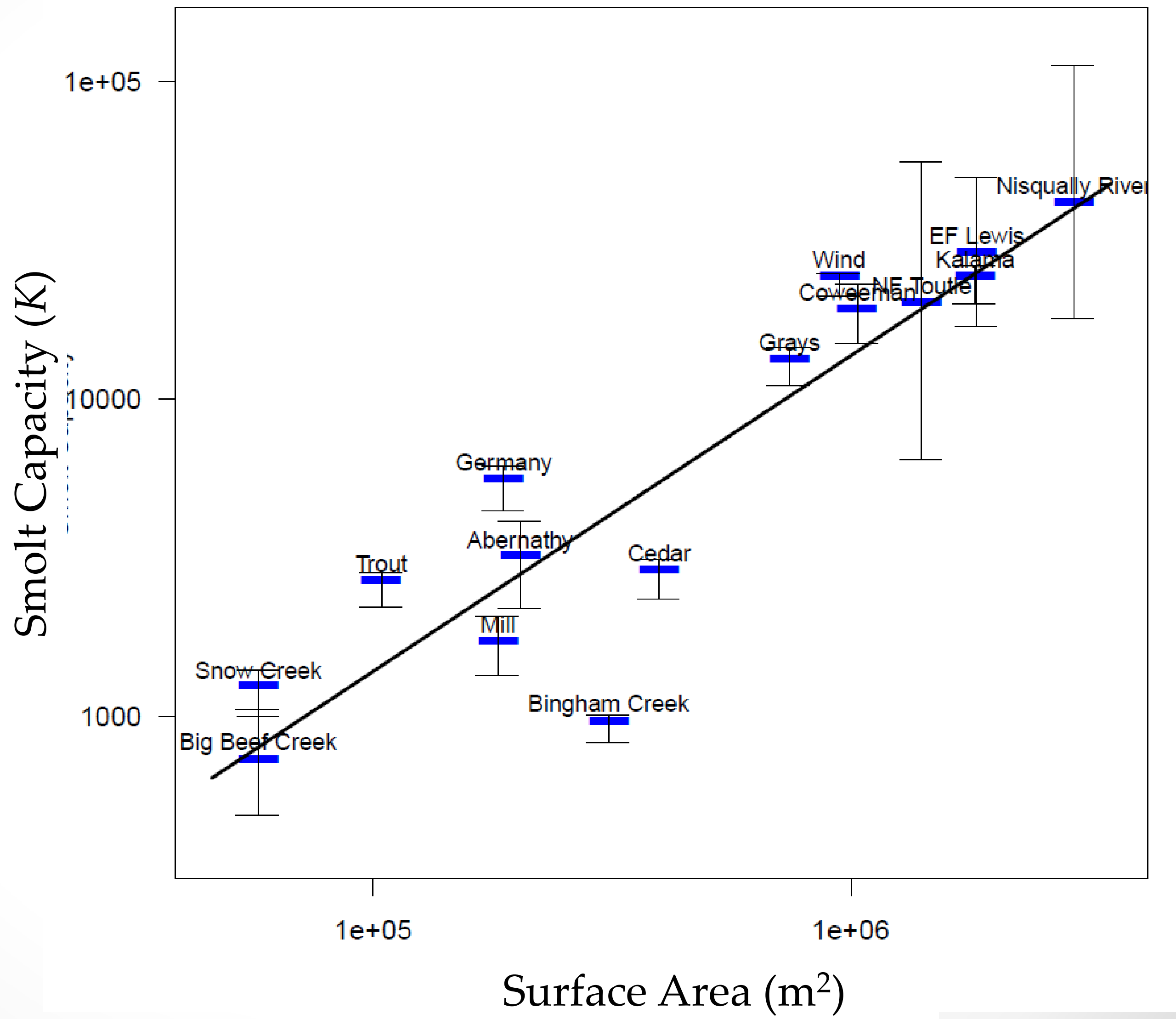


< or > 1 would indicate power relationship with habitat area

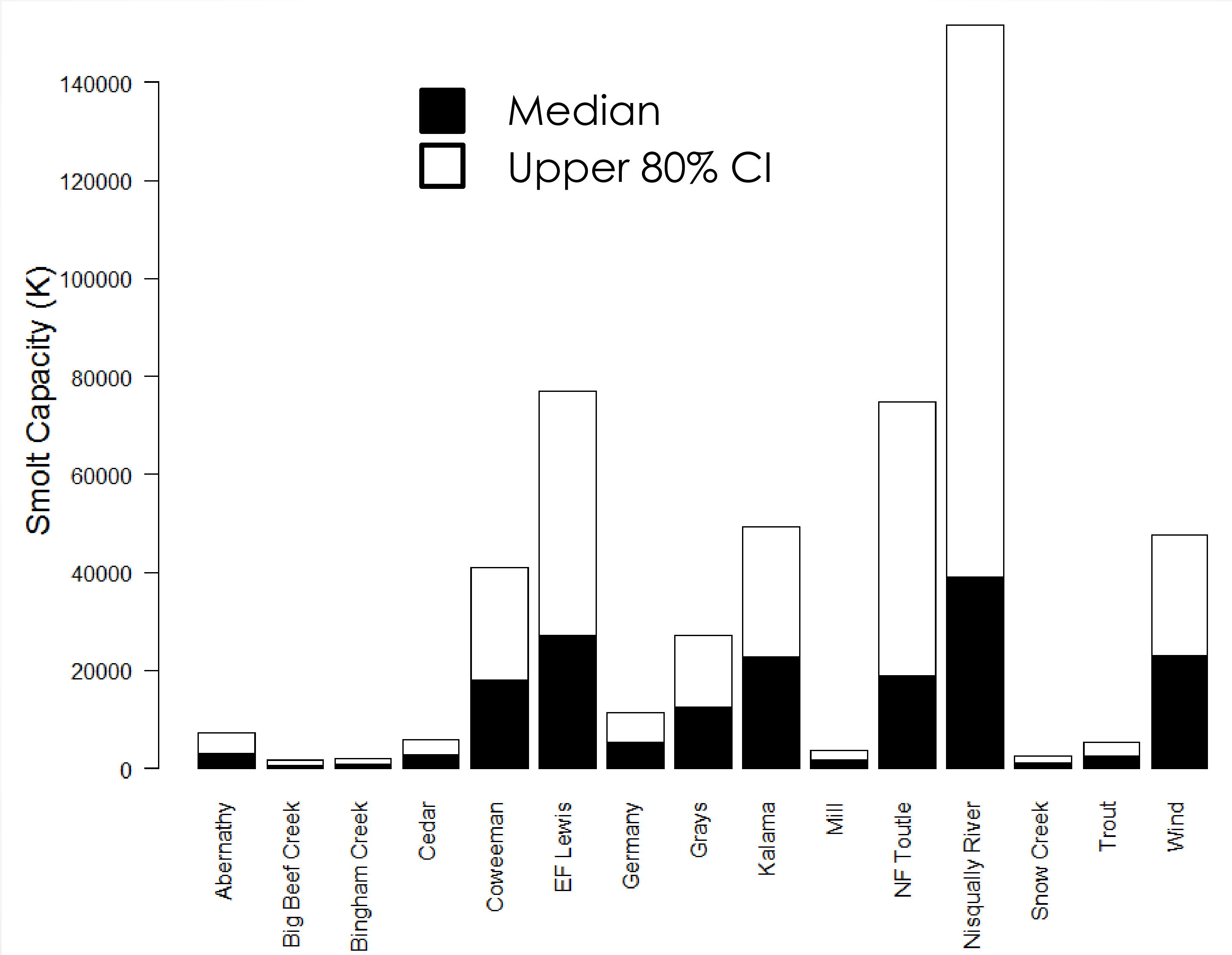

Abernathy
Big Beef Creek
Bingham Creek
Cedar
Coweeman
EF Lewis
Germany
Grays
Kalama
Mill
NF Toutle
Nisqually River
Snow Creek
Trout
Wind
w/SR data
habitat−only
Steelhead Smolt Abundance
Steelhead Spawner Abundance

Surface Area vs. Smolt Capacity (*K*)

- Capacity strongly correlated with habitat surface area
- Uncertainty proportional to number of SR data points

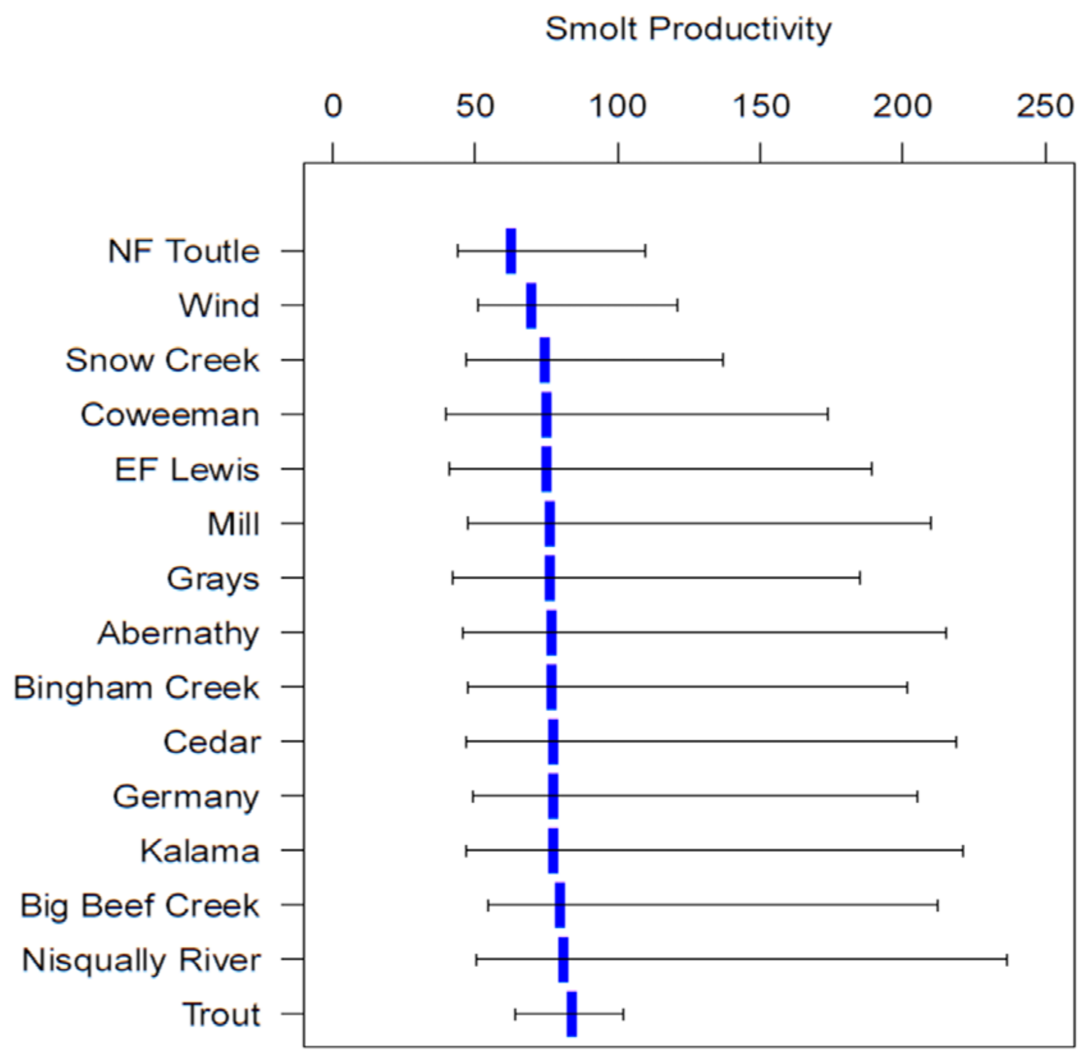


Smolt Capacity (*K*)



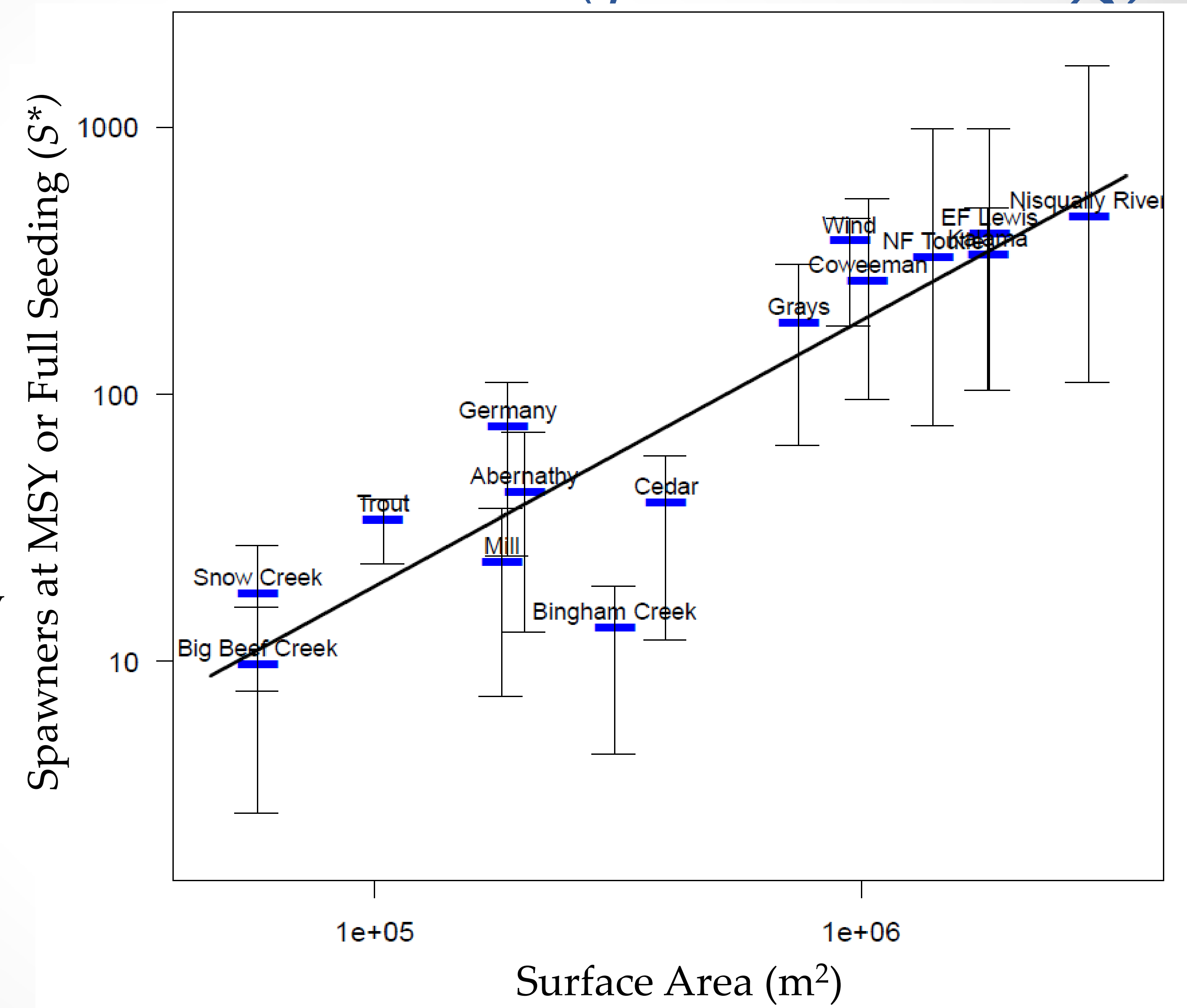
Productivity (α)

- This is expected number of recruits per spawner when S < S*
- Productivity less variable among pops
- High uncertainty for virtually all
- Likely related to few SR points for almost all pops where S > S*

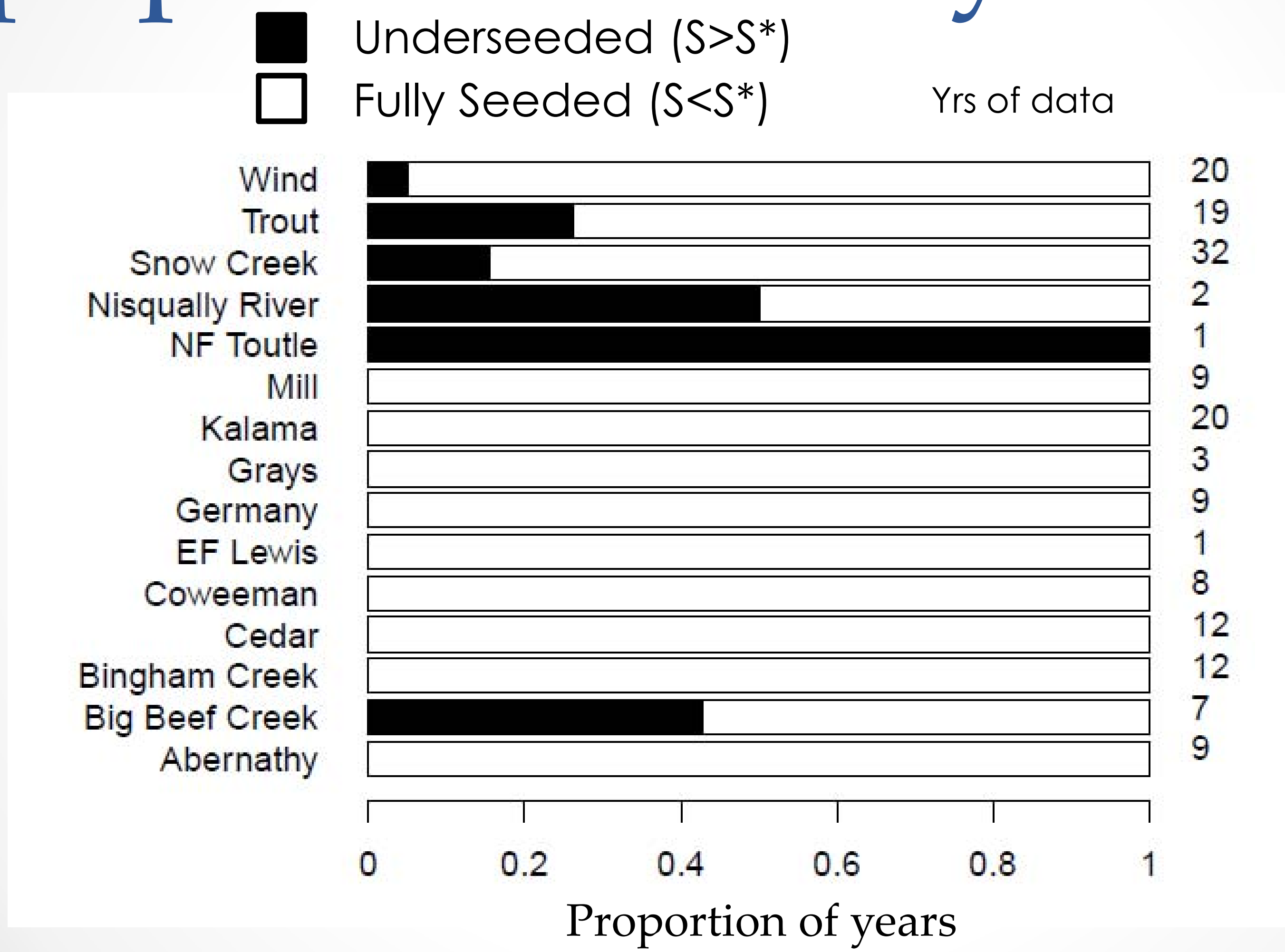


Surface Area vs. *S* (full seeding)*

- Variable *S** but correlated with surface area
- Uncertainty ~ proportional to number of SR data points
- More uncertainty than smolt capacity
- Likely related to few points where S < S*

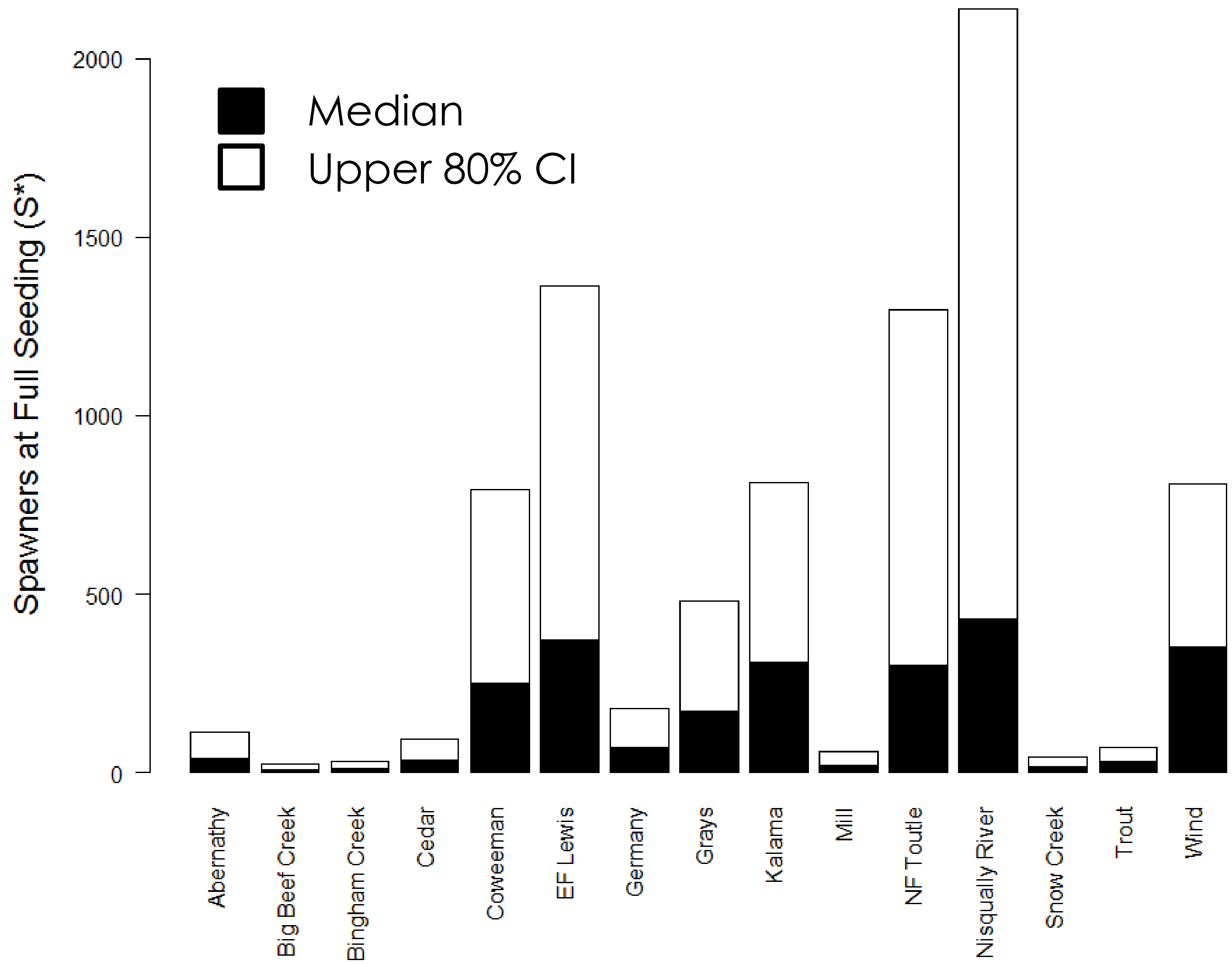


Most years most populations fully seeded



Spawners at Full Seeding (*S**)

- Estimates highly uncertain
- In order to have an 80% certainty (as opposed to 50%) of fully seeding watersheds, you would need to double spawner abundance (**98%,** range 28-296%)



More Issues With Full Seeding and Capacity

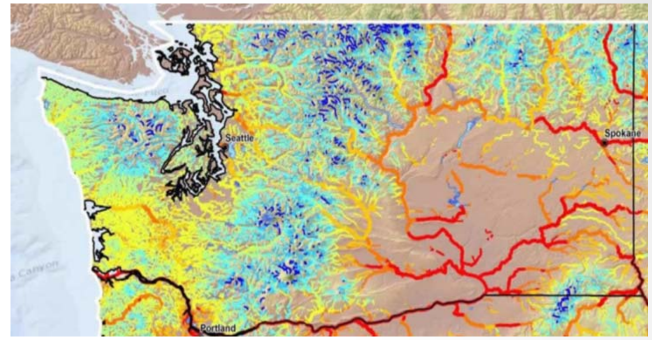
- Model Based on:
    - Current habitat
    - Current fitness
        - Legacy hatchery and harvest impacts
        - Spatial & temporal occupancy and life-history

What we've learned so far

- Stream surface area better predictor of capacity than IP model, stream length, watershed size, discharge.
- Relationship with surface area linear across modeled watershed sizes; may not be true with larger watersheds
- Hierarchical models allowed estimation of SR parameters for data-poor pops
- Reasonable estimates of capacity with low uncertainty where a lot of data exist
- Productivity, spawner abundance to achieve full seeding highly uncertain! (need to double escapement to ensure watersheds seeded)

Next Steps (partial list!)

- Compare results using Beverton-Holt



NorWest Stream Temp Model

- Explore additional covariates:
    - Stream Gradient
    - Temperatures from NorWest Model
    - Covariates for productivity

- Multiple variable models

- Explore development of alternative IP models based on empirical data (depth, velocity preference and tolerance)

- Move to state-space framework to incorporate uncertainty in abundance and age estimates in SR models (***data are NOT all of equal quality!***)

- Collect more SR time-series!!!!!!

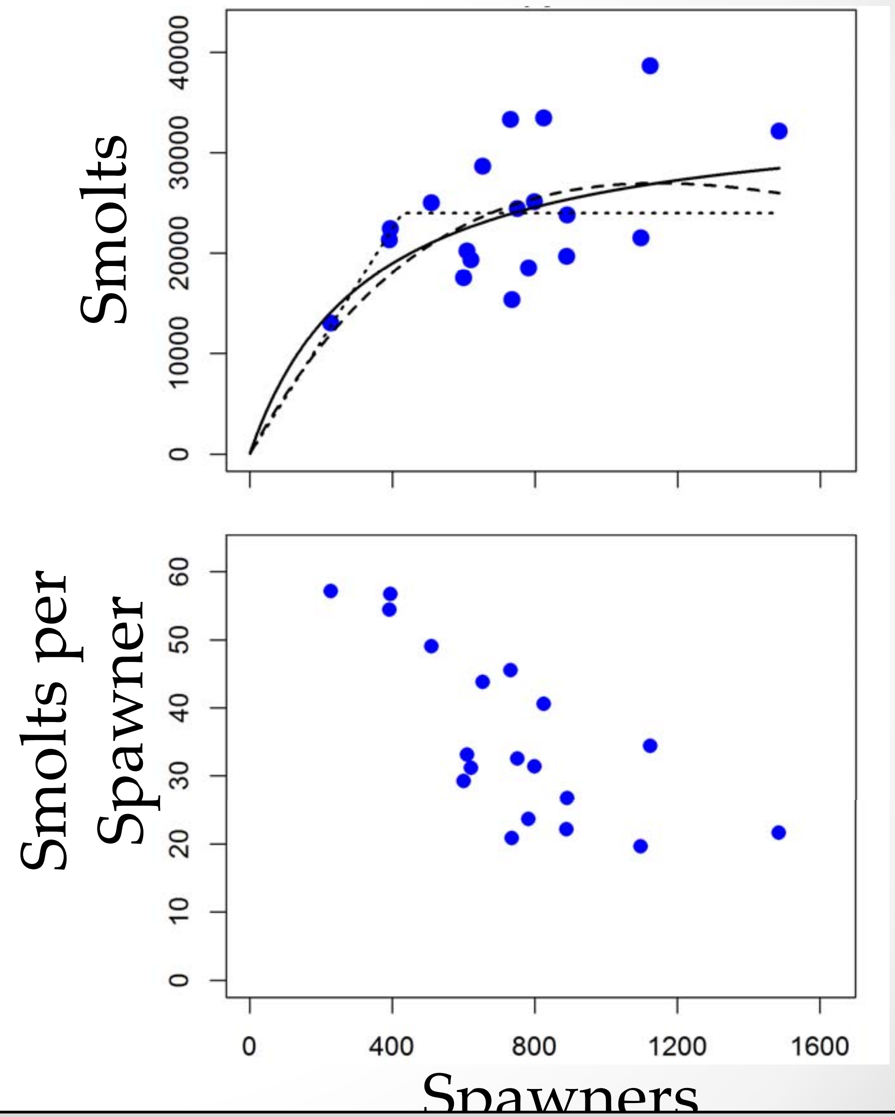
Thanks!
Questions?

TO do

- Intro
  - questions
- Methods
  - Sketch of hierarchicial model how it works
- Results
  - S* per sq km
  - Seq per sq km
  - S*.Seq
  - Bev Holt
  - Plots of

Spawner to smolt survival

- Strong evidence of density dependence
- Steepness appears to vary among pops
- Capacity, adjusted for habitat quantity appears to vary



Spawner-Recruit model

Data

R = Smolt Recruits

S = Spawners

X_1 = Habitat Attribute

Standard Hockey Stick Model

$$R = \min\ (\alpha S, K) = \begin{cases} \alpha S, = \text{if } \alpha S < K \\ K, = \text{if } \alpha S \geq K \end{cases}$$

Parameters

α = Asymptotic recruits per spawner

K = Smolt recruits at carrying capacity

β_0 = habitat var. intercept

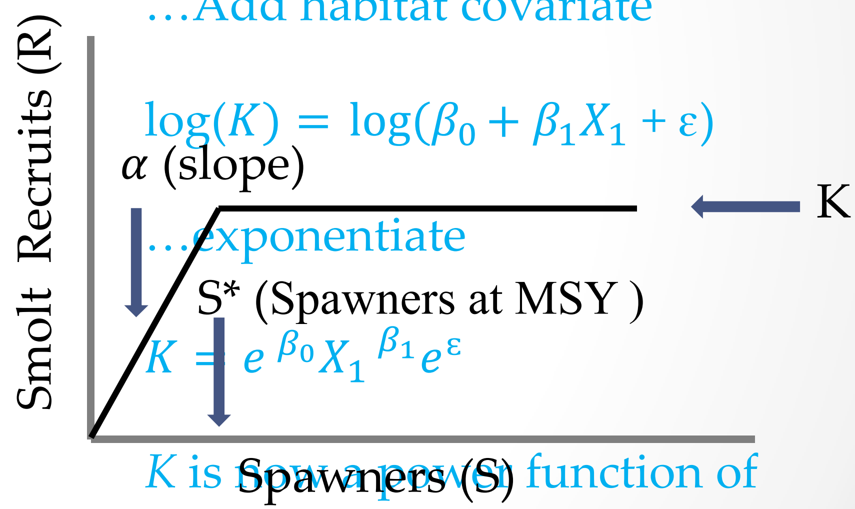
β_1 = habitat var. slope

…Add habitat covariate

$$\log(K) = \log(\beta_0 + \beta_1 X_1 + \varepsilon)$$

…exponentiate

$$K = e^{\beta_0} X_1{}^{\beta_1} e^{\varepsilon}$$



K is now a power function of habitat variable of interest

$$\boldsymbol{R = min\ (\alpha S, \beta_0 + \beta_1 X_1 + \varepsilon) = \begin{cases} \alpha S, = \text{if } \alpha S < \beta_0 + \beta_1 X_1 + \varepsilon \\ K, = \text{if } \alpha S \geq \beta_0 + \beta_1 X_1 + \varepsilon \end{cases}}$$