Carry-over effects: why are they important, and what are they?

Lisa Crozier

Northwest Fisheries Science Center

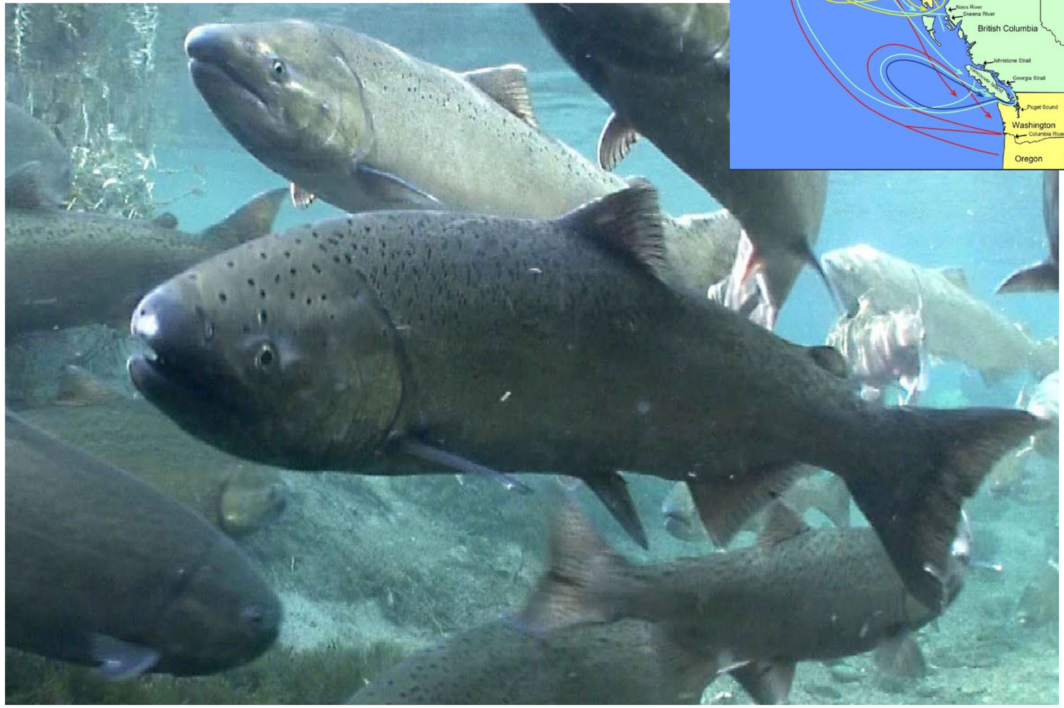
Seattle, WA

Northwest Power and Conservation Council
Ocean Forum
January 19, 2022
Virtual Event

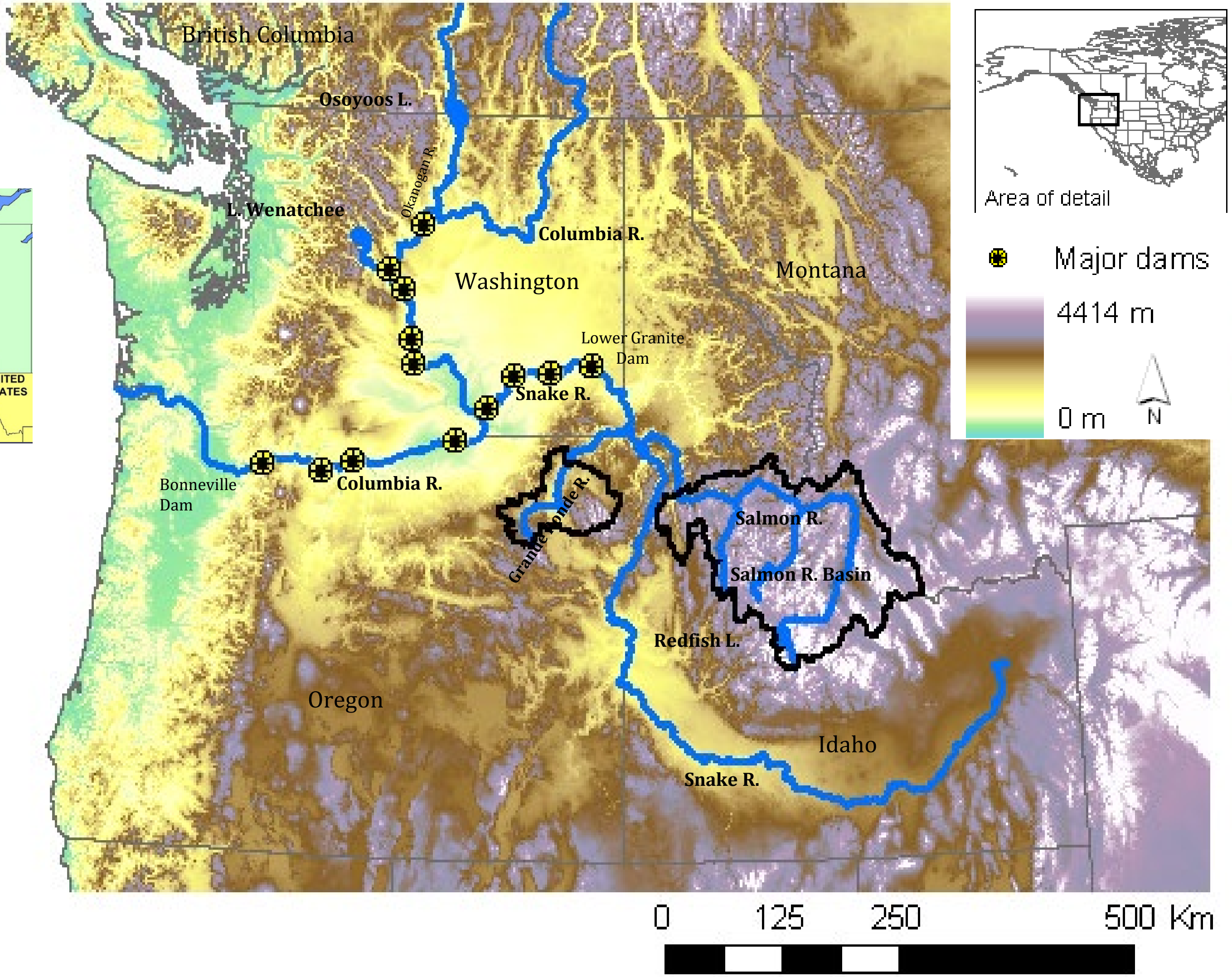
Marine survival is catastrophically low for many salmon in a warm ocean

Salmon migrations are legendary

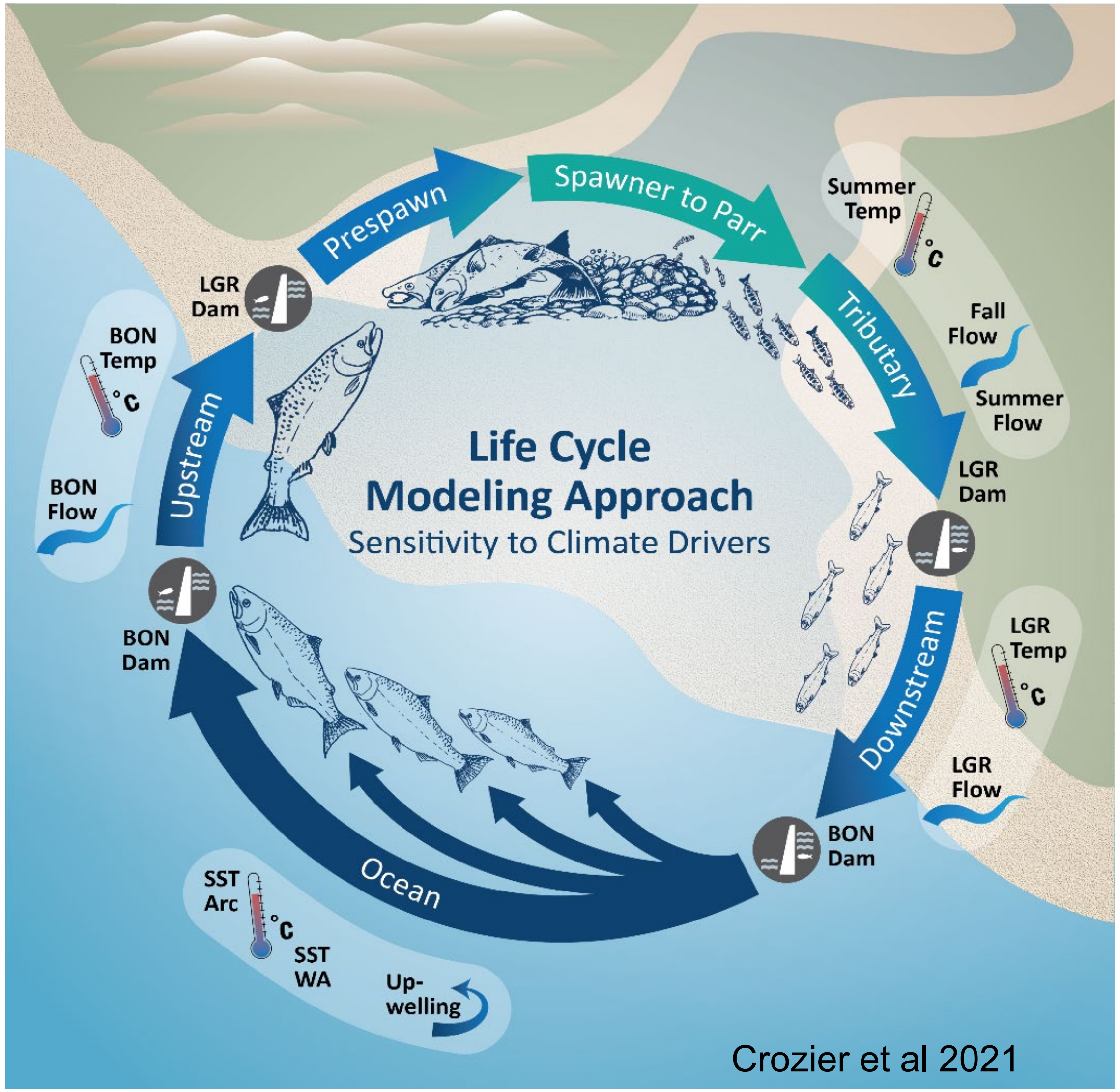
- Snake River spr/su Chinook: 1100-1400 km freshwater migration
- 1-4 years in marine, BC, GOA, Bering Sea



Snake River spring/summer Chinook salmon ESU



Life cycle models used to account for mortality in different life stages and project into the future



Crozier et al 2021

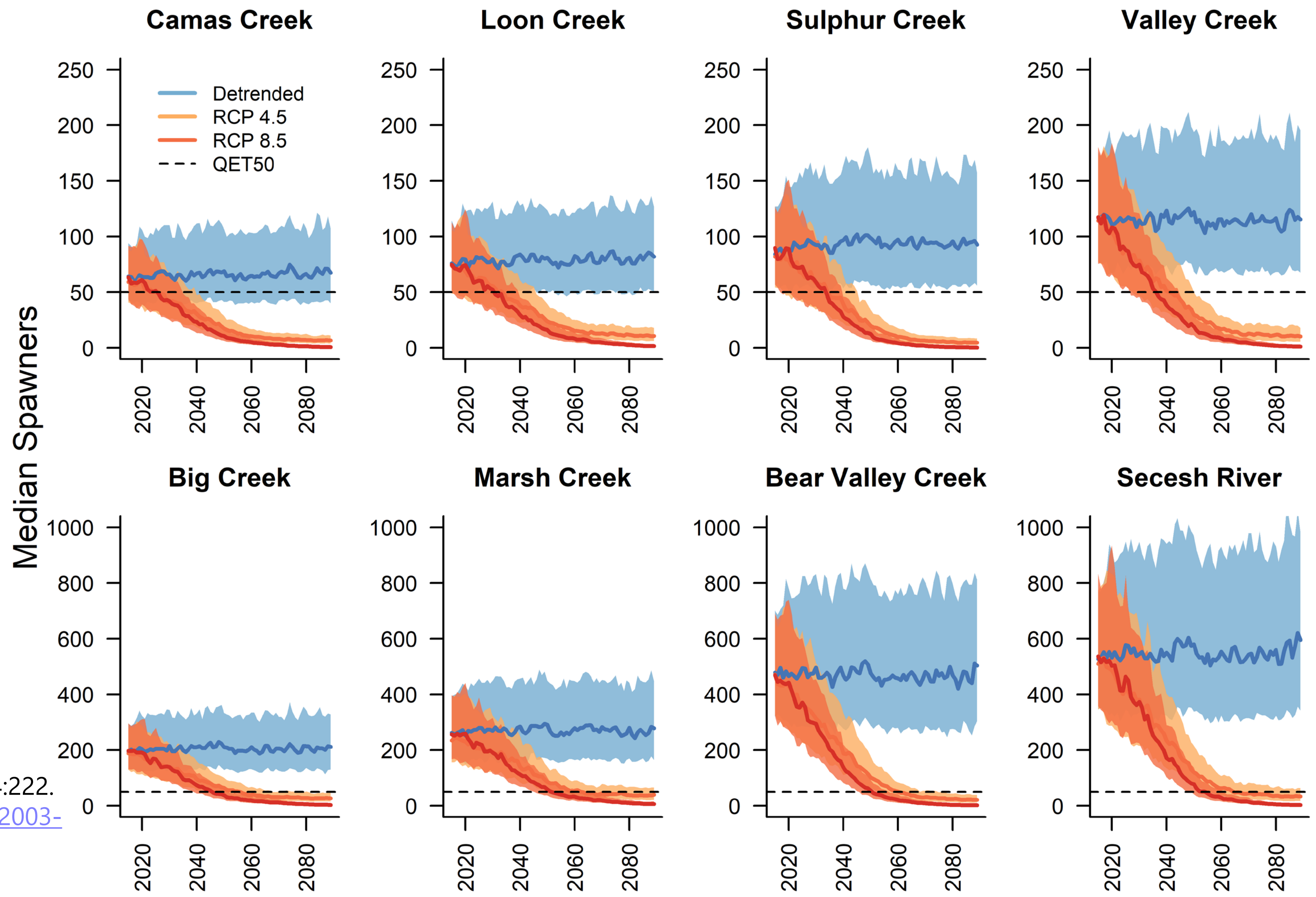
LOTS of pit-tag and redd data

Life stage	Years	N	Reference
Spawner abundance	1998-2016	33542	IDFG et al. 2018; Nez Perce Tribe 2019
Stributary (s_2)	2000-2014	171004	Lamb et al. 2018
Smainstem (s_2)	2000-2014	~1,600,000	Faulkner et al. 2019
SAR (s_3, s_0)	2000-2017	33795	Chasco et al. 2021
Supstream	2004-2017	7553	Crozier et al. 2016, Crozier et al. 2018

Crozier, L. G., B. J. Burke, B. E. Chasco, D. L. Widener, and R. W. Zabel. 2021. Climate change threatens Chinook salmon throughout their life cycle. Communications Biology 4:222. https://doi.org/10.1038/s42003-021-01734-w

NOAA FISHERIES

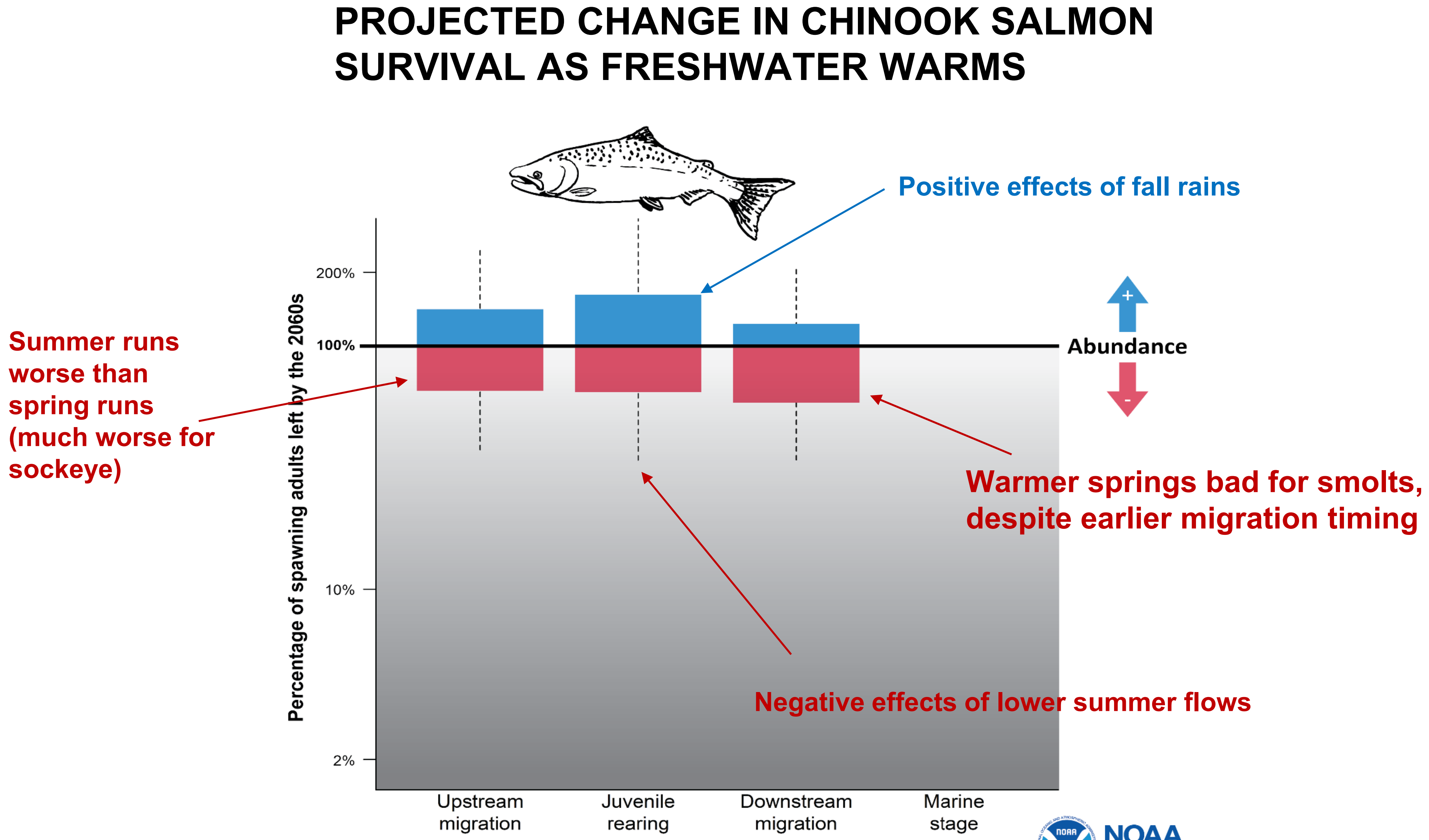
RESULTS: Populations quickly declined in climate change scenarios



Crozier et al. 2021.
Communications Biology 4:222.
https://doi.org/10.1038/s42003-021-01734-w

NOAA FISHERIES

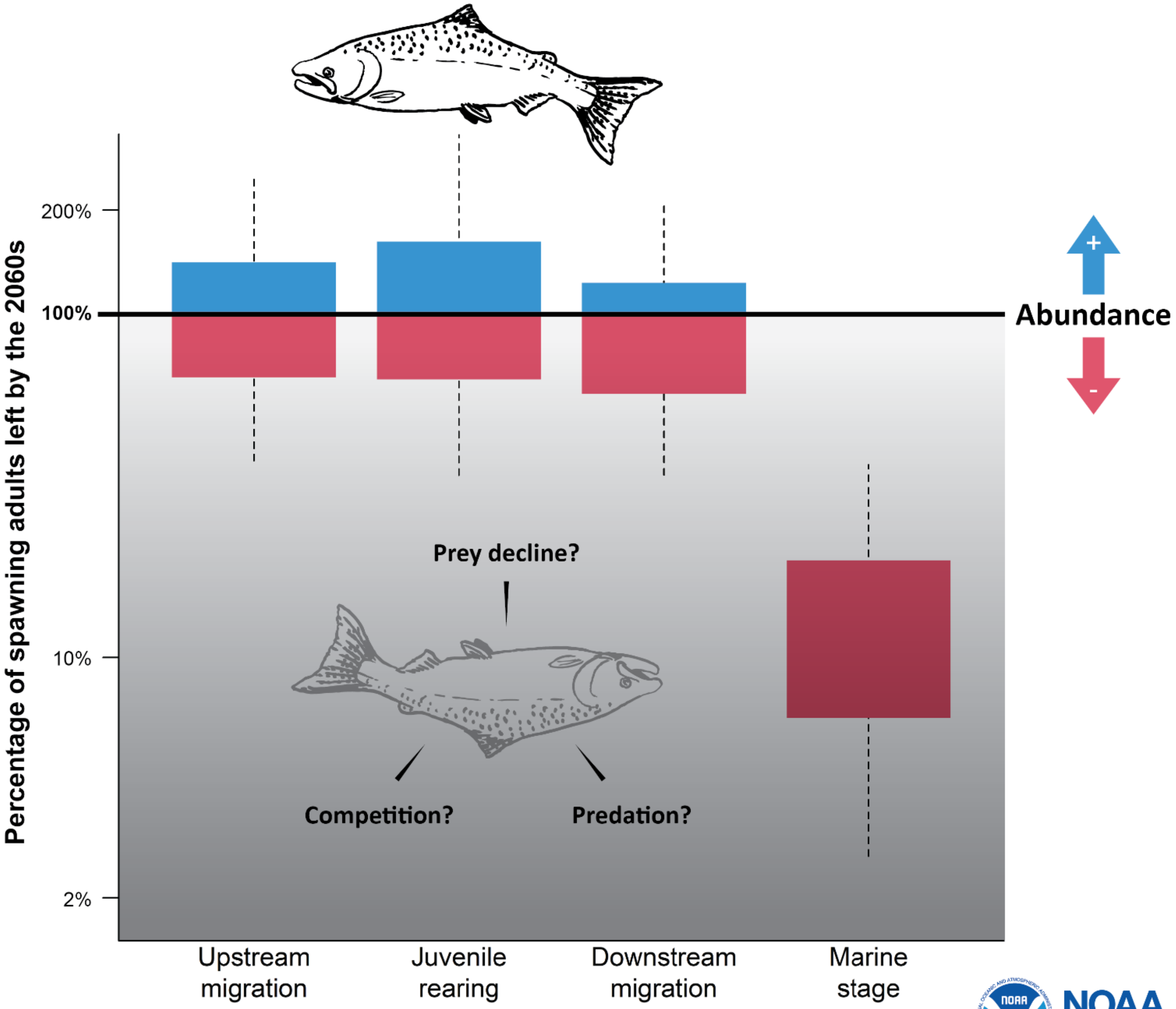
Sensitivity in different life stages:



https://www.fisheries.noaa.gov/feature-story/warming-ocean-will-challenge-snake-river-salmon-survival-coming-decades-new-research

NOAA FISHERIES

Sensitivity in different life stages:

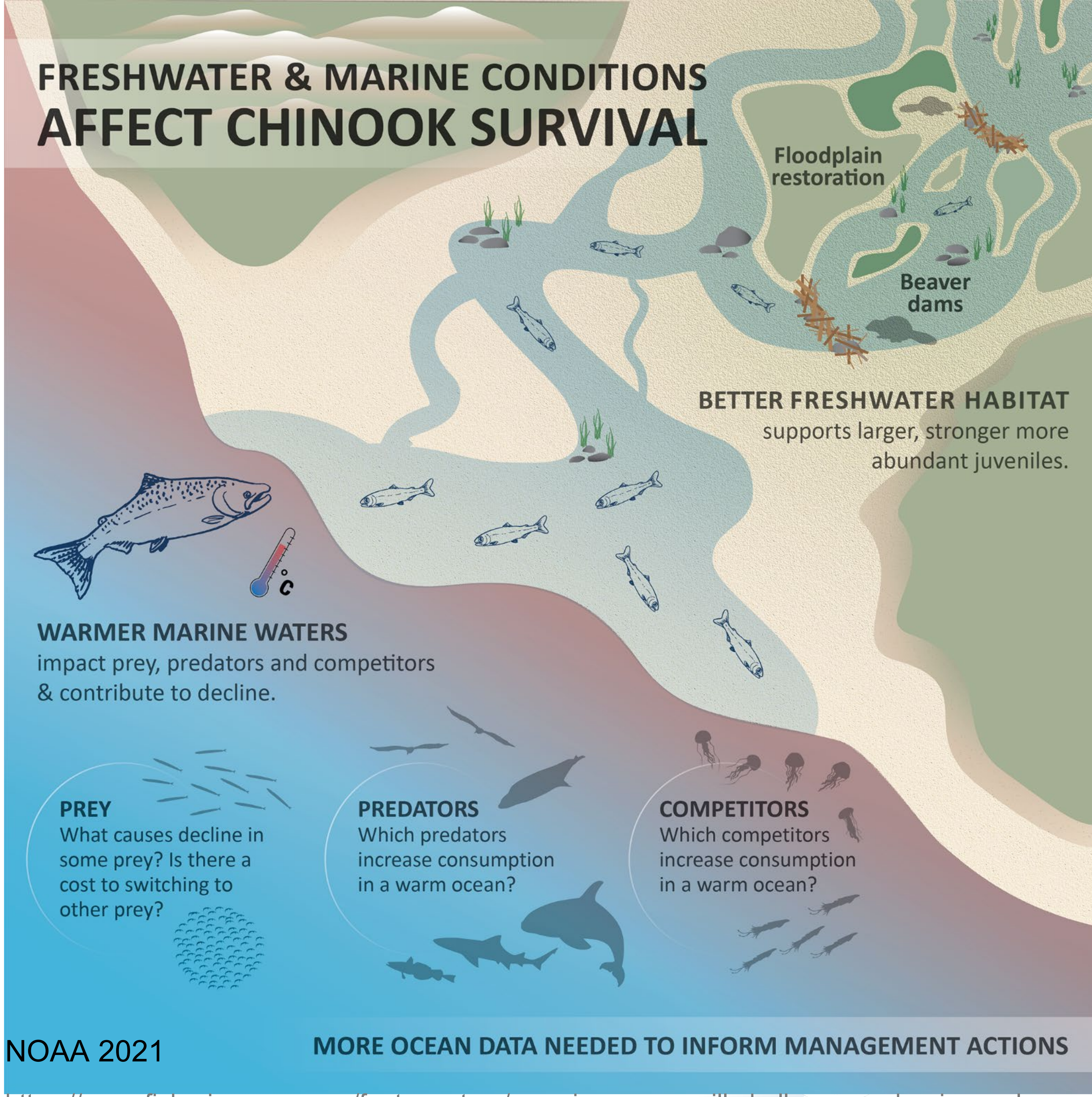


NOAA FISHERIES

https://www.fisheries.noaa.gov/feature-story/warming-ocean-will-challenge-snake-river-salmon-survival-coming-decades-new-research

So what can we do?

- Study marine interactions
- ID marine “levers”
  - Fisheries on other species
  - Predator management
  - Global hatchery production
- **Carry-over effects:**
  - **Actions in freshwater that affect marine survival**



NOAA 2021

https://www.fisheries.noaa.gov/feature-story/warming-ocean-will-challenge-snake-river-salmon-survival-coming-decades-new-research

What are carryover effects?

Jennifer Gosselin, UW

- Growth conditions in tributaries
  - Size and timing of smolts at LGR
- Hydrosystem – direct and indirect effects
  - Transported vs in-river migrants
  - Temperatures experienced in river
  - Flow, plume, water transit times, spill vs bypass,…
  - Timing of ocean entry
- Marine conditions
  - Ocean conditions (PDO, upwelling, SST, …)

Snake River Basin Differential Delayed Mortality Synthesis
FINAL REPORT
JJ Anderson KD Ham
JL Gosselin

Transactions of the American Fisheries Society

ISSN: 0002-8487 (Print) 1548-8659 (Online) Journal homepage: http://www.tandfonline.com/loi/utaf20

Combining Migration History, River Conditions, and Fish Condition to Examine Cross-Life-Stage Effects on Marine Survival in Chinook Salmon

esa ECOSPHERE

FRESHWATER ECOLOGY

Role of carryover effects in conservation of wild Pacific salmon migrating regulated rivers

Jennifer L. Gosselin,[1,†] Eric R. Buhle,[2] Christopher Van Holmes,[1] W. Nicholas Beer,[1] Susannah Iltis,[1] and James J. Anderson[1]

[1]School of Aquatic and Fishery Sciences, University of Washington, 1122 NE Boat Street, Seattle, Washington 98105 USA
[2]Biomark Applied Biological Services, Boise, Idaho 83702 USA

Citation: Gosselin, J. L., E. R. Buhle, C. Van Holmes, W. N. Beer, S. Iltis, and J. J. Anderson. 2021. Role of carryover effects in conservation of wild Pacific salmon migrating regulated rivers. Ecosphere 12(7):e03618. 10.1002/ecs2.3618

Juvenile Chinook Salmon that differed in their freshwater experience in passing dams as run-of-the-river or barged fish were tested in challenge experiments at 23.5°C…

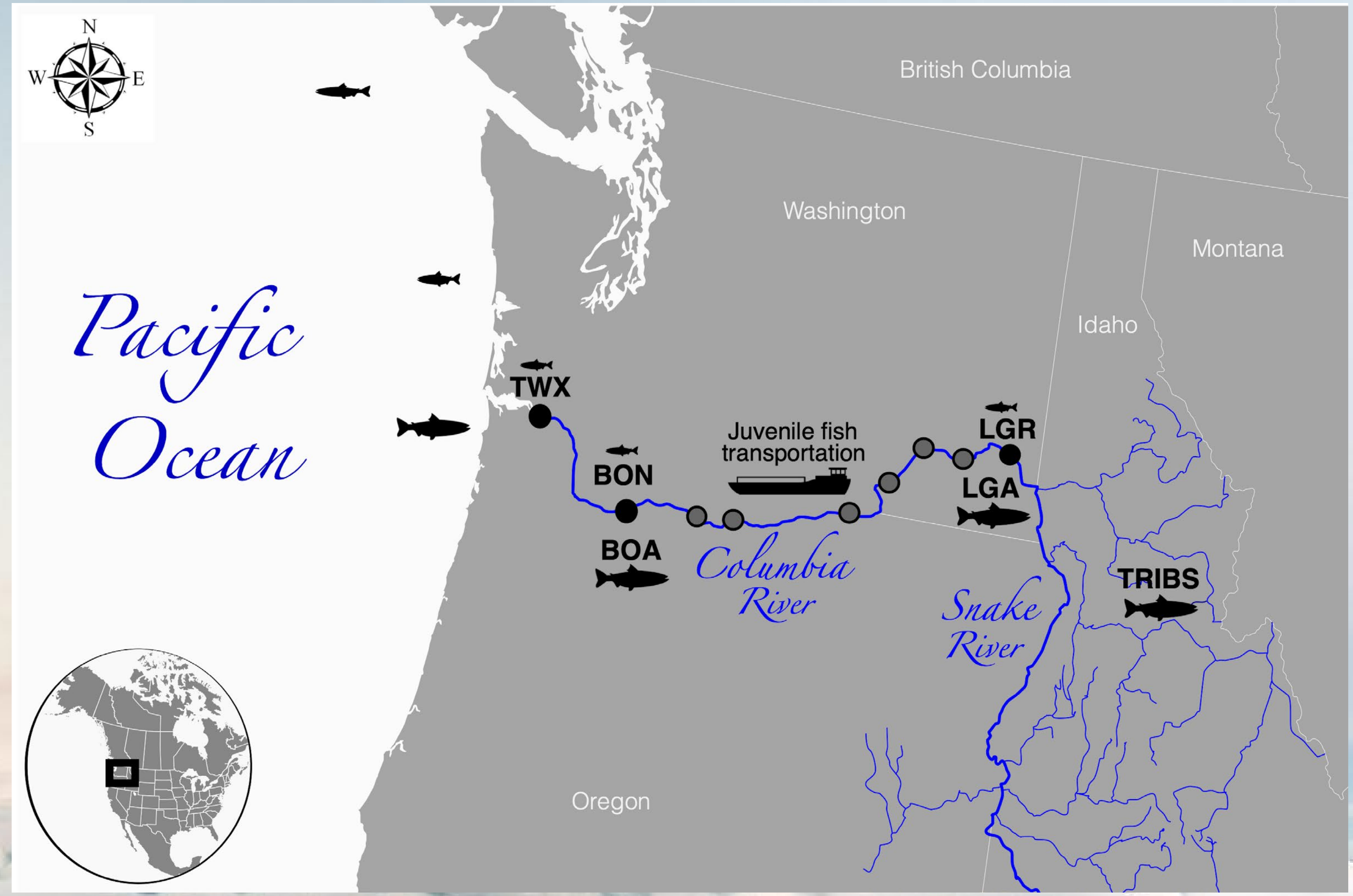
Seasonal patterns of freshwater experiences during hydropower system passage influence the biological condition of juvenile salmon at seawater entry and consequently their seasonal pattern of marine survival to the adult stage

Salmon

life stages

in Snake and Columbia

rivers, Pacific Northwest



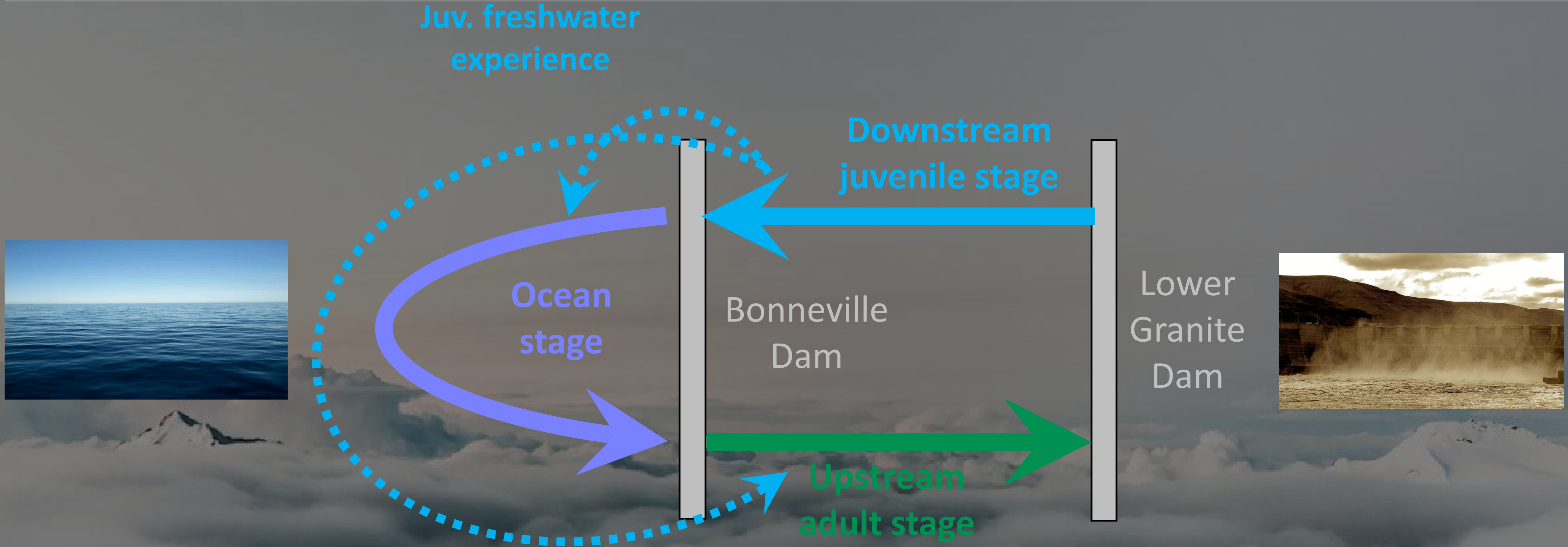
Gosselin, J. L., E. R. Buhle, C. Van Holmes, W. N. Beer, S. Iltis, and J. J. Anderson. 2021. Role of carryover effects in conservation of wild Pacific salmon migrating regulated rivers. Ecosphere 12(7):e03618.

Slide courtesy of Jenn Gosselin

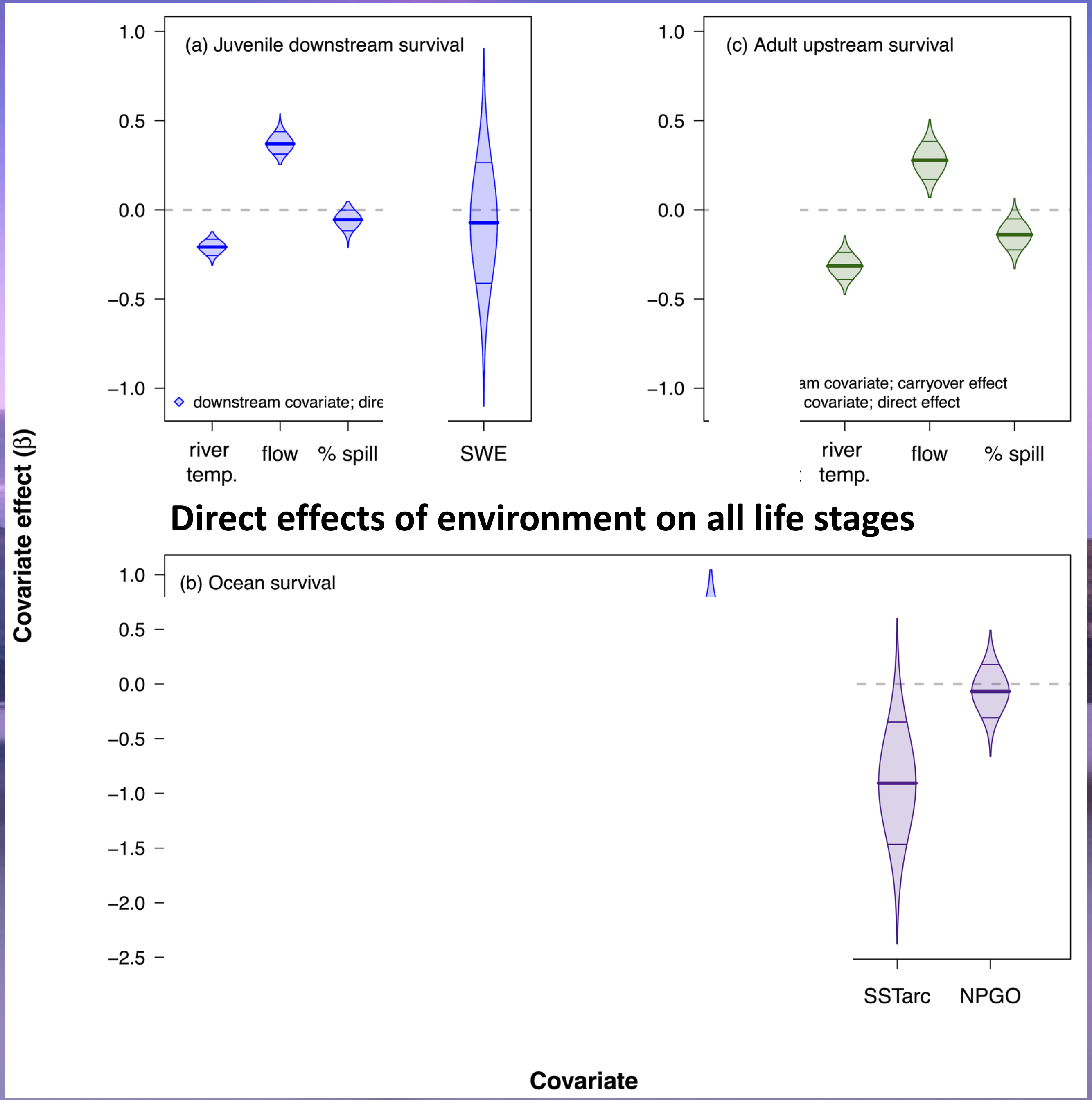
Juvenile to adult stages through hydropower system

Direct: same life stage

Carryover: across life stages



Slide courtesy of Jenn Gosselin



Results

Juvenile downstream stage:

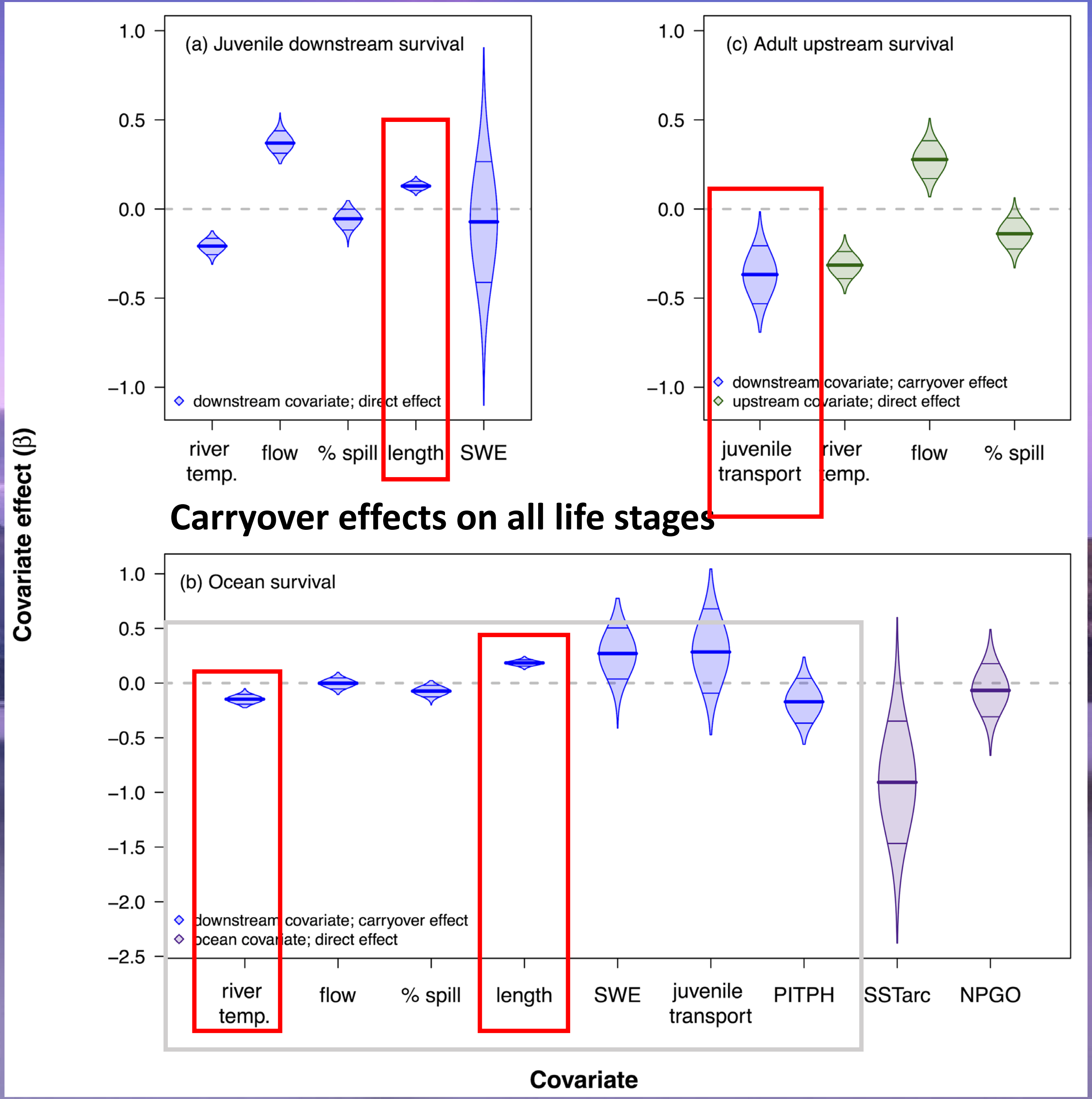
- River temperature, negative effect
- Flow, positive effect
- Fish length, positive effect

Ocean stage:

- SSTarc, strongest direct effect
- River temperature, negative carryover
- Fish length, positive carryover
- SWE, juv. transport, positive & uncertain
- Dam powerhouse passage PITPH, negative & uncertain

Adult upstream stage:

- Juvenile transportation, temperature, % spill, negative carryover effects
- Flow, positive effect



Covariate effects

Juvenile downstream stage:

- River temperature, negative effect
- Flow, positive effect
- Fish length, positive effect

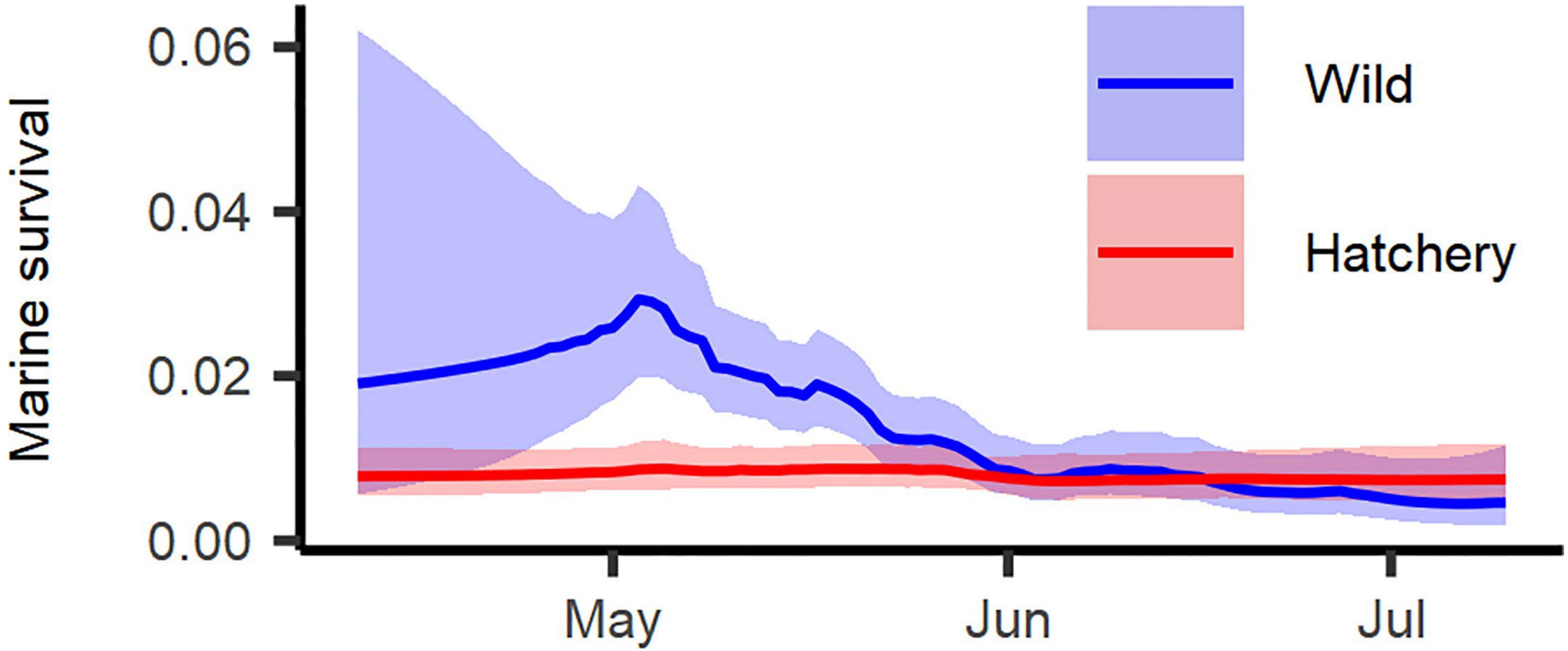
Ocean stage:

- SSTarc, strongest direct effect
- River temperature, negative carryover
- Fish length, positive carryover
- SWE, juv. transport, positive & uncertain
- Dam powerhouse passage PITPH, negative & uncertain

Adult upstream stage:

- Juvenile transportation, temperature, % spill, negative carryover effects
- Flow, positive effect

But bigger isn't always better

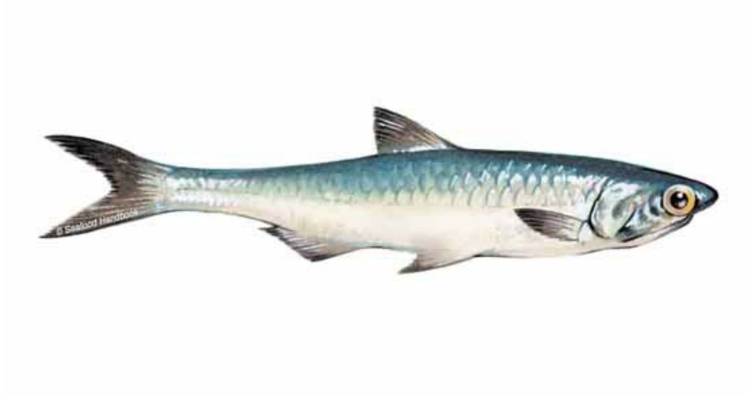


Differential impacts of freshwater and marine covariates on wild and hatchery Chinook salmon marine survival

Brandon Chasco
1*, Brian Burke2, Lisa Crozier
2, Rich Zabel2

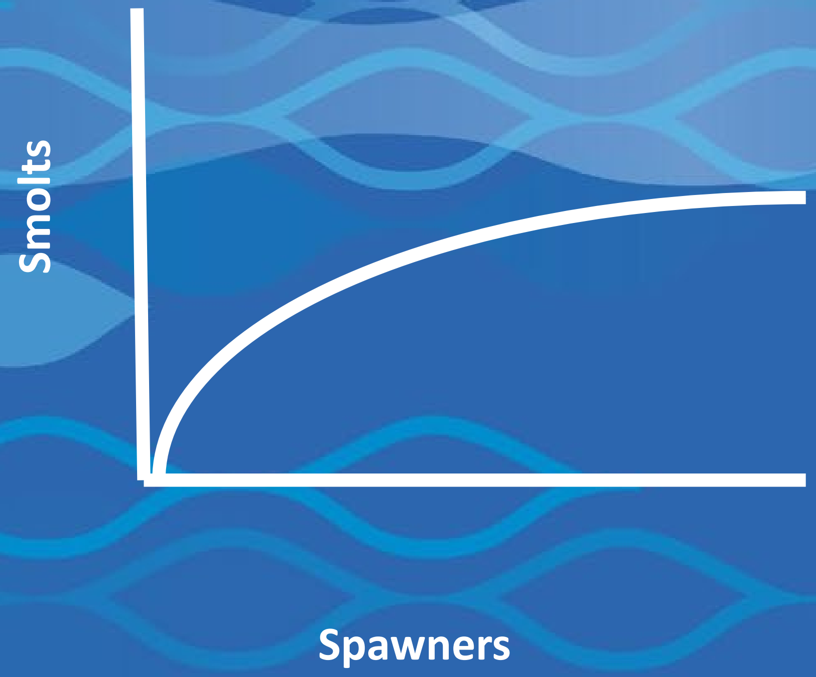
(2021) PLoS ONE 16(2):
e0246659. https://doi.org/10.1371/journal.pone.0246659

Alternate prey for salmon predators (e.g., seals) can increase salmon survival

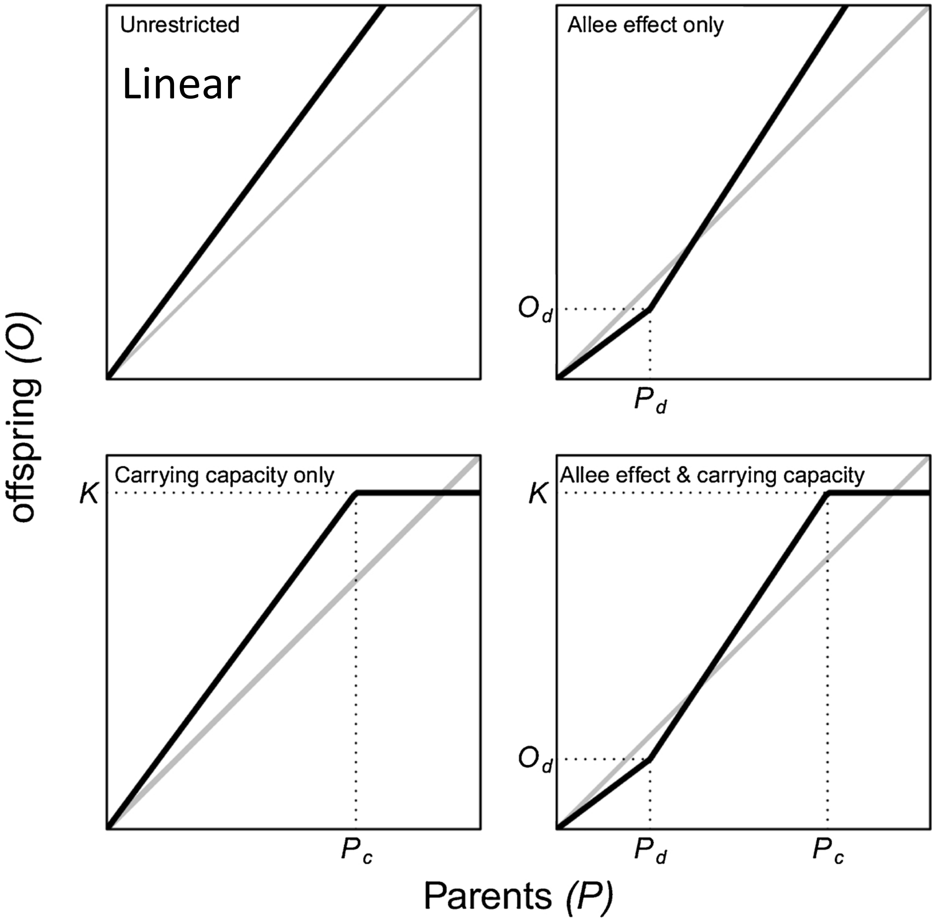


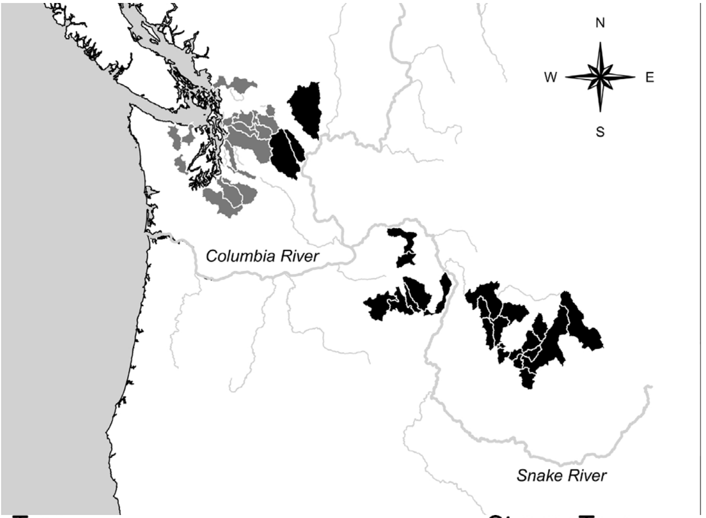
- Moore, M. E., B. A. Berejikian, C. M. Greene, and S. Munsch. 2021. Environmental fluctuation and shifting predation pressure contribute to substantial variation in early marine survival of steelhead. Marine Ecology Progress Series 662:139-156.
  - we provide data from telemetered harbor seals and steelhead indicating that the resulting high abundance of age-1+ anchovy provided an alternative prey source for predators of migrating steelhead smolts.

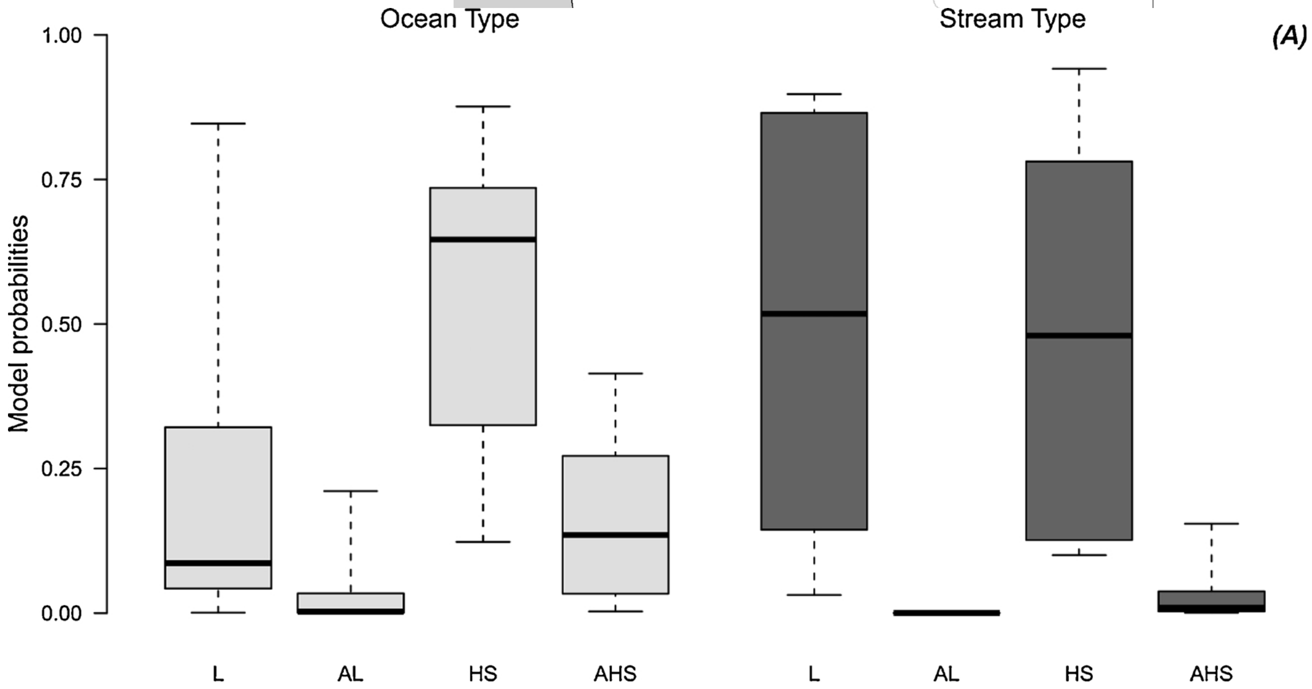
Abundance: What about density dependence?



Density dependence



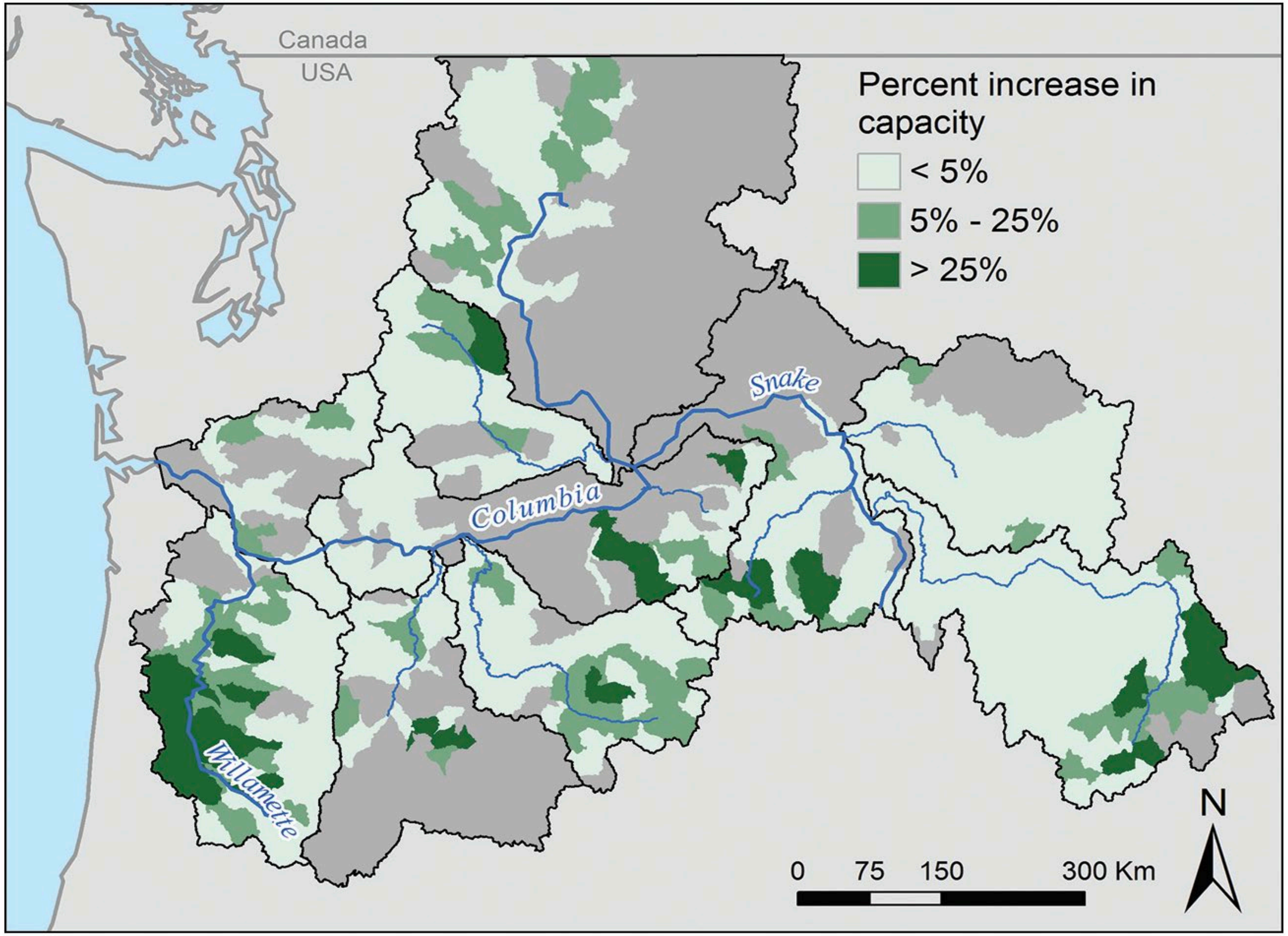




Linear	Allee effects	Carrying Capacity Only (k)	Both Allee + k

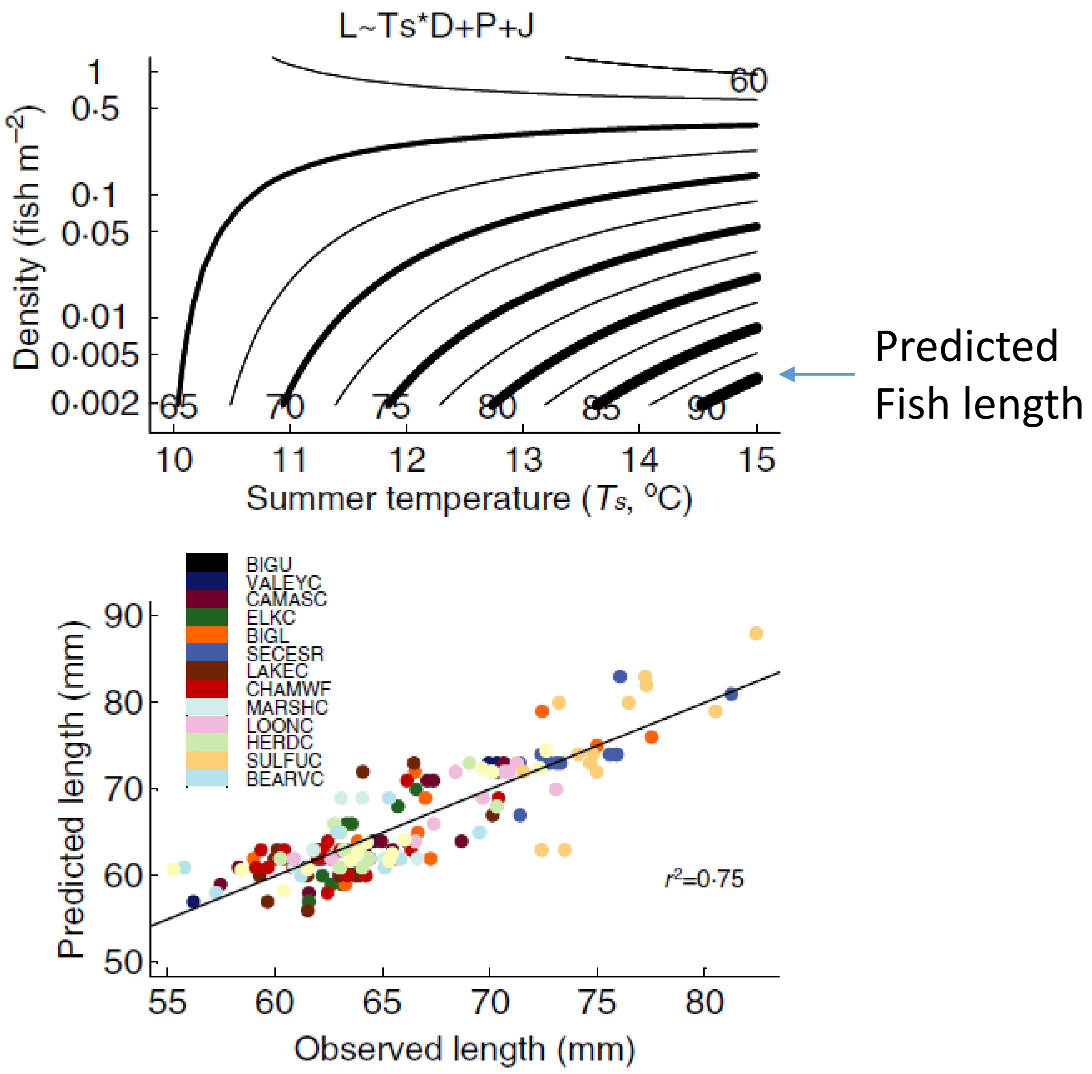
Bal, G., M. D. Scheuerell, and E. J. Ward. 2018. Characterizing the strength of density dependence in at-risk species through Bayesian model averaging. Ecological Modelling 381:1-9.

Improve habitat condition and connectedness



Bond, M. H., T. G. Nodine, T. J. Beechie, and R. W. Zabel. 2019. Estimating the benefits of widespread floodplain reconnection for Columbia River Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences 76(7):1212-1226.

Density dependence is stronger in a warmer climate



Journal of Animal Ecology

British Ecological Society

Journal of Animal Ecology 2010, **79**, 342–349 doi: 10.1111/j.1365-2656.2009.01641.x

Interacting effects of density and temperature on body size in multiple populations of Chinook salmon

Lisa G. Crozier*, Richard W. Zabel, Eric E. Hockersmith and Stephen Achord

NWFSC, NOAA-Fisheries, 2725 Montlake Blvd E., Seattle, WA 98112, USA

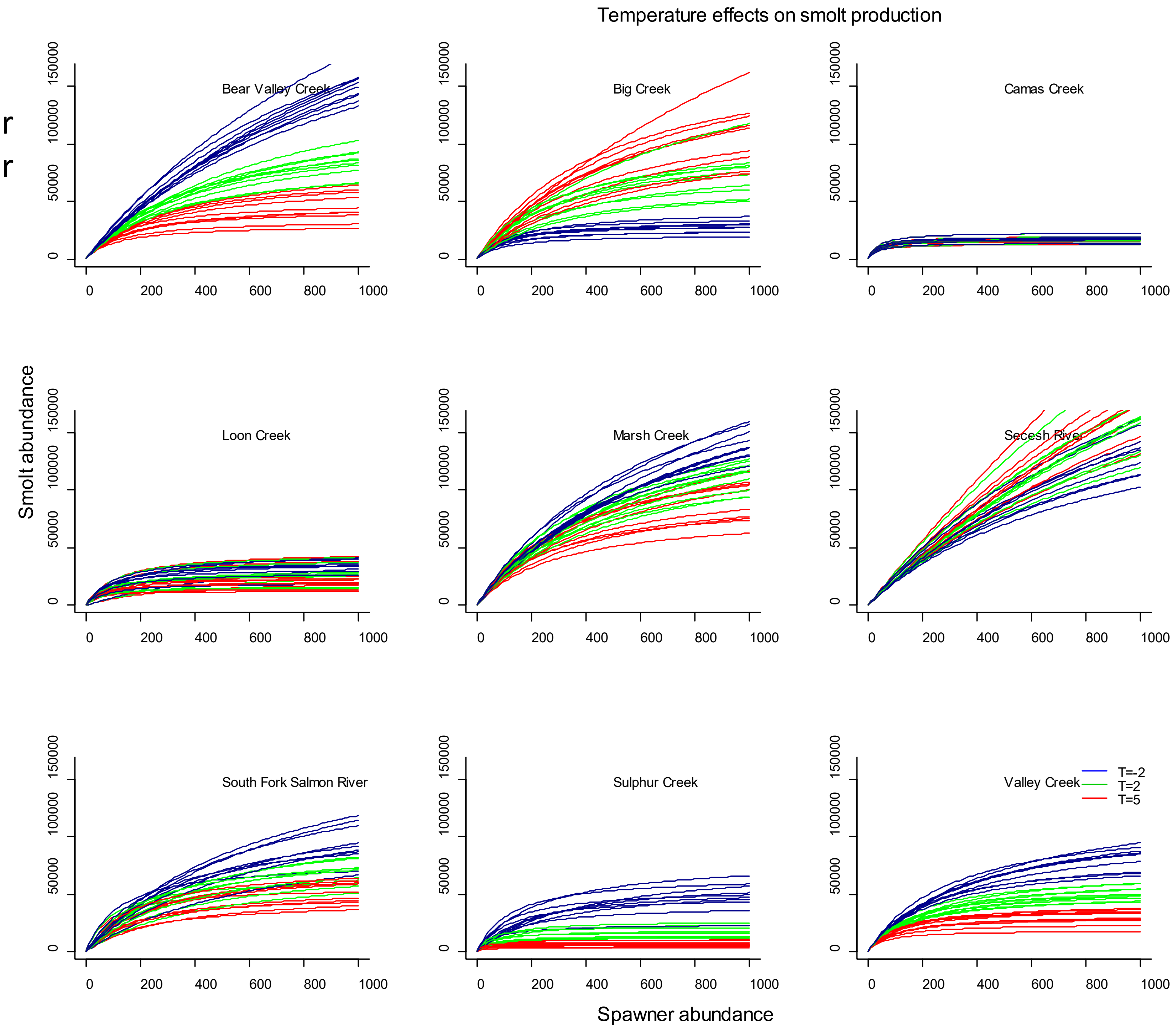
Fig. 3. Predicted fish length (L) and fit to the data for the best model, $L \sim T_s \times D + P + J$ where T_s is summer temperature, D is fish density, P is population and J is sample day. (a) The contours show the predicted fish length as a function of summer temperature and density at the mean sample day. (b) Model predictions and observed fish size for the entire dataset, with the populations differentiated by colour.

---- 2C cooler

---- 2C warmer

---- 5C warmer

Flow and temperature alter growth & carrying capacity



Predator swamping vs attraction?

- Fish school for a reason (or multiple reasons)
  - Schooling reduces predation risk for individuals,
  - May increase ability to find food and navigate migration routes
  - But increased local competition can mean less food
- Predators are smart, and hang out when and where there are lots of salmon
  - Tributary release sites
  - Choke points at dams (bypass exits, fish ladders)
  - Columbia River plume during migration season, hatchery releases

Competition in the ocean

Generally worse in warmer years

Kendall, N. W., B. W. Nelson, and J. Losee. 2020. Density-dependent marine survival of hatchery-origin Chinook salmon may be associated with pink salmon. Ecosphere 11(4).

We analyzed 30 yr of data and found that density-dependent survival of hatchery Chinook salmon released into the central and southern parts of the Salish Sea (Washington, USA; and British Columbia, Canada) may be associated with the presence of naturally produced pink salmon

Morita, K., and M. A. Fukuwaka. 2020. Intra- and interspecific density-dependent growth and maturation of Pacific salmon in the Bering Sea. Ecological Research 35(1):106-112.

We interrogate long-term (1972-2010) monitoring data from the Bering Sea for evidence of intra- and interspecific density-dependent growth among three species of Pacific salmon: sockeye, chum and pink. Partial correlation analysis, using intraspecific density as a control variable, identified interspecific density-dependent growth among these three salmon species.

Frost, T. J., E. M. Yasumiishi, B. A. Agler, M. D. Adkison, and M. V. McPhee. 2021. Density-dependent effects of eastern Kamchatka pink salmon (Oncorhynchus gorbuscha) and Japanese chum salmon (O. keta) on age-specific growth of western Alaska chum salmon. Fisheries Oceanography 30(1):99-109.

Our results support previous evidence that chum salmon are affected by intraspecific competition, and to a lesser extent interspecific competition, in the North Pacific

Connors, B., M. J. Malick, G. T. Ruggerone, P. Rand, M. Adkison, J. R. Irvine, R. Campbell, and K. Gorman. 2020. Climate and competition influence sockeye salmon population dynamics across the Northeast Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences 77(6):943-949.

Conclusion

- Climate change is a major threat
- Actions in freshwater affect marine survival

- Size (condition), timing, and abundance affect survival in later life stages
- Bet hedging is really important
  - Other species matter
  - Lots we don't understand
- Need to discuss learning opportunities

NOAA FISHERIES

Many thanks to:

State Fish and Wildlife Agencies:

Washington Dept. of Fish and Wildlife

Oregon Dept. of Fish and Wildlife

Idaho Dept. of Fish and Game

Tribes and Tribal Consortia:

Nez Perce Tribe

Shoshone-Bannock Tribe

Colville Confederated Tribes

Umatilla Tribe

Warm Springs Tribe

Yakama Nation

Columbia River Inter-Tribal Fish Commission

Northwest Indian Fisheries Commission

Federal Fish and Wildlife Agencies:

U.S. Fish and Wildlife Service

NOAA Fisheries/National Marine Fisheries Service

Other Involved Entities:

Pacific States Marine Fisheries Commission, StreamNet Project

U.S. Fish and Wildlife Service, Fish Inventory System (FINS)

WA Governors Salmon Recovery Office

WA Recreation and Conservation Office

Northwest Power and Conservation Council