

# Effects of warming climate and competition in the ocean for life-histories of Pacific salmon



Timothy J Cline  
Jan Ohlberger  
Daniel E. Schindler

School of Aquatic and Fishery Sciences  
University of Washington

# Biodiversity > species diversity



Species



Populations



Life-history



Individual

Biological diversity stabilizes ecosystems

Cline et al. 2019



# Life-history diversity



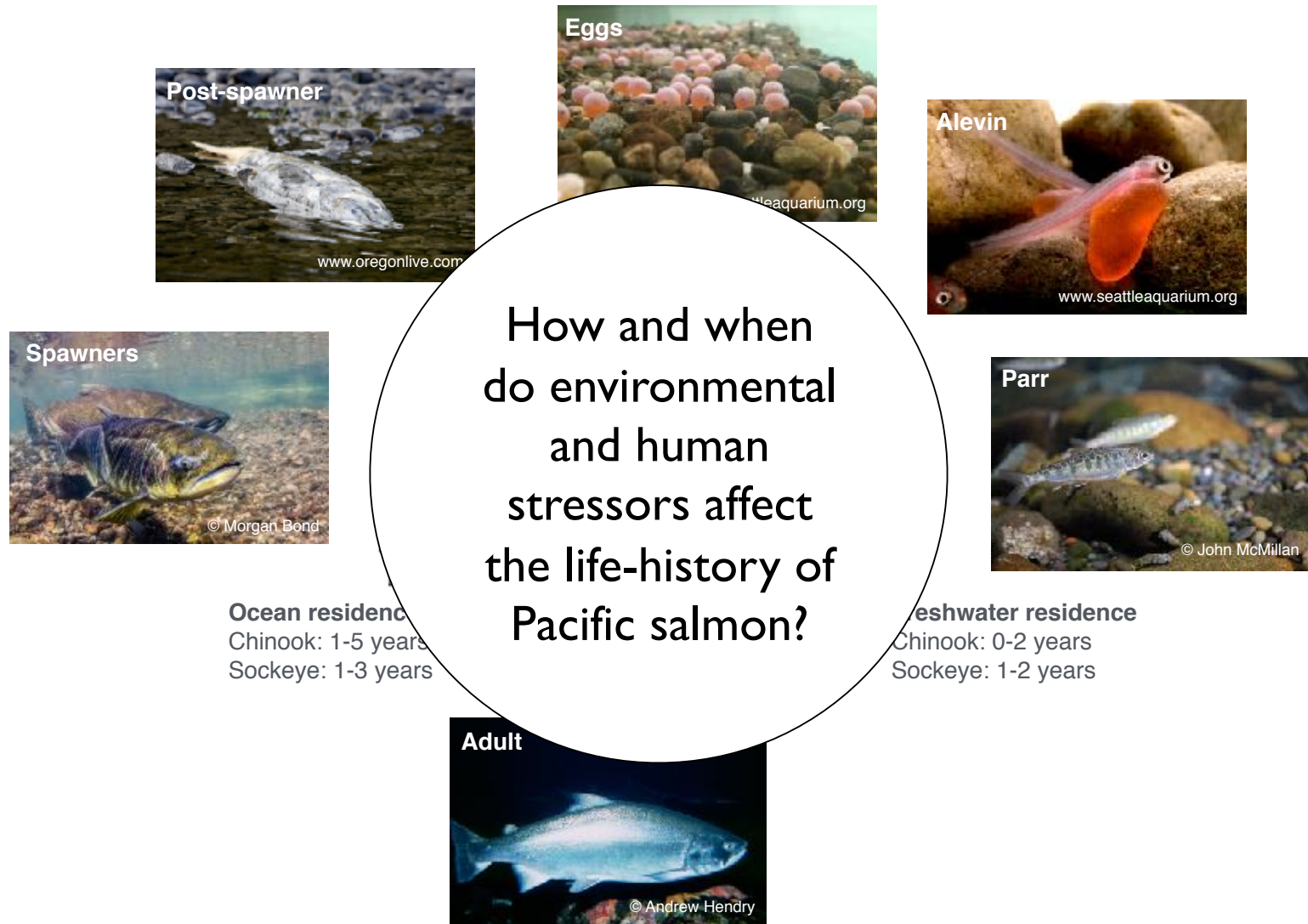
Reduces the chance that an entire cohort encounters unfavorable or catastrophic environment

Age structured salmon populations are 2x more stable  
(Schindler et al. 2010, *Nature*)

Cline et al. 2019

# Salmon life-cycle

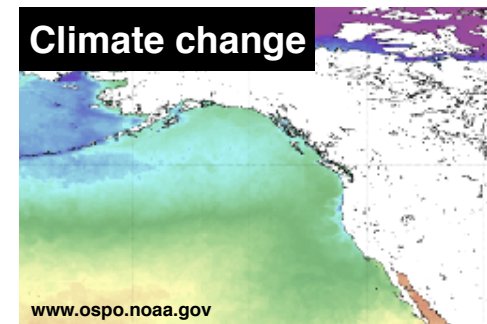
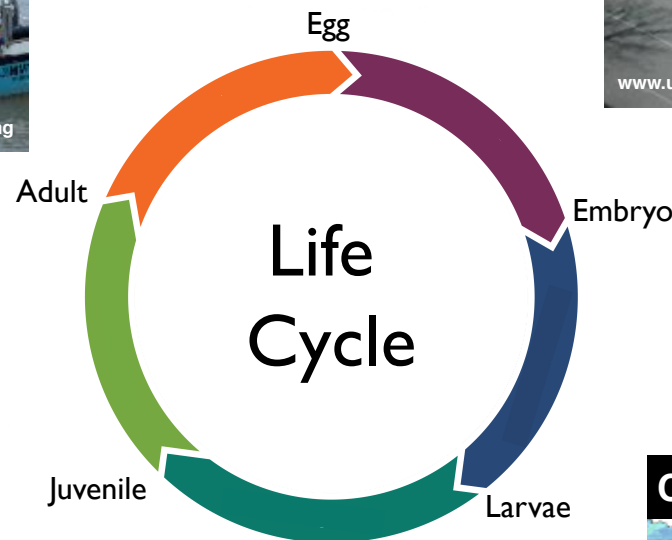
A complex life-cycle with multiple stages and long-distance migrations





# Global change

Multiple human and natural stressors affect growth, survival, reproduction





1. Have there been changes in the prevalence of certain life-history strategies of Pacific salmon over time?

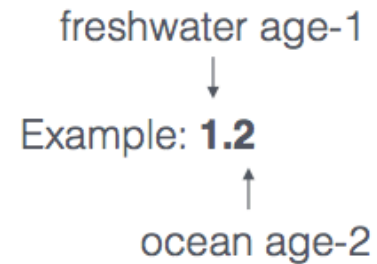
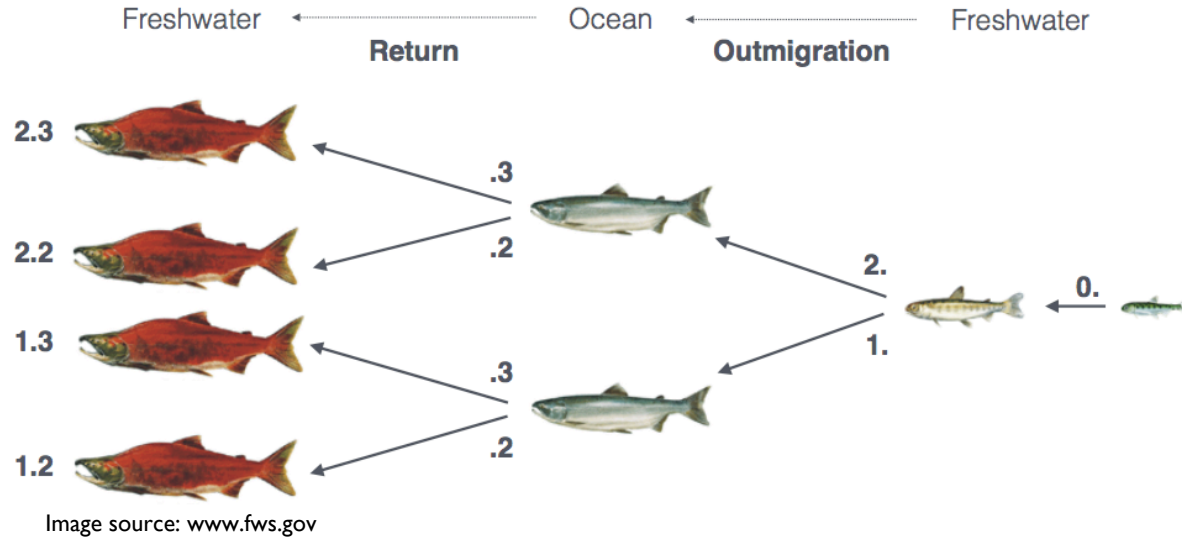
2. Can changes in life-history be described by climate or other anthropogenic stressors?

3. Which life-stages are affected and are these effects independent?

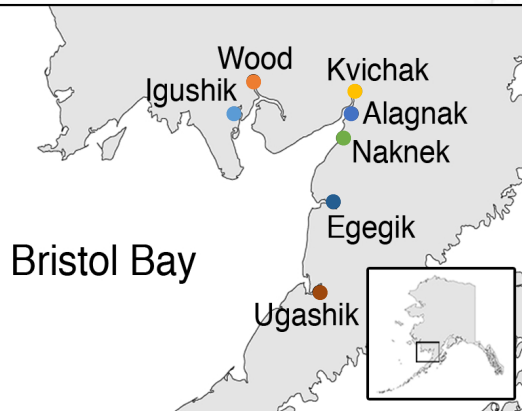




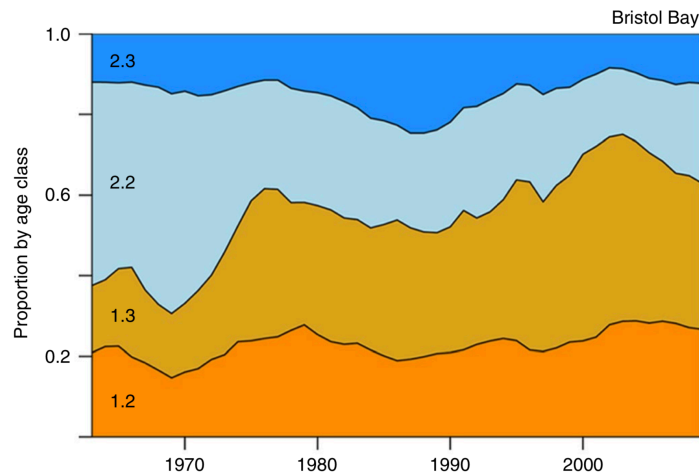
# Sockeye salmon life-history diversity



# Alaska



- 50-60 million fish returned in recent years
- Over 50% of run is typically harvested
- ~50% of global annual sockeye harvest

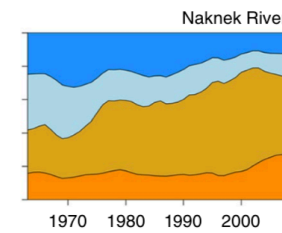
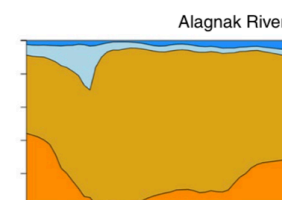
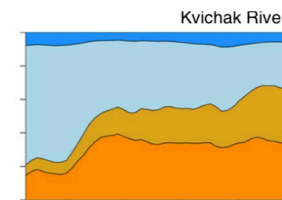
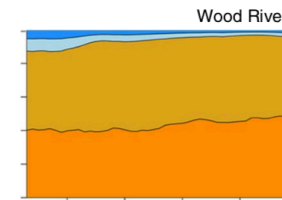
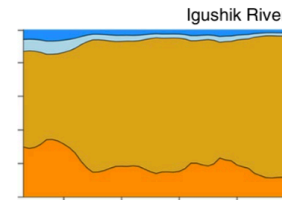
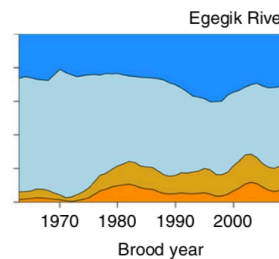
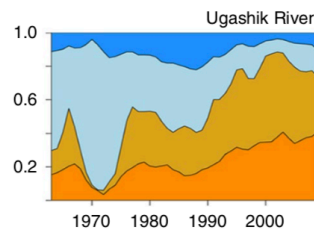
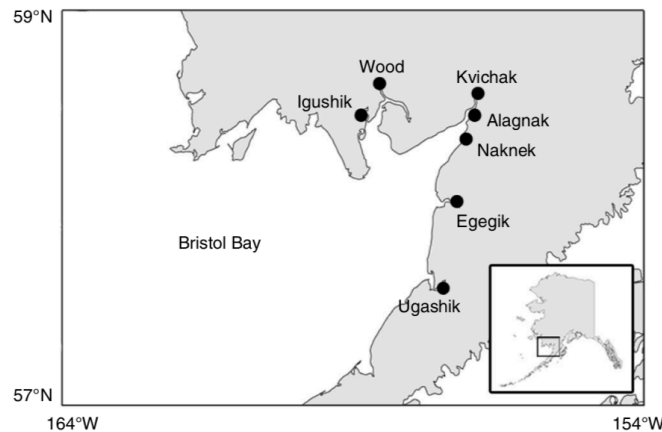
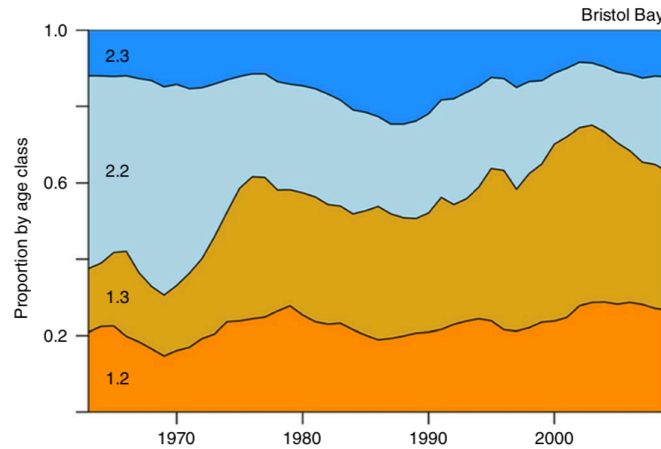
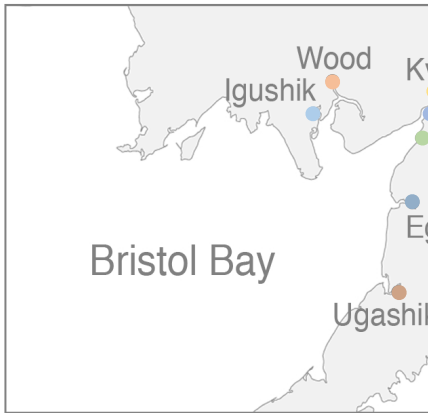


>95% of all returning sockeye belong to 4 age groups (1.2, 1.3, 2.2, 2.3)

Intact habitats and sustainably managed fisheries

Cline et al. 2019

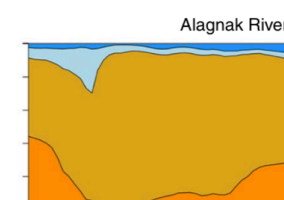
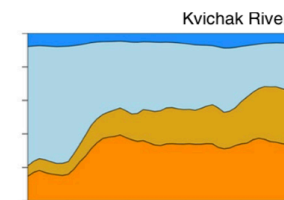
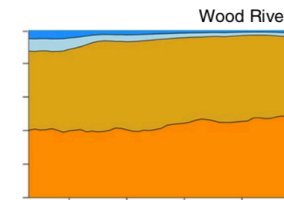
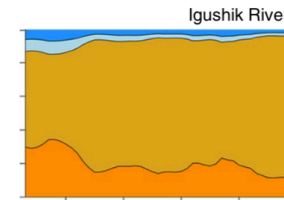
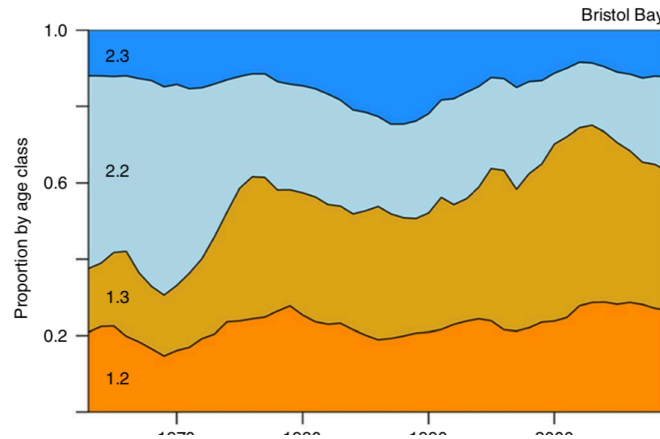
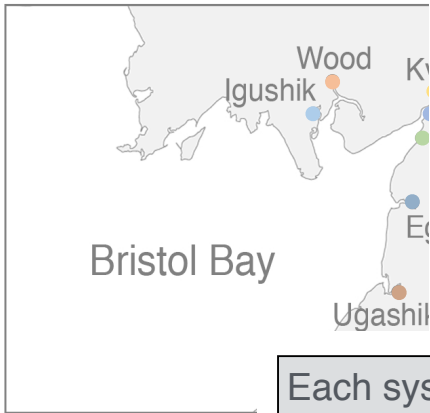




>95% of all returning sockeye belong to 4 age groups (1.2, 1.3, 2.2, 2.3)

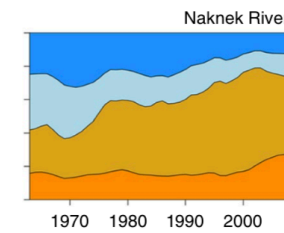
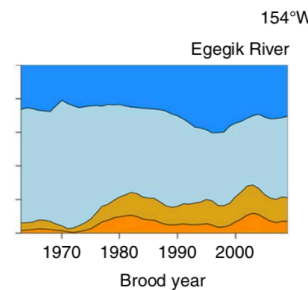
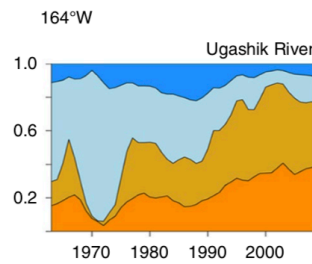
Intact habitats and sustainably managed fisheries

Cline et al. 2019



Each system has its characteristic age structure

- ➔ Multivariate autoregressive state-space model (MARSS) fit to both life-stages:
  - 1) Proportion **freshwater** age-1 (vs. age-2)
  - 2) Proportion **ocean** age-3 (vs. age-2)
- ▶ Linear combinations of (shared) autocorrelated processes and **covariates**



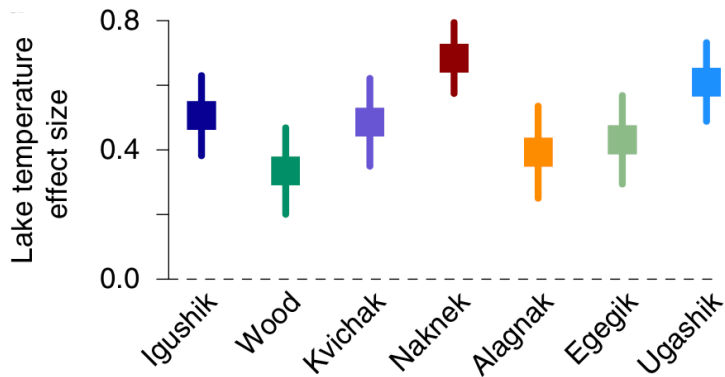
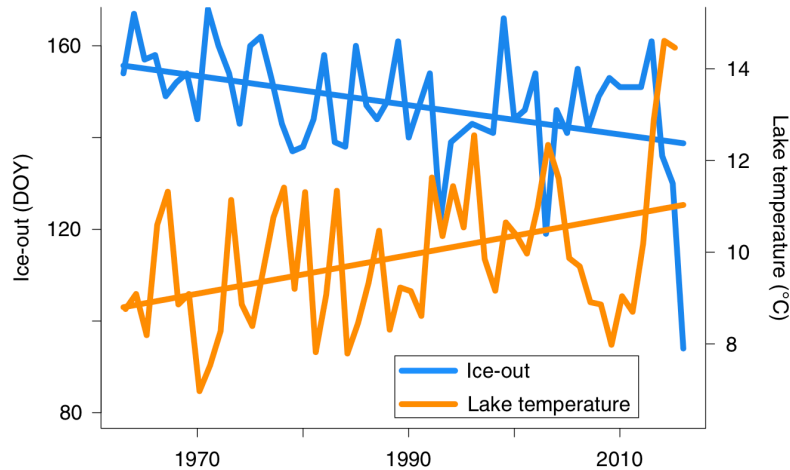
>95% of all returning sockeye belong to 4 age groups (1.2, 1.3, 2.2, 2.3)

Intact habitats and sustainably managed fisheries



# Freshwater residence

Effect of lake temperature on proportion freshwater age-I

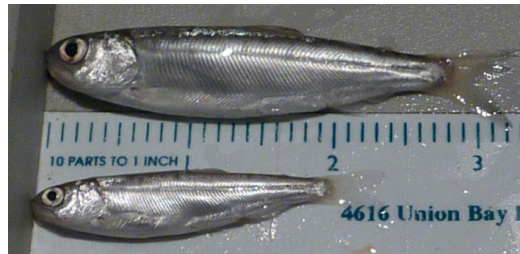
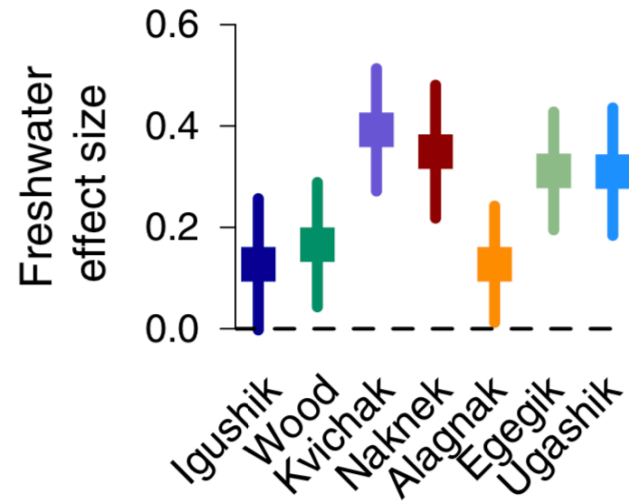
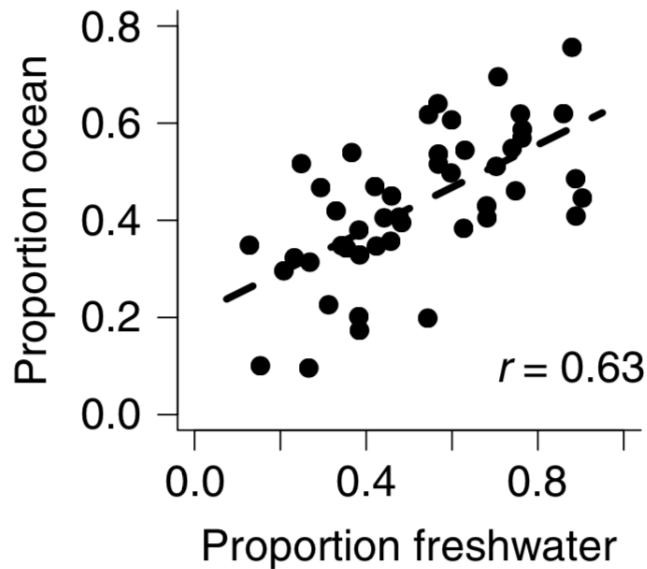


Warming nursery lakes have improved growing conditions for juvenile sockeye

Associated with earlier migration to sea  
(increased proportion I.x)

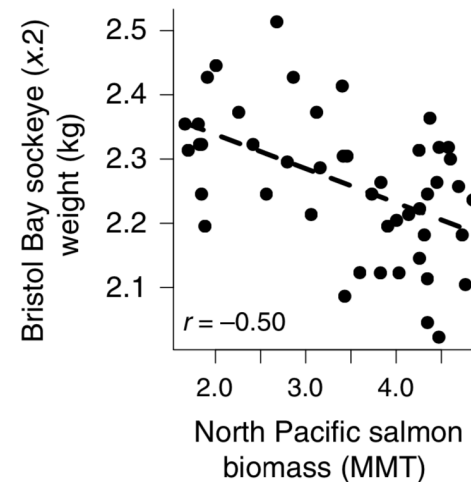
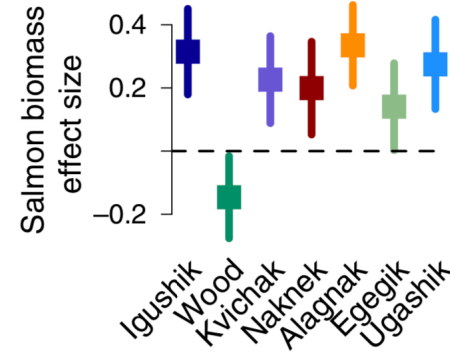
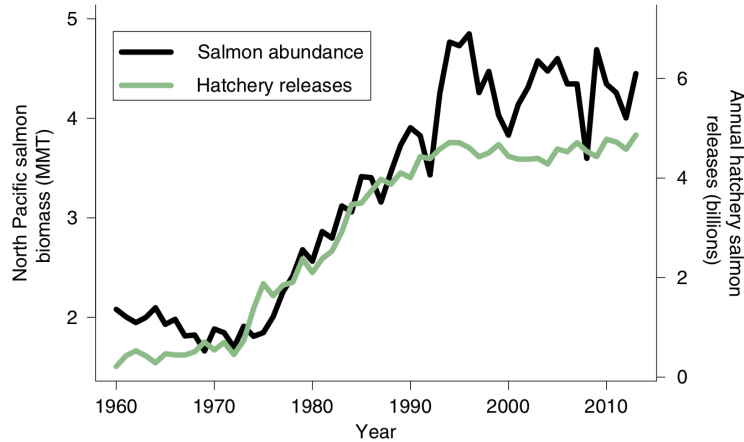
# Ocean residence

Effect of shorter freshwater residence on proportion ocean-3



# Ocean residence

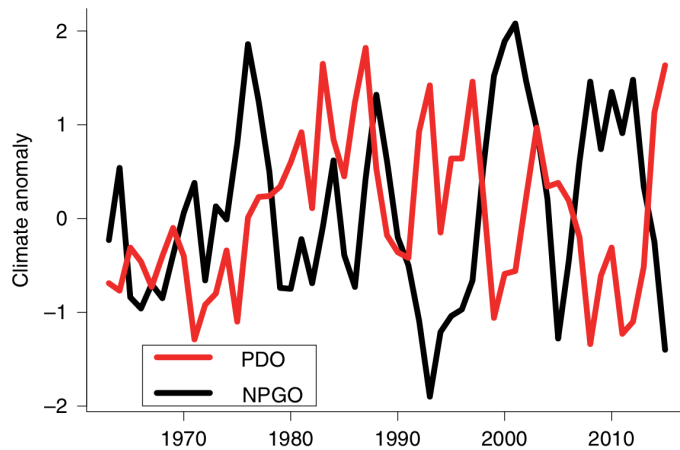
Effect of salmon biomass in the ocean on proportion ocean-3





# Ocean residence

Are there effects of ocean temperature and harvest on proportion ocean-3?

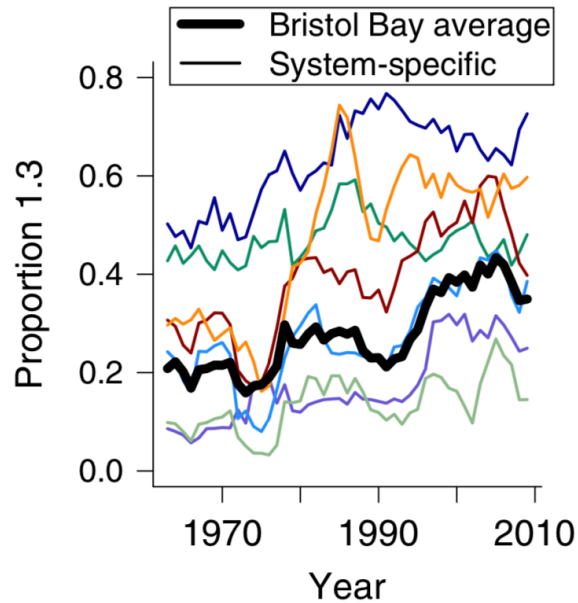


No strong evidence for NPGO and PDO

- time dependent phenomenon (Litzow et al. 2019)

No strong evidence for the influence of commercial exploitation rate on ocean age

# Changes favor single age class



Consistent increase in the proportion 1.3 across all systems



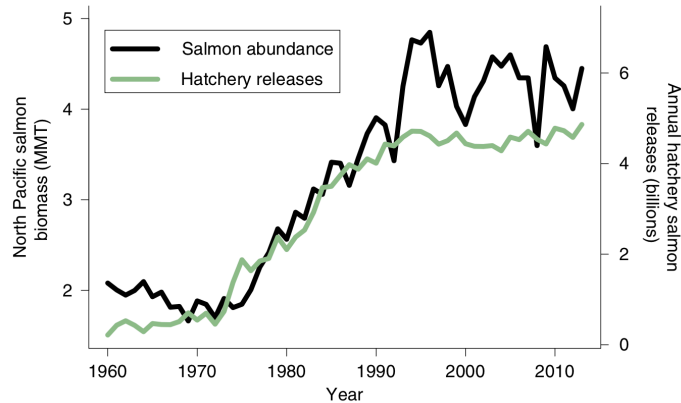
Jason Ching

Cline et al. 2019

# Carry-over effect and density-dependence

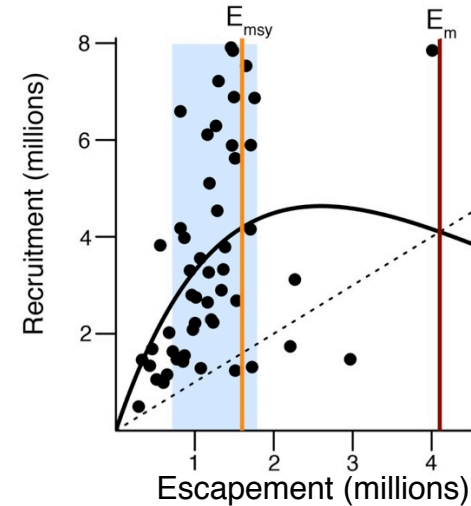
Management approach:

Produce hatchery fish to increase yield



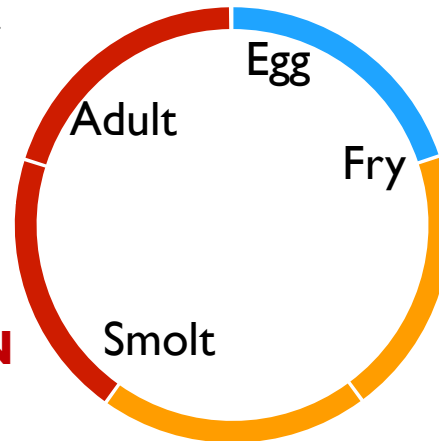
Management approach:

Optimize spawning density for MSY



**OCEAN**

**FRESHWATER**



Consequences of ocean scale management



Carry-over effect between life-stages  
Cline et al. 2019



# Acknowledgements



Daniel Schindler  
University of Washington



Jan Ohlberger  
University of Washington

## Other colleagues (data sharing and discussions)

- Timothy Walsworth
- Jackie Carter
- Curry Cunningham (run-reconstructions)

## Institutions (support, data collection and sharing)

- UW School of Aquatic and Fishery Sciences (SAFS)
- Alaska Department of Fish and Game (ADFG)
- University of Washington Alaska Salmon Program (ASP)



# Questions



## References

1.) Cline, T.J., J. Ohlberger, D.E. Schindler. 2019. Effects of warming climate and competition in the ocean for life-histories of Pacific salmon, *Nature Ecology and Evolution* 3: 935–942.