

Effects of climate and competition on the productivity and demography of Pacific salmon



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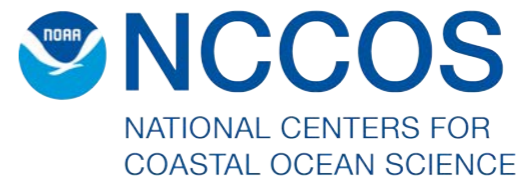
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Acknowledgements

Collaborators

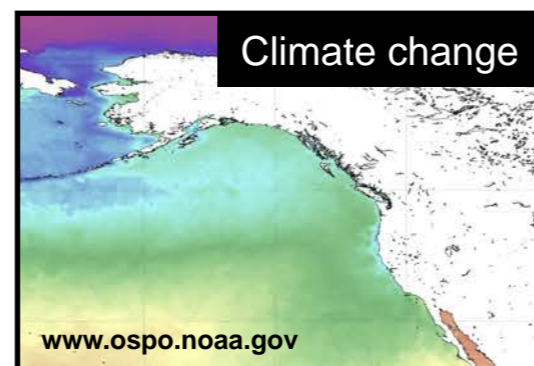
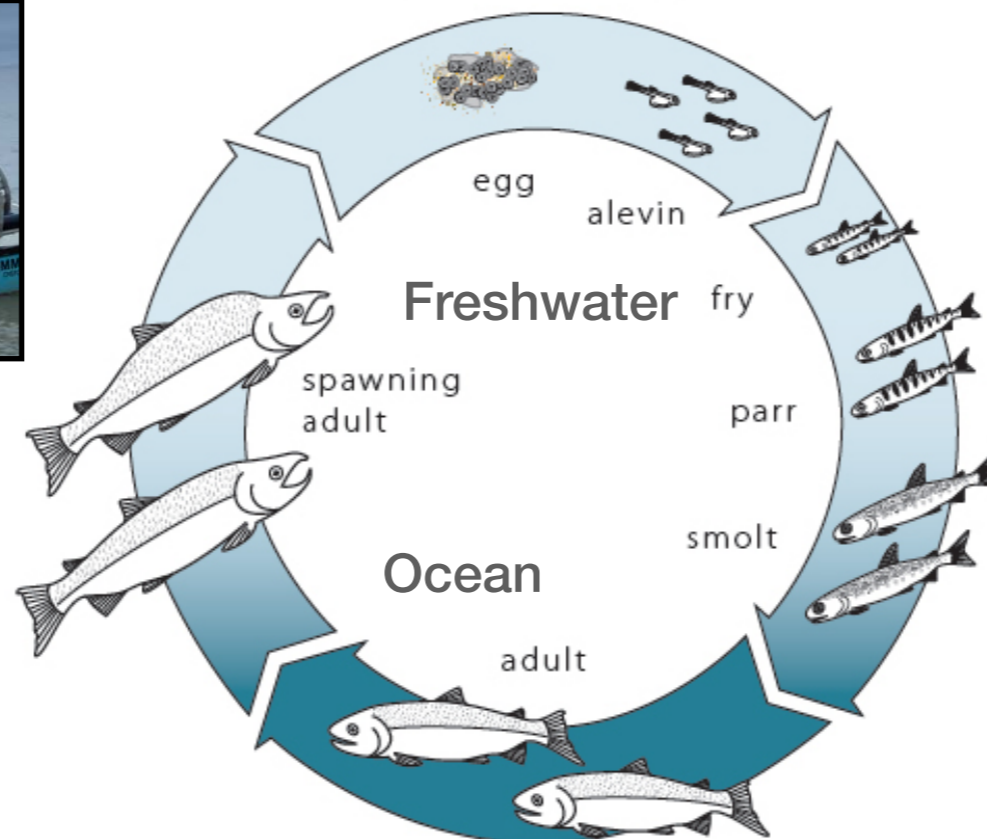
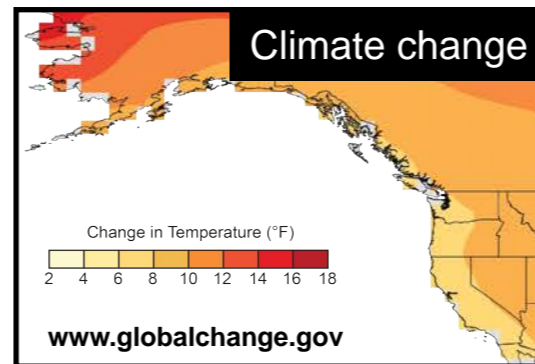
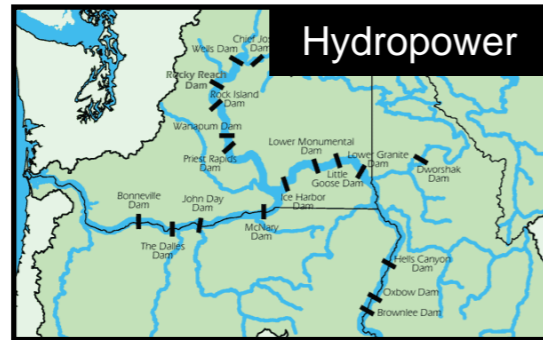
- Daniel Schindler (UW)
- Tim Cline (U Michigan)
- Eric Ward (NOAA)
- Bert Lewis (ADFG)
- Rich Brenner (ADFG)
- Mary Hunsicker (NOAA)
- Stormy Haught (DFO)
- Dave Finnoff (U Wyoming)
- Mike Litzow (NOAA)
- Toby Schwoerer (UAF)
- Greg Ruggerone (NRC)
- Claudine Hauri (UAF)
- Sam Brenkman (NPS)
- Pat Crain (NPS)
- Ray Hilborn (UW)
- Tom Quinn (UW)
- George Pess (NOAA)
- Jeff Duda (USGS)

Funding



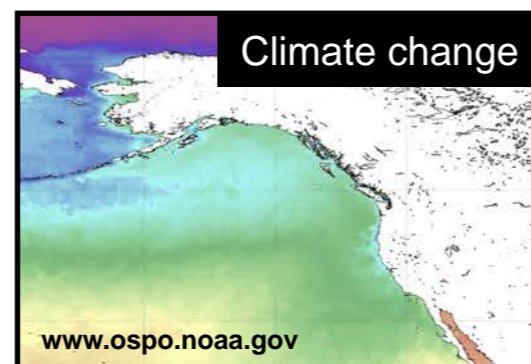
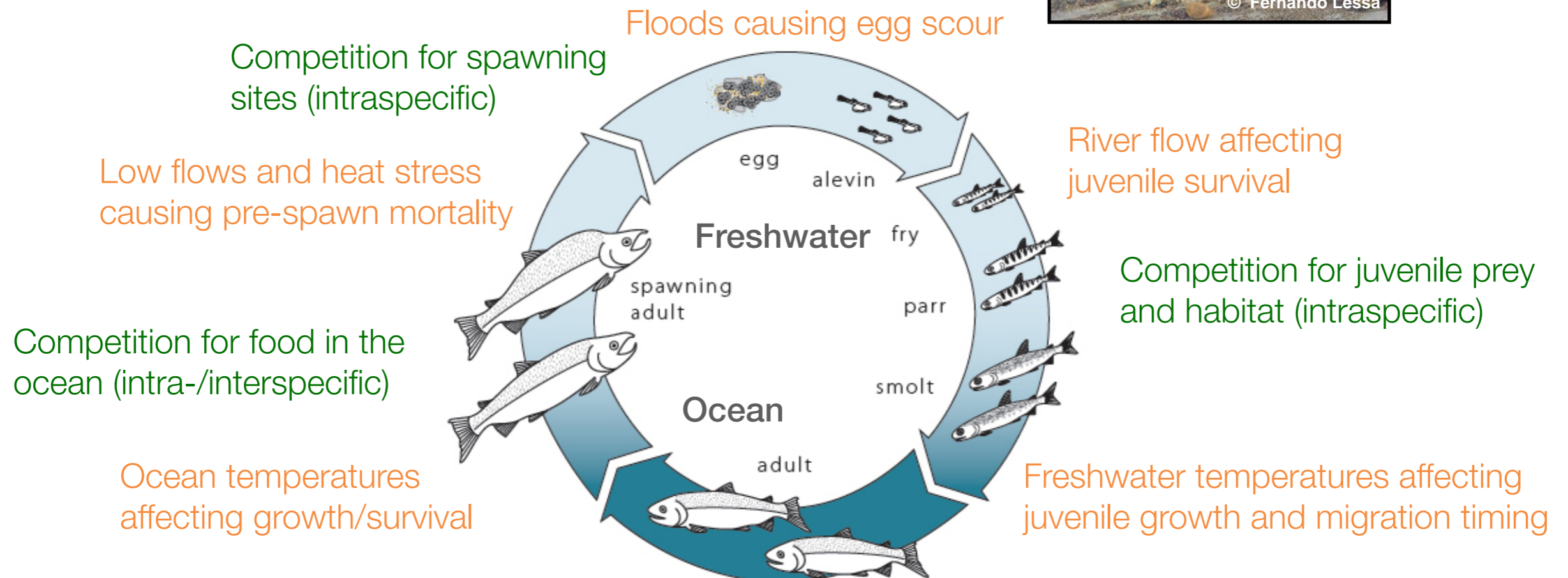
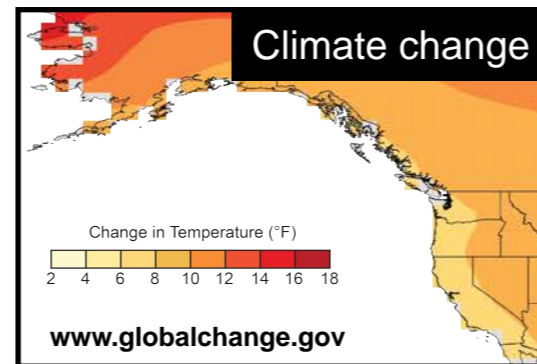
Causes of changing productivity & demography

Multiple natural and human stressors affecting salmon growth and survival



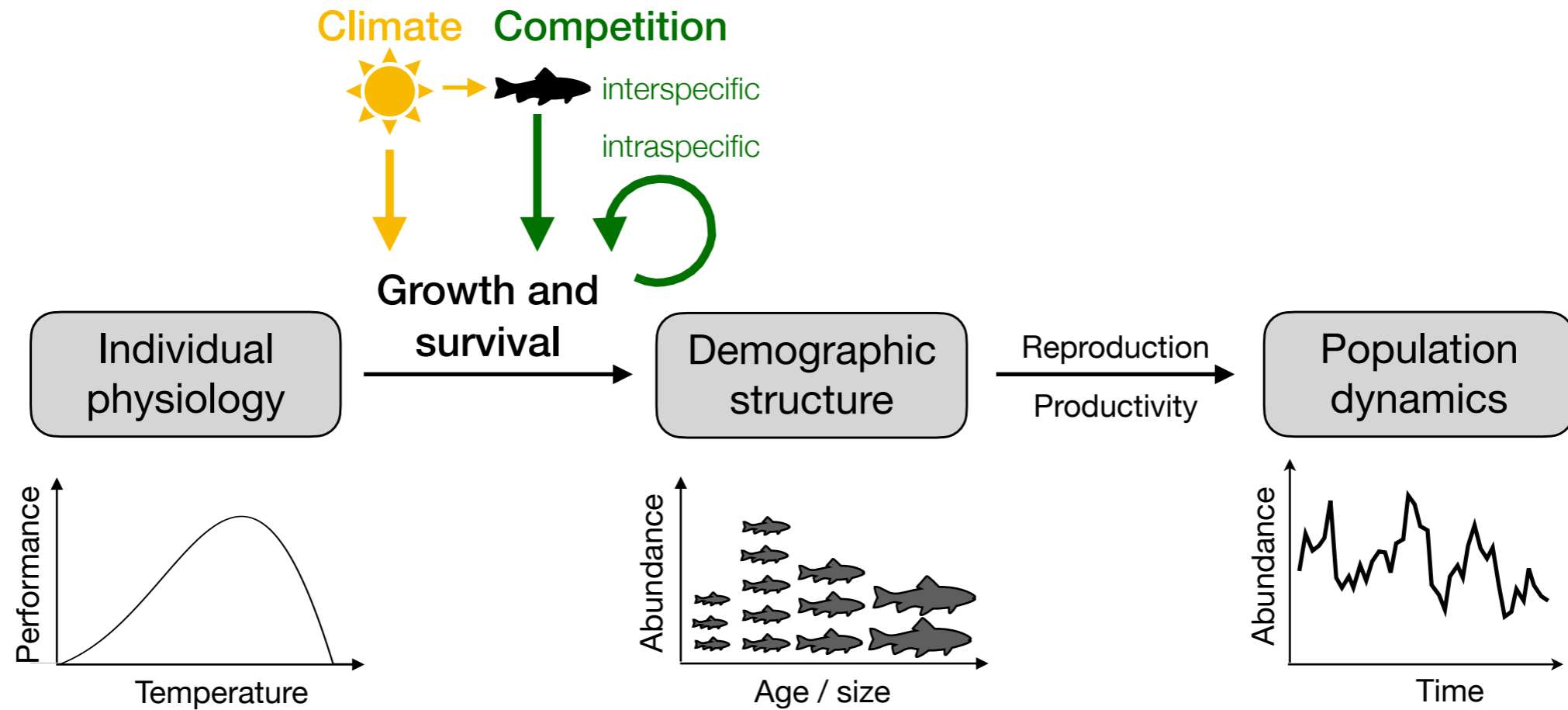
Causes of changing productivity & demography

Effects of climate and competition



Causes of changing productivity & demography

Effects of climate and competition



Demography

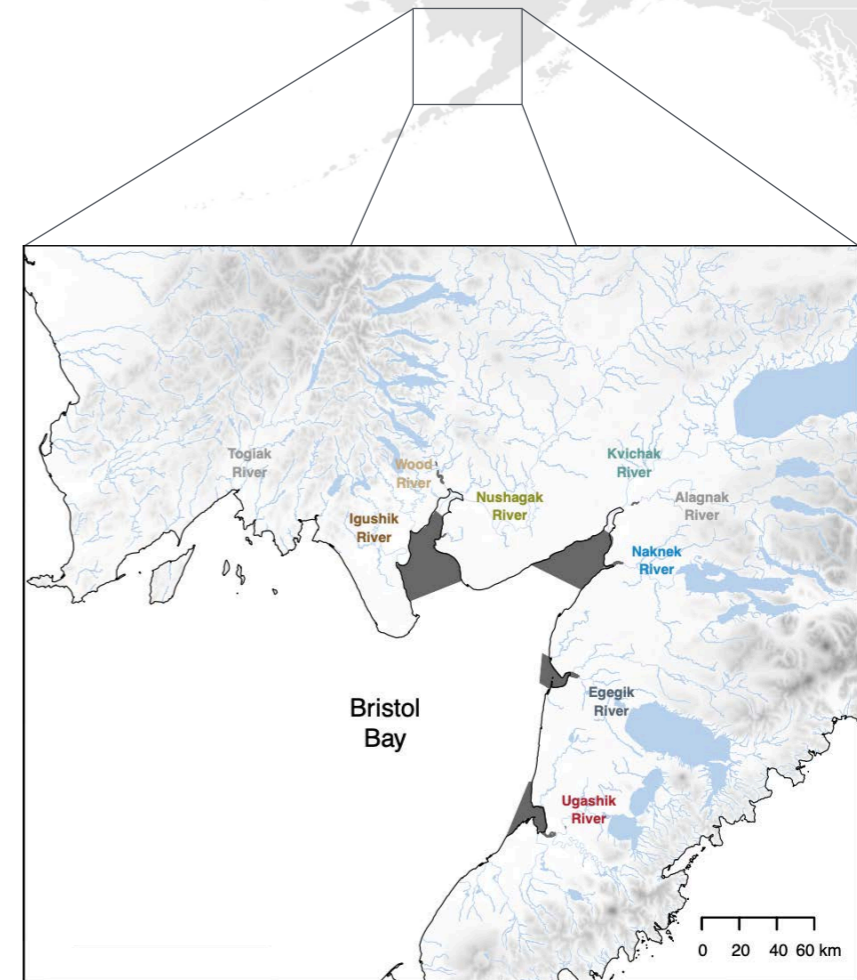
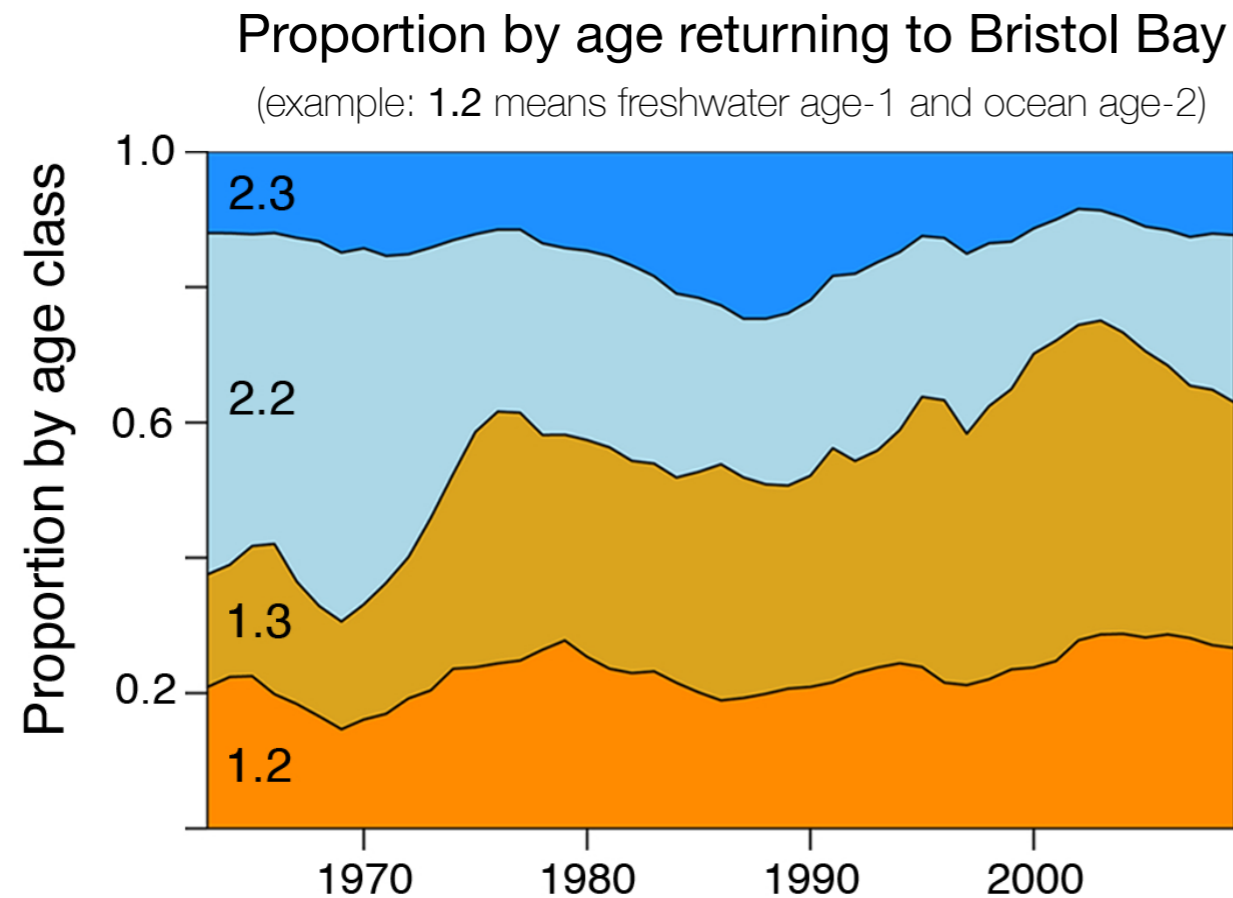
Sockeye salmon
Bristol Bay

Chinook salmon
coast-wide



Sockeye salmon in Bristol Bay

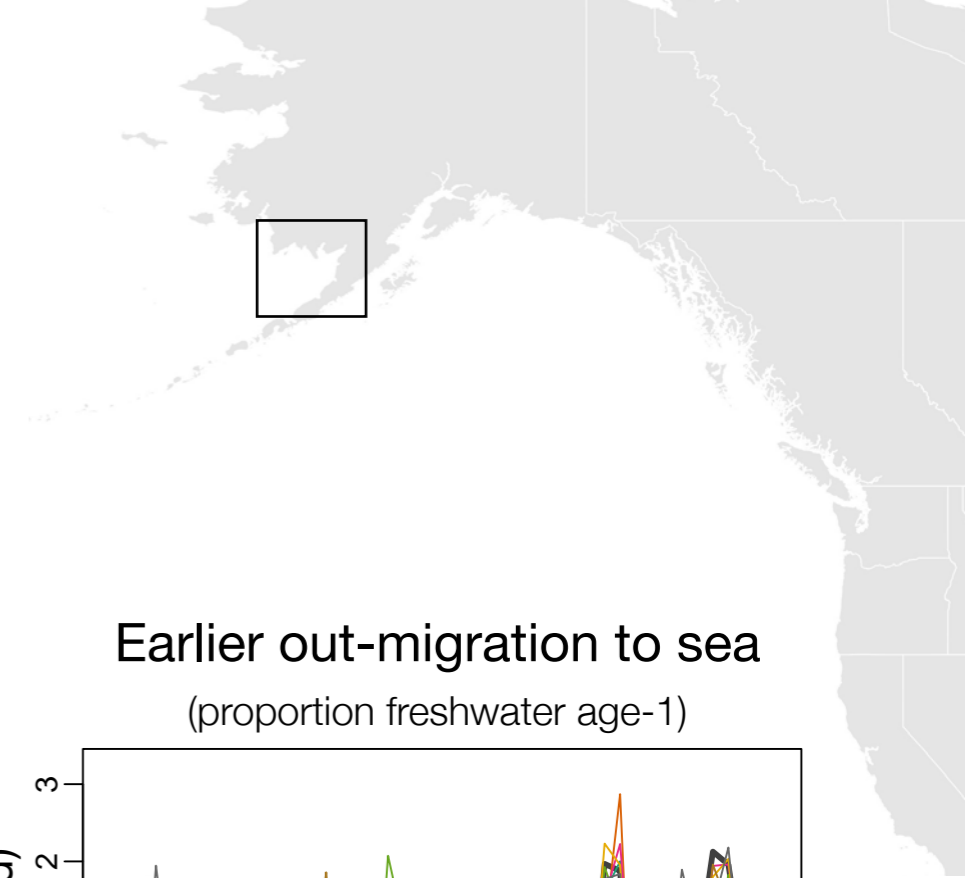
Changes in life-history characteristics



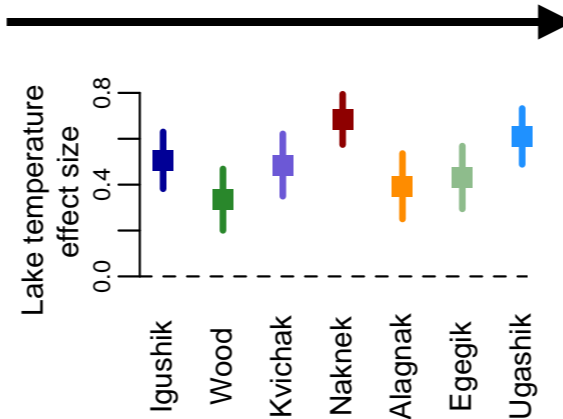
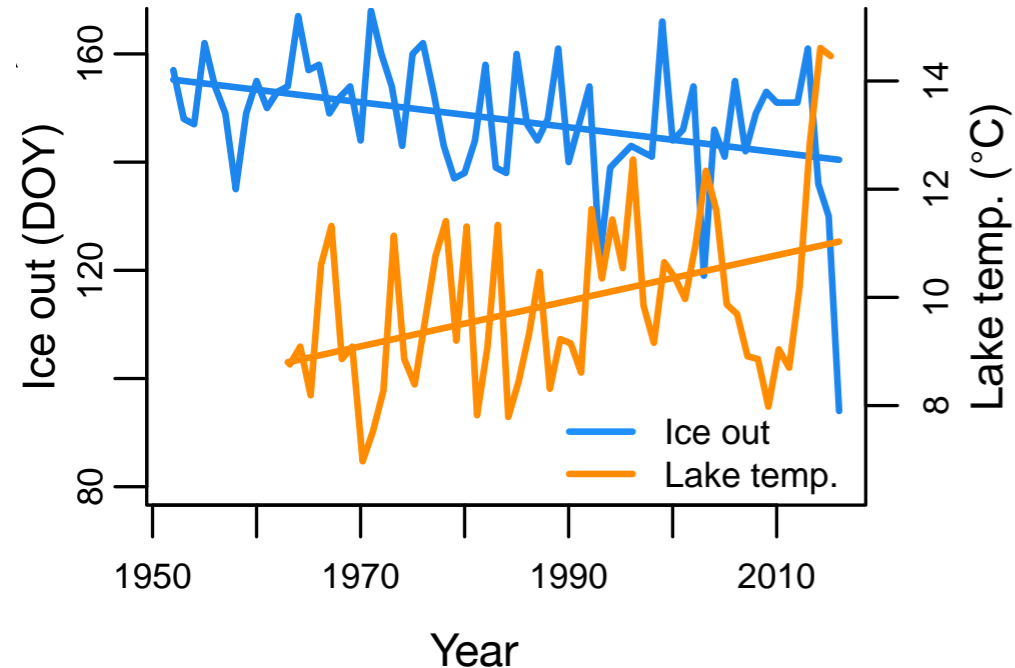
Are changes in freshwater and ocean residence associated with climate warming and/or competition in the ocean?

Sockeye salmon in Bristol Bay

Climate effects on juvenile outmigration timing

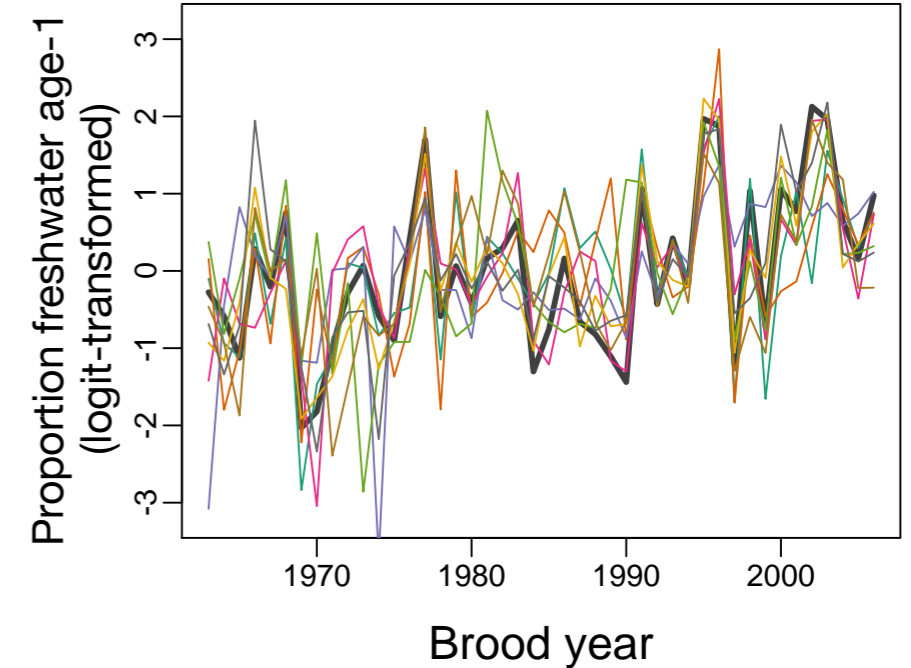


Warming of nursery lakes



Earlier out-migration to sea

(proportion freshwater age-1)

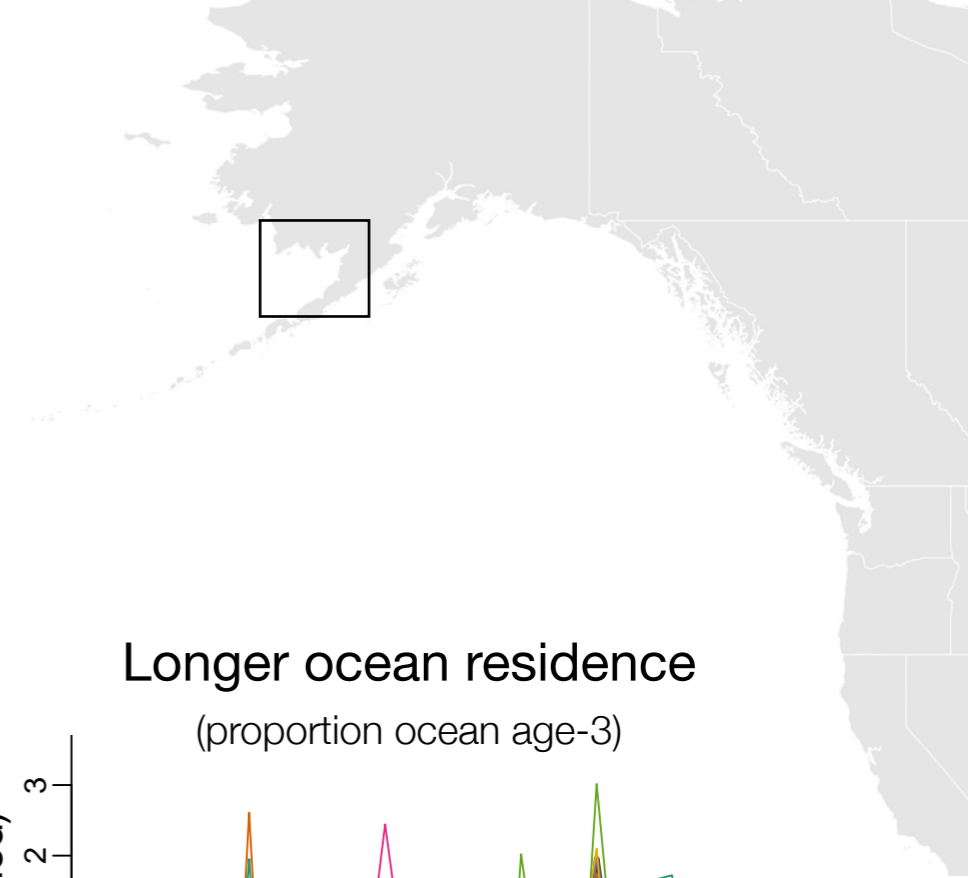


Cline et al. 2019

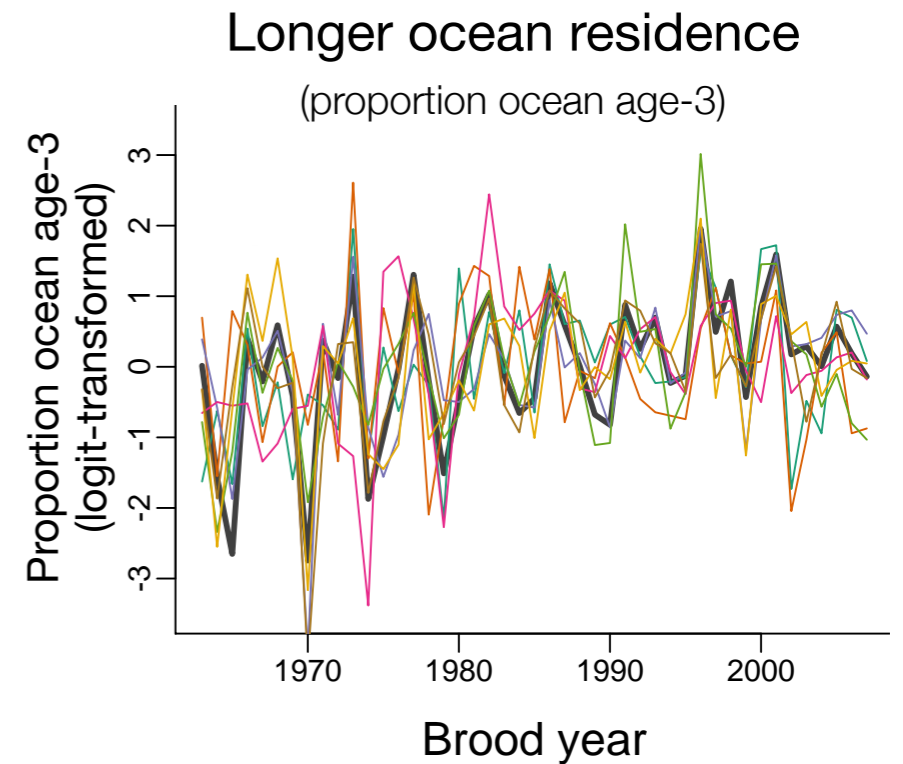
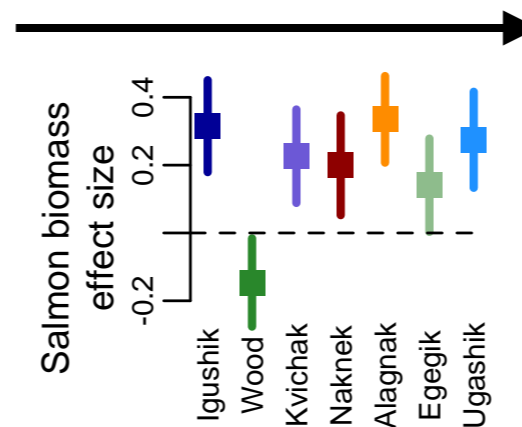
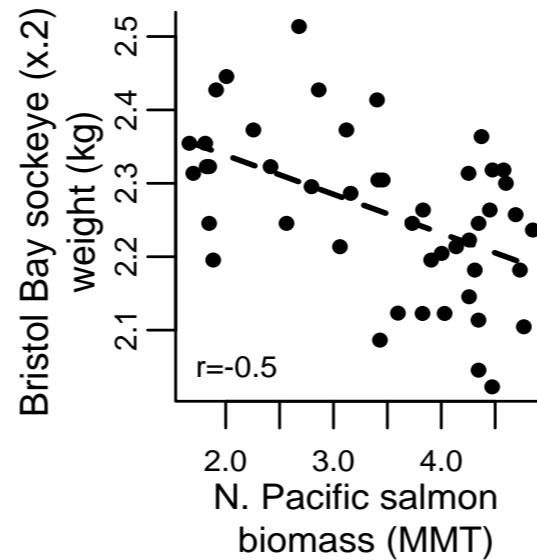
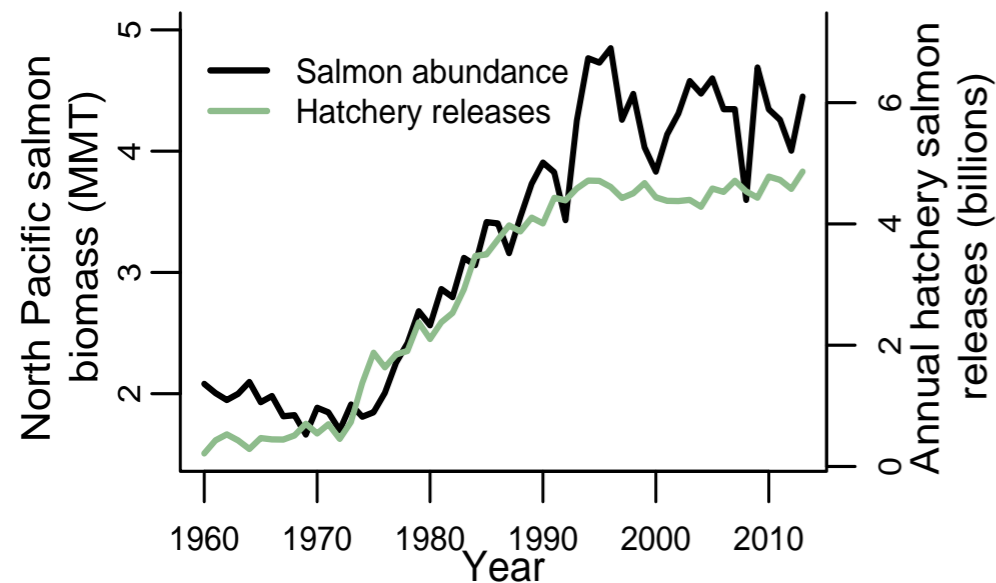
Evidence for shorter freshwater residence due to warming of nursery lakes

Sockeye salmon in Bristol Bay

Competition effects on ocean residence



Salmon biomass in the ocean

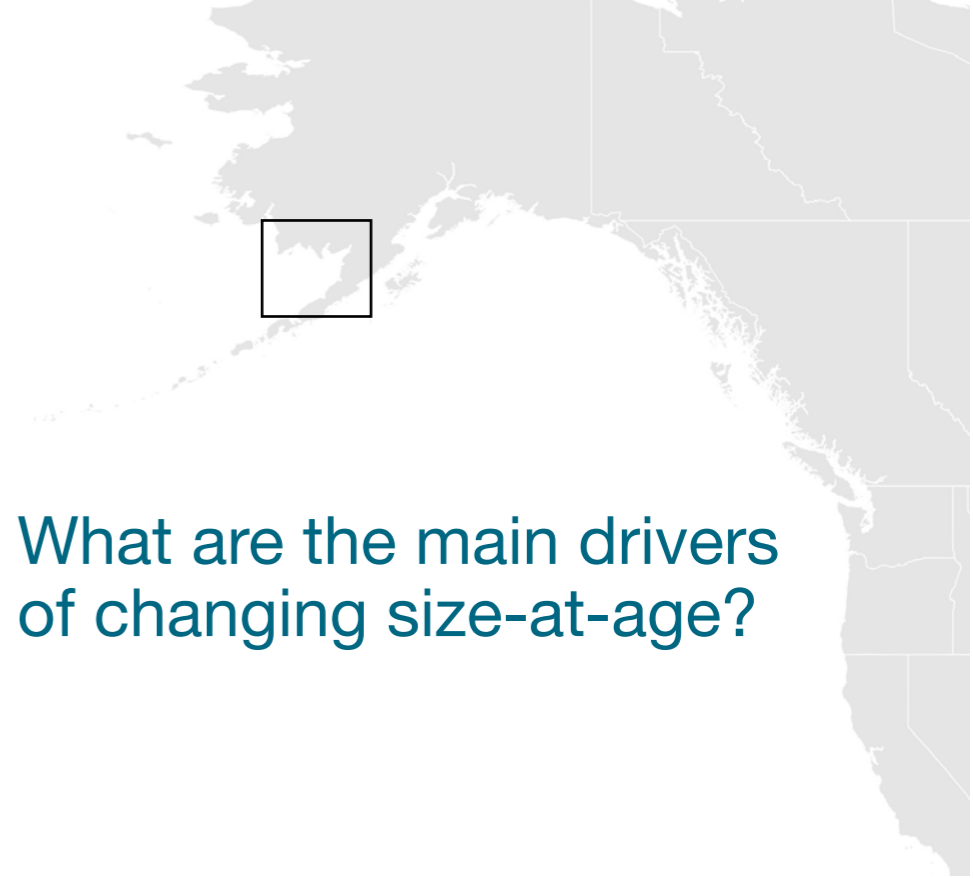


Cline et al. 2019

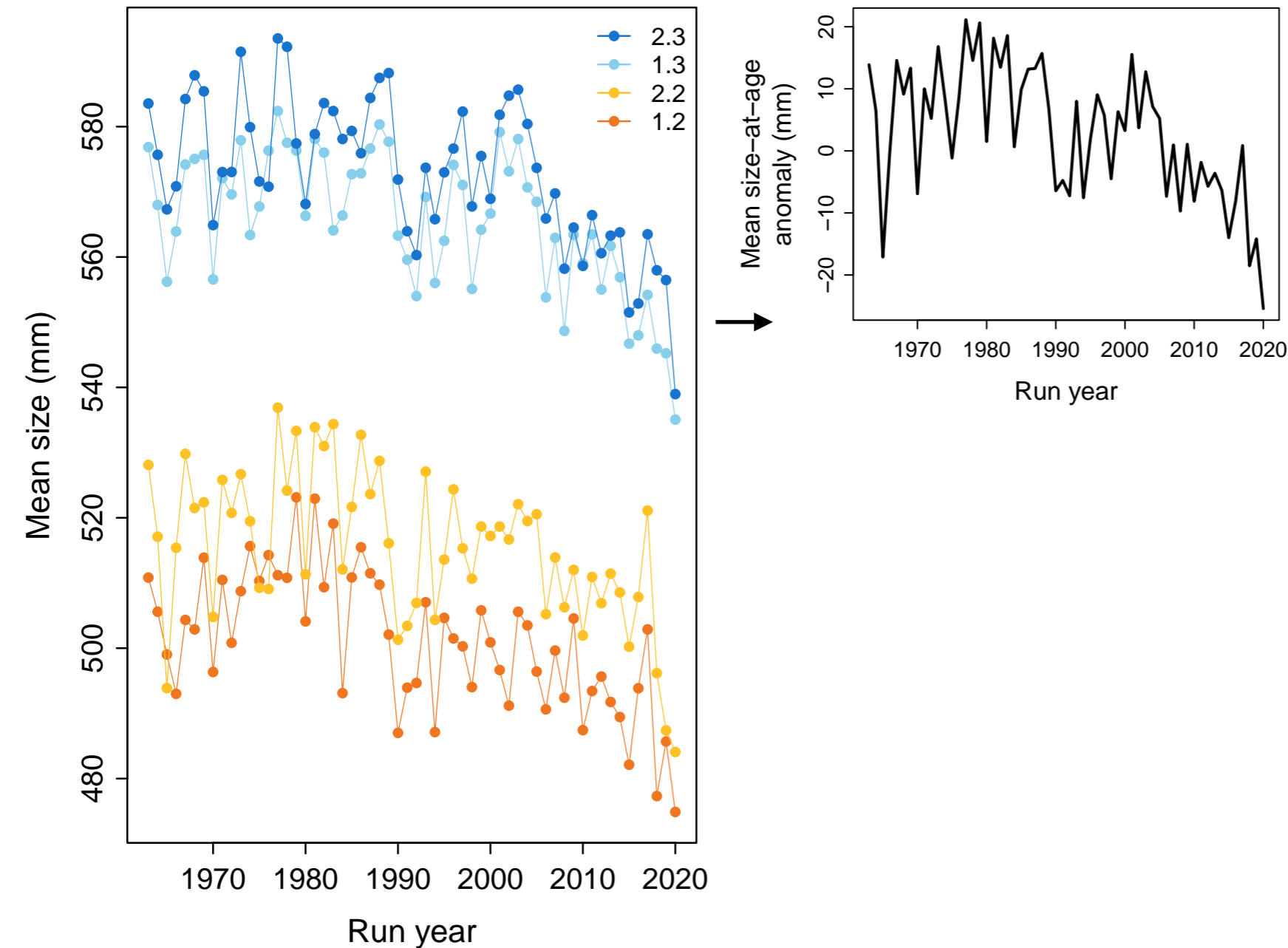
Evidence that interspecific competition contributes to longer ocean residence

Sockeye salmon in Bristol Bay

Effects of competition and climate on size

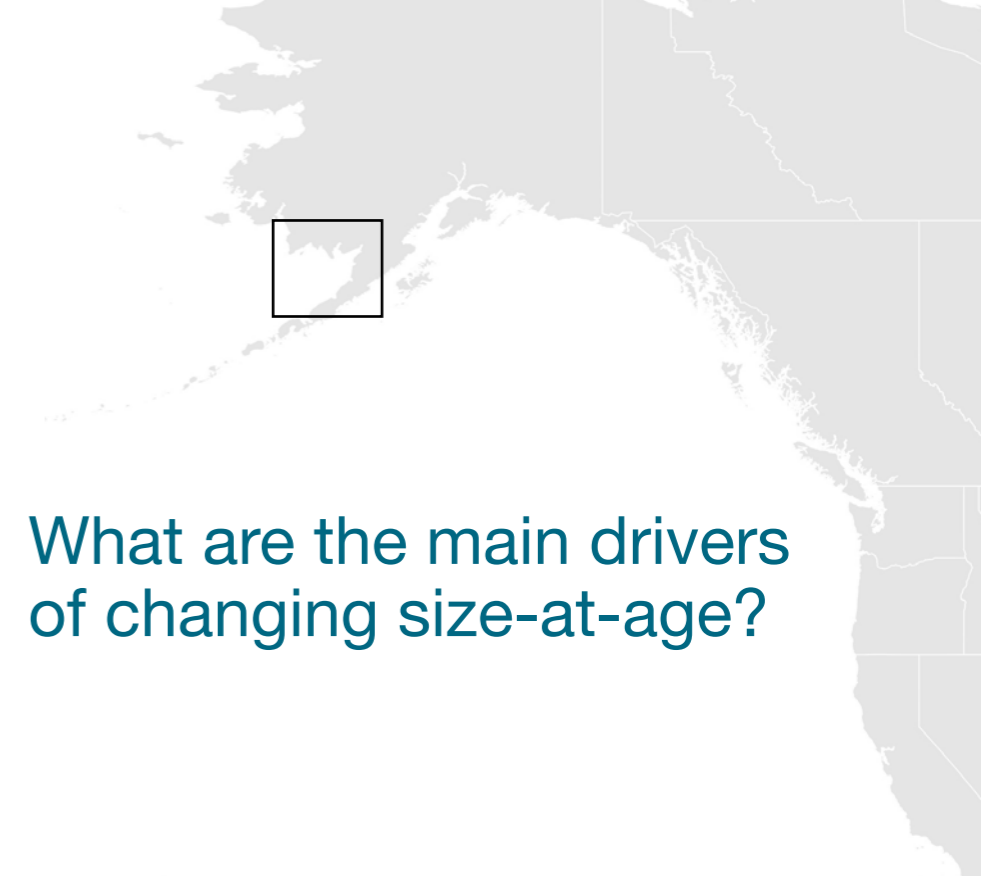


What are the main drivers of changing size-at-age?

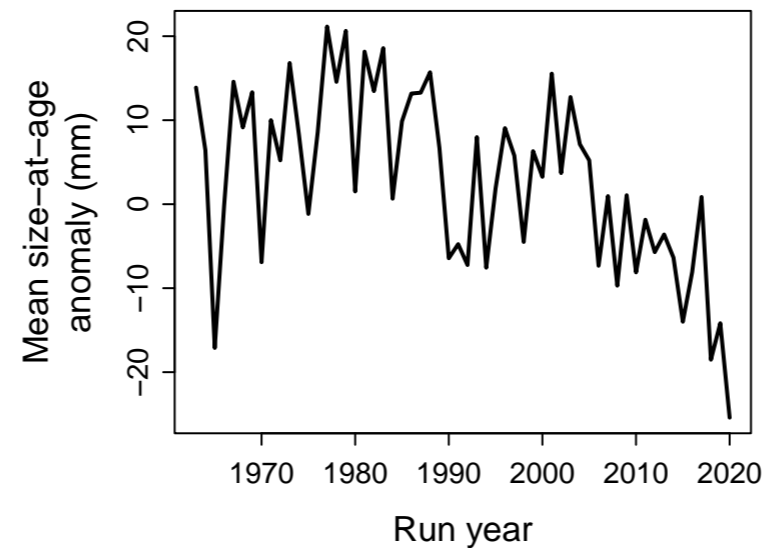


Sockeye salmon in Bristol Bay

Effects of competition and climate on size



What are the main drivers of changing size-at-age?



Competition

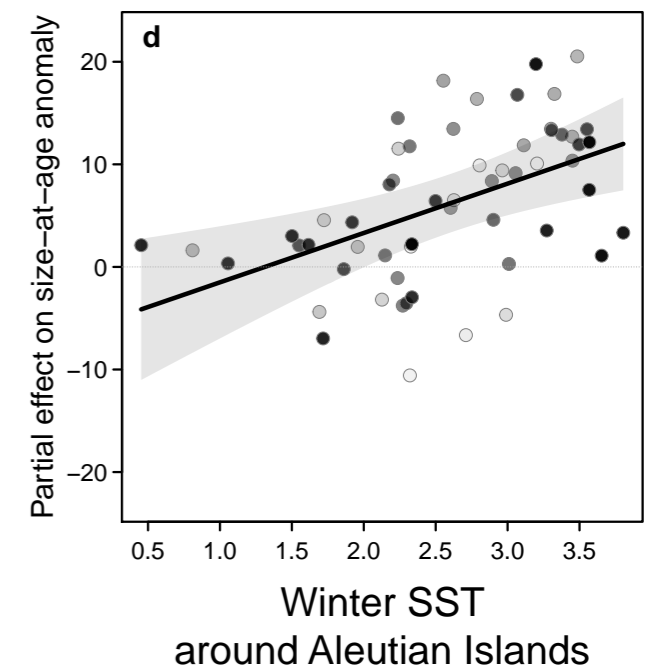
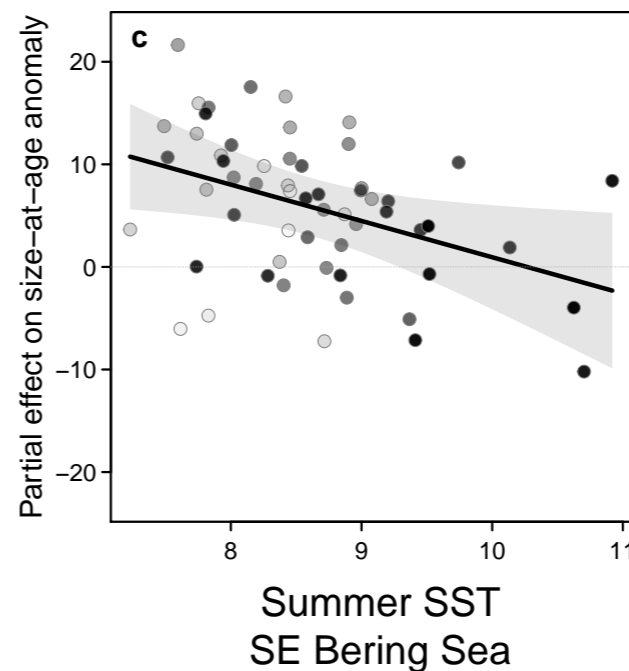
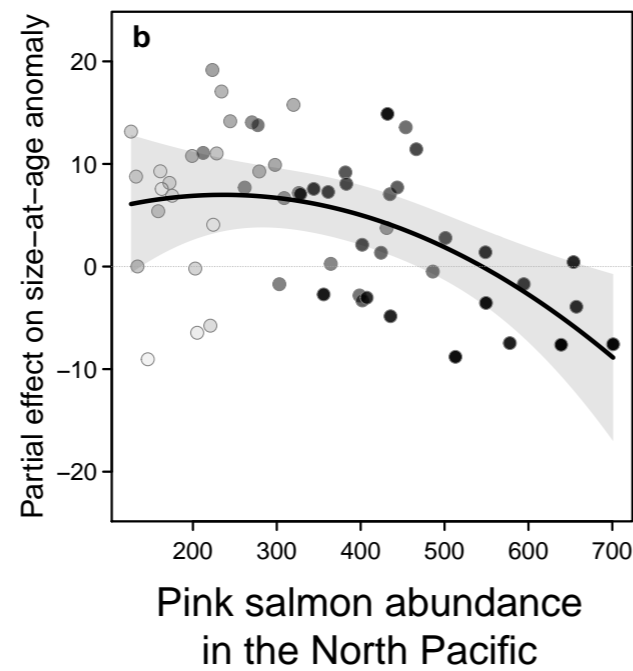
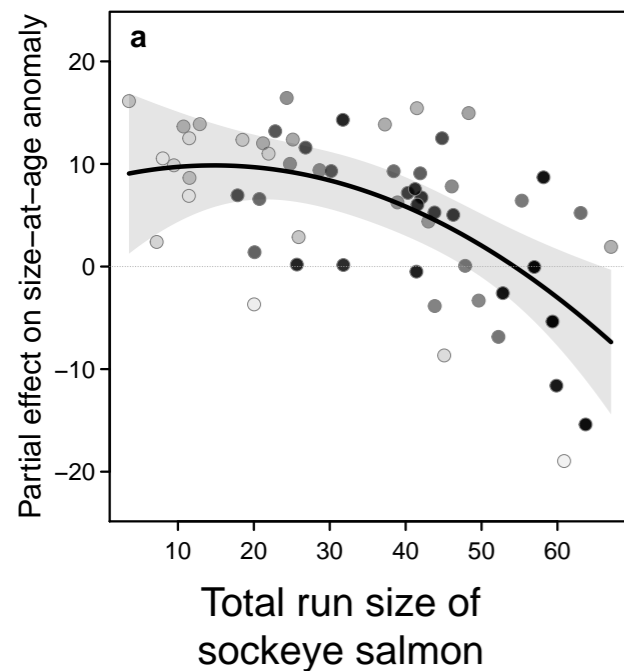
Climate

Intraspecific

Interspecific

Summer

Winter

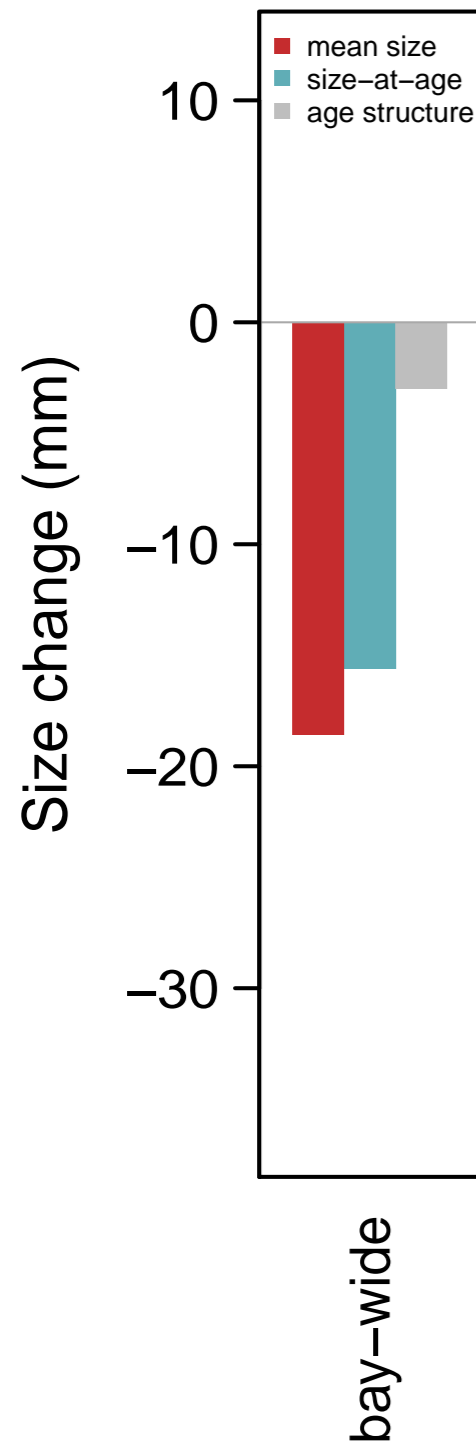


Ohlberger et al. *unpublished*

Evidence for negative effect of competition and season-specific temperature effects

Sockeye salmon in Bristol Bay

Effects of competition and climate on size



What are the contributions of shifts in size-at-age vs age structure to changes in mean body size?

Changes in size-at-age

Changes in age structure

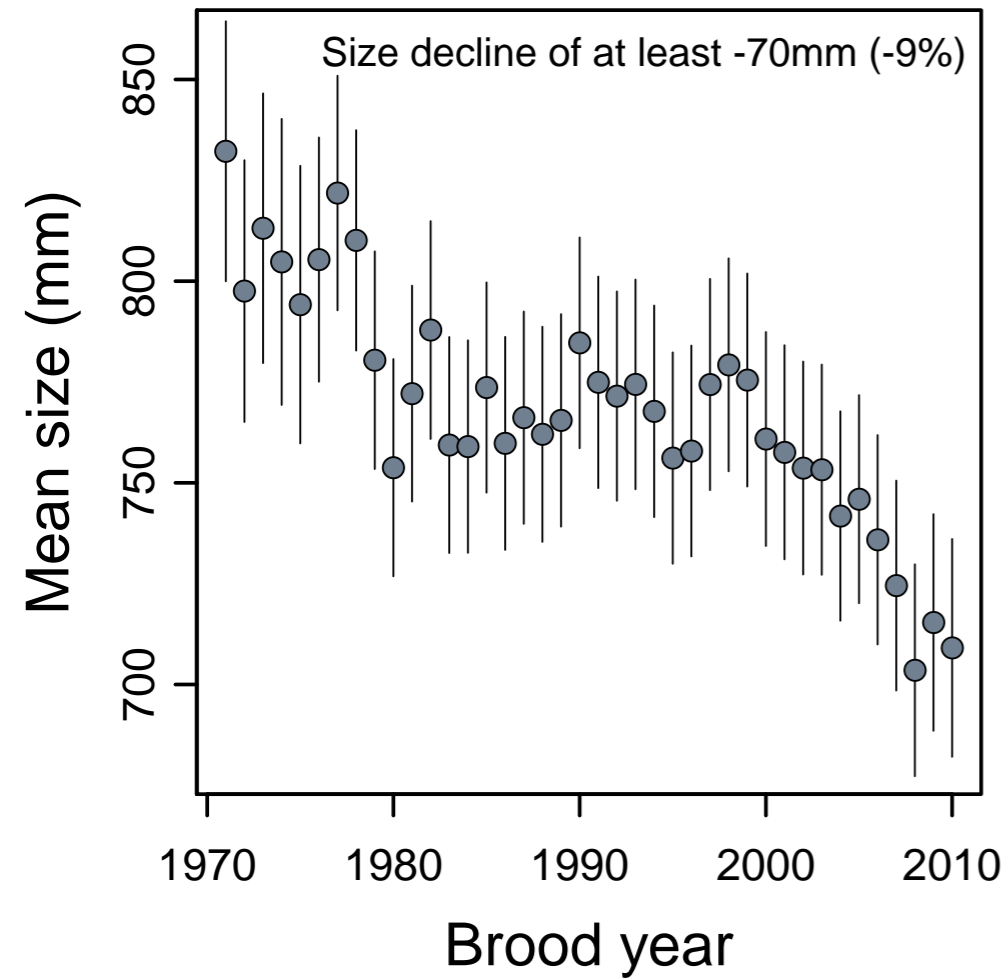
Changes in mean size

Ohlberger et al. *unpublished*

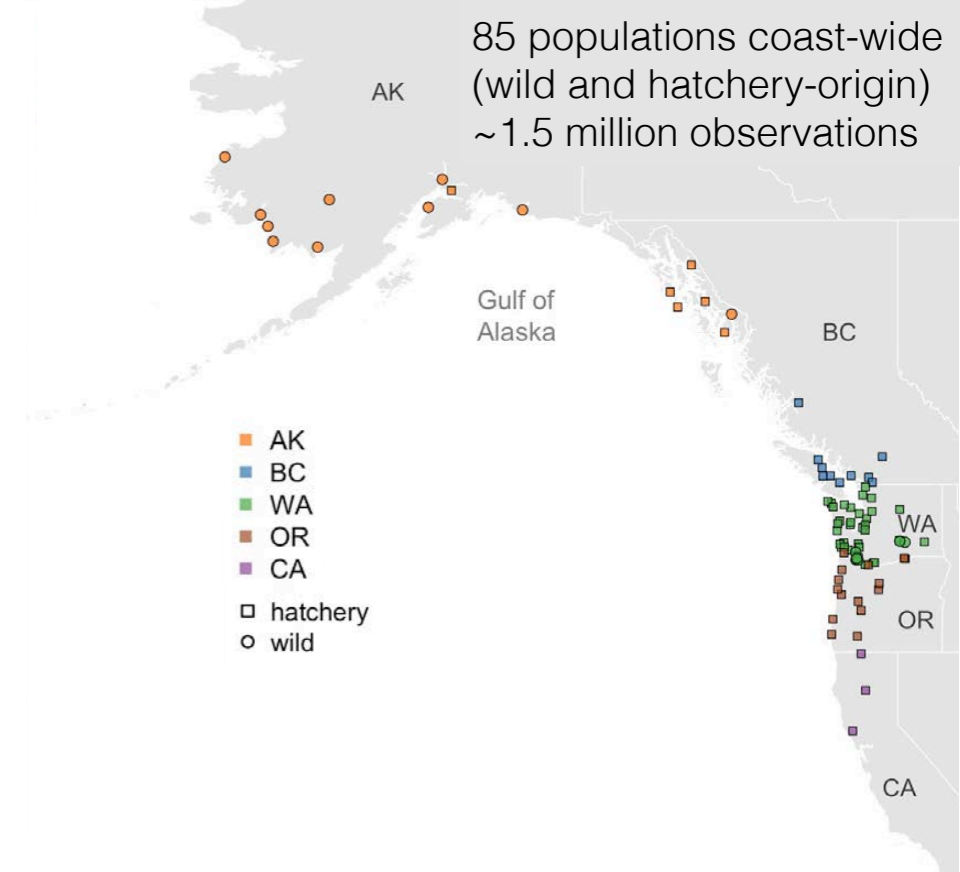
Shifts in size-at-age were the main contributor to changes in mean body size

Chinook salmon coast-wide

Declines in mean size in escapements



Climate?
Competition?
Predation?
Fishing?

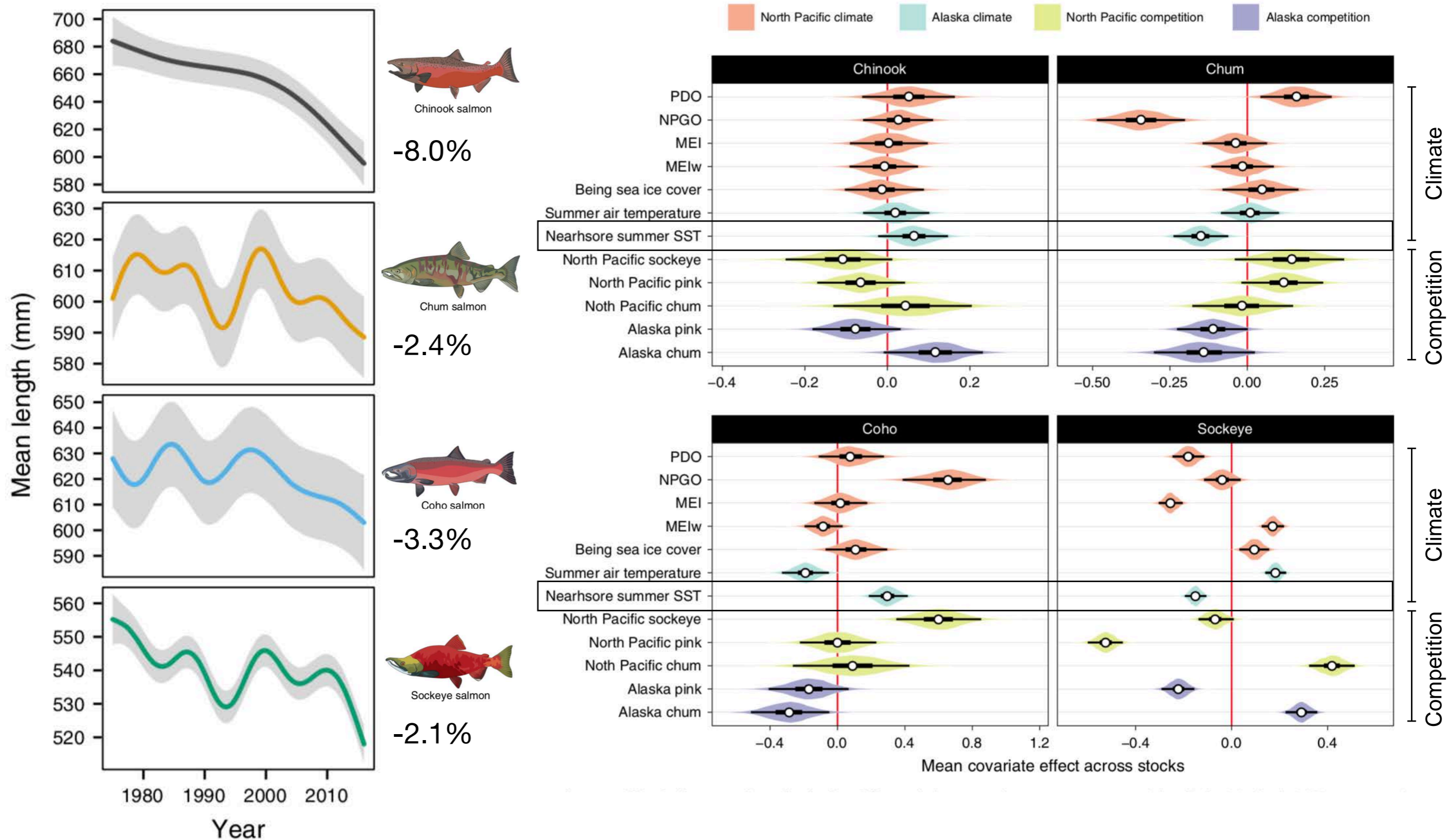


Ohlberger et al. 2019

Stronger size declines in Chinook compared to sockeye and other salmon species

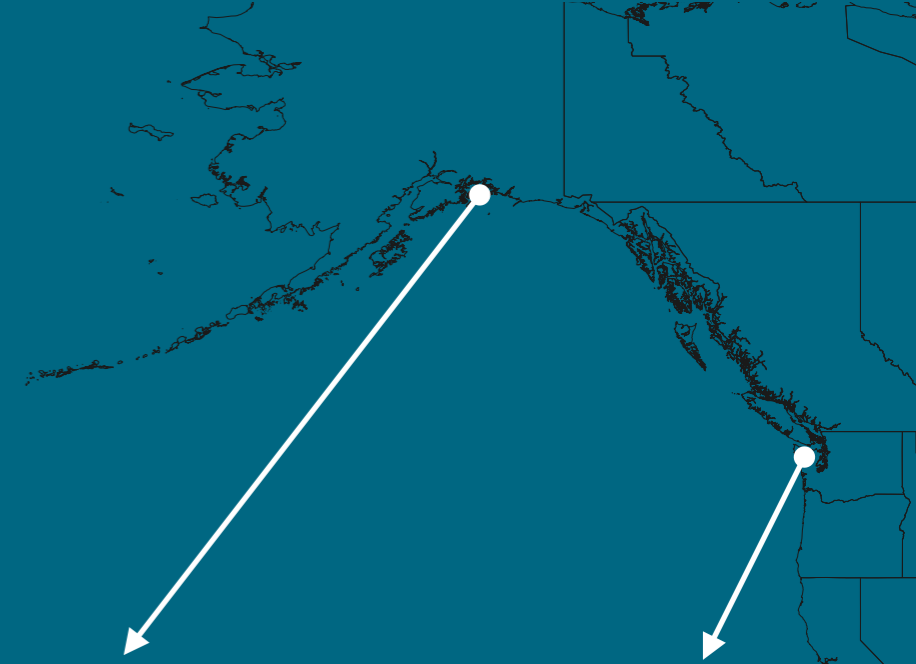
Pacific salmon in Alaska

Changes in body size of Chinook, chum, coho, and sockeye salmon (Oke et al. 2020)



Size trends and effects of climate and competition vary by species

Productivity



Pink salmon
Prince William Sound

Coho salmon
Washington coast



Photo by Jason Ching



Photo by Jason Ching



Photo by Morgan Bond



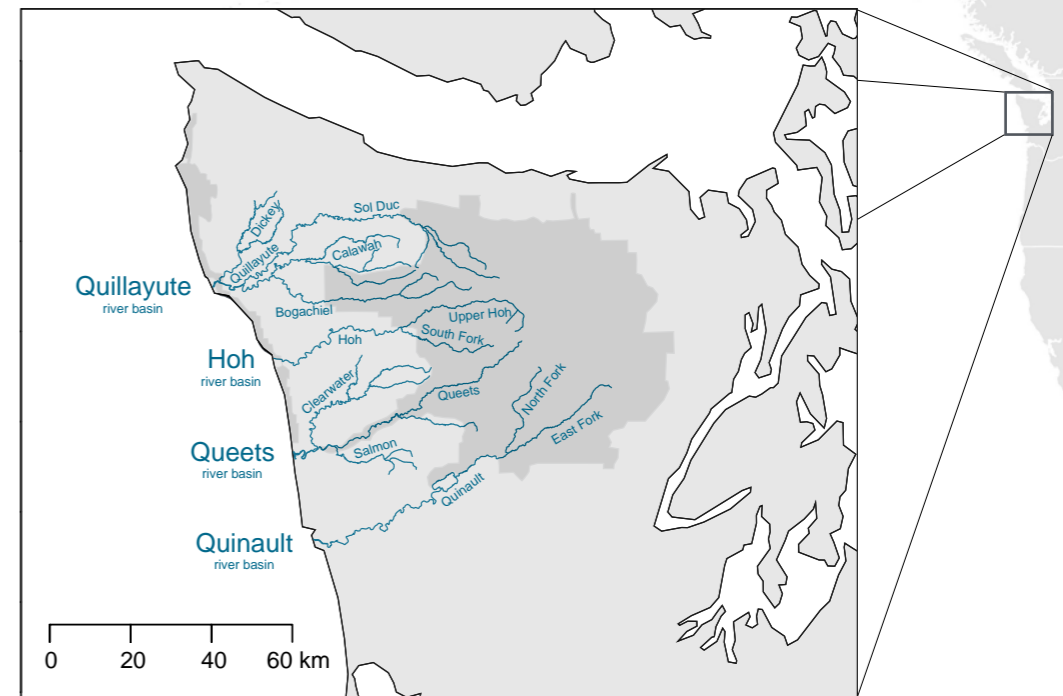
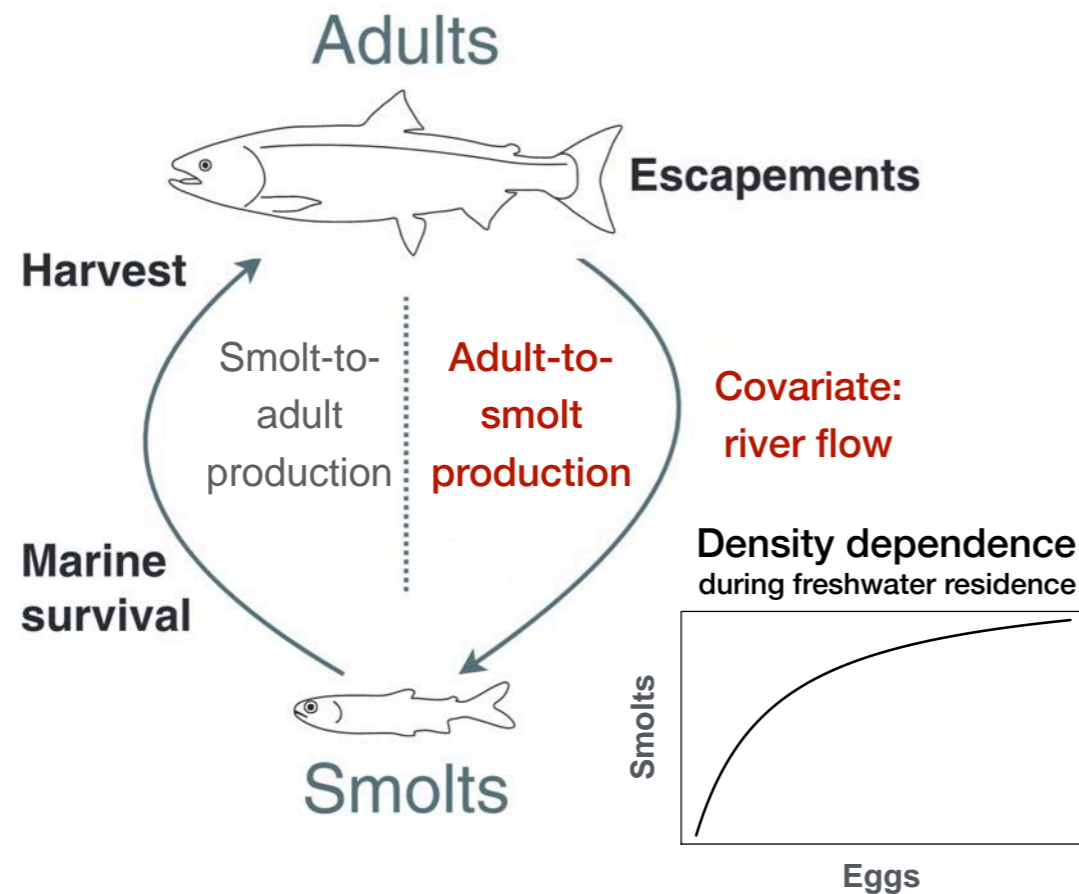
Photo by Jason Ching



Photo by Fernando Lessa

Coho salmon on the WA coast

Effects of river flow on freshwater productivity

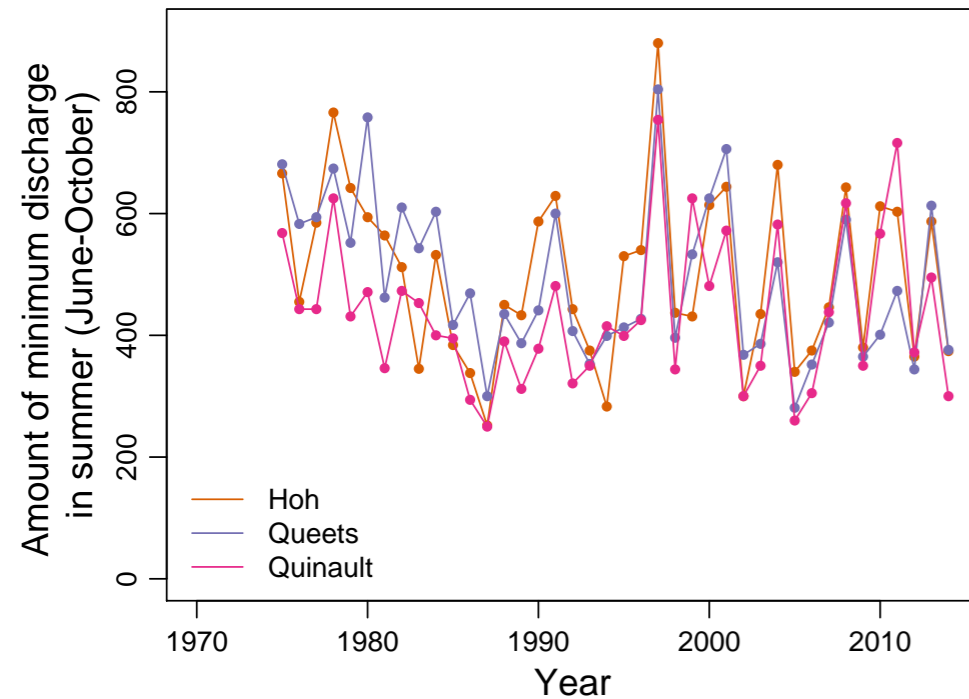


Coho salmon on the WA coast

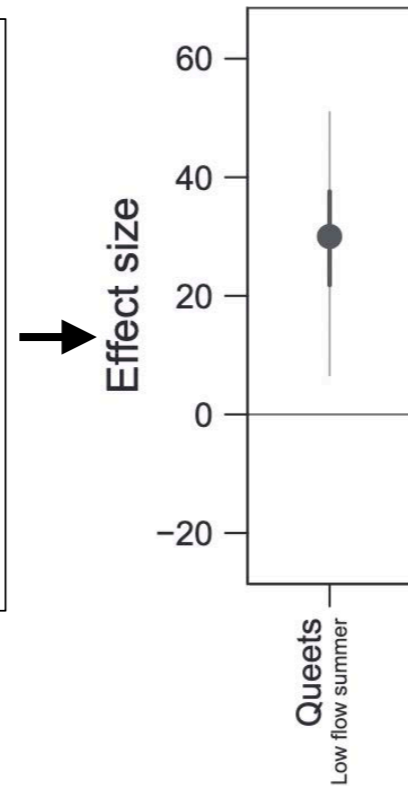
Effects of river flow on freshwater productivity



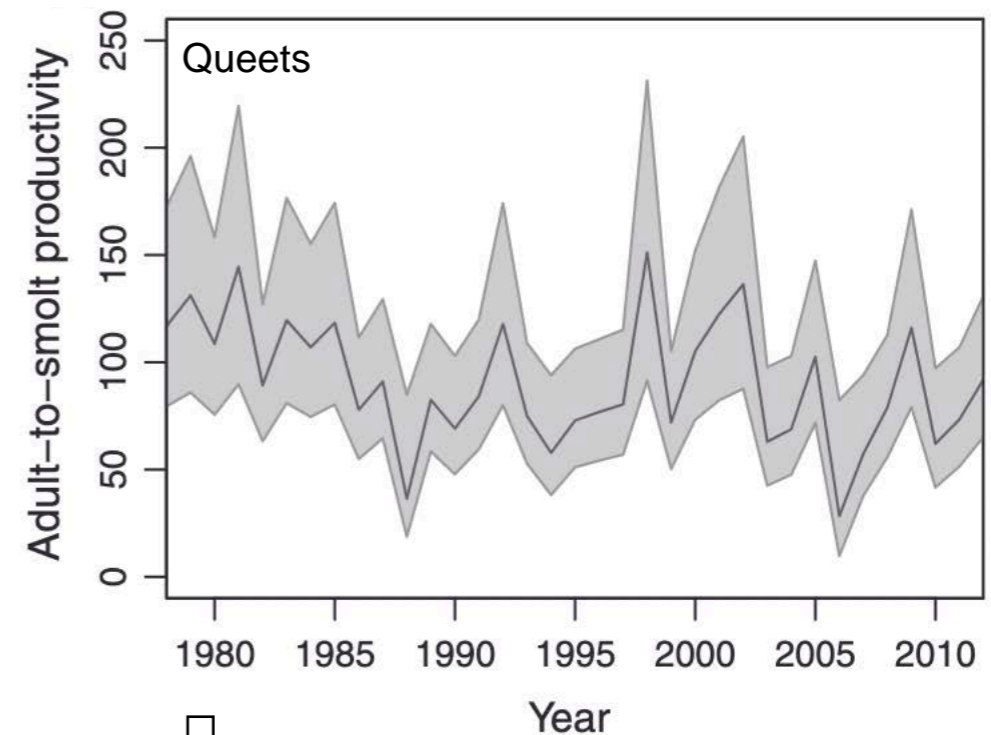
Minimum river flow (May-October)



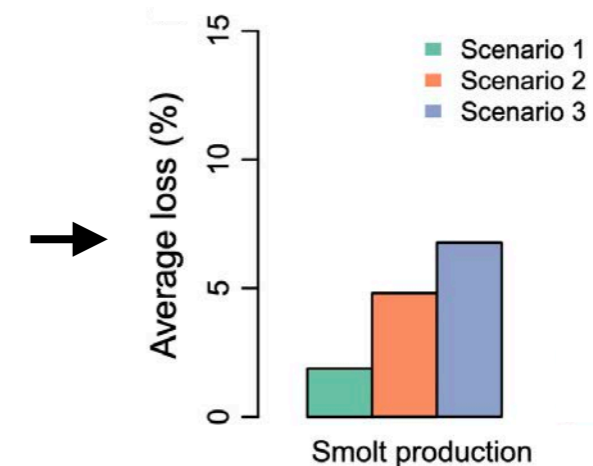
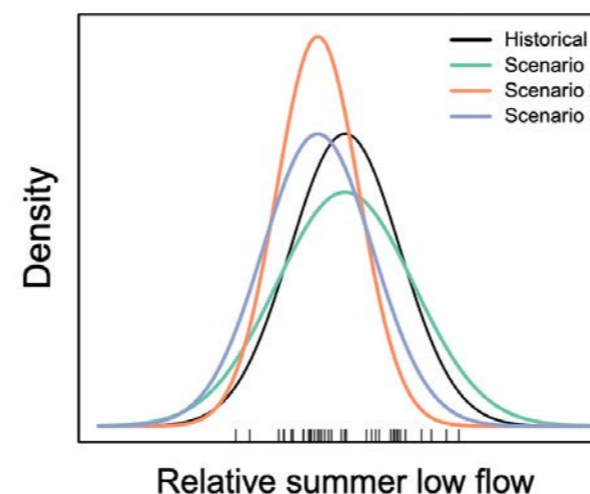
Effect on productivity



Estimated adult-to-smolt productivity



Simulated loss in future smolt production



Ohlberger et al. 2018

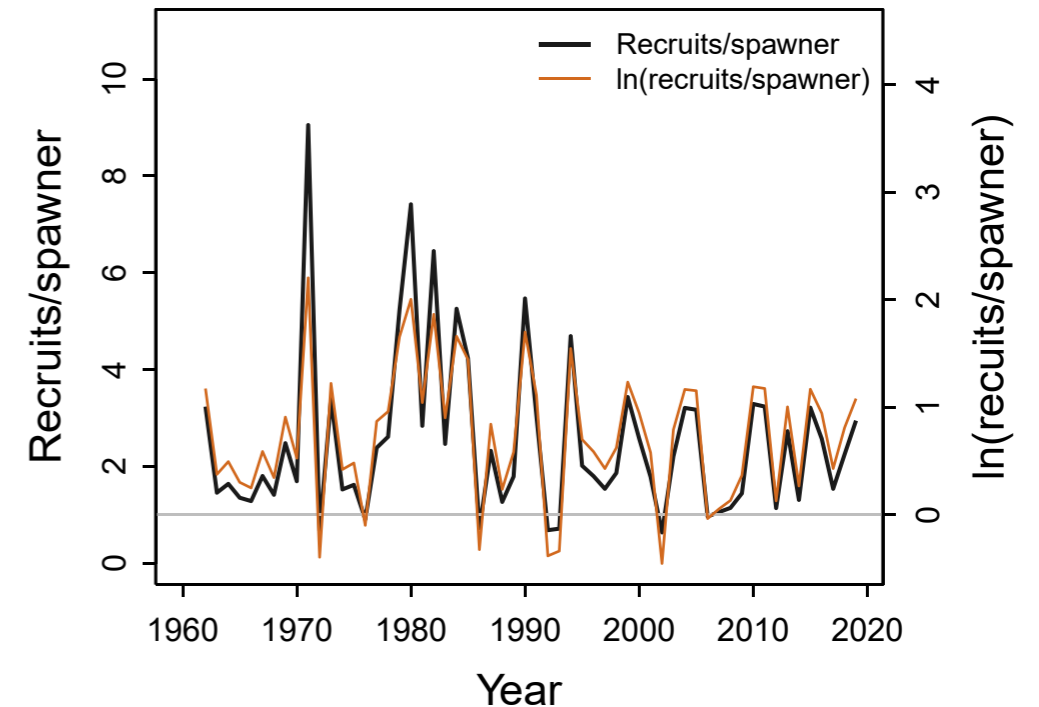
Evidence that extreme low flows during summer decrease freshwater productivity

Pink salmon in PWS

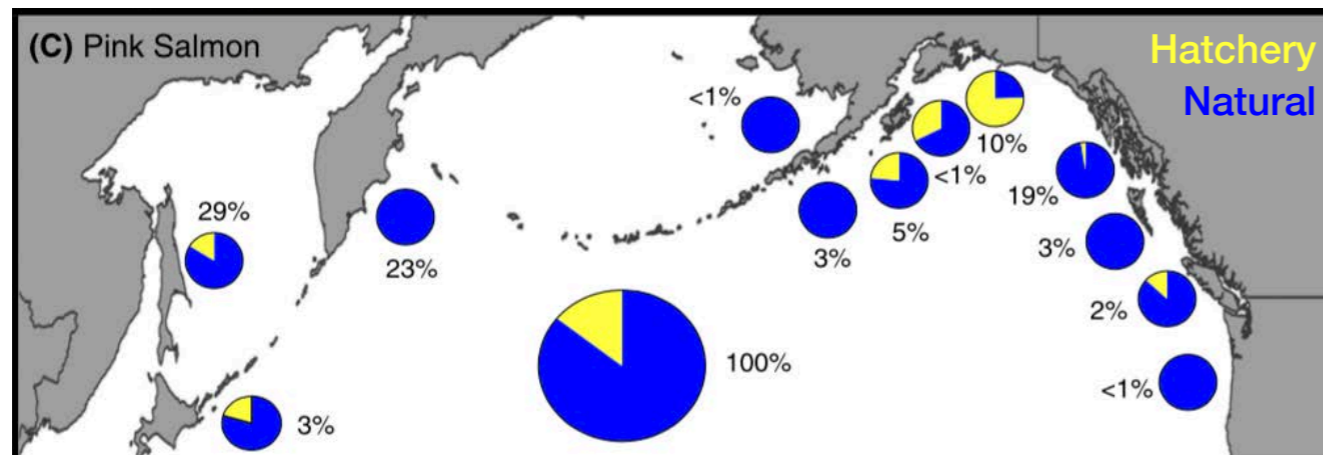
Effects of climate and competition on wild pink salmon productivity

Are wild pink salmon impacted by climate warming, ocean acidification, and/or competition with hatchery pinks?

PWS wild pink salmon productivity
measured as $\ln(\text{recruits/spawner})$



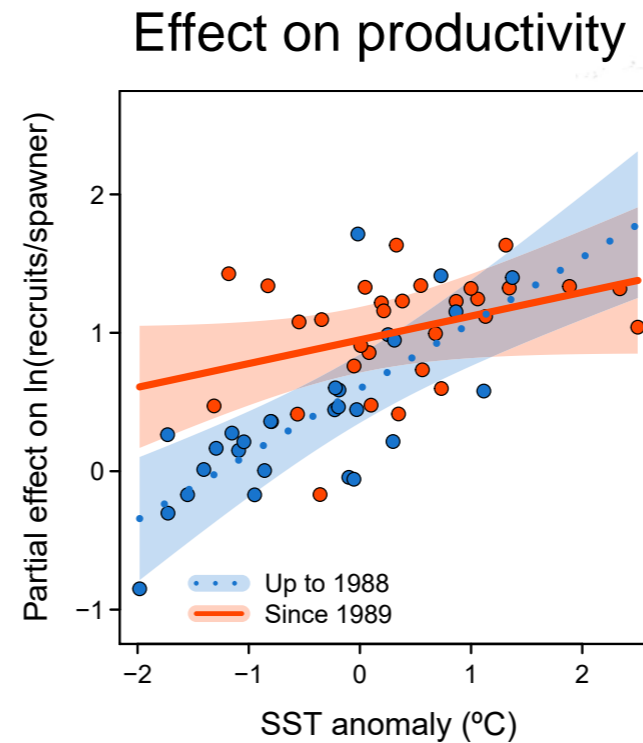
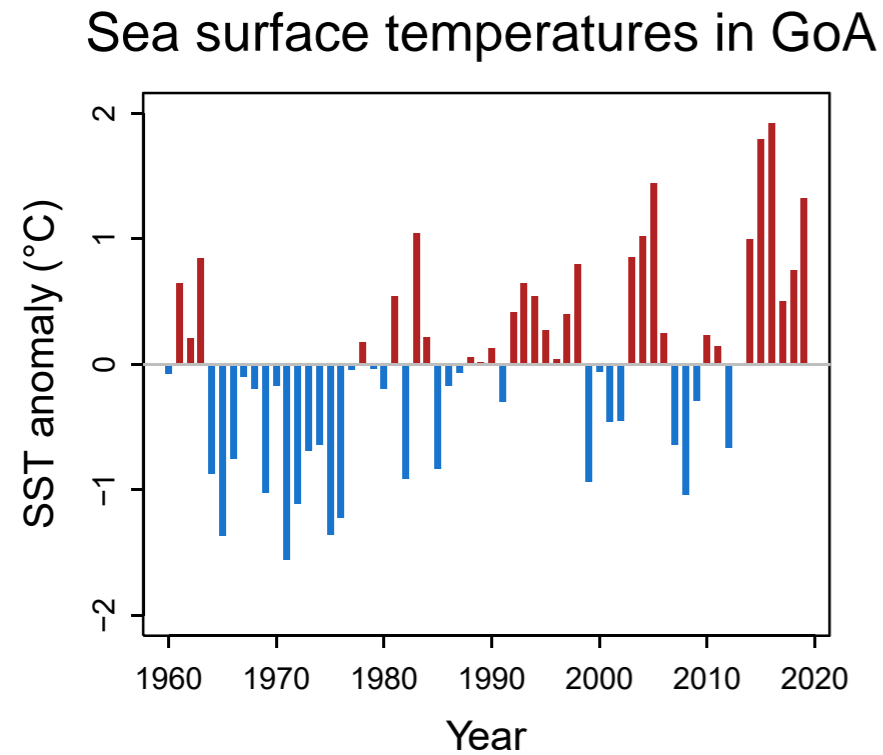
Majority of pink salmon returns are natural-origin, except in PWS



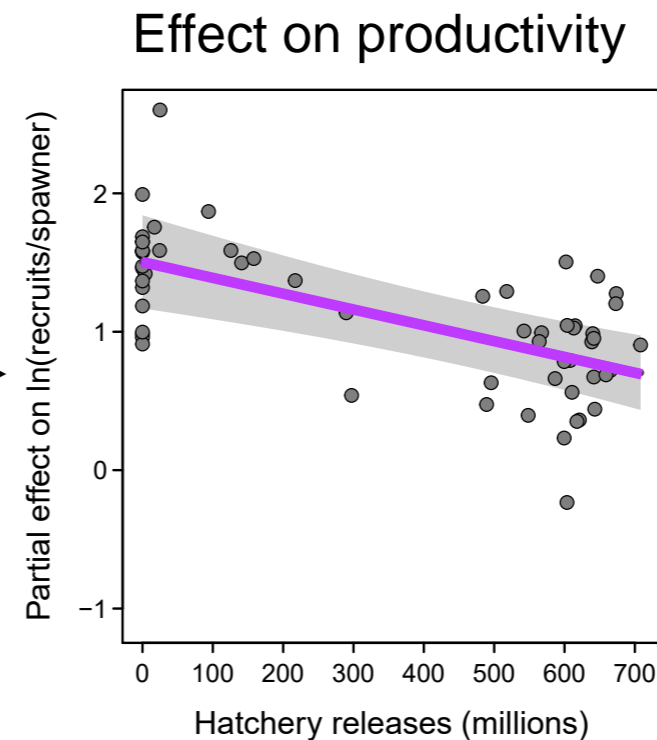
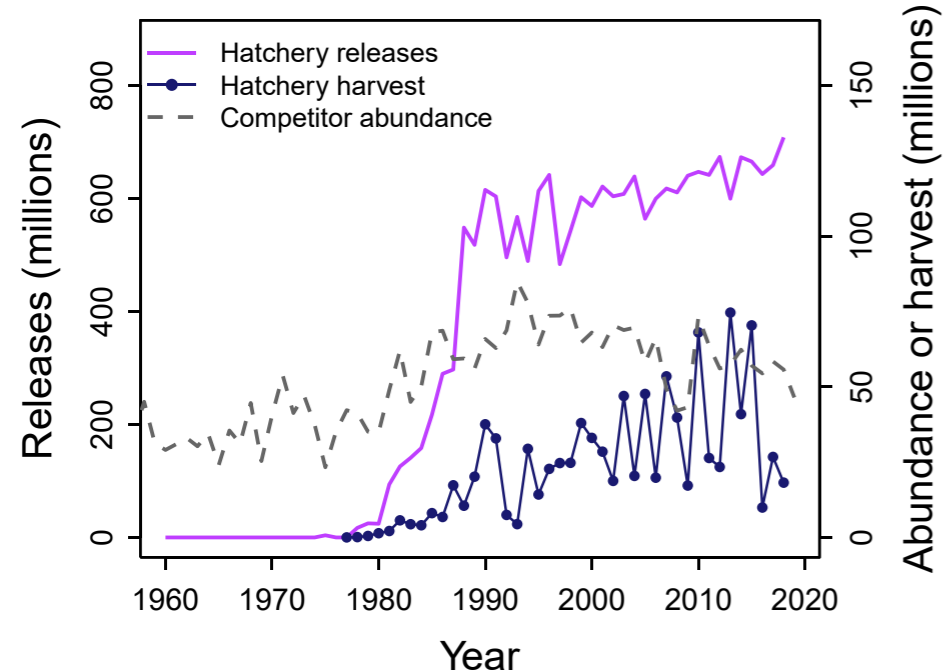
Source: Ruggerone and Irvine 2018

Pink salmon in PWS

Effects of climate and competition on wild pink salmon productivity



Hatchery releases of PWS pink salmon

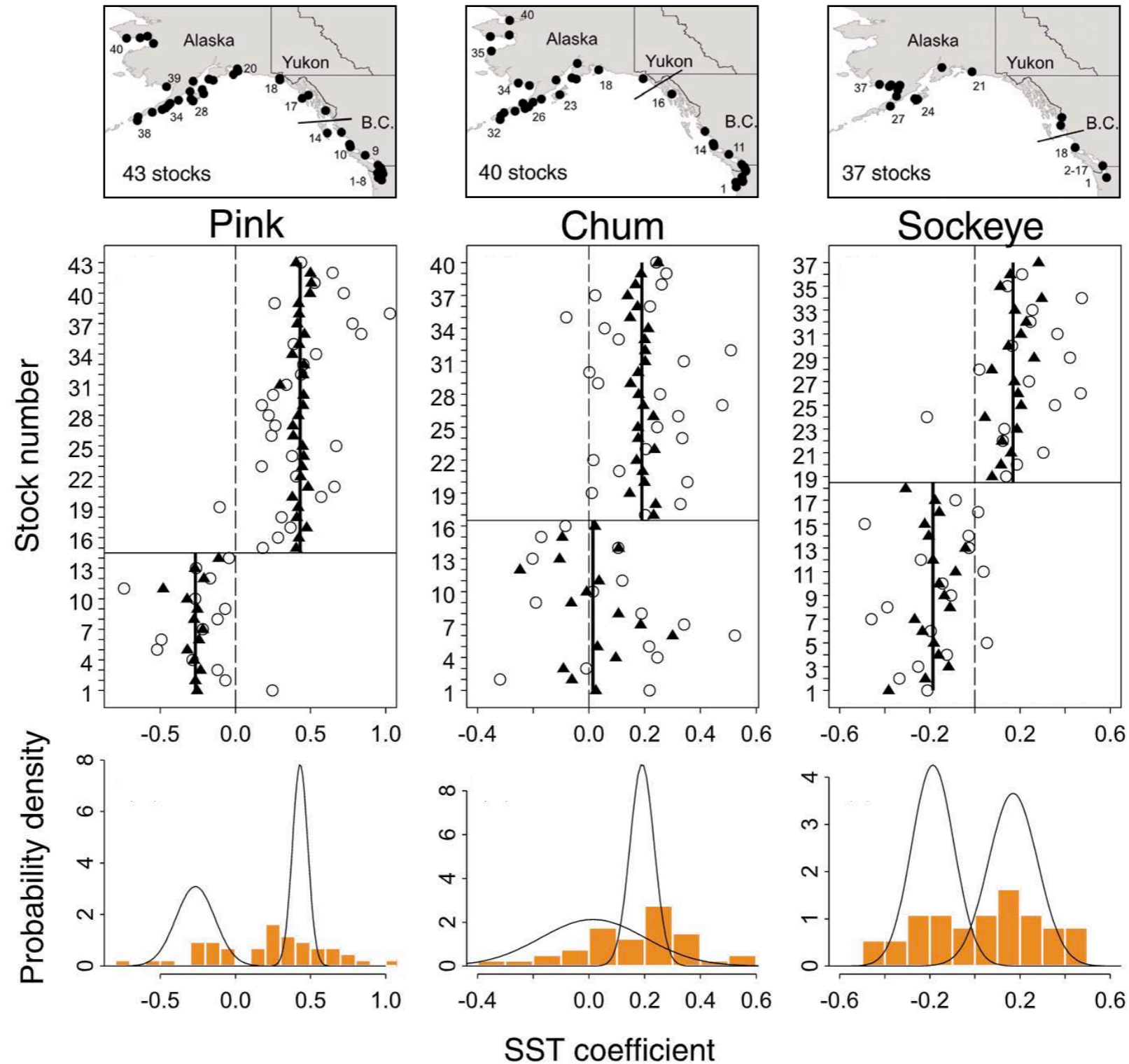


Ohlberger et al. 2022

Evidence for negative effects of hatchery production and non-stationary climate effects

Pacific salmon coast-wide

Effects of SST on pink, chum, and sockeye salmon productivity (Mueter et al. 2002)



Large-scale spatial variation in magnitude and direction of climate effects

Conclusions

- Climate and competition affect population productivity but also life-history traits and demographic structure
- Salmon growth and survival at sea are impacted by competition within species and among species
- Effects of climate change can vary by life-stage, season, latitude, species, and may be non-stationary



Outlook

Challenges in salmon research, conservation, and management

1. Limited inference about the ocean ecology of salmon

- ▶ How do we best manage based on incomplete information (e.g. correlations rather than process studies)?
- ▶ Are experimental manipulations at the basin-wide scale possible (e.g. changing hatchery production)?

2. Promoting climate resilience of salmon populations

- ▶ Which management strategies or conservation actions are most likely to promote the biological diversity of stocks, life-histories, genetics?
- ▶ Given climate change, where is recovery of at risk populations likely to be possible over the next few decades?

3. Monitoring and managing populations for ecosystem change

- ▶ How can we build flexible systems that can detect and respond to ongoing ecosystem changes?

4. Uncertainty in population models and future projections

- ▶ How certain are projections for unobserved ecosystem states (e.g. extreme events, tipping points, non-linearities, 'no analogue' futures)?
- ▶ What are the most robust strategies for assessing and managing populations given large knowledge gaps and limitations in predicting the future?