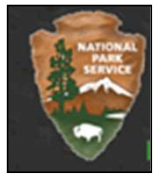


# Ecosystem response to the removal of two large dams in the Pacific Northwest



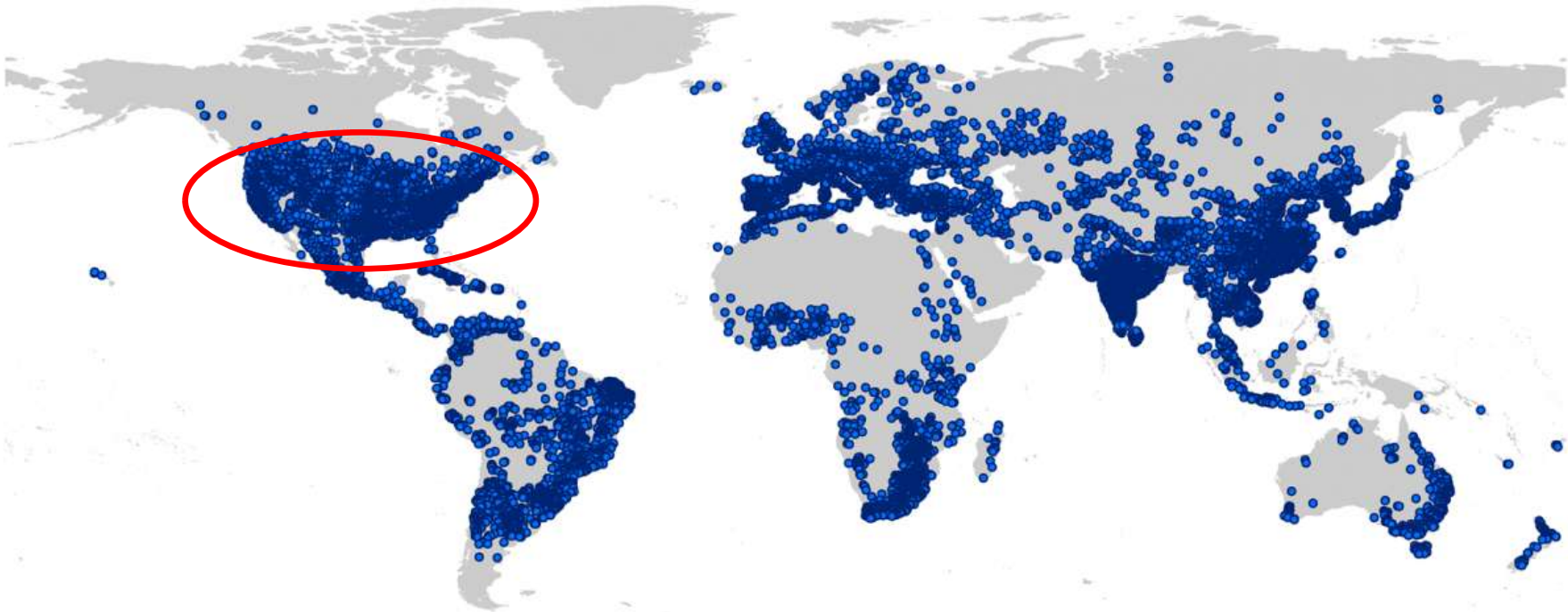
December 2025

# Today's talk

- Dams built and dam removal
- The Elwha River prior to dam removal
- The Elwha River Ecosystem & Fisheries Restoration Act
- How did dam removal happen?
- What has occurred with the removal of the Elwha River dams?
- Place, sediment, salmon, and the ecosystem
- Summary



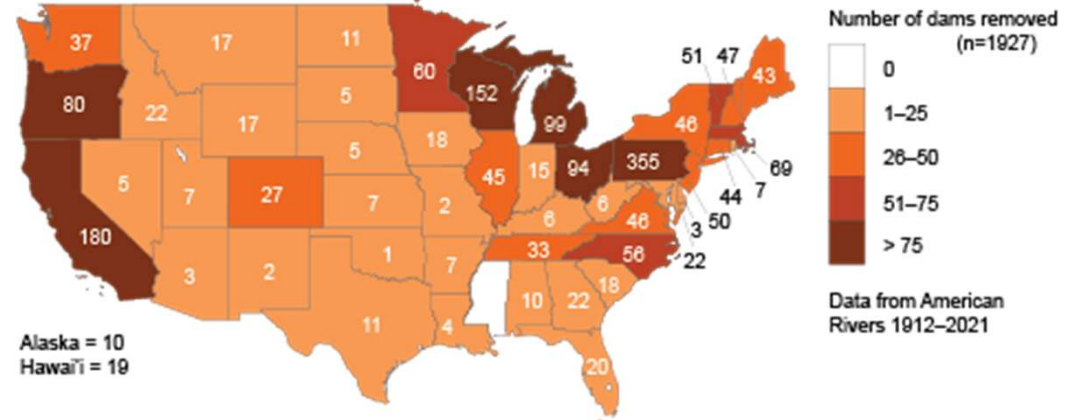
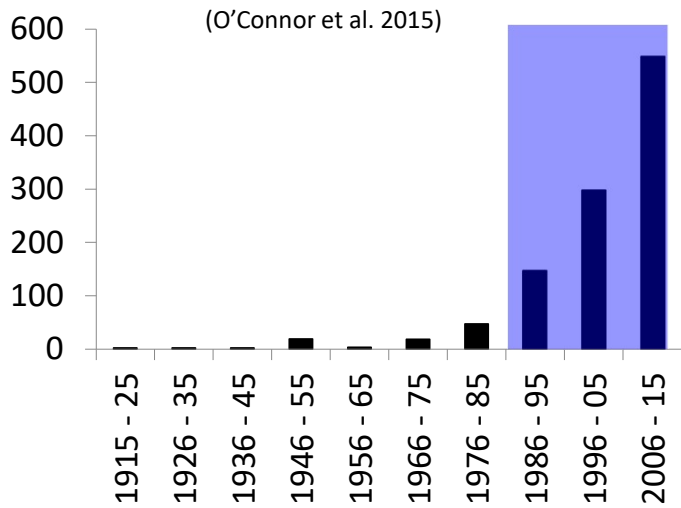
# Global distribution of dams & reservoirs



<http://globaldamwatch.org/our-research/>

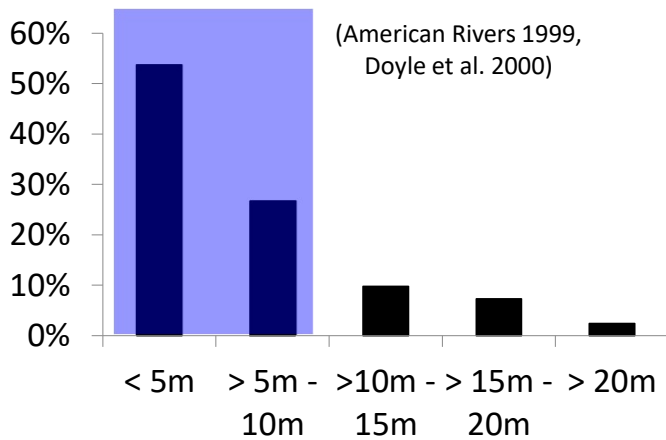
# Dam removal in the United States

## Number of dams removed



Increased removal over last 30 years

## Percent of total removed

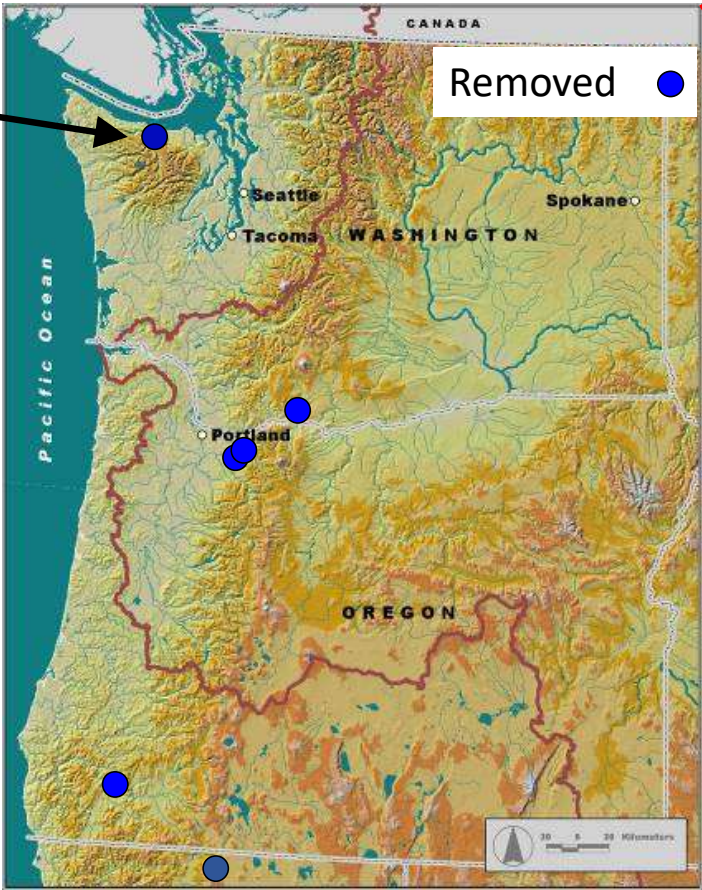


Most dams less than 10m in height

# Dam removal in the Pacific Northwest of the United States

Elwha River

- White Salmon River
- Sandy River
- Little Sandy River
  
- Rogue River
- Klamath River



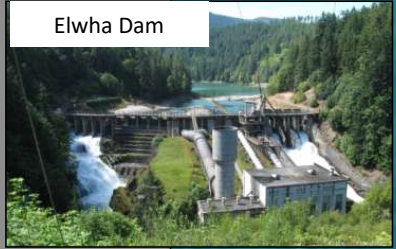
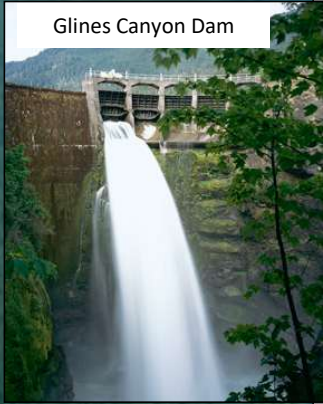
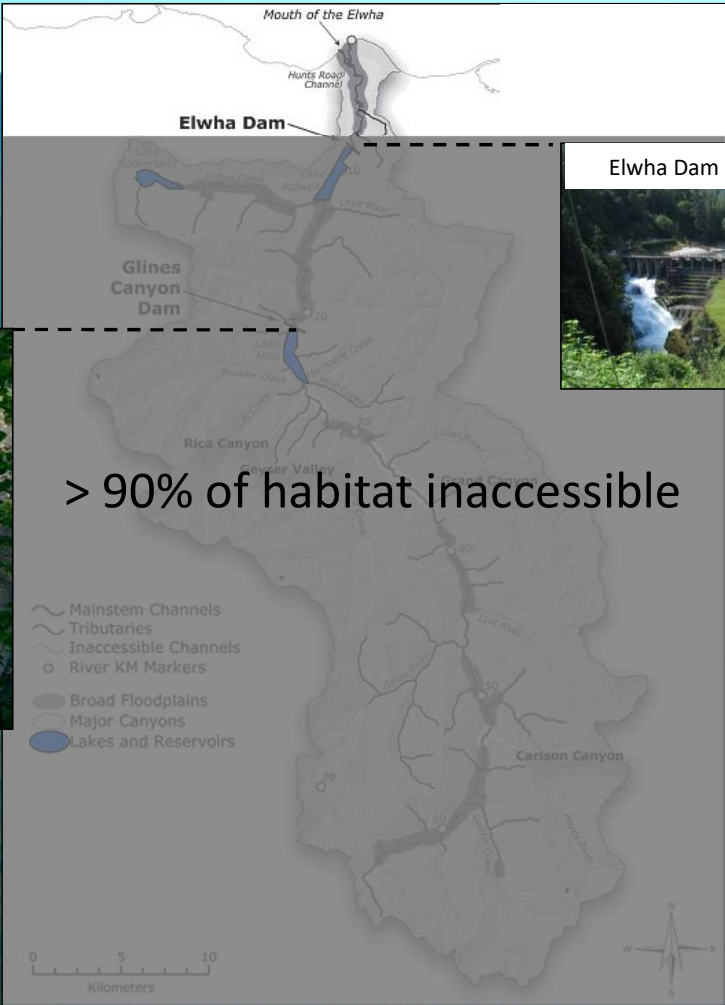
Average height ~30m

<https://www.cia.gov/library/publications/the-world-factbook/geos/us.html>

# Dam removal in the Pacific Northwest of the United States



## The Elwha River Basin

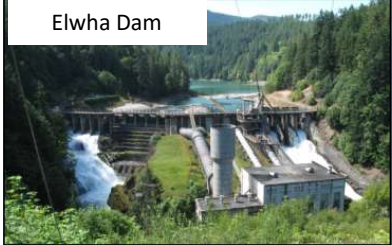
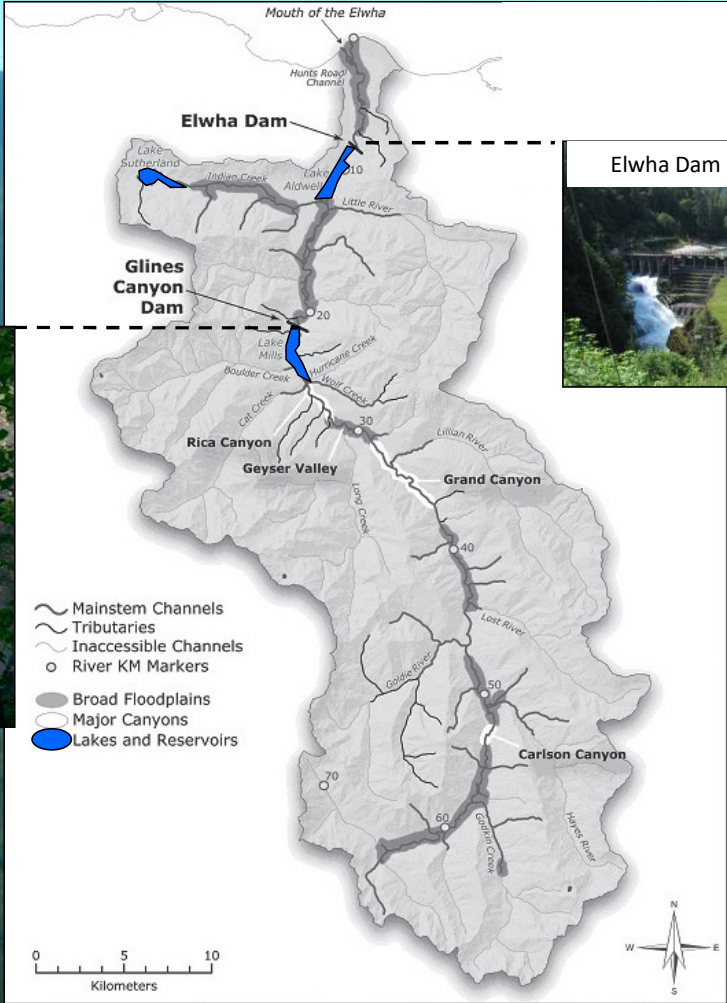


> 90% of habitat inaccessible

# Dam removal in the Pacific Northwest of the United States

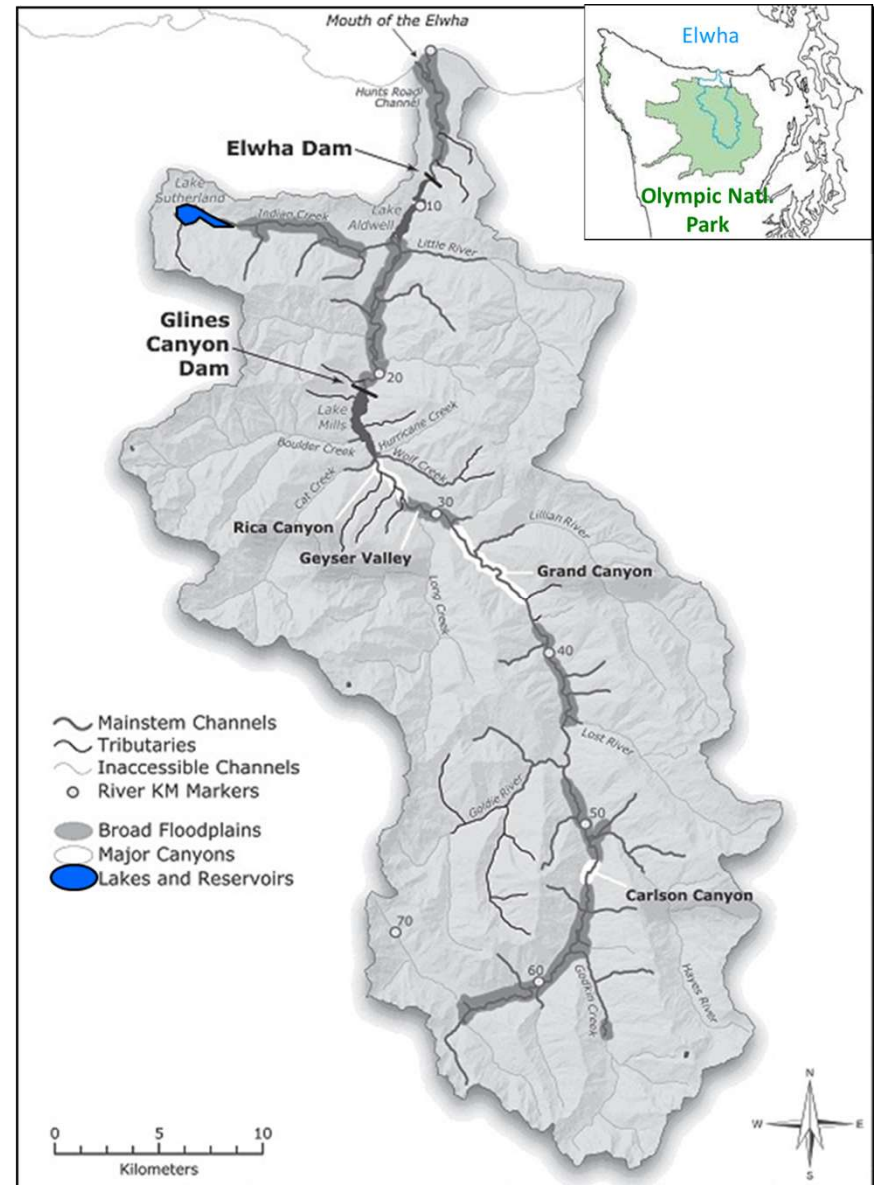


## The Elwha River Basin



# Elwha River

- 833 km<sup>2</sup>
- ~72 km of mainstem habitat
- 8 major tributaries
- 80% of watershed in Olympic National Park
- ~21 million m<sup>3</sup> of sediment released
- Initial salmon and steelhead population in low thousands and mostly hatchery



# Elwha River Fishes

Coho salmon



Pink salmon



Chinook salmon



Steelhead



Chum salmon



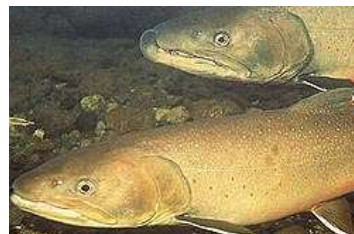
Sockeye salmon



Eulachon



Bull trout

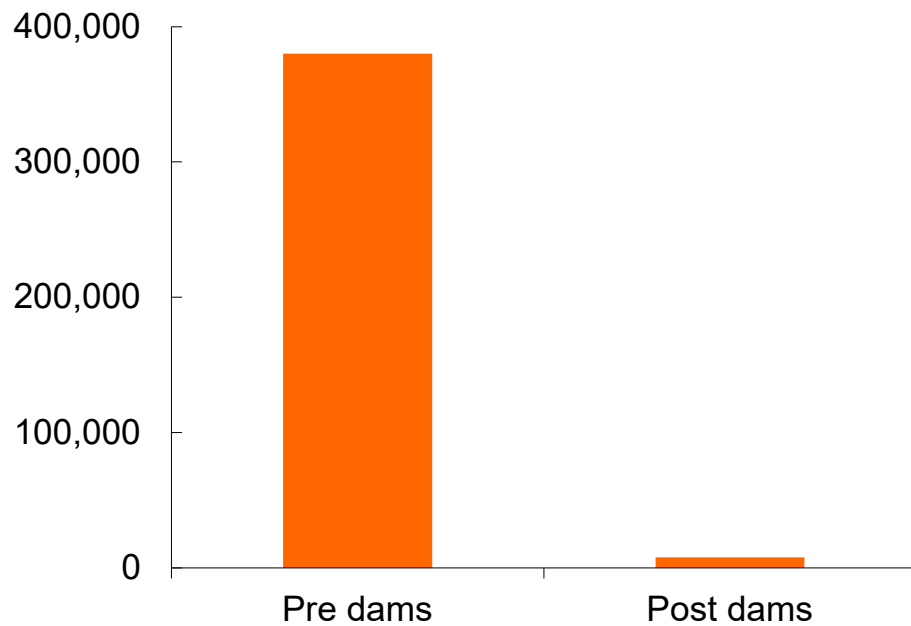


Pacific lamprey

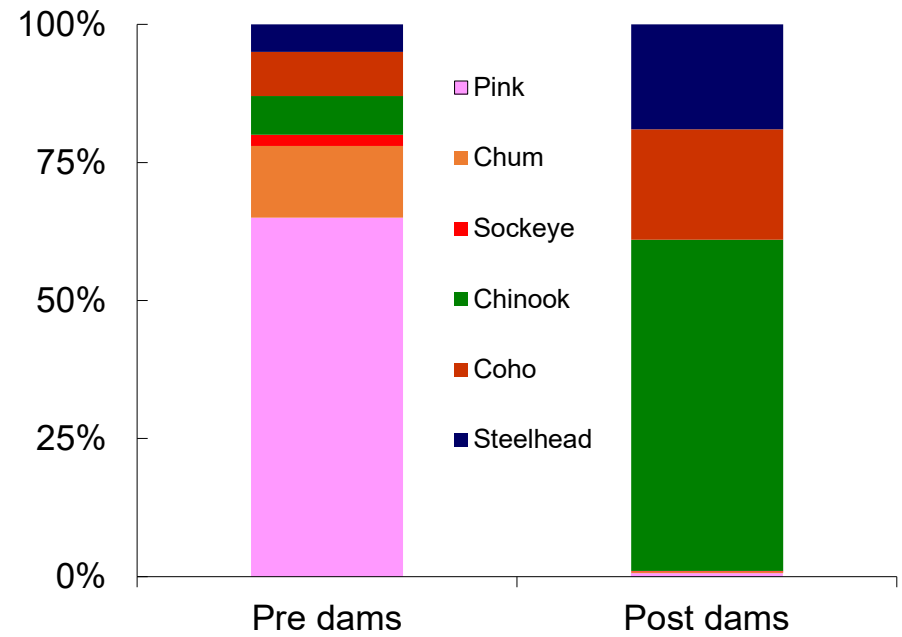


# Impacts to Elwha River salmon populations

Total population decline



Shift in species composition



Pess et al. 2008

All native populations were very low in abundance

# Elwha River Ecosystem and Fisheries Restoration Act

“...for the removal of the dams and full restoration of the Elwha River ecosystem and native anadromous fisheries.”

102<sup>nd</sup> Congress of the U.S.A. January 3, 1992



Photo by John McMillan

# What's going to happen to all the sediment?

~ 21 million m<sup>3</sup> of sediment accumulated in reservoirs

- ~ 54% fine, ~46% coarse
- ~40%-60% predicted to erode downstream

## Predictions

- suspended-sediment > 10,000 ppm
- temporary deposition of fines in pools
- more dynamic floodplain
- bed build up (aggradation) in lower river
- beach formation in estuary



N. Chism/Lighthawk

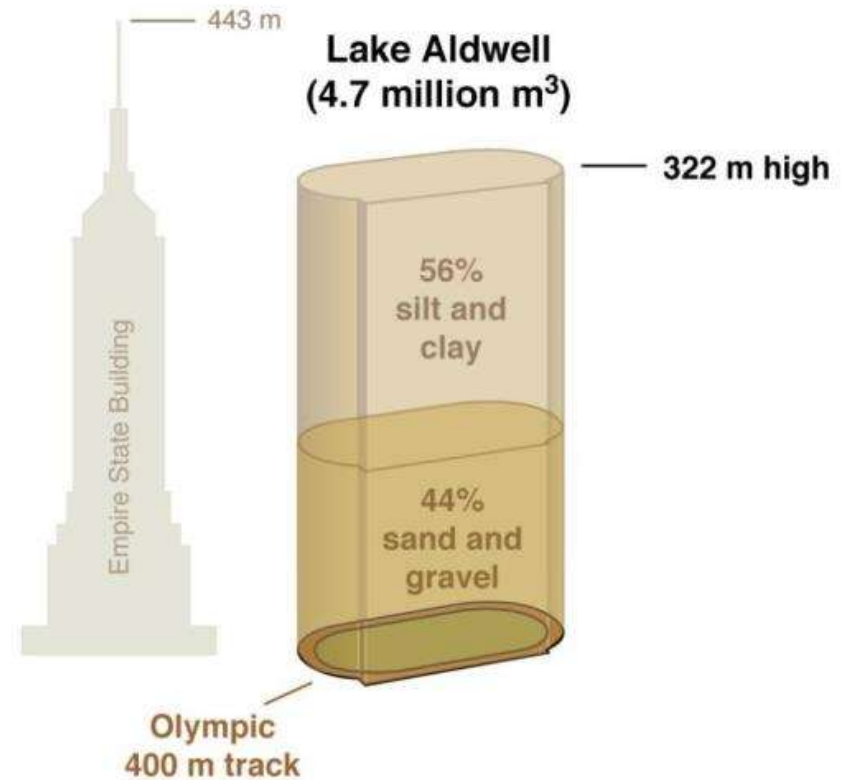
# Elwha Dam removal

Before Dam Removal: September, 2011



*Elwha Webcams courtesy NPS*

- Completed in 1912
- 33m concrete gravity dam





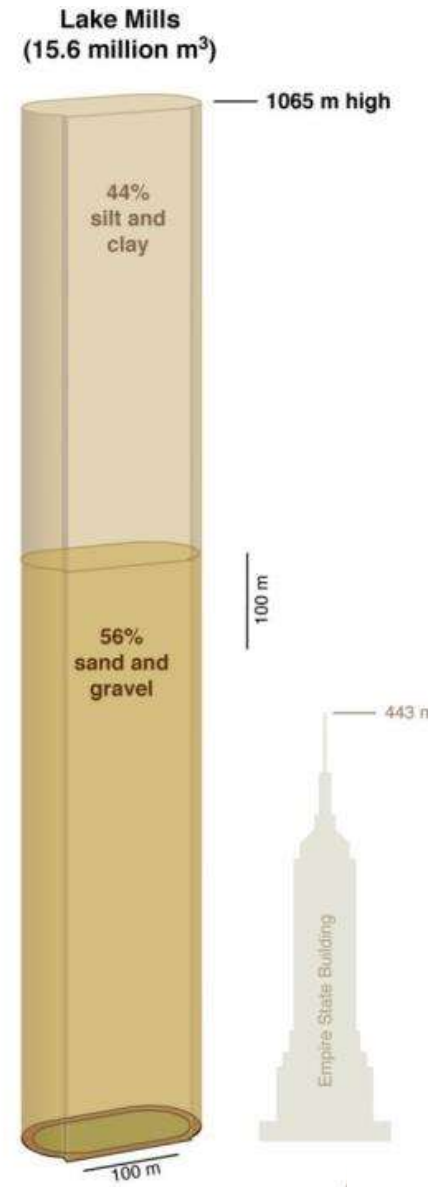
# Glines Canyon Dam removal

Before Dam Removal: September, 2011



Elwha Webcams courtesy NPS

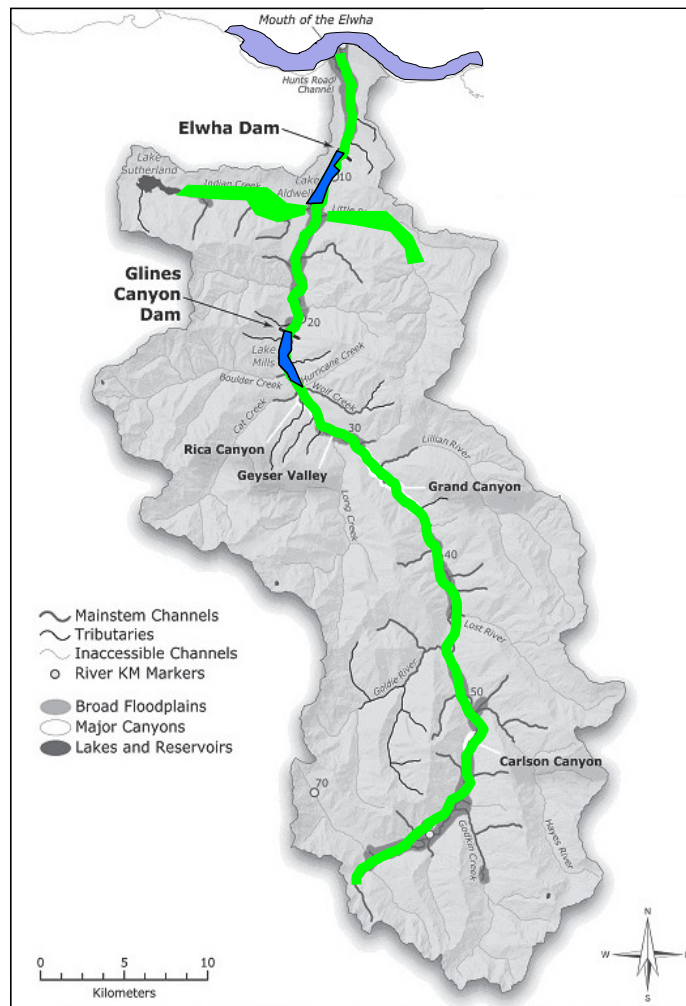
- Completed in 1927
- 64m concrete arch dam



May 12 14 08:32:59



# What has occurred with the removal of the Elwha River dams?



## Location

- Dams & former reservoirs
- Nearshore
- River ecosystem

## Processes

Sediment dynamics

Fish reintroduction



Riverine foodwebs

Terrestrial linkages

Revegetation

# Elwha River dam removal hypotheses

- Channel widening, aggradation, migration, development of river delta
- Initial decrease in primary & secondary productivity due to sediment
- Long term increase in marine derived nutrients & detrital input
- Salmonids will establish self-sustaining populations in the middle & upper Elwha from lower river, nearby watersheds, and resident populations
- “Reawake” salmon life history strategies
- Sediment impacts to immobile life stages
- Floodplain channels – sediment or refuge areas?



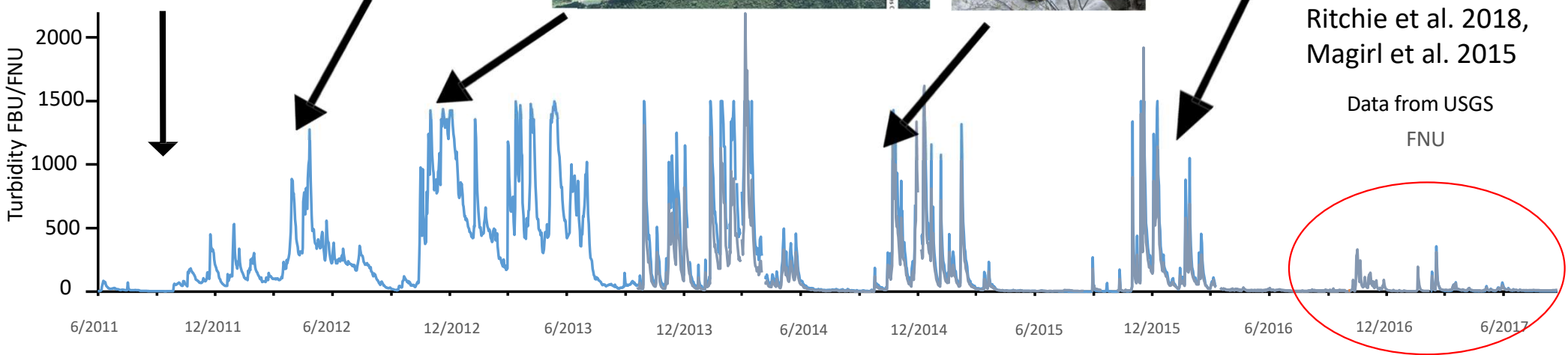
# How did sediment supply change due to the dam removal?



5 large flood events  
> 10,000 cubic feet/sec

Warrick 2020,  
Ritchie et al. 2018,  
Magirl et al. 2015

Data from USGS  
FNU



# Elwha River Estuary - Before and After

June 25, 2009 - ~ 2 years before dam removal



July 29, 2021 - ~ 7 years after dam removal





Photo courtesy of Andy Ritchie



Photo courtesy of Andy Ritchie

# Former Mills reservoir Mouth of Boulder Creek

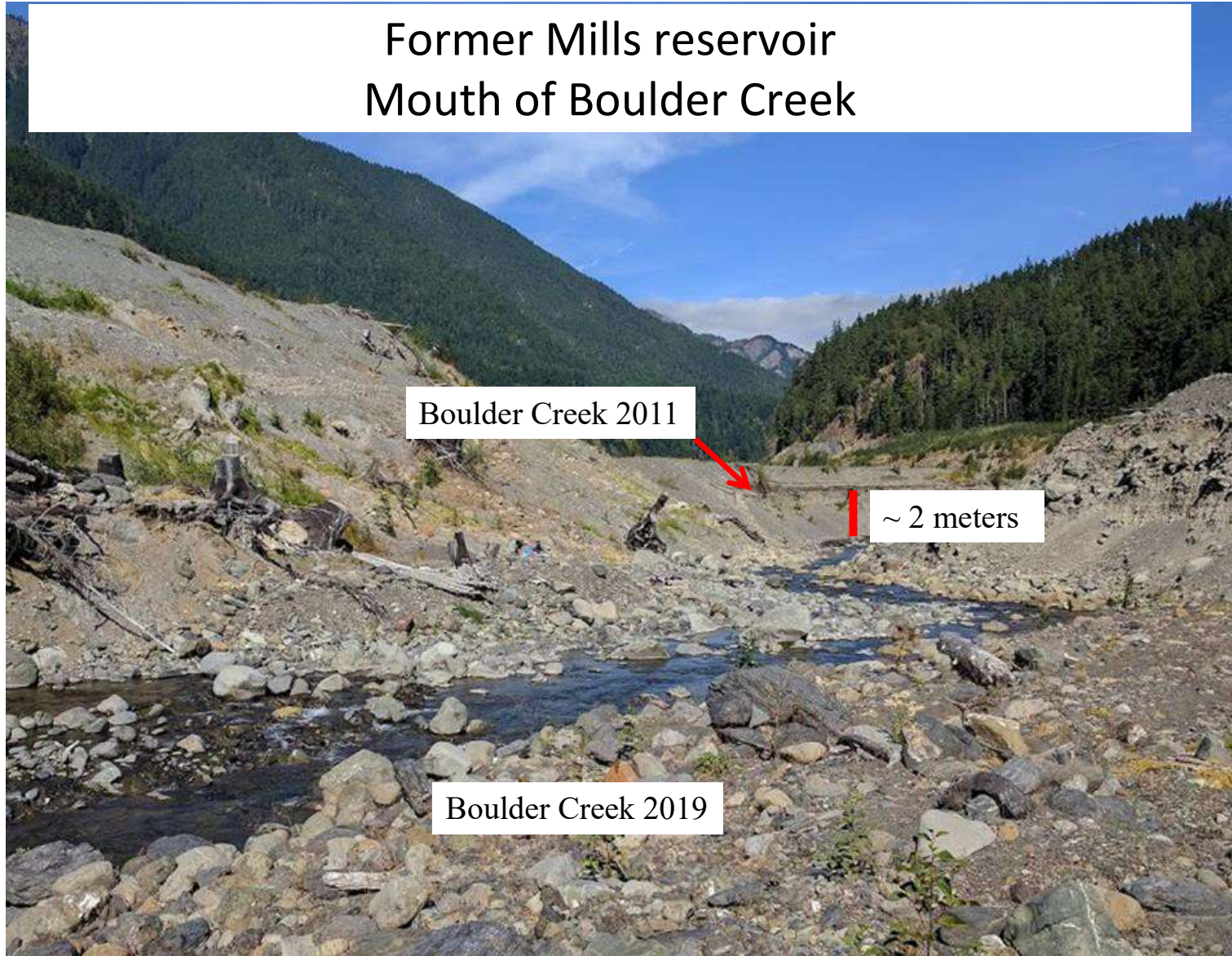


Boulder Creek

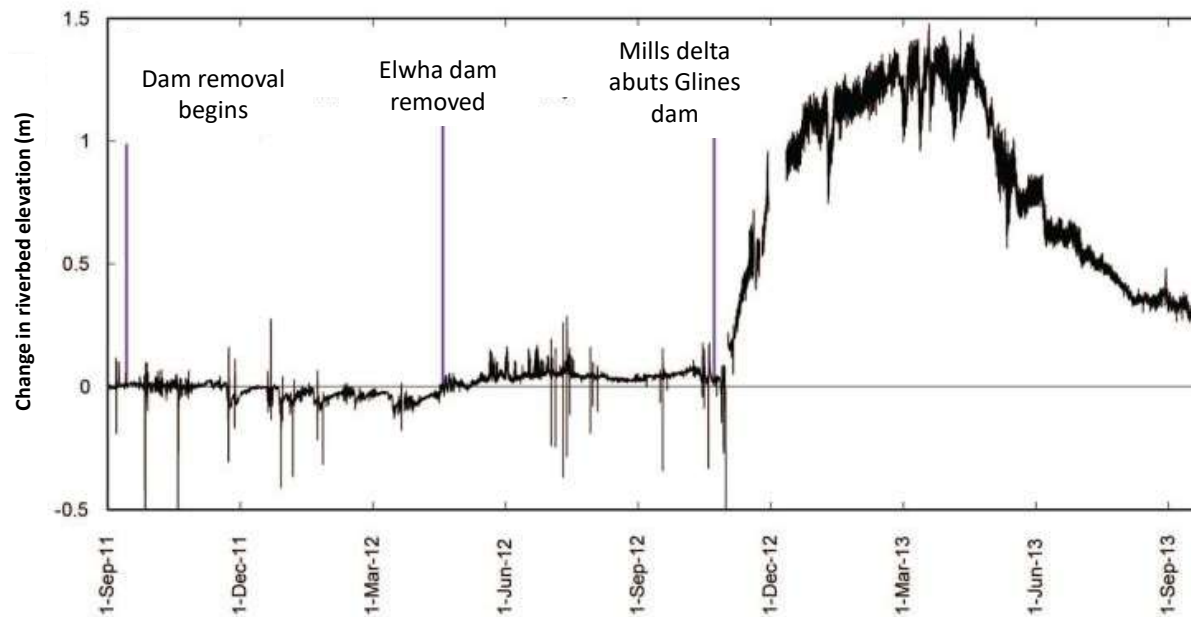
September 2011

Photo by John Gussman

# Former Mills reservoir Mouth of Boulder Creek



# How has freshwater habitat downstream of the dams changed with the increase in sediment supply?

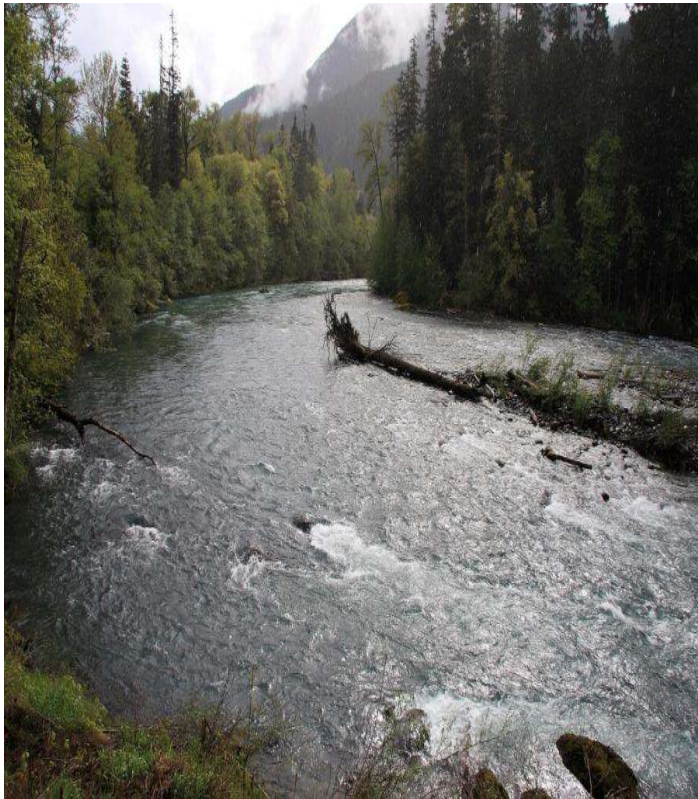


Magirl, C. S., Hildale, R. C., Curran, C. A., Duda, J. J., Straub, T. D., Domanski, M., & Foreman, J. R. (2014). Large-scale dam removal on the Elwha River, Washington, USA: Fluvial sediment load. *Geomorphology*.

# Middle Elwha main stem & floodplain response



# Gravel bar development & wood accumulation in the Middle Elwha River

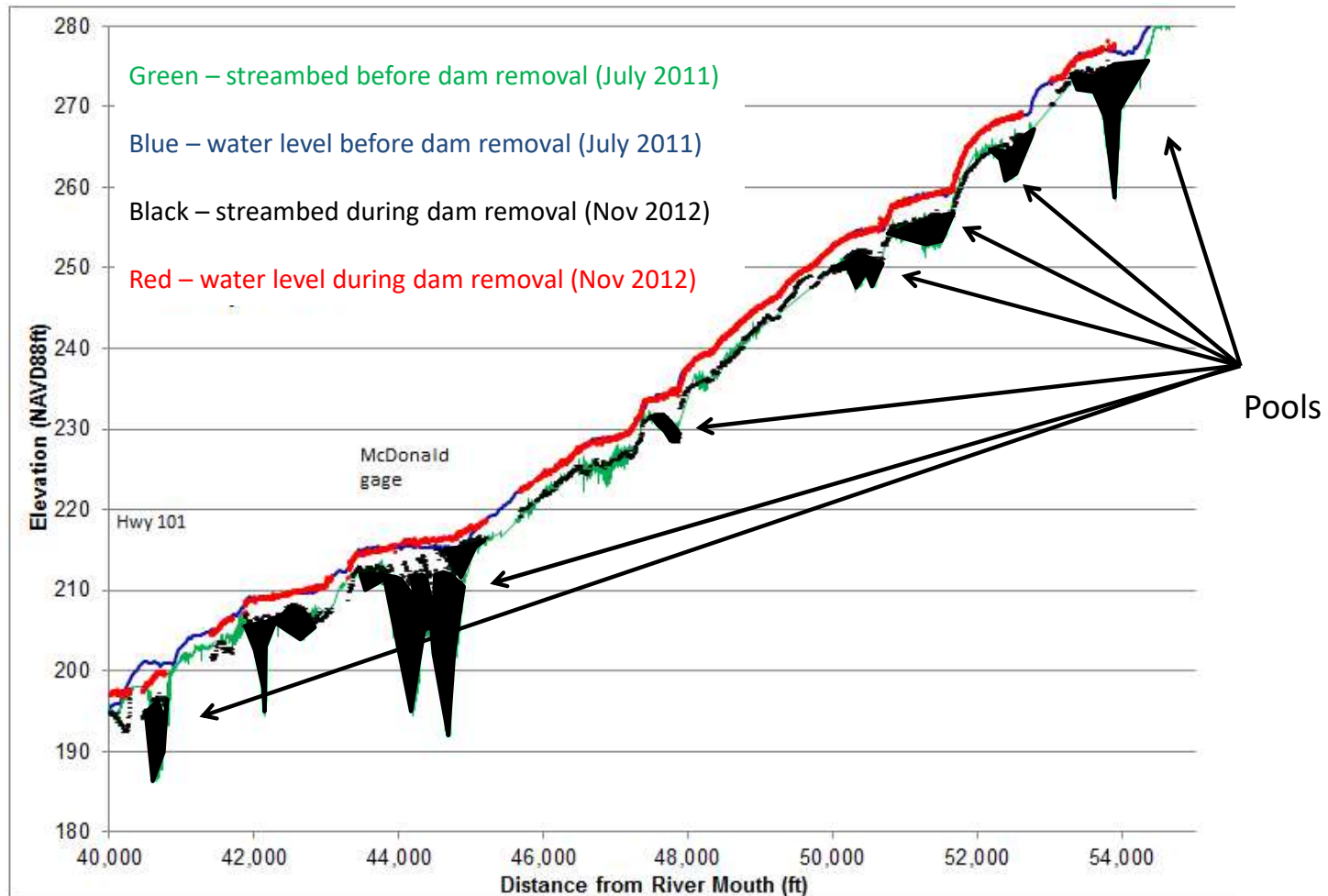


October 2012



March 2013

## Change in Middle Elwha mainstem depths during dam removal



- Slide courtesy of Jennifer Bountry and Tim Randle, Bureau of Reclamation



# How much sediment and where did it go?

~21 million m<sup>3</sup> released



~7% stored in main stem



~60% of sediment transported to Strait of Juan de Fuca



~29% deposited in nearshore

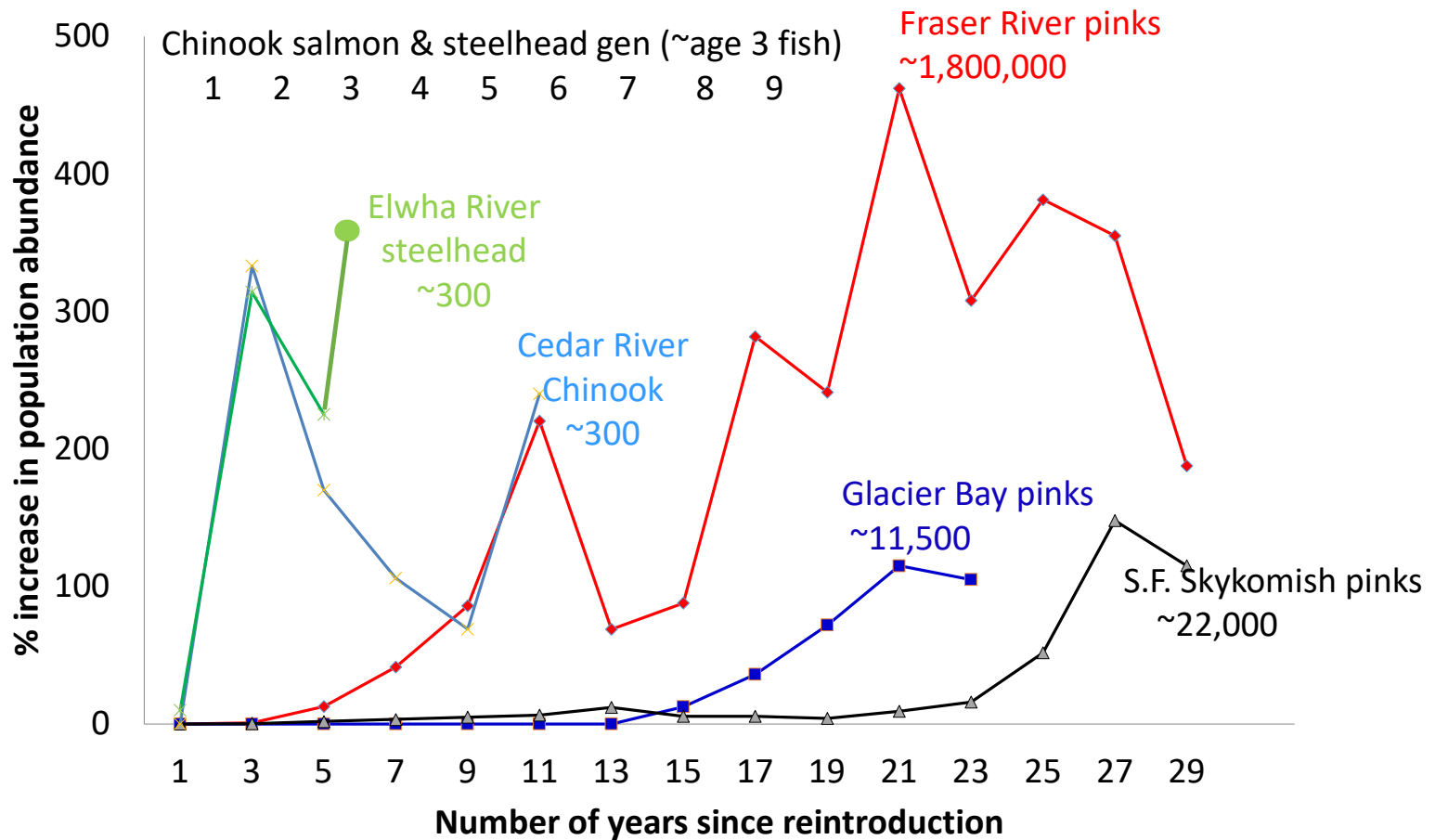


~4% stored in floodplain channels



Ritchie, A.C., Warrick, J.A., East, A.E., Magirl, C.S., Stevens, A.W., Bountry, J.A., Randle, T.J., Curran, C.A., Hildale, R.C., Duda, J.J. and Gelfenbaum, G.R., 2018. Morphodynamic evolution following sediment release from the world's largest dam removal. Scientific reports, 8(1), p.13279.

# Salmon and steelhead can successfully reoccupy newly available habitats



# Elwha River salmon reintroduction above the former dams

- Assisted Relocation

- Hatchery & wild adult coho salmon
- Hatchery & wild steelhead



Liermann et al. 2017,  
Pess et al. 2024

- Natural reintroduction

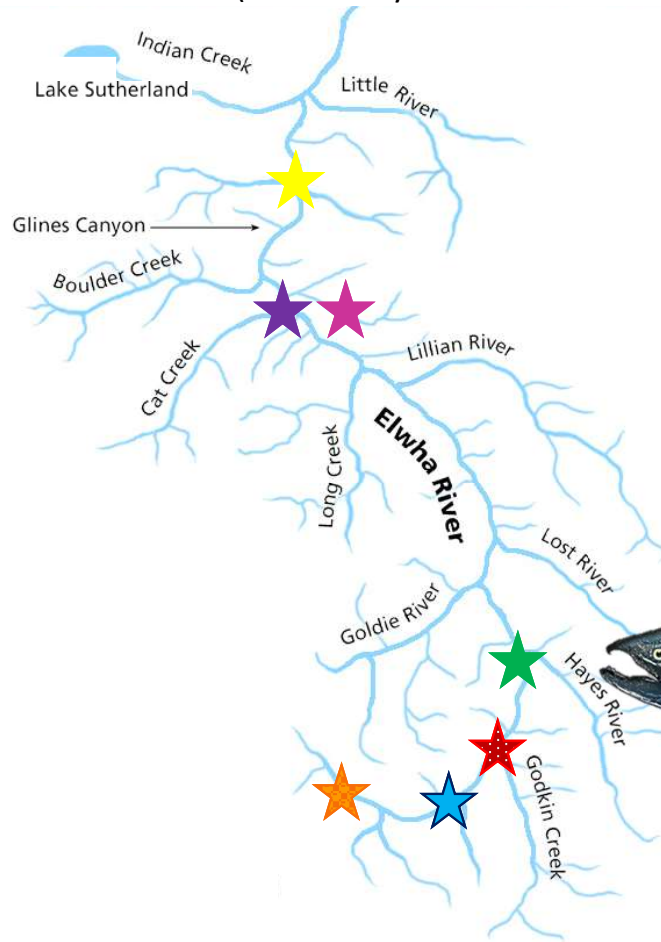
- Steelhead, Chinook salmon, Coho salmon, Pink salmon, Sockeye salmon, Bull Trout & Pacific Lamprey



Reintroduction is a combination of relocation & natural reintroduction by adult salmonids & other species

# Where and how long did it take to get above the former dams?

(Glines Canyon dam removed Aug 2014, Rockfall removed Oct 2015)



**Chum**-rkm 21 (Nov 2014)



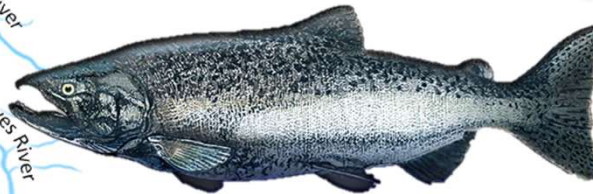
**Pink**-rkm 26 (Aug 2019)



**Coho**-rkm 26 (Oct 2016)



**Sockeye**-rkm 58 (Aug 2015)



**Chinook**-rkm 58 (Sept 2014)

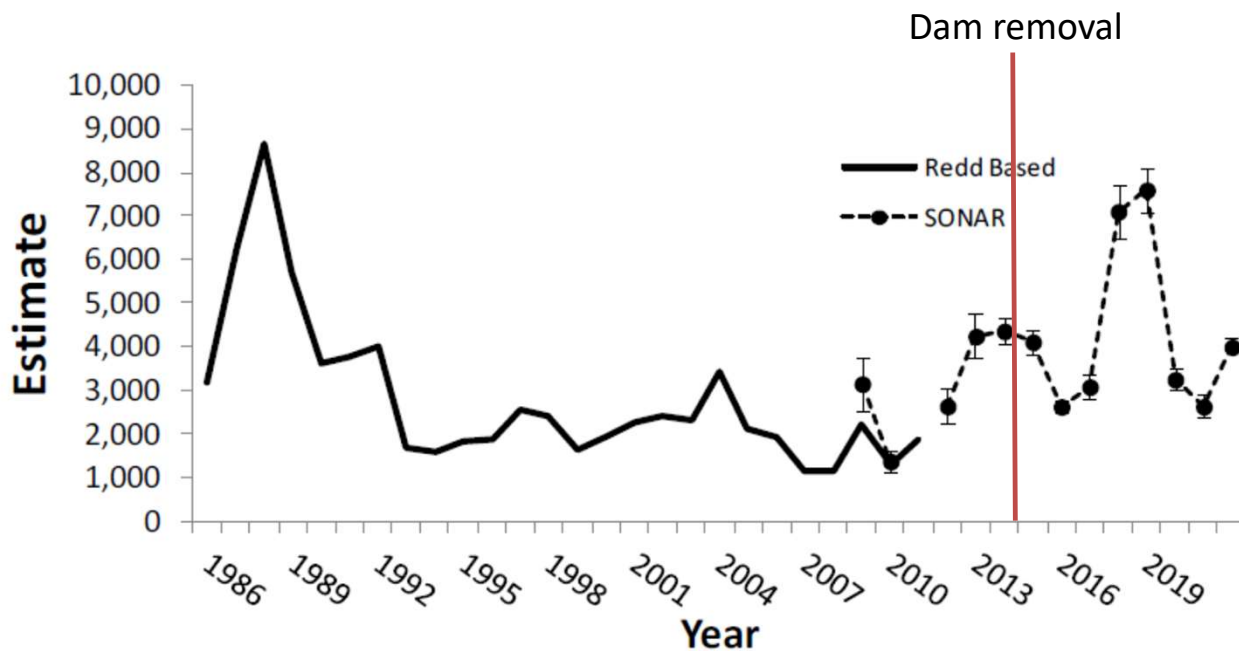


**Steelhead**-rkm 60 (Jul 2014)



**Bull Trout**-rkm 65 (Aug 2014)

# There are more Chinook salmon in the Elwha River after the removal of the dams Chinook salmon (majority hatchery Chinook salmon)



Denton et al. 2022



Photo by John McMillan

# There are more coho salmon in the Elwha River after the removal of the dams

Coho salmon (initially mostly hatchery coho salmon ~1,000)

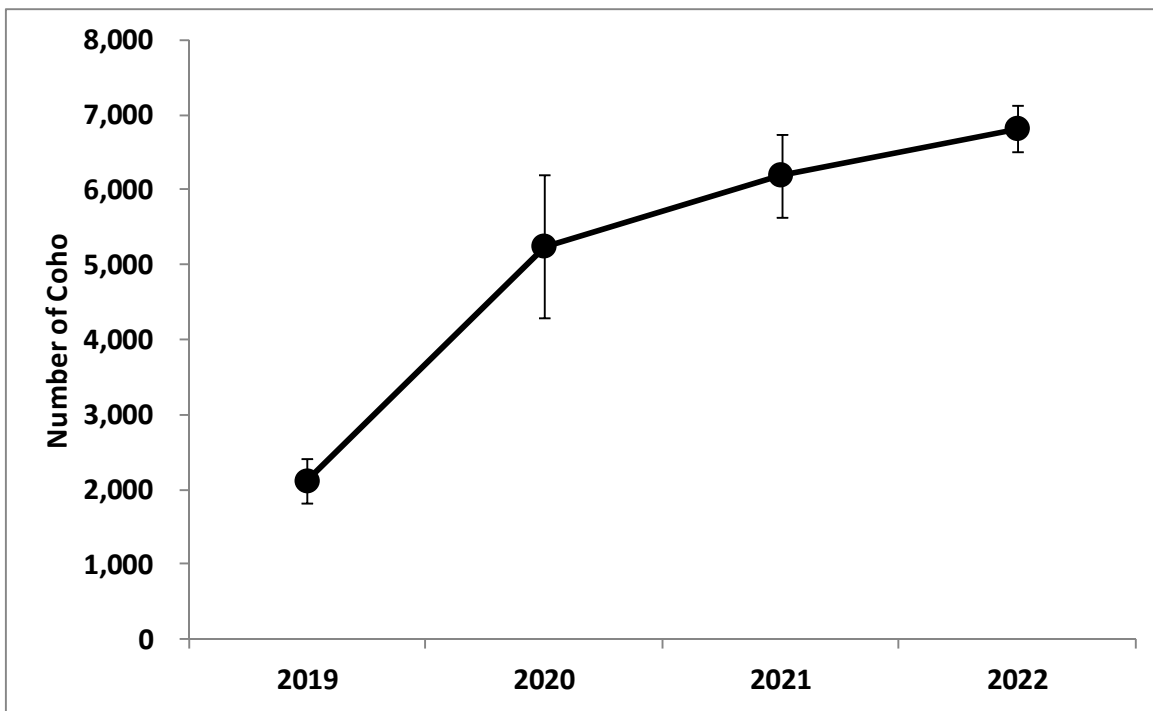
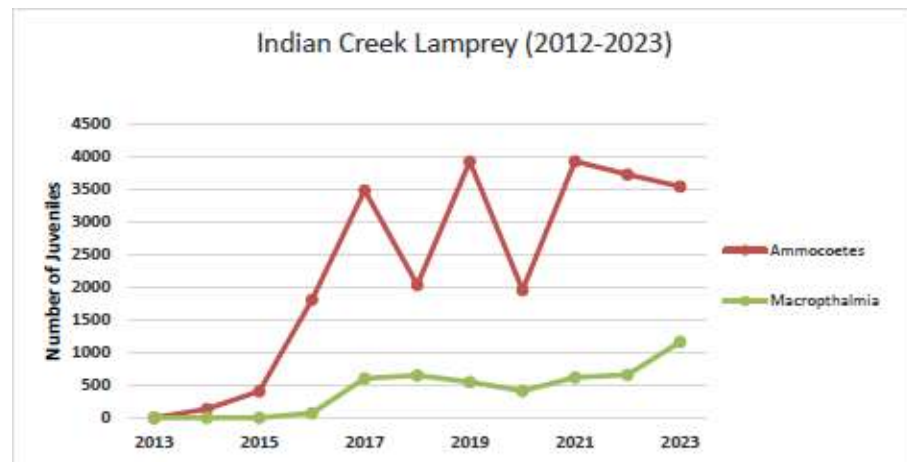


Photo by John McMillan

Denton et al. 2023

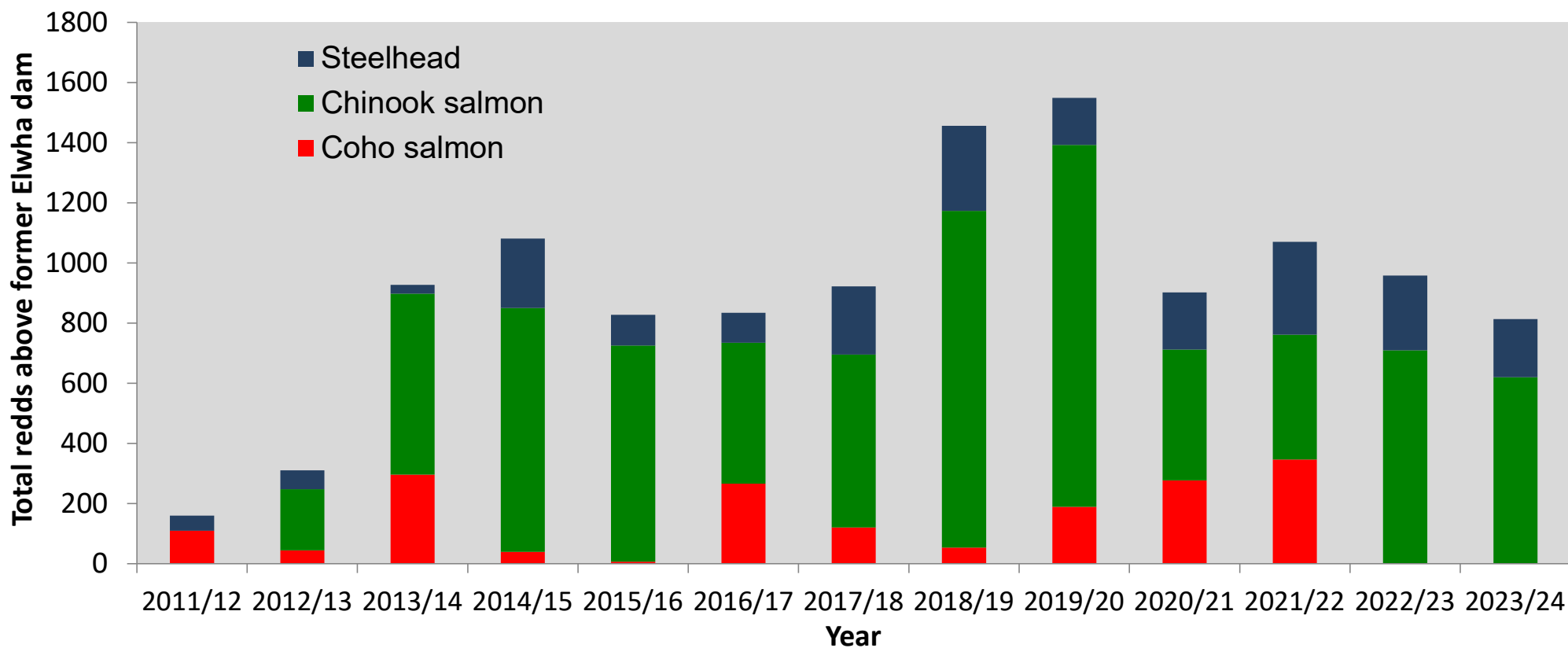
# Elwha River Pacific lamprey

- Elwha River Pacific lamprey - a 12-fold increase three years following dam removal (Hess et al, 2021).
- First documented above former Elwha dam 2013 and above former Glines Canyon dam 2016
- Increasing captured of juveniles at smolt traps



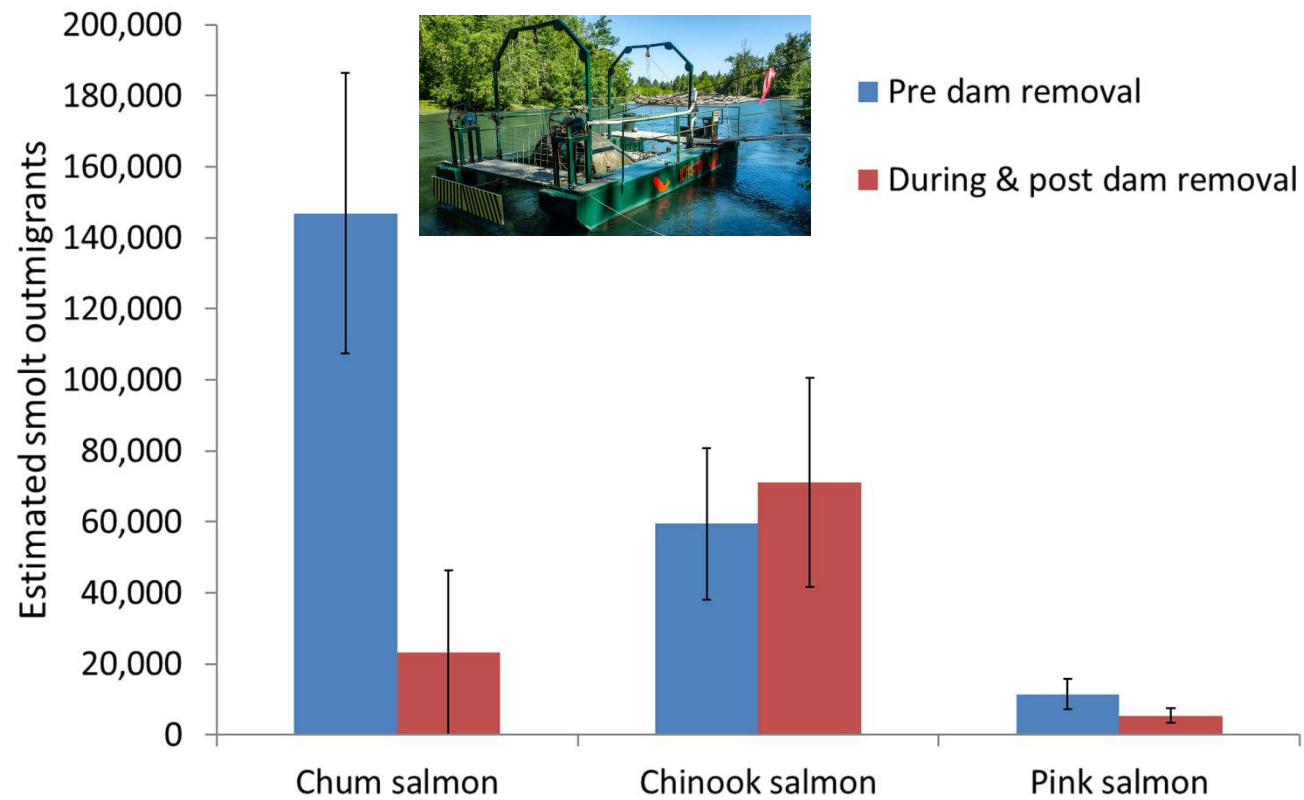
# Salmon recolonization above the former dams

## Chinook salmon, Steelhead, & Coho salmon

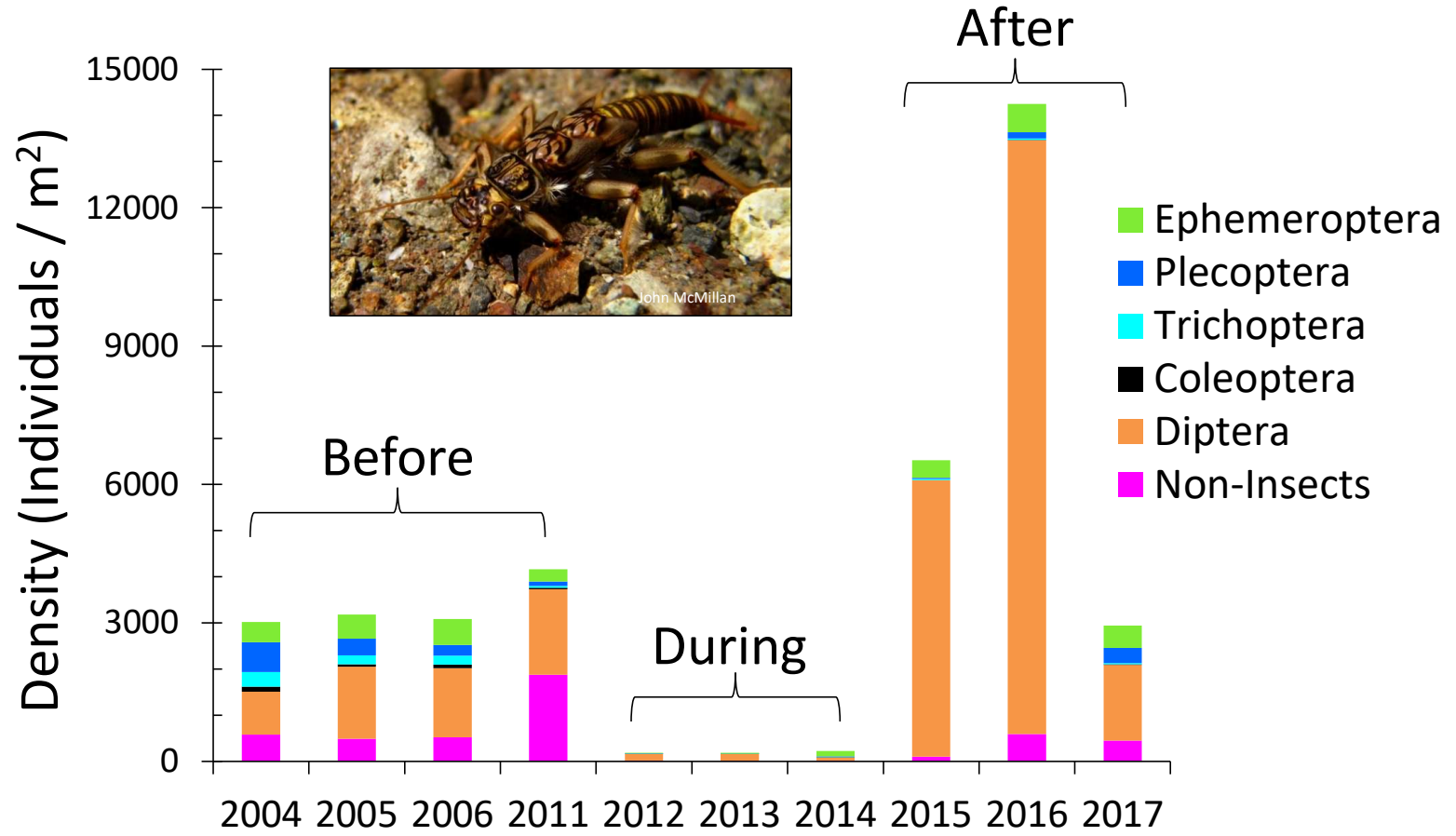


Note – no coho salmon redd data for 2022/23 and 2023/24. Coho salmon population has increased during those years.

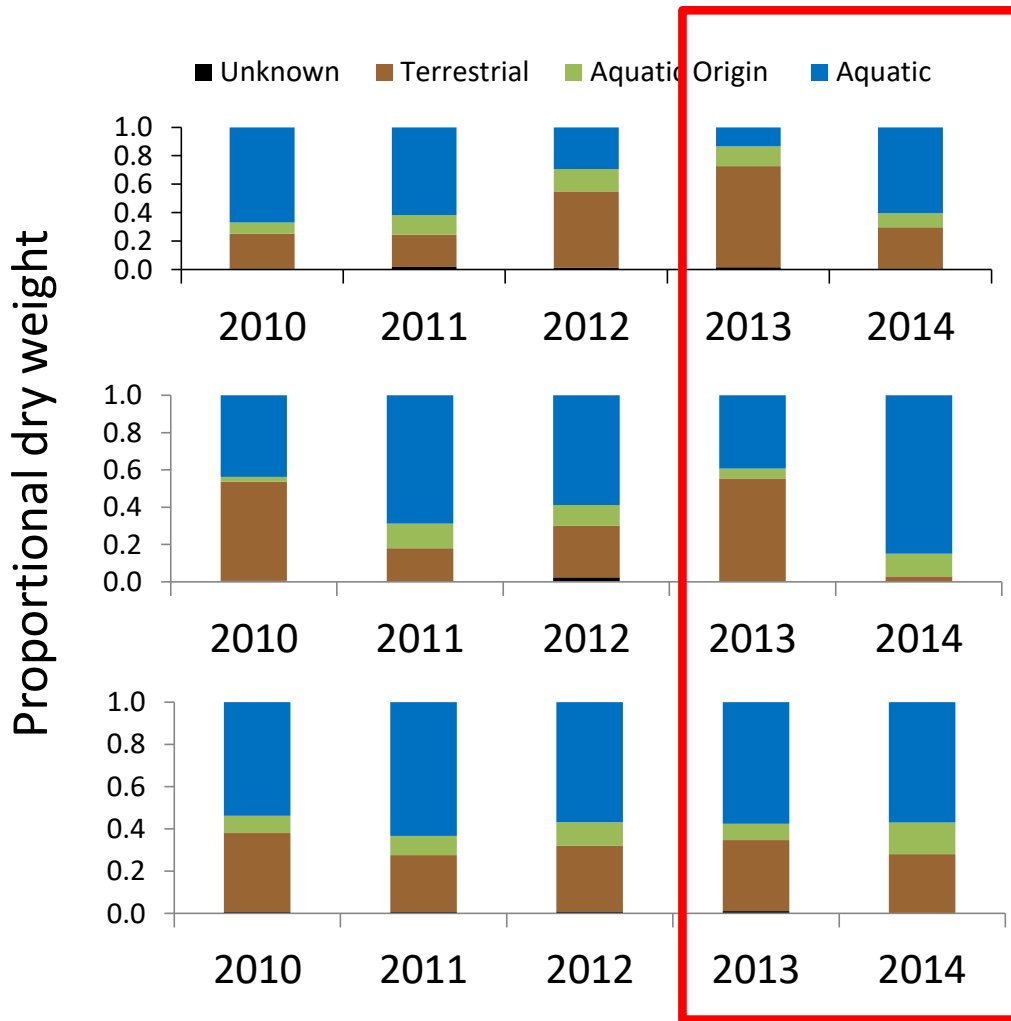
# Sediment had an impact on juvenile salmon, especially during dam removal



# Changes to benthic invertebrate density below the Elwha River dams



# Changes to Elwha River juvenile rainbow trout (*O. mykiss*) summer diet origin



Below Dams

Between Dams

Tributaries



Morley et al. 2020

## The American dipper has changed its behavior and benefited from spawning salmon

- Adult dippers **13 times more likely to be year-round residents** below salmon obstructions
- Dippers below salmon obstructions **20 times more likely to attempt multiple broods**
- **Higher survival** below salmon obstructions due to salmon eggs

Tonra et al. 2015, 2016



# Wildlife reoccupation of former reservoirs



- There is a diverse array of species, including elk, cougars, bobcats, bears, weasels, and woodpeckers
- Small mammal abundance and diversity increased with increased vegetation development
- Beavers have successfully recolonized both former reservoirs
- Deer and elk are found on both former reservoirs
- Deer and elk browse pressure is high but it has not impeded revegetation processes



McCaffery et al. 2018, 2020; Happe et al. 2020

# Vegetation change due to dam removal sediment dynamics & new landforms



Expansion of delta created sites for pioneer vegetation

New intertidal water bodies = expansion of emergent marsh vegetation

New gravel bars = increased plant species diversity



Different vegetation trajectories on landforms - submerged valley walls, high terraces, & dynamic floodplains

Strait of Juan de Fuca



Elwha Dam

Elwha Dam

Glines Canyon Dam

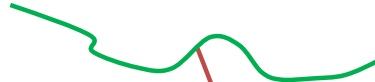
Glines Canyon Dam

**Chinook  
salmon**

All photos by John McMillan

0 5 10km

Strait of Juan de Fuca



Elwha Dam

Glines Canyon Dam

**Bull Trout**



0 5 10km



Elwha Dam

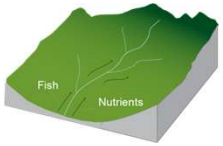
Glines Canyon Dam

**Steelhead/  
Rainbow  
Trout**

0 5 10km

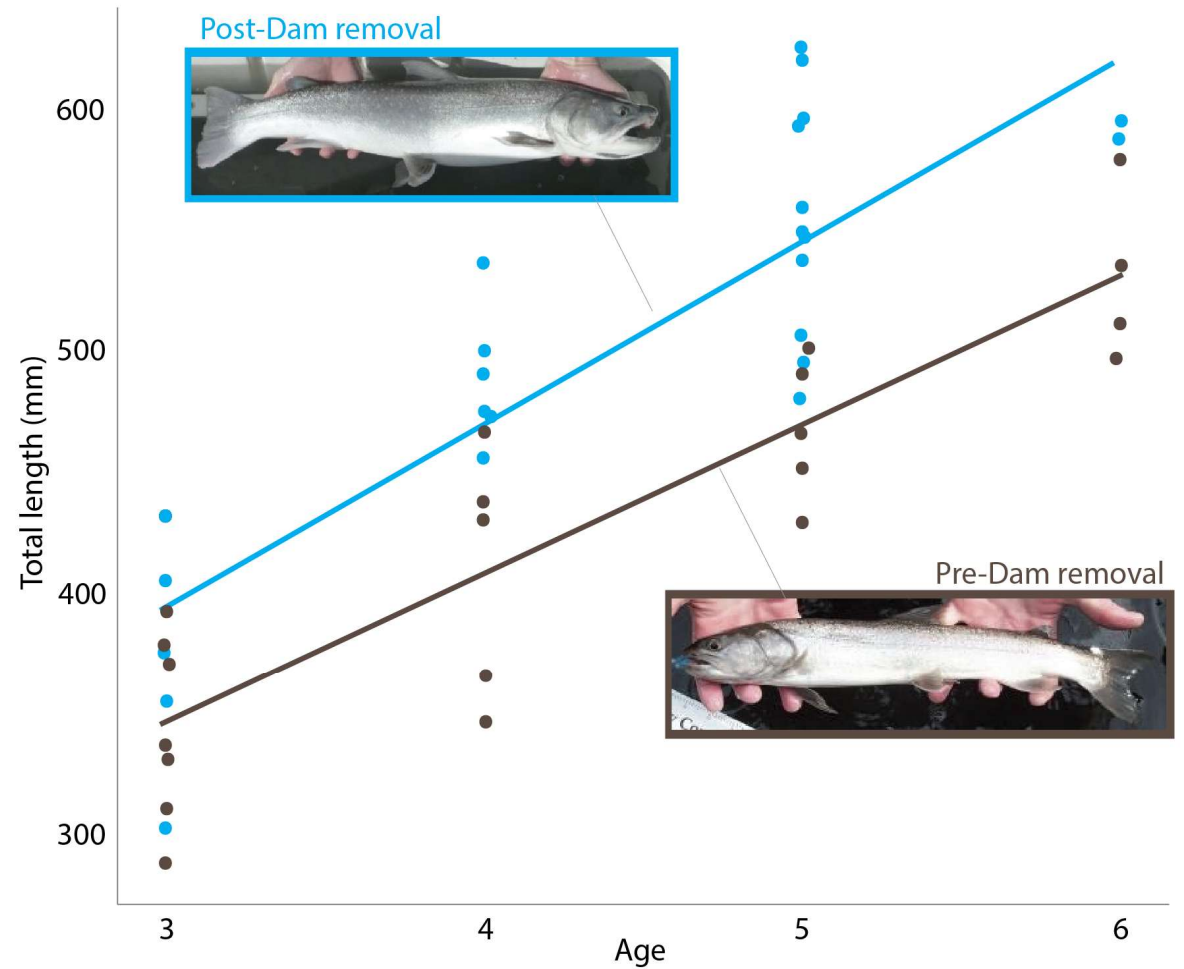
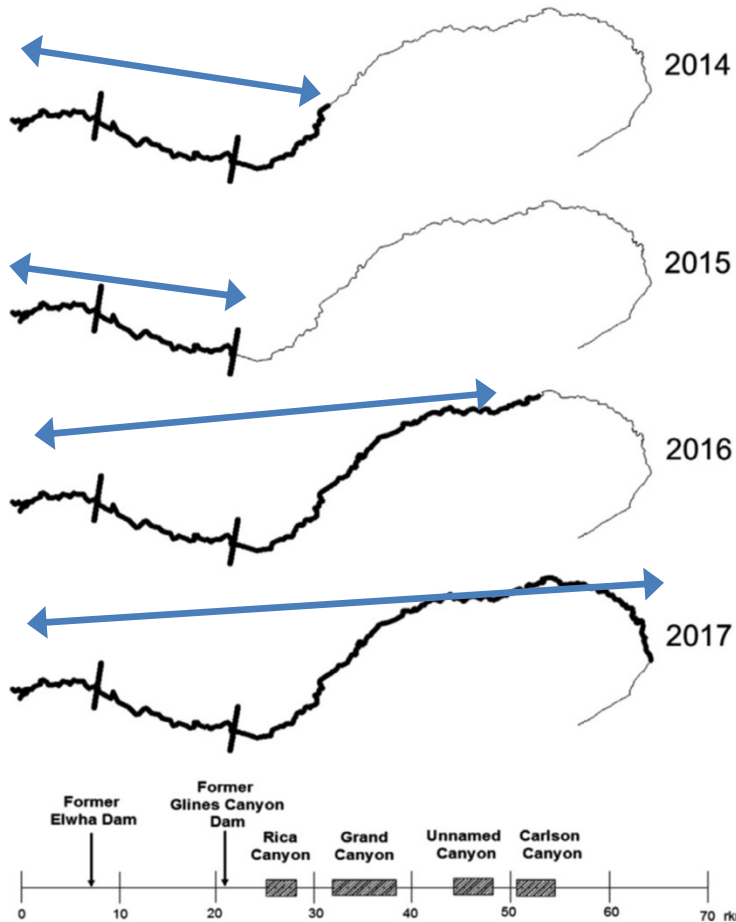


0 5 10km



# Bull trout & re-awakening whole-river migration

Upstream migration via radio-telemetry  $\leftarrow$



# There are more steelhead in the Elwha River after the removal of the dams

Winter Steelhead (2025 ~74% NOR)

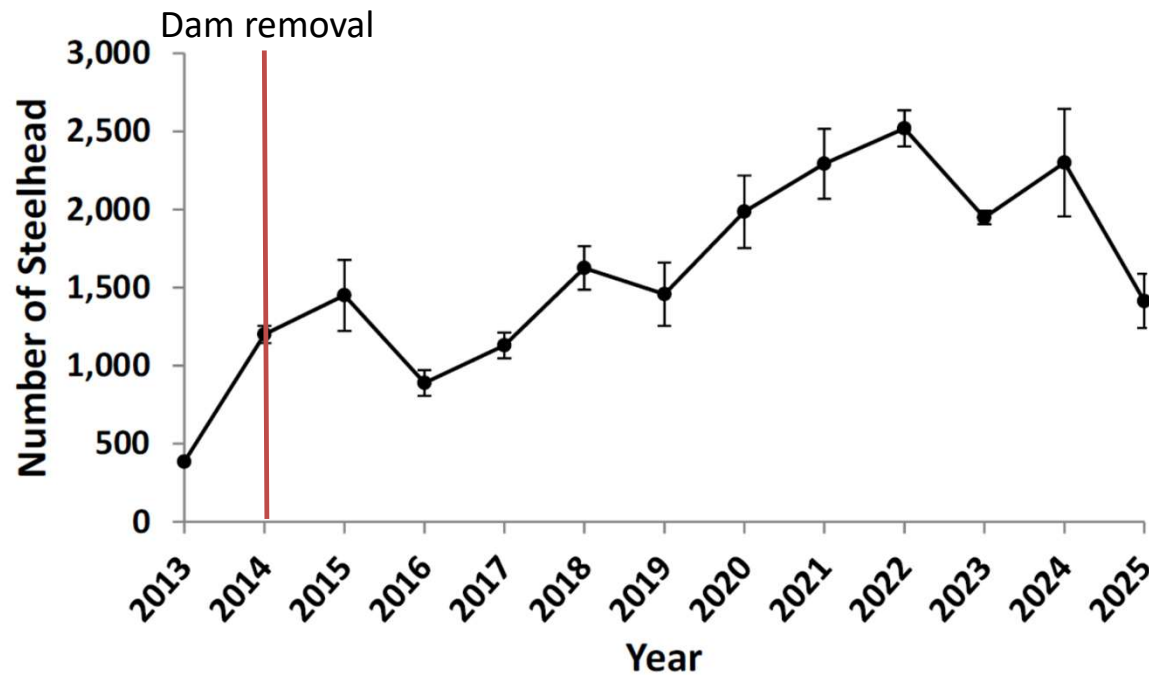


Photo by John McMillan

Denton et al.2025

# Naturally spawning Elwha River *O. mykiss* have greater life history diversity

Naturally spawning Elwha River *O. mykiss* (n = 513)

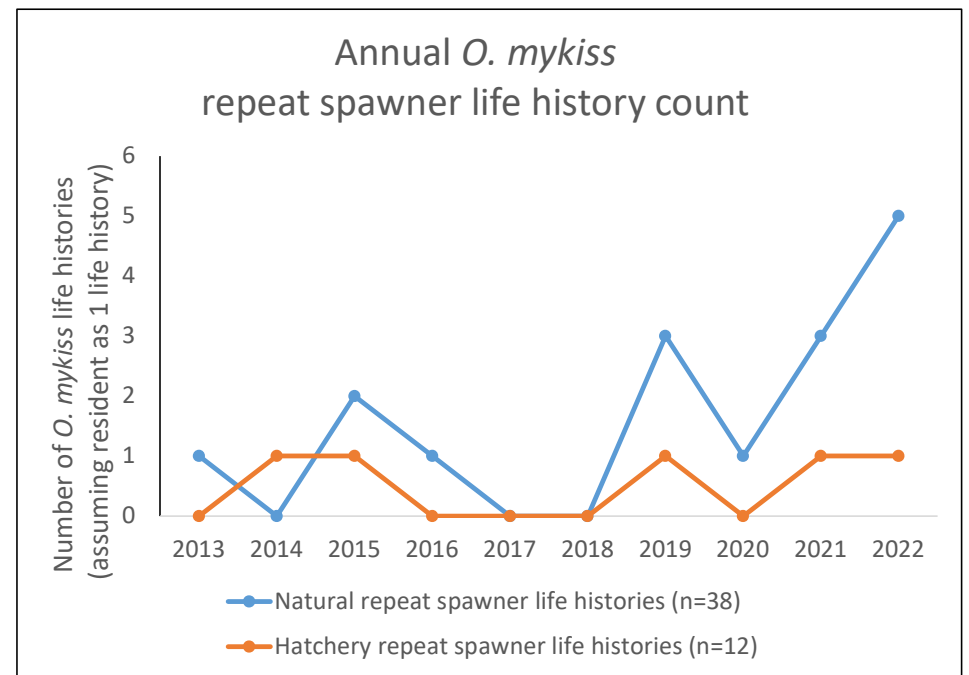
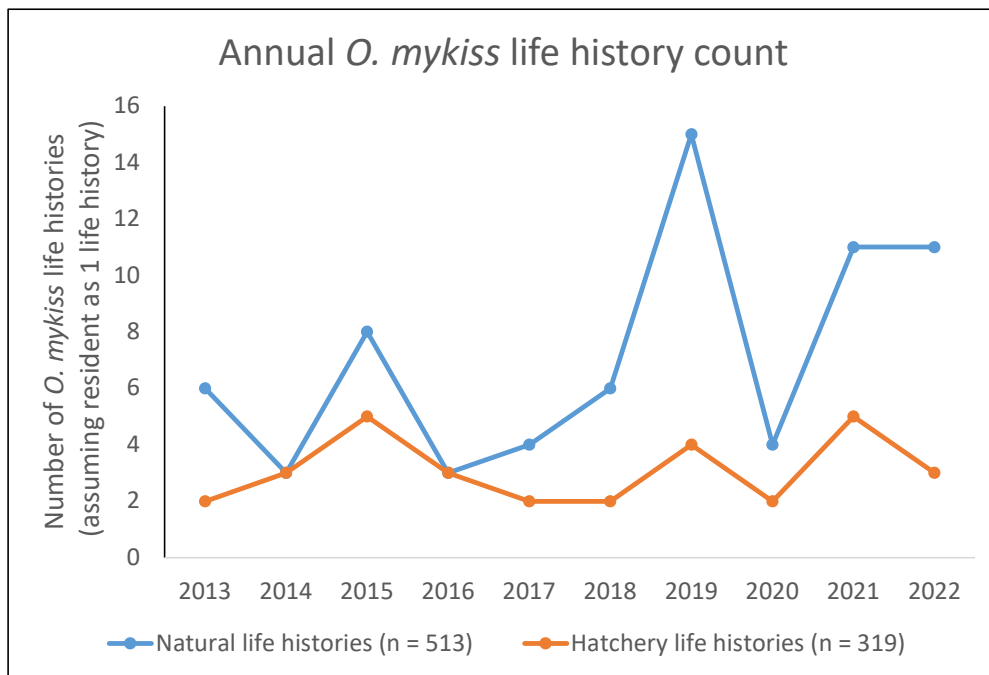
Hatchery Elwha River *O. mykiss* (n= 319)

General life history	General patterns
Resident <i>O. mykiss</i>	<ul style="list-style-type: none"> <li>- Six age groups including 2 through 7</li> <li>- Majority are 4 year olds</li> </ul>
Summer steelhead	<ul style="list-style-type: none"> <li>- <b>4 life histories</b></li> <li>- Majority are 2.2</li> <li>- <b>Repeat spawners include multiple spawning events</b></li> </ul>
Winter steelhead	<ul style="list-style-type: none"> <li>- <b>12 life histories</b></li> <li>- Majority are 2.1</li> <li>- 2<sup>nd</sup> majority is 3.1</li> <li>- <b>Repeat spawners average 10%</b></li> <li>- <b>Repeat spawners include multiple spawning events</b></li> </ul>

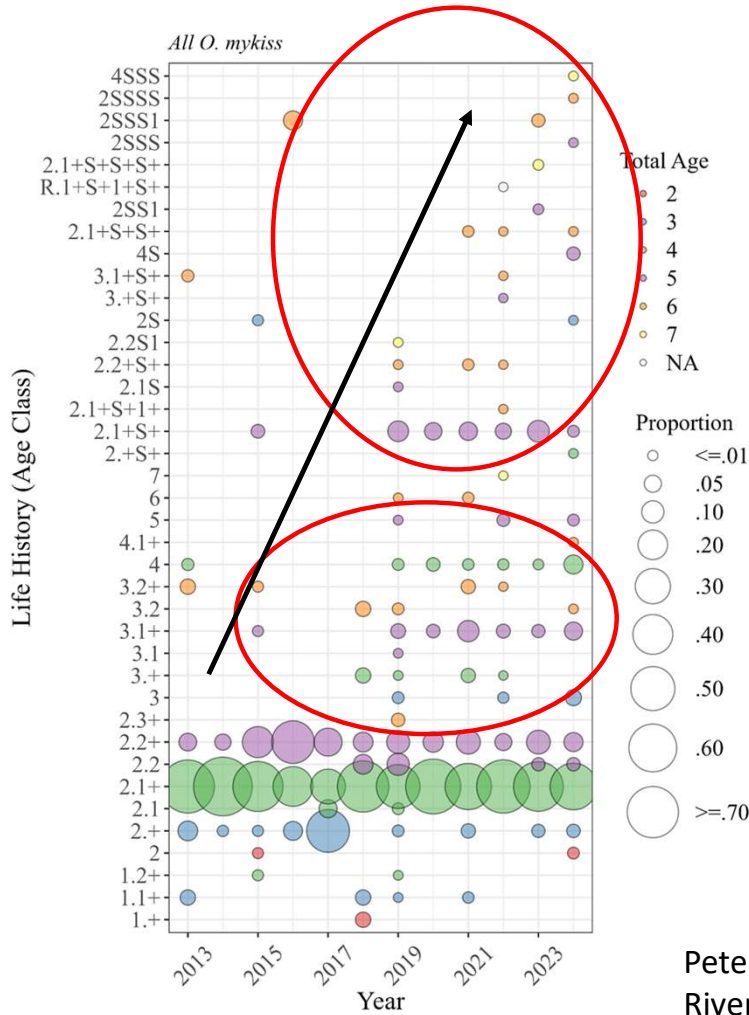
General life history	General patterns
Resident <i>O. mykiss</i>	<ul style="list-style-type: none"> <li>- 3 and 5 year olds</li> </ul>
Winter steelhead	<ul style="list-style-type: none"> <li>- <b>4 life histories</b></li> <li>- Majority are 2.1</li> <li>- <b>Repeat spawners average 1%</b></li> </ul>

Life history defined for this exercise as different combinations of freshwater/saltwater residency time and the times of repeat spawning (one v. multiple)

# Naturally spawning Elwha River *O. mykiss* have greater life history diversity



# *o. mykiss* life history expansion



2013 to 2018 – 1 to 3 life histories

2018 to 2020 – up to 4 life histories

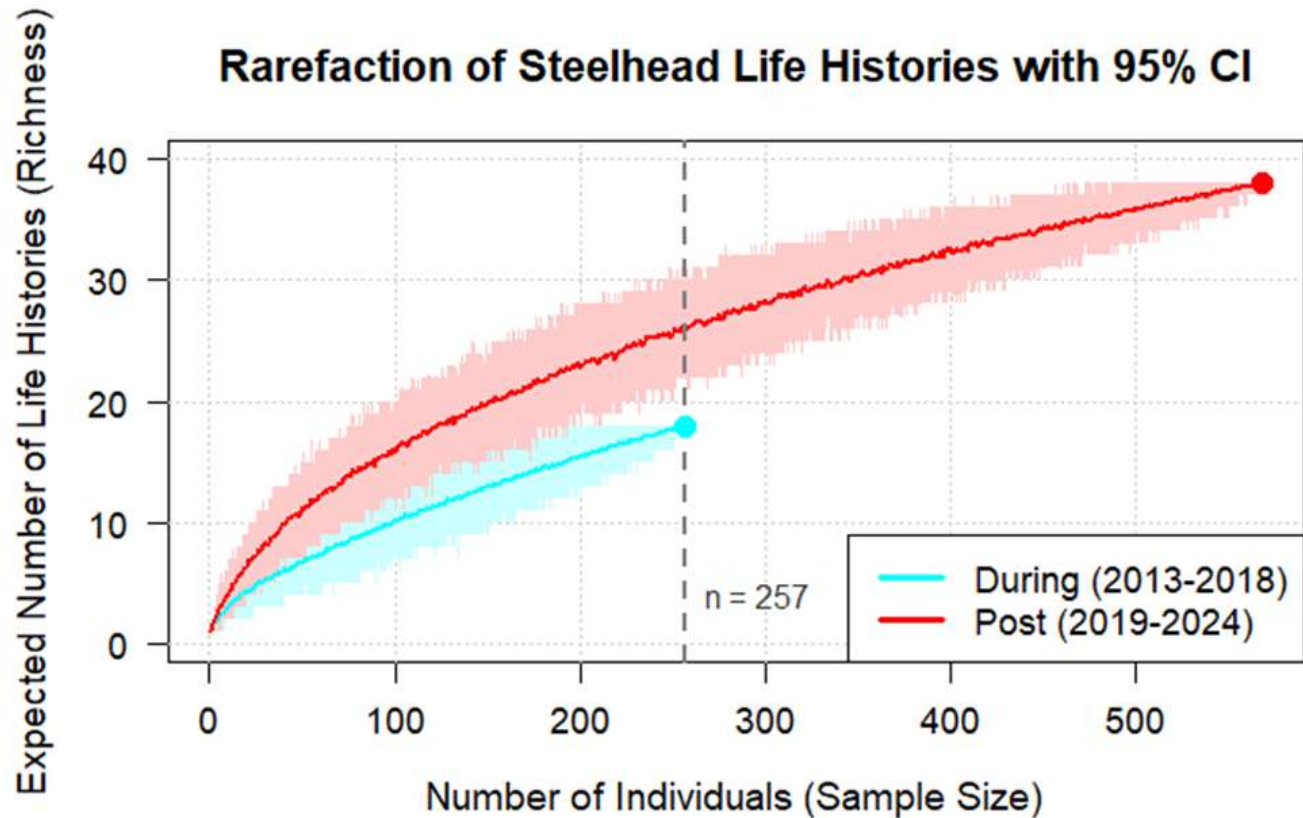
2021 to 2024 – 3 to 8 life histories per year

2018 to 2024 – More 3 plus fish

2018 to 2024 – More repeat spawners

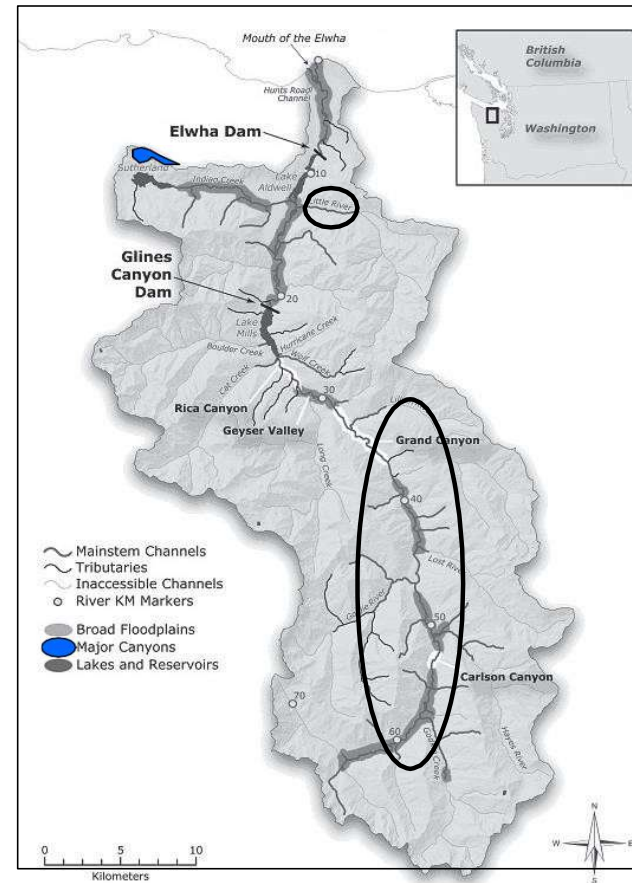
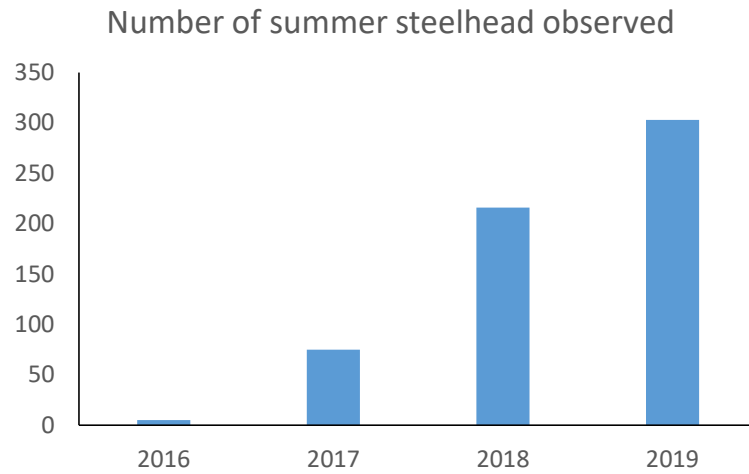
Peters et al. in review. Life history diversity of *oncorhynchus mykiss* in the Elwha River during and following dam removal. *Frontiers in Ecology and Evolution*

# *o. mykiss* life history expansion not a sampling phenomenon

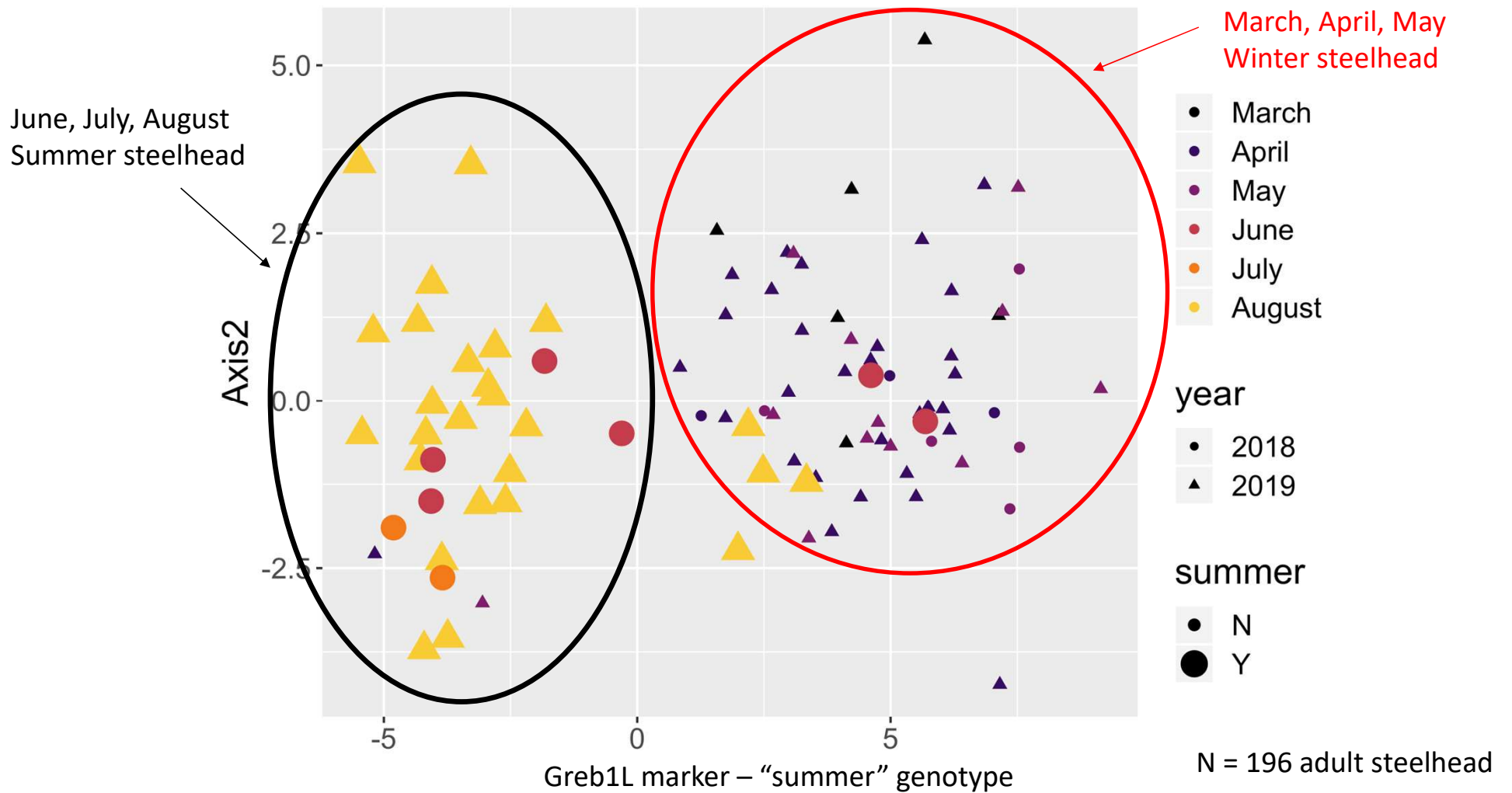


Peters et al. in review. Life history diversity of *oncorhynchus mykiss* in the Elwha River during and following dam removal. *Frontiers in Ecology and Evolution*

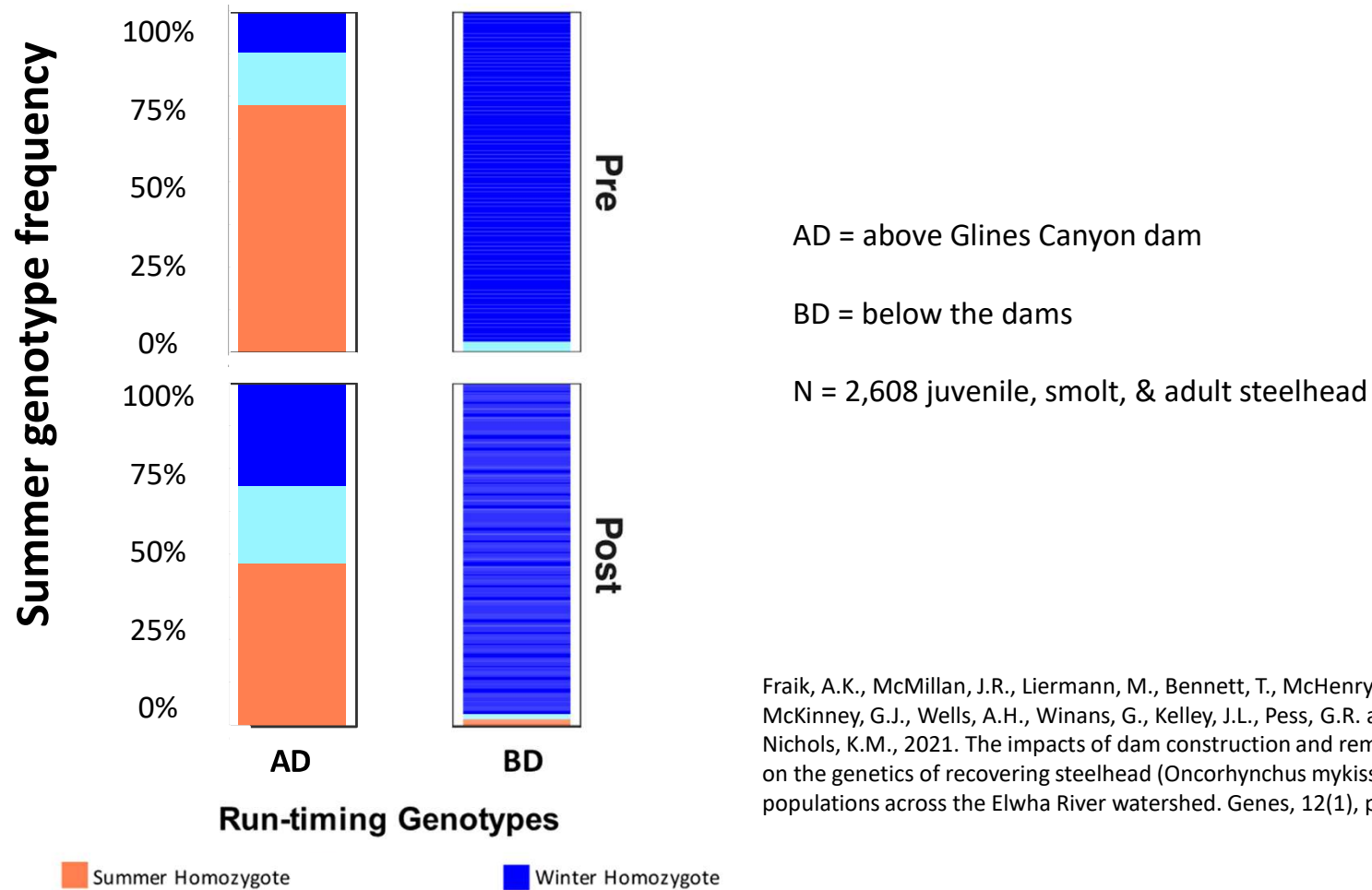
# The reawakening of summer steelhead in the Elwha River



# 2018 & 2019 Returning Elwha River wild summer & winter steelhead



# A higher frequency of “summer” genotype above dams (AD) before & after dam removal



# Elwha River dams and former reservoirs

- Elwha and Glines Canyon dam removal complete



- > ~65% of total stored sediment has been released

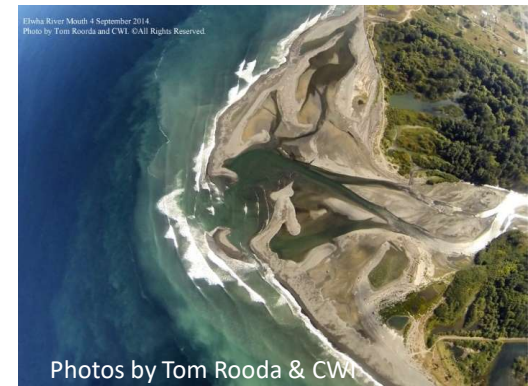
Pre dam removal



2015

# Elwha River nearshore, delta and main stem

- ~90% of sediment transported to Strait of Juan de Fuca
- There is now a ~60 hectare delta at the Elwha river mouth
- ~10% of sediment stored in-river, supplying spawnable gravels and changing habitats



# Elwha River fish reintroduction

- Adult salmon making it above former dams and spawning in the hundreds to thousands
- Both hatchery and wild fish are contributing to the development of self-sustaining populations
- Pacific Lamprey growing in numbers
- Bull Trout anadromy allows for growth benefits
- 'Re-awakening' of summer steelhead



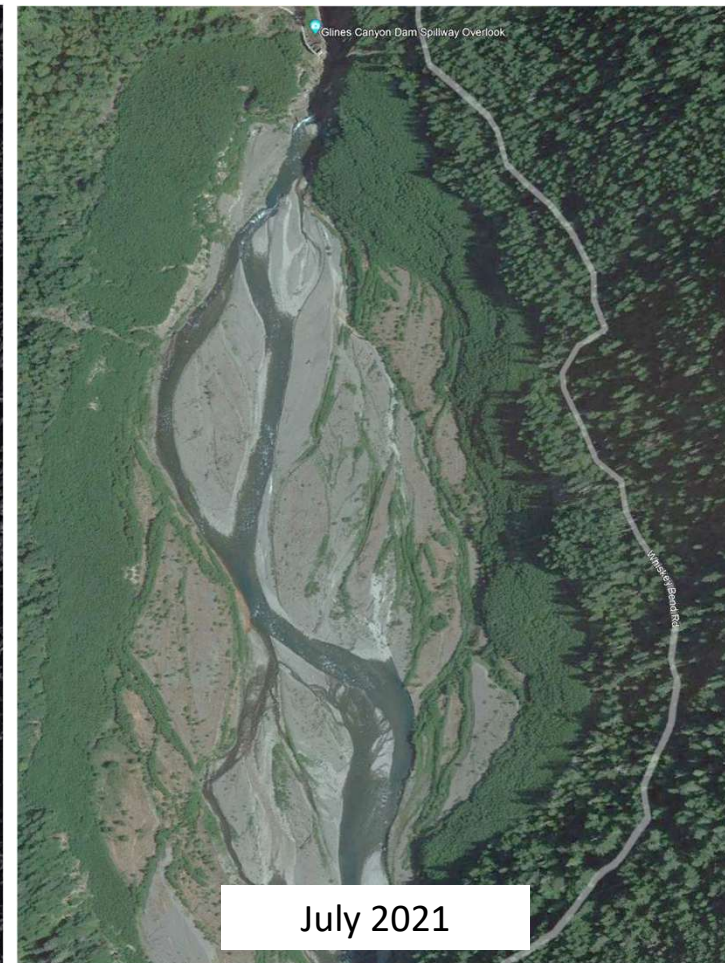
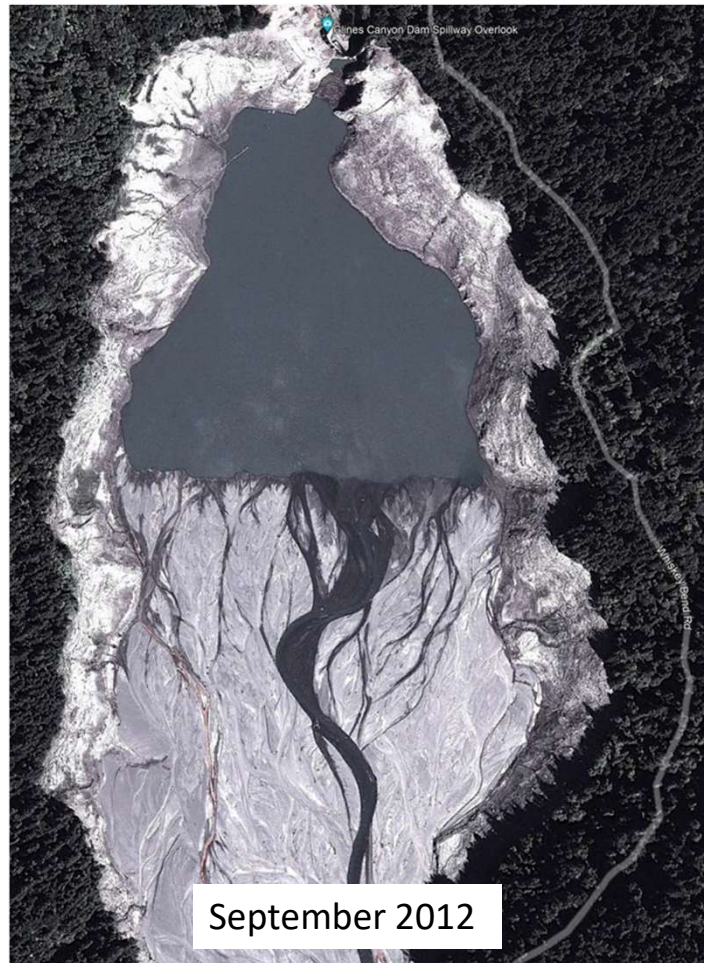
# Elwha River riverine foodwebs

- Benthic invertebrates reduced over 95% in lower Elwha, now making a comeback
- Juvenile salmon diet shift – aquatic to terrestrial back to aquatic
- American dippers have altered their migratory behavior and have productivity benefits from salmon



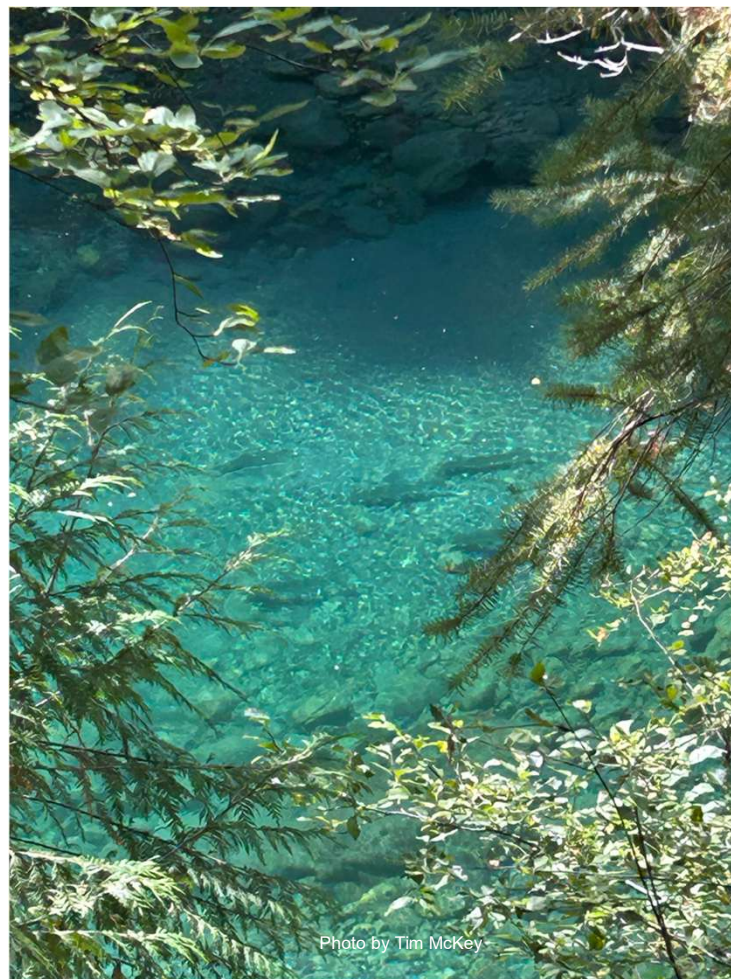
# Elwha River re-vegetation

- Vegetation change due to:
  - dam removal
  - sediment flux
- the creation of new landforms
  - delta,
  - river, and
  - former reservoirs



# Elwha River *o. mykiss*

- *o. mykiss* have increased in abundance 3 to 5 times since dam removal
- We have identified 39 different *o. mykiss* life history strategies in the Elwha River from 2013 to 2024
- Life history diversity has increased during that time, accounting for differences in sample size
- Since 2018 there has been an increase in 3+ anadromous, older resident *O. mykiss*, and repeat spawners



Thank you



Photo by John McMillan



Photo by Tim McKey