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

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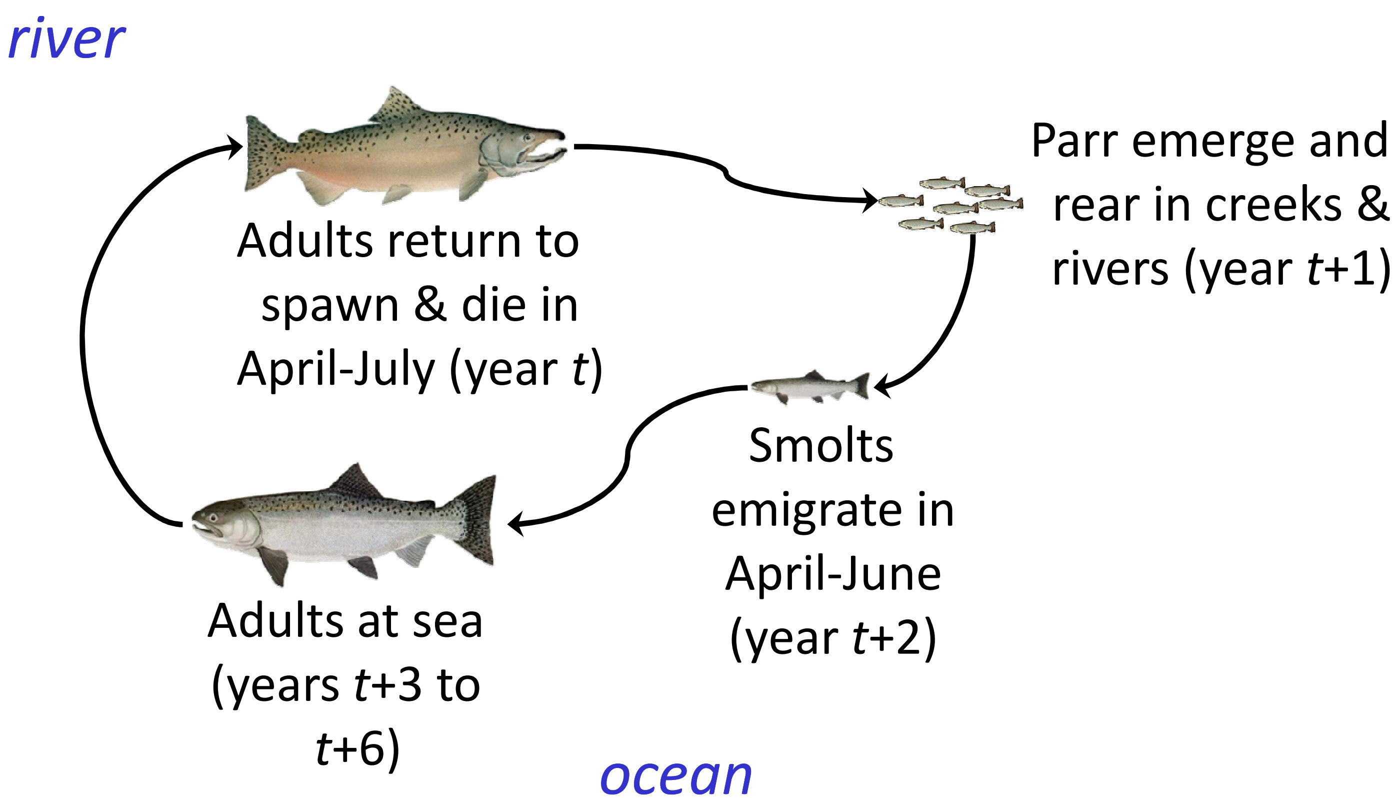
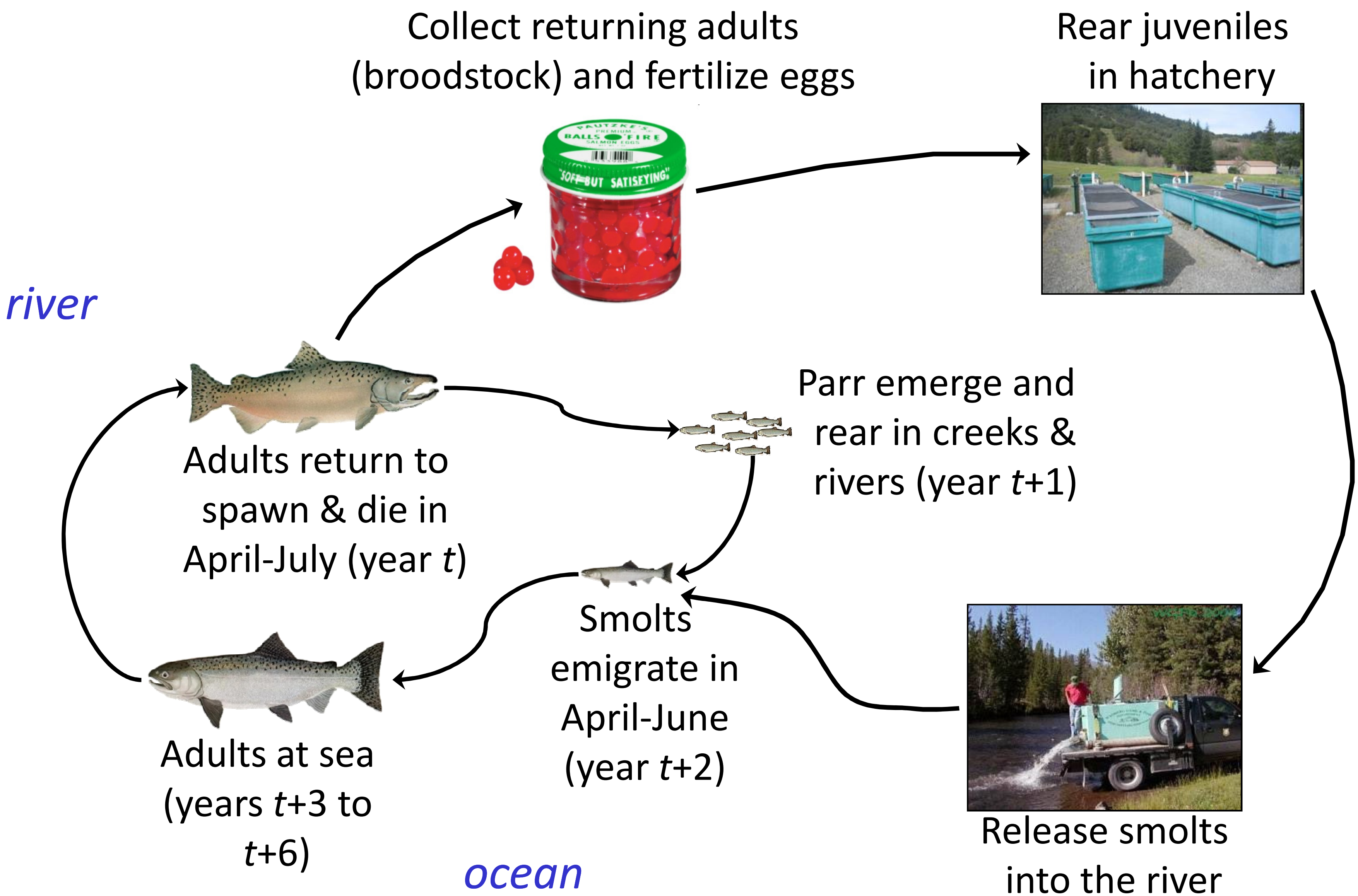

river
Adults return to spawn & die in April-July (year t)
Parr emerge and rear in creeks & rivers (year t+1)
Smolts emigrate in April-June (year t+2)
Adults at sea (years t+3 to t+6)
ocean


Collect returning adults (broodstock) and fertilize eggs
Rear juveniles in hatchery
river
Adults return to spawn & die in April-July (year *t*)
Parr emerge and rear in creeks & rivers (year *t*+1)
Smolts emigrate in April-June (year *t*+2)
Release smolts into the river
Adults at sea (years *t*+3 to *t*+6)
ocean

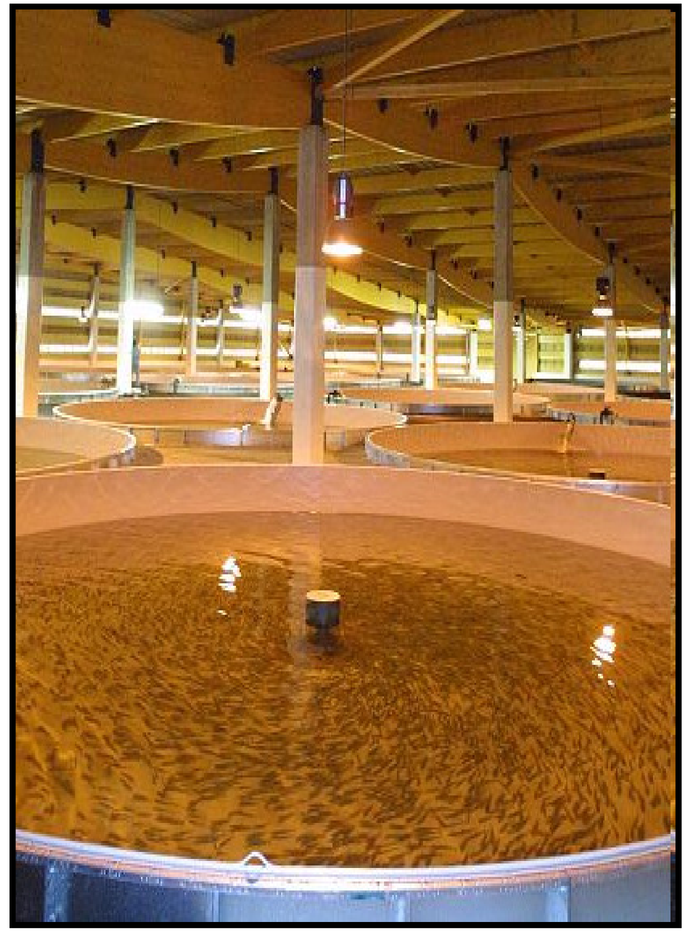
Concerns About Hatcheries

Effectiveness

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

Impacts on wild populations

- Overharvest of wild populations in mixed-stock fisheries
- Genetic effects (domestication selection, introgression)
- Ecological effects (competition, predator subsidies, disease)



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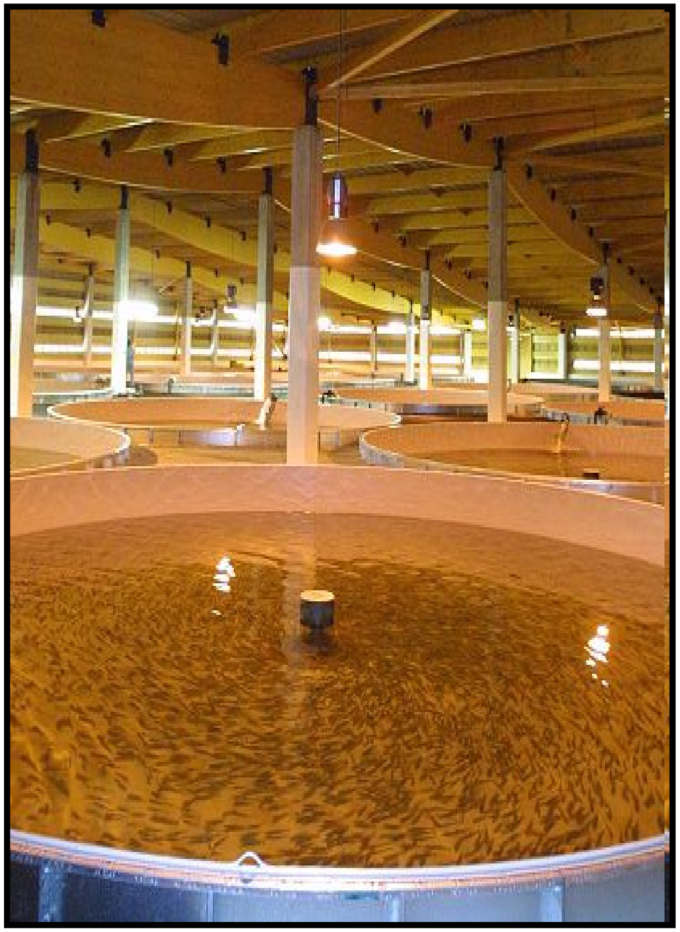
- Overharvest of wild populations in mixed-stock fisheries
- Genetic effects (domestication selection, introgression)
- Ecological effects (competition, predator subsidies, disease) → altered population dynamics?



Case Studies

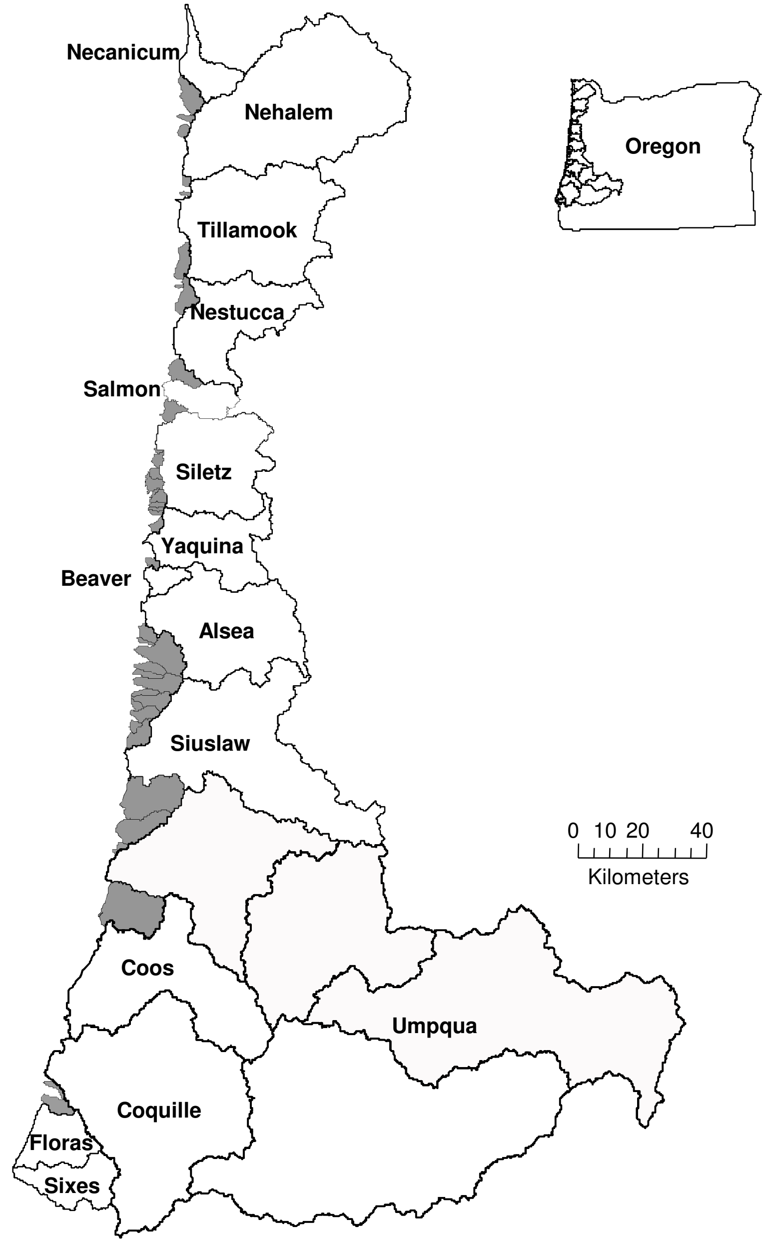
Oregon Coast coho salmon

- Was there a detectable population-dynamic response to hatchery reform in the 1990s?

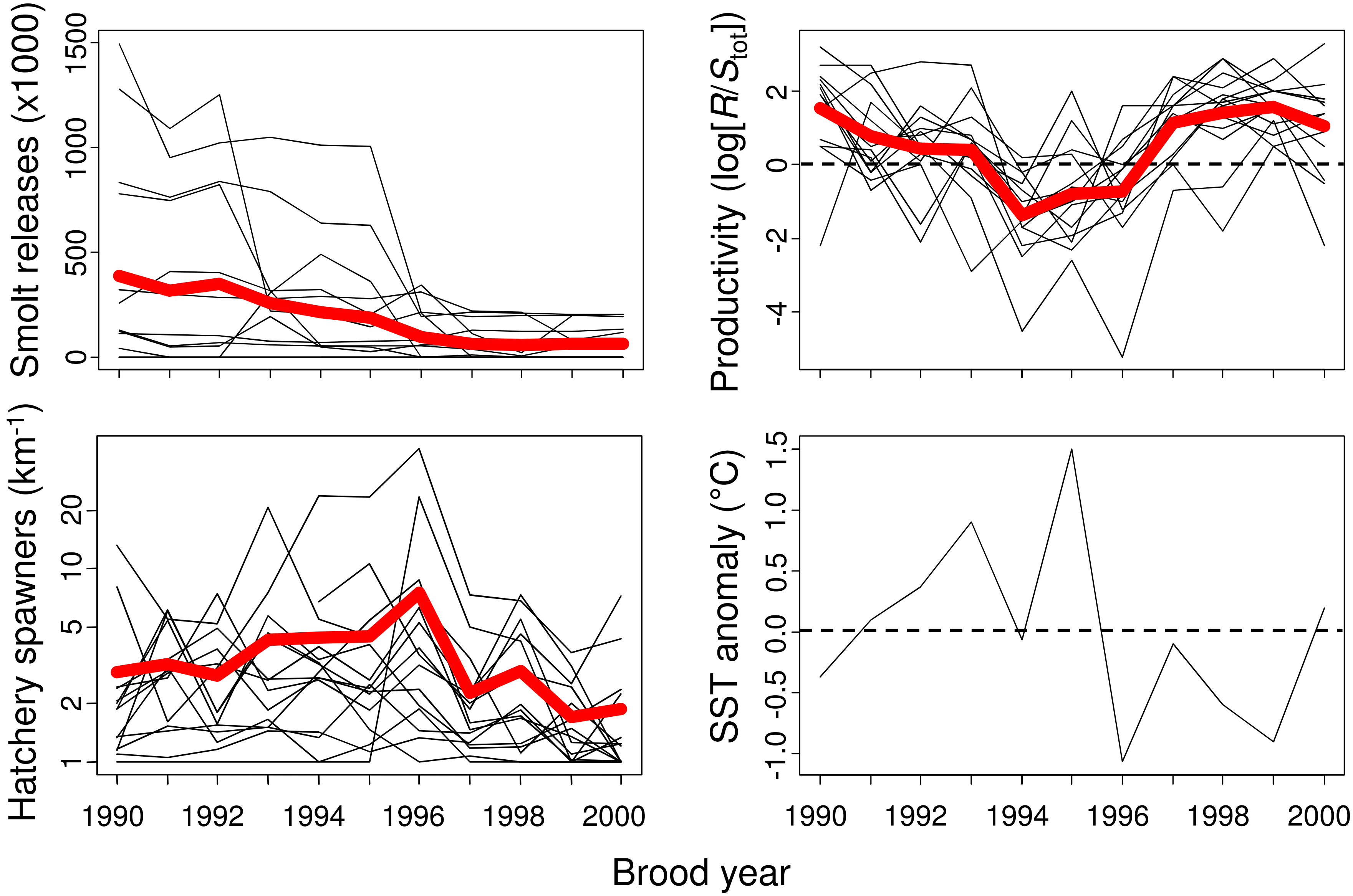
Snake River spring/summer Chinook salmon

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



Extended Ricker Models

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

intrinsic productivity (pop-specific)

spawner density (W, H)

fry releases (fish/km)

smolt releases (# of fish)

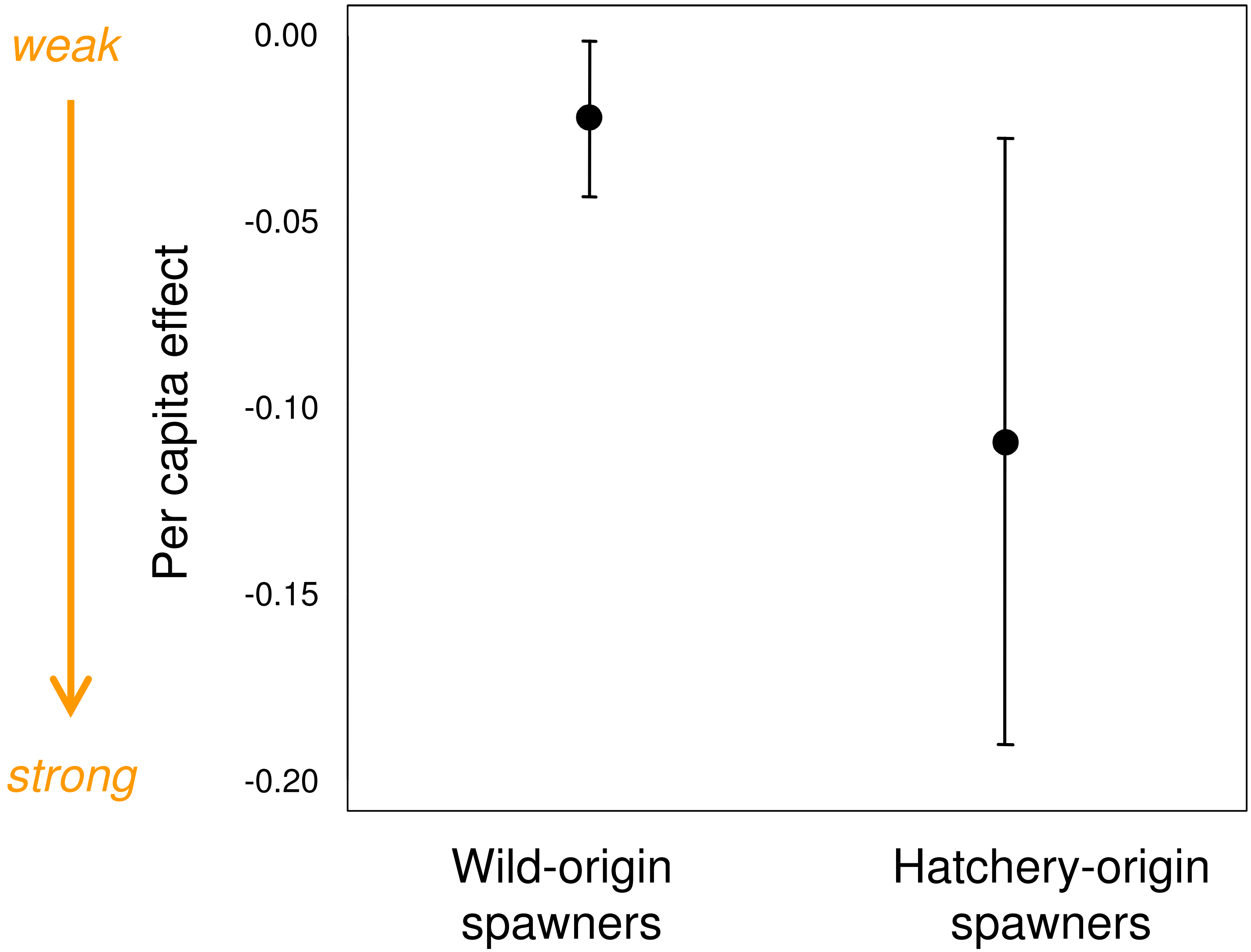
freshwater habitat capacity (Nickelson 1998)

ocean conditions (SST, Logerwell et al. 2003)

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

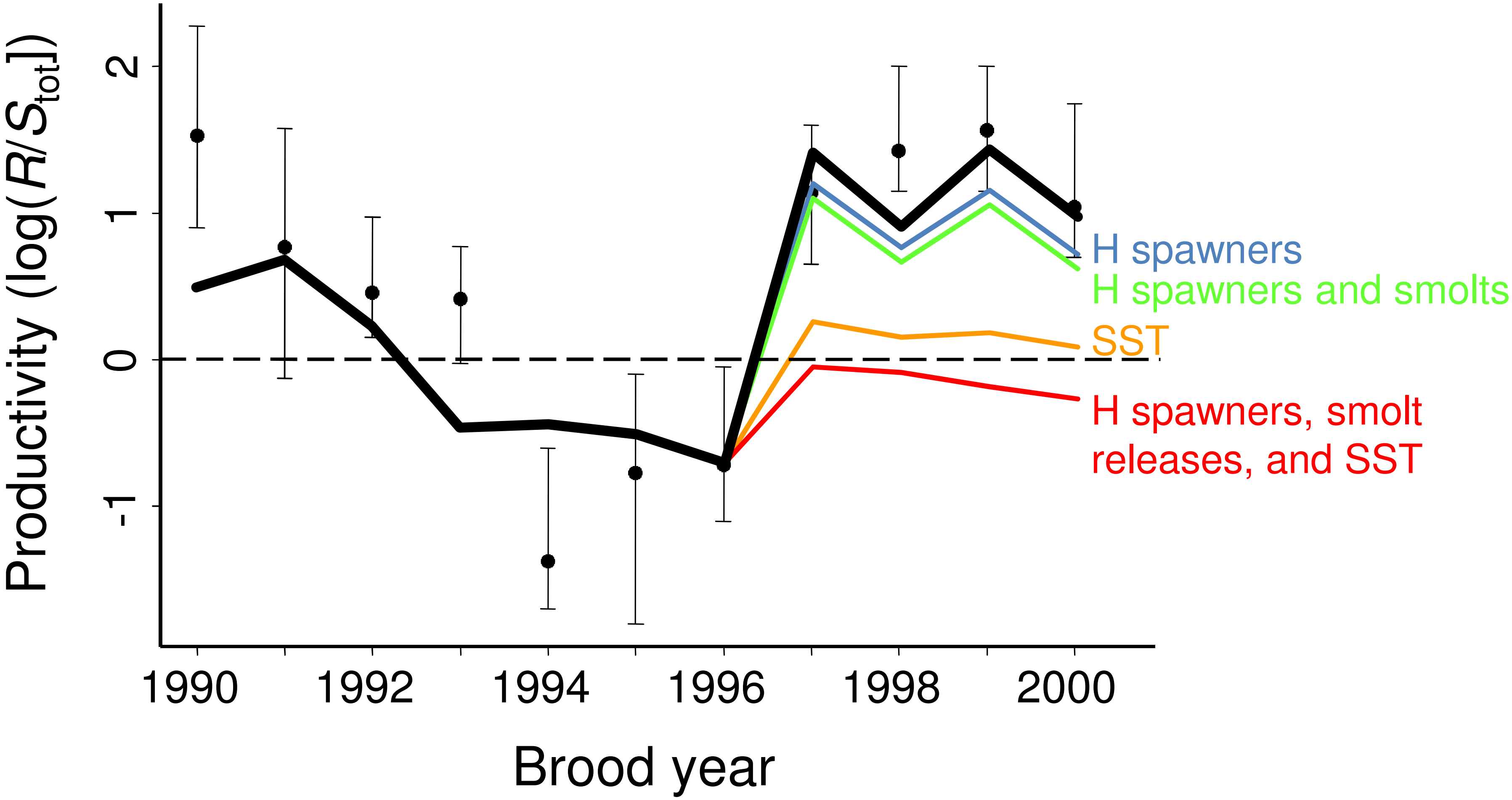


Relative Importance of Drivers

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 × 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



Buhle et al., *Biol. Cons.* (2009)

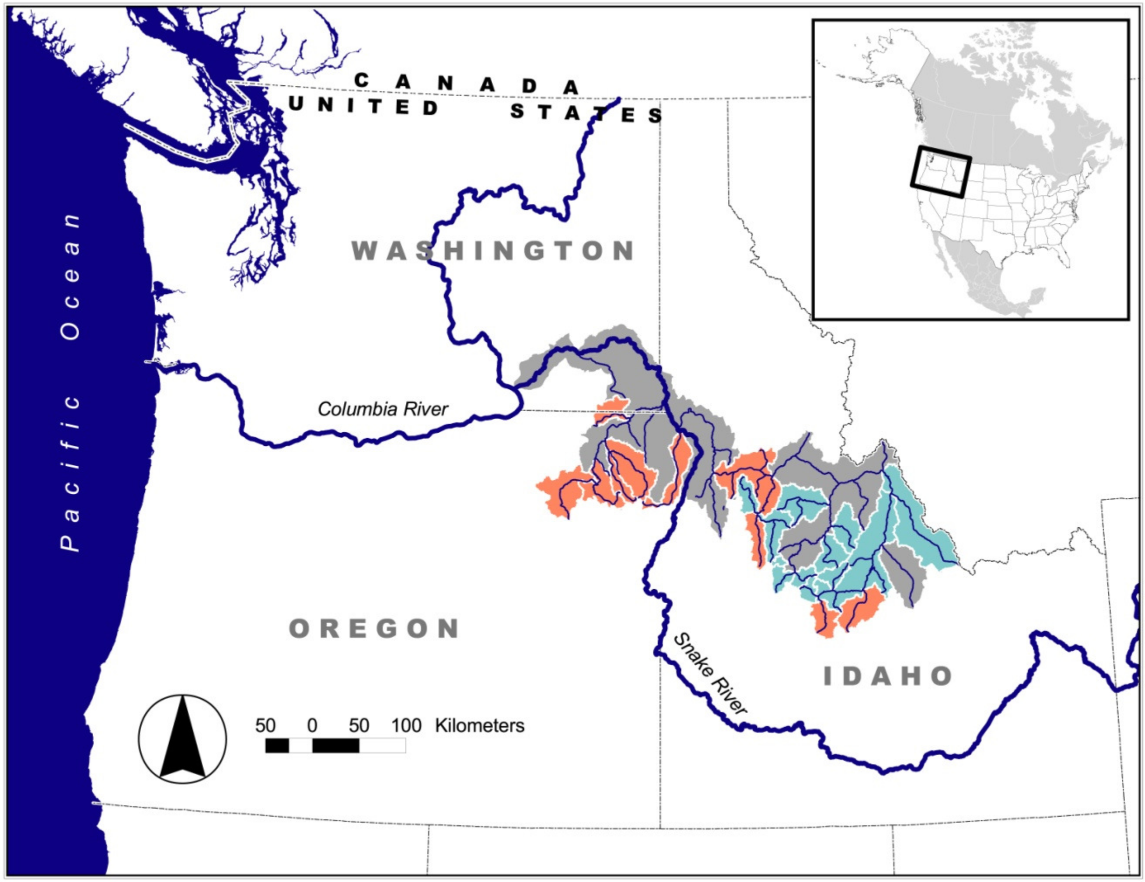
Case Studies

Oregon Coast coho salmon

Snake River spring/summer Chinook salmon

- Has supplementation altered density-independent and/or density-dependent aspects of population dynamics?

Snake River Spring/Summer Chinook



Data

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

Model Structure

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

$$R = S_{\mathrm{w}} f_{\mathrm{w}} \left(S_{\mathrm{w}}, S_{\mathrm{h}}\right) + S_{\mathrm{h}} f_{\mathrm{h}} \left(S_{\mathrm{w}}, S_{\mathrm{h}}\right)$$

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

Leslie-Gower model

a = intrinsic growth rate of wild-born spawners

K = carrying capacity of wild-born spawners

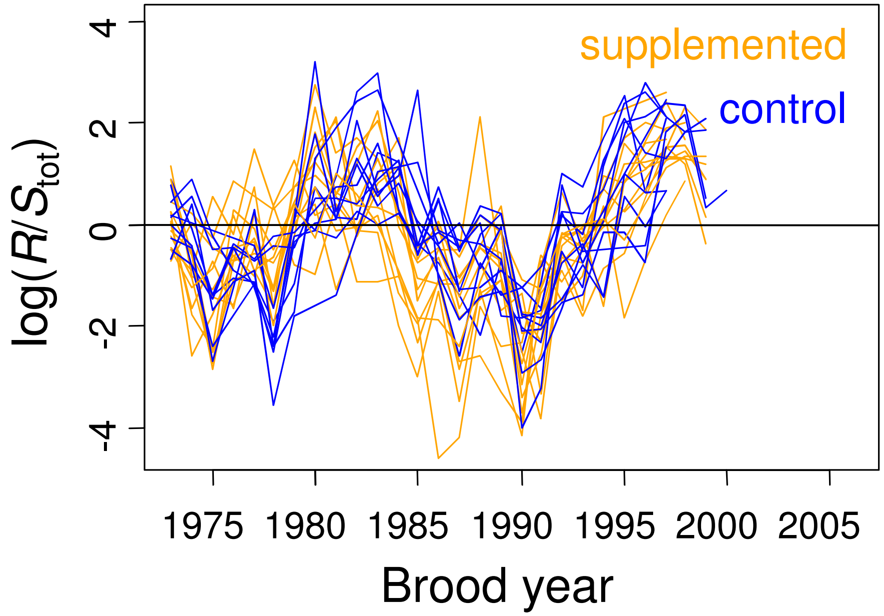
α = intrinsic growth rate discount for hatchery-reared spawners

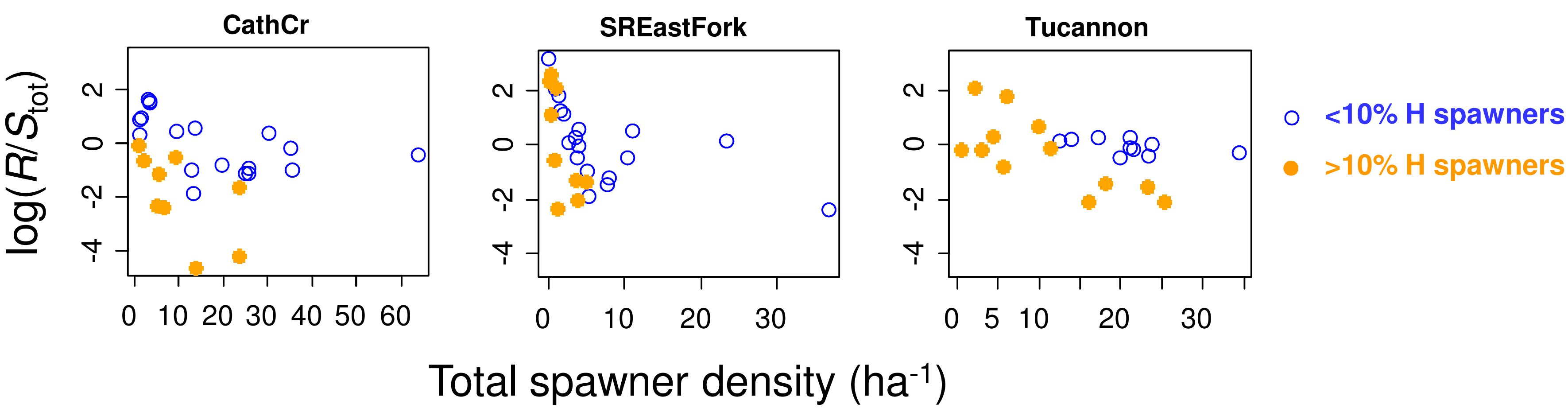
δ = carrying capacity discount for hatchery-reared spawners

Fitting the Models

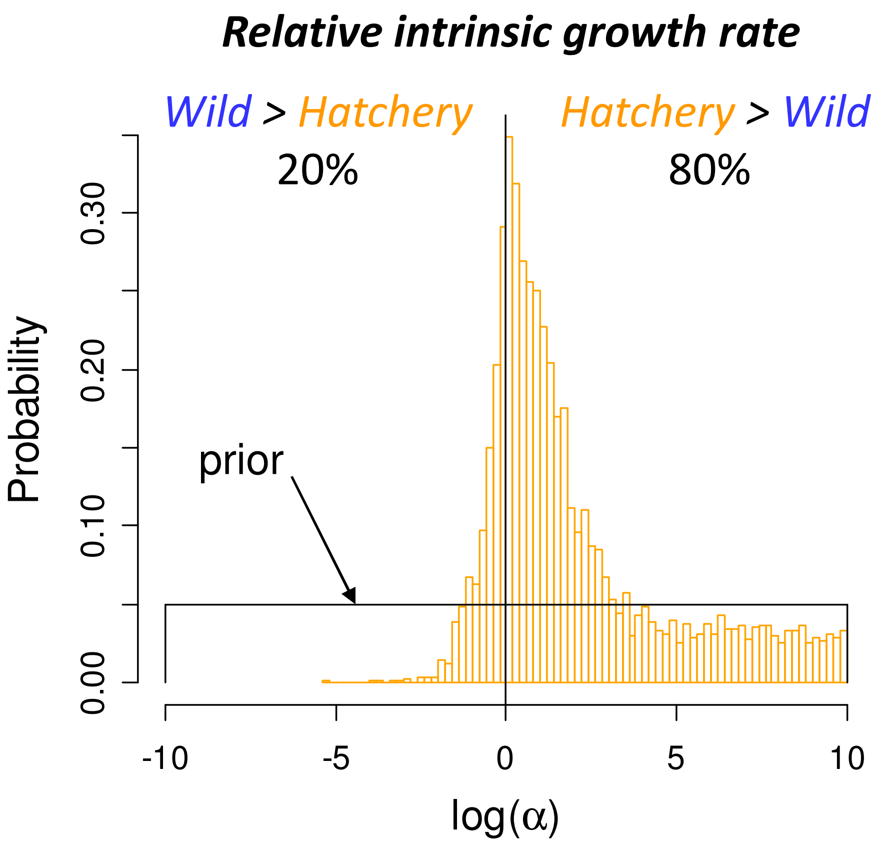
- Hierarchical Bayesian framework
- Model variation among populations as lognormal random effects on a and K
- Account for large-scale temporal fluctuations (climate, etc.) via a year-specific random effect on survival
- Data are observed density of wild and hatchery spawners, and wild recruits from each cohort

Hatchery Influence and Productivity





Hatchery vs. Wild Parameters



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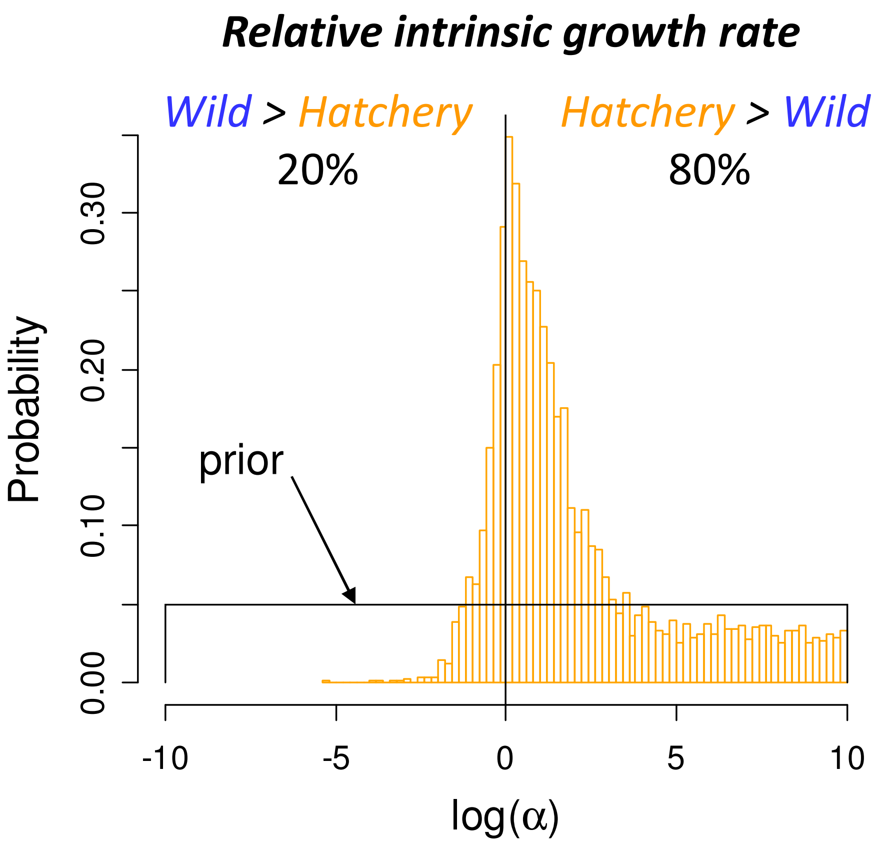
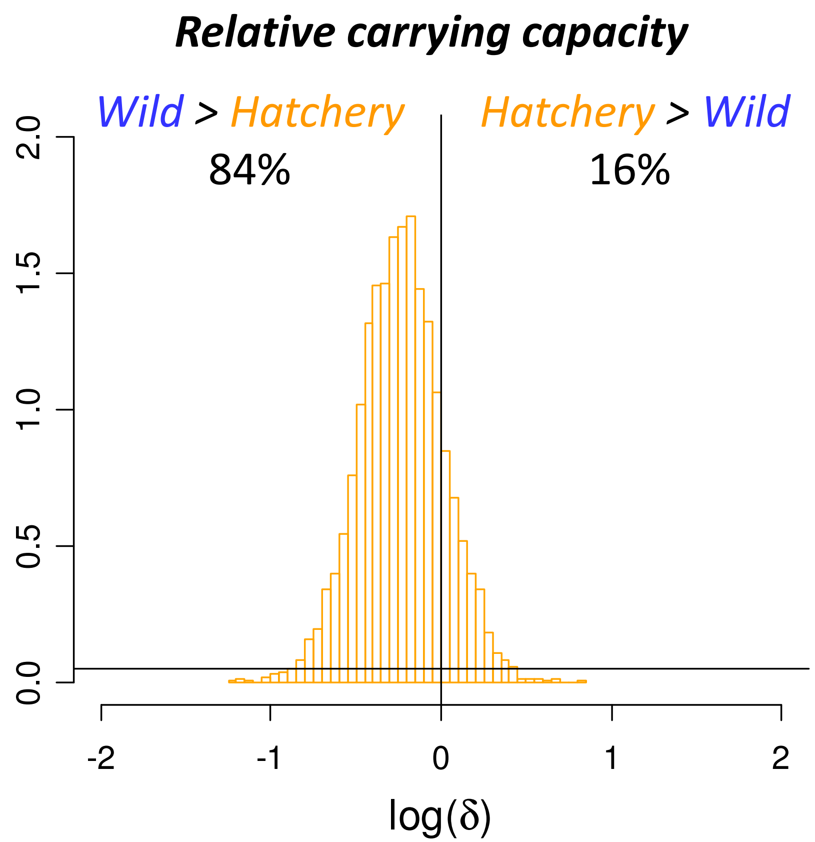
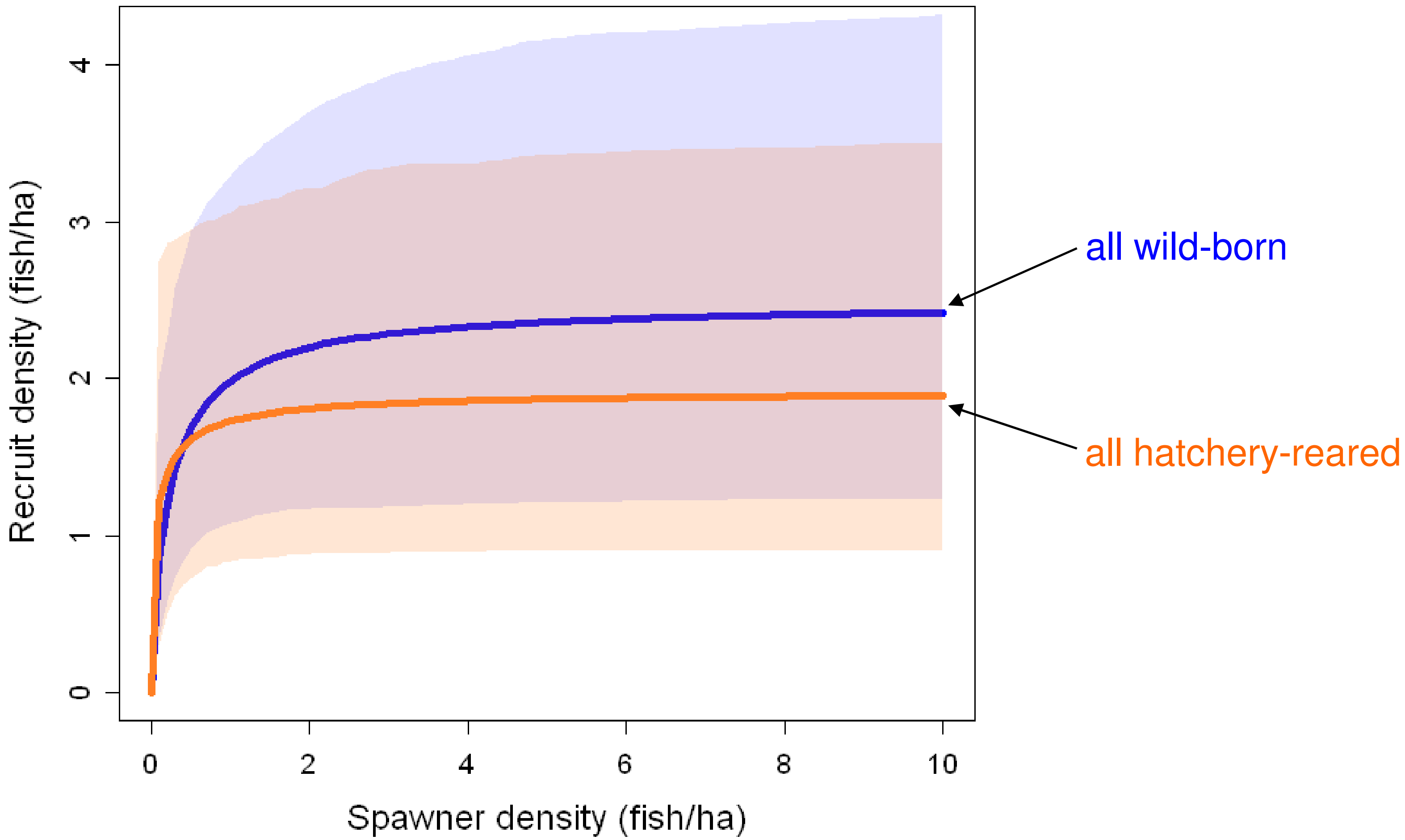




Consequences for Productivity



Conclusions

- 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

Thanks…

Data

Federal, state and tribal biologists

Advice and motivation

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