Elwha River response to dam removals through four years and a big flood:

Lessons learned, channel response, and sediment effects from the world's largest engineered dam removal

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Amy East – USGS Research Geologist, Santa Cruz (talk "ringer")

Acknowledgments

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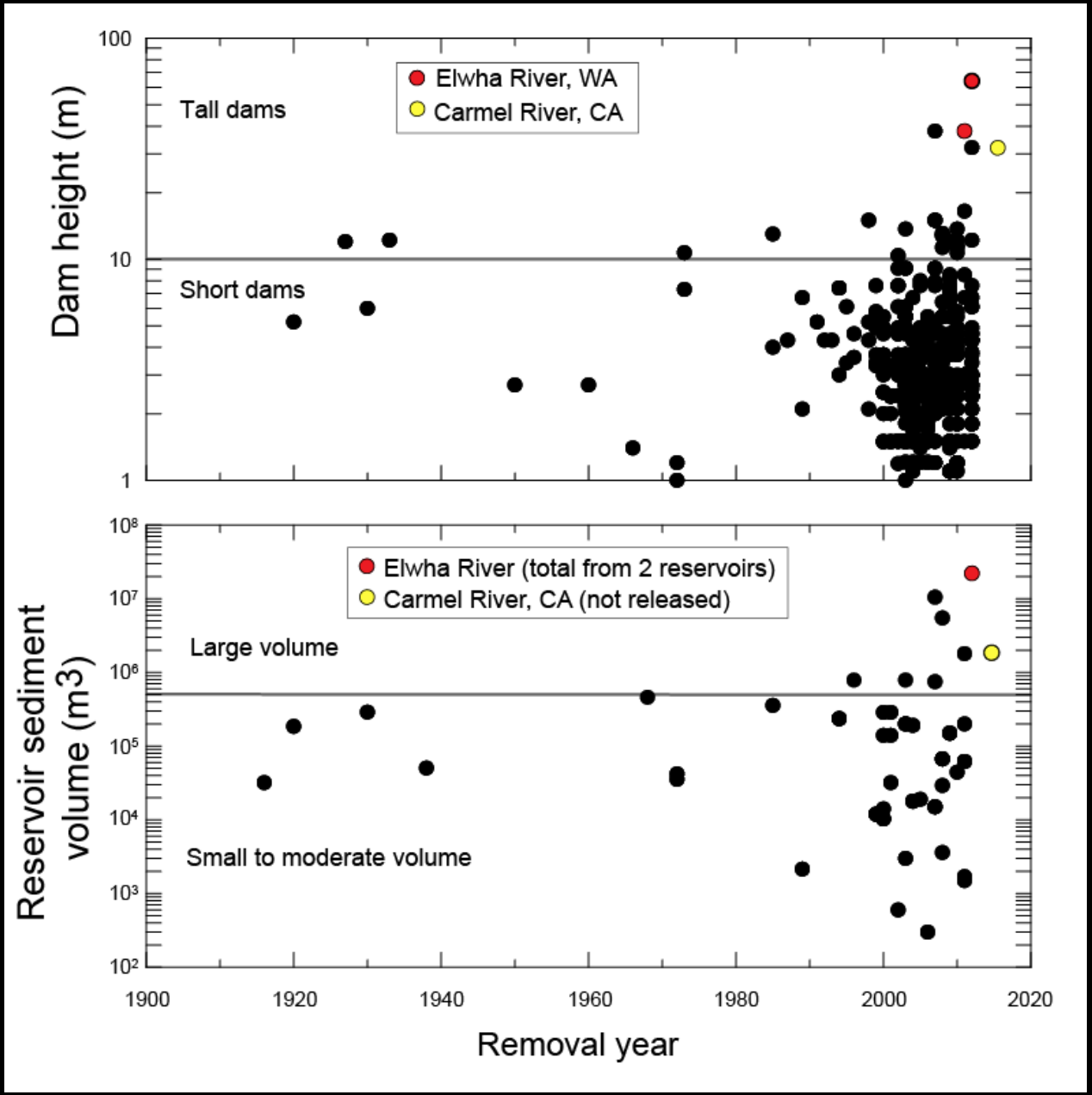
  - USGS
  - NOAA
  - Army Corps of Engineers
  - Bureau of Reclamation
  - USFWS
  - Elwha Klallam Tribe
  - University of Washington
  - Seattle University
  - Volunteers
  - Many others

Elwha River

Elwha watershed, Olympic Peninsula, WA

Dam removal in the U.S.

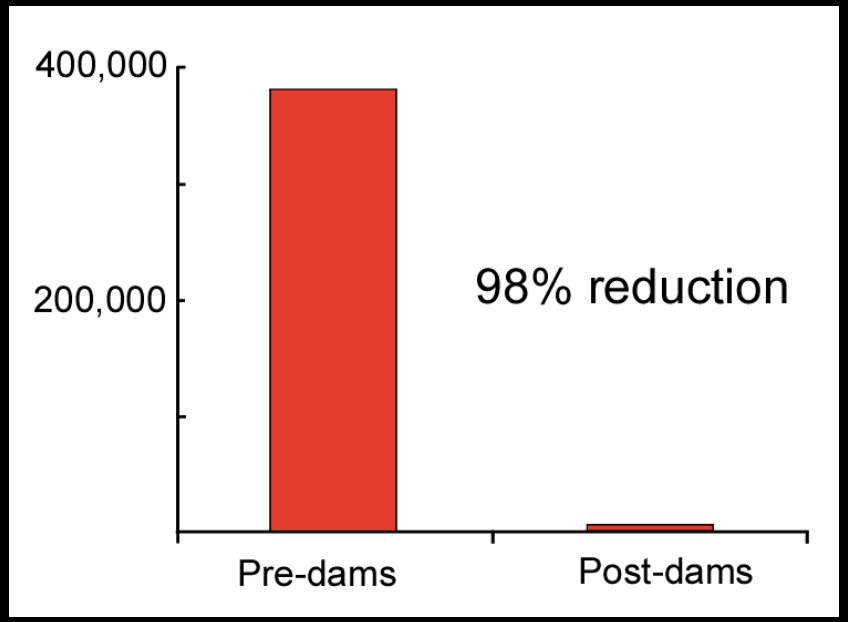


The Elwha River Basin

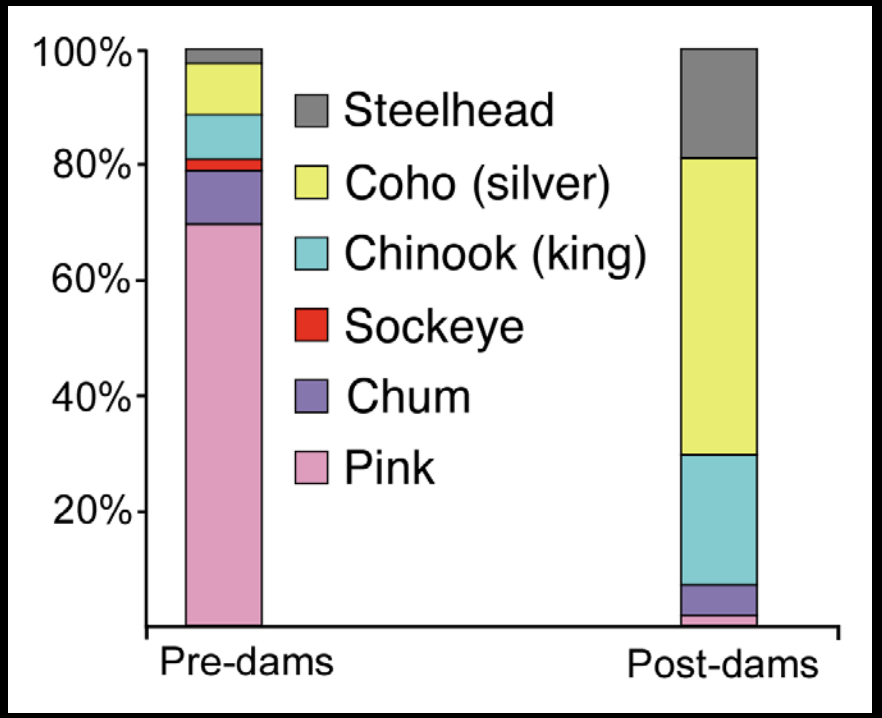
Photos: John Gussman

Impacts of dams on Elwha River fish

Total population decline



Shift in species composition



All native populations are very low in abundance

Data from George Pess, NOAA

Natural erosion of reservoir sediment

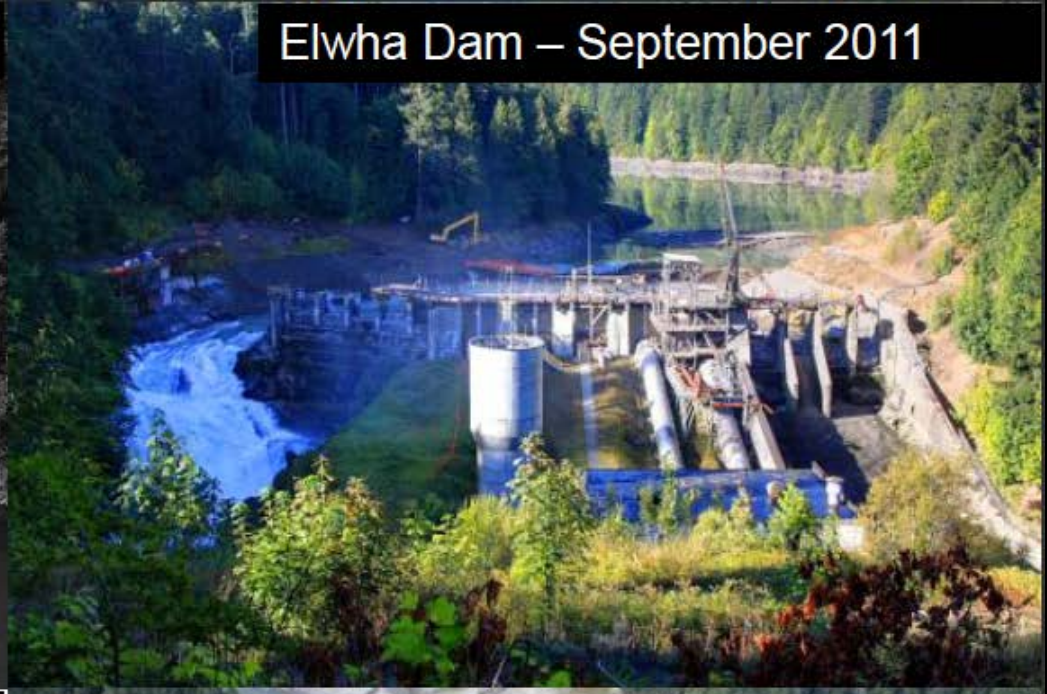
Lakes Aldwell and Mills stored 21 million m^3 of sediment.

Removal had to be:

- **Fast enough to limit impacts to fish**
- **Slow enough to be tolerated by infrastructure downstream, and minimize floodplain deposition**

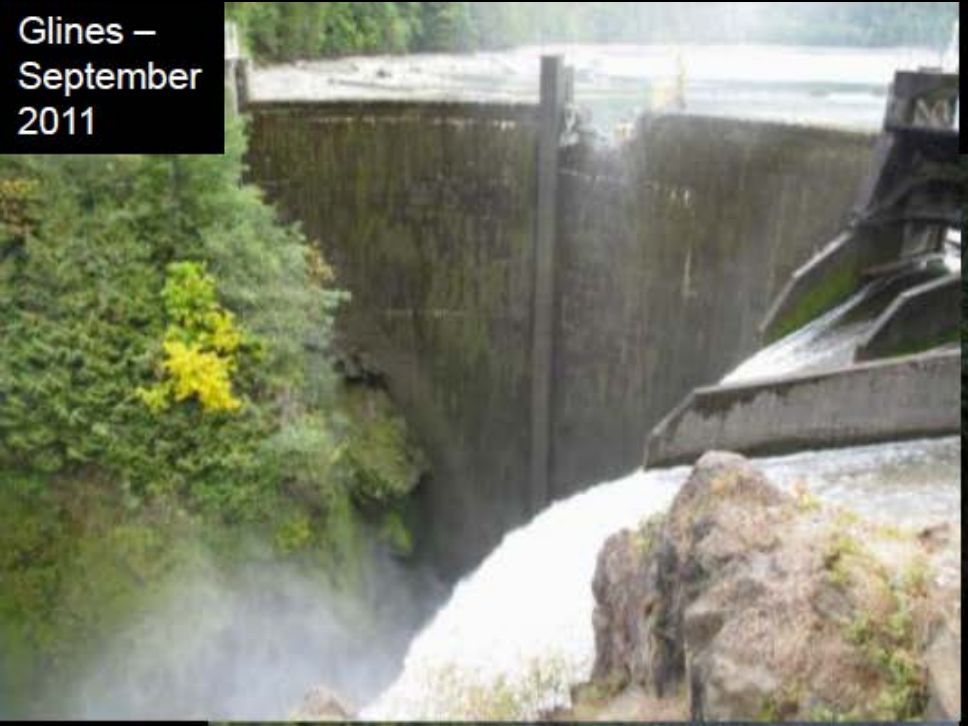
Former lakebed, Lake Mills reservoir


Elwha Dam


Elwha Dam – September 2011

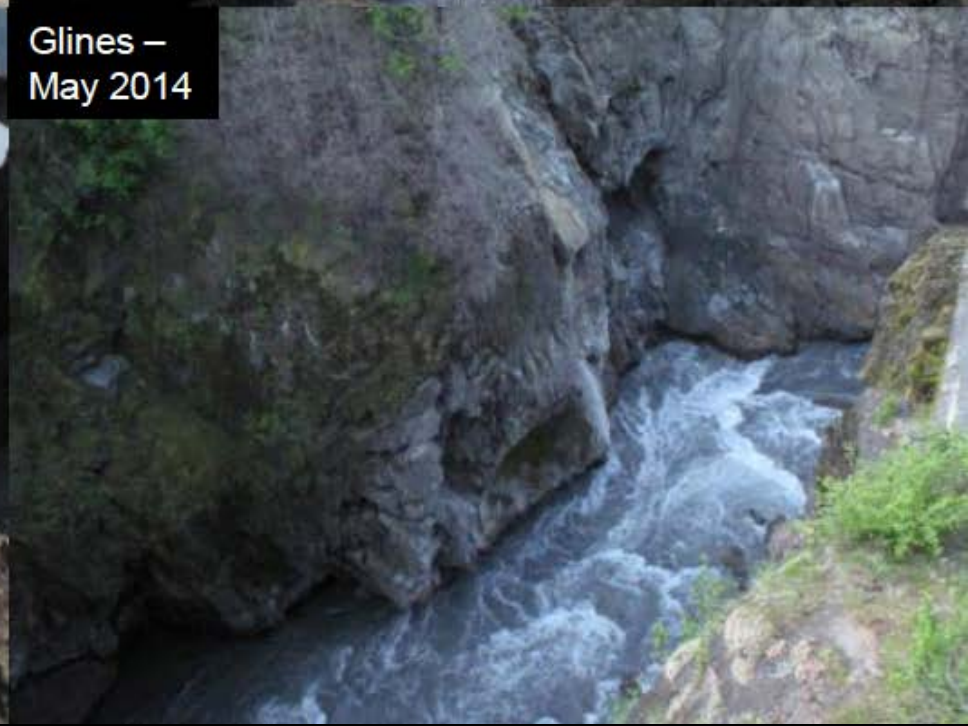

Elwha Dam – February 2012


Elwha Dam –
August 2012

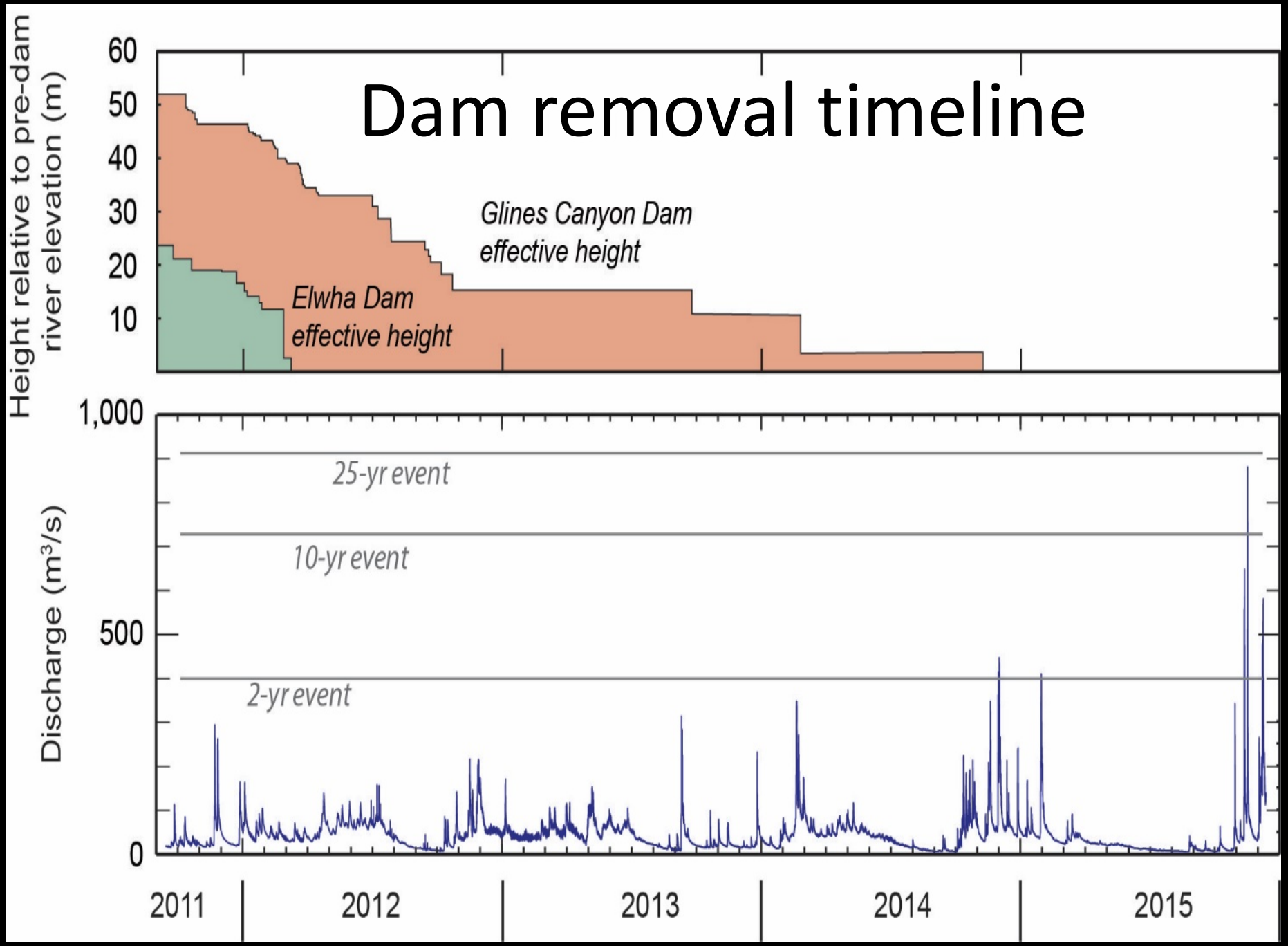

Glines – September 2011


Glines – January 2012


Glines – August 2012


Glines – May 2014

Dam removal timeline



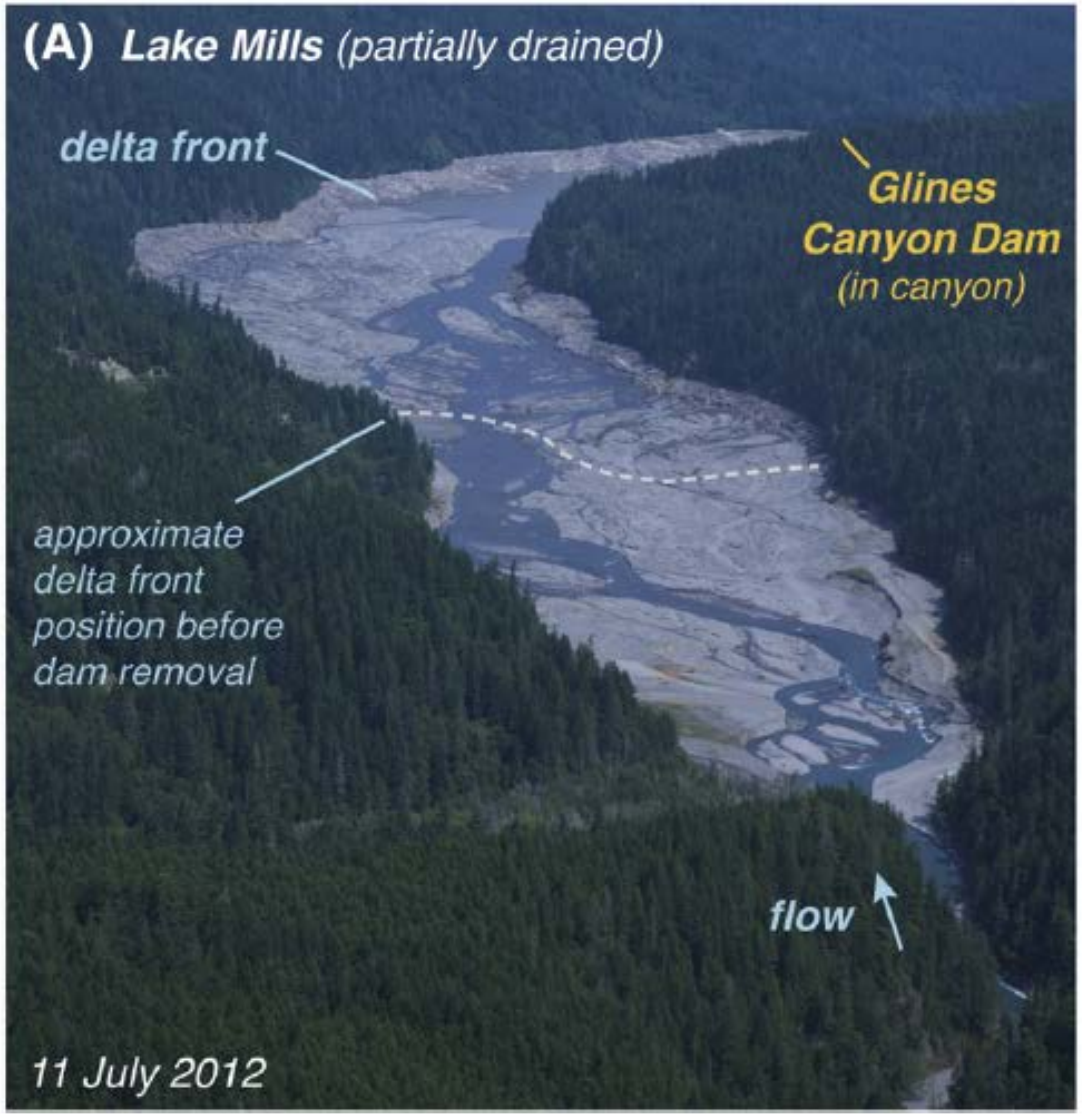
Reservoirs at beginning of dam removal

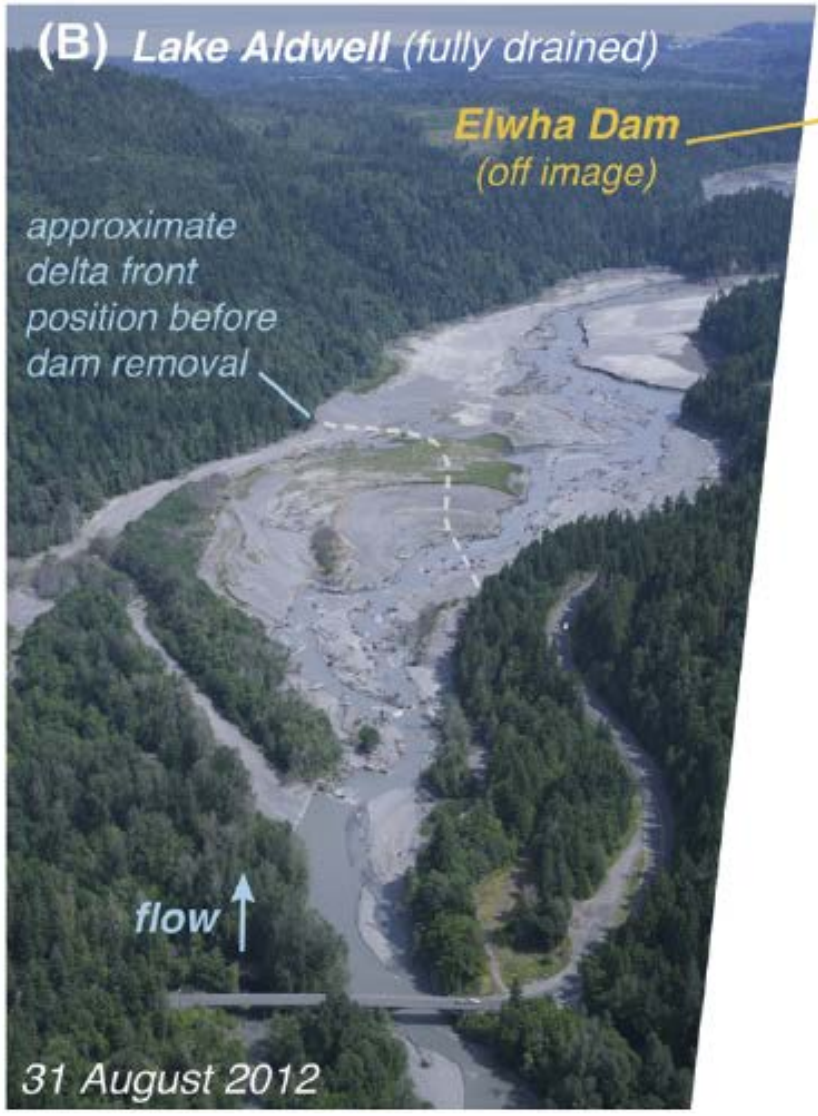
(1/2 full of sediment*)

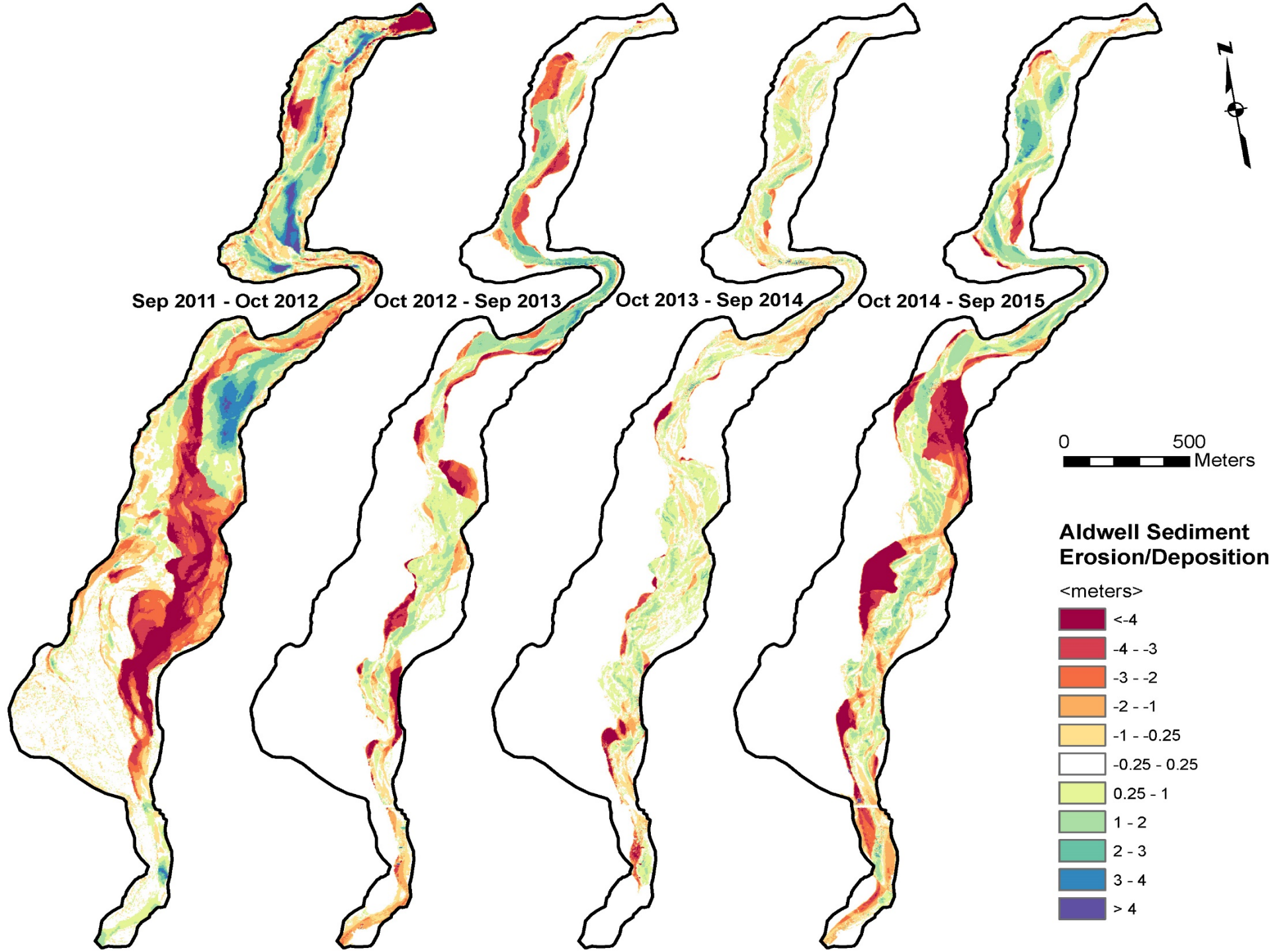
(1/3 full of sediment*)

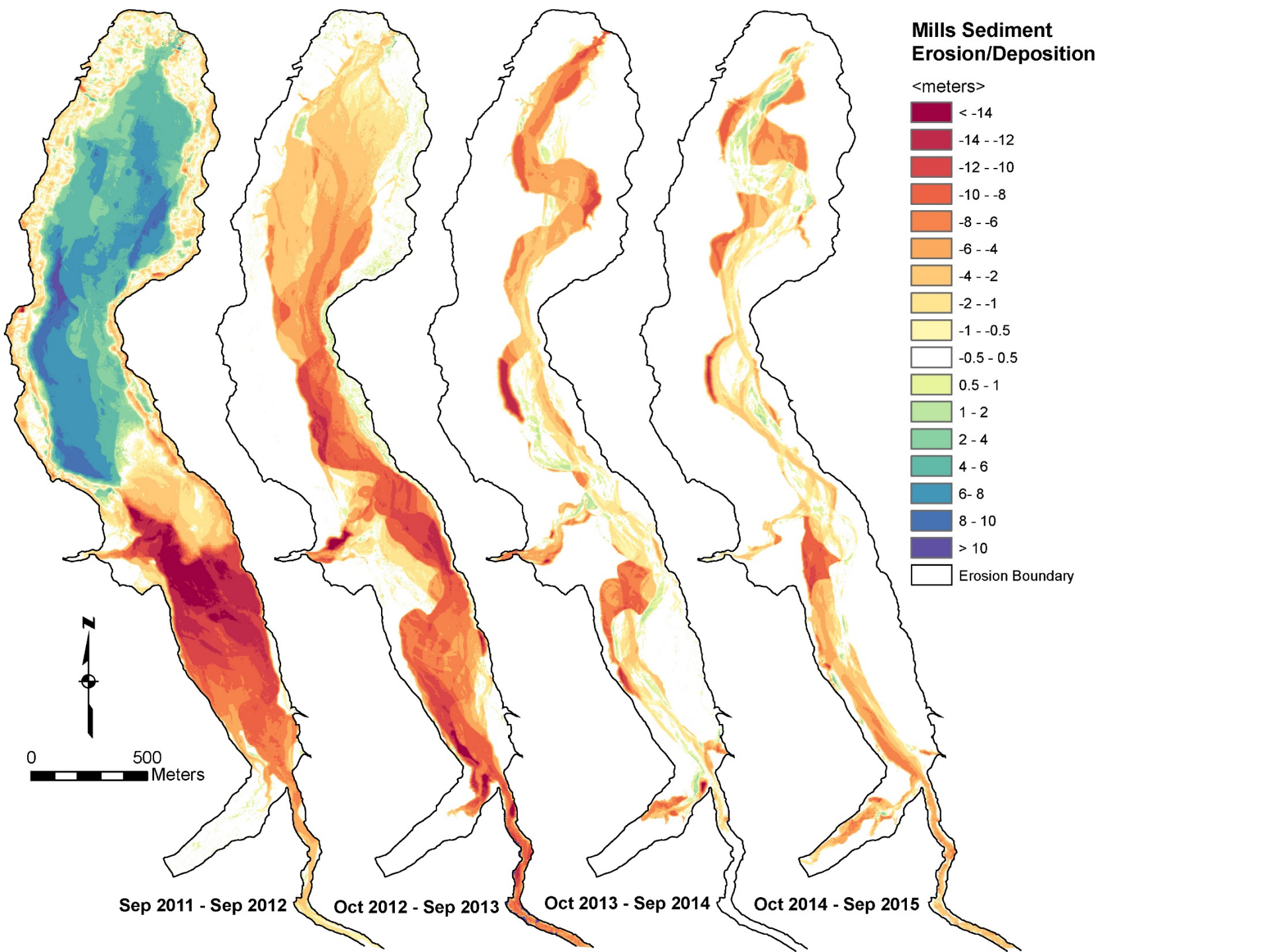
**Rough estimate based on starting pool volume, but some sediment was upstream of full pool.*

Reservoirs after a year of dam removal






Sep 2011 - Oct 2012
Oct 2012 - Sep 2013
Oct 2013 - Sep 2014
Oct 2014 - Sep 2015
N
0
500
Meters
Aldwell Sediment Erosion/Deposition
<meters>
<-4
-4 - -3
-3 - -2
-2 - -1
-1 - -0.25
-0.25 - 0.25
0.25 - 1
1 - 2
2 - 3
3 - 4
> 4


Mills Sediment
Erosion/Deposition
<meters>
< -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - -1
-1 - -0.5
-0.5 - 0.5
0.5 - 1
1 - 2
2 - 4
4 - 6
6- 8
8 - 10
> 10
Erosion Boundary
N
0
500
Meters
Sep 2011 - Sep 2012
Oct 2012 - Sep 2013
Oct 2013 - Sep 2014
Oct 2014 - Sep 2015

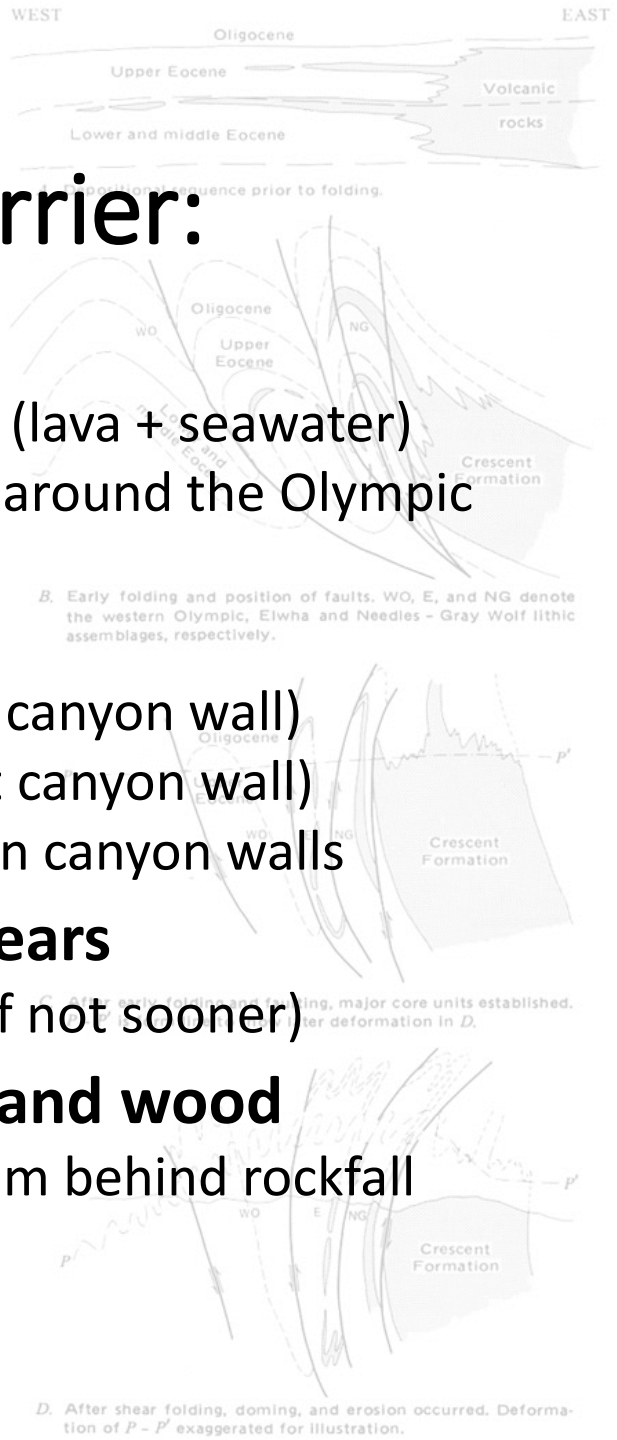
Dam complications

- Changed conditions related to construction of both dams were not entirely addressed by dam removal

- Fish passage and navigability were impacted

Recipe for a fish passage barrier:

- **1 part unstable geology**
  - Crescent basalt erupted underwater (lava + seawater)
  - Tilted, faulted, folded, and wrapped around the Olympic Peninsula over last 30+ million years
- **2 parts human disturbance**
  - Drill and blast diversion tunnel (east canyon wall)
  - Drill and blast penstock tunnel (west canyon wall)
  - Build a dam that works by pushing on canyon walls
- **Add 200 feet of water, wait 100 years**
  - (rockfall occurs in first few decades if not sooner)
- **Remove water, release sediment and wood**
  - Wood and sediment forms debris dam behind rockfall



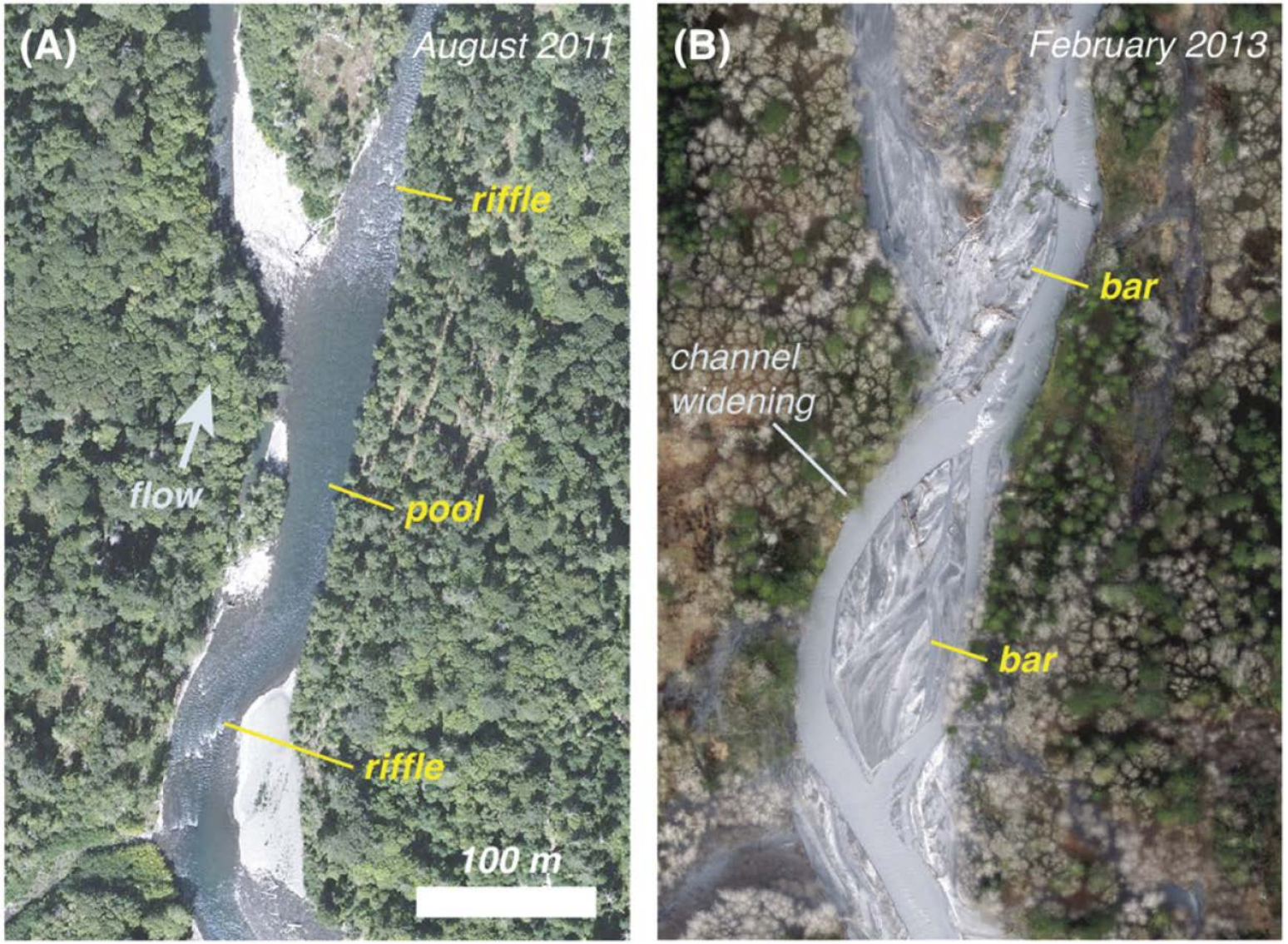
Glines Canyon Dam site rockfall blasting

Sep-Oct 2015

River response to dam removal

- Primary sediment pulse filled pools, raised bed elevation. Mainstem and floodplain channel aggradation.
- Active channel widening, increased braiding
- River now incising through its new sediment
- Many pools still partially filled (scour & fill now common), most riffles re-exposed

Mainstem channel aggradation, new bars and braids



Warrick et al., 2015, Large-scale dam removal on the Elwha River, Washington, USA: Source-to-sink sediment budget and synthesis. Geomorphology, doi: 10.1016/j.geomorph.2015.01.010

Floodplain channel filling meant decreased refugia below dam sites during removal

Example of one floodplain channel

Before dam removal 2013

East et al., 2015, Large-scale dam removal on the Elwha River, Washington, USA: River channel and floodplain geomorphic change. Geomorphology, v. 228, p. 765–786, doi:10.1016/j.geomorph.2014.08.028.

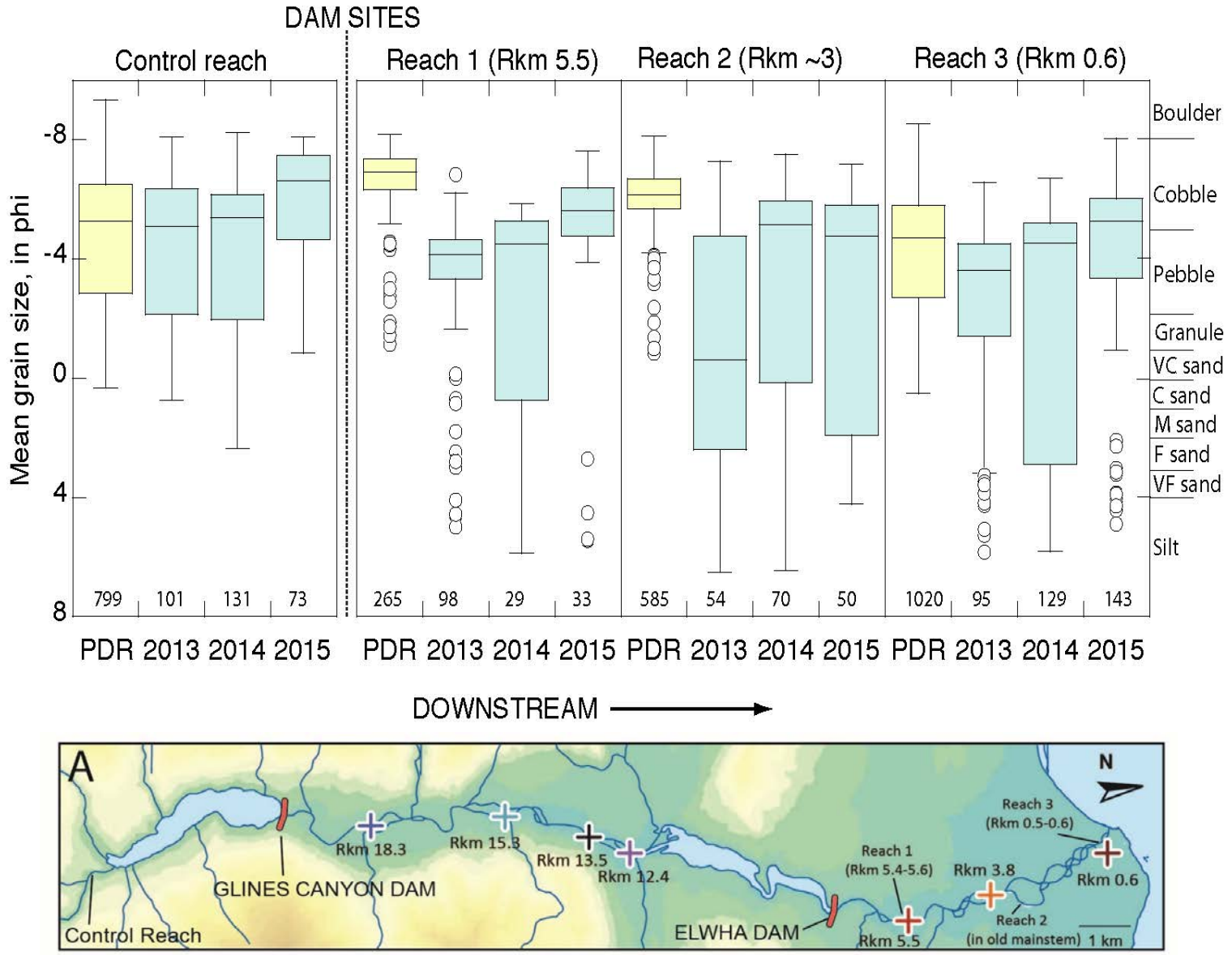
Mainstem bed habitat: Before vs. After

September 2011

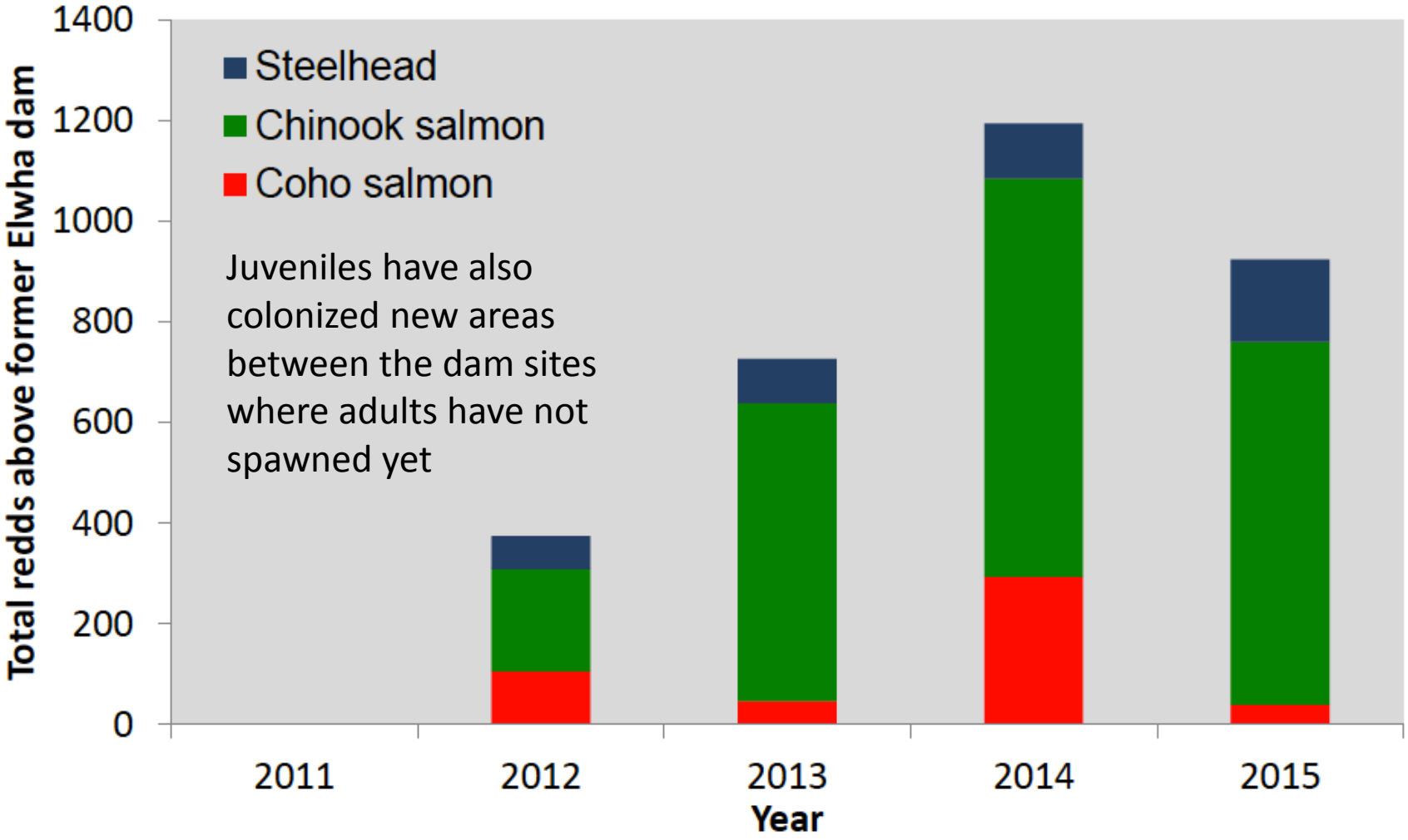
September 2014

5.5 km upstream from Elwha River mouth

Bed-sediment grain-size changes



Fish quickly colonized new habitat



NOAA data (courtesy of George Pess)

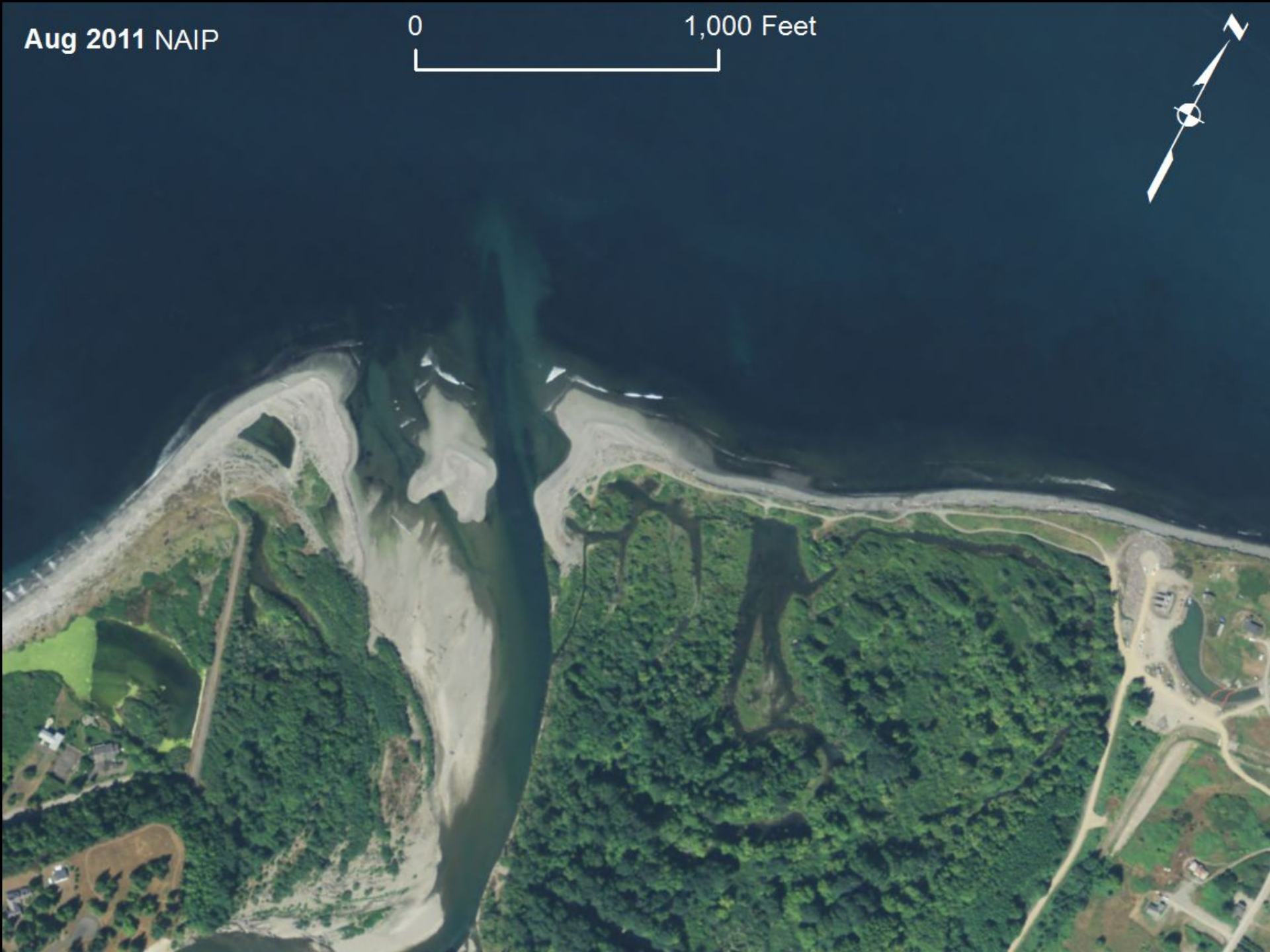
Ecosystem adaptation

Marine-derived nutrients (from fish) already detected moving into other parts of ecosystem above former Elwha Dam site (Tonra et al., 2015)

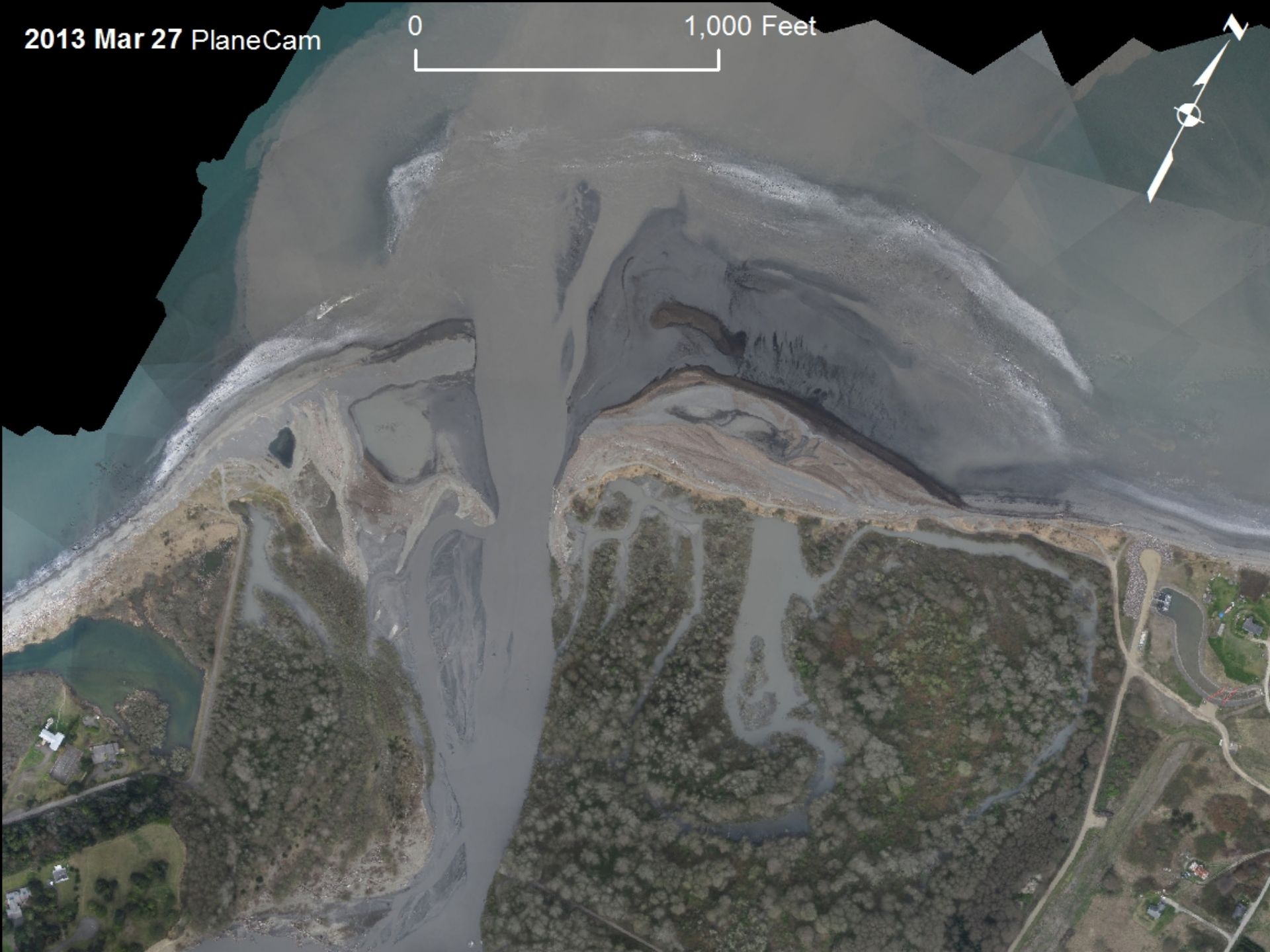
American dipper with salmon egg, Elwha River, 2012 (John McMillan)

Evolution of the river mouth

- Coastal delta enlarged substantially
- At first estuary vanished, transitioning to complex new estuarine habitat farther offshore as lowermost river elongated
- Beach spits and estuary stabilizing after several years of rapid change


Aug 2011 NAIP
0
1,000 Feet
N


2013 Feb 13 PlaneCam
0
1,000 Feet
N


2013 Mar 27 PlaneCam
0
1,000 Feet

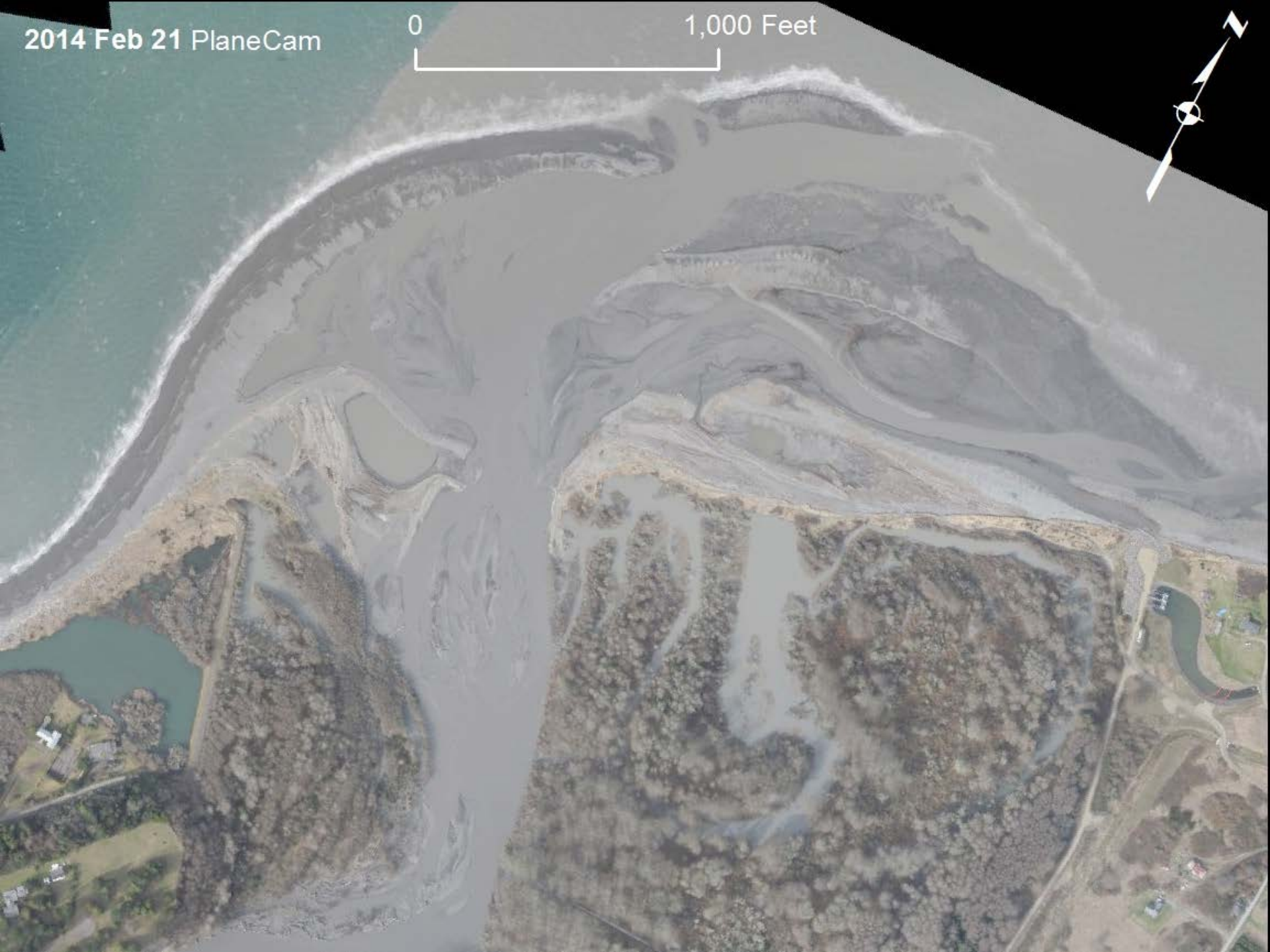

2013 Apr 16 PlaneCam
0
1,000 Feet


2013 Apr 30 PlaneCam
0
1,000 Feet
N


2013 May 31 PlaneCam
0
1,000 Feet


2013 Oct 23 PlaneCam
0
1,000 Feet
N


2013 Nov 22 PlaneCam
0
1,000 Feet


2014 Feb 21 PlaneCam
0
1,000 Feet
N


2014 Mar 10 PlaneCam
0
1,000 Feet

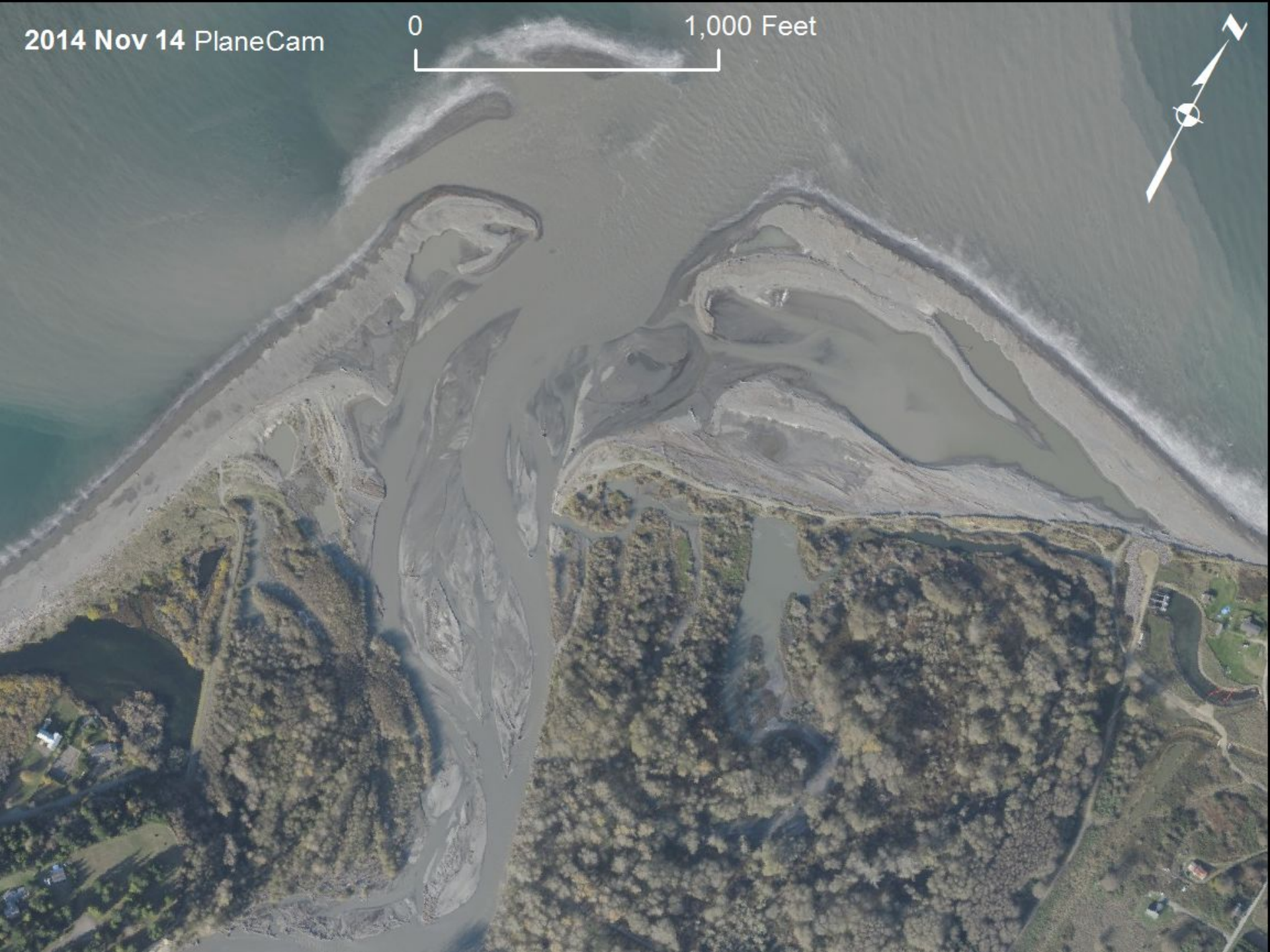

2014 Mar 24 PlaneCam
0
1,000 Feet


2014 Apr 10 PlaneCam
0
1,000 Feet
N


2014 Jun 06 PlaneCam
0
1,000 Feet


2014 Jul 16 PlaneCam
0
1,000 Feet
N


2014 Sep 30 PlaneCam
0
1,000 Feet
N

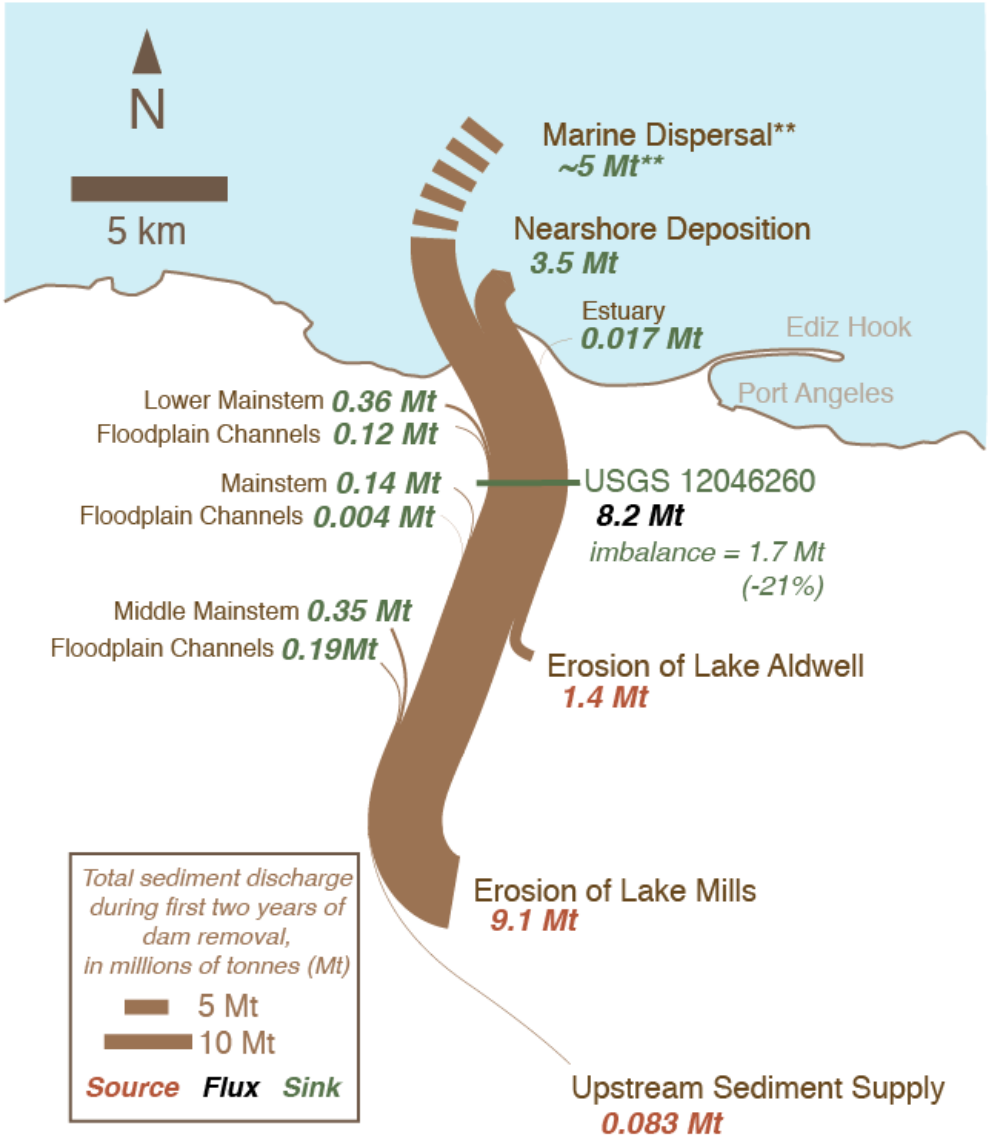

2014 Nov 14 PlaneCam
0
1,000 Feet
N


2014 Dec 30 PlaneCam
0
1,000 Feet


2015 Apr 09 PlaneCam
0
1,000 Feet
N


2015 Jun 04 PlaneCam
0
1,000 Feet
N

Tracking the fate of sediment…



10.5 million tons of reservoir sediment eroded over the first two years (about 1/3 of the total stored)

Now up to ~18 million tons – almost 2/3 of the total stored!

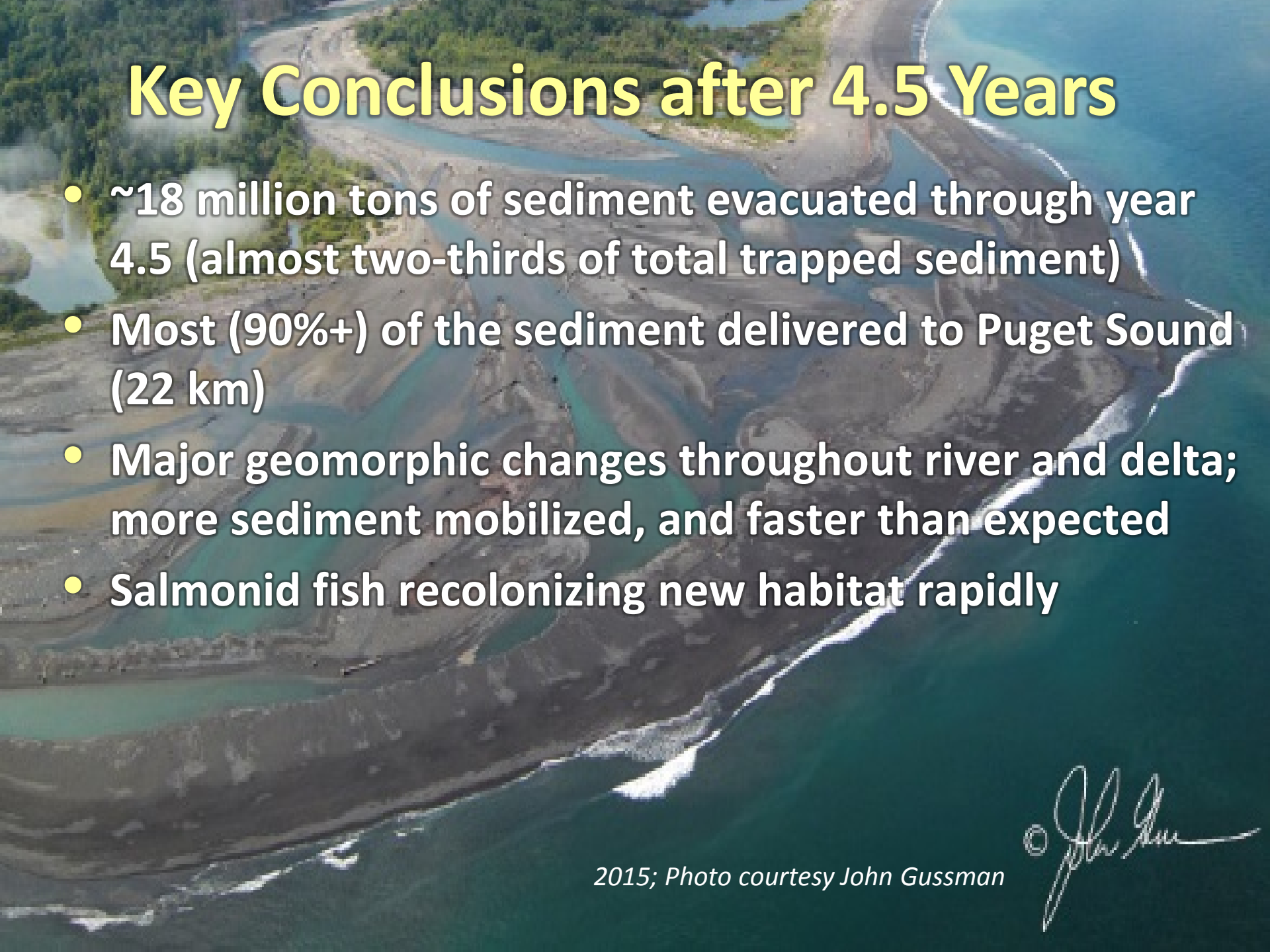
90% made it to river mouth

Rivers can efficiently export sediment even without flood flows

Warrick et al., 2015

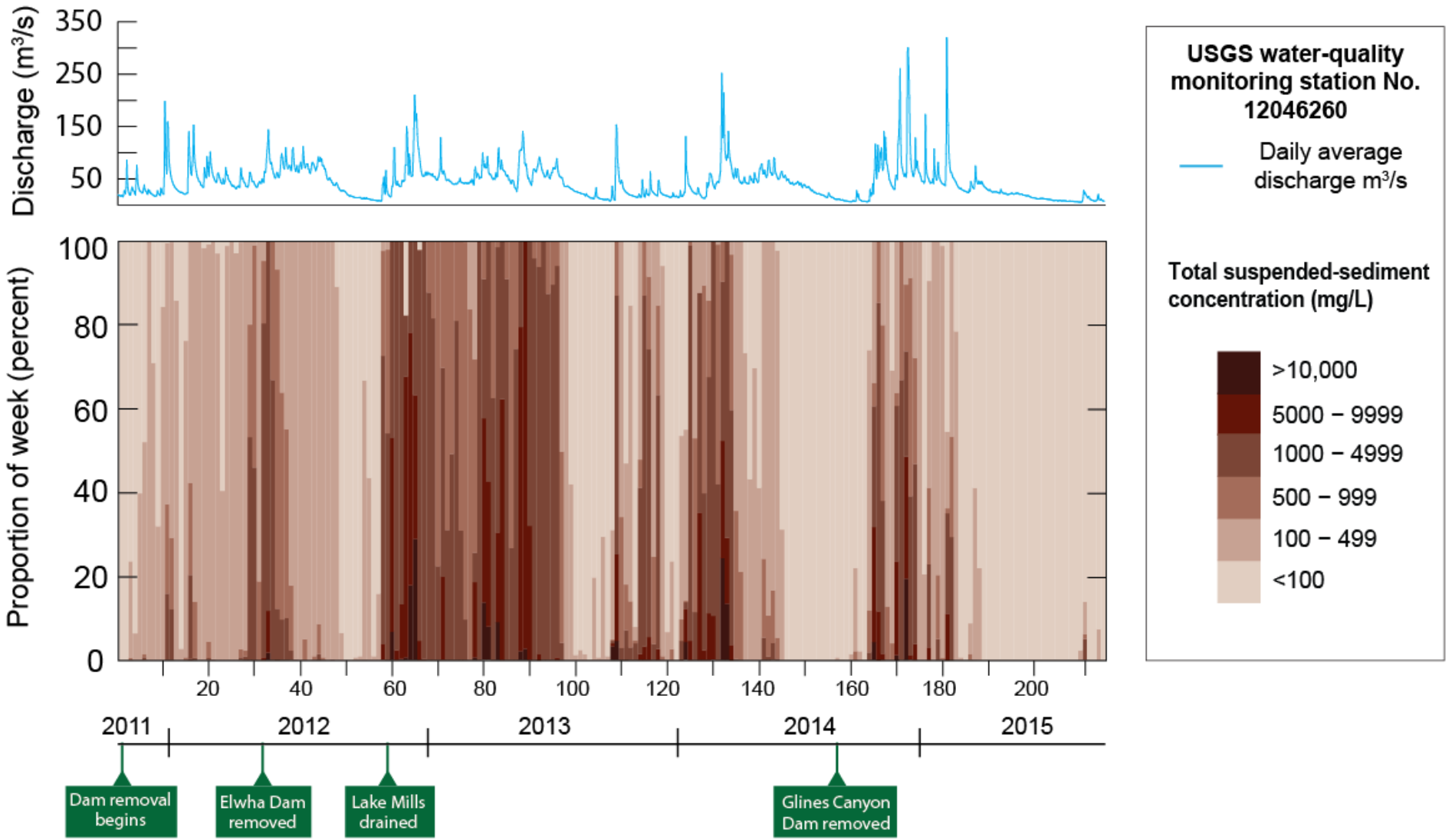
Key Conclusions after 4.5 Years

- ~18 million tons of sediment evacuated through year 4.5 (almost two-thirds of total trapped sediment)
- Most (90%+) of the sediment delivered to Puget Sound (22 km)
- Major geomorphic changes throughout river and delta; more sediment mobilized, and faster than expected
- Salmonid fish recolonizing new habitat rapidly



2015; Photo courtesy John Gussman

Water quality during dam removal



Lessons learned after 4 years

- Dam sites are complicated. Effects on water surface elevations should be considered during all stages of planning and removal
- Reservoir sediment eroded more effectively than original estimates, possibly because of a prolonged (1-year) hold period from sediment treatment plant failure
- River response filled pools and side channels, limiting refugia during dam removal. Channel became more dynamic with wood and sediment
- Turbidity did not notably decrease during “fish window” hold periods – instead was driven by hydrology
- Both losses and gains in habitat quality, quantity, complexity