Ecosystem response during the removal of the Elwha River Dams

June 2016

USGS science for a changing world

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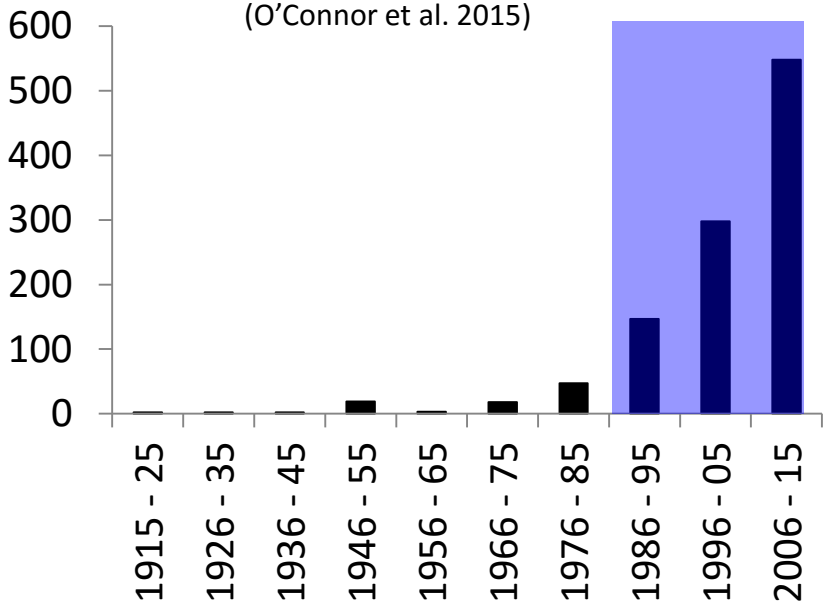
Today's talk

- A national context for dam removal
- Watershed description
- Impacts of the Elwha river dams
- The Elwha River Ecosystem & Fisheries Restoration Act
- How much sediment is there & what is going to happen?
- The removal of the Elwha River dams
- What has occurred during & since dam removal?
- Summary

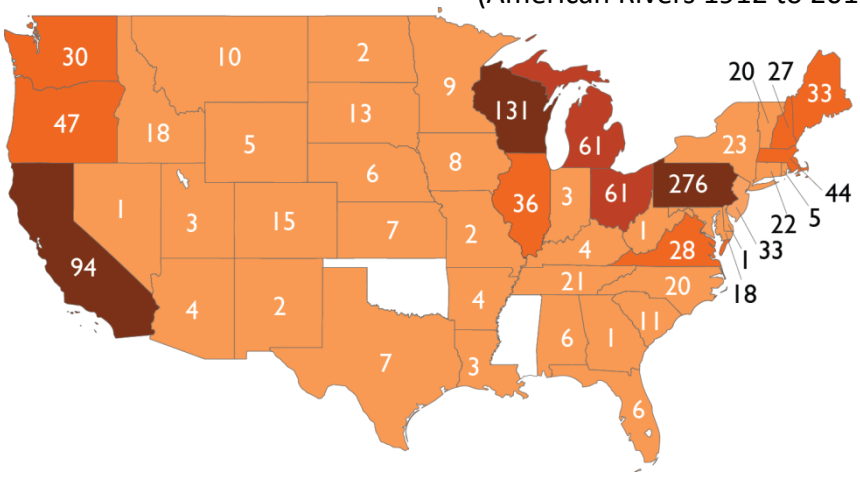
Dam Removal in the United States

Number of dams removed

(O'Connor et al. 2015)



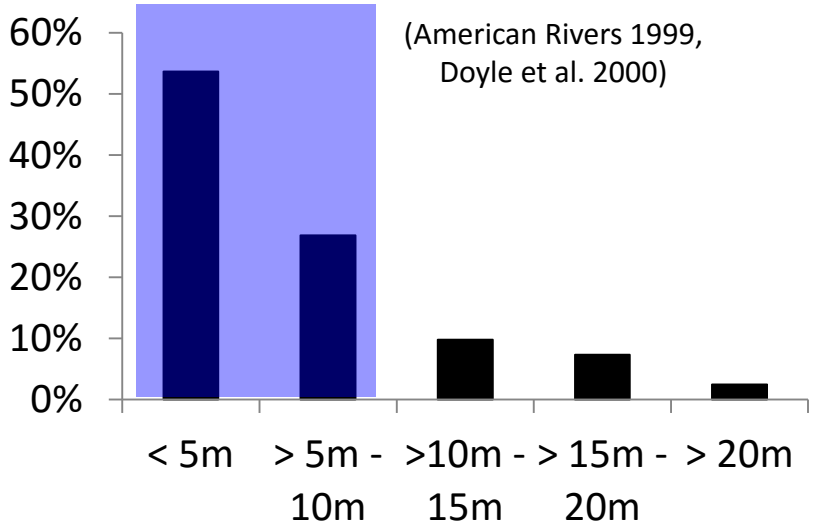
(American Rivers 1912 to 2014)



Increased removal over last 30 years

Percent of total removed

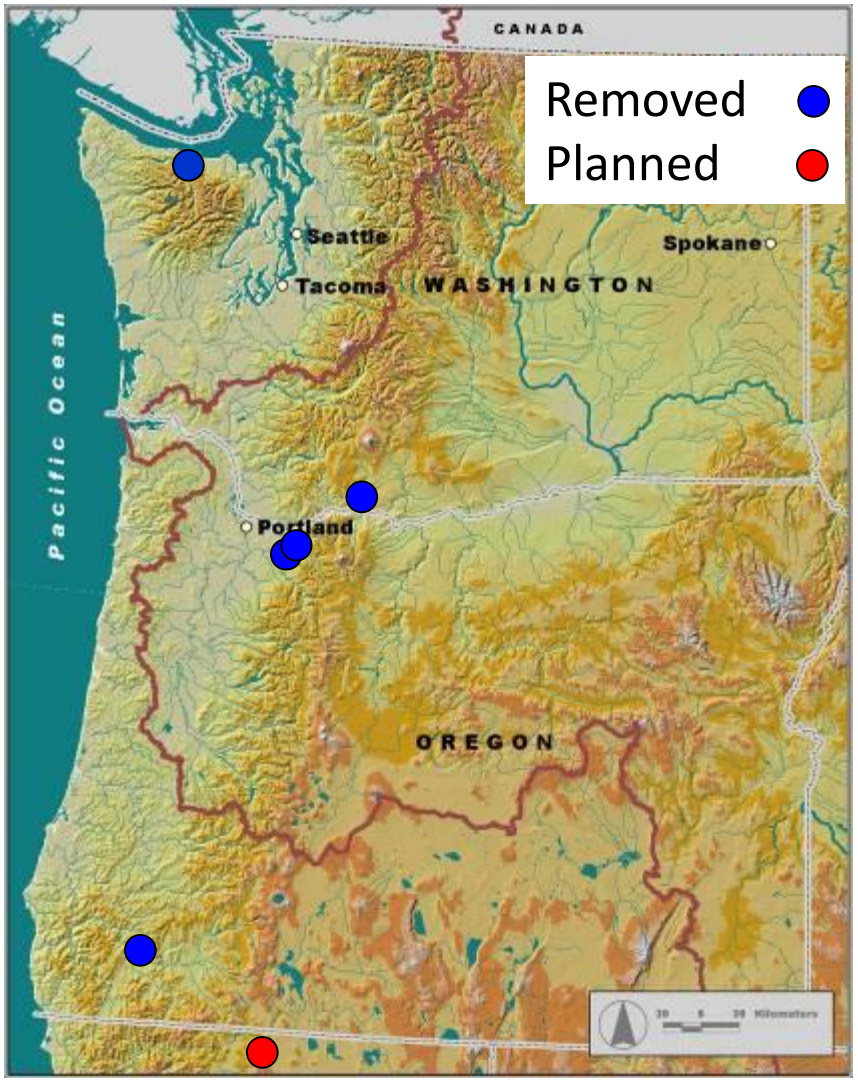
(American Rivers 1999, Doyle et al. 2000)



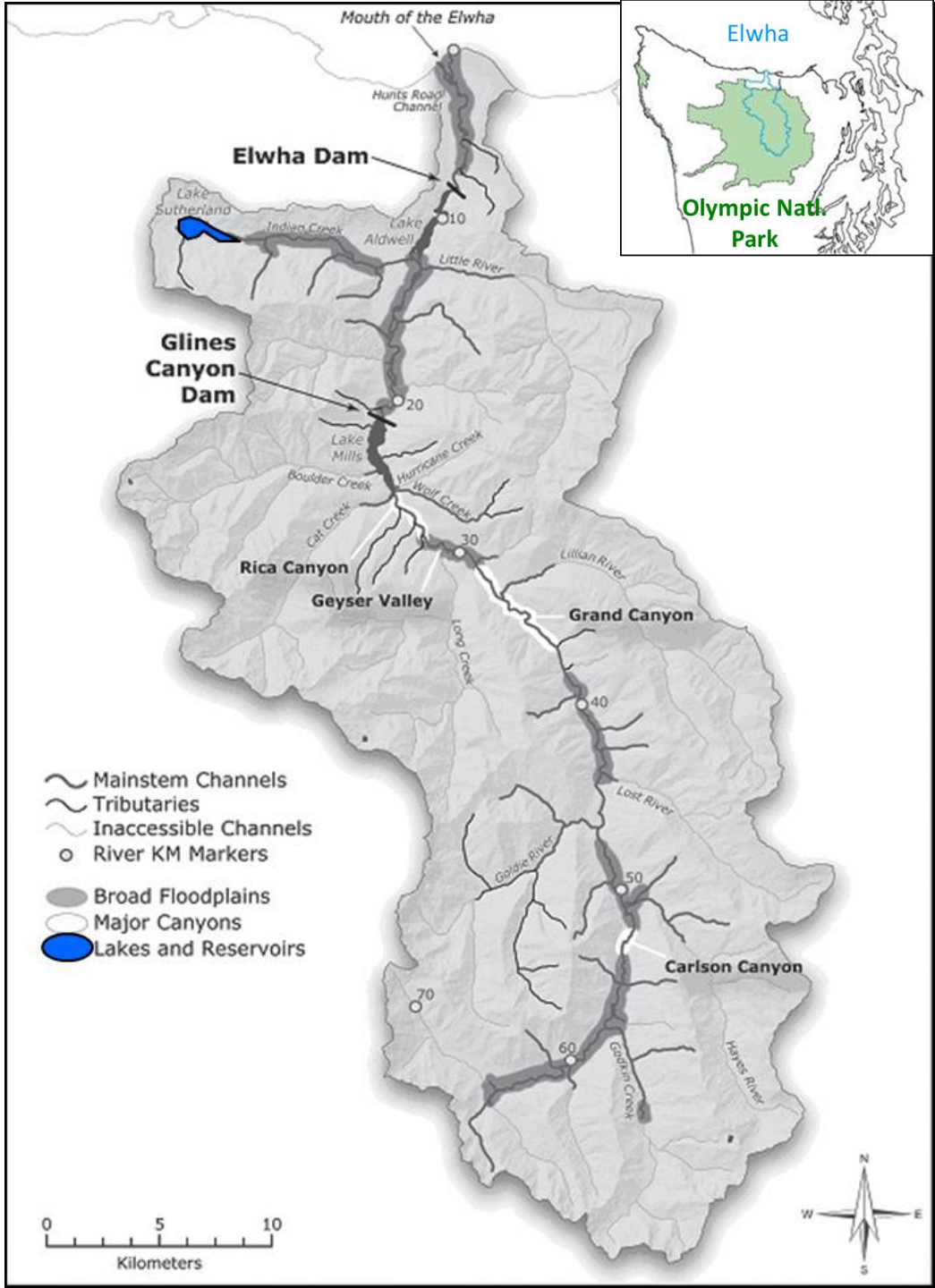
Most dams less than 10m in height

Large Dam Removal in the Pacific Northwest

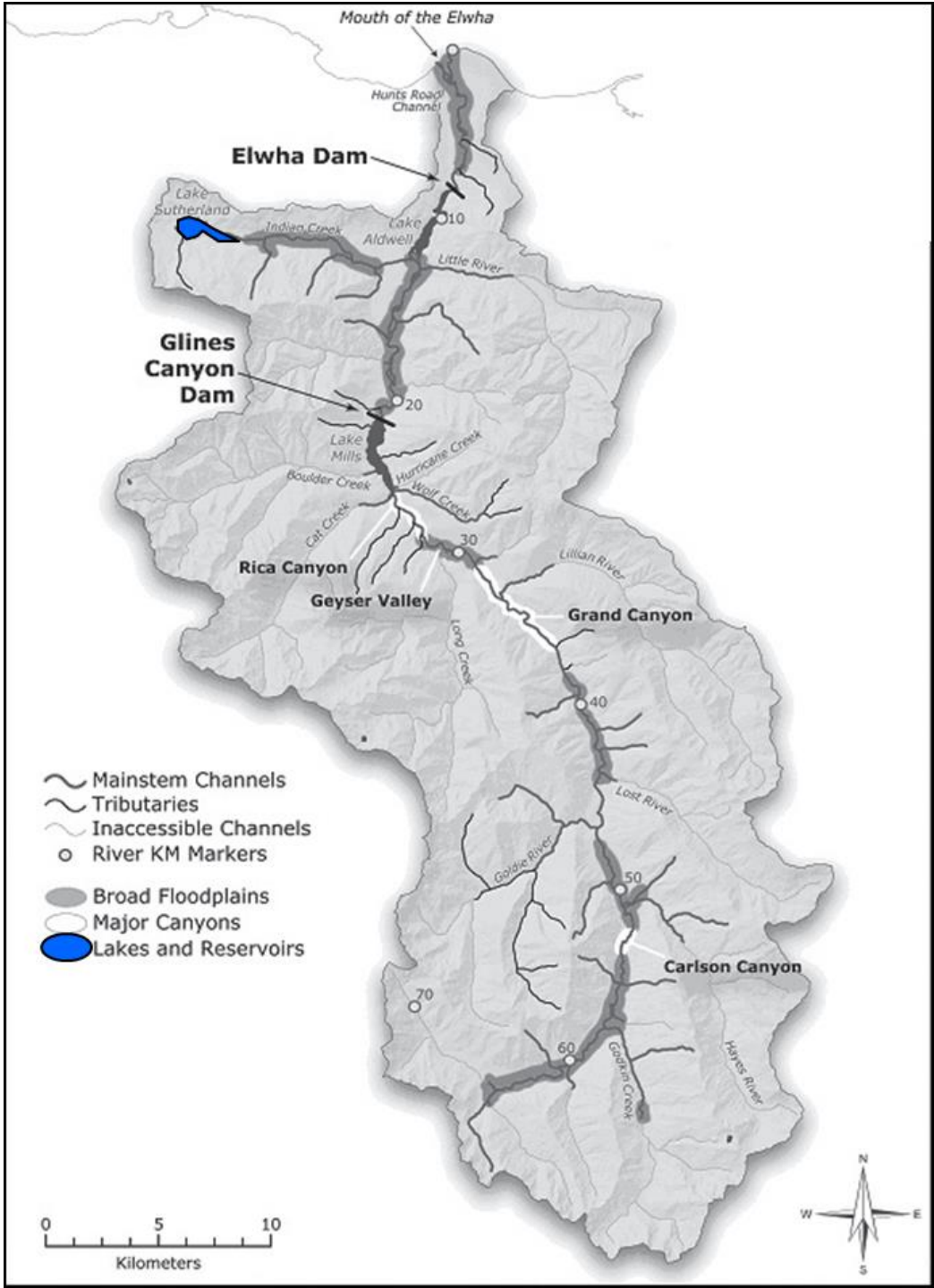
- Elwha River
- White Salmon River
- Sandy River
- Little Sandy River
- Rogue River
- Klamath River



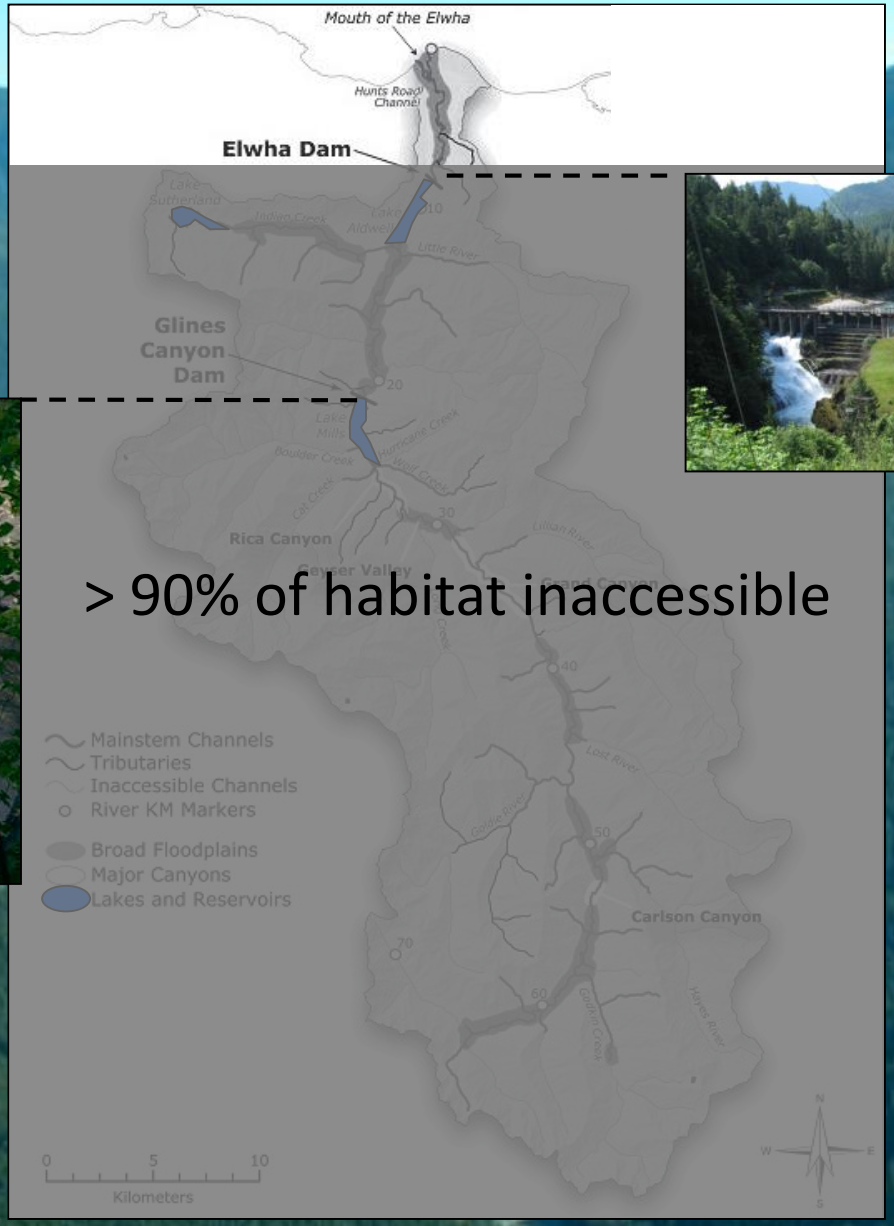
- 833 km^2
- ~72km of mainstem habitat
- 8 major tributaries
- Sea level to 1,372m
- Dry, warm summers and cool, wet winters
- Marine sedimentary, Crescent basalt, and Unconsolidated glacial till
- Western hemlock, Douglas Fir, Western Red Cedar, Red alder, cottonwood, and big leaf maple

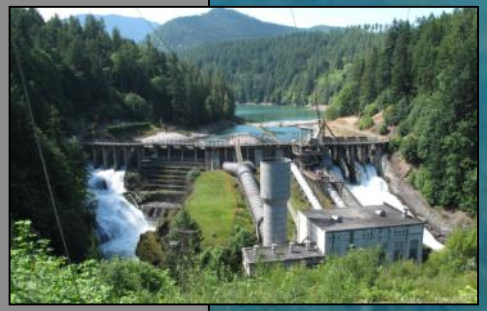


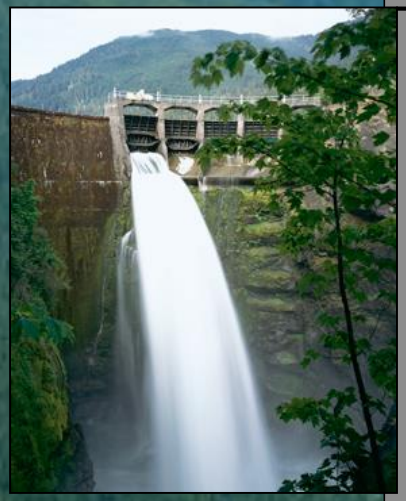
- Coho salmon (*Oncorhynchus kisutch*)
- Sockeye salmon (*O. nerka*)
- Pink salmon (*O. gorbuscha*)
- Chum salmon (*O. keta*)
- Steelhead/rainbow trout (*O. mykiss*, summer&winter)
- Chinook salmon (*O. tshawytscha* spring&fall)
- Pacific lamprey (*Entosphenus tridentatus*)
- Coastal cutthroat trout (*O. clarki clarki*)
- Bull trout (*Salvelinus confluentus*)
- Eulachon (*Thaleichthys pacificus*)
- Multiple species of sculpin (*Cottus spp*.)
- Redside shiner (*Richardsonius balteatus*)
- Brook trout (*S. fontinalis*)



The Elwha River Basin



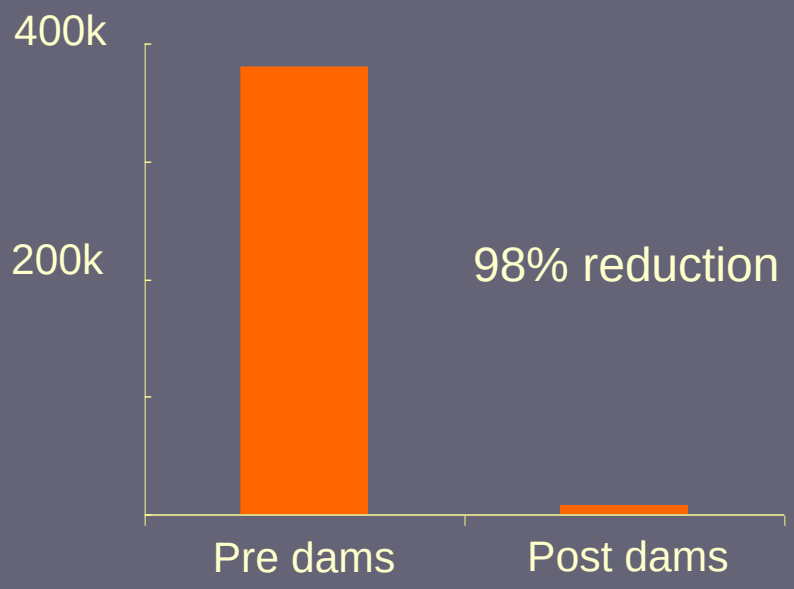




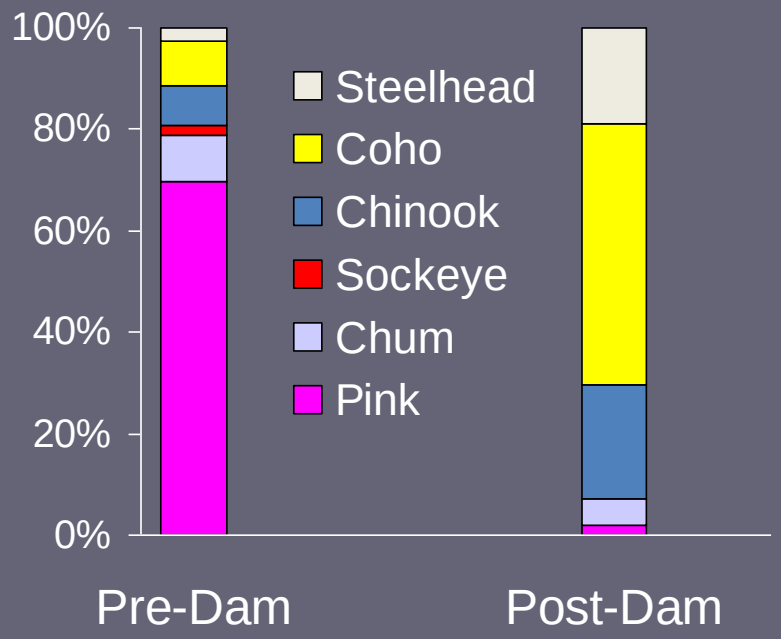
> 90% of habitat inaccessible

Impacts to Elwha River salmon populations

Total population decline



Shift in species composition



All native populations are very low in abundance

Elwha River salmon population estimates before dam removal

Species	Estimated population size below dams	% Hatchery
Spring Chinook	Unknown	Unknown
Summer/Fall Chinook	~2,000	**~75**
Coho	~2,000	**~76**
Chum	~100	0
Pink	~100	0
Sockeye	~25	0
Winter steelhead	~300	**~?**
Summer steelhead	~50	0
Sea-run cutthroat	Unknown	0
Char	~500	0

Pess, G. R., M. McHenry, T. J. Beechie, J. R. Davies. 2008. Biological impacts of the Elwha River dams and potential salmonid responses to dam removal. Northwest Science, 82(sp1):72-90.

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."

102nd Congress of the U.S.A.
January 3, 1992

What's going to happen to all the sediment?

~ 21 million m^3 of sediment accumulated in reservoirs

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

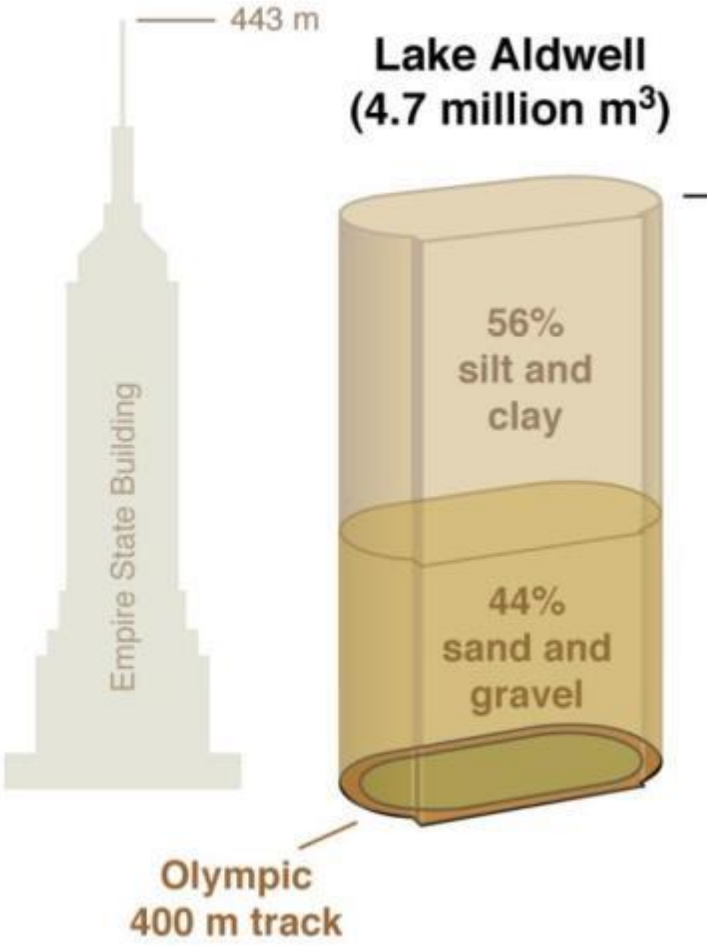
Predictions

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

Elwha Dam removal

Before Dam Removal: September, 2011

Elwha Webcams courtesy NPS



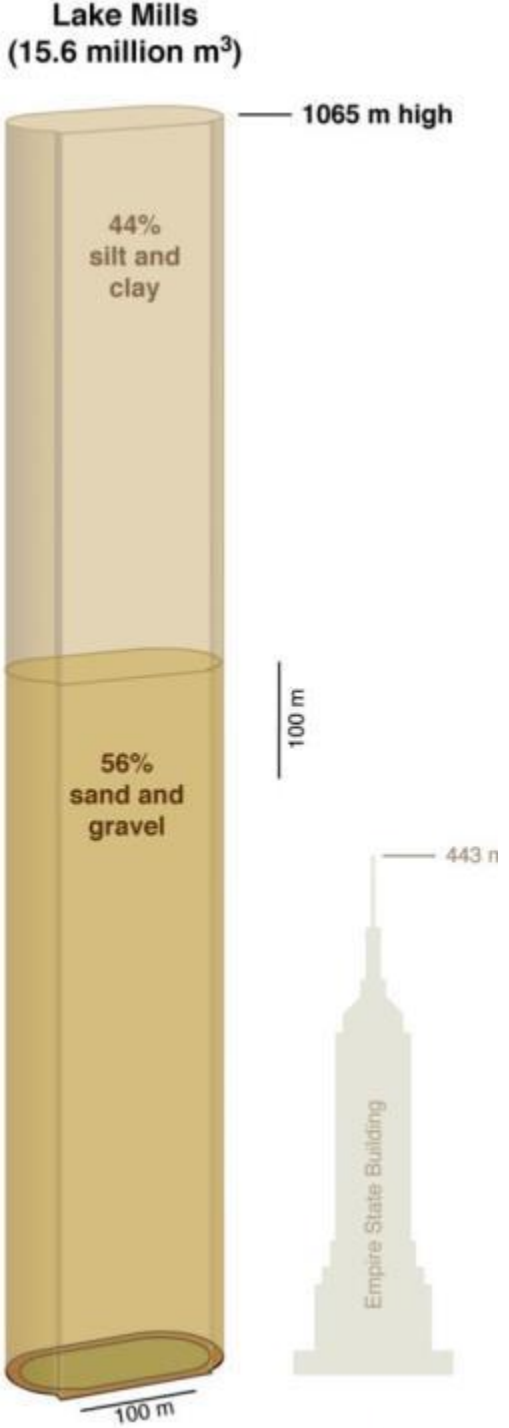
- Completed in 1912
- 33m concrete gravity dam

Glines Canyon Dam removal

Before Dam Removal: September, 2011

Elwha Webcams courtesy NPS

- Completed in 1927
- 64m concrete arch dam

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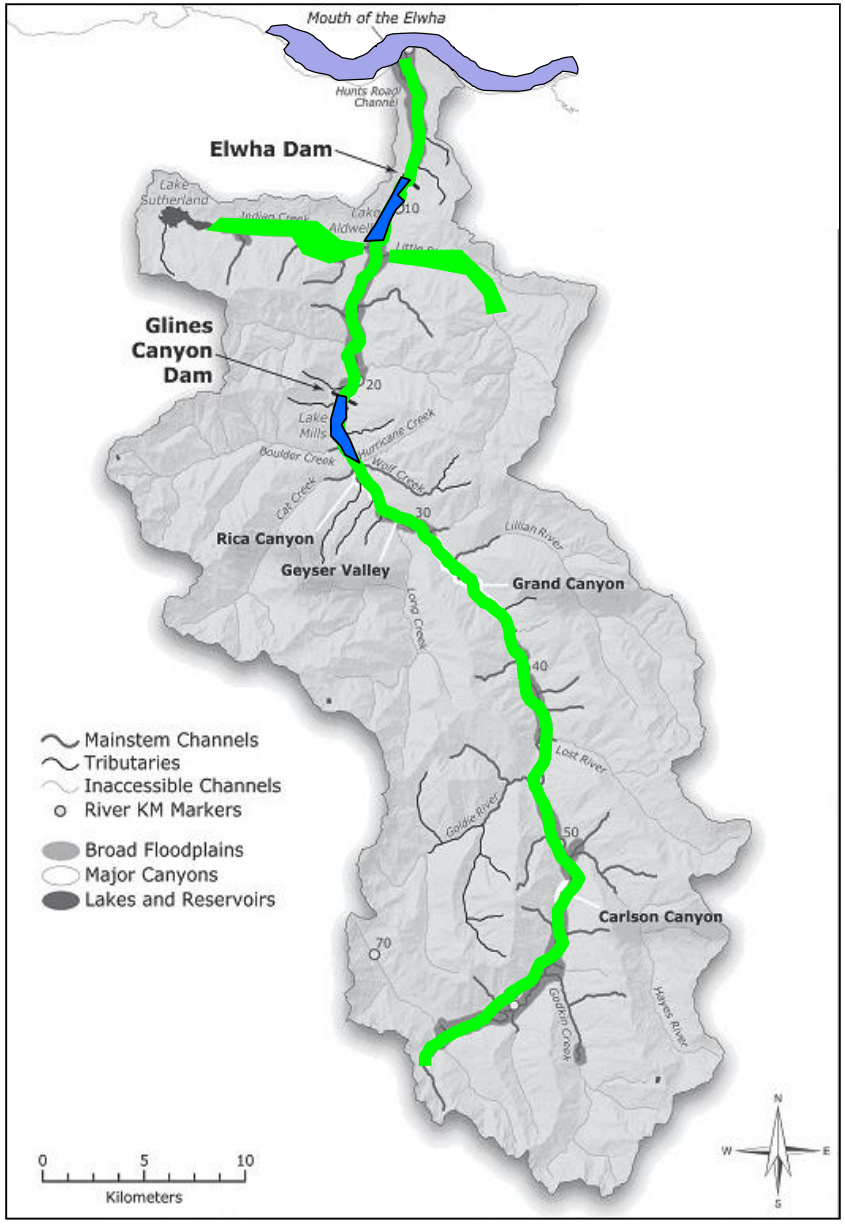
Blasting at Glines Canyon Dam

John Gussman

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



Location

- Dams & former reservoirs
- Nearshore
- River ecosystem

Processes

Sediment dynamics

Fish recolonization

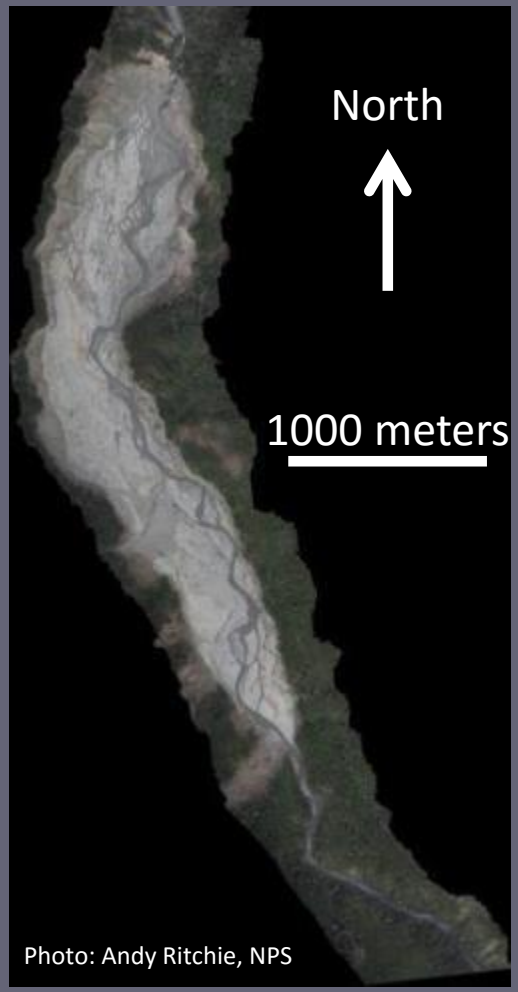
↓

Riverine foodwebs

Terrestrial linkages

Revegetation

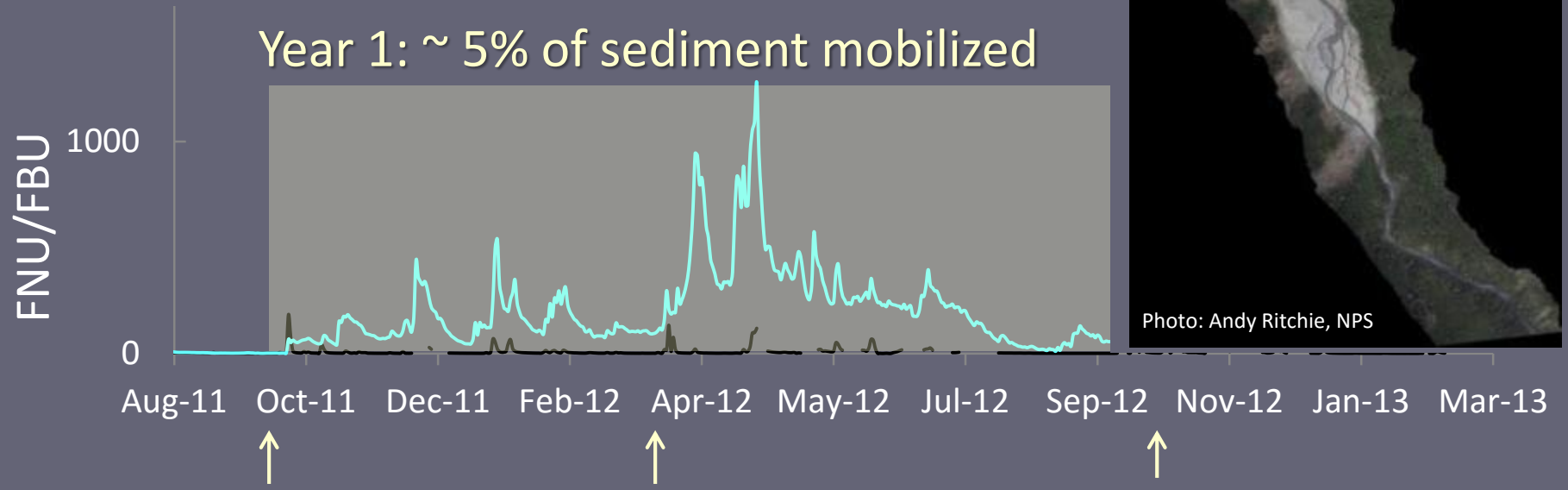
How has sediment supply changed?



Above Dams

Below Dams

Year 1: ~ 5% of sediment mobilized



Dam removal begins

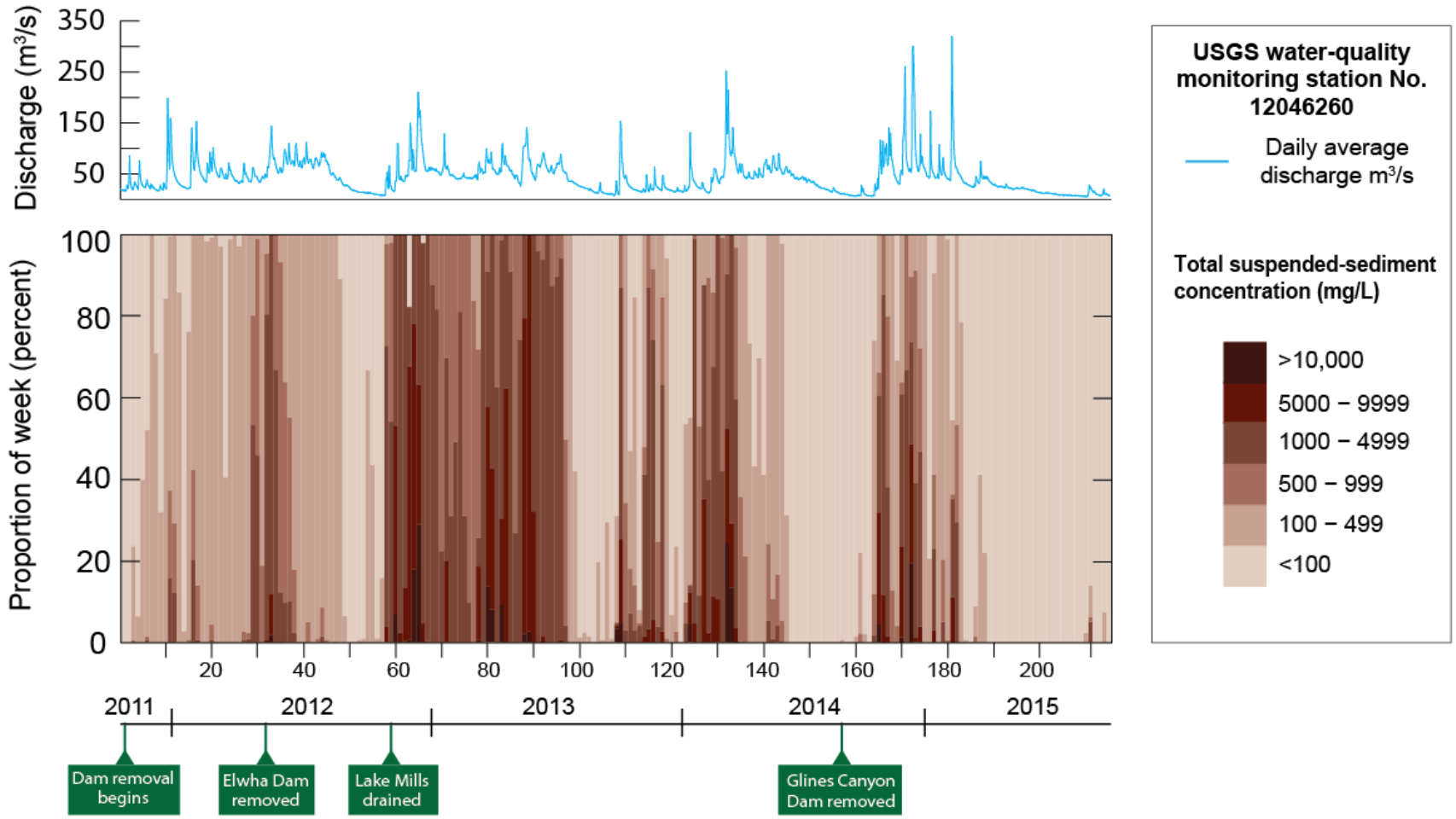
Elwha Dam removed

Mills reservoir gone

Datasource: USGS

How has sediment supply changed?

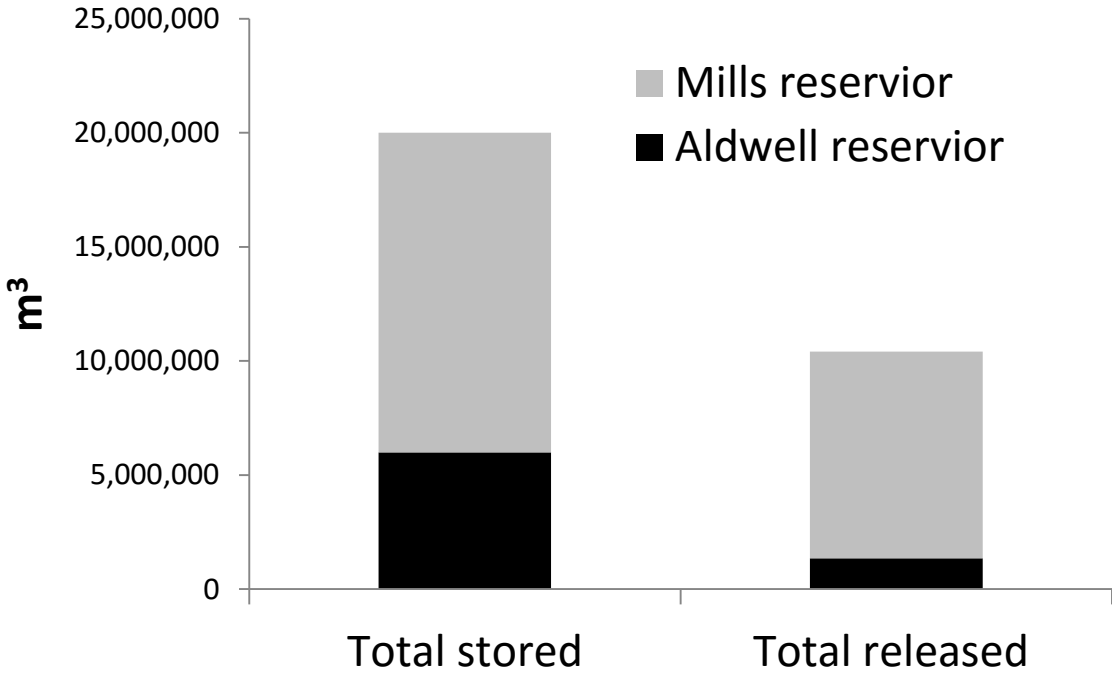
Suspended sediment concentrations peaked after mills reservoir was drained and have been reduced in most of 2015



Data courtesy of Chris Curran, USGS

How much sediment has been released?

Between 40% to 60% of the total stored sediment was estimated to be released during & post dam removal.



~ 58% of the total stored released as of October 2015

Mills reservoir

Pre dam removal 2015

Randle, T.J., et al., 2015. Large-scale dam removal on the Elwha River, Washington, USA: Erosion of reservoir sediment. Geomorphology.

Photo courtesy of Andy Ritchie

Photo courtesy of Andy Ritchie

Former Mills reservoir

Former Mills reservoir

Former Aldwell reservoir

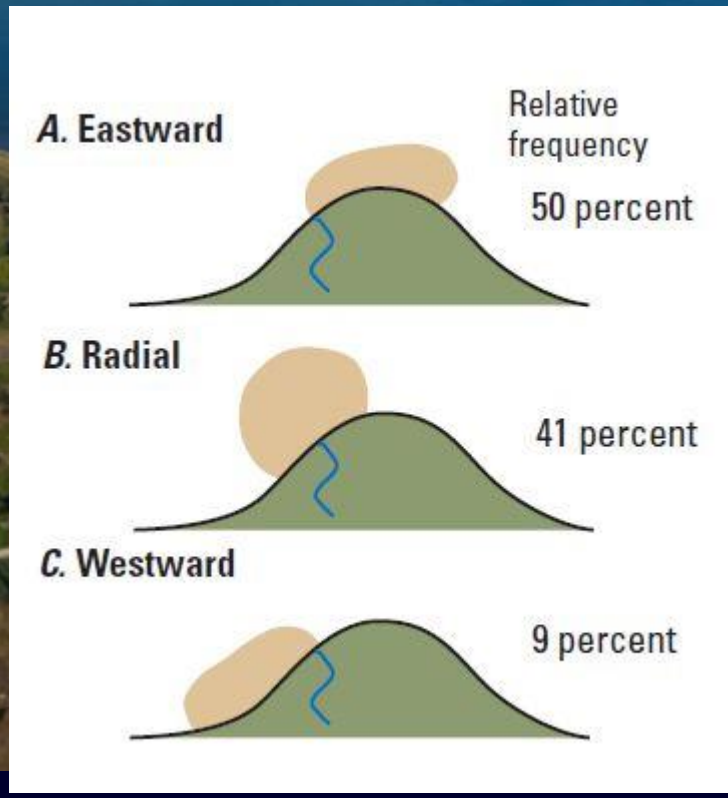
Former Aldwell reservoir

March 2016

Former Aldwell reservoir

Mouth of the Elwha River - nearshore

Photo: Matt Beirne, Lower Elwha Klallam Tribe



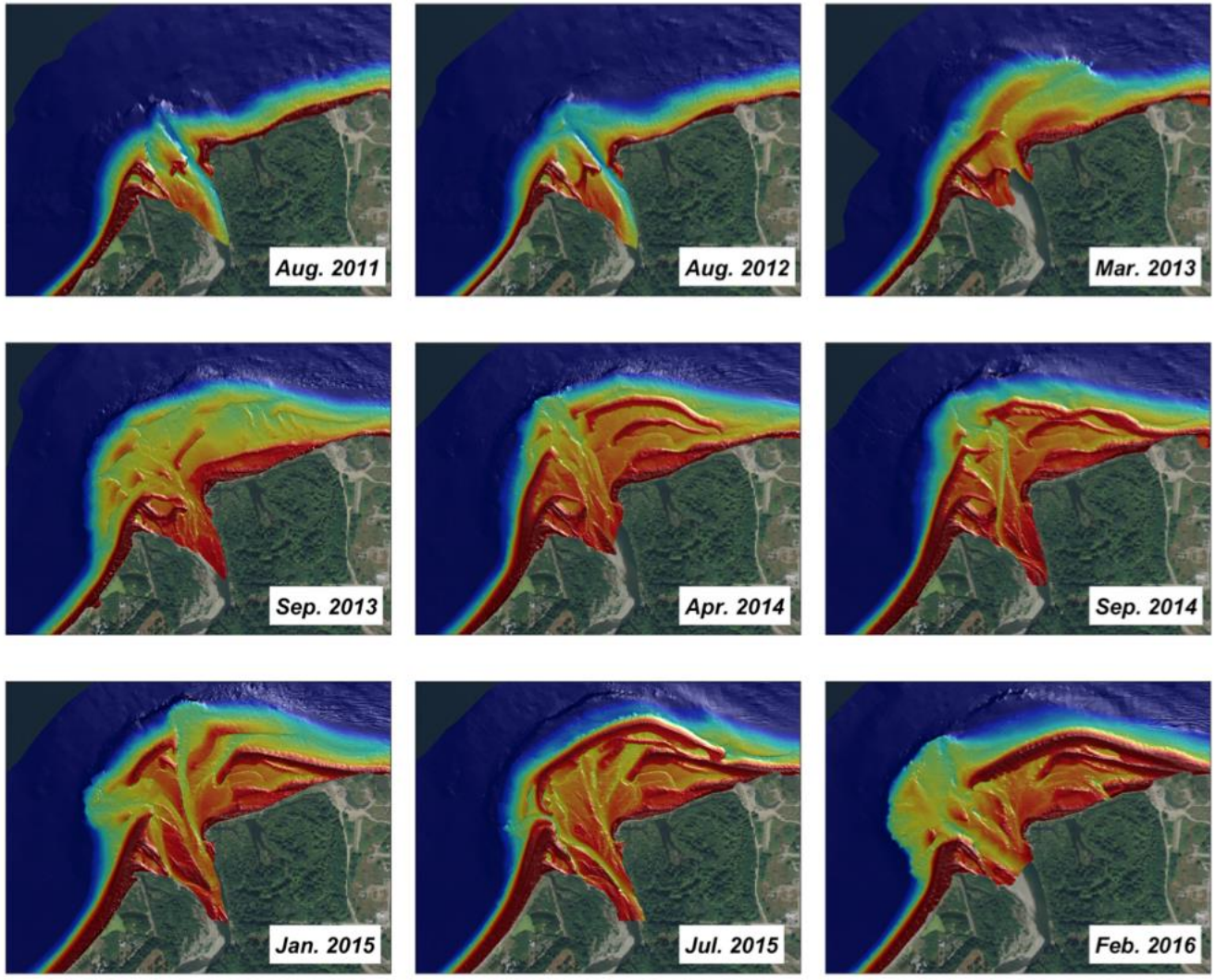
Warrick, J.A., and Stevens, A.W., 2011, A buoyant plume adjacent to a headland - observations of the Elwha River plume: Continental Shelf Research, v. 31, p. 85-97.

Mouth of the Elwha River - April 2012

Much suspended sediment transported to the Strait of Juan De Fuca

Mouth of the Elwha River - April 2014

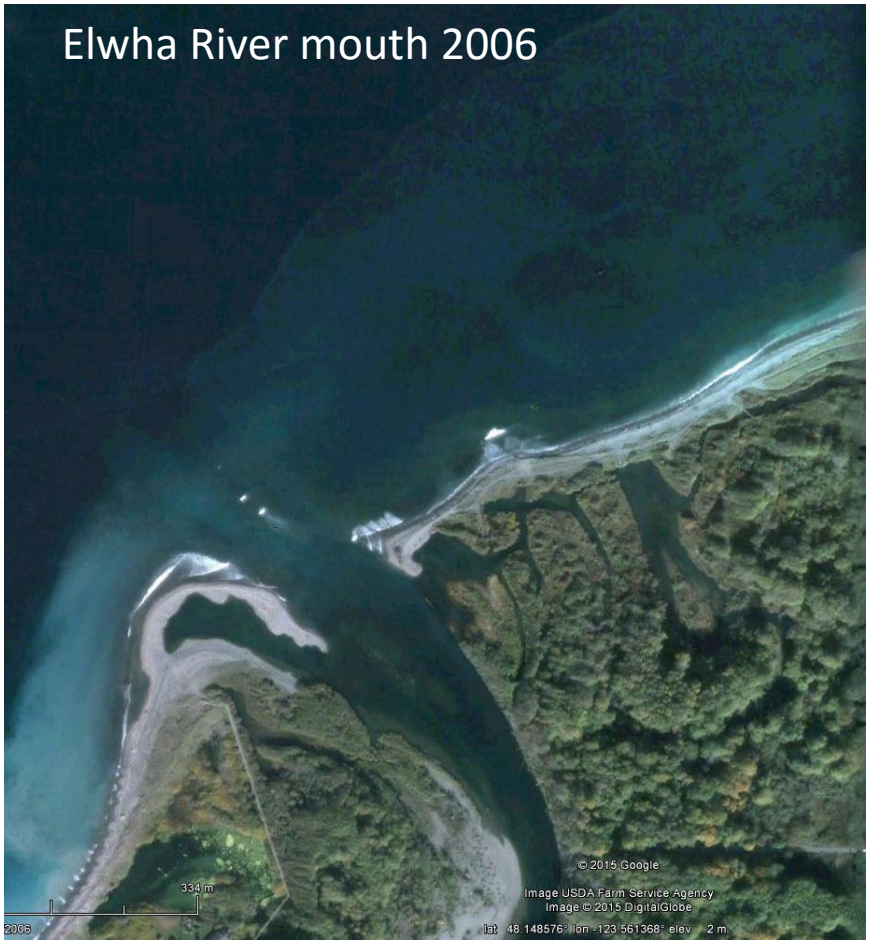
Elwha River mouth, estuary, & nearshore 2011 to 2016

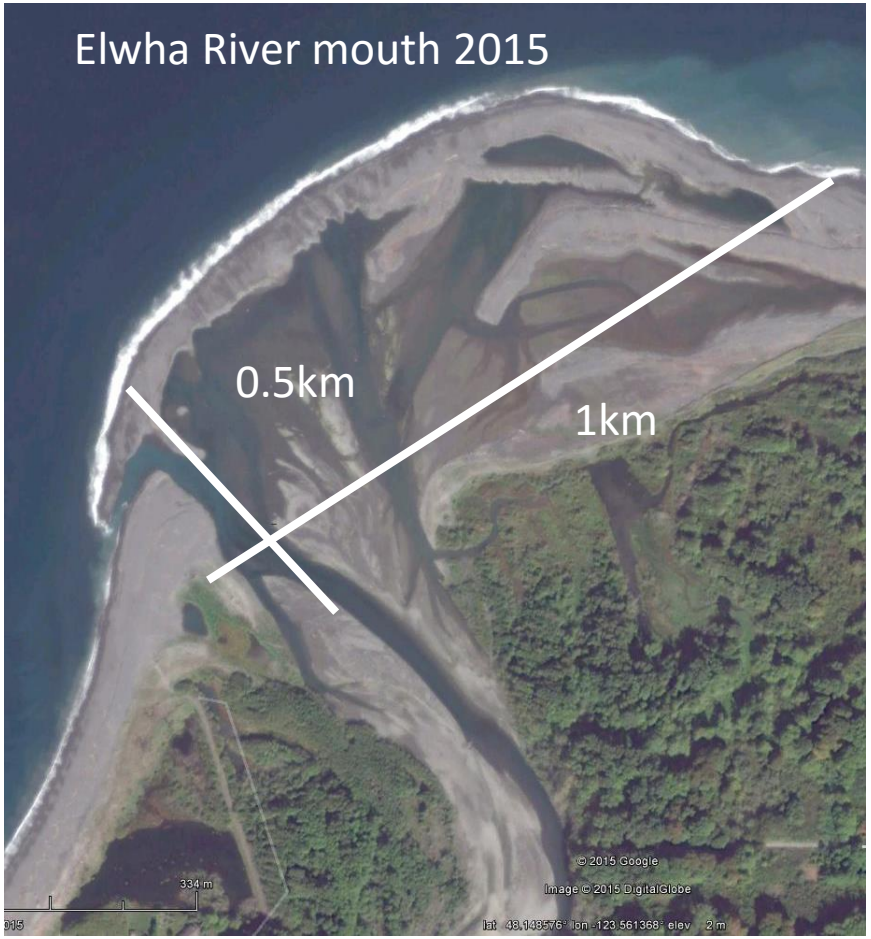


LiDAR slide & work courtesy of Jon Warrick, USGS

Elwha River mouth, estuary, & nearshore

The majority of sediment deposited in the nearshore would be eastward or radial and not westward





The majority of Elwha River delta is eastward and radial

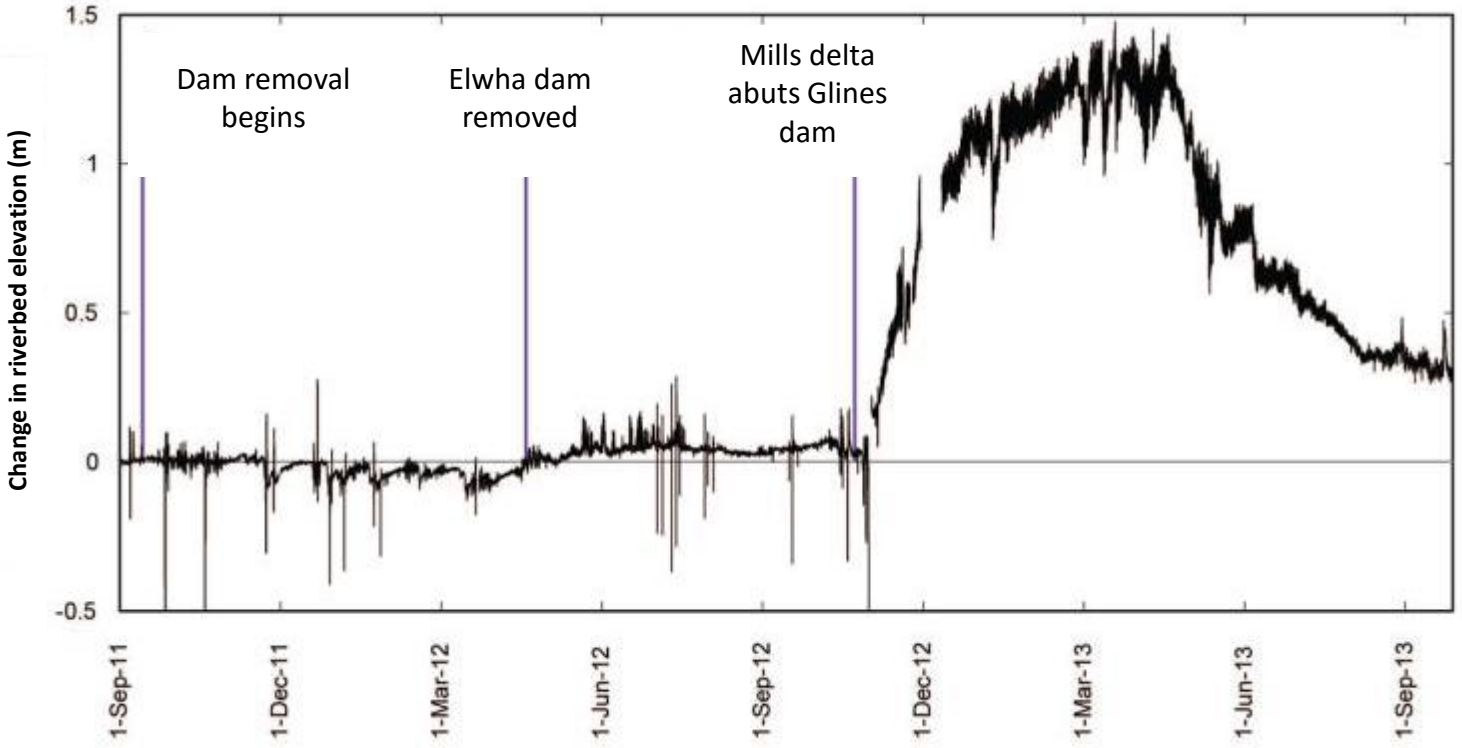
-Warrick & Stevens, 2011

Mouth of the Elwha River - Nearshore Biota

S. Rubin, N. Elder, et al.

USGS science for a changing world

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



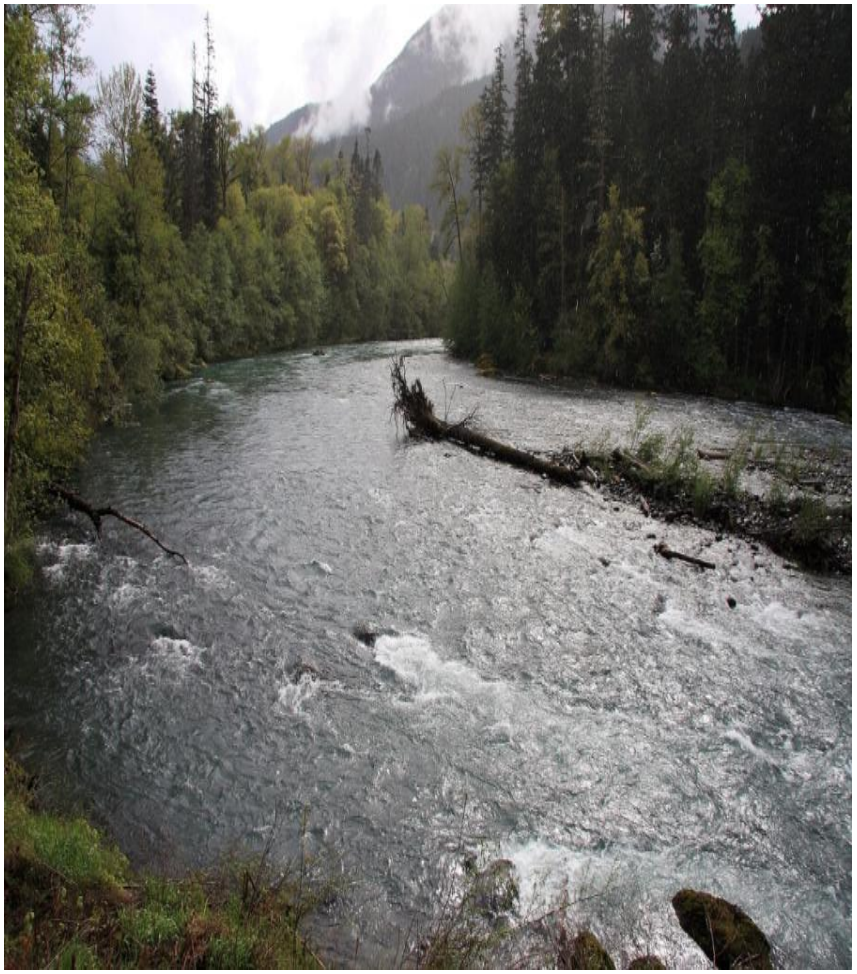
Magirl, C. S., Hilldale, R. C., Curran, C. A., Duda, J. J., Straub, T. D., Domanski, M., & Foreman, J. R. (2014). Large-scale dam removal on the Elwha River, Washington, USA: Fluvial sediment load. Geomorphology.


How has freshwater habitat downstream of the dams changed with the increase in sediment supply?
Former Glines Canyon Dam
Middle Elwha
Former Elwha Dam
Lower Elwha
Elwha River
Elwha
2078 m
Image © 2015 DigitalGlobe
© 2015 Google
Image © 2015 TerraMetrics
Google earth

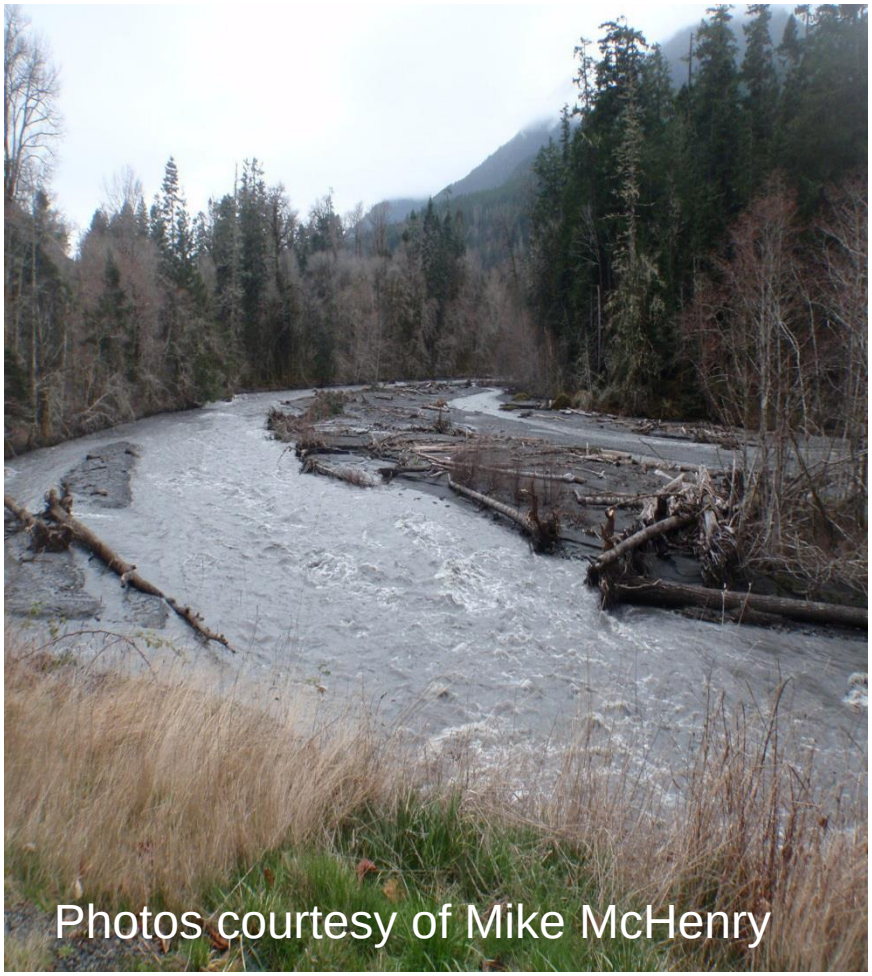
Middle Elwha mainstem & floodplain response


Aug 2011
Feb 2013
Gravel bar development & wood accumulation in the Middle Elwha River
Sed XS 19
Sed XS 19
200
Feet
Photos courtesy of Andy Ritchie

Gravel bar development & wood accumulation in the Middle Elwha River

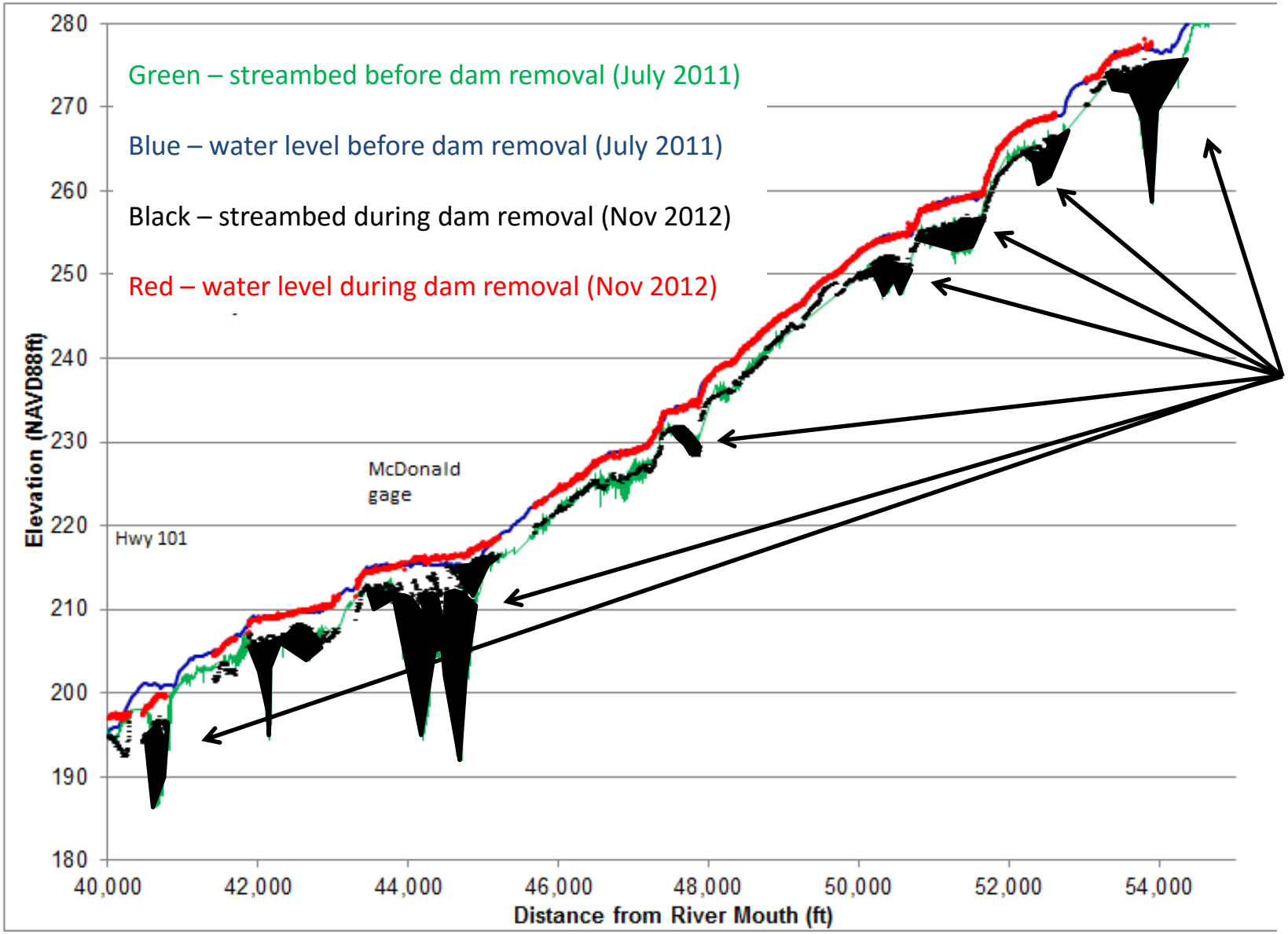


October 2012



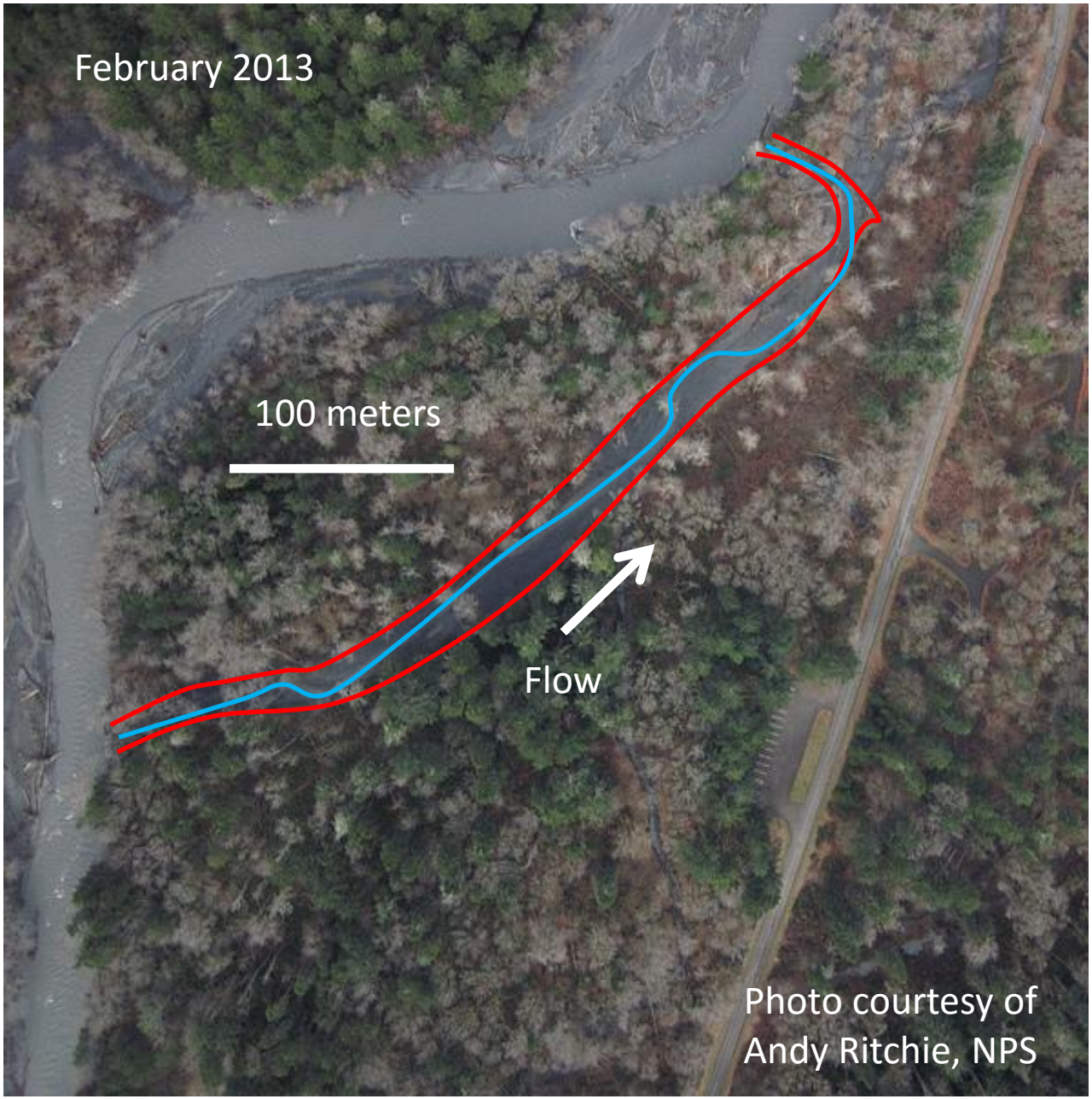
March 2013

Change in Middle Elwha mainstem depths during dam removal

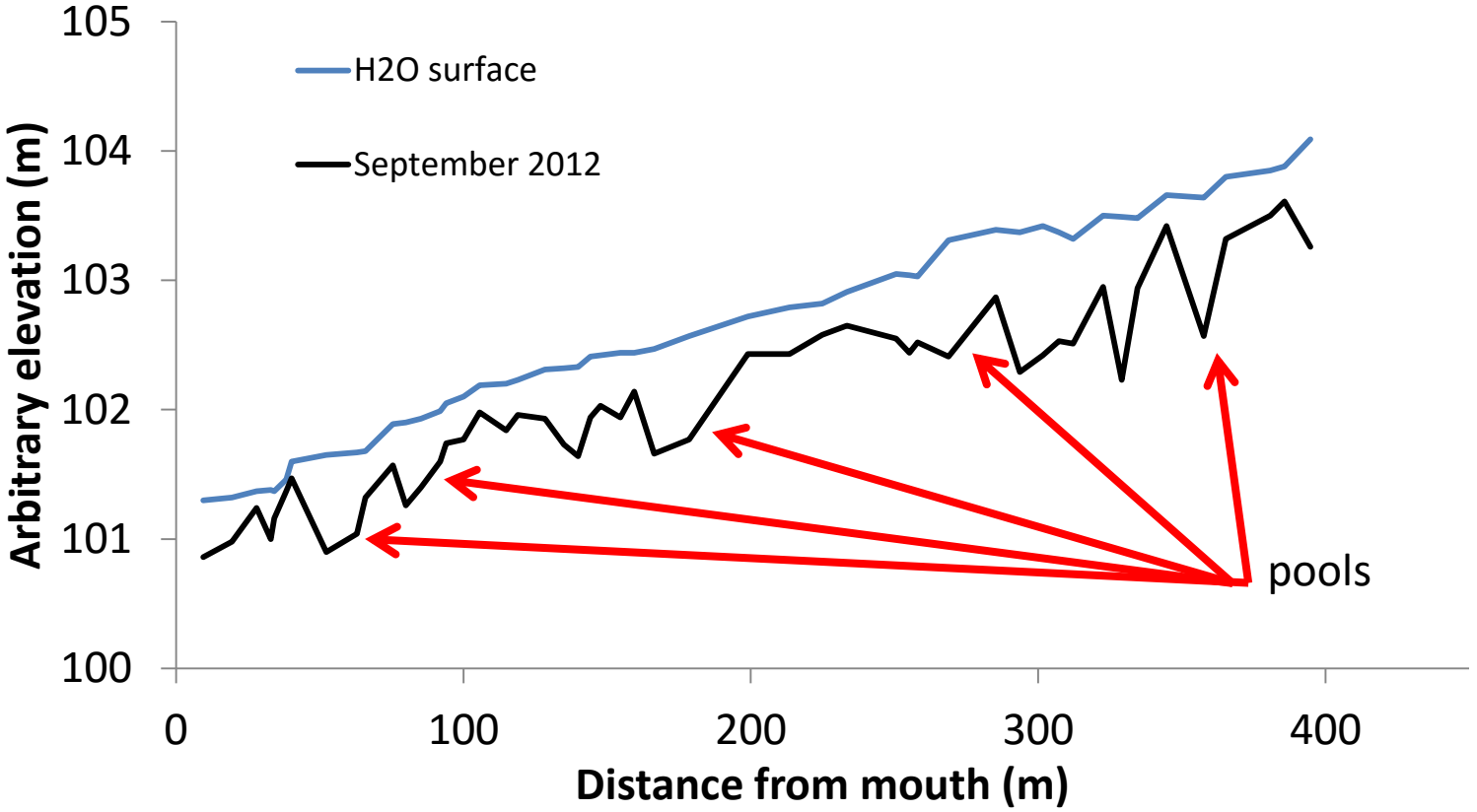


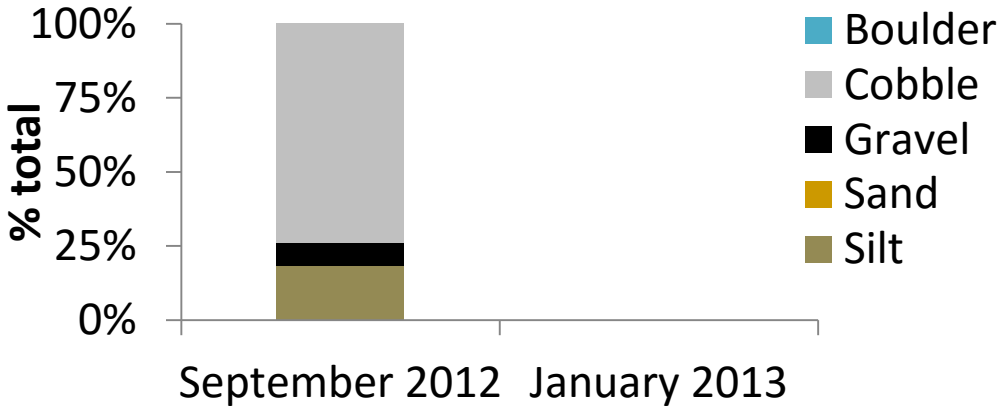
Slide courtesy of Jennifer Bountry and Tim Randle, Bureau of Reclamation

Sediment accumulation in Middle Elwha floodplain channels

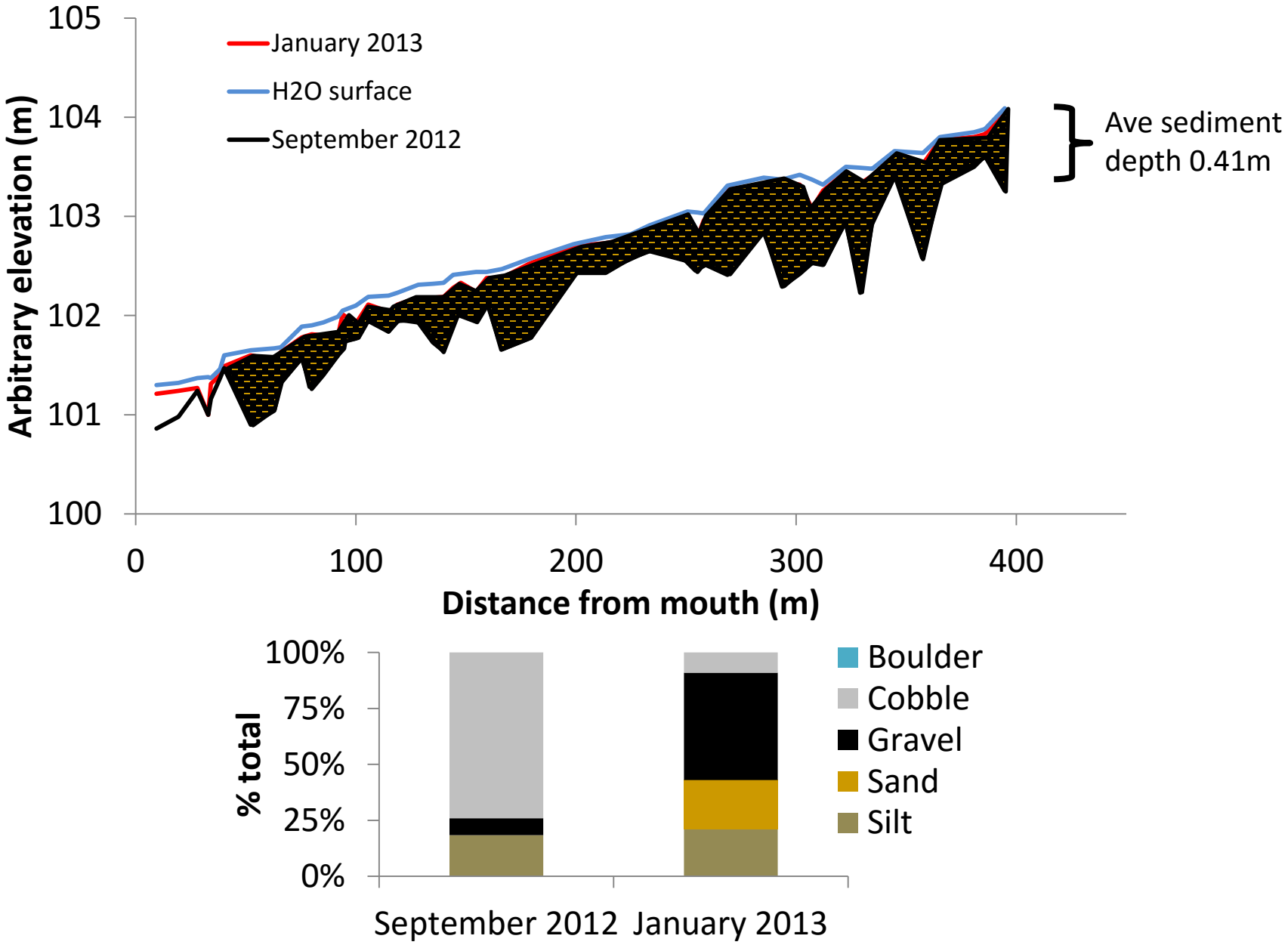


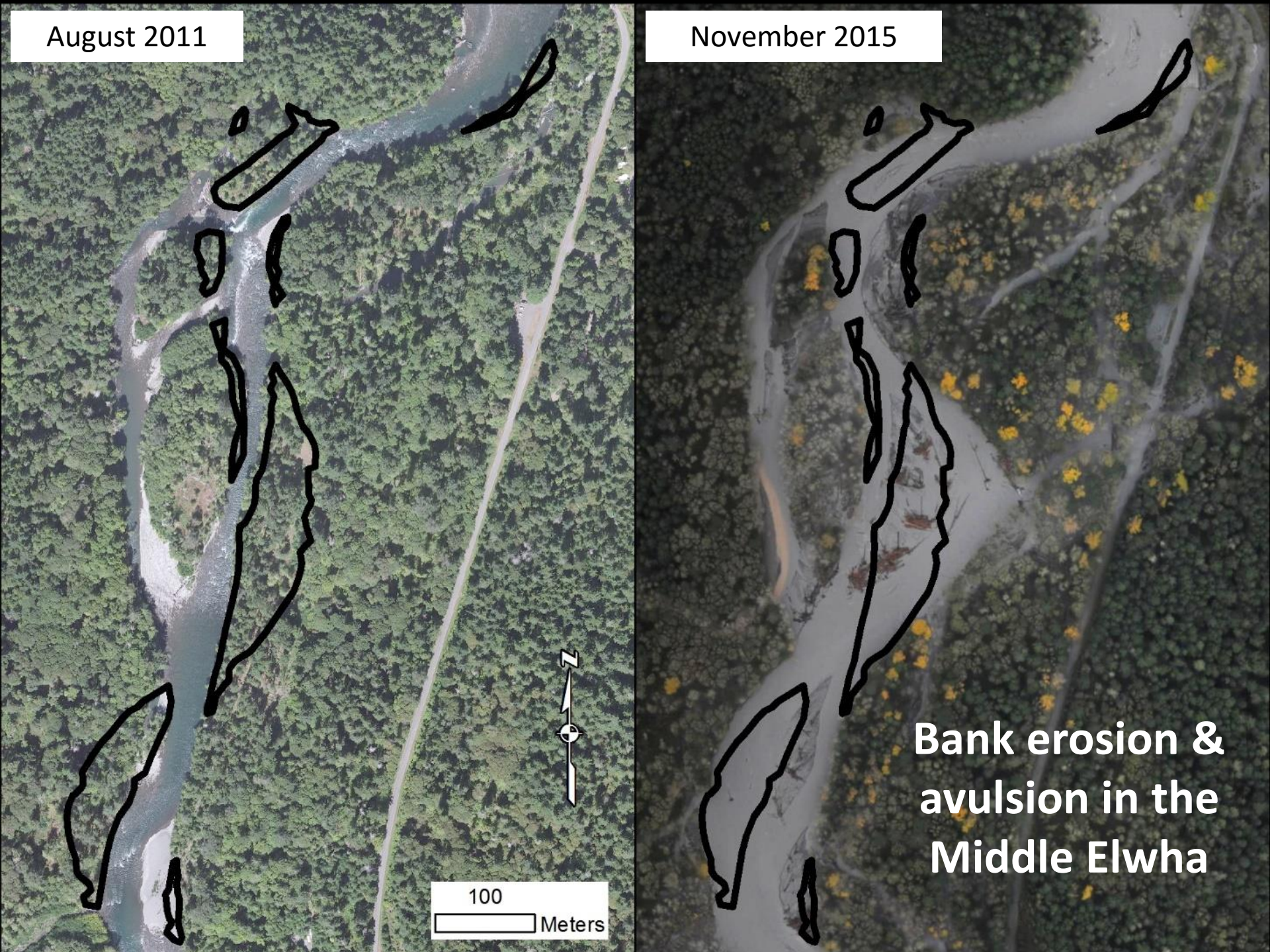
Sediment accumulation in Middle Elwha floodplain channels



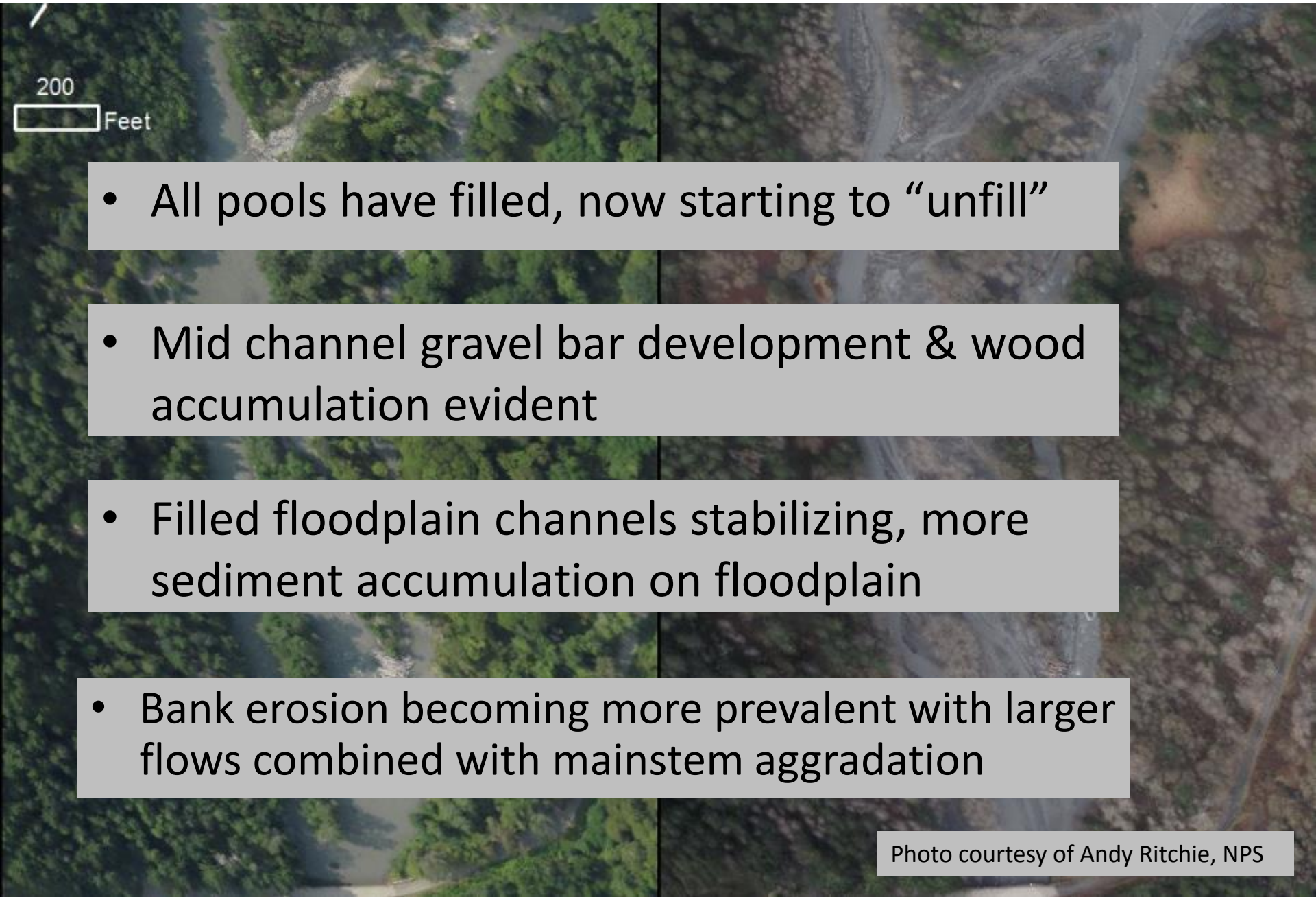


Sediment accumulation in Middle Elwha floodplain channels




August 2011
November 2015
N
100
Meters
Bank erosion & avulsion in the Middle Elwha

Middle Elwha mainstem & floodplain response



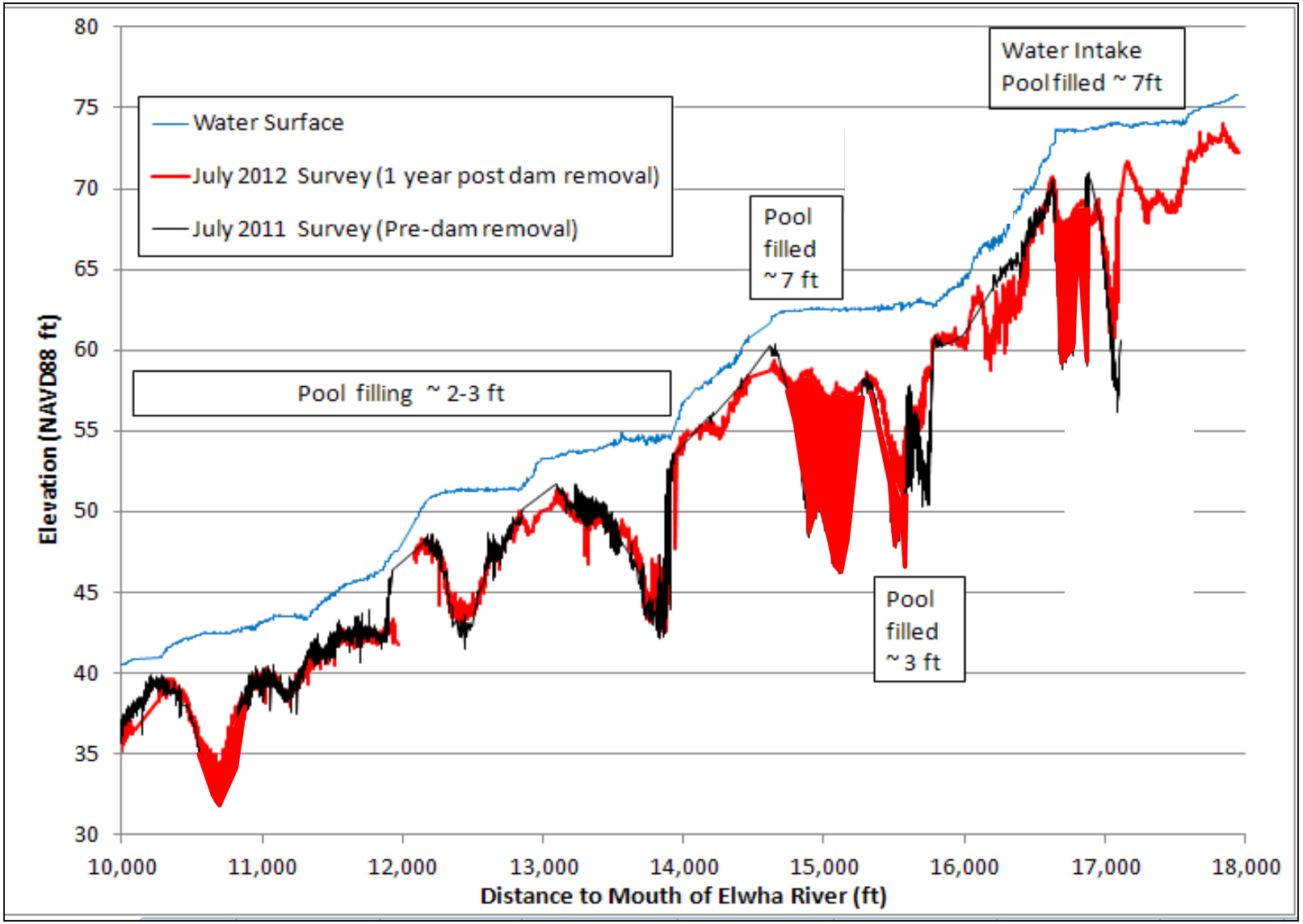
- All pools have filled, now starting to “unfill”
- Mid channel gravel bar development & wood accumulation evident
- Filled floodplain channels stabilizing, more sediment accumulation on floodplain
- Bank erosion becoming more prevalent with larger flows combined with mainstem aggradation

Photo courtesy of Andy Ritchie, NPS


Lower Elwha River
mainstem & floodplain response
Glines Canyon Dam
Elwha Dam
Sediment accumulation
In floodplain channels
Longitudinal profile
Change in streambed particle size

East, A. E., **Pess, G. R.**, Bountry, J. A., Magirl, C. S., Ritchie, A. C., Logan, J. B., & Shafroth, P. B. 2015. Large-scale dam removal on the Elwha River, Washington, USA: River channel and floodplain geomorphic change. Geomorphology, 228, 765-786.

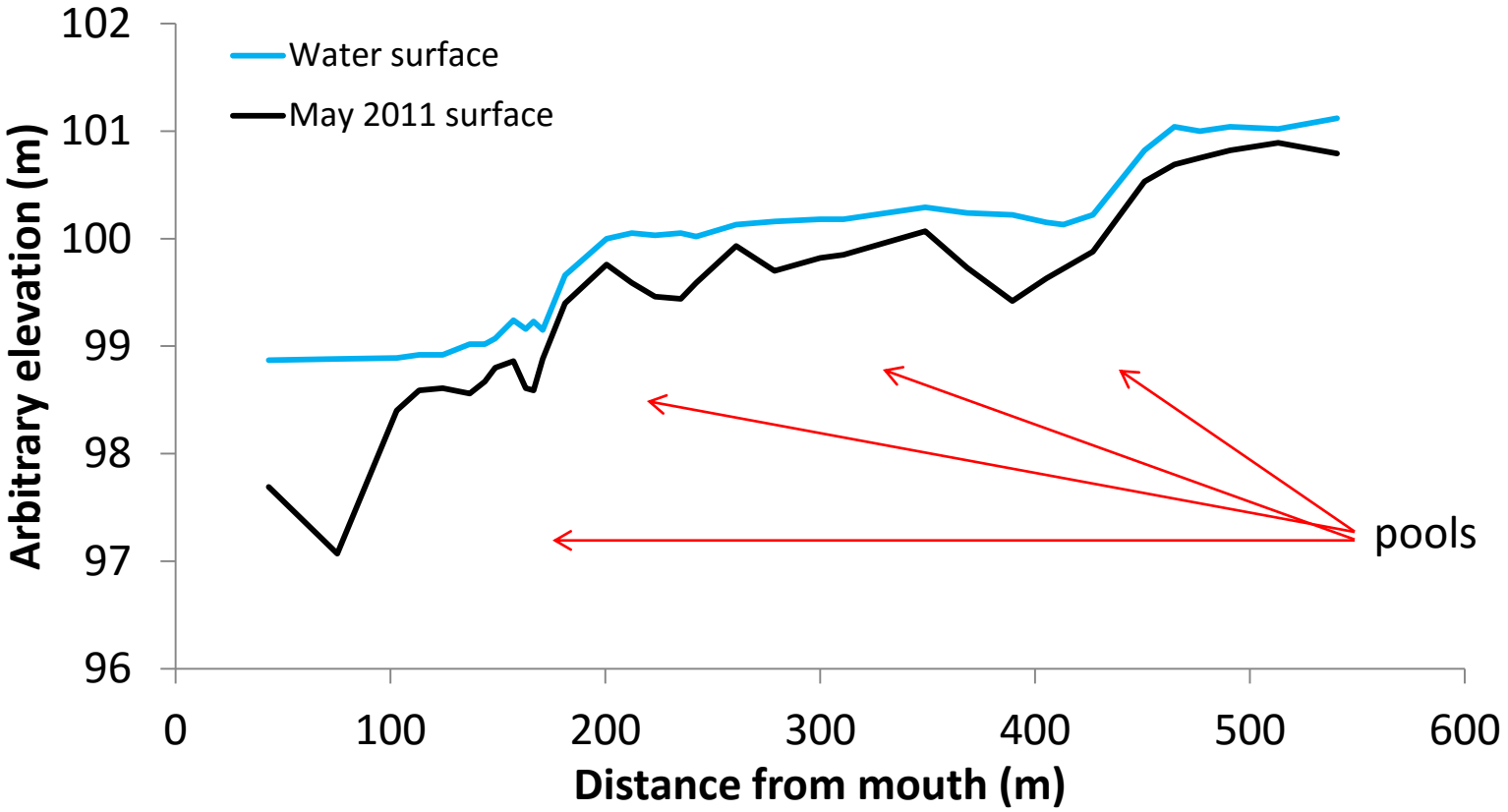
Change in Lower Elwha mainstem depths during dam removal

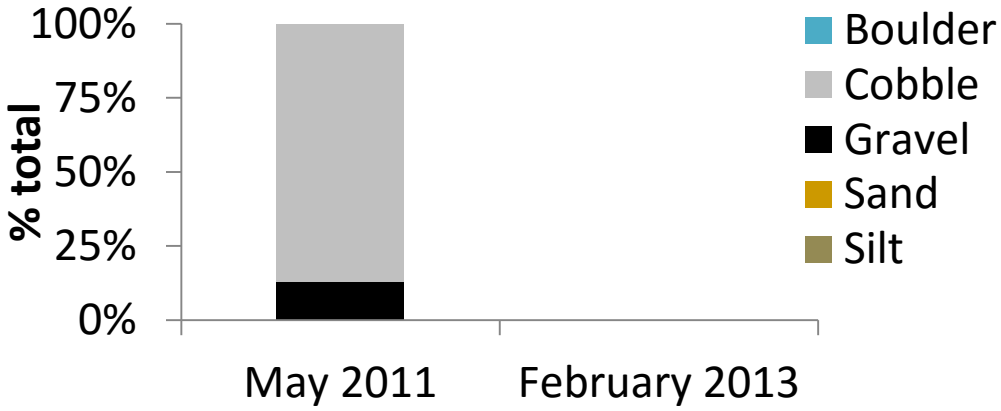


Slide courtesy of Jennifer Bountry and Tim Randle, Bureau of Reclamation

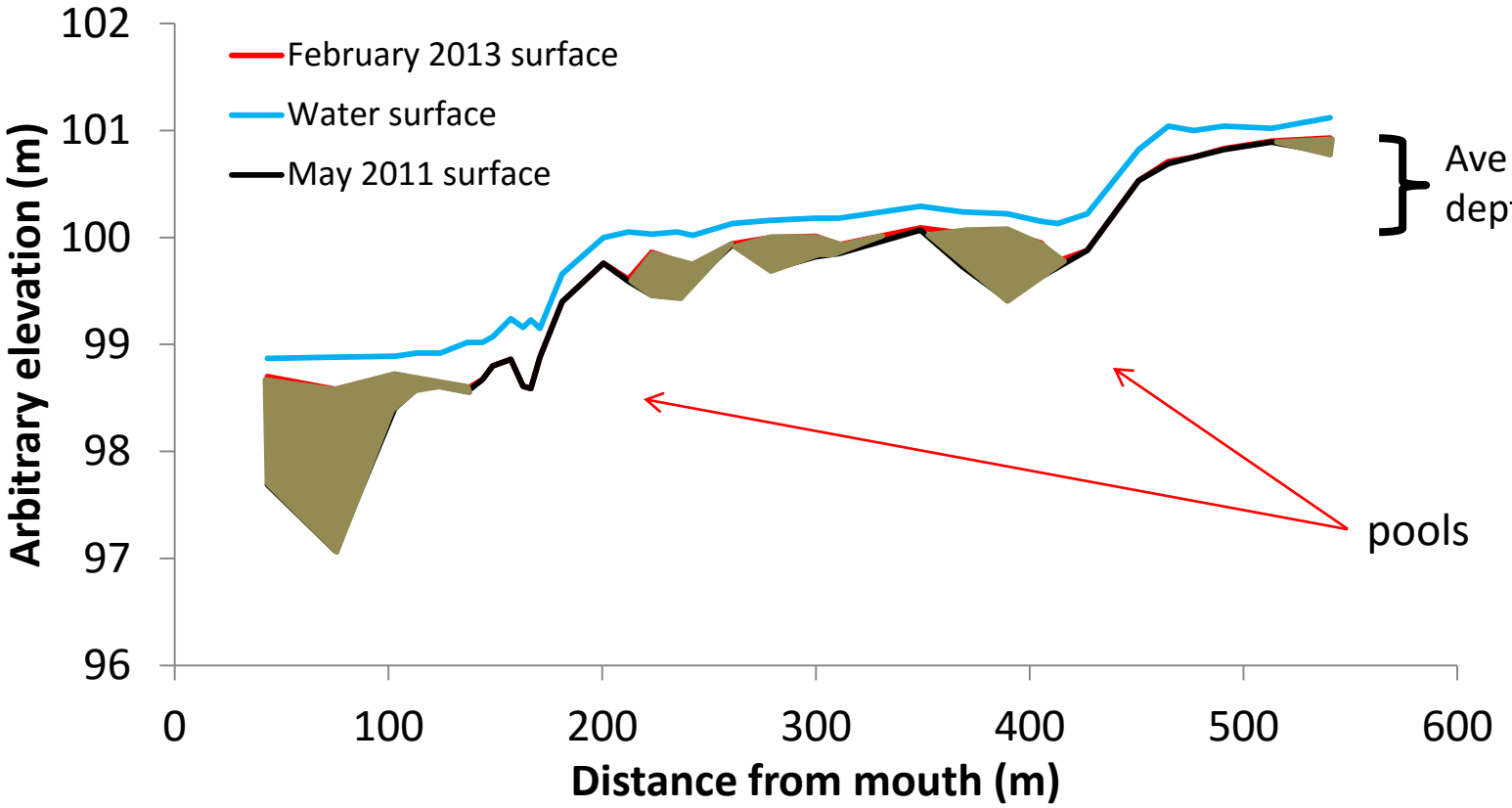
Sediment accumulation in Lower Elwha floodplain channels

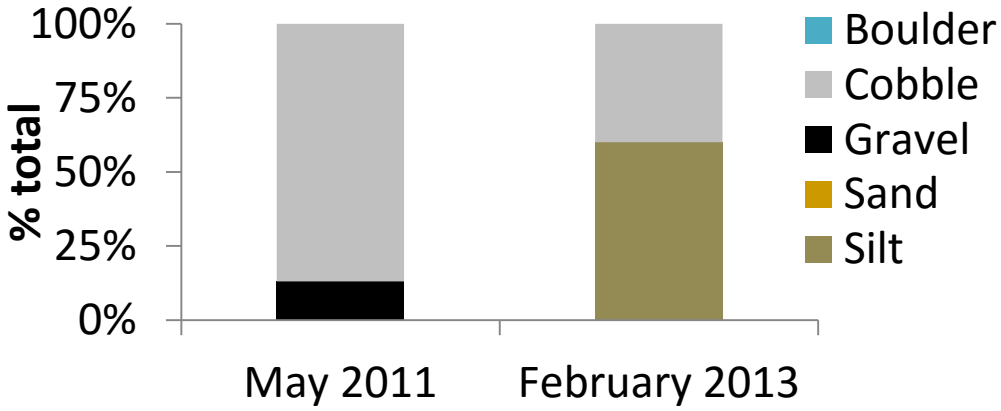
Sediment accumulation in Lower Elwha floodplain channels



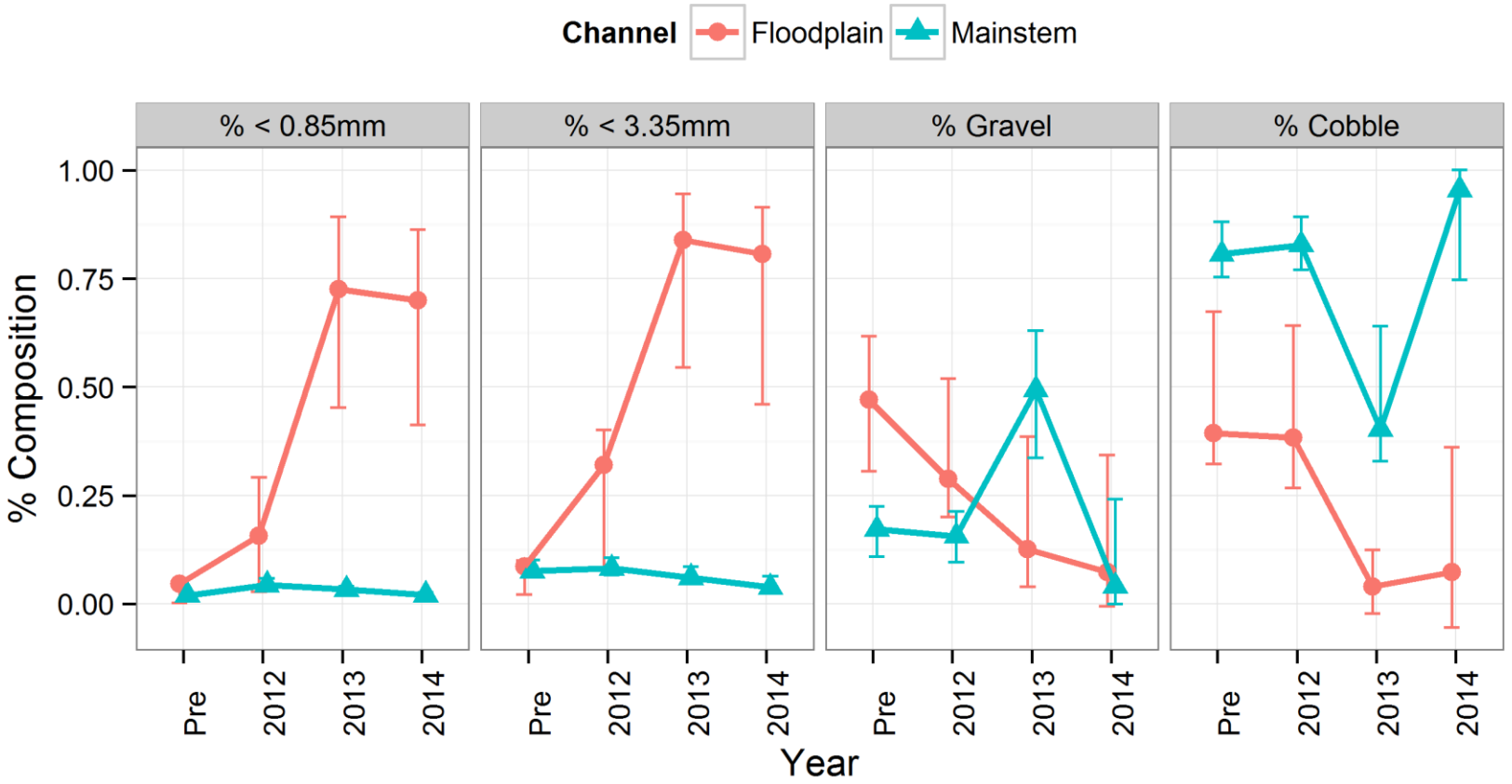


Sediment accumulation in Lower Elwha floodplain channels





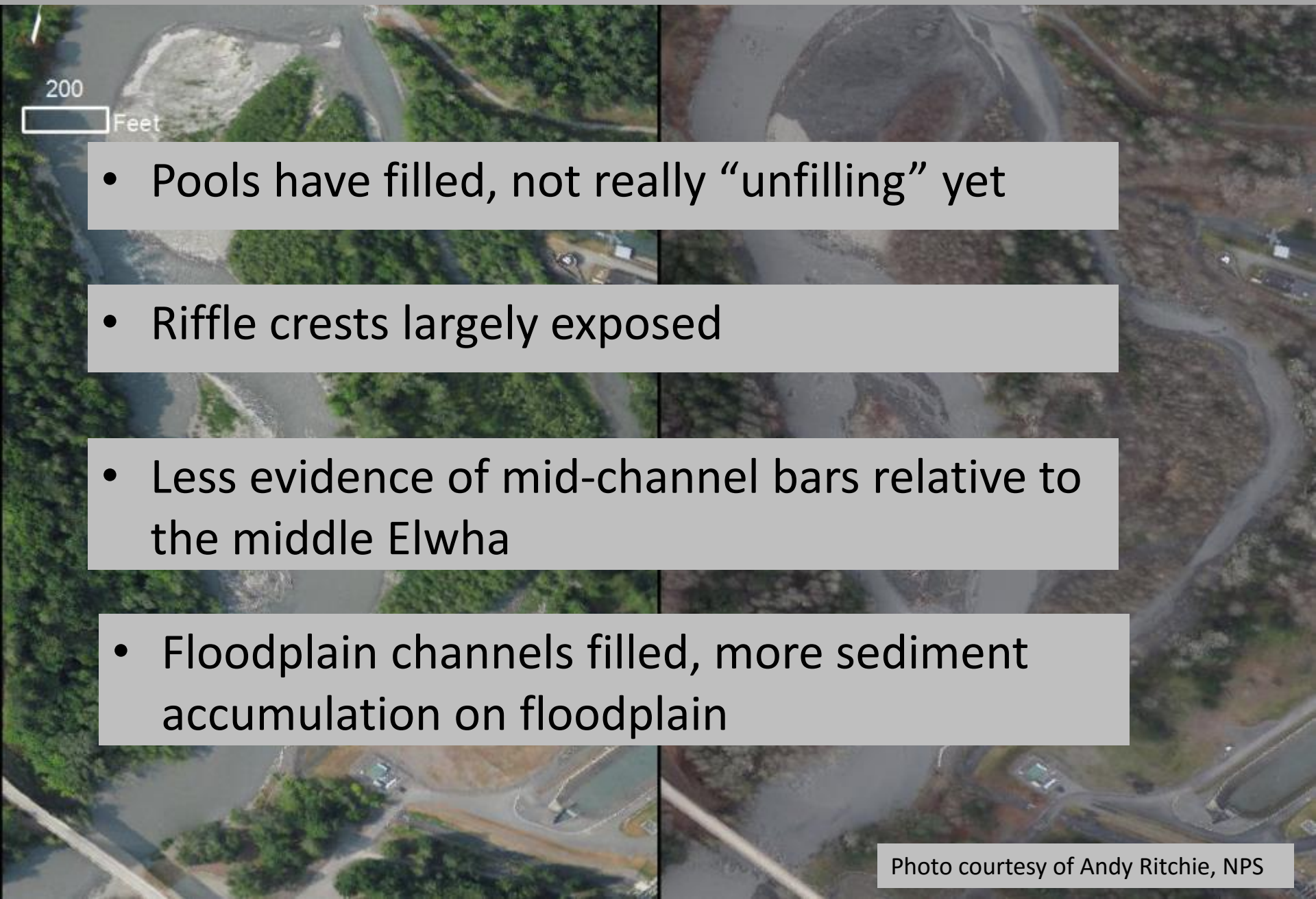
Differences in the change in streambed particle size in the mainstem Elwha v. its floodplain channels



Mainstem riffles fined to gravel but have returned to cobble
Floodplain riffles still dominated by sand

- Peters et al, in prep; East et al 2015. Geomorphology;

Lower Elwha mainstem & floodplain response



- Pools have filled, not really “unfilling” yet
- Riffle crests largely exposed
- Less evidence of mid-channel bars relative to the middle Elwha
- Floodplain channels filled, more sediment accumulation on floodplain

Photo courtesy of Andy Ritchie, NPS

Where has the sediment gone during dam removal?

~10million m^3 released

12% stored in main stem (7%)
& floodplain channels (5%)

39% of sediment transported to Strait of Juan de Fuca

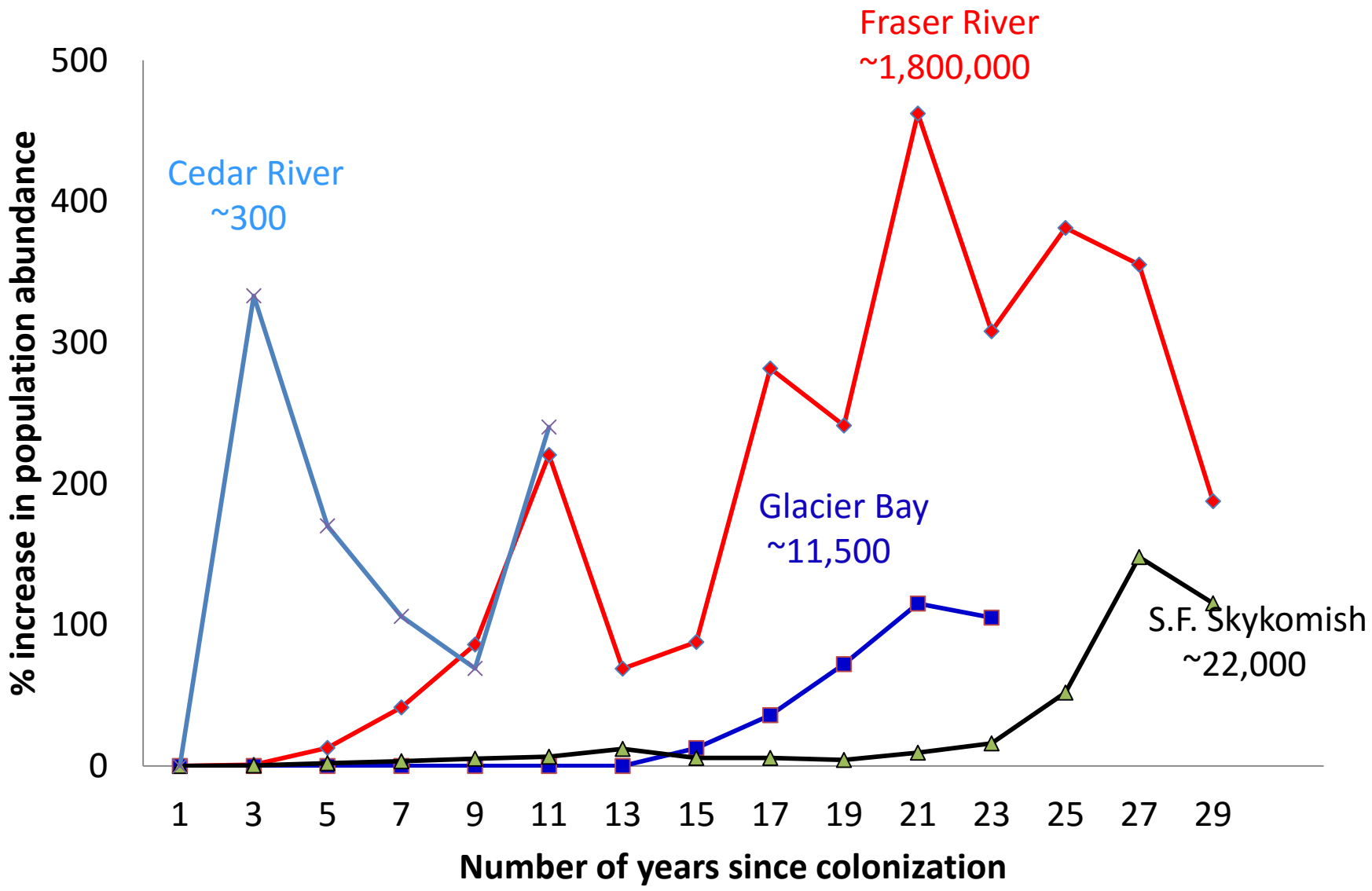
34% deposited in nearshore

Warrick, T.J., et al. 2015. Large-scale dam removal on the Elwha River, WA, USA: source-to-sink sediment budget & synthesis. Geomorphology.

How will salmon populations change with the removal of the Elwha River dams?

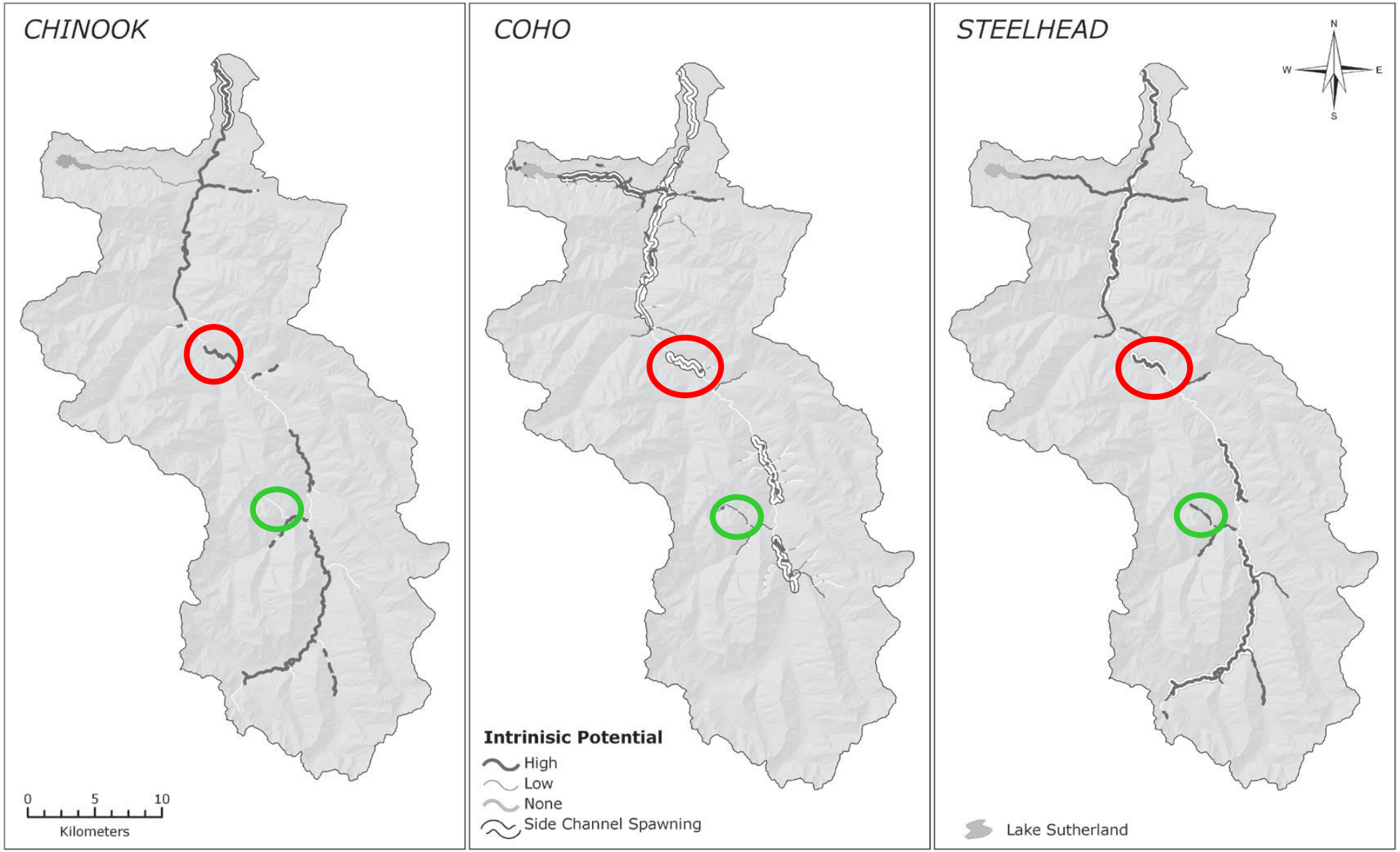
- How long will it take salmon to colonize & establish spawning populations?
- What habitats & locations will different salmon species colonize?
- How many more salmon will there be?
- How is change measured?
- What are some of the results to date?

Salmon can successfully colonize newly available habitats



What habitats and locations will different salmon species colonize in the Elwha River?

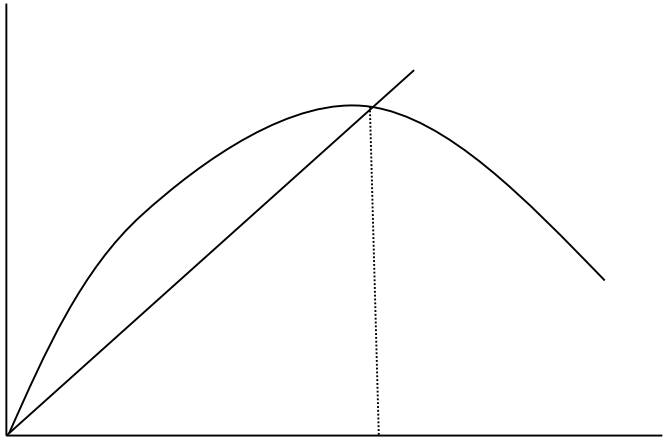
Pess, G. R., M. McHenry, **T. J. Beechie, J. R. Davies**. 2008. Biological impacts of the Elwha River dams and potential salmonid responses to dam removal. Northwest Science, 82(sp1):72-90.



How many more salmon will there be in the Elwha River?

$$S_{rep} = \chi \hat{b} * e^{\ln \hat{a} + (\frac{\hat{\sigma}^2}{2})}$$

χ = drainage area (km^2)

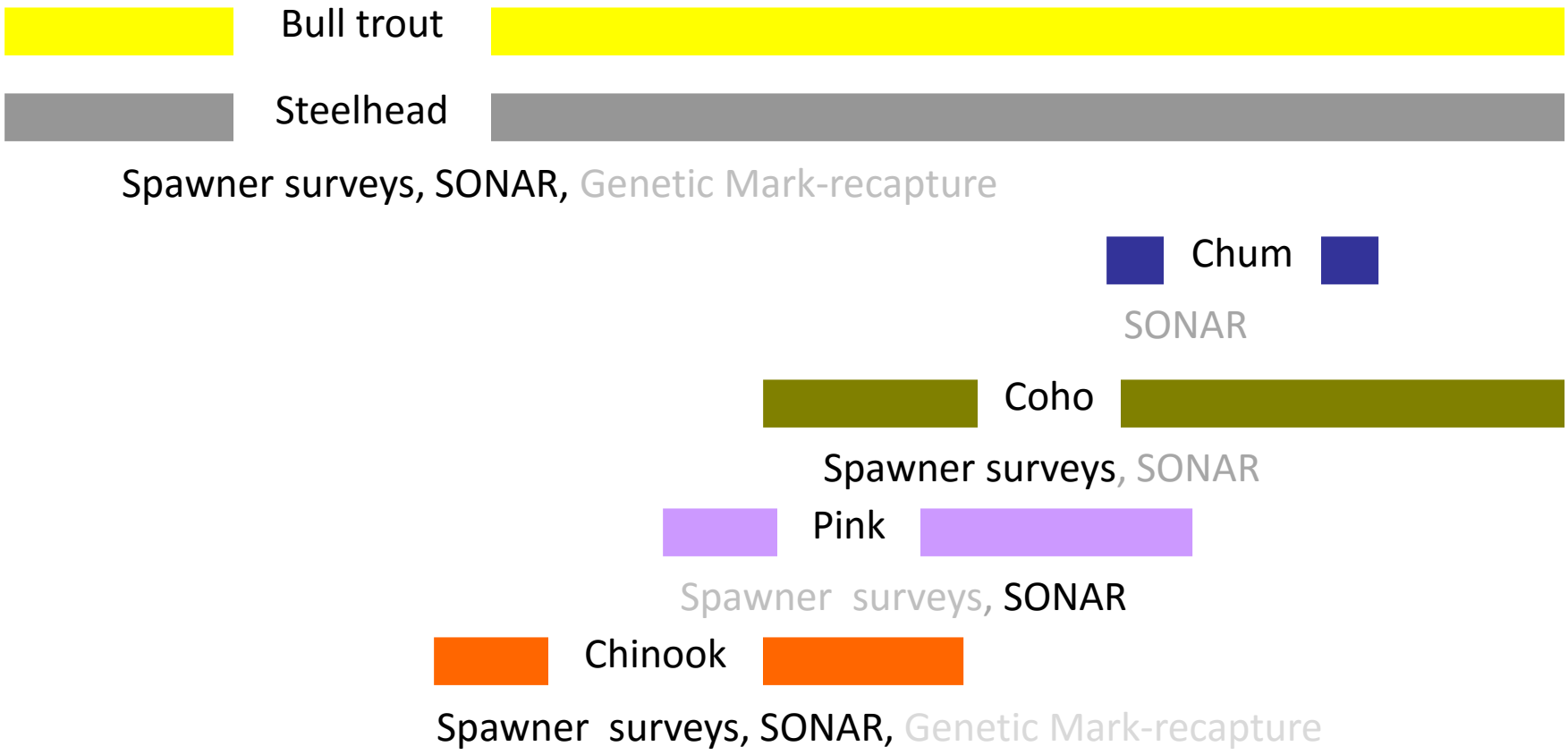


$S_{rep} = EquilibriumPopulationSize$

Elwha Chinook Estimate	Equilibruim Population Size
Stream type	**4,589**
Ocean type	**10,099**

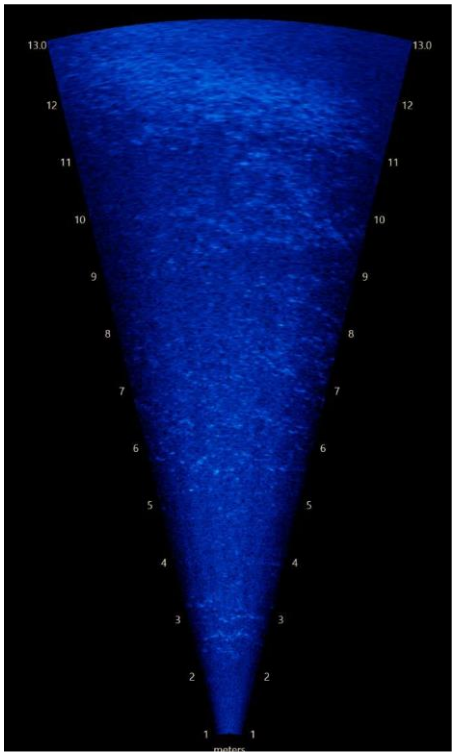
Peters, R.J., J.J. Duda, **G.R. Pess**, M. Zimmerman, P. Crain, Z. Hughes, A. Wilson, **M.C. Liermann**, **S.A. Morley**, **J.R. McMillan, K. Denton**, D. Morrill, and K. Warheit. 2014. Guidelines for monitoring and adaptively managing restoration of Chinook salmon and Steelhead on the Elwha River . USFWS. 101 pages. Lacey, WA

How is change measured for Elwha River adult salmon?

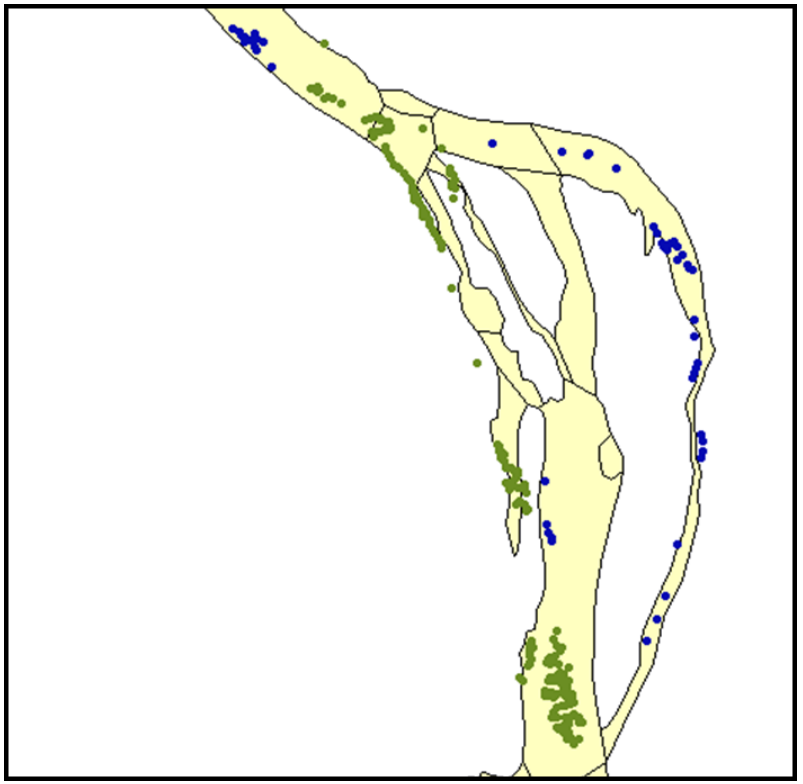


How are the methods used to determine adult populations & their spatial distribution?

SONAR

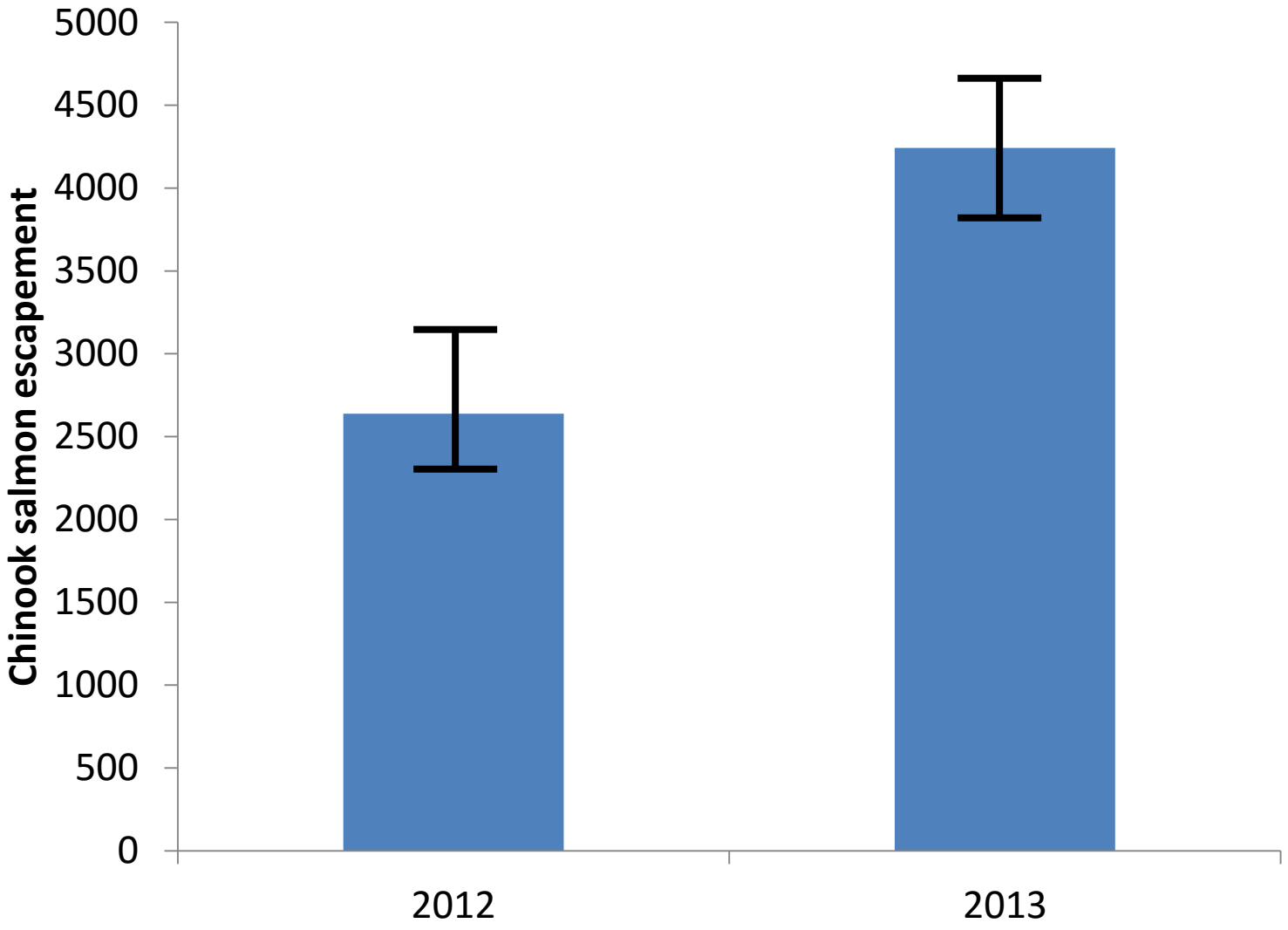


Redd surveys



Elwha River SONAR location to enumerate adult Chinook salmon & Steelhead

Estimated Elwha River Chinook salmon escapement using SONAR



Denton, K., R. Moses, **E. Ward, M. Liermann, O. Stefankiv**, W. Wells, and **G. Pess**. 2014. 2014 Elwha River Chinook escapement based in DIDSON/ARIS multi-beam SONAR data. Report to Olympic National Park by the LEKT. Port Angeles, WA.

Denton, K., M. McHenry, R. Moses, **M. Liermann,** and **G. Pess**. 2013. 2013 Elwha River Chinook escapement based in DIDSON/ARIS multi-beam SONAR data. Report to Olympic National Park by the LEKT. Port Angeles, WA.

Salmon recolonization in the Middle Elwha

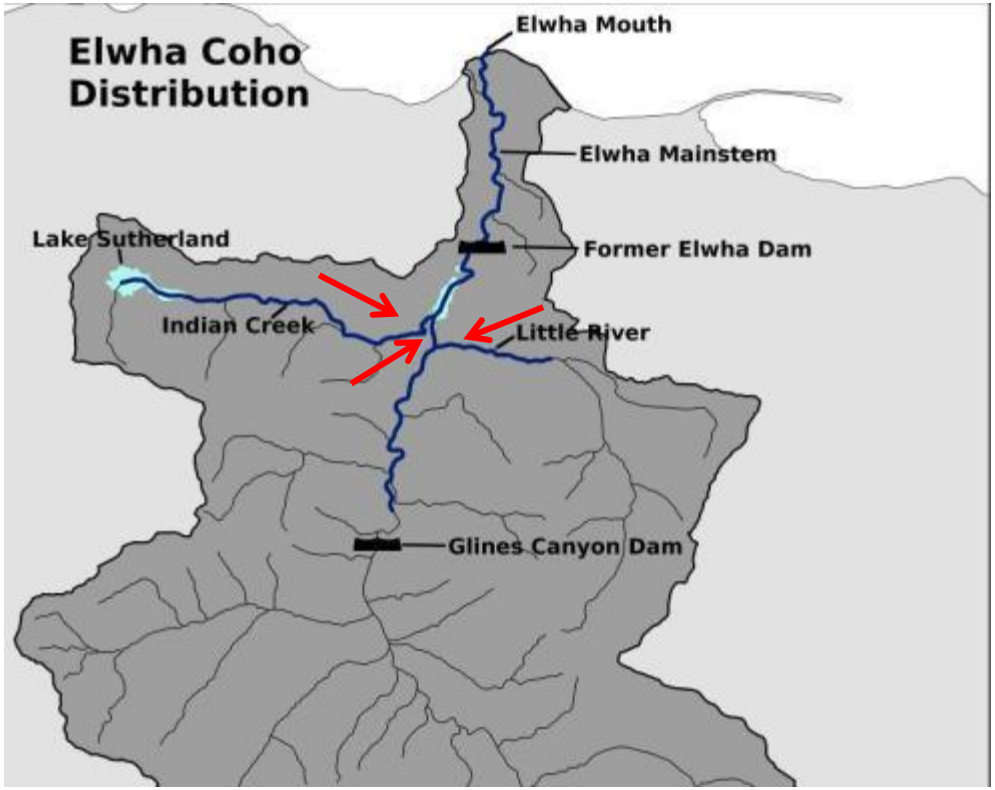
- Assisted Relocation
  - Hatchery & wild adult coho salmon
  - Wild steelhead

- Natural colonization
  - Steelhead, Chinook salmon, Coho salmon, Pink salmon, Sockeye salmon, & Pacific Lamprey

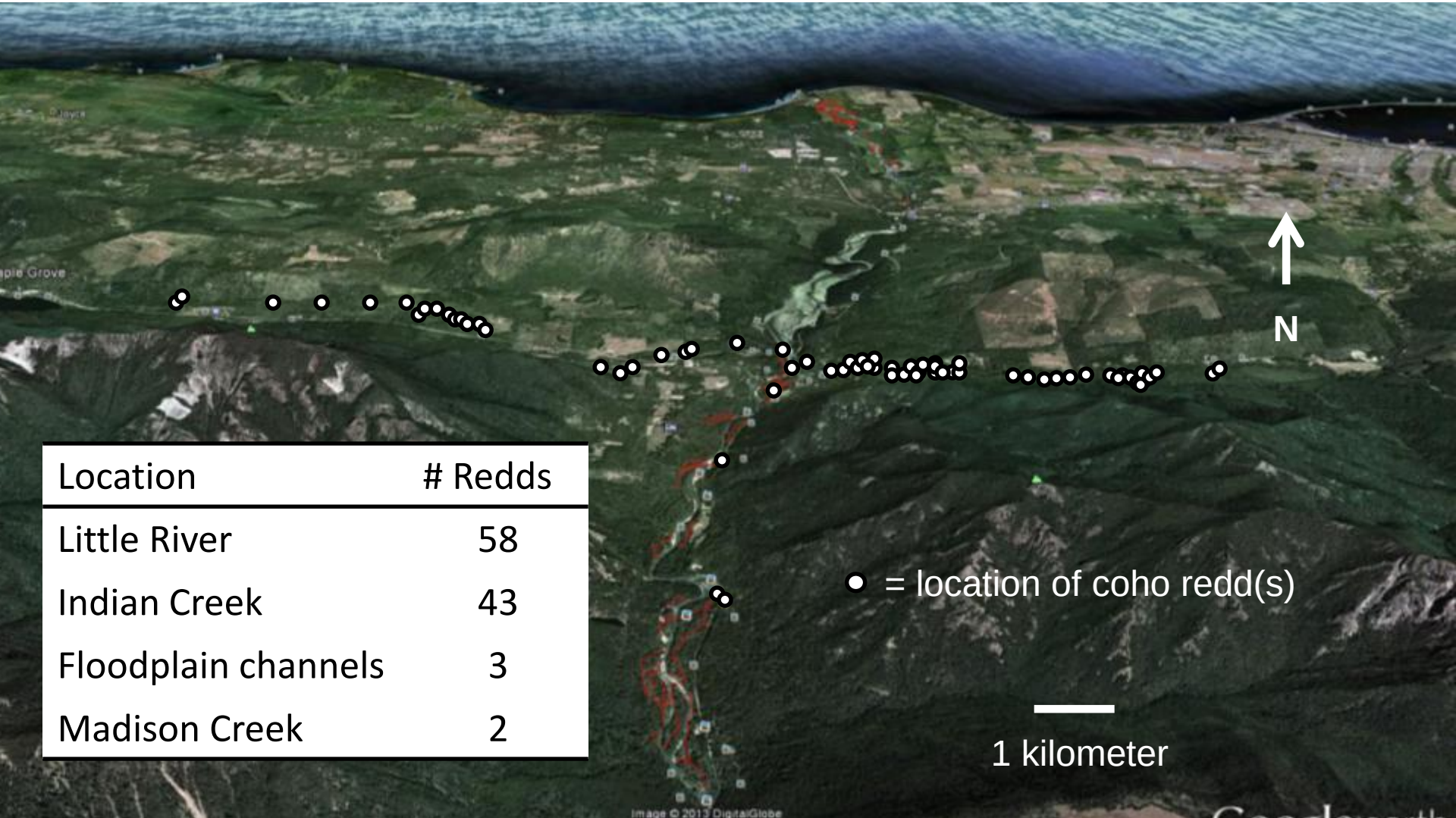
Recolonization is a combination of relocation & natural colonization by adult salmonids & other species

Relocation of adult coho salmon in the middle Elwha Fall of 2011

Release Location	Male Coho	Female Coho
Mainstem Elwha	260	223
Little River	102	70
Indian Creek	28	43



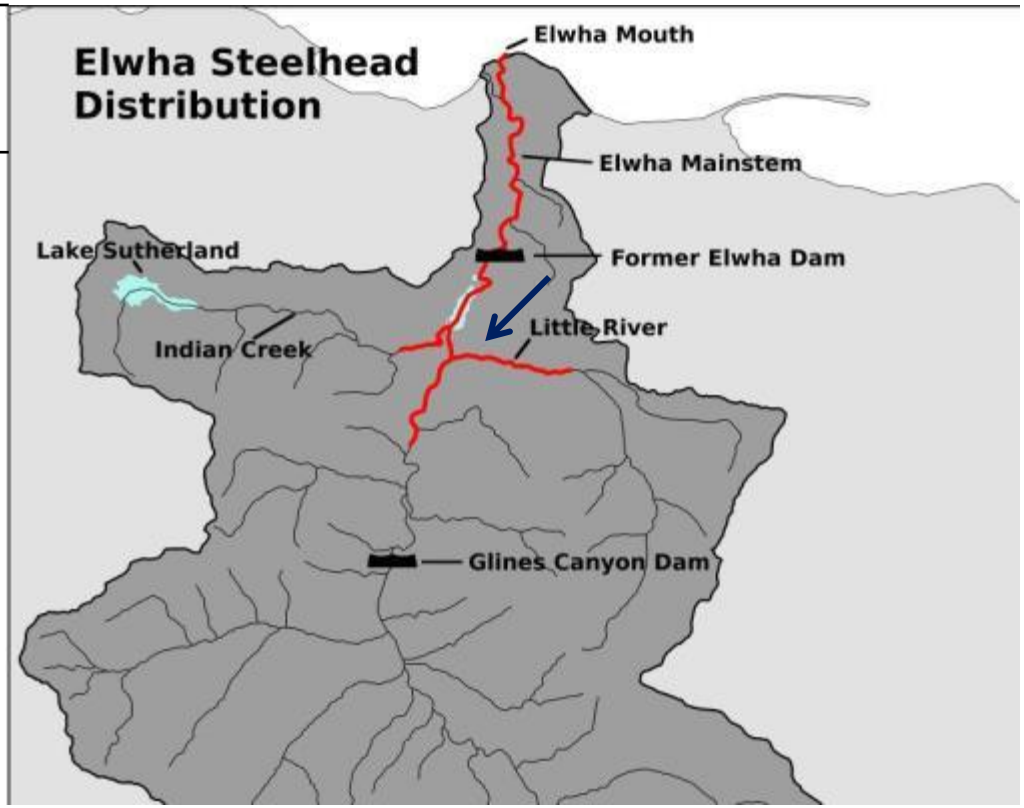
Coho salmon redds in the middle Elwha Fall of 2011



Location	# Redds
Little River	58
Indian Creek	43
Floodplain channels	3
Madison Creek	2

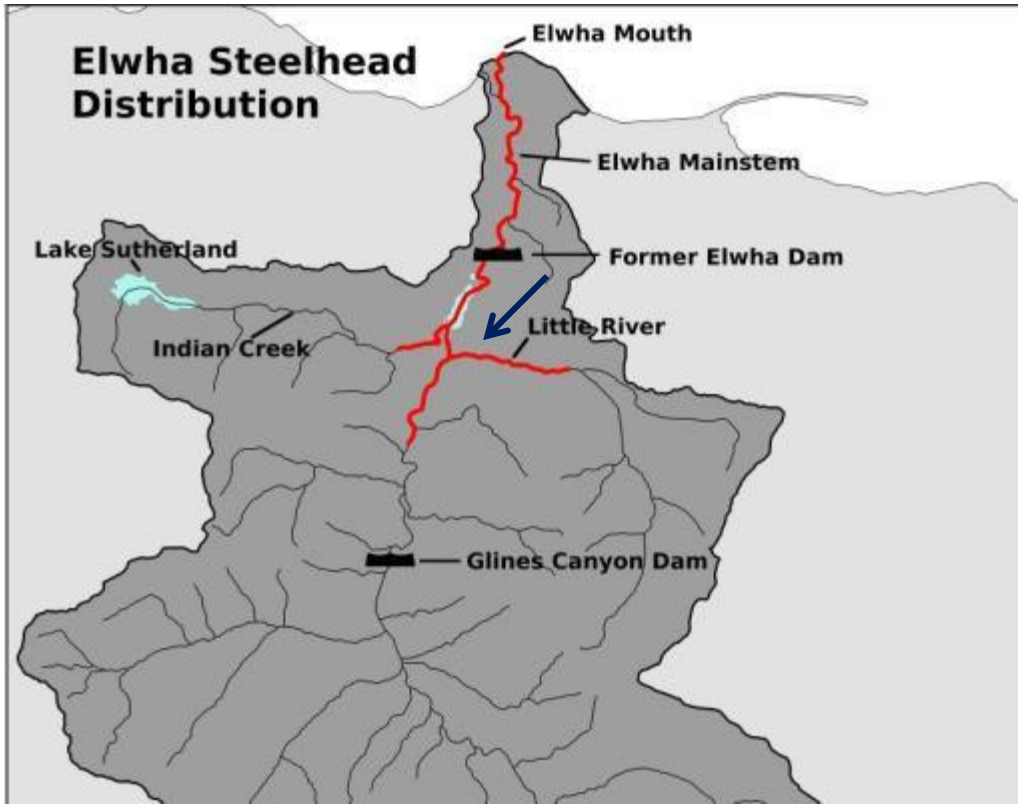
Relocation of adult steelhead in the middle Elwha River - Spring of 2012

Release Location	Male Stlhd	Female Stlhd	Rainbow trout
Little River	11	39	15

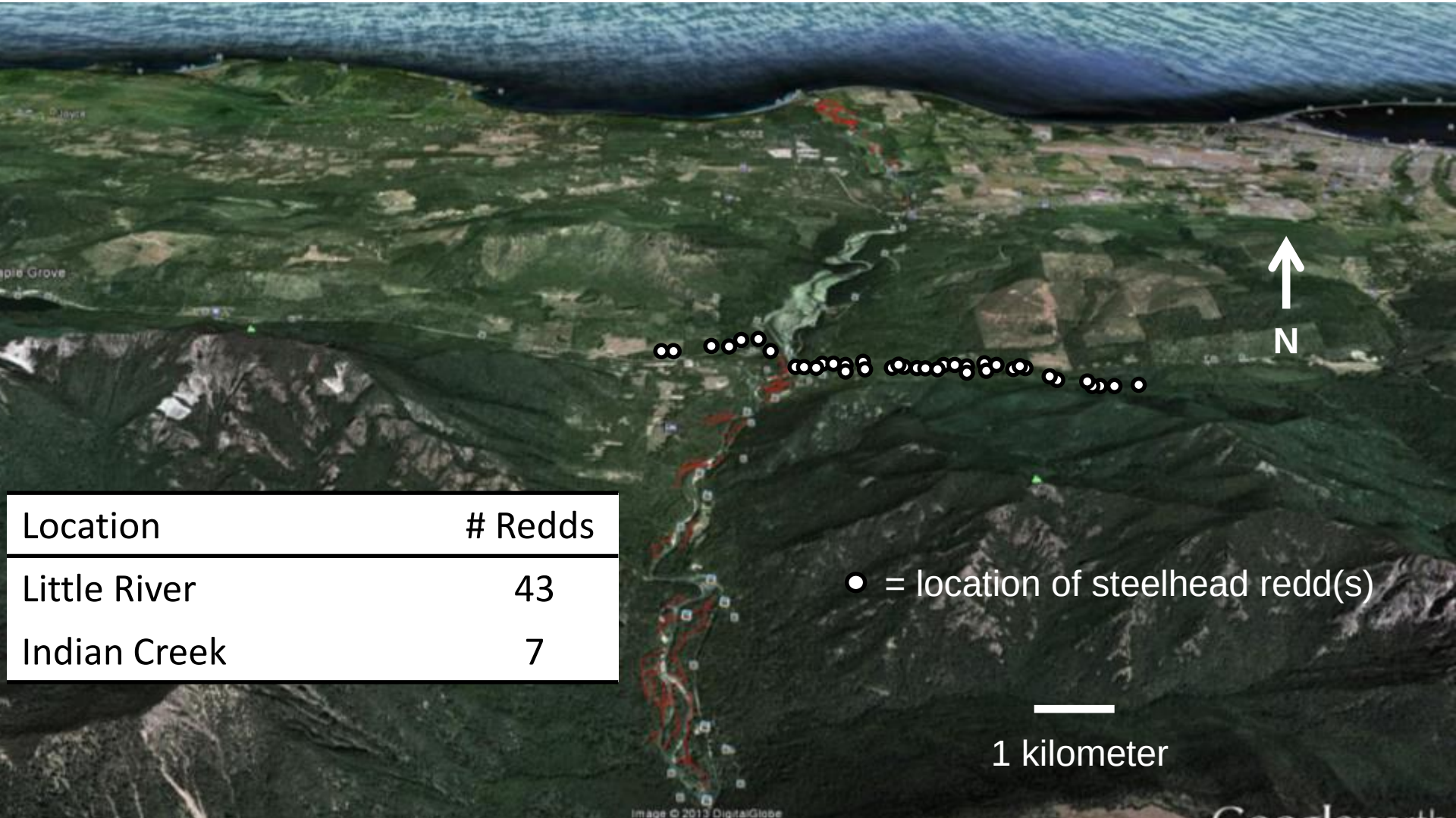


Natural colonization of adult steelhead in the middle Elwha River - 2011 to 2013

Natural colonizers	Male Stlhd	Female Stlhd
Little River	5	3
Indian Creek	6	4



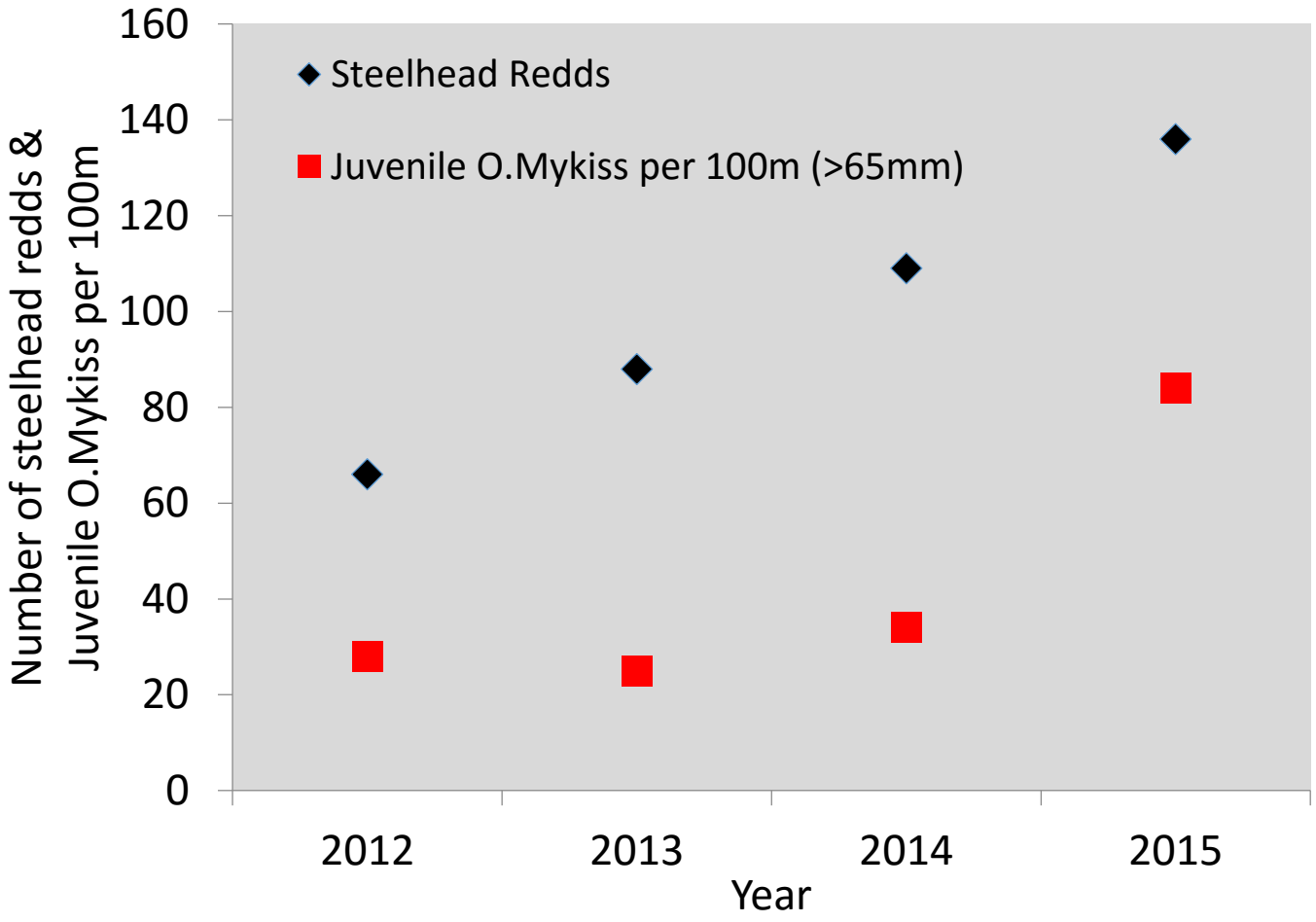
Steelhead redds in the middle Elwha River – Spring & summer of 2012



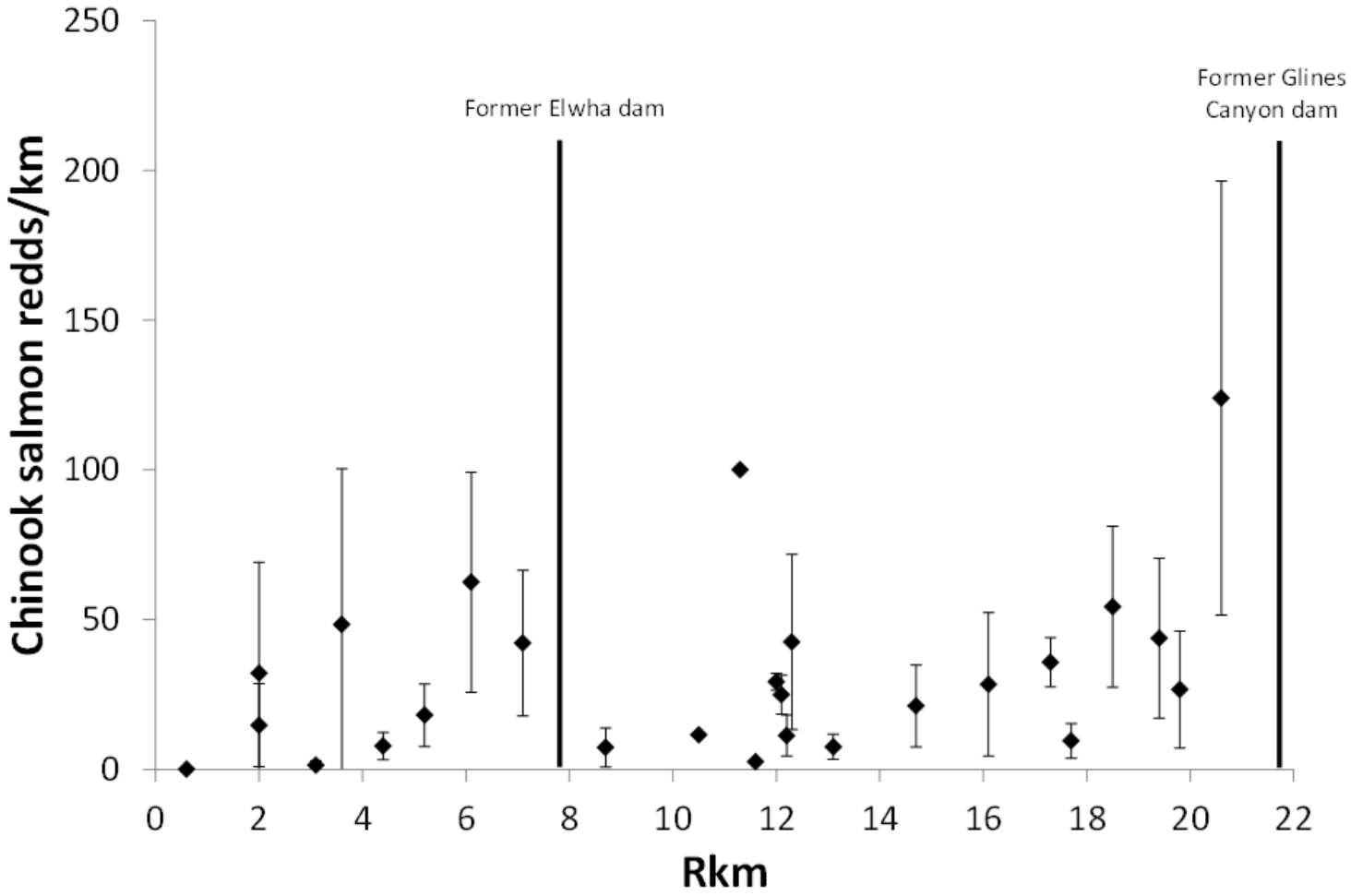
Location	# Redds
Little River	43
Indian Creek	7

● = location of steelhead redd(s)

Number of steelhead redds & juvenile *O. Mykiss* abundance in the Middle Elwha River – 2012 to 2015



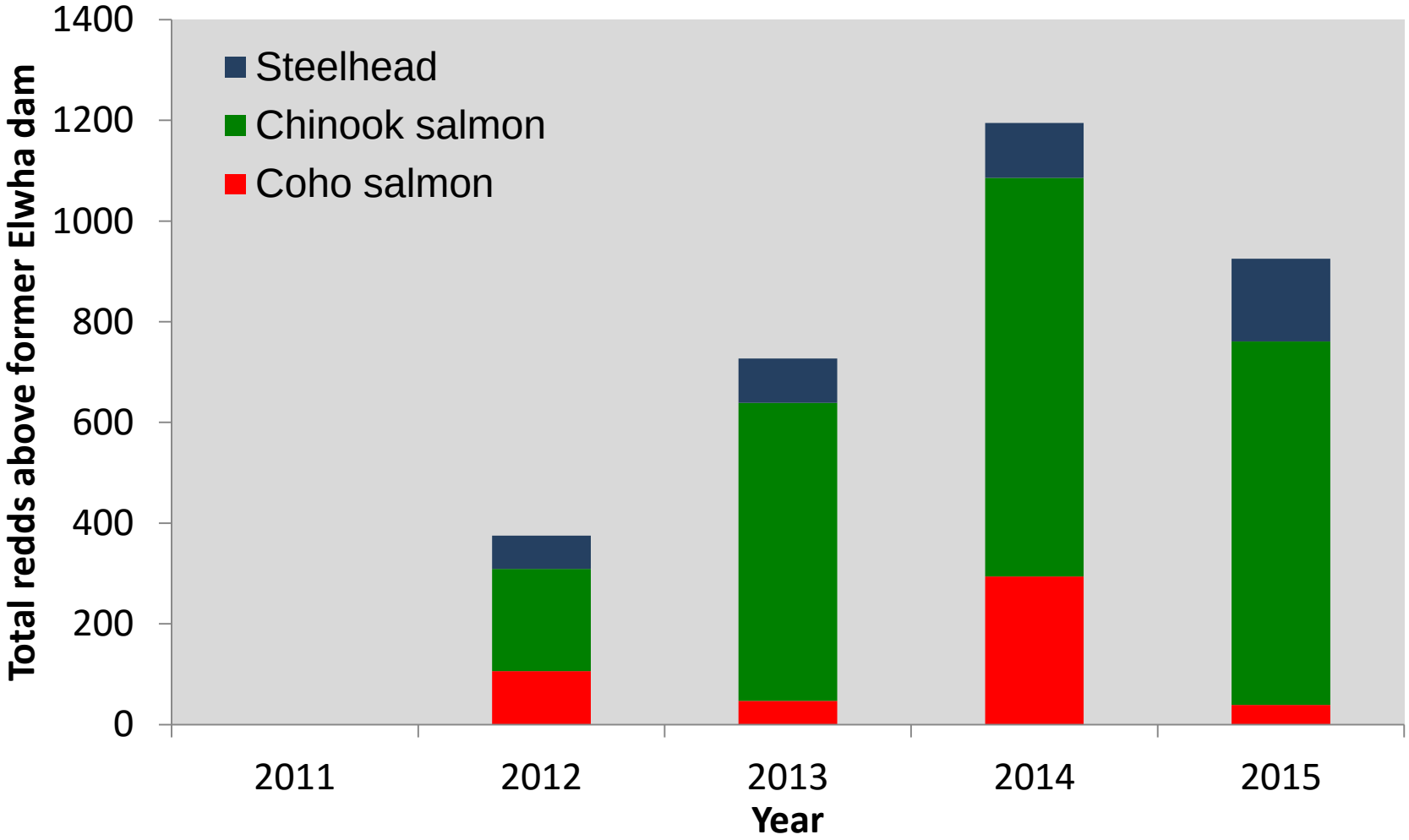
Natural recolonization of Chinook salmon in the Middle Elwha River – 2012 to 2014



McHenry, M., G. Pess, R. Moses, S. Brenkman, P. Crain, & J. Anderson. 2015. Spawning distribution of Chinook salmon in the Elwha River, Washington State during dam removal from 2012 to 2014. LEKT. Port Angeles, WA. 23pp.

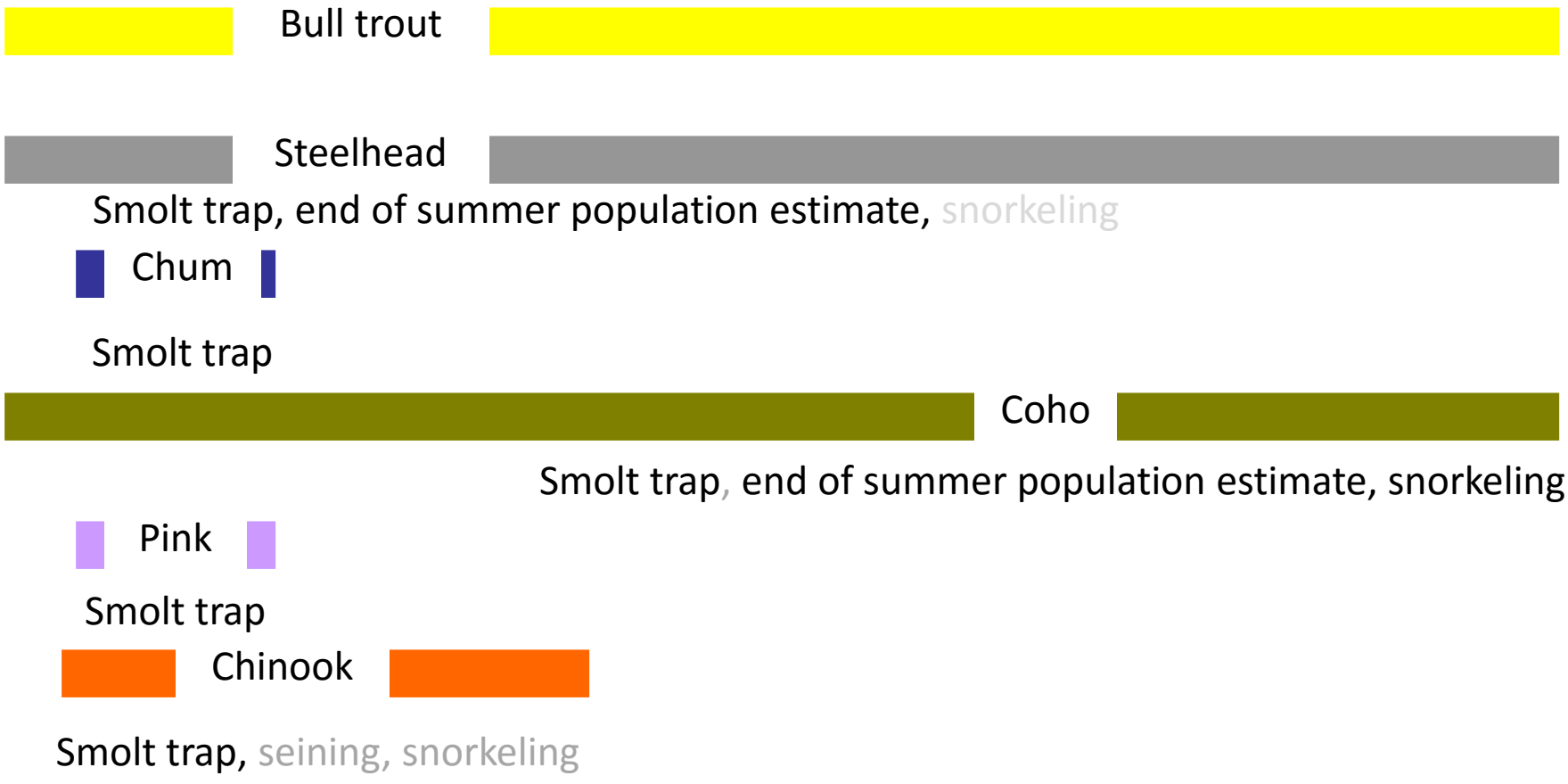
Flow

Salmon recolonization in the Middle Elwha



Recolonization rates for Chinook salmon & steelhead are similar to previous recolonization events (1.95 & 1.61/year) (Pess et al. 2014)

How will we measure change for juvenile salmon in the Elwha River?



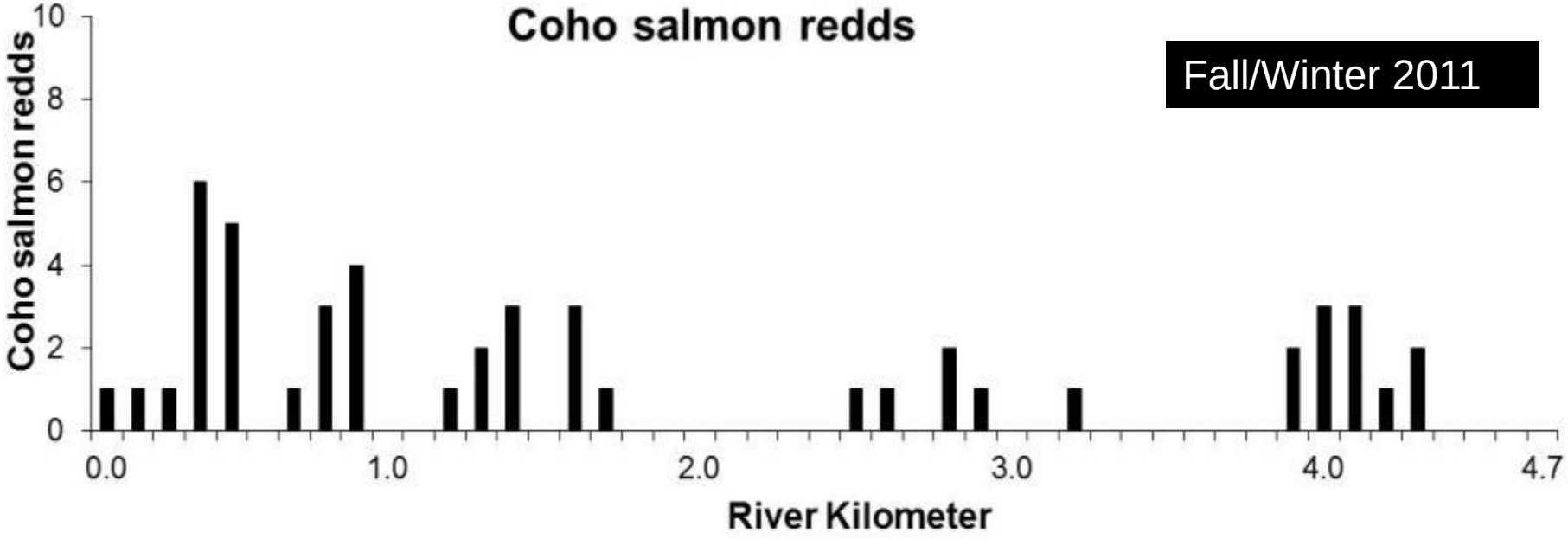
How are the methods used to determine juvenile populations & their spatial distribution?

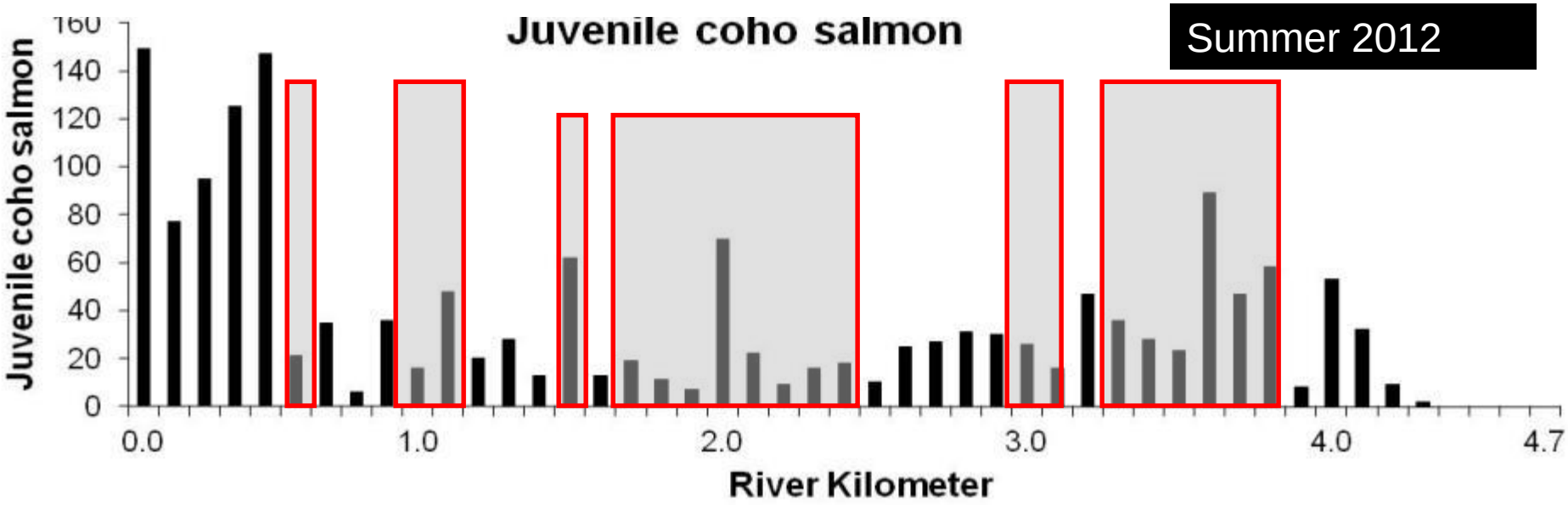
Screw traps

Electrofishing

Snorkel surveys

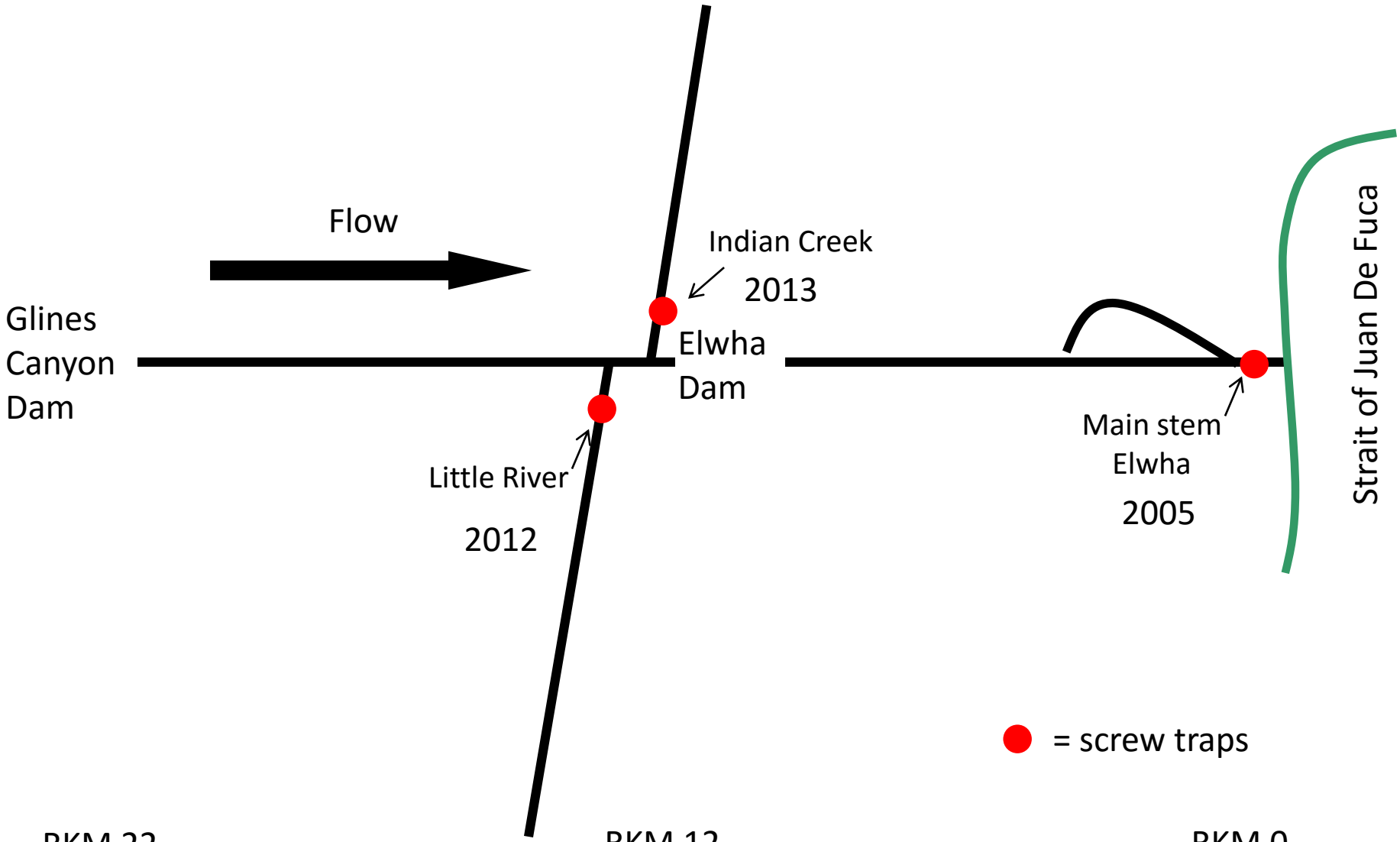
Little River coho salmon redd & juvenile snorkel surveys





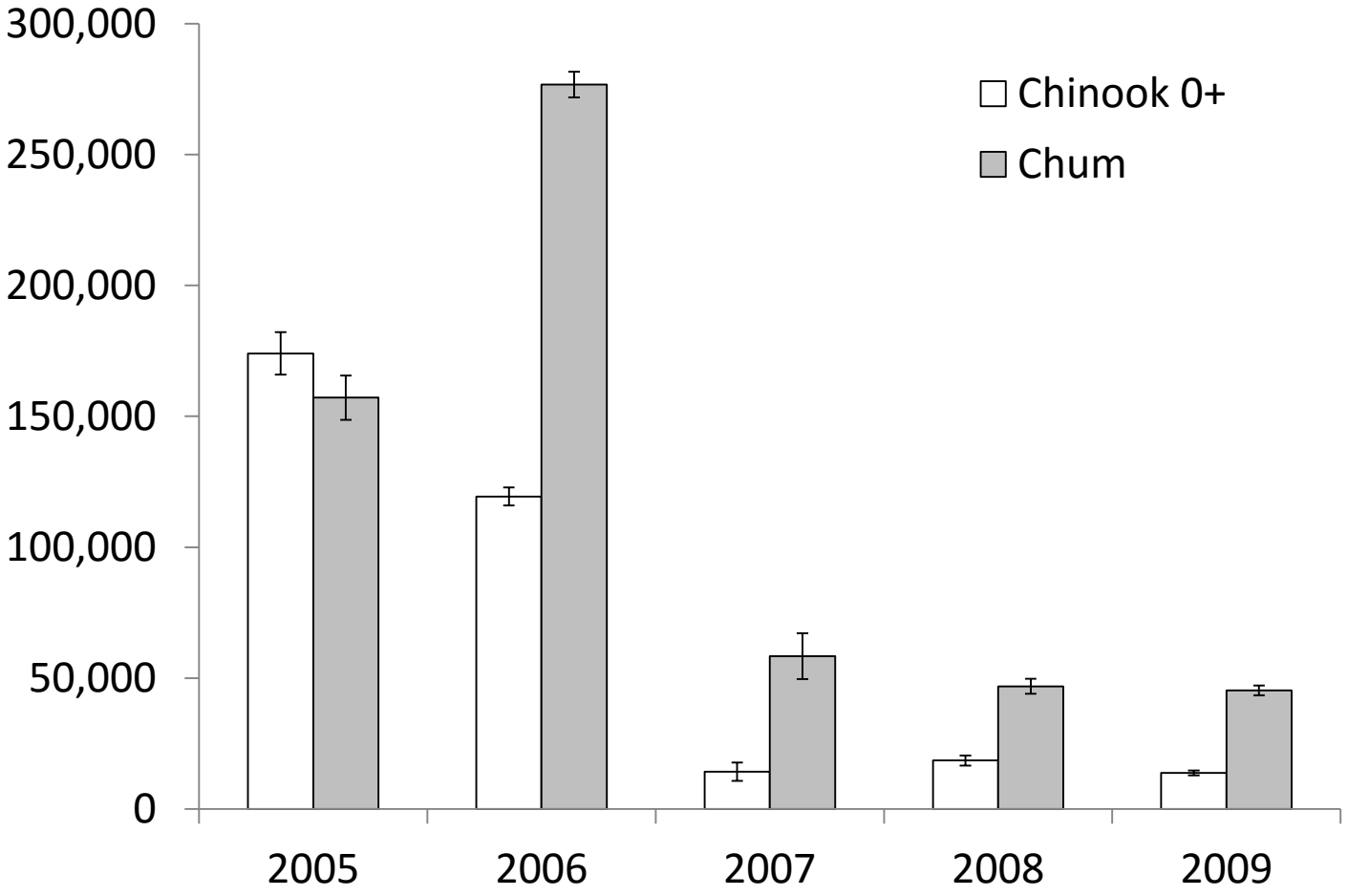
- Juveniles have dispersed in new habitats between the dams in areas where adults have not spawned

Elwha River smolt trap locations

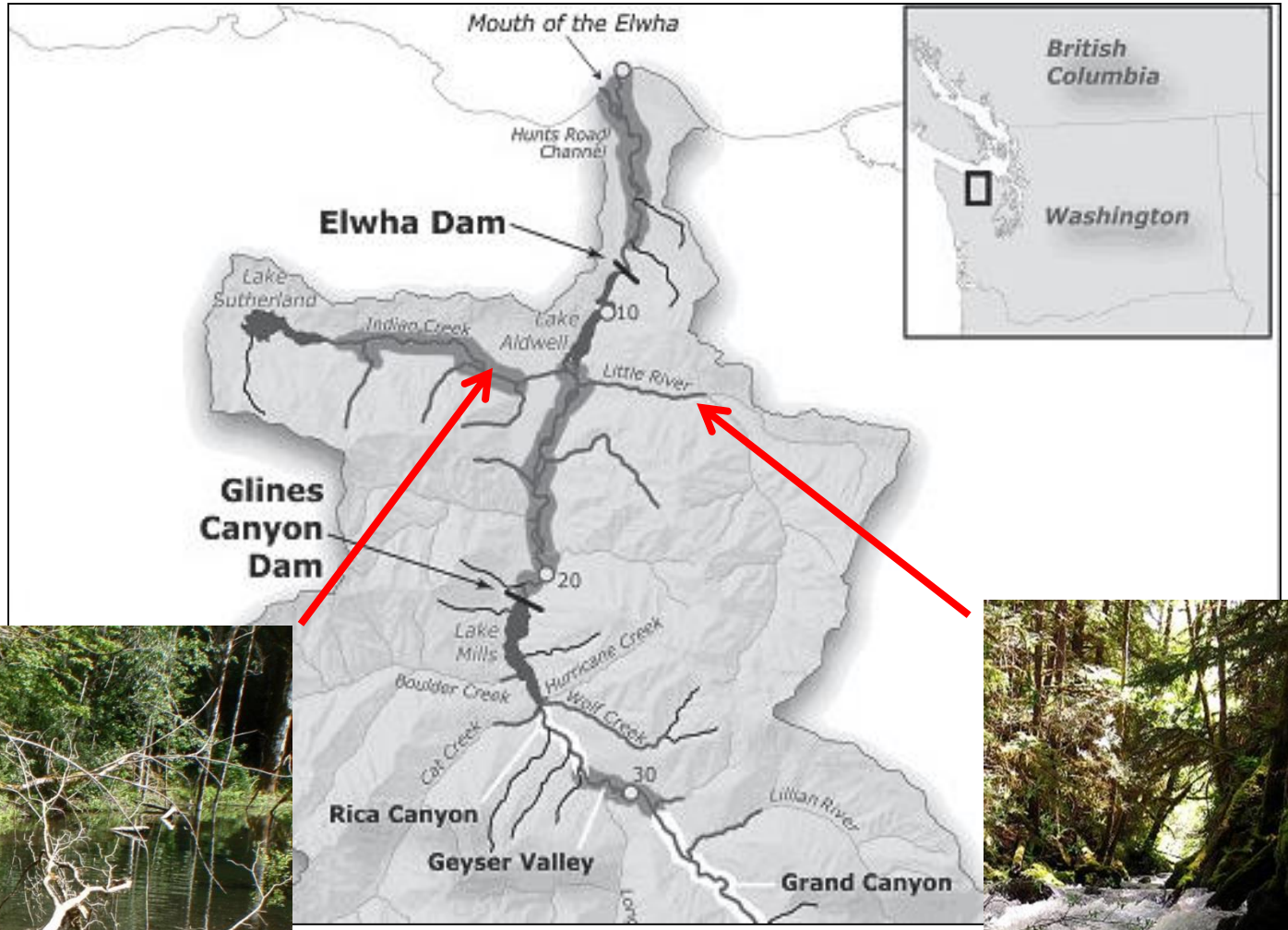


Elwha River smolt production

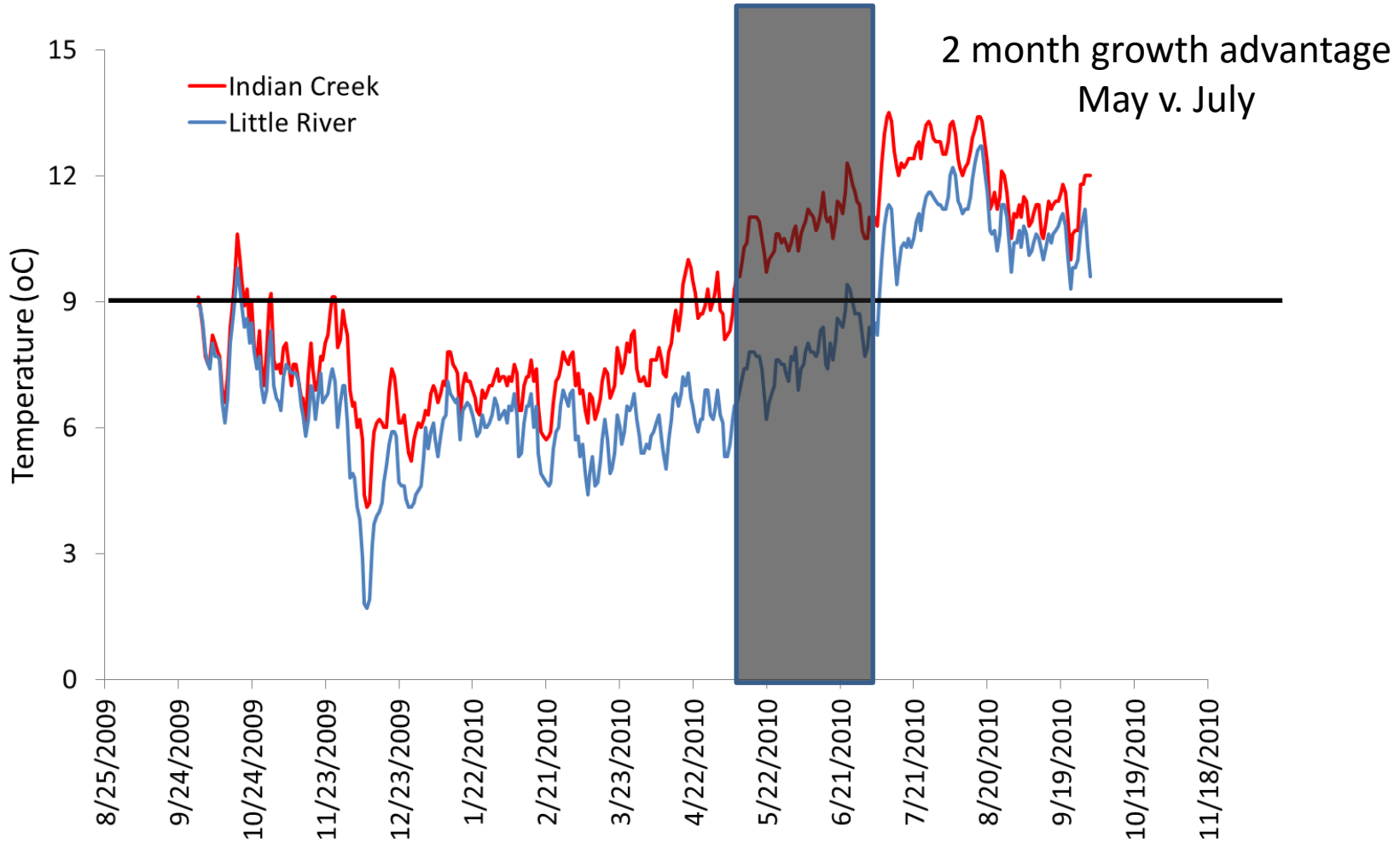
Lower Elwha river smolt production pre dam removal



Indian Creek & Little River – A tale of 2 watersheds



Indian Creek & Little River stream temperature



Differences in life history strategies of juvenile salmonids can emerge as a function of local environmental conditions such as stream temperature

Indian Creek & Little River juvenile coho salmon outmigration

Length ~ 70mm

Length ~ 150mm

The progeny of the first generation of anadromous salmonids has resulted in different life history strategies of individuals with the same genetic composition in Indian & Little

Middle Elwha River fish recolonization highlights

- First documented lamprey above Elwha dam

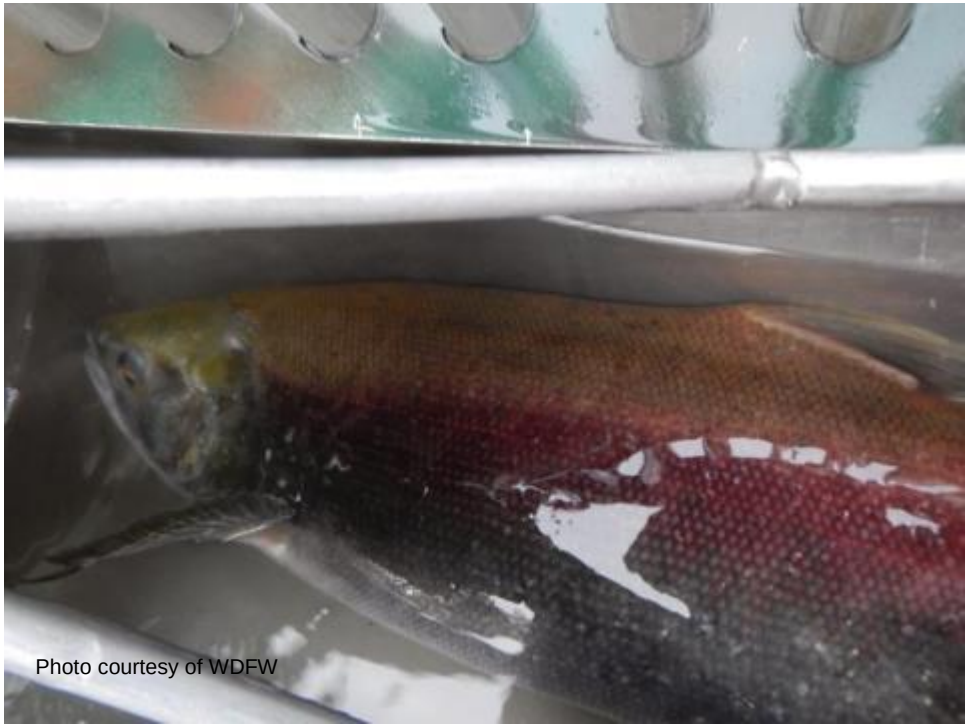
- First documented sockeye salmon in Indian Creek

- First documented summer steelhead in Little River

Middle Elwha River fish recolonization highlights

- First documented lamprey above Elwha dam.

- First documented sockeye salmon in Indian Creek

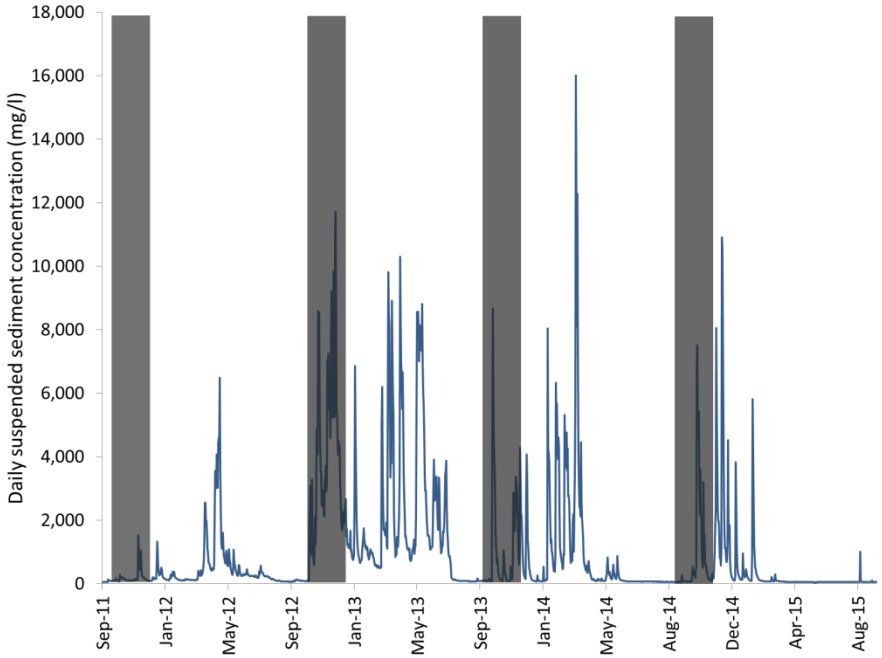


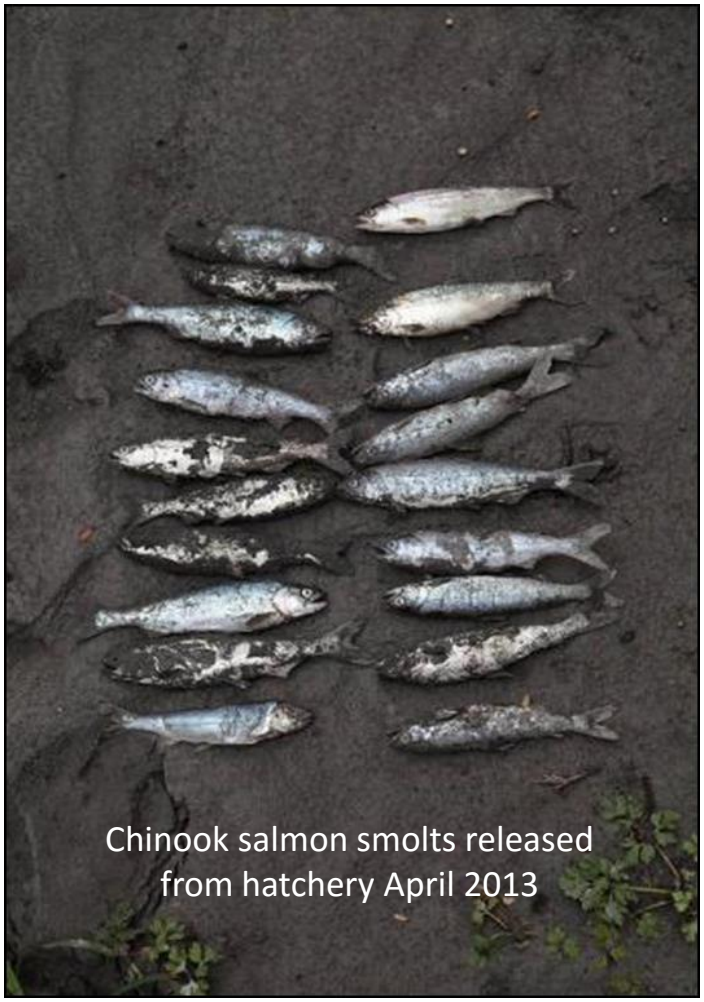
- First documented summer steelhead in Little River

Middle Elwha River fish recolonization highlights

- First documented lamprey above Elwha dam.
- First documented sockeye salmon in Indian Creek
- First documented summer steelhead in Little River

Short-term impacts to salmonids due to increased sediment levels





- Curran, C. A., C. S. Magirl, and J. J. Duda. "Suspended-sediment concentrations during dam decommissioning in the Elwha River." Washington: US Geological Survey Data Set, doi 10 (2014): F7M043DB.
- Data post Sept 15, 2013 is provisional and subject to change. Please contact Chris Curran, USGS for further information
- Smolt data Lower Elwha Klallam Tribe unpublished data

Adult salmon having issues at former Glines Canyon dam

Former Glines Canyon Dam rockfall blast September/October 2015

Photos courtesy of Andy Ritchie , NPS

Benthic foodweb

Consumers
Resident Fish

Secondary Producers
Invertebrates

Direct
(tissue & eggs)

Spawners
Anadromous

Primary Producers
Periphyton

Indirect
(nutrients)

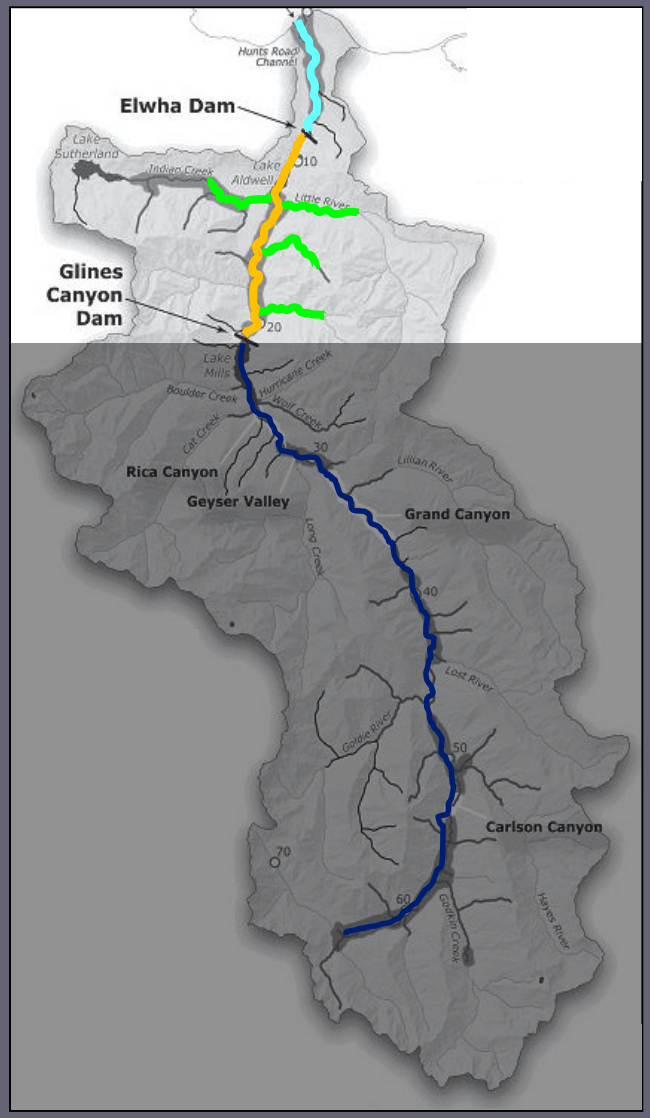
Physical Habitat

Water Chemistry

Sarah Morley, NOAA
Jeff Duda, USGS

Photos: J. McMillan, A. Draut

Elwha River dam removal benthic foodweb study design



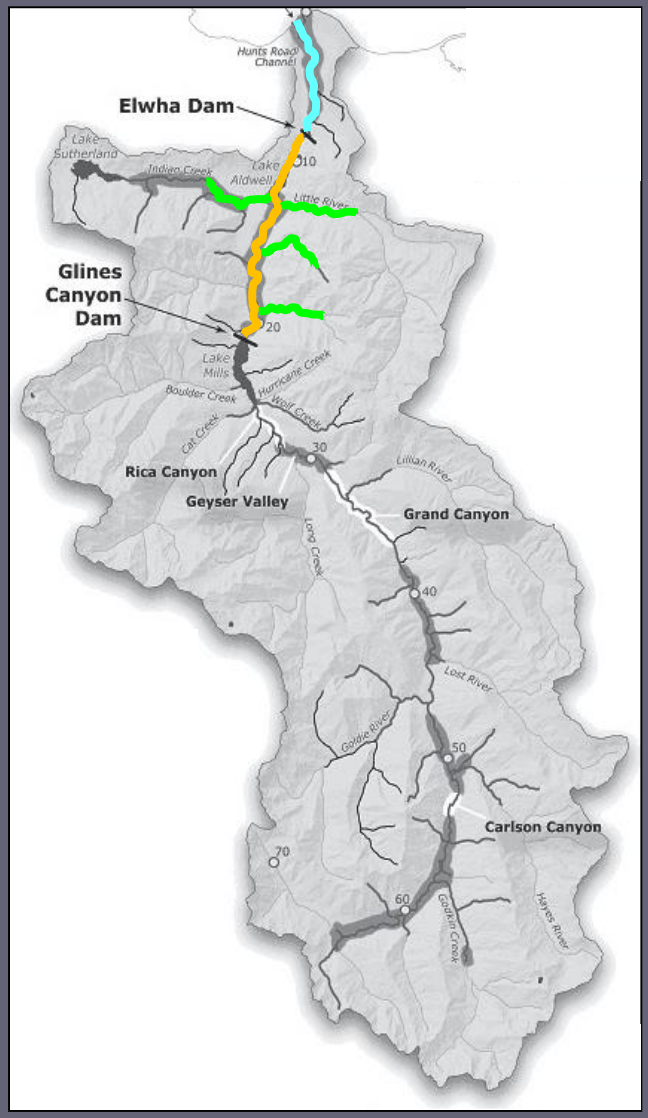
River sections: Below
Between
Above

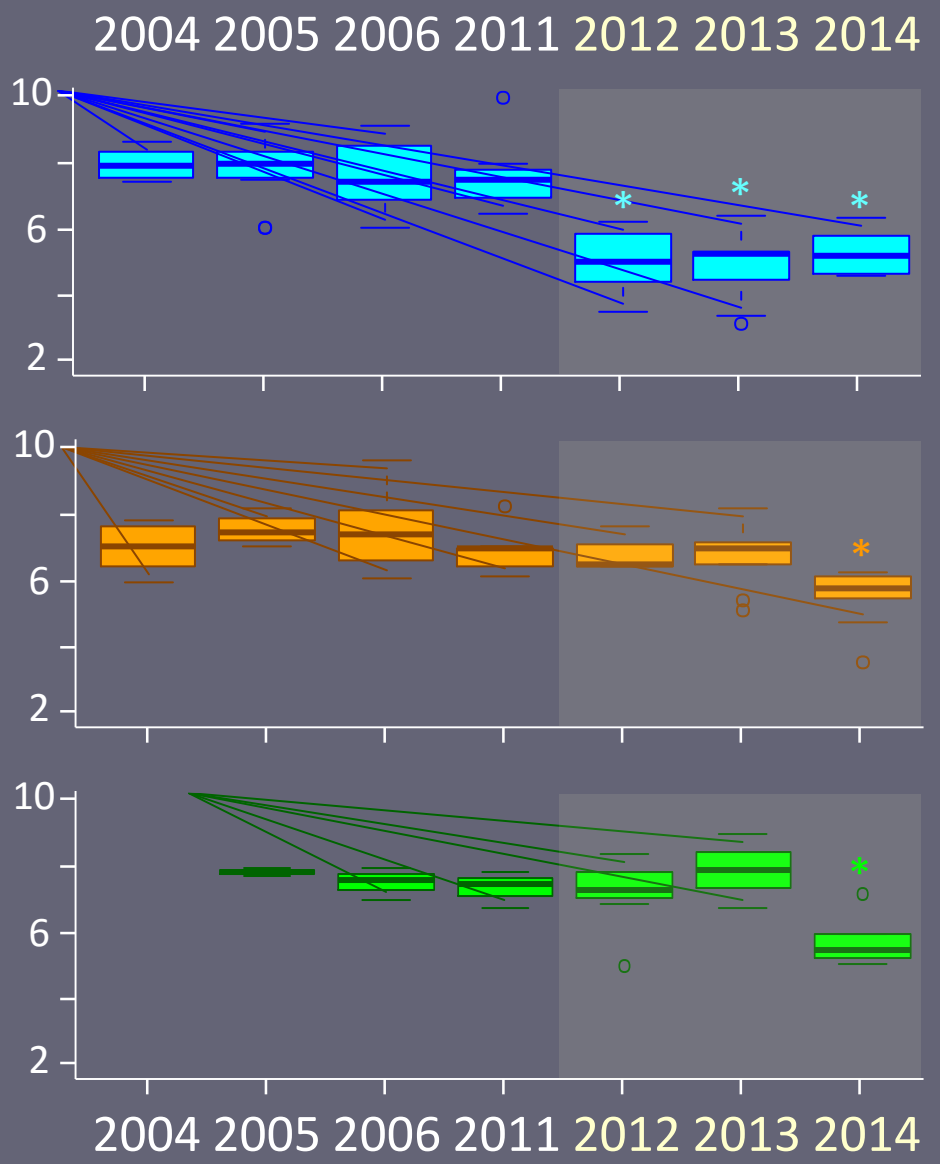
Habitat types: Mainstem
Side channels
Tributaries

Pre-removal: 2004-2011

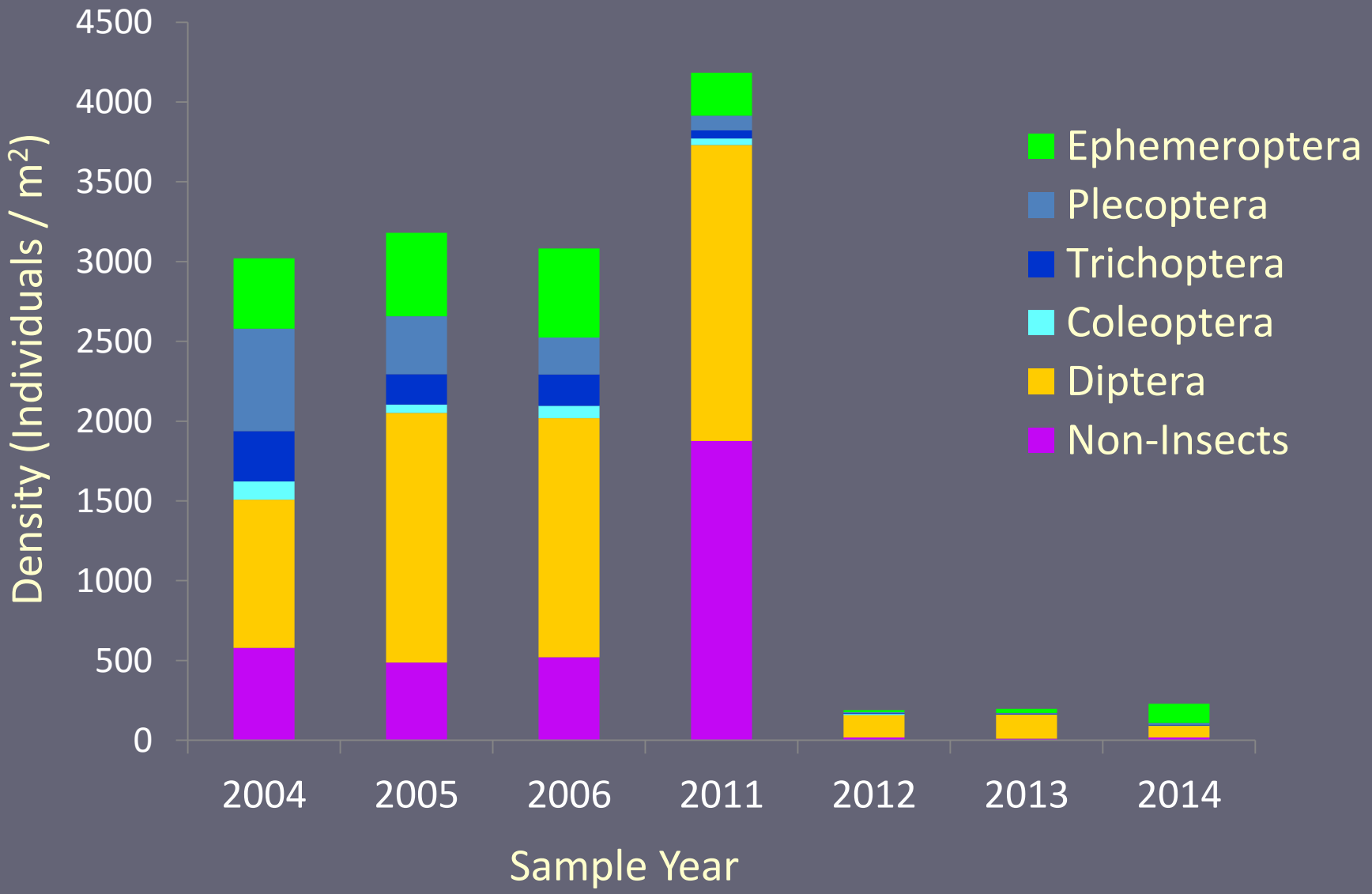
During-removal: 2012-2014

Benthic Invertebrate Densities – Pre vs. During Removal



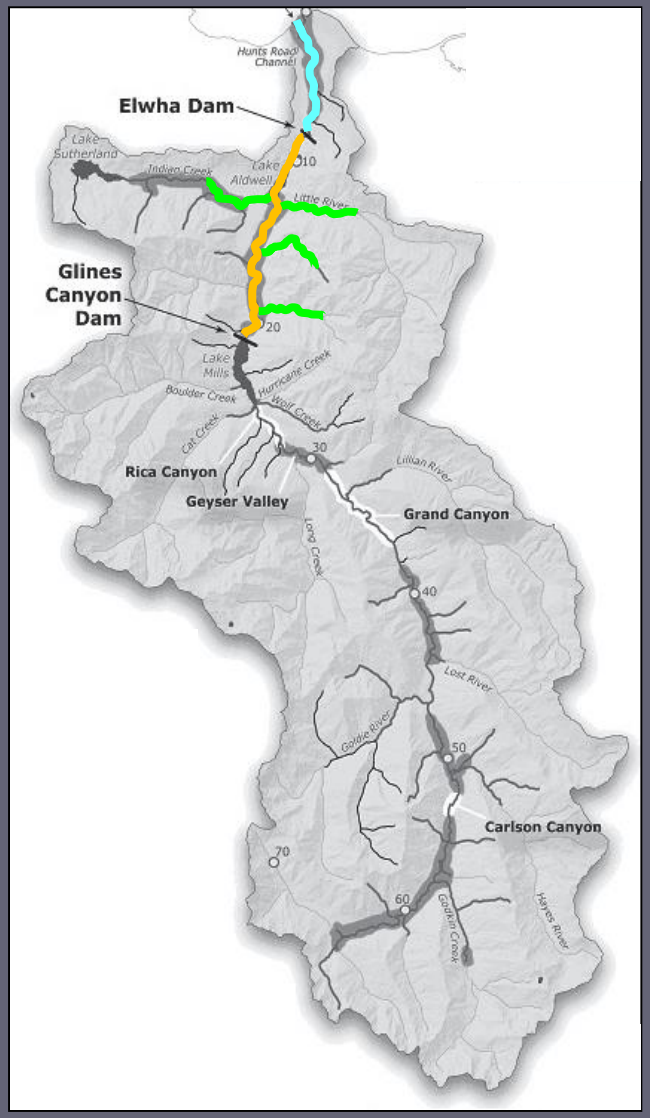


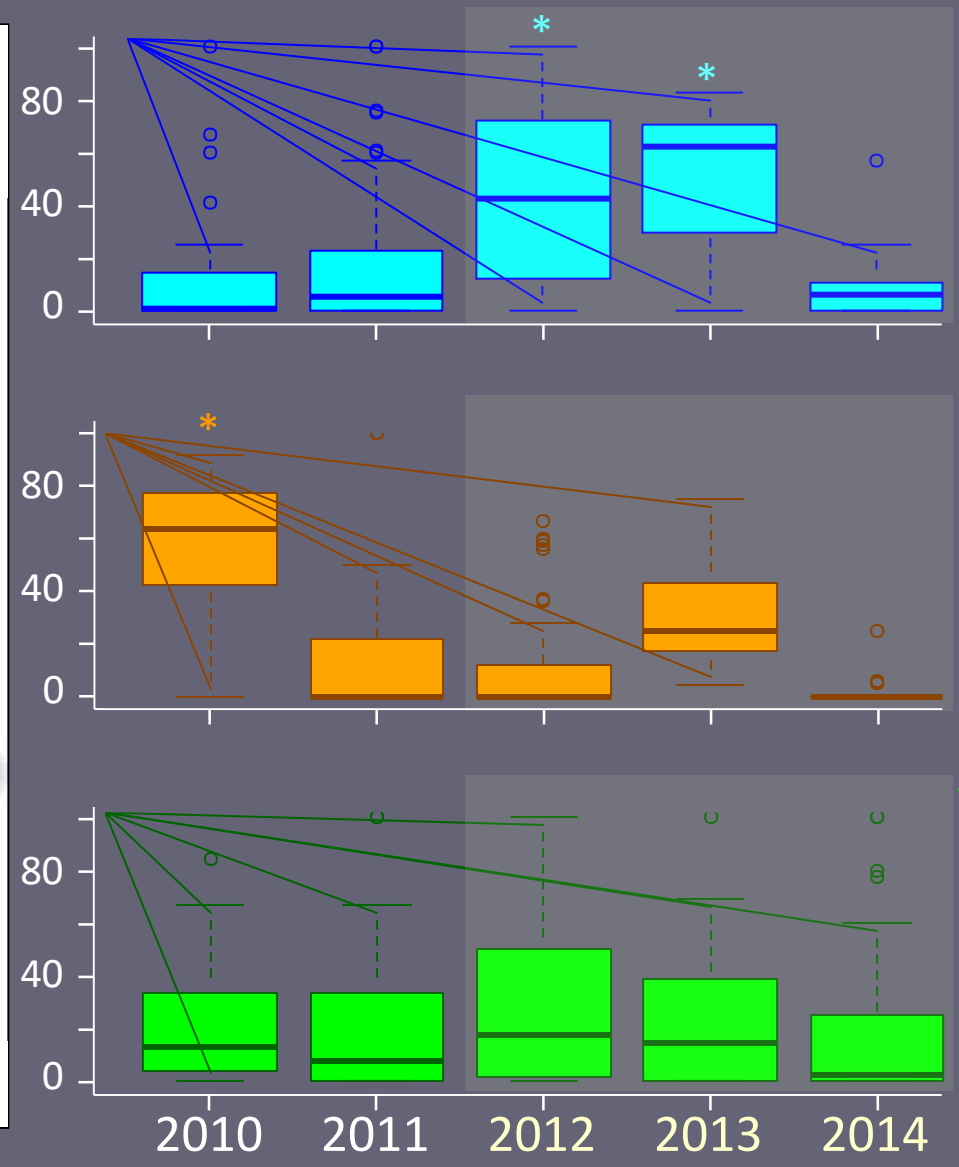
Benthic invertebrate density & taxonomic composition below former Elwha Dam



Diet Results

Juvenile Salmonid (*O. mykiss*) Diet – % Terrestrial





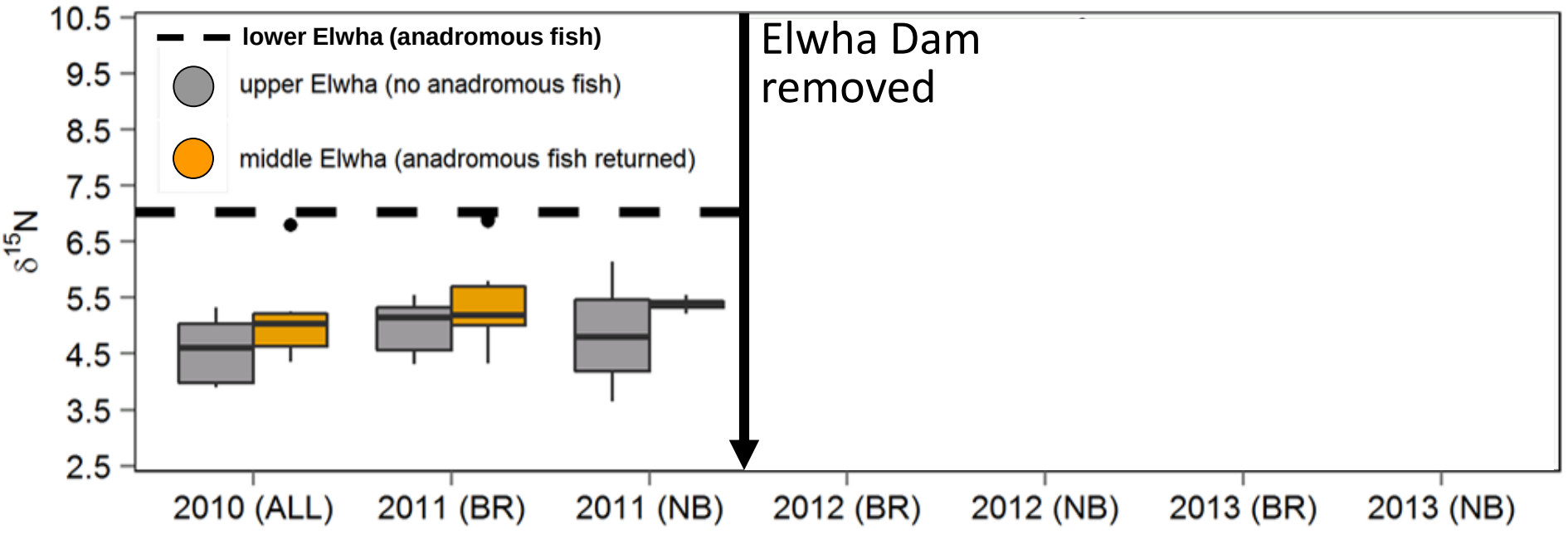
Terrestrial linkages
Marine-derived nutrients in the Elwha foodweb

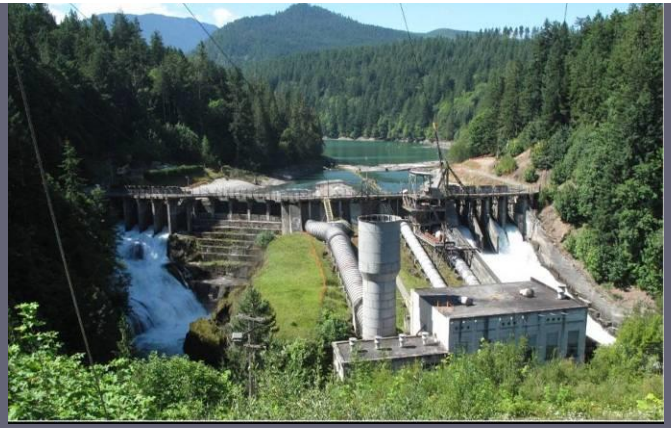
The case of the American dipper (*Cinclus mexicanus*)

Photo by Chris Tonra

Photo by John McMillan

Return of Marine-derived Nutrients to Elwha Foodweb



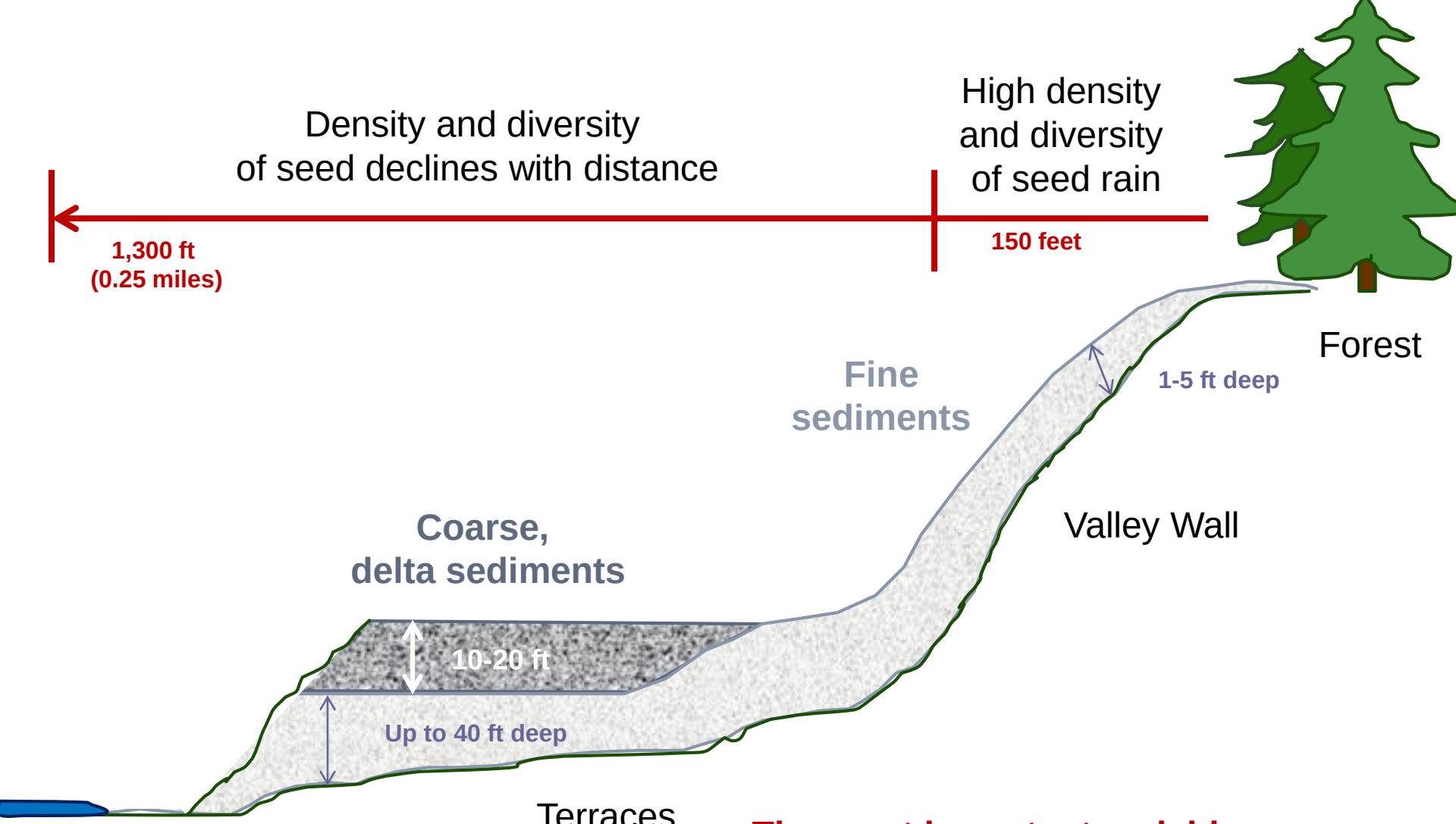


Modified from: Tonra, C. M., et al. 2015. The rapid return of marine-derived nutrients to a freshwater food web following dam removal. Biological Conservation

Revegetation - Reservoir revegetation plan

- 7 year plan
- Plant 400,000 native plants
- Sow 5,000 pounds of locally harvested seed

Slide courtesy Josh Chenoweth



The most important variables:

- **Moisture**
- **Sediment texture**
- **Distance from forest**

Slide courtesy of Josh Chenoweth, NPS

Revegetation – Josh Chenoweth, NPS

2012

2014

Fine sediments

Coarse sediments

Elwha River dams and former reservoirs

- Elwha and Glines canyon dam removal complete.
- ~58% of total stored sediment has been released as of October of 2015.
- Reservoirs being re-vegetated both naturally and with restoration efforts.

Elwha River nearshore, main stem, & floodplains

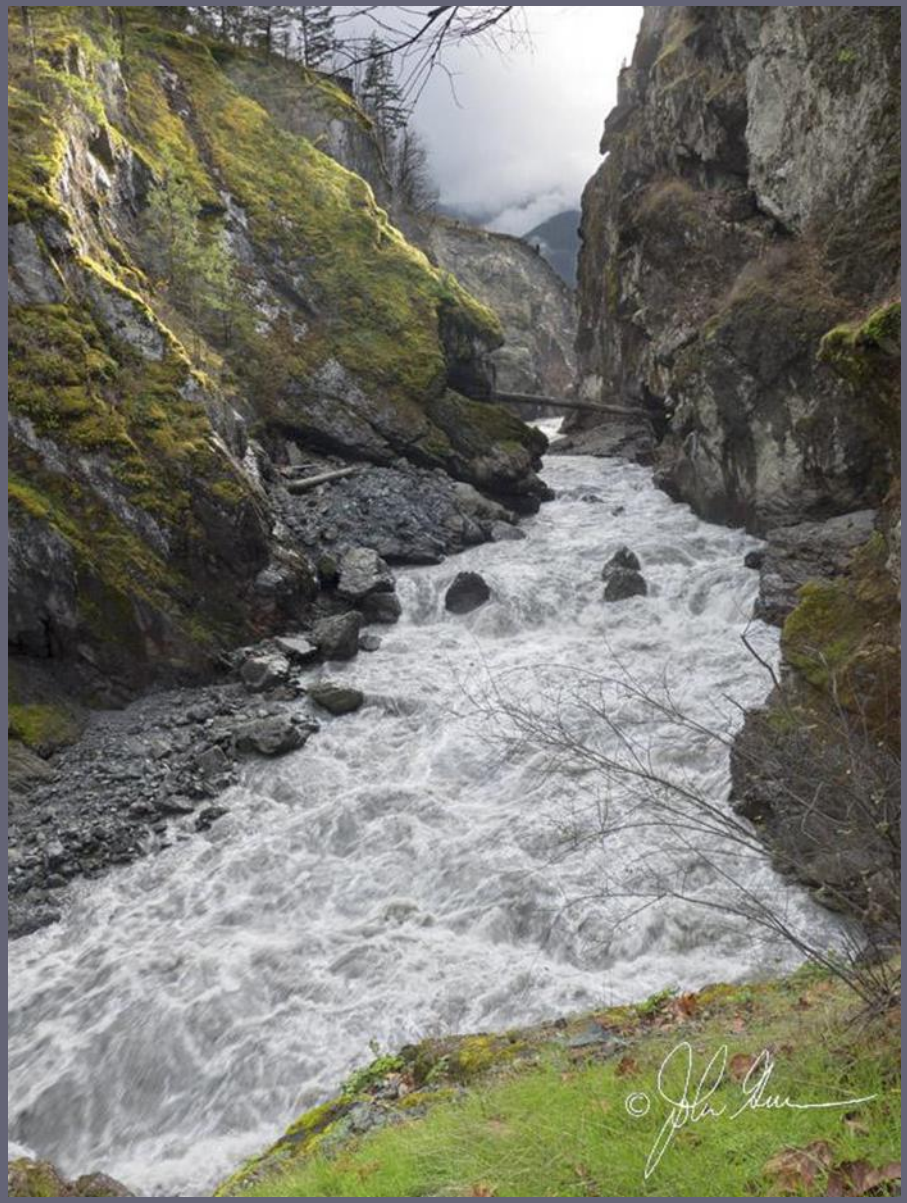
- Majority of sediment transported to Strait of Juan de Fuca
- Delta at river mouth has prograded into the Strait of Juan De Fuca.
- ~12% of sediment stored in-river.
- Main stem & floodplain channels downstream of dams aggraded (~1-2m)
- Gravels bars developed, large increase in wood accumulation
- Floodplain channels filled with sediment
- Floodplain surface now accumulating sediment

Photo by Tom Rooda & CWI


John McMillan

Fish Recolonization

- Adult salmonids making it above former Elwha Dam.
- Full passage at former Glines Canyon Dam?
- Coho, steelhead & Chinook salmon redds are increasing each year in the middle Elwha River.
- Juveniles are dispersing to colonize new areas.
- New species are being seen
- Salmonids are adapting to the local environmental conditions resulting in differences in life history strategies



Riverine Foodwebs

- Benthic invertebrates reduced over 95% in lower Elwha & shift in species composition.

- Juvenile salmon relying more on terrestrial food sources

- American dippers benefiting from return of salmon & altering their migratory behavior

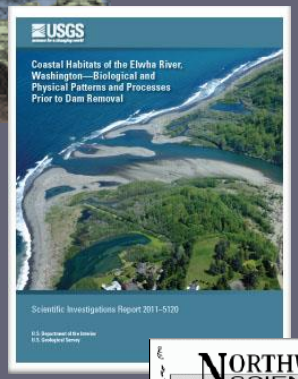
Revegetation

- Reservoirs being re-vegetated both naturally and with restoration efforts.
- Natural regeneration and plantings readily establish and thrive on fine sediments
- Coarse sediments proving to be a difficult substrate for most plants

Photo courtesy of Josh Chenoweth, NPS

Where to Find Additional Information

Geomorphology 2014-2015. Large-scale dam removal on the Elwha River, Washington USA. Series of five papers.



USGS Scientific Investigations Report, 2011. Coastal Habitats of the Elwha River, Washington: Biological and Physical Patterns and Processes Prior to Dam Removal.

Northwest Science Special Issue, 2008, Vol. 82: Dam Removal and Ecosystem Restoration in the Elwha River Watershed, Washington State.

www.elwharesearchconsortium.wildapricot.org/
www.nps.gov/olym/naturescience/elwha-ecosystem-restoration.htm

Thank you