SKAGIT CLIMATE SCIENCE CONSORTIUM

Salmon Responses to Climate Change

Dr. Correigh Greene
NOAA Fisheries

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WSU, Mt. Vernon

Importance of Salmon in the Skagit

- Importance to the ecosystem
- Tribal rights
- Recreational value to local economy
- ESA listings constrain resource management

Climate Science and Salmon

Most published studies come from other systems. For example,

Welch, D.W., Ward, B.R., Smith, B.D., and Eveson, J.P. 2000. Temporal and spatial responses of British Columbia steelhead (Oncorhynchus mykiss) populations to ocean climate shifts. Fish. Oceanogr. 9(1): 17-32.

Reiman, B.E., D. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce, and D. Myers. 2007. Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River Basin. Trans. Am. Fish. Society 136:1552-1565.

Some Skagit-specific analyses

Greene, C.M., D.W. Jensen, E. Beamer, G.R. Pess, and E.A. Steel. 2005. Effects of environmental conditions during stream, estuary, and ocean residency on Chinook salmon return rates in the Skagit River, WA. Transactions of the American Fisheries Society, 134:1562-1581.

Mantua, N.J., I. Tohver, and A.F. Hamlet. 2009. Impacts of climate change on key aspects of freshwater salmon habitat in Washington State. Chapter 6 *in* The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, Washington.

Large scale marine migration phase analyses

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78: 1069-1079.

Abdul-Aziz, O.I., N.J. Mantua, and K.W. Myers. 2011. Potential climate change impacts on thermal habitats of Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean and adjacent seas. Can. J. Fish. Aq. Sci. 68: 1660-1680.

OVERVIEW

- Habitat-specific life cycles of 8 salmonids in Skagit River
- Freshwater threats
- Estuarine, nearshore, & marine threats
- Vulnerability assessment for each species
- Adapting to climate change

Are all salmon
similarly affected
by climate change?

NO!

Climate Affects Salmon & Their Habitats

Climate impacts affect salmon across all their life history stages

- Indirectly on habitat (e.g., less access to side channels during low flows)
- Indirectly on prey (e.g., ocean acidification and zooplankton)
- Directly on fish behavior or condition (e.g., outmigration timing)
- Directly on fish survival (e.g., egg scour)

Evaluating Vulnerability of Salmon to Climate Change

- Season & habitat of salmon life stages
- Season & habitat of climate change threats
- Sensitivity of species to threats

Season

Summer
Fall
Winter
Spring
Summer
Fall
Winter
Spring
Summer

Life Stage	Climate change (examples)
Adult migration	↑ Migration temp
Mainstem spawning	
Incubation in gravel	↑ Floods
Nearshore rearing	↑ Sea level
Ocean rearing	↓ pH

SKAGIT SALMONID LIFE HISTORY PATTERNS

Juvenile Life History Variation

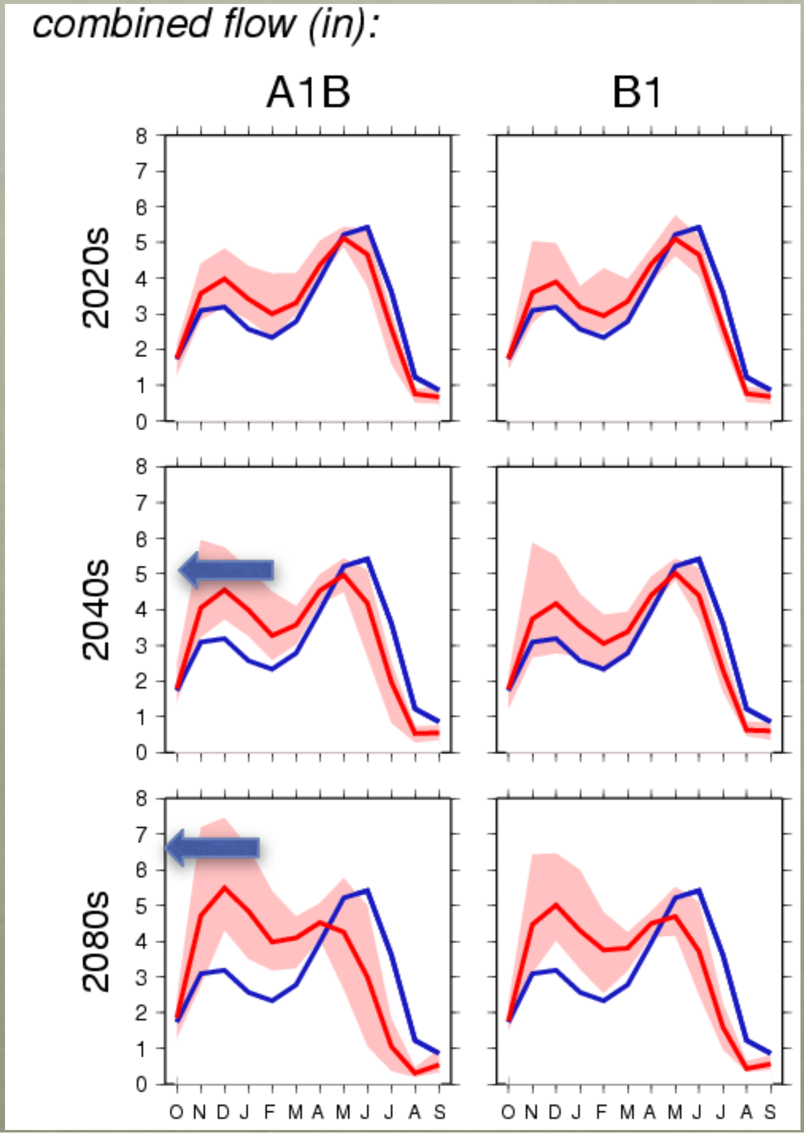
	Delta fry	Subyearlings (ocean type) Fry migrants	 Parr migrants	Yearlings (stream type)
River residency (mos.)	1-2	<1	3	16
Delta residency (mos.)	0.5-2	----	----	----
Primary rearing habitat	Tidal delta	Shorelines	River	River

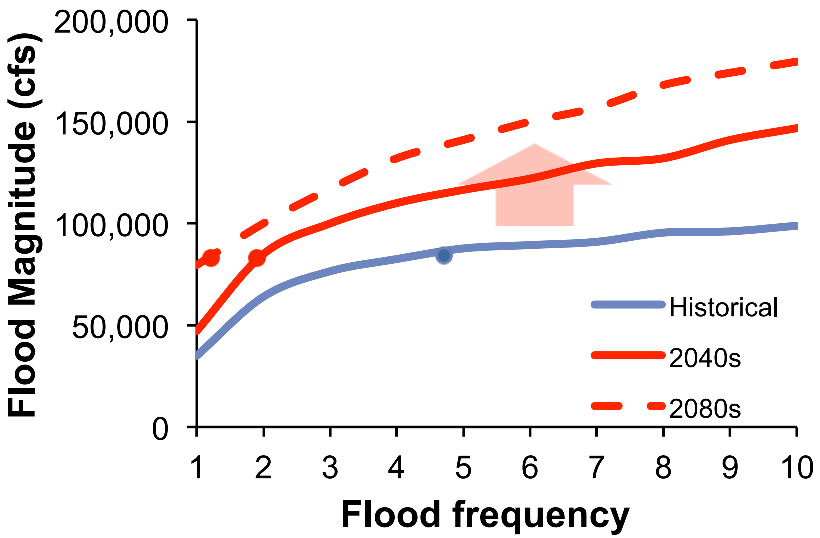
SKAGIT SALMONID LIFE HISTORY PATTERNS

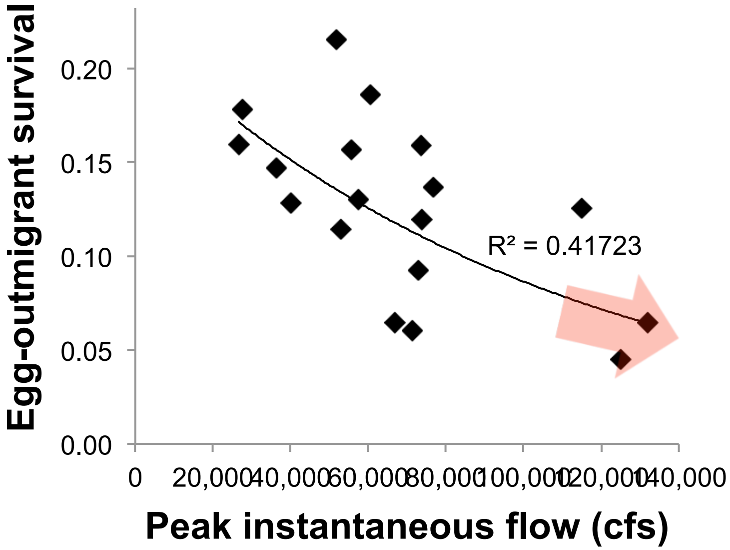
Climate Impacts to Freshwater Life Stages

- **Spawning**
  - ↓ Flow
  - ↑ Migration temp
- **Incubation**
  - ↑ Temp
  - ↑ Floods & scour
- **Freshwater rearing**
  - ↓ Summer flow
  - ↑ Temp

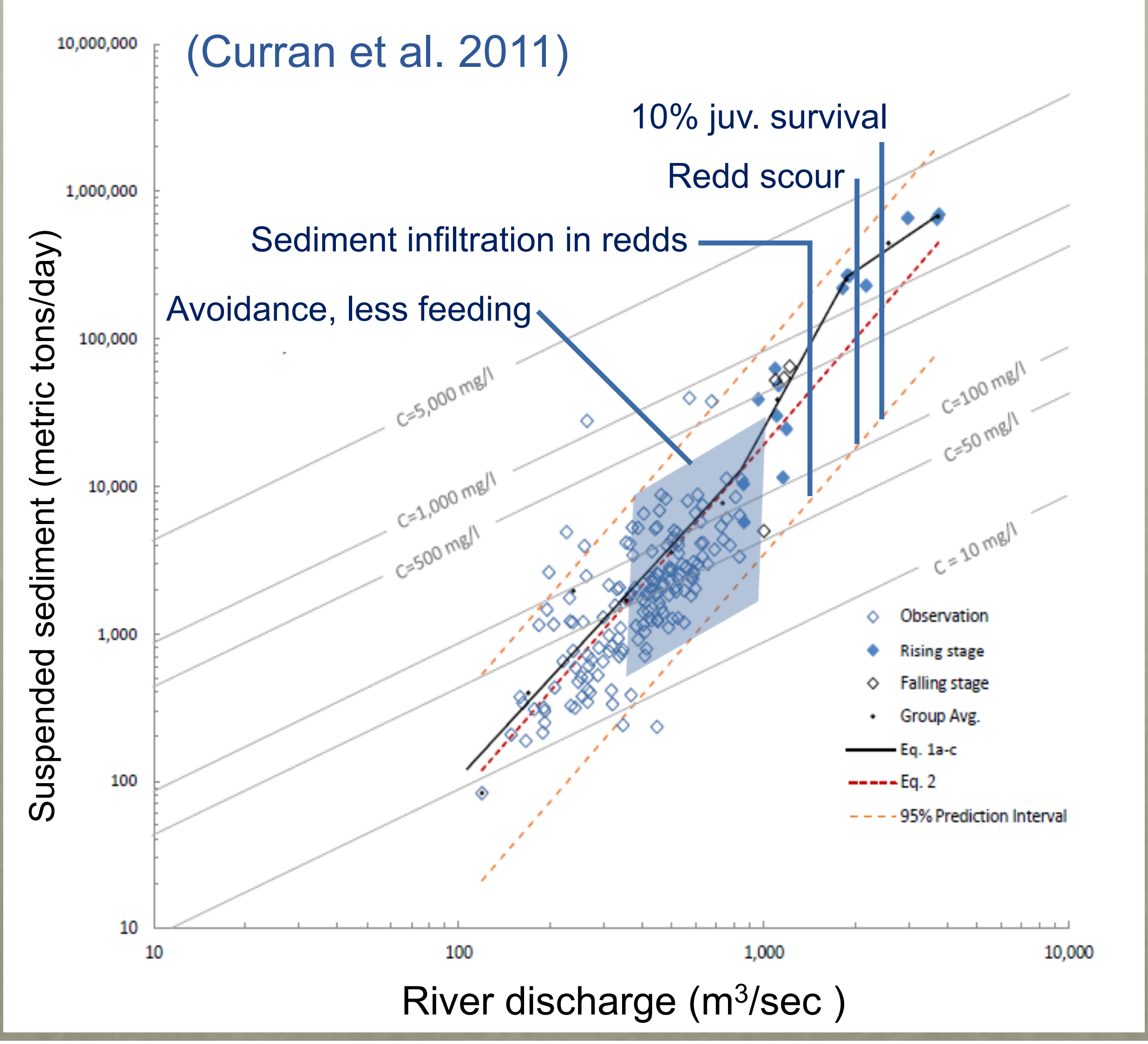
Increased Peak Flows Reduce Salmon Survival





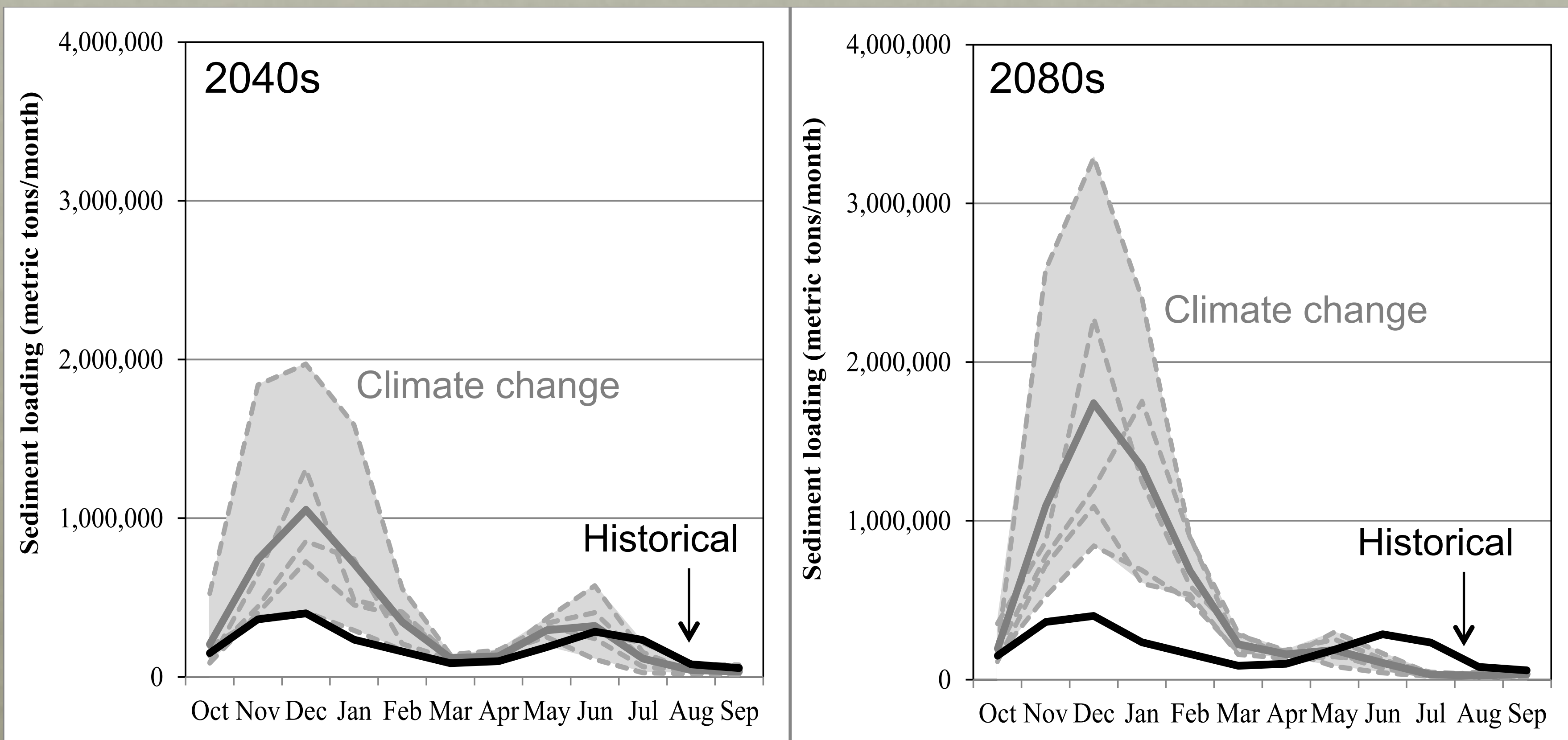


A Primary Mechanism: Increased Sediment Loading



Chum Blinded by Sediment

Climate Change Will Increase Sediment Loading



(Source: Curran et al. 2011)

Salmonid Spawning and Rearing: Responses to Low Flows

- Prediction: during fall spawning stages, lower flows and resulting higher temperatures are threats

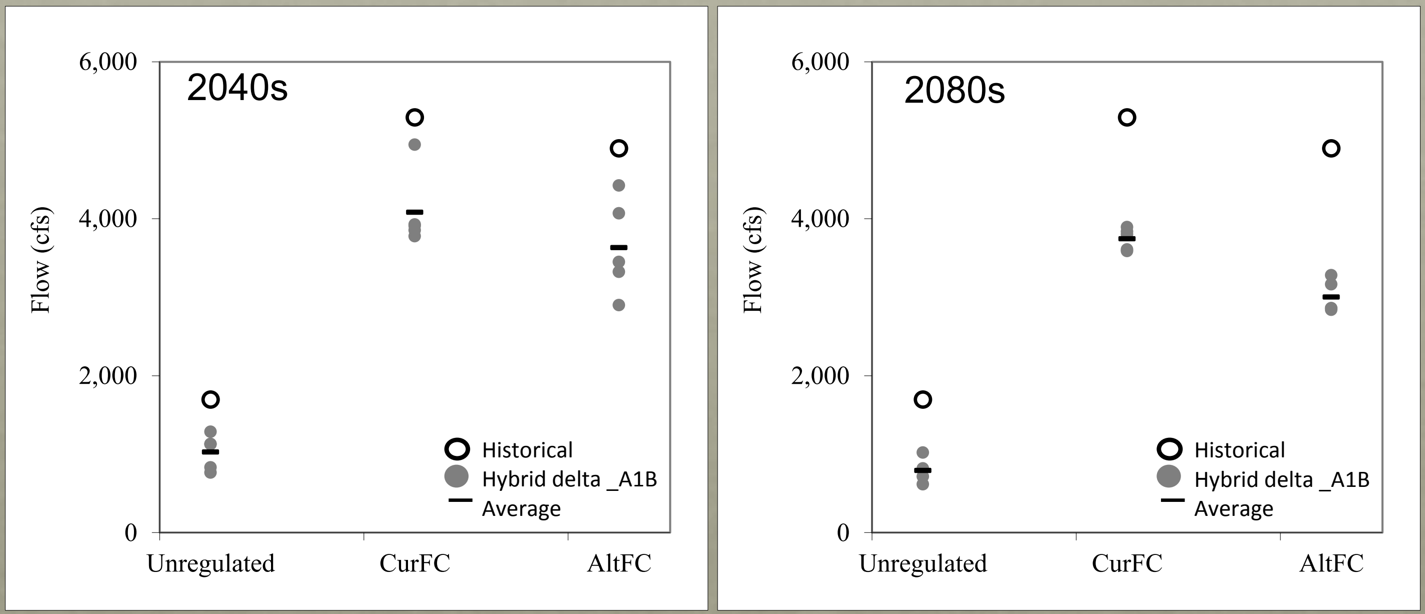
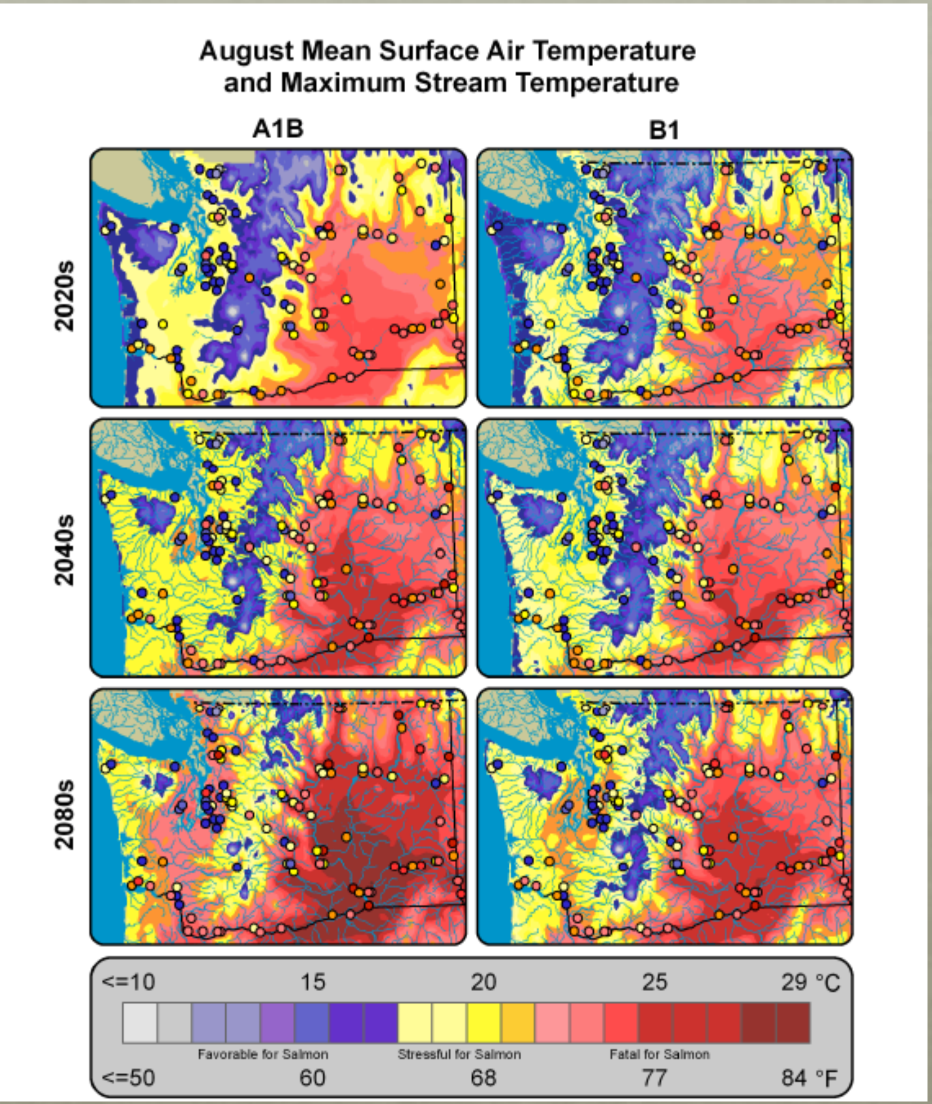


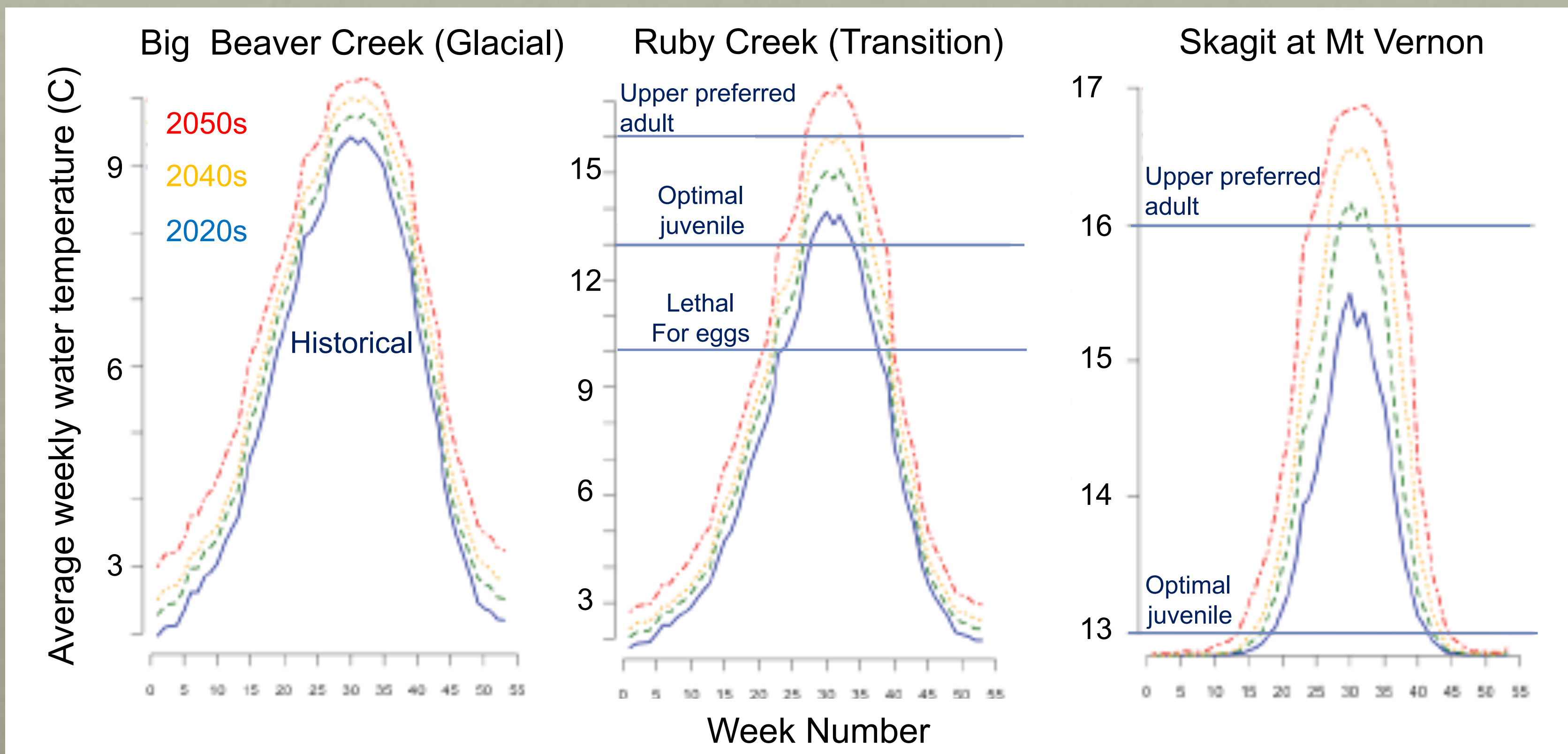
Figure 11. The magnitude of low flow statistic (7Q10) at the Skagit River near Mount Vernon for unregulated flows and for regulated flows under current flood control operations (CurFC) and alternative operations (AltFC). Historical run and echam5 A1B scenarios for the 2040s and the 2080s are considered.

Changes in Temperature

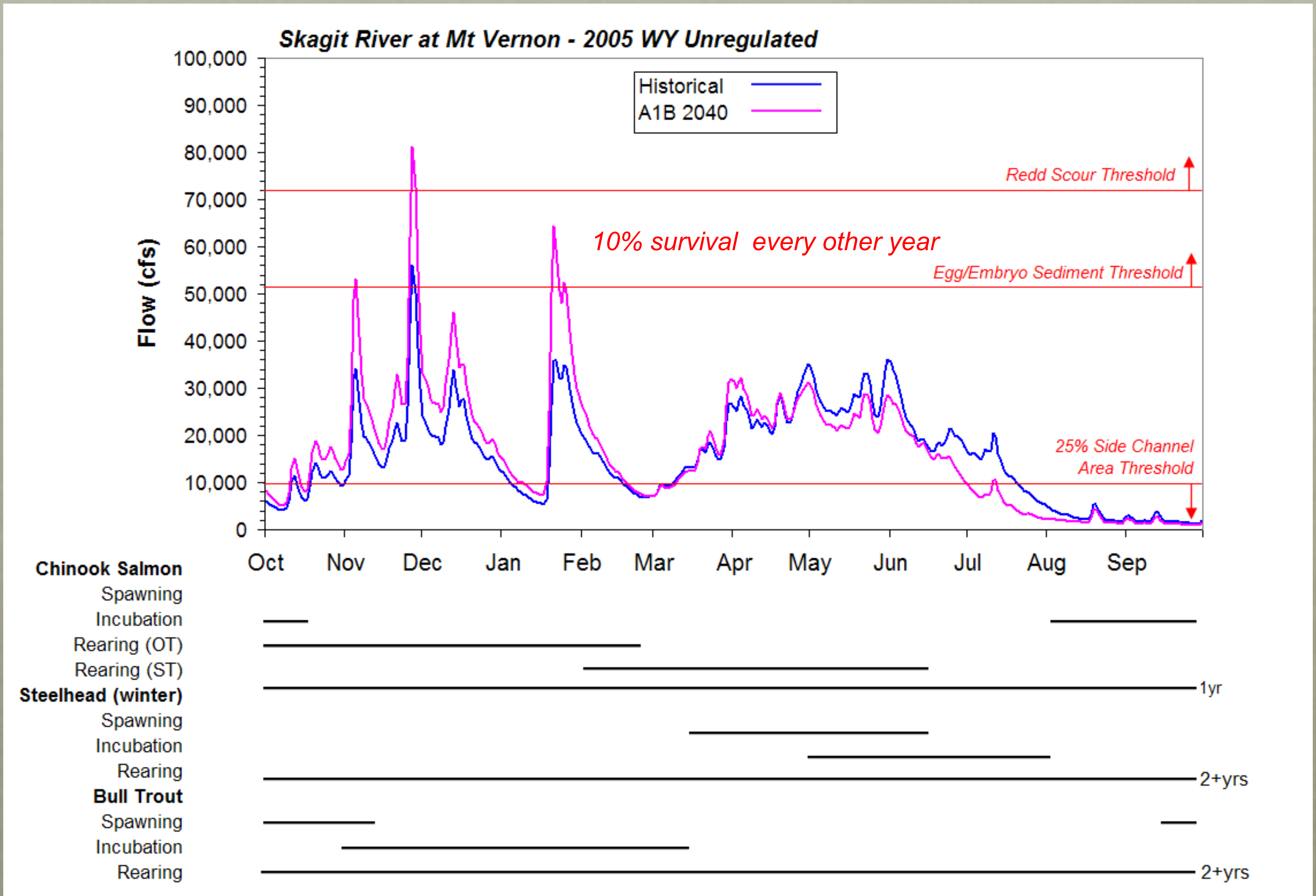
- Elevated air temperatures will lead to higher water temperatures
- Buffering possible by glaciers, Ross Lake, and hyporheic refuges
- Rainfall-dominated tributaries at highest risk of future temperature problems



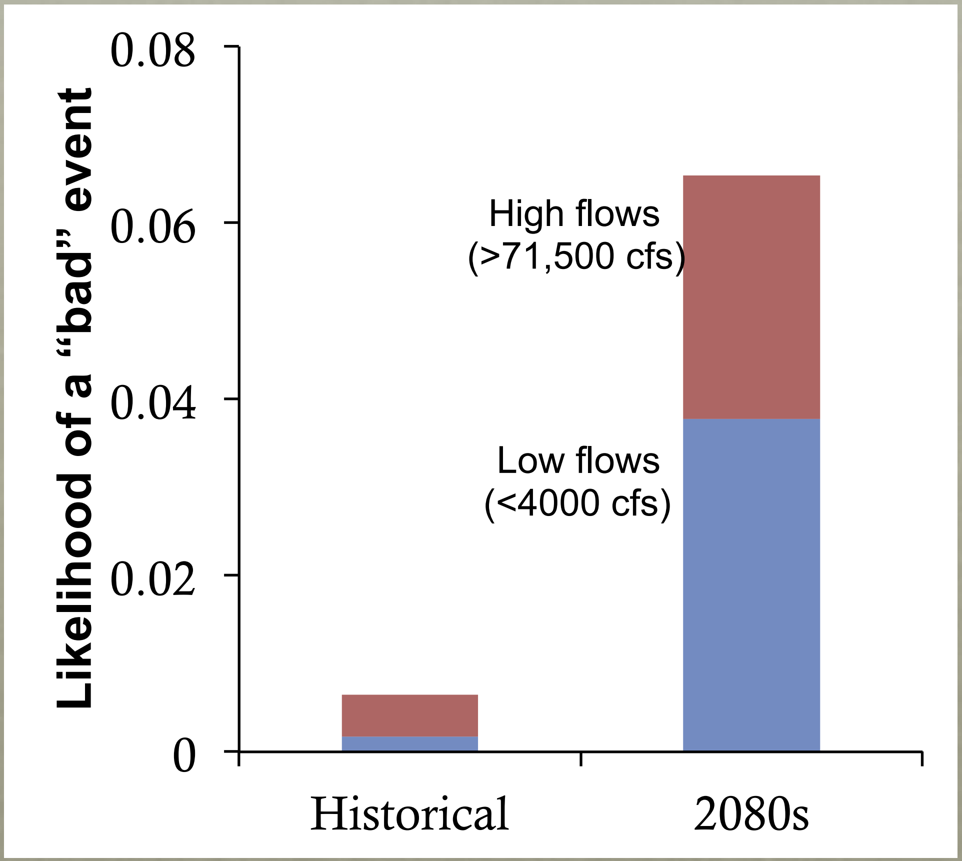
Projected Temporal Changes Affecting Bull Trout



Climate Impacts in Freshwater: 2040



Climate Impacts in Freshwater: 2080



Climate Change and Regulated Instream Flows

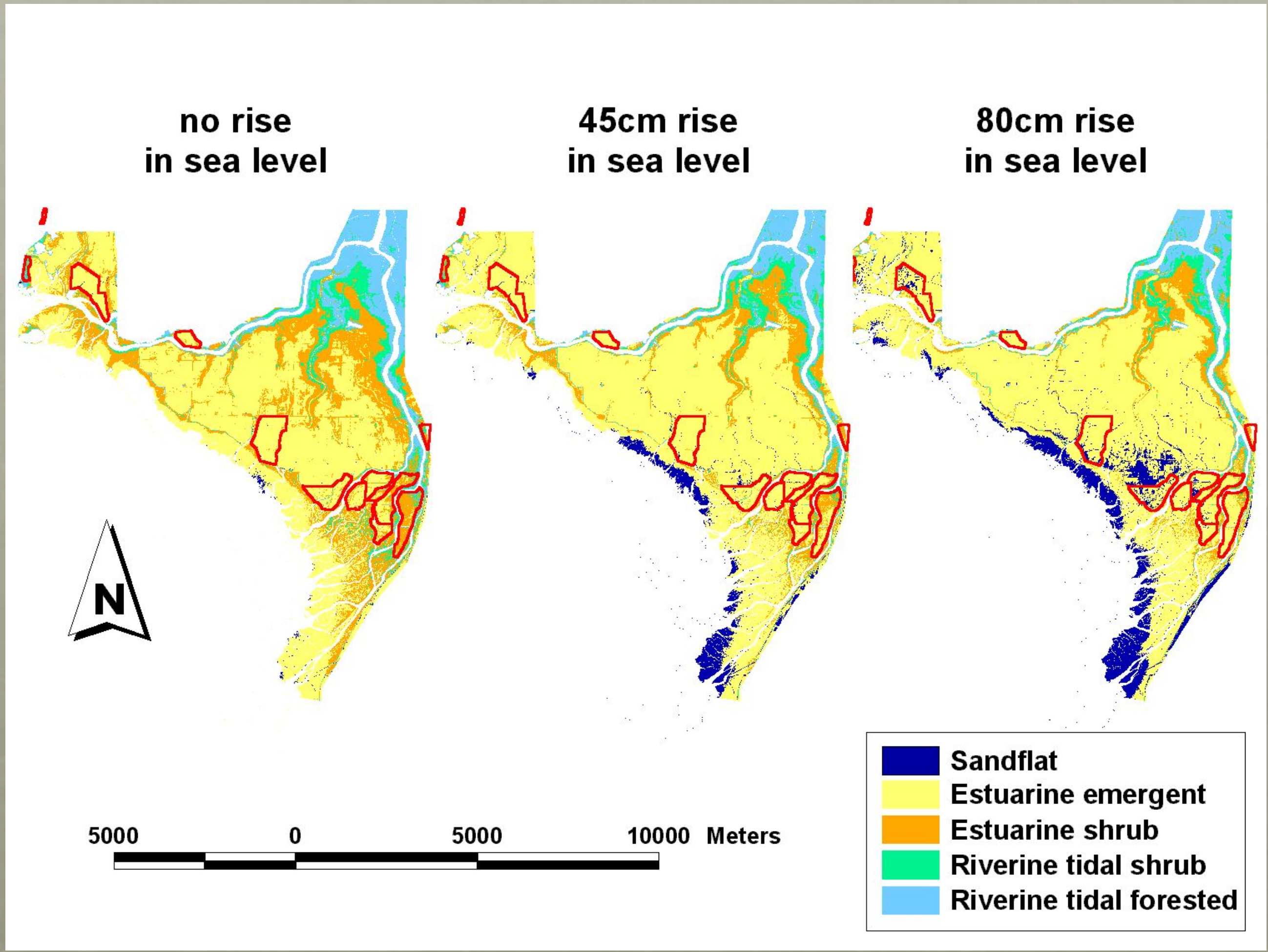
- Reservoirs reduce peak flows by 17%
- Reservoirs increase minimum flows by 36%
- Fish management flows provide protections from low flow events down to Skagit estuary
- Flow augmentation of 1,650 cfs by SCL reservoirs will become more important under future low flows
- Reservoirs have limited additional capacity to offset increased peak flows caused by climate change (55% of Skagit Basin is unregulated)

Climate Impacts to Estuary, Nearshore, & Marine Life Stages

- **Estuary Rearing**
  - ↑ Temp
  - ↑ Sea level
- **Nearshore Rearing**
  - ↑ Temp
  - ↑ Sea level
  - ↓ pH
- **Ocean Rearing**
  - ↑ Temp
  - ↓ pH & DO

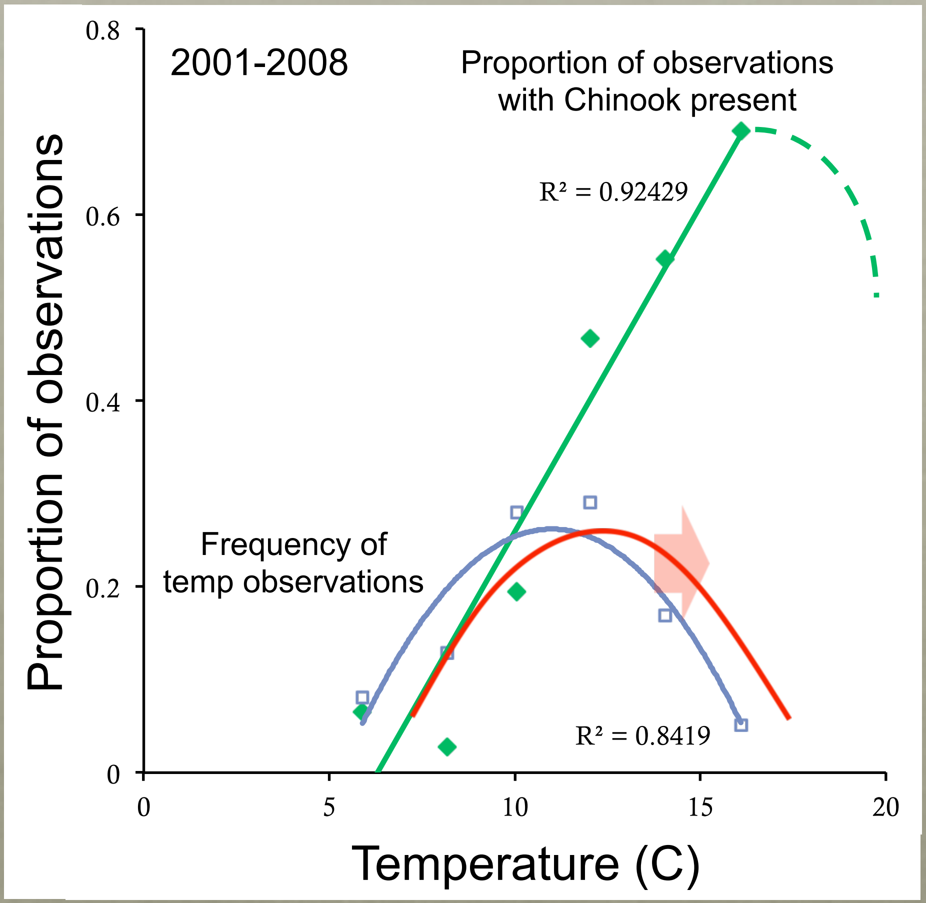
Sea Level Rise

- **Observed: 10 - 28 cm over last 100 years**
- **2040s: 8 - 55 cm rise projected**
- **Loss of estuary rearing habitat**
- **Increased warming potential**
- **Loss of restoration opportunities**



Marine Temperatures

- Observed sea surface temperature increase: 0.9 ˚C
- Projected increase in Puget Sound: 1.2 ˚C by 2040s
- Climate change will lead to narrower temperature window of preferred temperatures in open ocean (Abdul-Aziz et al 2011)
- Critical temperature effects may occur during winter



Ocean Acidification

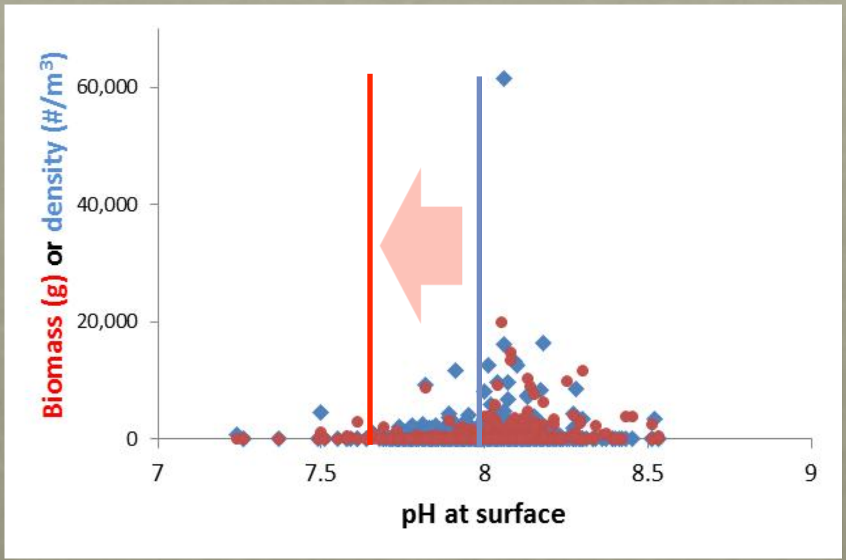
Historical: pH = 8.2

Observed decreases 2000-2008 at Neah Bay

Projected: pH decline of 0.14 –0.35 by 2100

Across Puget Sound in 2011, strong correspondence of crustacean densities and salmon biomass as a function of pH

Strong climate driven changes in pH would be at odds with pH distribution for both salmon and their prey



Stratification and Hypoxia

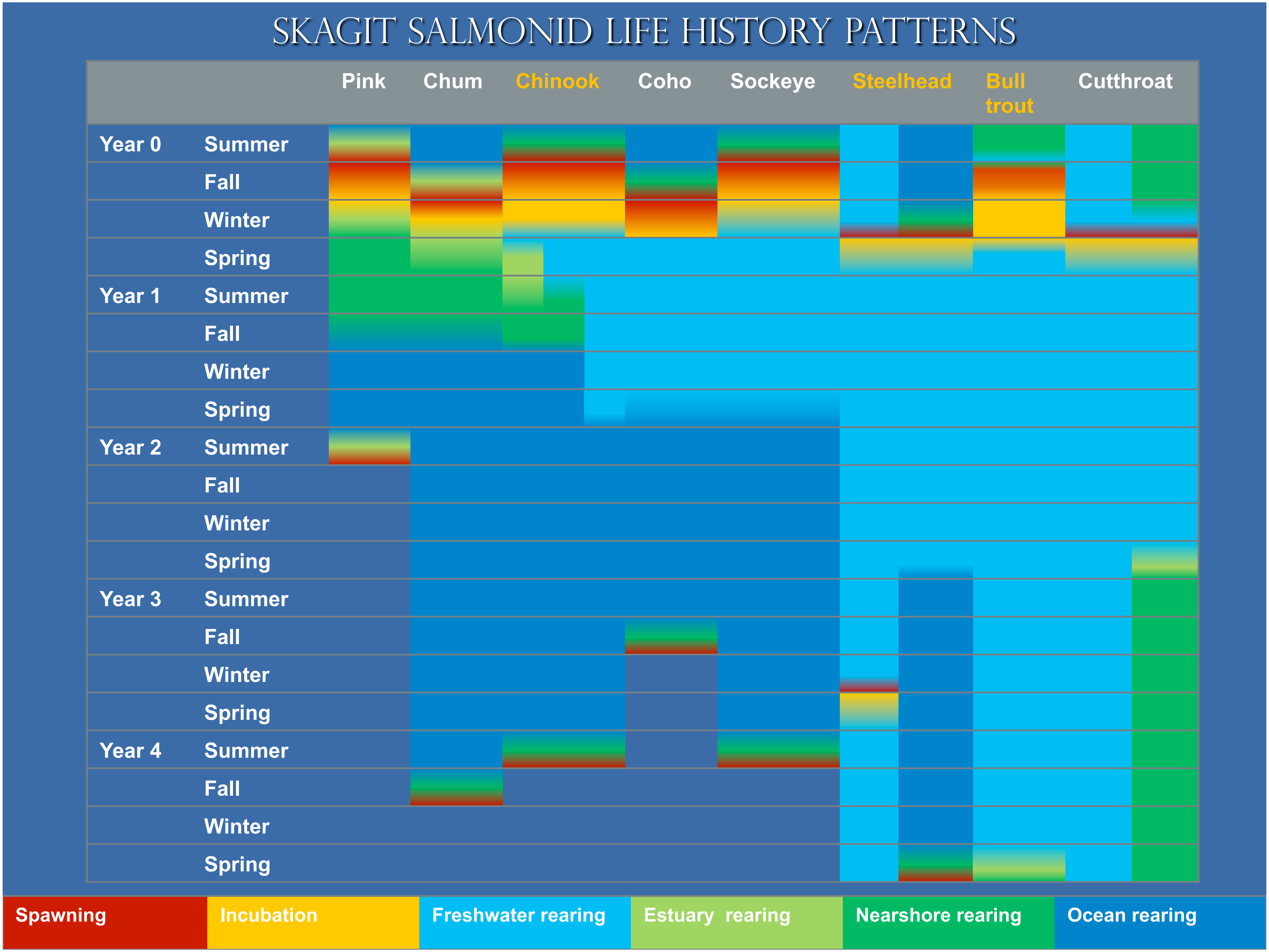
Within Puget Sound, increased temperatures and changes in stratification:

- reduced vertical mixing
- reduced primary production
- DO problems for fish

On the coast, climate-driven shifts in upwelling

- potential changes in wind directions
- reduced upwelling
- prey reductions and hypoxia for fish

Putting it all together –
A vulnerability assessment for Skagit salmonids


SKAGIT SALMONID LIFE HISTORY PATTERNS
Pink
Chum
Chinook
Coho
Sockeye
Steelhead
Bull trout
Cutthroat
Year 0
Summer
Fall
Winter
Spring
Year 1
Summer
Fall
Winter
Spring
Year 2
Summer
Fall
Winter
Spring
Year 3
Summer
Fall
Winter
Spring
Year 4
Summer
Fall
Winter
Spring
Spawning
Incubation
Freshwater rearing
Estuary rearing
Nearshore rearing
Ocean rearing

Salmon & Climate Drivers Overview

- **Spawning**
  - ↑ Migration temp
  - ↓ Flow
- **Incubation**
  - ↑ Temp
  - ↑ Floods and scour
- **Fresh Water Rearing**
  - ↑ Temp
  - ↓ Summer flow
- **Estuary Rearing**
  - ↑ Temp
  - ↑ Sea level
- **Nearshore Rearing**
  - ↑ Temp
  - ↑ Sea level
  - ↓ pH & DO
- **Ocean Rearing**
  - ↑ Temp
  - ↓ pH

Climate Change Threats: Preliminary Results

	Pink	Chum	Chinook	Coho	Sockeye	Steelhead	Bull trout	Cutthroat
Spawning								
↑ Migration temp			Lower river		low tolerance		low tolerance	
↓ Flow	Δ in redd depth		Δ in redd depth		Δ in redd depth			
Incubation								
↑ Temp						Tail of incubation	low tolerance	
↑ Floods	scouring	scouring	scouring	scouring	scouring		scouring	
FW rearing								
↑ Temp			cold water	floodplains	lake rearing	tributaries	tributaries	tributaries
↓ Summer flow			cold water	floodplains	lake rearing	tributaries	tributaries	↓ habitat

	Threat	
Uncertainty	**L**	**M-H**
L		
M-H		

CLIMATE CHANGE THREATS: PRELIMINARY RESULTS

	Pink	Chum	Chinook	Coho	Sockeye	Steelhead	Bull trout	Cutthroat
Estuary rearing								
↑ Temp			↓ residence					↓ habitat
↑ Sea level		↓ habitat	↓ habitat					
Nearshore rearing								
↑ Temp	↓ habitat	↓ habitat	↓ habitat				low tolerance	
↑ Sea level	shoreline habitat	shoreline habitat	shoreline habitat					
↓ pH & DO	plankton feeding	foodweb	foodweb	foodweb	plankton feeding	foodweb	foodweb	foodweb
Ocean rearing								
↑ Temp	summer habitat	summer habitat	summer habitat	summer habitat	summer habitat	summer habitat		
↓ pH & DO	plankton feeding	foodweb	foodweb	foodweb	plankton feeding	foodweb		

	Threat	
Uncertainty	**L**	**M-H**
L		
M-H		

CLIMATE CHANGE THREATS: PRELIMINARY RESULTS

	Pink	Chum	Chinook	Coho	Sockeye	Steelhead	Bull trout	Cutthroat
Spawning								
↑ Migration temp			Lower river		low tolerance		low tolerance	
↓ Flow	Δ in redd depth		Δ in redd depth		Δ in redd depth			
Incubation								
↑ Temp						Tail of incubation	low tolerance	
↑ Floods	scouring	scouring	scouring	scouring	scouring		scouring	
FW rearing								
↑ Temp			cold water	floodplains	lake rearing	tributaries	tributaries	tributaries
↓ Summer flow			cold water	floodplains	lake rearing	tributaries	tributaries	↓ habitat
Estuary rearing								
↑ Temp			↓ residence					↓ habitat
↑ Sea level		↓ habitat	↓ habitat					
Nearshore rearing								
↑ Temp	↓ habitat	↓ habitat	↓ habitat				low tolerance	
↑ Sea level	shoreline habitat	shoreline habitat	shoreline habitat					
↓ pH & DO	plankton feeding	foodweb	foodweb	foodweb	plankton feeding	foodweb	foodweb	foodweb
Ocean rearing								
↑ Temp	summer habitat	summer habitat	summer habitat	summer habitat	summer habitat	summer habitat		
↓ pH & DO	plankton feeding	foodweb	foodweb	foodweb	plankton feeding	foodweb		

Adapting to impacts of climate change

Habitat Change and Predicted Population Effects

	Directional change in habitat characteristic	**Predicted population effect**
Incubation	↑ Flood magnitude & scour ↑ Winter temperature	↑ Egg mortality ↓ Emergence time
Spawning, freshwater rearing	↓ Summer flow	↓ Rearing area ↑ Juvenile mortality
	↑ Summer temperature	↕ Growth rate ↑ Juv./adult mortality
Estuary rearing	↑ Rearing temperature ↑ Sea level	↓ Residence time ↓ Rearing area
Nearshore/ ocean rearing	↑ Rearing temperature ↓ pH & DO ↑ Winter temperature	↕ Growth rate ↓ Growth rate ↕ Juvenile mortality

LIFE HISTORY VARIATION IS KEY FOR RESILIENCE

Improved viability of populations with diverse life-history portfolios

Correigh M. Greene[1,*], Jason E. Hall[1], Kimberly R. Guilbault[2] and Thomas P. Quinn[3]

[1]*Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, USA*
[2]*Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO 80523, USA*
[3]*School of Aquatic and Fisheries Sciences, University of Washington, Seattle, WA 98195, USA*
**Author for correspondence* (correigh.greene@noaa.gov).

Conclusion: Life history variation reduces population fluctuations and mitigates against greater variations caused by climate change

Population diversity and the portfolio effect in an exploited species

Daniel E. Schindler[1], Ray Hilborn[1], Brandon Chasco[1], Christopher P. Boatright[1], Thomas P. Quinn[1], Lauren A. Rogers[1] & Michael S. Webster[2]

LETTER

Synchronization and portfolio performance of threatened salmon

Jonathan W. Moore[1], Michelle McClure[1], Lauren A. Rogers[2], & Daniel E. Schindler[2]

[1] Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA 98110, USA
[2] School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195, USA

Juvenile Life History Variation

	Subyearlings (ocean type)			Yearlings (stream type)
	Delta fry	Fry migrants	Parr migrants	
River residency (mos.)	1-2	<1	3	16
Delta residency (mos.)	0.5-2	----	----	----
Primary rearing habitat	Tidal delta	Shorelines	River	River

Mitigating Climate Change

	Directional change in habitat characteristic	Predicted population effect	Potential targets for adaptation
Incubation	↑ Flood magnitude & scour ↑ Winter temperature	↑ Egg mortality ↓ Emergence time	Logging roads Sediment supply Constrained floodplains
Spawning, freshwater rearing	↓ Summer flow ↑ Summer temperature	↓ Rearing area ↑ Juvenile mortality ↕ Growth rate ↑ Juv./adult mortality	Riparian zones Constrained floodplains
Estuary rearing	↑ Rearing temperature ↑ Sea level	↓ Residence time ↓ Rearing area	Riparian zones Levees
Nearshore/ Ocean rearing	↑ Rearing temperature ↓ pH and DO ↑ Winter temperature	↕ Growth rate ↓ Growth rate ↕ Juvenile mortality	Nonnatal estuaries

Mitigating Climate Change

	Directional change in habitat characteristic	**Predicted population effect**	**Potential targets for adaptation**
Incubation	↑ Flood magnitude & scour ↑ Winter temperature	↑ Egg mortality ↓ Emergence time	Logging roads Sediment supply **Constrained floodplains**
Spawning, freshwater rearing	↓ Summer flow ↑ Summer temperature	↓ Rearing area ↑ Juvenile mortality ↕ Growth rate ↑ Juv./adult mortality	**Riparian zones** **Constrained floodplains**
Estuary rearing	↑ Rearing temperature ↑ Sea level	↓ Residence time ↓ Rearing area	Riparian zones **Levees**
Nearshore/ Ocean rearing	↑ Rearing temperature ↓ pH and DO ↑ Winter temperature	↕ Growth rate ↓ Growth rate ↕ Juvenile mortality	Nonnatal estuaries

SUMMARY

- Habitat-specific life cycles of 8 salmonids in Skagit River

→ **Patterns of residency differ among salmon**

- Freshwater threats

→ **Strong combined effects of low and high flows**

- Estuarine, nearshore, & marine threats

→ **Strong effects of sea level rise, other threats more uncertain**

- Vulnerability assessment for each species

→ **Threats differ for different salmonids**

- Adapting to climate change

→ **Multispecies view argues for restoration in floodplains?**