

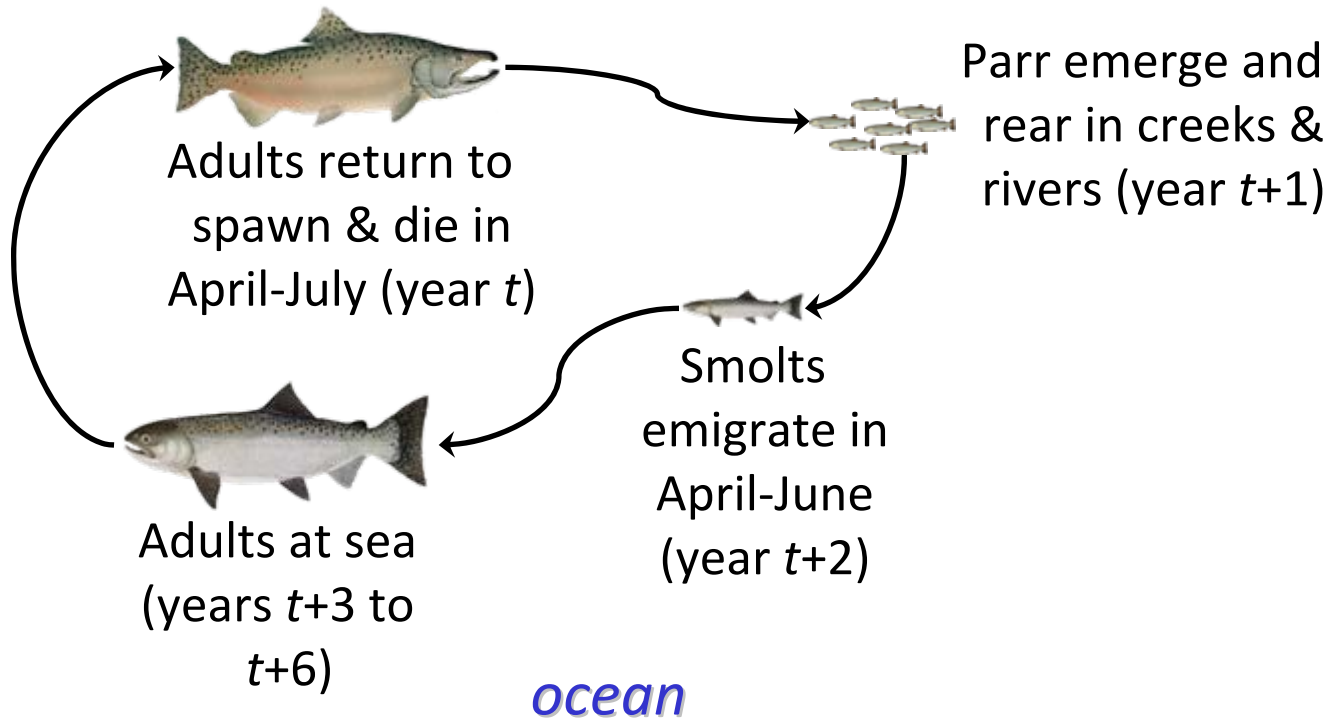
Unintended consequences of supplementation: Impacts of hatcheries on salmon population dynamics

Eric Buhle, Mark Scheuerell,
Kirstin Holsman, Mike Ford, Tom Cooney,
Rich Carmichael, and Andrew Albaugh

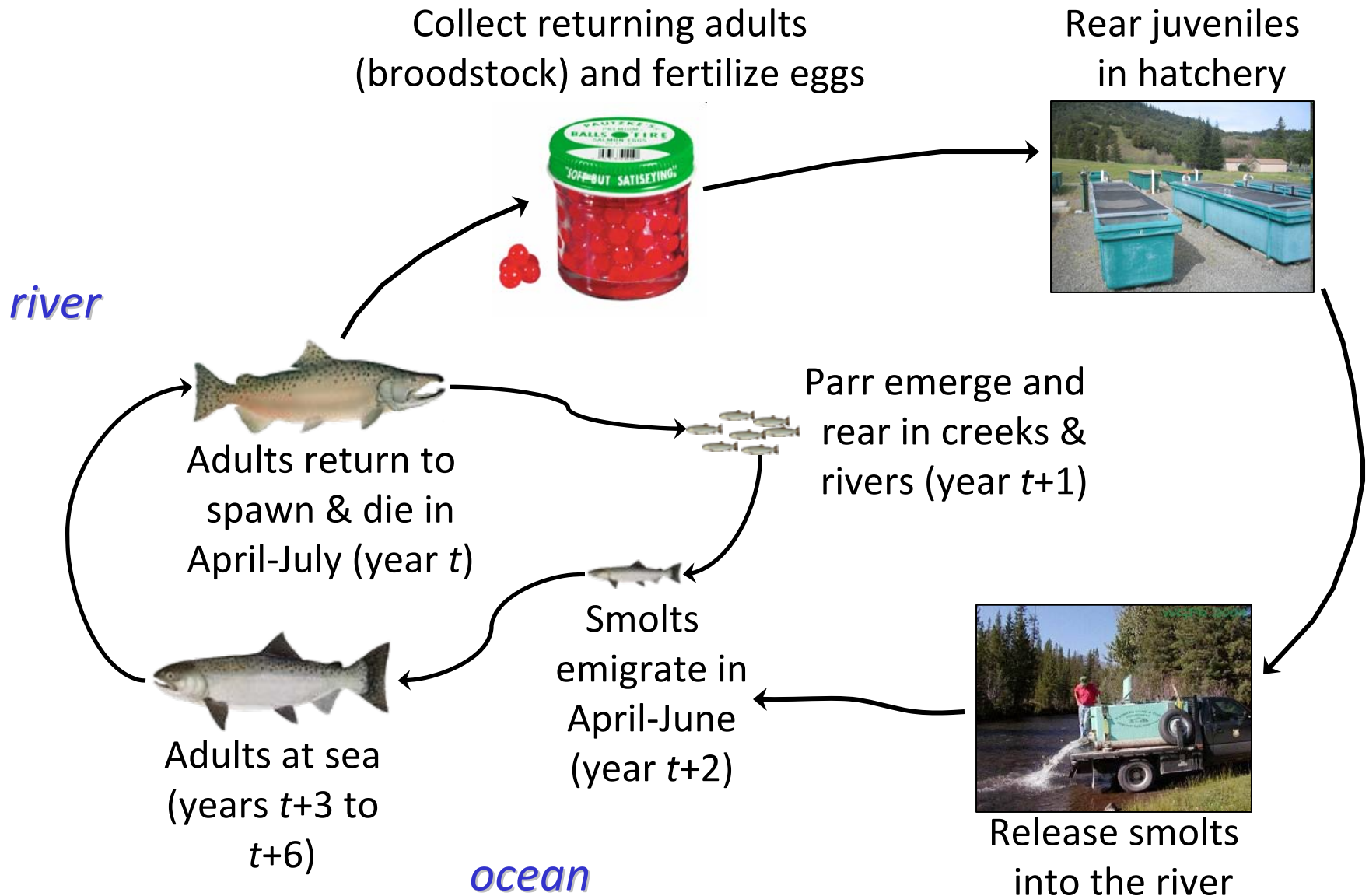




river



ocean



Concerns About Hatcheries

Effectiveness

- Do hatchery programs increase salmon abundance? Are they cost-effective?

Impacts on wild populations

- Overharvest in mixed-stock fisheries
- Genetic effects: domestication selection, introgression (eg, Araki et al. 2008)
- Ecological effects: competition, predator subsidies, disease (eg, Hilborn & Eggers 2000, Levin al. 2001, Chilcote 2003)



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→ **altered population dynamics?**



Case Studies



Oregon Coast coho salmon

- Have hatcheries altered the productivity of supplemented populations?
- Was there a detectable population-dynamic response to hatchery reform in the 1990s?

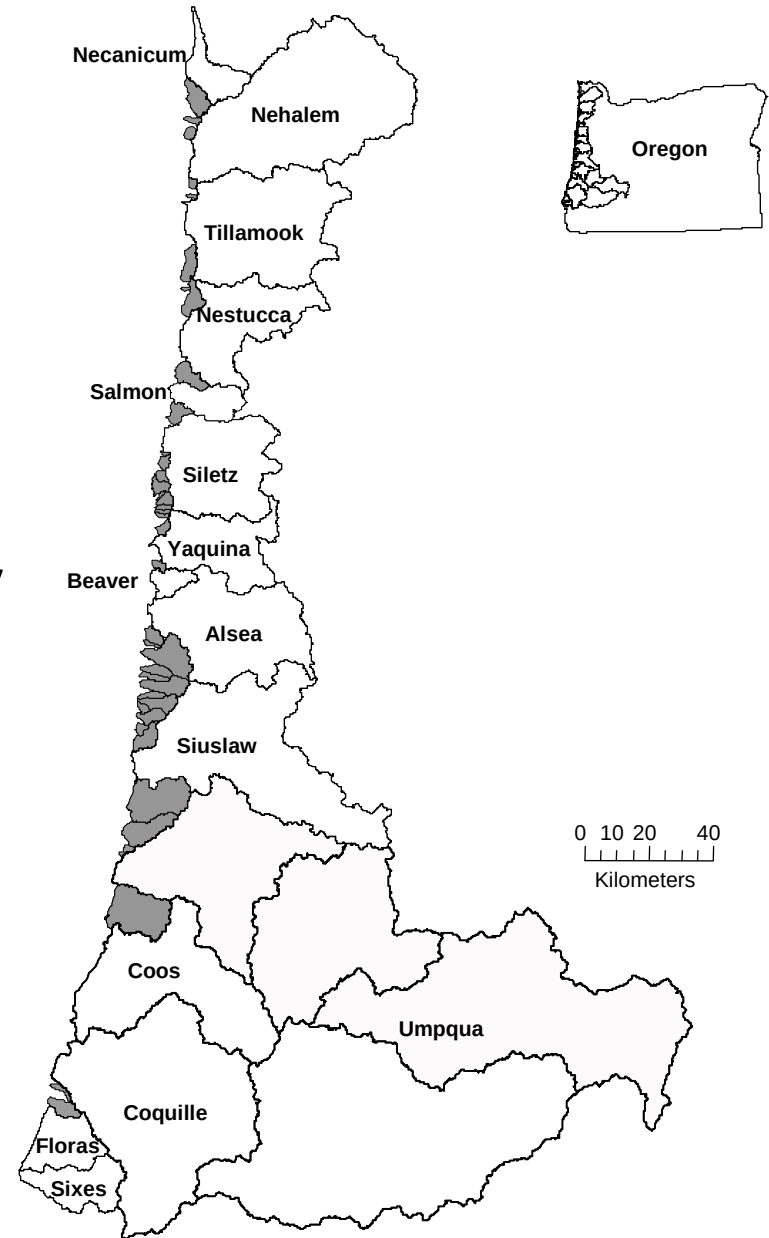


Snake River spring/summer Chinook salmon



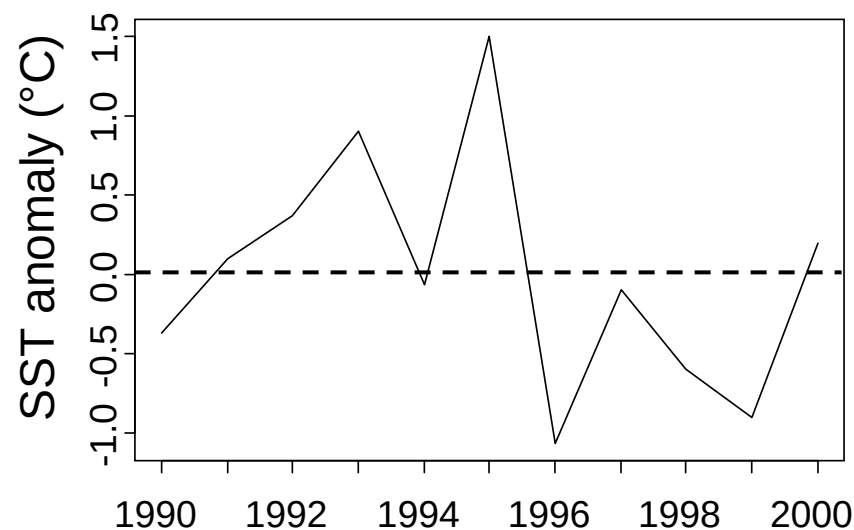
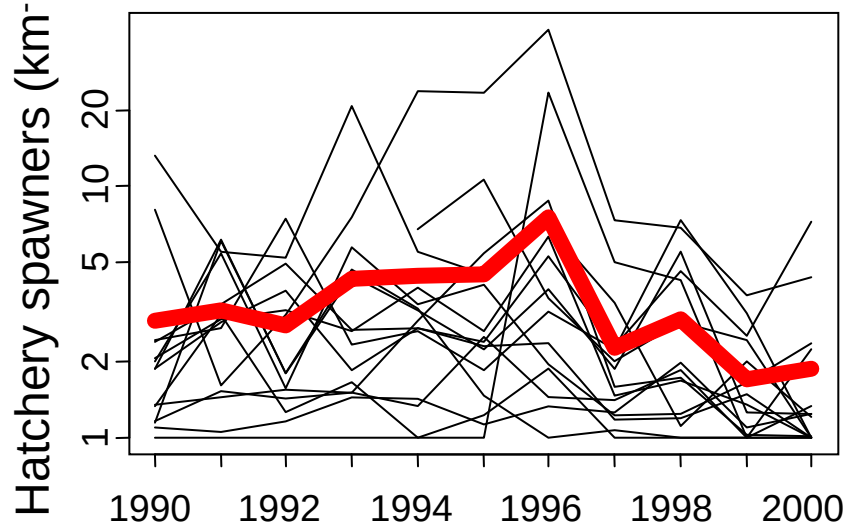
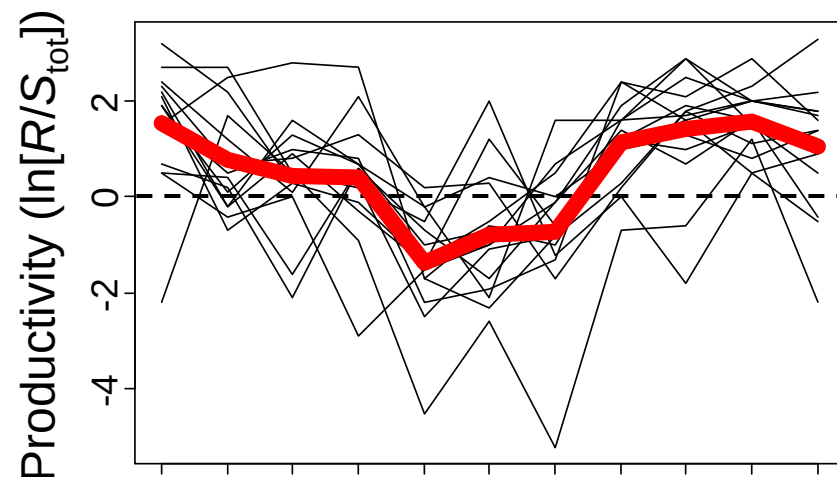
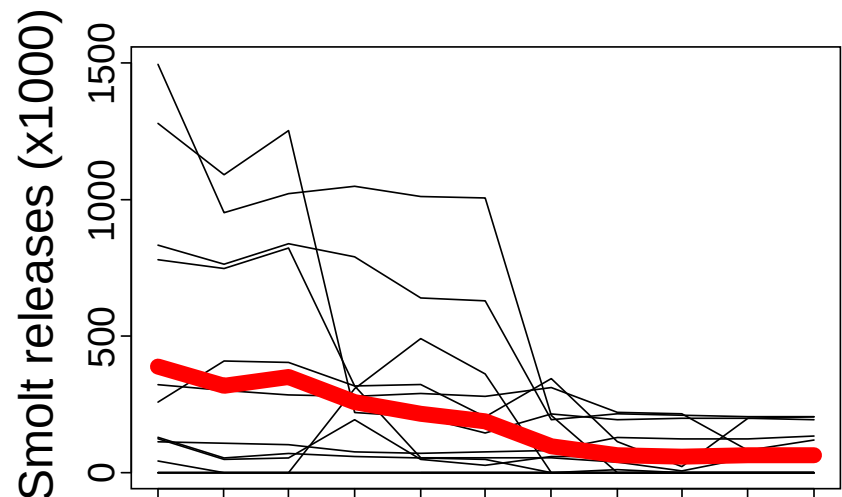
Oregon Coast Coho Salmon

- 57 populations, 21 “independent”
- (Re)listed as Threatened, 2008
- Threats include poor ocean survival, habitat degradation, high harvest (historically), and hatchery influence
- Impact of naturally spawning hatchery adults is a key uncertainty





Hatcheries on the Oregon Coast



Brood year



Extended Ricker Models

$$\log\left(\frac{R_{jt}}{S_{jt}}\right) = a_j + b_w S_{w,jt} + b_h S_{h,jt} + b_1 F_{j,t+1} + b_2 M_{j,t+2} + b_3 K_j + b_4 T_{t+2} + b_5 T_{t+3} + b_6 M_{j,t+2} T_{t+3}$$

Diagram illustrating the Extended Ricker Model equation, showing the relationship between the log ratio of recruits to spawners and various environmental and biological factors. Arrows indicate the mapping from the equation terms to their descriptions:

- a_j : intrinsic productivity (pop-specific)
- $b_w S_{w,jt}$: spawner density (W, H)
- $b_h S_{h,jt}$: fry releases (fish/km)
- $b_1 F_{j,t+1}$: smolt releases (# of fish)
- $b_2 M_{j,t+2}$: smolt releases (# of fish)
- $b_3 K_j$: freshwater habitat capacity (Nickelson 1998)
- $b_4 T_{t+2}$ and $b_5 T_{t+3}$: ocean conditions (SST, Logerwell et al. 2003)
- $b_6 M_{j,t+2} T_{t+3}$: smolt releases x ocean

- Each model assumes either (1) only wild spawners produce recruits, or (2) all spawners contribute equally to recruits
- Fit set of 82 candidate models by maximum likelihood
- Rank models based on AIC_c



Asymmetric Density-Dependence

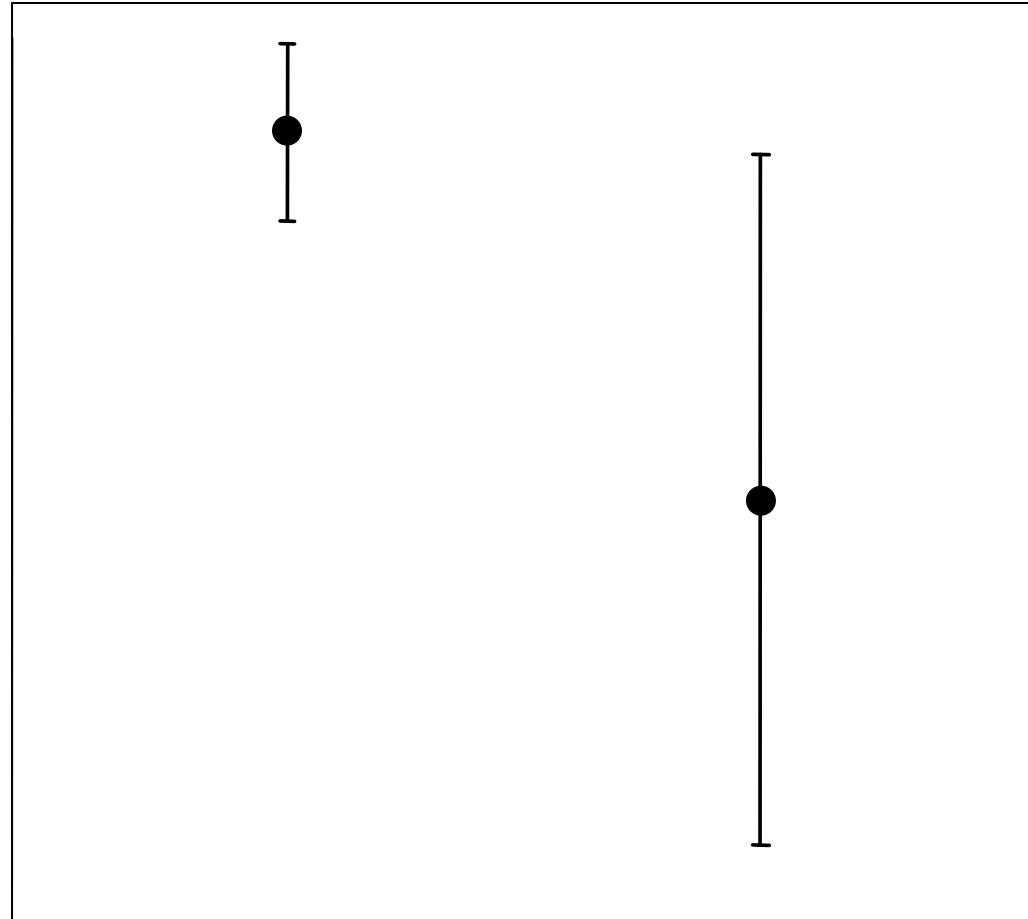
weak



strong

Per capita effect

0.00
-0.05
-0.10
-0.15
-0.20



Wild-origin
spawners

Hatchery-origin
spawners



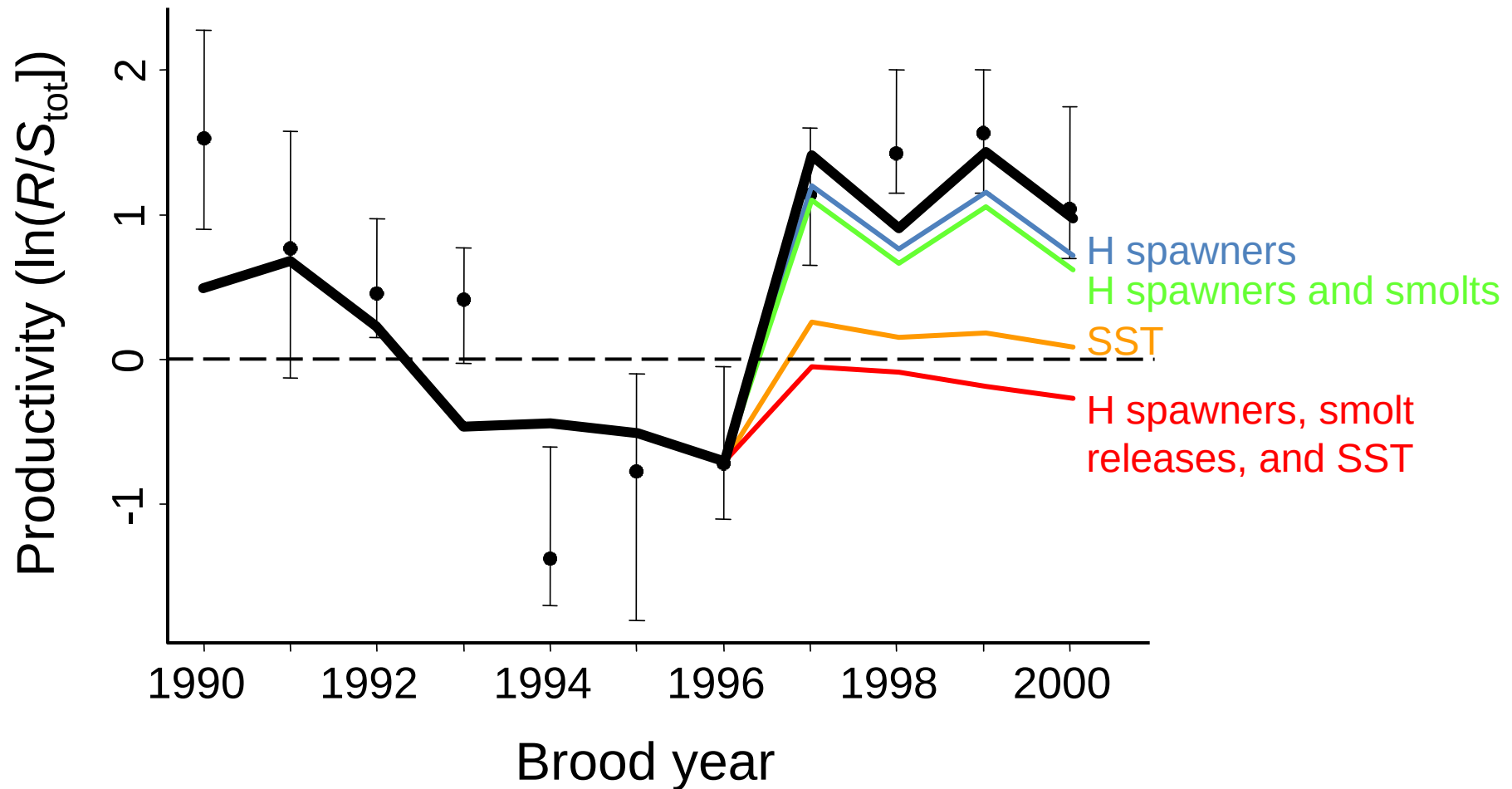
Relative Importance of Drivers

Variable	Akaike weight	Coefficient (SE)
Wild spawner density	1.0	-0.02 (0.01)
Hatchery spawner density	1.0	-0.11 (0.04)
Hatchery smolt releases	0.73	-0.50 (0.34)
Hatchery fry density	0.50	0.0005 (0.0004)
Freshwater smolt capacity	0.57	0.00010 (0.00006)
Winter SST in ocean entry year	1.0	-0.68 (0.13)
Winter SST in ocean residence year	1.0	-0.51 (0.14)
Hatchery smolt $\times$ SST interaction	0.36	-0.74 (0.49)

- Data support asymmetric density-dependence (weight = 0.82)
- BUT, data also indicate wild and hatchery spawners contribute to recruits (weight = 0.76)



Climate and Hatchery Scenarios



Case Studies



Oregon Coast coho salmon

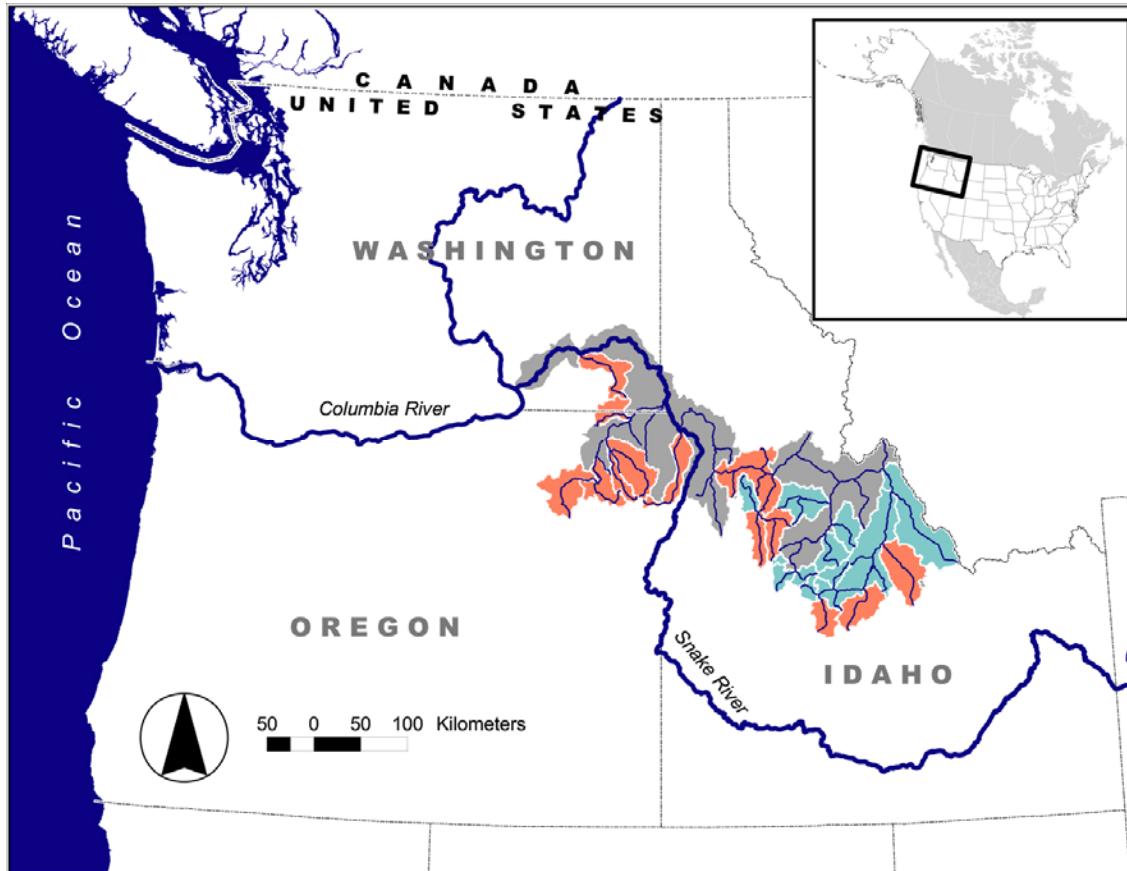


Snake River spring/summer Chinook salmon

- Has supplementation altered density-independent and/or density-dependent aspects of population dynamics?
- Can we distinguish hatchery impacts from overall density-dependence?



Snake River Spring/Summer Chinook



Data (via ICTRT)

- 23 populations:
 - 12 supplemented,
 - 11 “reference”
- Adult (spawner) density, 1973-2006
- Annual harvest rates
- Adult age composition
- Wild- vs. hatchery-origin proportions



Model Structure

recruits from cohort t = progeny of wild-born spawners + progeny of hatchery-reared spawners

$$R = S_w f_w (S_w, S_h) + S_h f_h (S_w, S_h)$$

$$R = \frac{aS_w}{1 + (a-1)\left(\frac{S_w}{K} + \frac{S_h}{\delta K}\right)} + \frac{\alpha a S_h}{1 + (\alpha a - 1)\left(\frac{S_w}{K} + \frac{S_h}{\delta K}\right)}$$

*Leslie-Gower
model*

a = intrinsic growth rate of wild-born spawners

K = carrying capacity of wild-born spawners

α = intrinsic growth rate discount for hatchery-reared spawners

δ = carrying capacity discount for hatchery-reared spawners

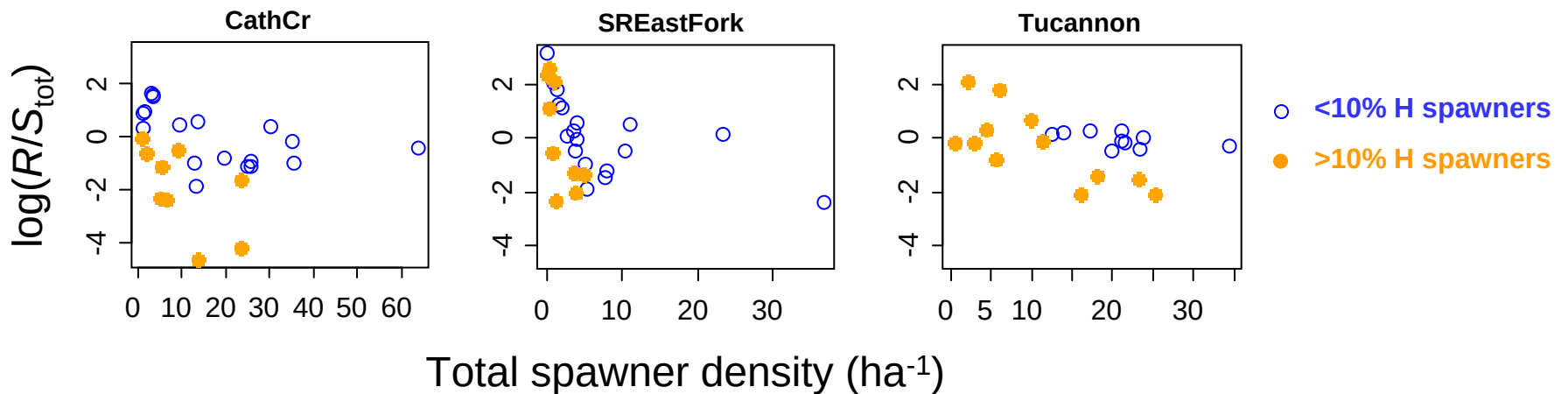
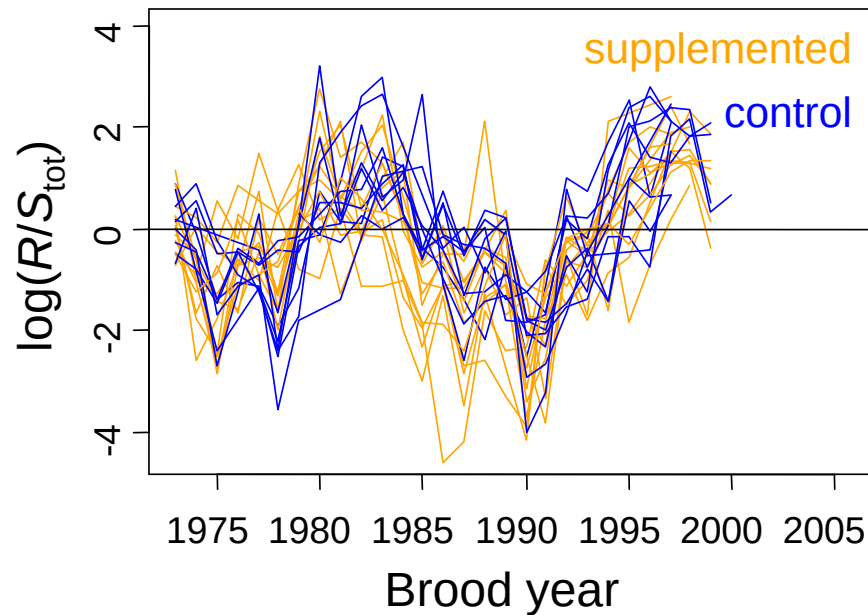


Fitting the Models

- Hierarchical Bayesian framework
- Model variation among populations via random effects on a and K
- Account for large-scale temporal fluctuations (climate, etc.) via a year-specific random effect on survival



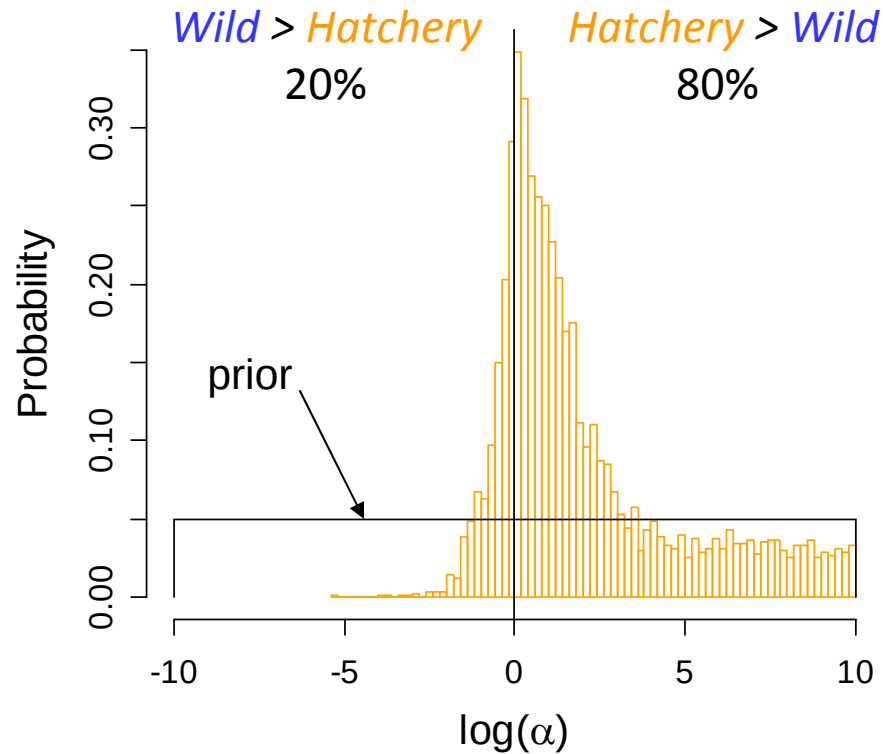
Hatchery Influence and Productivity





Hatchery vs. Wild Parameters

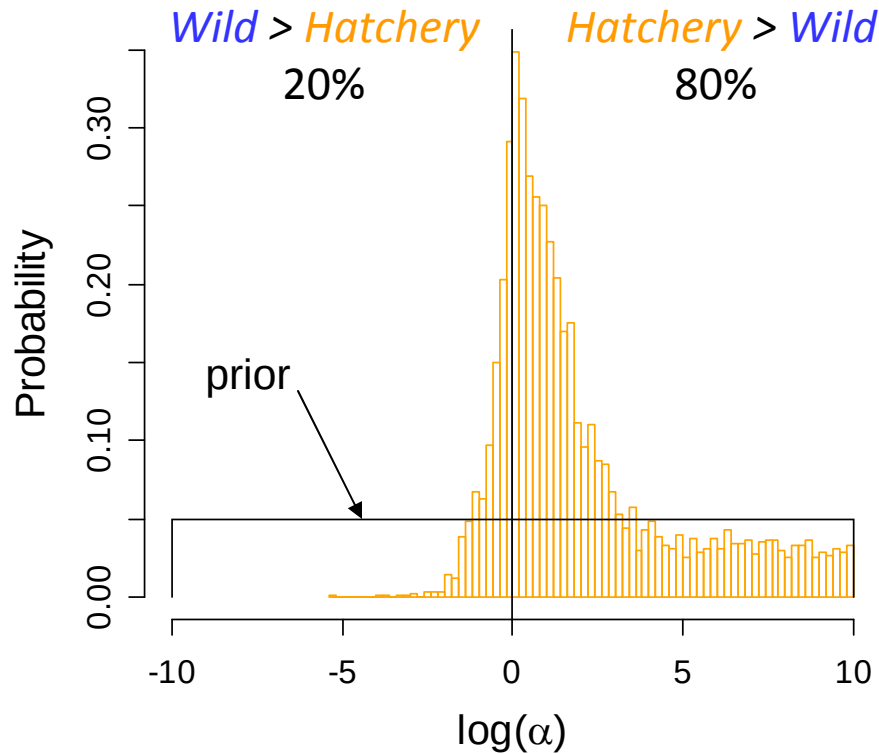
Relative intrinsic growth rate



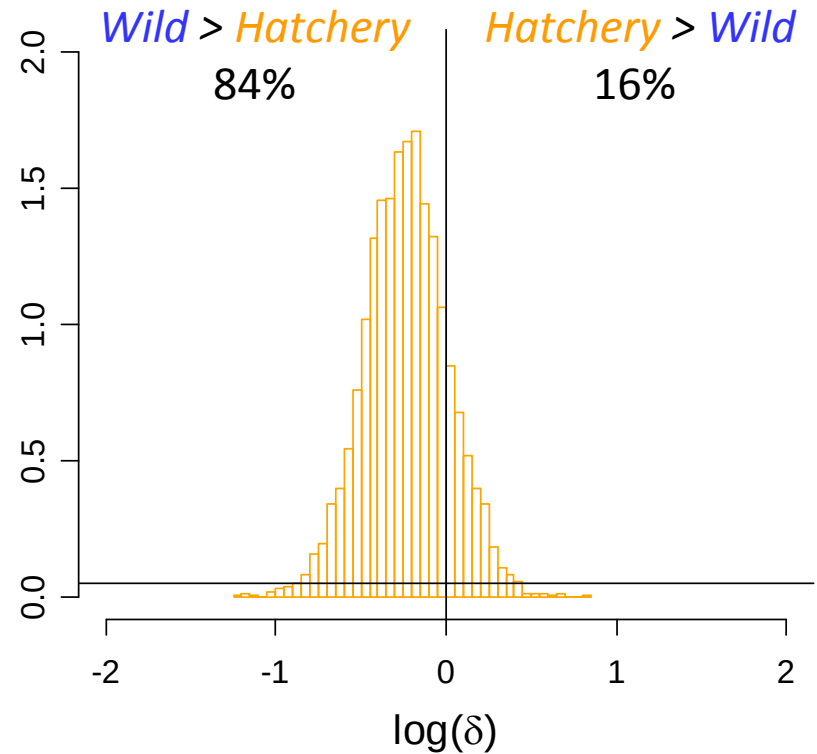


Hatchery vs. Wild Parameters

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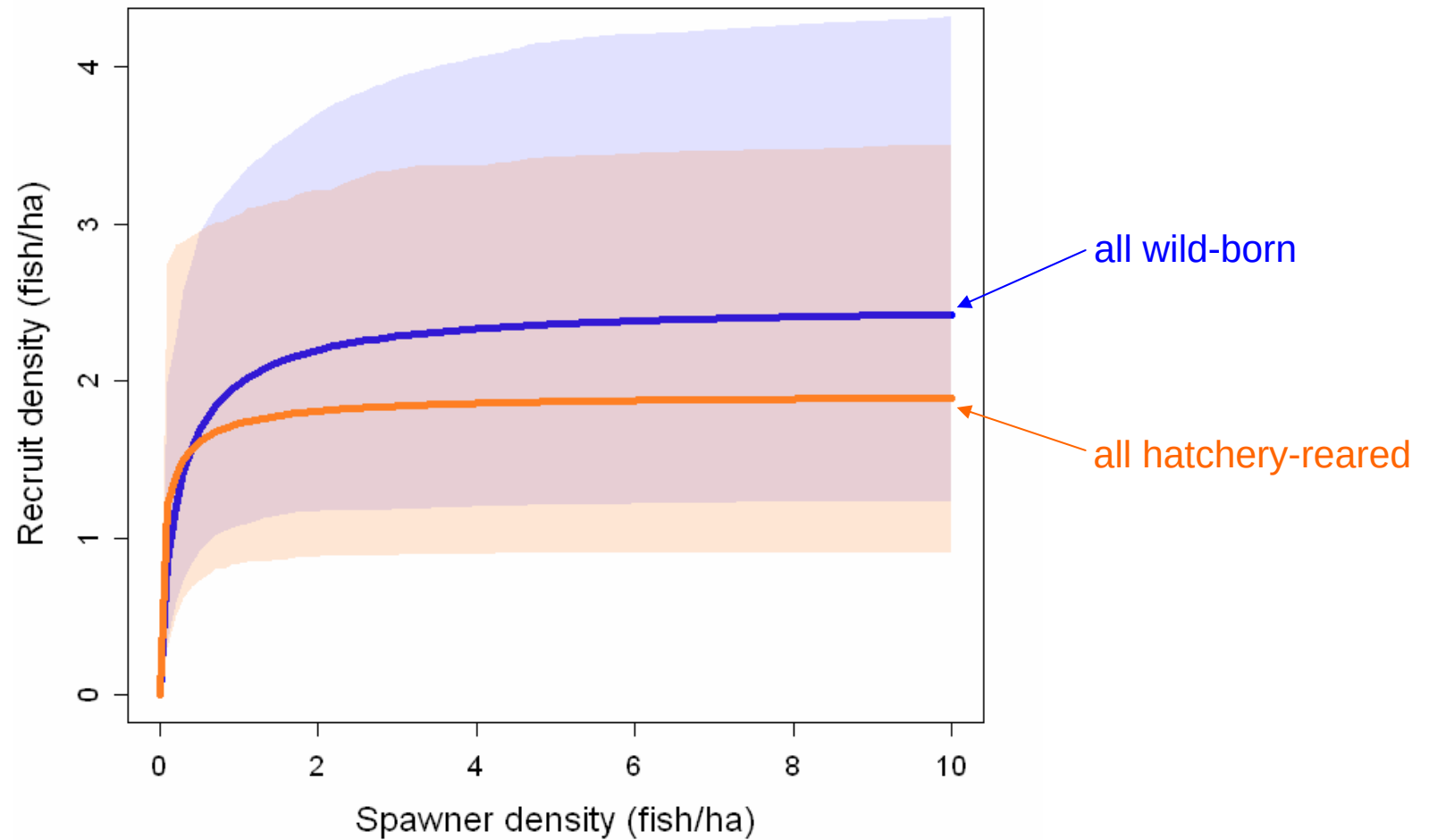


Relative carrying capacity





Consequences for Productivity



Conclusions and Future Directions

- Hatchery-reared salmon, reproducing in the wild, may be less productive than wild-origin fish
- Relative productivity of hatchery fish may decline as density increases (asymmetric density-dependence)
- Supplementation programs may face a trade-off: prevent extinction at very low abundance, but compromise rate of rebuilding
- How can experimental studies inform large-scale population-dynamic analyses and vice versa?

Thanks...

Data, advice, and motivation

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