Science and dam removal: Lessons learned from local to continental scales

J Duda_USGS

Free Flow 2024
Groningen, Netherlands
14 April 2024

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U.S. Geological Survey, Western Fisheries Research Center, Seattle
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Outline

- A dam removal story in 3 acts

- Act I: Elwha
- Act II: Powell Center Synthesis
- Act III: Now and into the future

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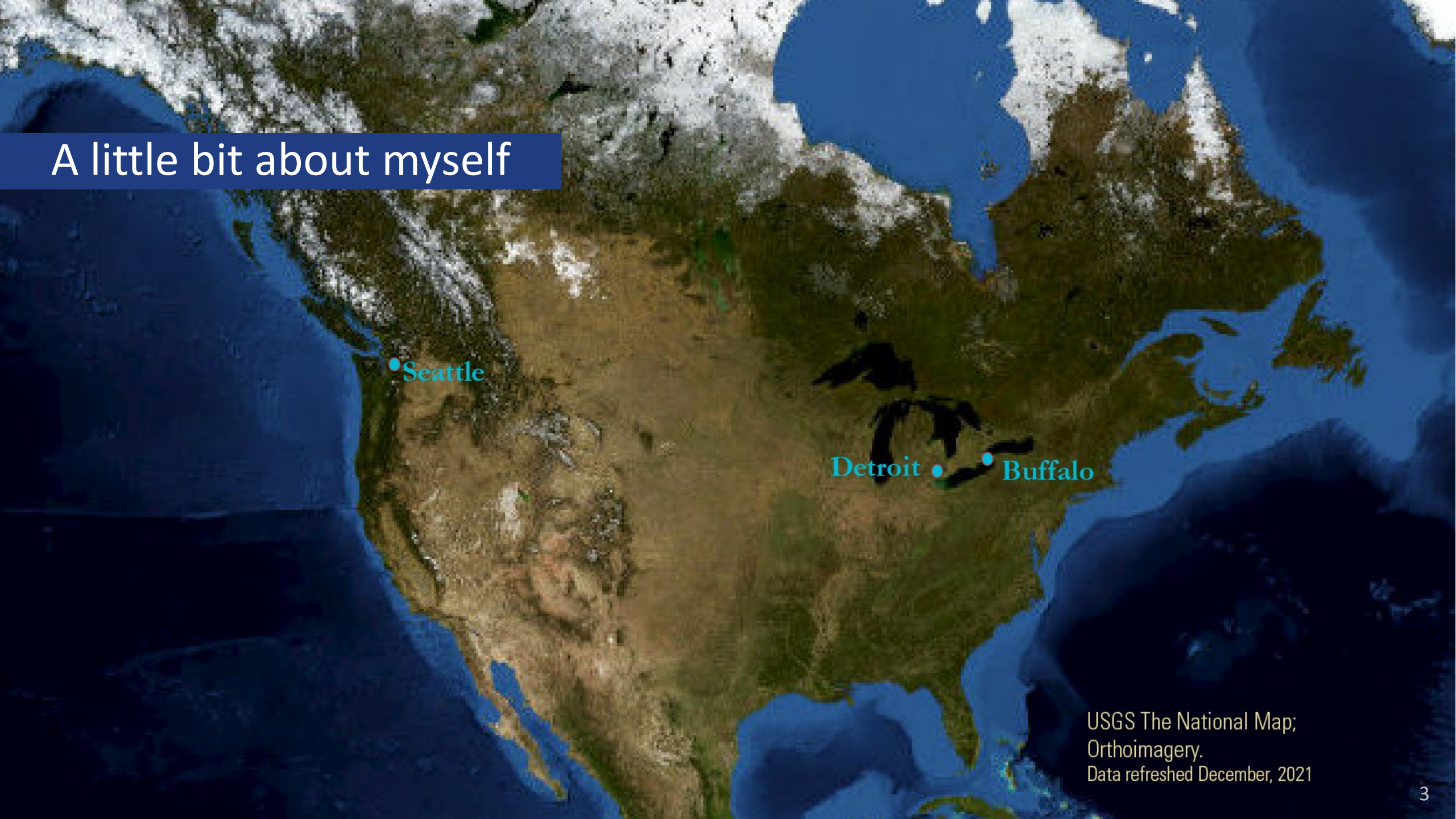
science for a changing world

A little bit about myself



USGS Ecosystem Mission Area

- Molecular to ecosystem-scale studies conducted to advance the understanding of the Nation's natural resources.
- Strictly a science agency
  - No management or regulatory authority
  - No creation of public policy
  - No advocacy.

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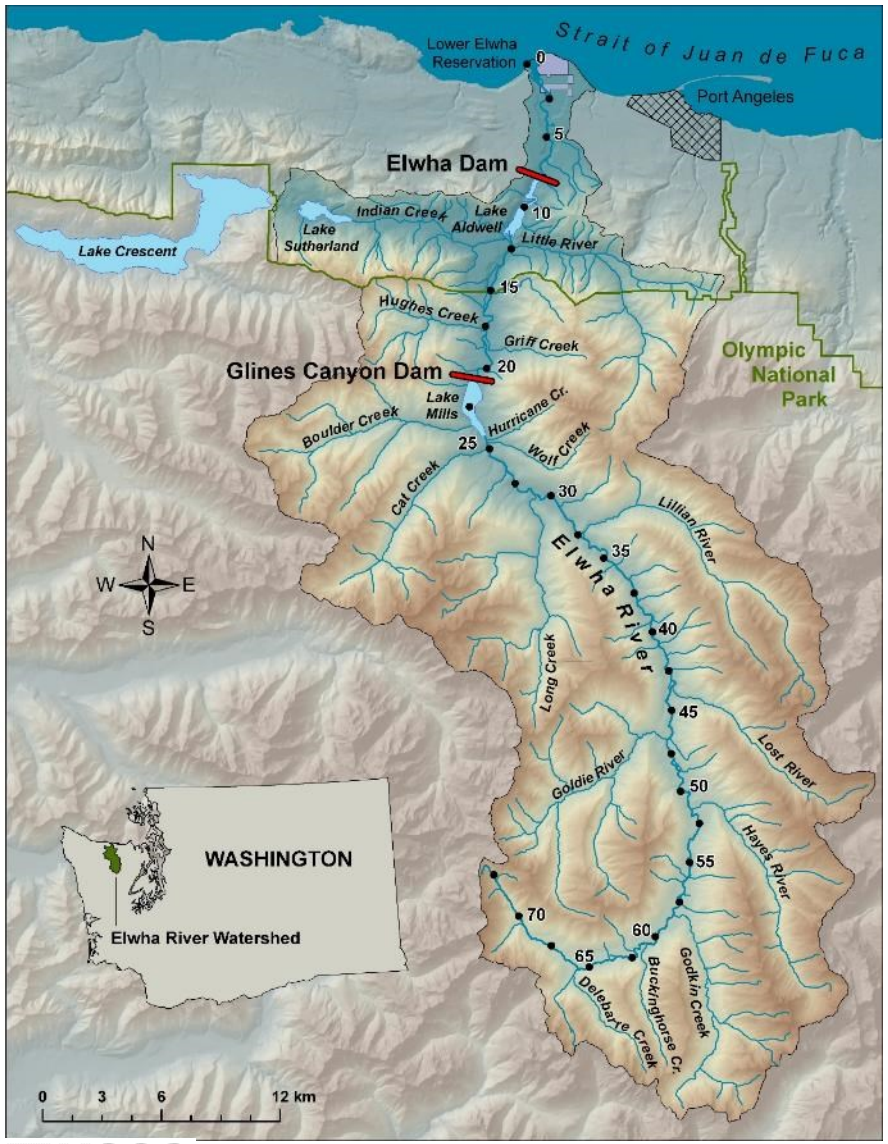
Act I: The Elwha

J Duda_USGS (all photos)

Elwha basics

>90% Habitat lost
~98% decline of salmon populations

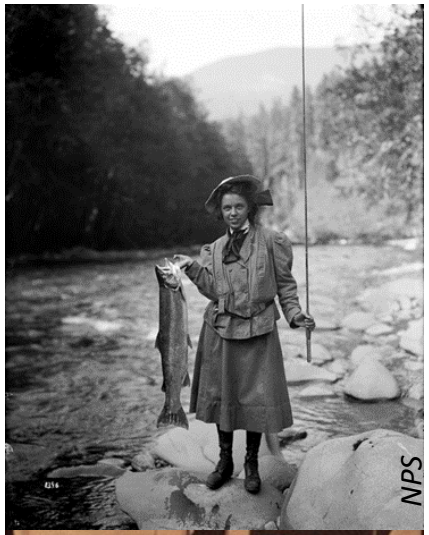


Elwha Dam

- 32 m concrete gravity
- Completed in 1912
- Removed in 2012
- ~8 mo.

Glines Canyon Dam

- 64 m concrete arch
- Completed in 1927
- Removed in 2014
- ~36 mo.



USGS

Dam photographs courtesy John Gussman

Why dam removal?

- Privately owned dams were old and required fish passage upgrades to receive FERC relicensing.
- Dams power production averaged 19 megawatts, enough for ~50% of a local paper mill's needs.
- Native Elwha salmon still present, but in critically low abundances supported by some hatchery production.
- High-quality habitat for salmon spawning and rearing available upstream of the dams, protected inside of Olympic National Park.
- *A perfect opportunity of economic necessity and environmental opportunity results in the* ***Elwha River Ecosystem and Fisheries Restoration Act*** *of 1992*

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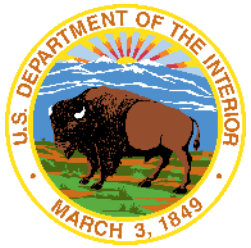
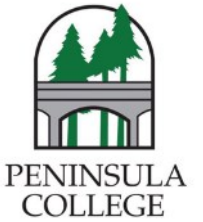
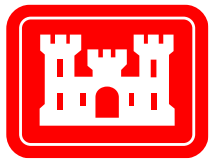
Planning and executing dam removal on the Elwha River

- Purchase of dams: $29 million US
- Cost of removal: $27 million US
- Dam removal mitigation: $269 million US
  - Industrial water treatment
  - Drinking water treatment
  - Raise flood control levees
  - Compensate floodplain property owners
  - Transition Tribal reservation from septic to city sewer
  - Rebuild Tribal fish hatchery
  - Revegetation of reservoir surfaces
  - Scientific monitoring (primarily flow and sediment)



CLALLAM COUNTY
MARINE RESOURCES COMMITTEE





Shreffler Environmental

K Denton & Associates

Elwha's Secret Sauce: Maintaining and Building Partnerships

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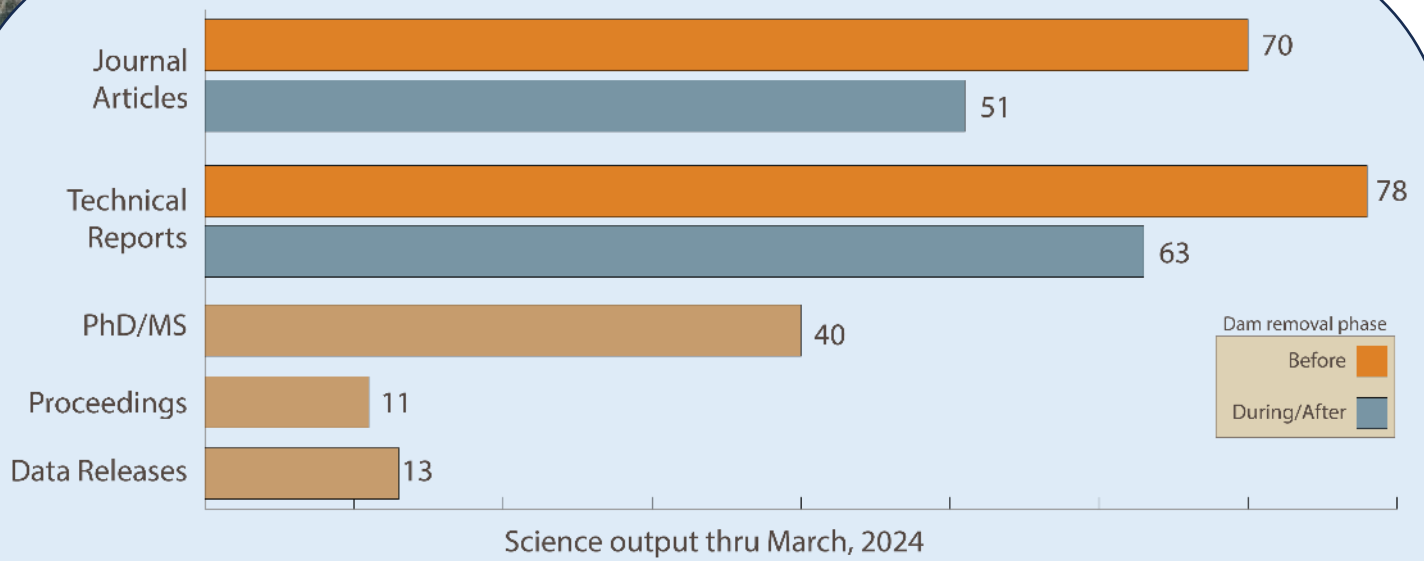
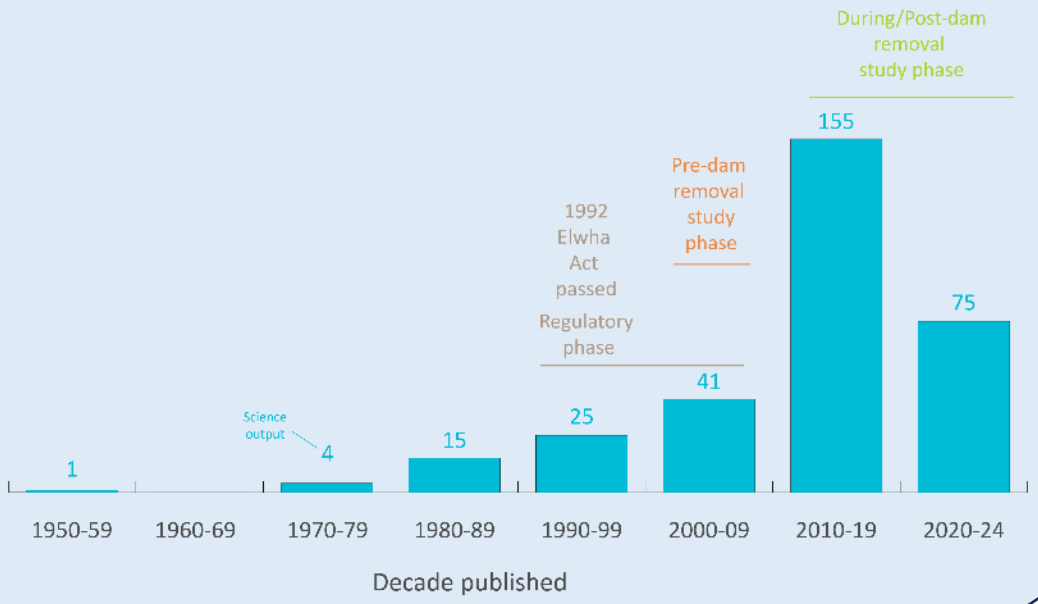


zotero
Elwha Research database

316 reports, journal articles, graduate degrees, & data sets

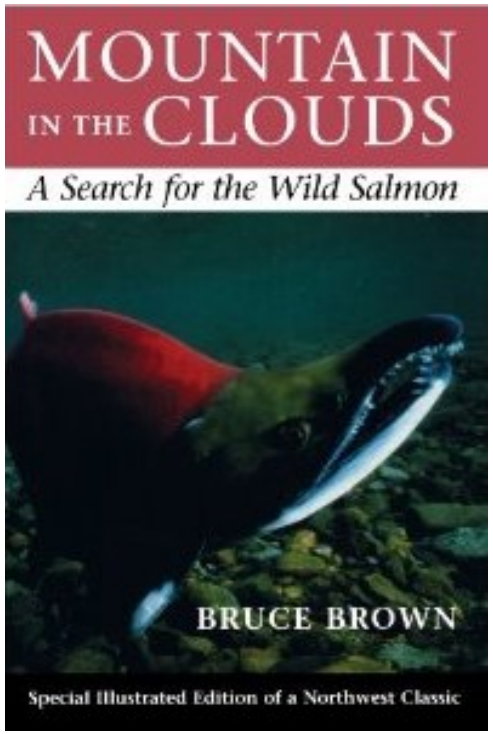


Collaboration is Key

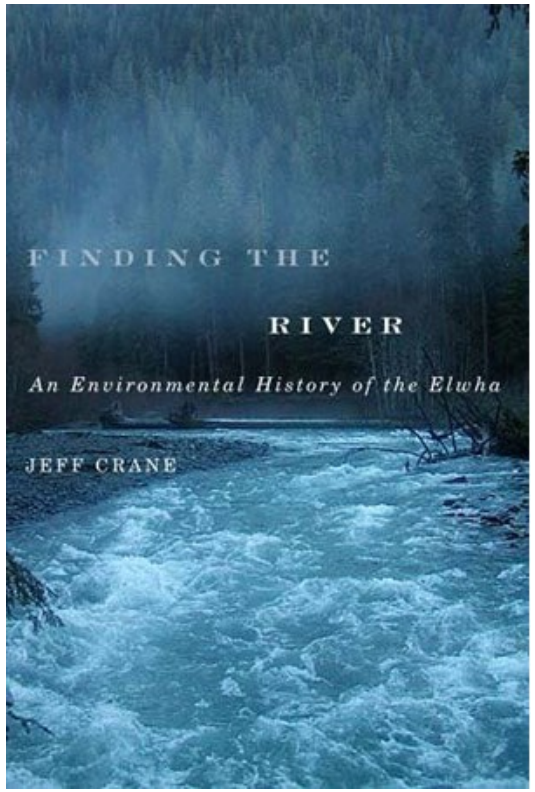
USGS science for a changing world

The impact of the Elwha in books…

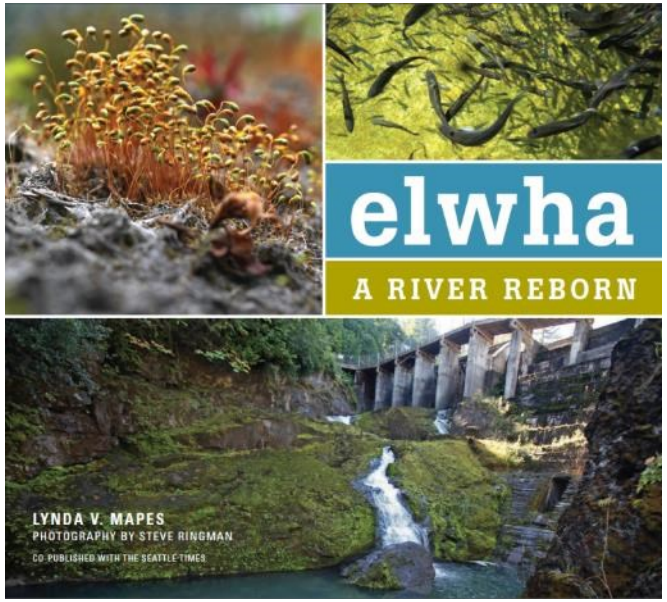
Published in 1995



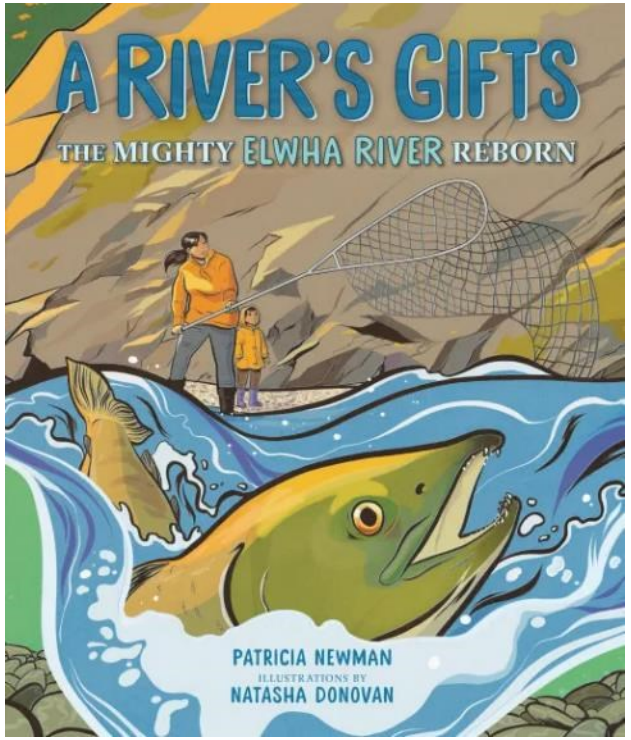
Published in 2012



Published in 2013

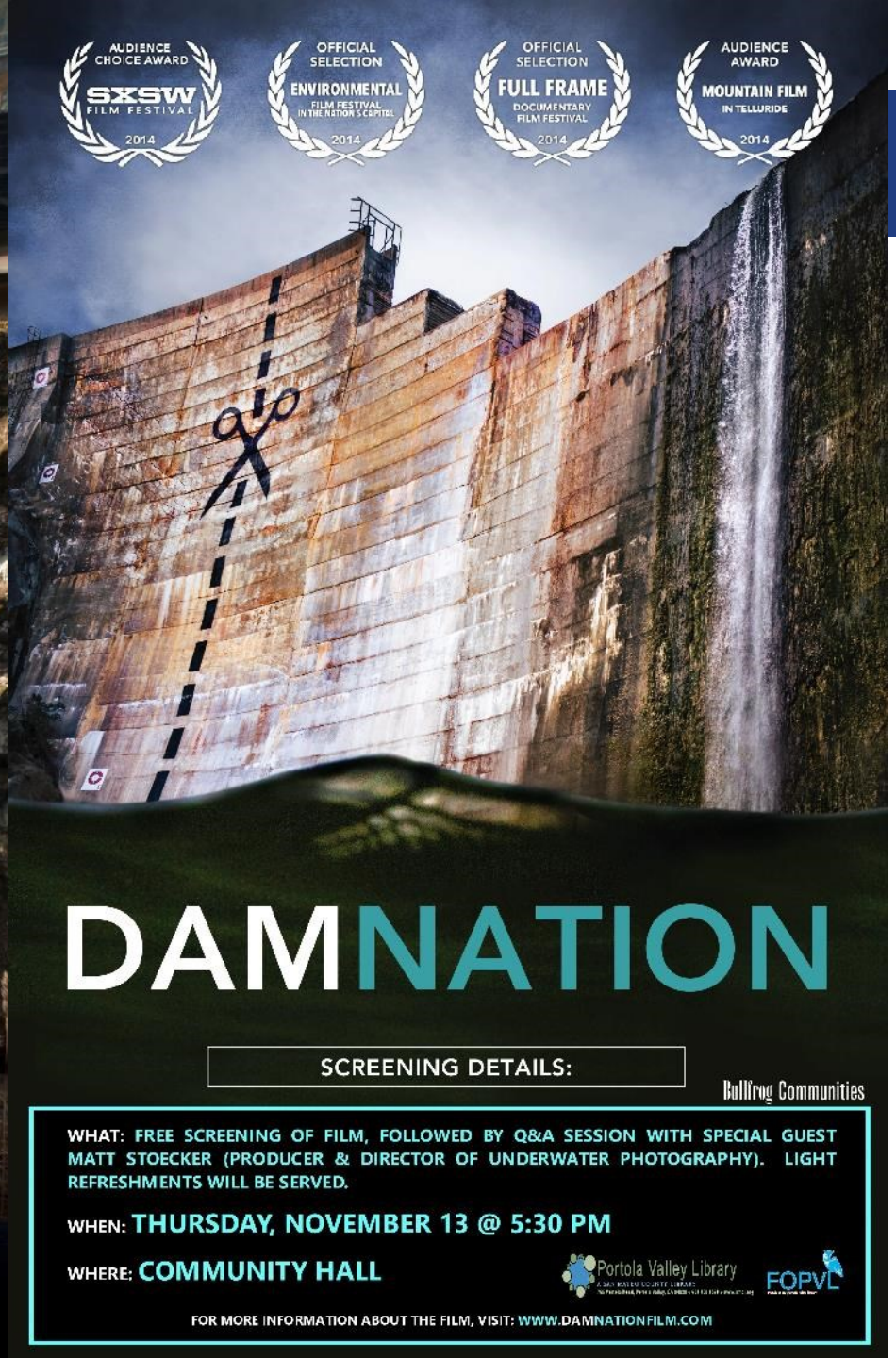


Published in 2022



… film …


RETURN of the RIVER
CHANGING COURSE IS POSSIBLE.
OFFICIAL SELECTION SOCIAL JUSTICE FILM FESTIVAL
OFFICIAL SELECTION TACOMA FILM FESTIVAL 2014
WINNER - Best International Documentary Kuala Lumpur Eco Film Festival 2014
AUDIENCE CHOICE AWARD BEST FEATURE DOCUMENTARY PTFF 2014
MOUNTAINFILM 2014 OFFICIAL SELECTION
"RETURN OF THE RIVER"
CO-DIRECTORS JOHN GUSSMAN & JESSICA PLUMB PRODUCER JESSICA PLUMB WRITER JESSICA PLUMB EXECUTIVE PRODUCER SARAH HART DIRECTOR OF PHOTOGRAPHY JOHN GUSSMAN
EDITORS JESSICA PLUMB & EARTHEN WATSON ORIGINAL MUSIC BY JONATHAN HAIDLE HISTORICAL VOICEOVER TOM SKERRITT NARRATION DEBBE HIRATA ANIMATION DREW CHRISTIE
WWW.ELWHAFILM.COM


AUDIENCE CHOICE AWARD SXSW FILM FESTIVAL 2014
OFFICIAL SELECTION ENVIRONMENTAL FILM FESTIVAL IN THE NATION'S CAPITAL 2014
OFFICIAL SELECTION FULL FRAME DOCUMENTARY FILM FESTIVAL 2014
AUDIENCE AWARD MOUNTAIN FILM IN TELLURIDE 2014
DAMNATION
SCREENING DETAILS:
Bullfrog Communities
WHAT: FREE SCREENING OF FILM, FOLLOWED BY Q&A SESSION WITH SPECIAL GUEST MATT STOECKER (PRODUCER & DIRECTOR OF UNDERWATER PHOTOGRAPHY). LIGHT REFRESHMENTS WILL BE SERVED.
WHEN: THURSDAY, NOVEMBER 13 @ 5:30 PM
WHERE: COMMUNITY HALL
Portola Valley Library
FOPVL
FOR MORE INFORMATION ABOUT THE FILM, VISIT: WWW.DAMNATIONFILM.COM

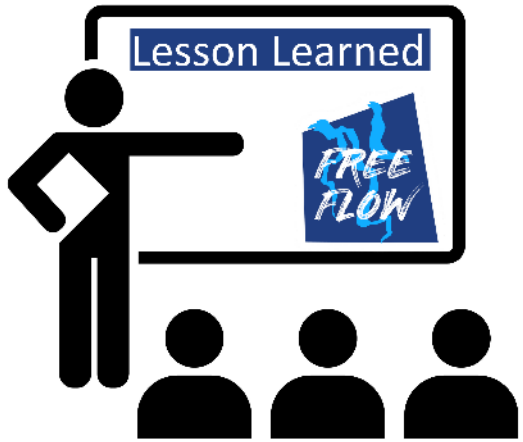
… news …

High Country News

When dams come down, fish come home

As dam removal nationwide accelerates, quickly rivers and fish respond.

Sarah Trent | Nov. 8, 2022 |



Communication Is Key

SCIENTIFIC AMERICAN

Climate Change Complicates the …m Debate

…aters where some native species shelter …ve predators

…14, 2017

Deseret News

America's dams are aging.

By Sofia Jeremias | Dec 10, 2019, 9:00pm PDT

…t US dam removal project, …yth

abc NEWS

WIRED

LIZZIE WADE SCIENCE MAY 19, 2016 7:00 AM

The Death and Birth of t…

The Reventazón and Klamath dams seem to be telling oppo…

…r plants are being …S – now salmon are …s

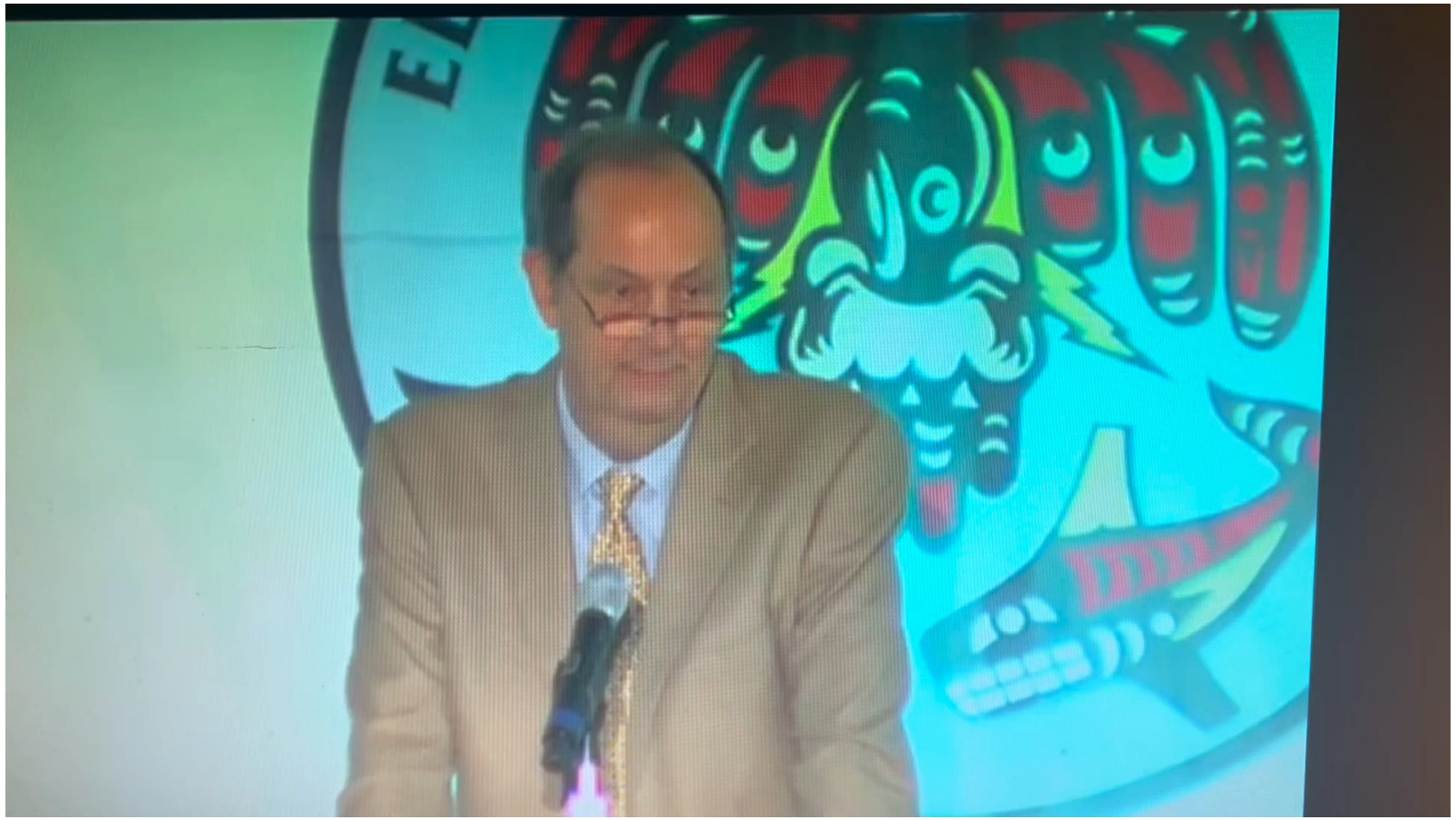
The largest released salmon river is the Elwha in the northwest corner of the United States. The migration of salmon back to the upper reaches began immediately after the dams were removed. The river was closed for a hundred years.

CBC

NB Power could learn from U.S. dam removal for Mactaquac plans

… and perspectives.

U.S. Senator Bill Bradley, 2011, at the Elwha Tribal celebration of the start of dam removal

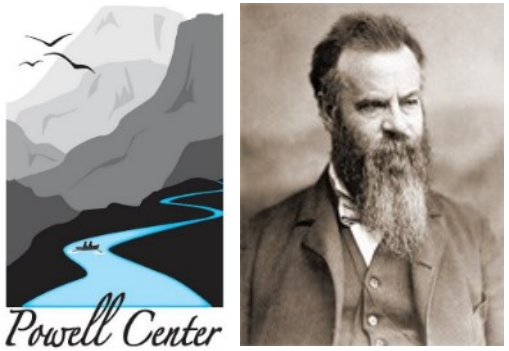


Source: Mark Anderson, clip from YouTube "Elwha River Dam Removal Ceremonies" footage at: https://www.youtube.com/watch?v=o5AYmWd4Zeg

DAM REMOVAL EUROPE

Champions are Key

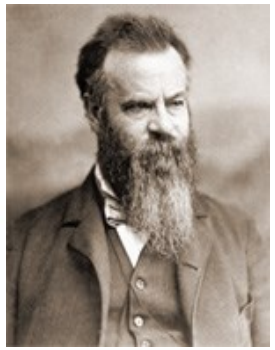
Act II: Dam Removal Synthesis



USGS John Wesley Powell Center for Analysis and Synthesis

Working Group

Dam removal: synthesis of ecological and physical responses



USGS John Wesley Powell Center for Analysis and Synthesis

Working Group

Dam removal: synthesis of ecological and physical responses

AGU PUBLICATIONS

Water Resources Research

COMMENTARY

10.1002/2017WR020457

The first six authors significantly contributed to the preparation of the article.

Dam removal: Listening in

M. M. Foley[1], J. R. Bellmore[2], J. E. O'Connor[3], J. J. Duda[4], A. E. East[1], G. E. Grant[5], C. W. Anderson[6], J. A. Bountry[7], M. J. Collins[8], P. J. Connolly[9], L. S. Craig[10], J. E. Evans[11], S. L. Greene[12], F. J. Magilligan[13], C. S. Magirl[14], J. J. Major[15], G. R. Pess[16], T. J. Randle[7], P. B. Shafroth[17], C. E. Torgersen[12], D. Tullos[18], and A. C. Wilcox[19]

sciencemag.org **SCIENCE**

PERSPECTIVES

ECOLOGY

1000 dams down and counting

Dam removals are reconnecting rivers in the United States

By J. E. O'Connor,[1] J. J. Duda,[2] G. E. Grant[3]

PLOS ONE

Landscape context and the biophysical response of rivers to dam removal in the United States

Melissa M. Foley, Francis J. Magilligan, Christian E. Torgersen, Jon J. Major, Chauncey W. Anderson, Patrick J. Connolly, Daniel Wieferich, Patrick B. Shafroth, James E. Evans, Dana Infante, Laura S. Craig

WIREs WATER

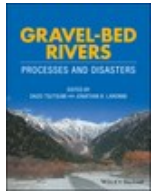
Advanced Review

Status and trends of dam removal research in the United States

J. Ryan Bellmore,[1]* Jeffrey J. Duda,[2] Laura S. Craig,[3] Samantha L. Greene,[4] Christian E. Torgersen,[4] Mathias J. Collins[5] and Katherine Vittum[2]

Geomorphic Responses to Dam Removal in the United States – a Two-Decade Perspective

Jon J. Major, Amy E. East, Jim E. O'Connor, Gordon E. Grant, Andrew C. Wilcox, Christopher S. Magirl, Mathias J. Collins, and Desiree D. Tullos



JAWRA JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

SYNTHESIS OF COMMON MANAGEMENT CONCERNS ASSOCIATED WITH DAM REMOVAL[1]

Desirée D. Tullos, Mathias J. Collins, J. Ryan Bellmore, Jennifer A. Bountry, Patrick J. Connolly, Patrick B. Shafroth, and Andrew C. Wilcox[2]

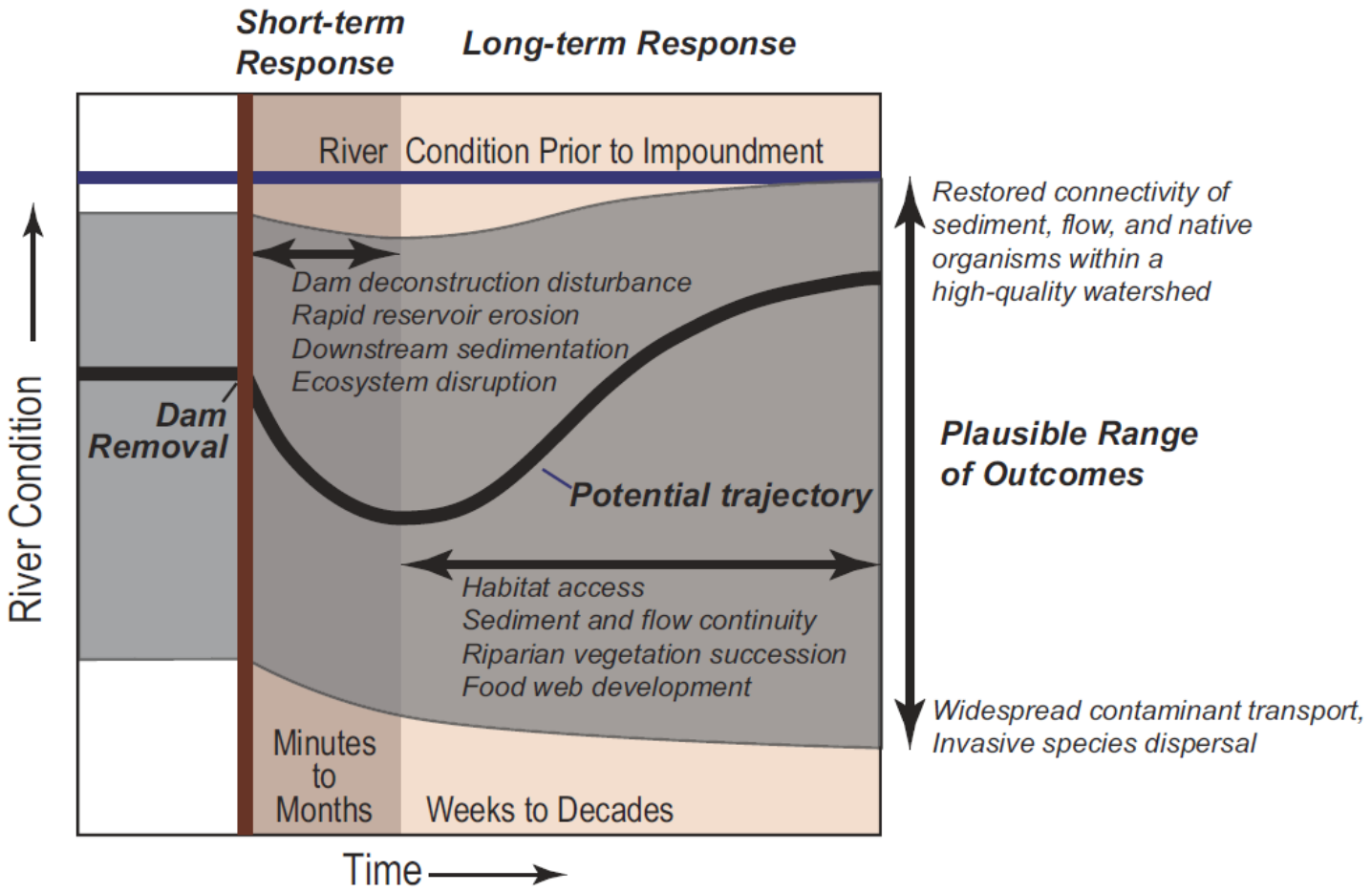
USGS

ELEMENTA Science of the Anthropocene

River restoration by dam removal: Enhancing connectivity at watershed scales

F.J. Magilligan[1]* • B.E. Graber[2] • K.H. Nislow[3] • J.W. Chipman[1] • C.S. Sneddon[4] • C.A. Fox[4]

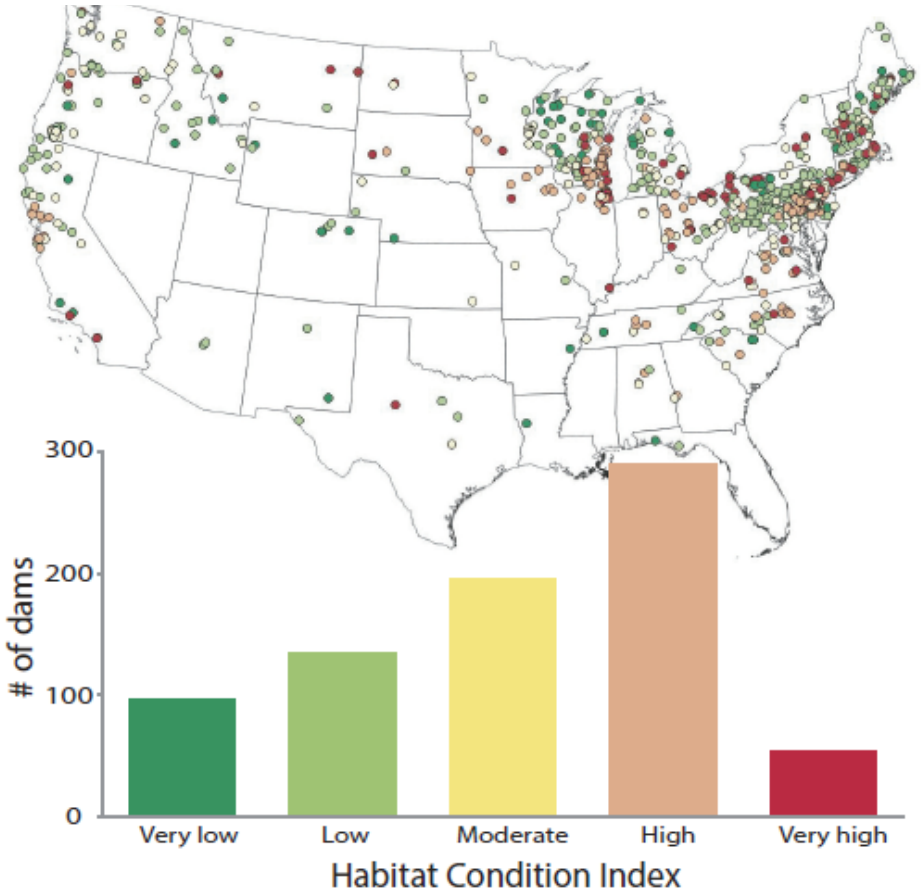
A heuristic model among a vast amount of variability



Foley et al. 2019 Water Resources Research

Challenge#1 in understanding and predicting recovery trajectories is that ecological responses vary spatially and temporally

Challenge#2: The local and regional context of each dam and watershed is distinct, and therefore, the responses to removal are unique.



Foley et al. 2017 PLoS ONE

Predicting dam removal outcomes

Overview Articles

BioScience • January 2019/ Vol. 69 No. 1

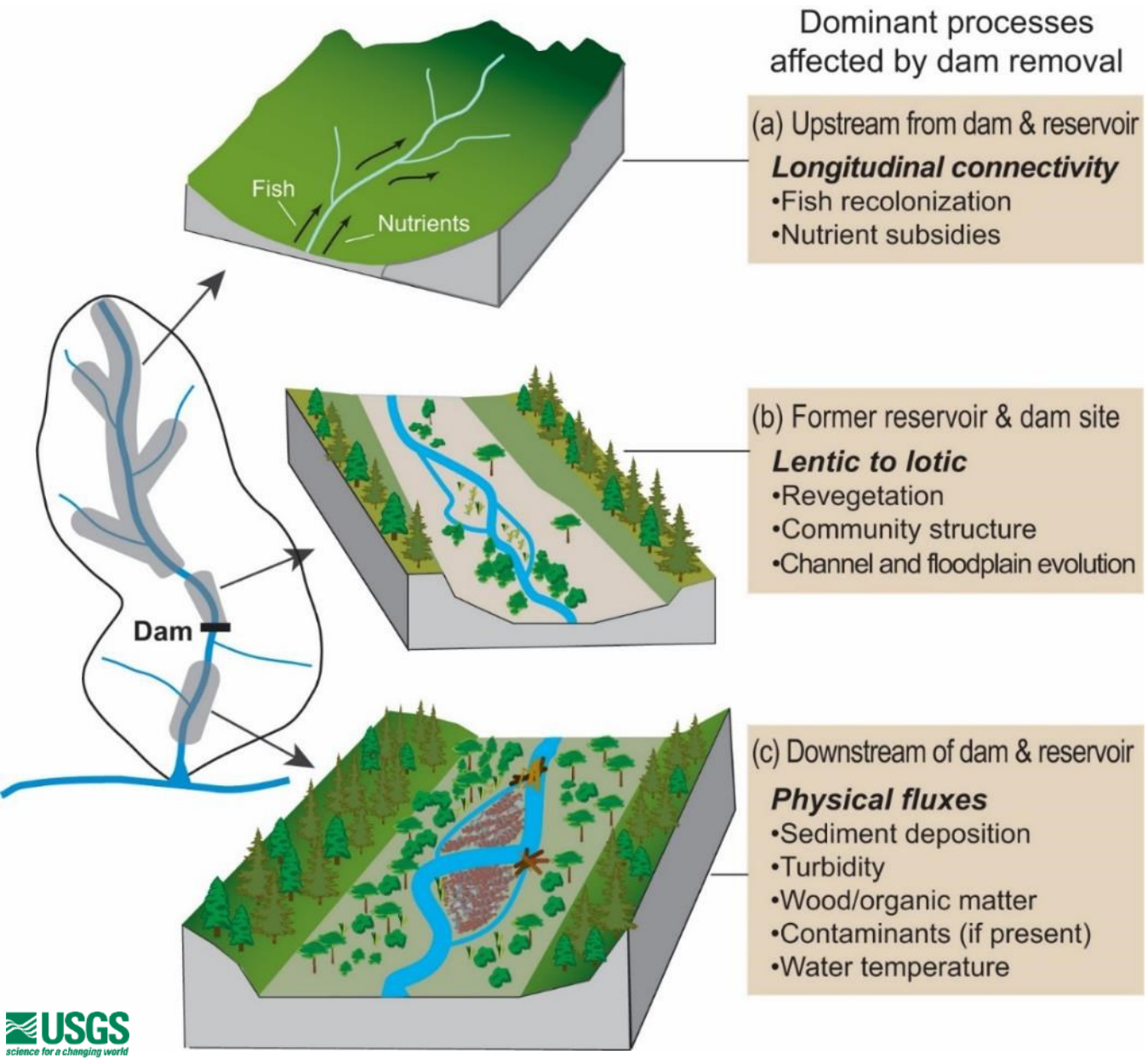
Conceptualizing Ecological Responses to Dam Removal: If You Remove It, What's to Come?

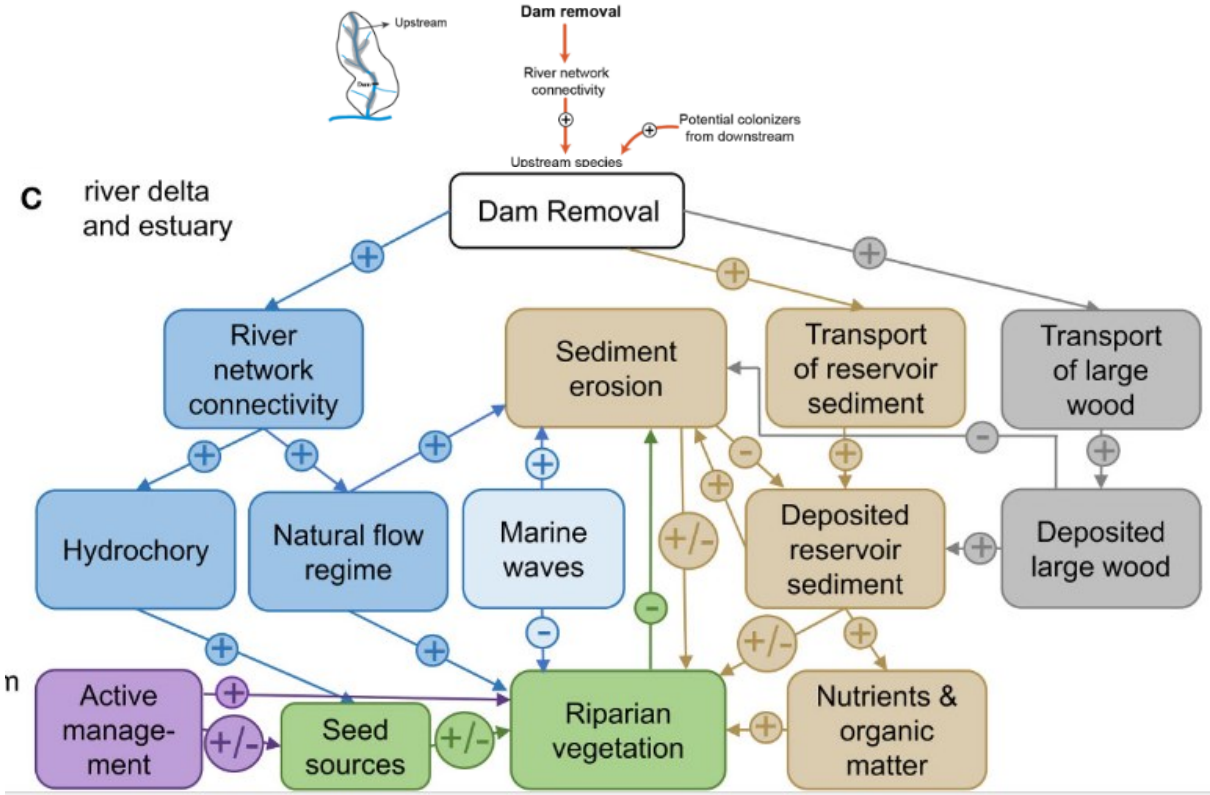
J. RYAN BELLMORE, GEORGE R. PESS, JEFFREY J. DUDA, JIM E. O'CONNOR, AMY E. EAST, MELISSA M. FOLEY, ANDREW C. WILCOX, JON J. MAJOR, PATRICK B. SHAFROTH, SARAH A. MORLEY, CHRISTOPHER S. MAGIRL, CHAUNCEY W. ANDERSON, JAMES E. EVANS, CHRISTIAN E. TORGERSEN, AND LAURA S. CRAIG

Use conceptual models to:

- Define the processes affecting ecological responses to dam removal
- Clarify how ecological transitions in 3 main spatial domains are affected by dam removal
- Illustrate that responses are complex but *predictable*

Conceptual Models





REVIEW article

Front. Ecol. Evol., 13 February 2024
Sec. Conservation and Restoration Ecology
Volume 12 - 2024 | https://doi.org/10.3389/fevo.2024.1272921

This article is part of the Research Topic
Large-Scale Dam Removal and Ecosystem Restoration
View all 23 Articles

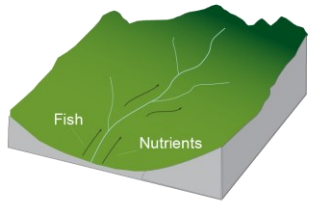
Vegetation responses to large dam removal on the Elwha River, Washington, USA

Patrick B. Shafroth[1*] Laura G. Perry[1,2] James M. Helfield[3] Joshua Chenoweth[4]
Rebecca L. Brown[5]

‡includes temperature, sediment, and nutrient regimes

USGS science for a changing world

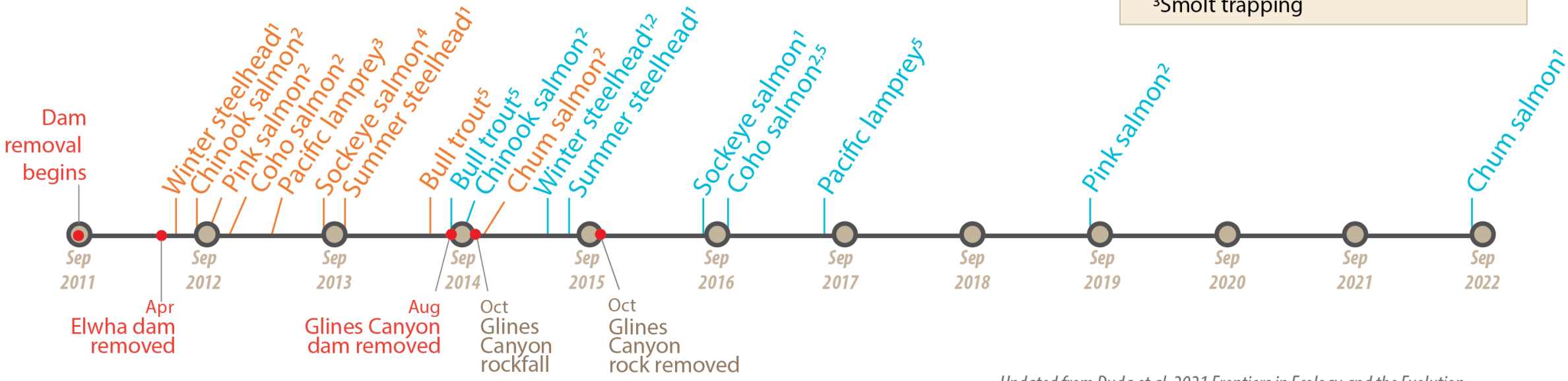
Summary of anadromous fish upstream of the dams



Timeline - Migratory fish response to a reconnected Elwha River

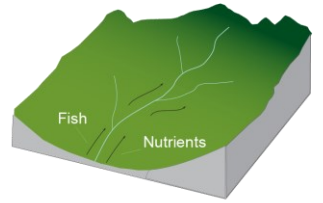
First adult observation
Upstream of Elwha Dam
Upstream of Glines Canyon Dam

Methods of detection
[1]Snorkeling
[2]Redd survey
[3]Smolt trapping
[4]Tangle netting
[5]Radio-telemetry



Updated from Duda et al. 2021 Frontiers in Ecology and the Evolution

Riverscape surveys before and after dam removal



The "Riverscape Approach"

- Continuously collected adult and juvenile fish data from headwaters to the sea.
- **Adults**: Bull Trout, Resident Trout, Chinook salmon, Steelhead
- **Juveniles**: Coho, Chinook, Trout.

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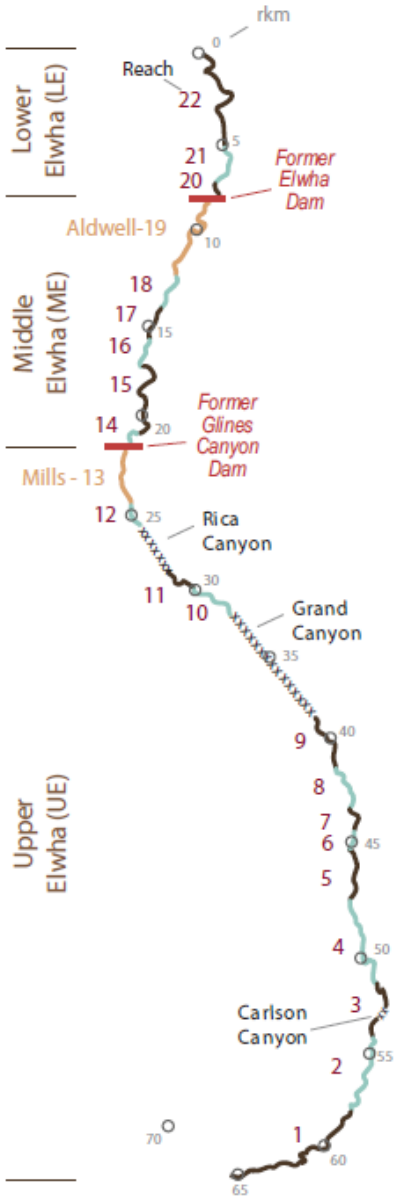

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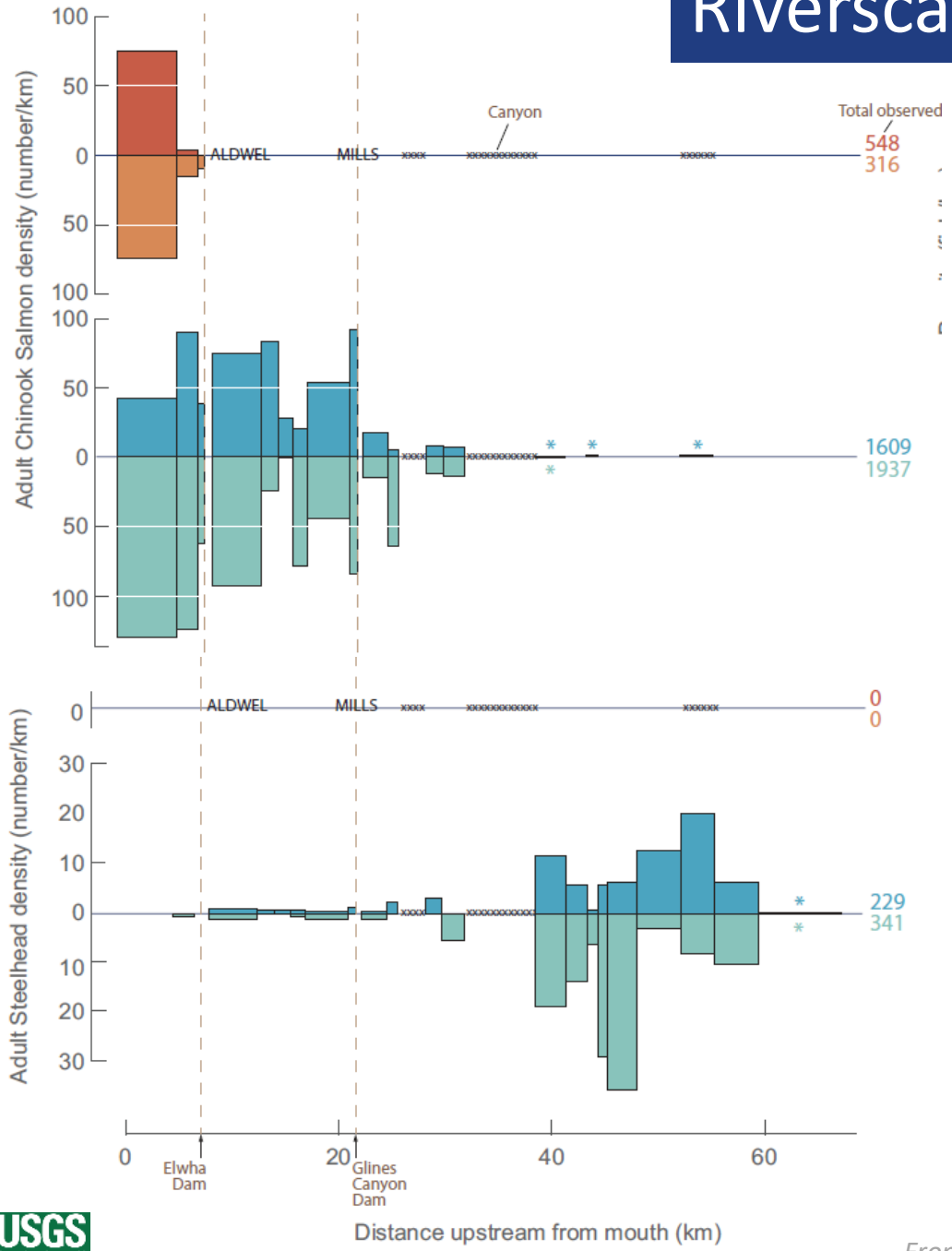
ORIGINAL RESEARCH
published: 09 December 2021
doi: 10.3389/fevo.2021.765488

River:

USGS science for a changing world

Riverscape results for two threatened species



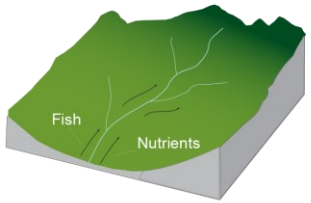
Chinook

- Before dam removal, Chinook limited to downstream of Elwha Dam
- After dam removal, adults detected upstream of each dam, but densities highest in reaches downstream of Glines Canyon

Summer Steelhead

- Before dam removal, scarce (presumably extirpated)
- After dam removal, large increases driven by "reawakening of anadromy" from resident trout populations (Fraik et al. 2021).

From Duda et al. 2021. Frontiers in Ecology and Evolution



Upstream of the dams: dippers respond to salmon nutrients

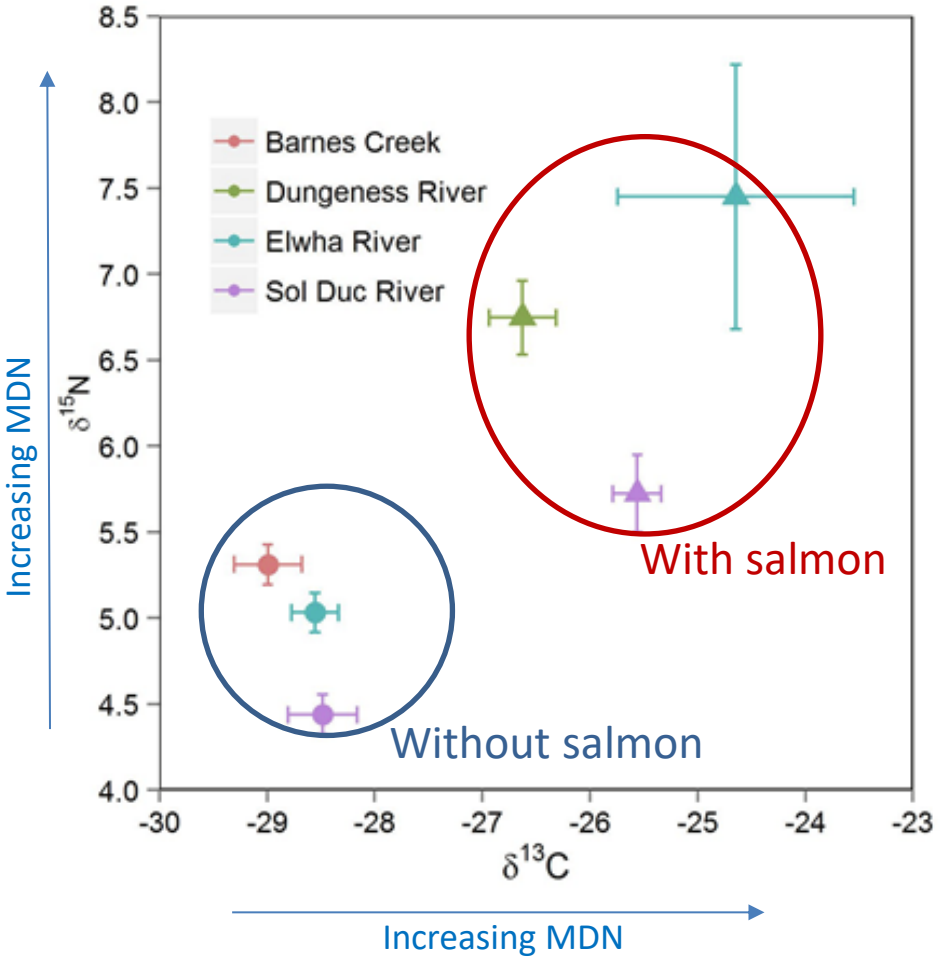
American dipper with salmon egg, Elwha River, 2012 (John McMillan)

Dippers feeding on Elwha salmon tissues and eggs:

- Increased marine derived nutrients (MDN) in tissues

In areas with salmon, dippers:

- Had higher survival (11%)
- 13x more likely to be year-round residents
- 20x more likely to attempt 2 broods per year instead of 1 brood



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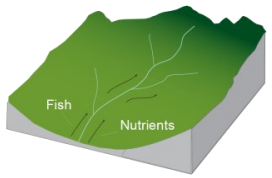
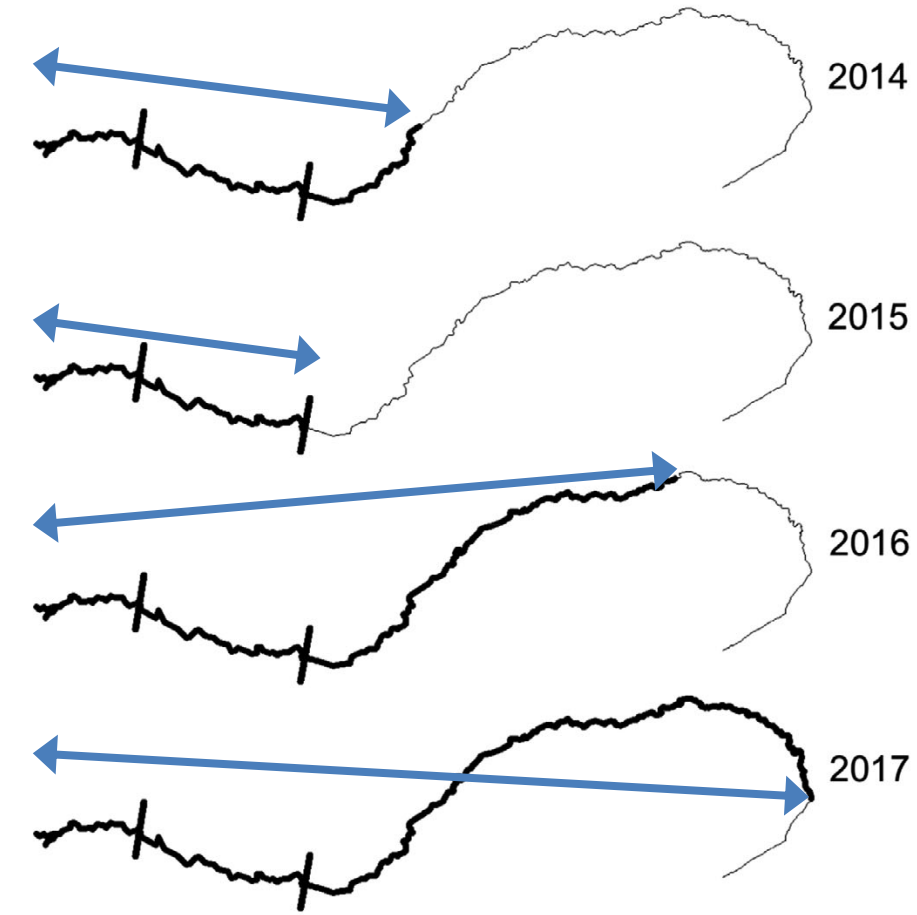
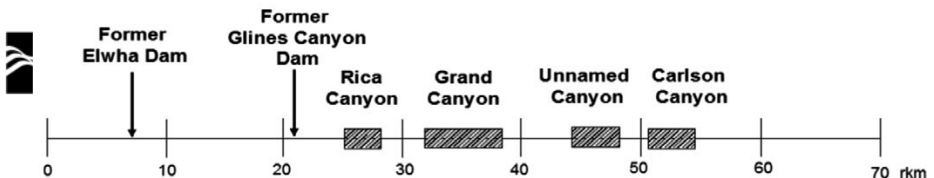
Tonra et al. 2015, Biological Conservation; Tonra et al. 2016 Ecography

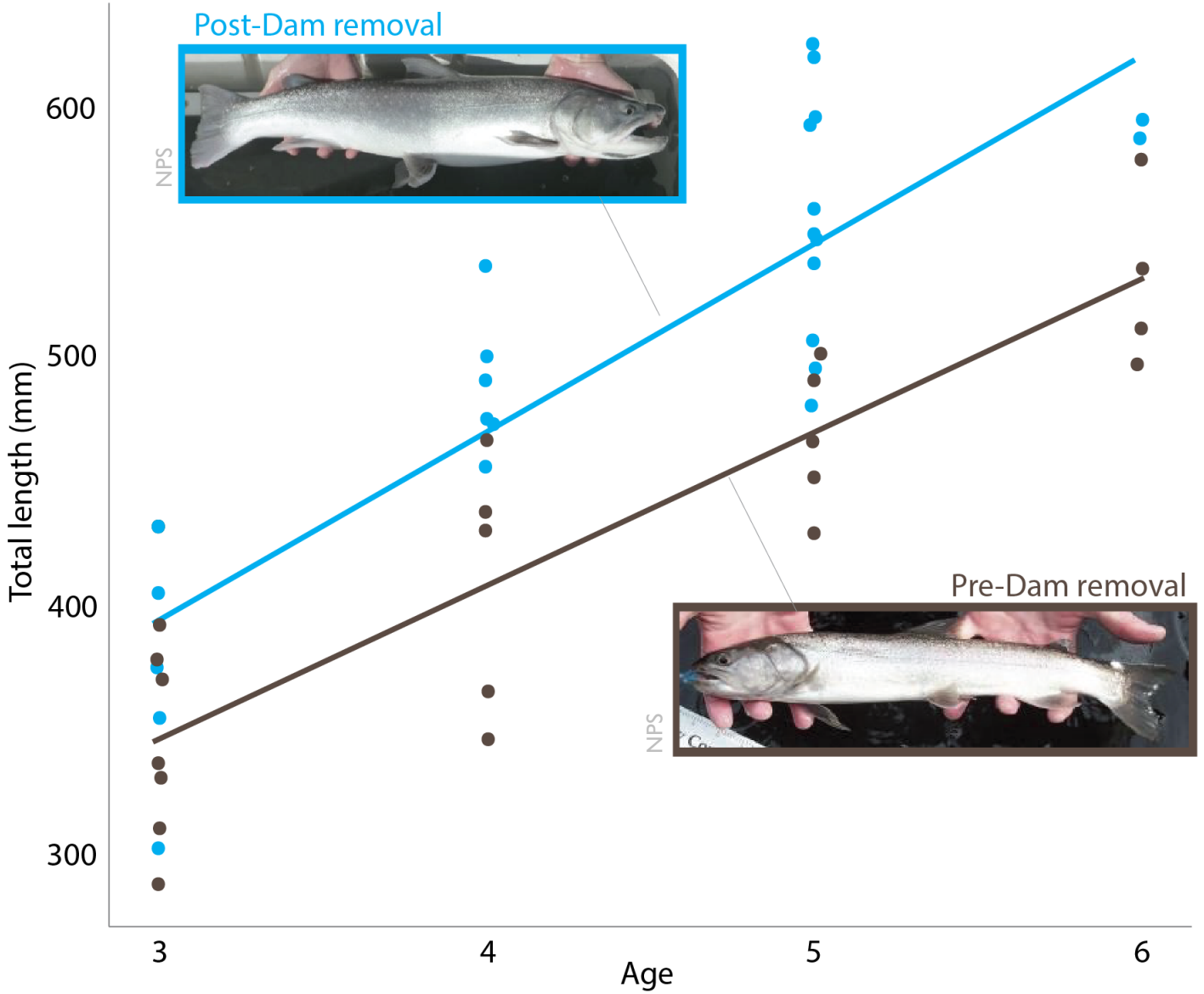


Bull trout: Reawakening of whole river migration

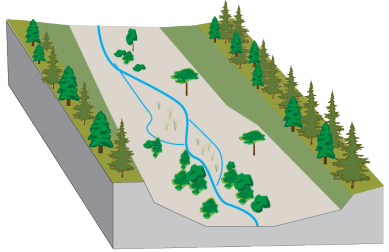
Upstream migration via radio-telemetry







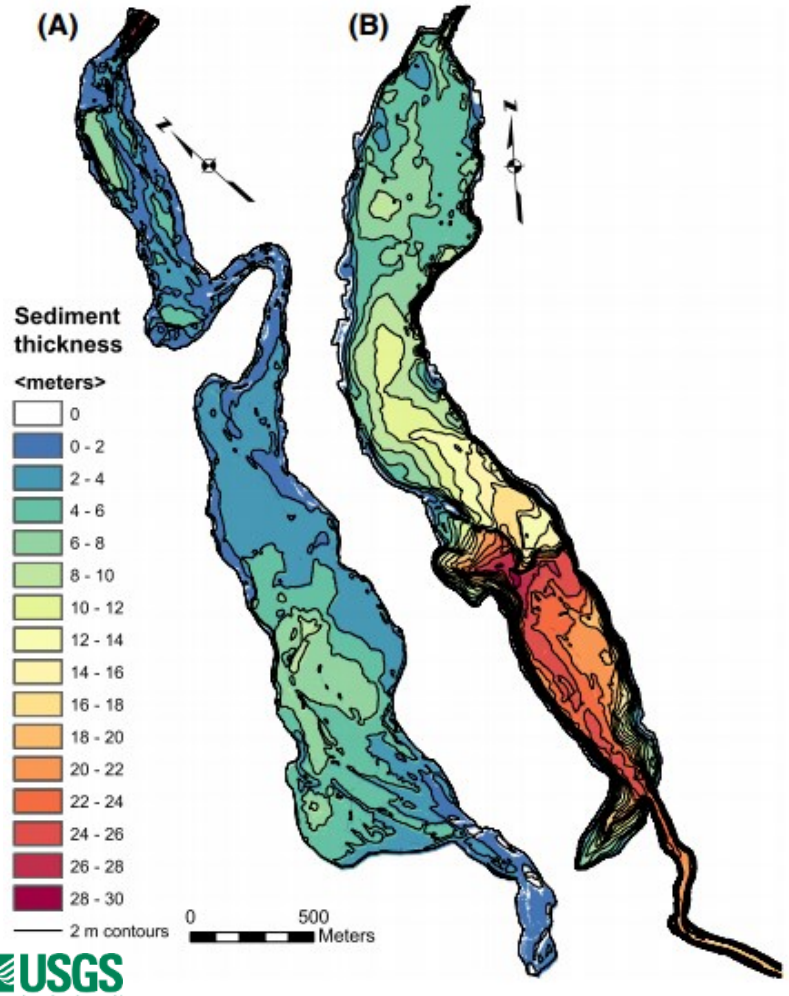
Brenkman et al. 2019
North American Journal of Fisheries Management

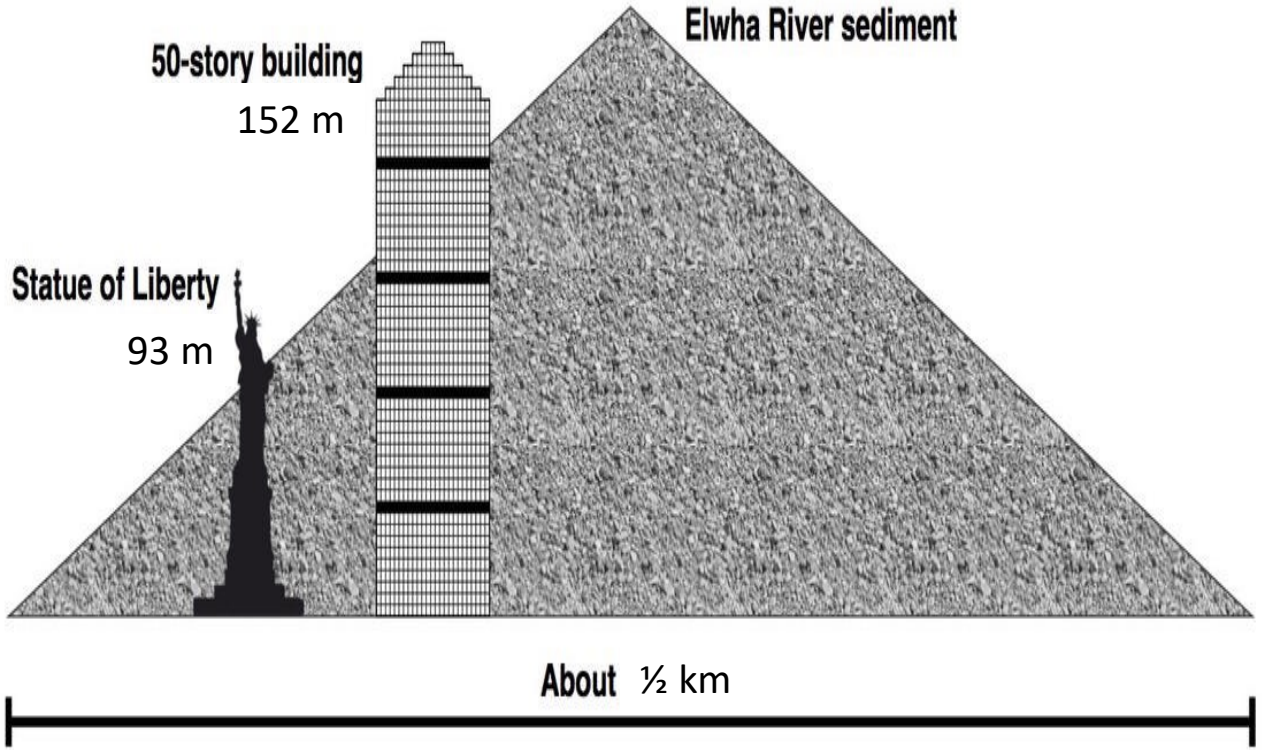


Former reservoirs – sediment redistribution

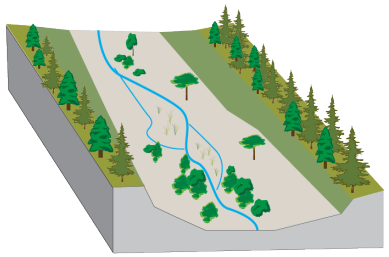
Both reservoirs contain 21 million m^3 of sediment

Aldwell Mills



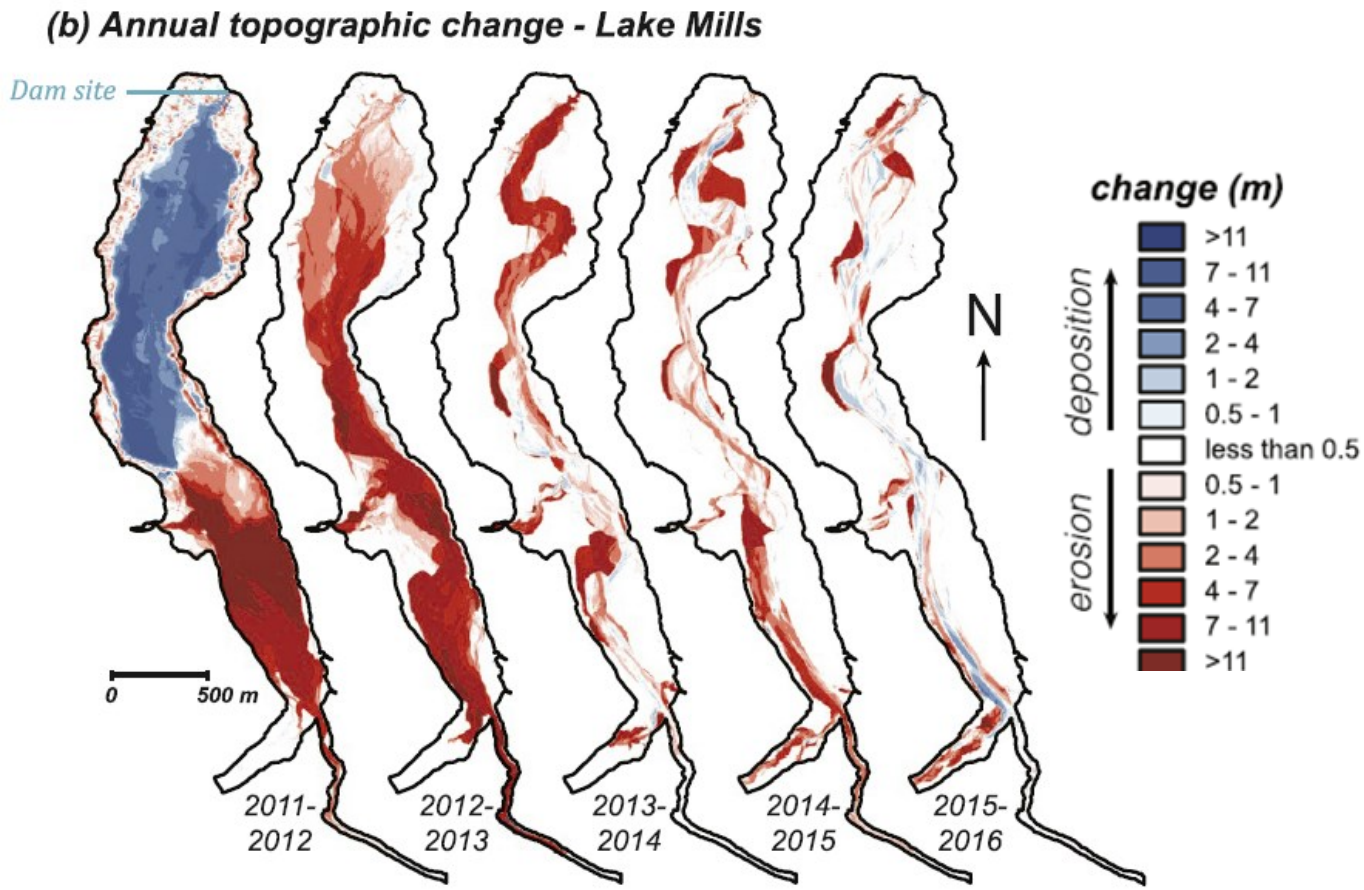


USGS science for a changing world

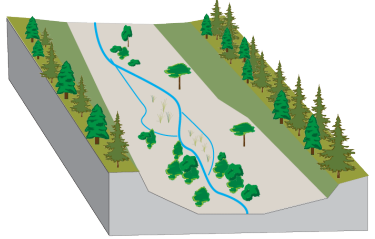


Former reservoirs – sediment redistribution

J Duda_USGS

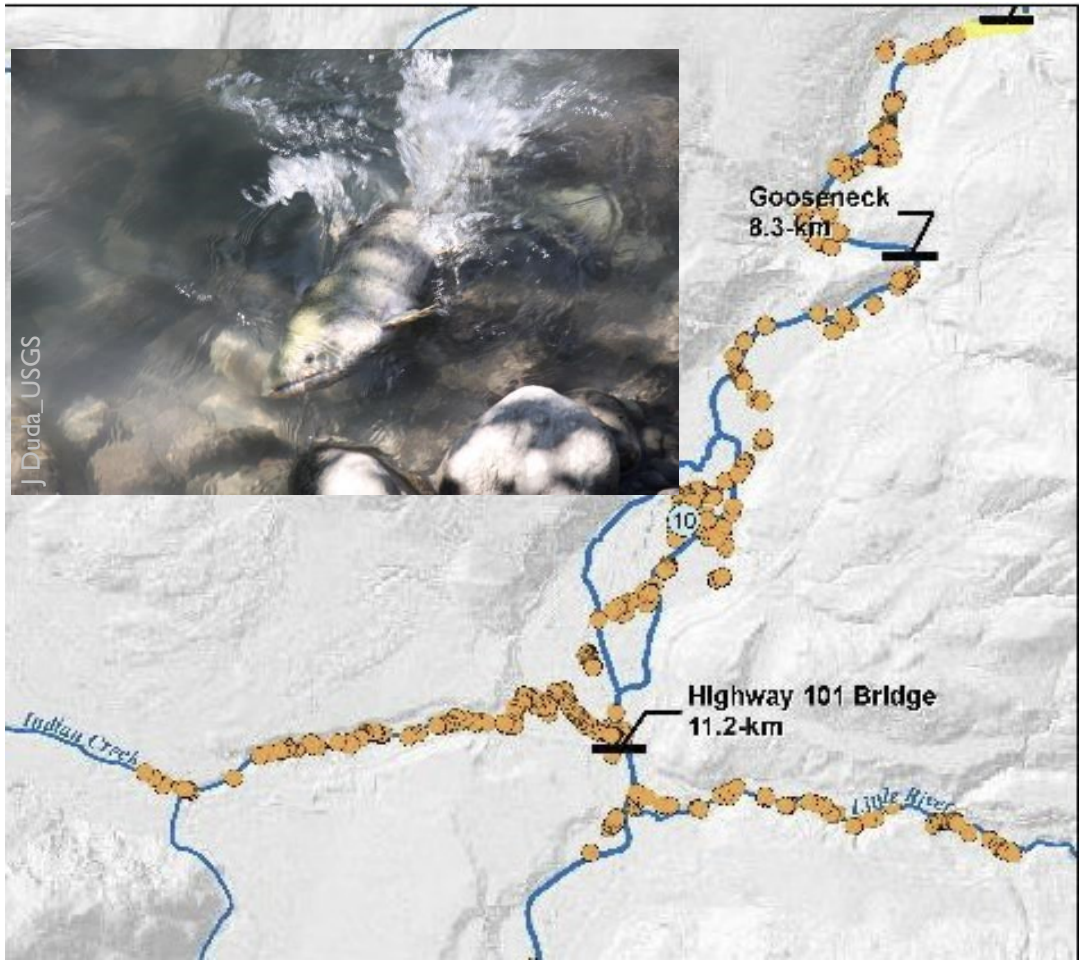


Ritchie et al. 2018. Scientific Reports



Former reservoirs – novel ecosystems emerge

Chinook spawning



Riparian/Upland revegetation

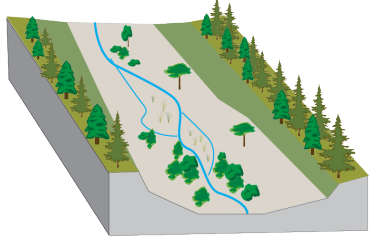

J Chenoweth NPS

	Coarse Sediments	*Fine Sediments*	*Significant Level*
No. of Plots	*25*	*38*	
Summarized cover of all species	11.58 ± 7.55	106.9 ± 35.4	***
No. of species	13.84 ± 5.47	17.76 ± 5.96	**
No. of wetland species	1.8 ± 1.04	5.45 ± 1.9	***
No. of alien species	3.68 ± 2.06	3.32 ± 1.86	NS

USGS science for a changing world

McHenry et al. Technical Report 2020

Prach et al. 2019 Restoration Ecology 2020



Former reservoirs – novel ecosystems emerge

BRIEF RESEARCH REPORT article

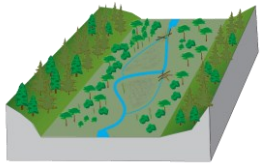
Front. Ecol. Evol., 26 March 2024
Sec. Conservation and Restoration Ecology
Volume 12 - 2024 | https://doi.org/10.3389/fevo.2024.1266474

This article is part of the Research Topic
Large-Scale Dam Removal and Ecosystem Restoration
View all 23 Articles >

Establishment of terrestrial mammals on former reservoir beds following large dam removal on the Elwha River, Washington, USA

Rebecca M. McCaffery[1*] Sara J. Cendejas-Zarelli[2] Katy R. Goodwin[1] Patricia J. Happe[3] Kurt J. Jenkins[1] Kimberly A. Sager-Fradkin[2*]

Lower Elwha Klallam Tribe (with permission)



Downstream– here comes the sediment, wood, and shifting geomorphologies

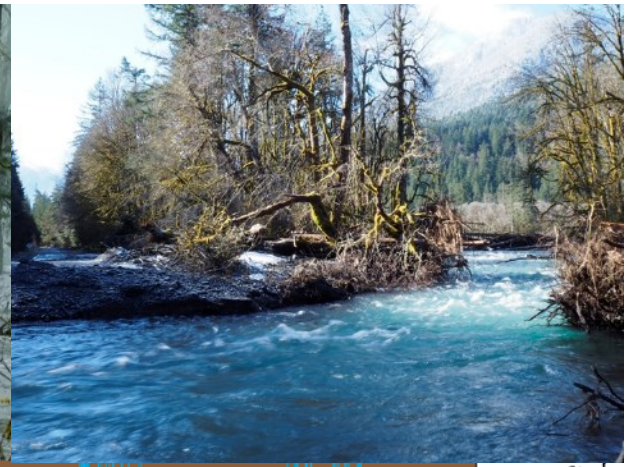
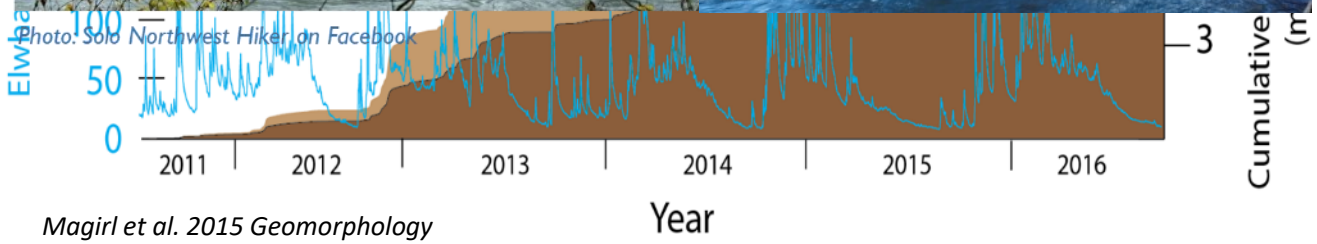


Photo: Solo Northwest Hiker on Facebook



Magirl et al. 2015 Geomorphology

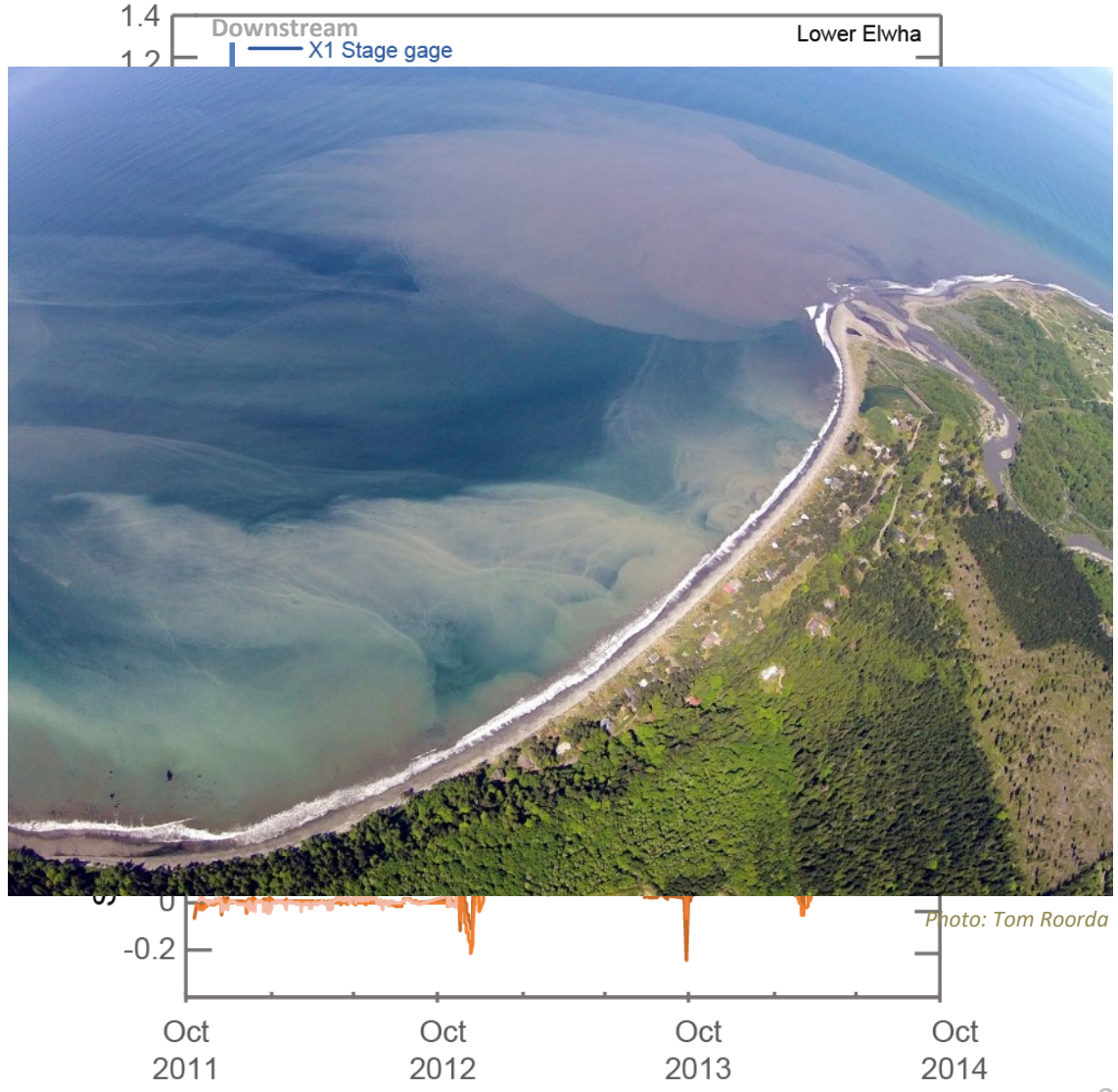
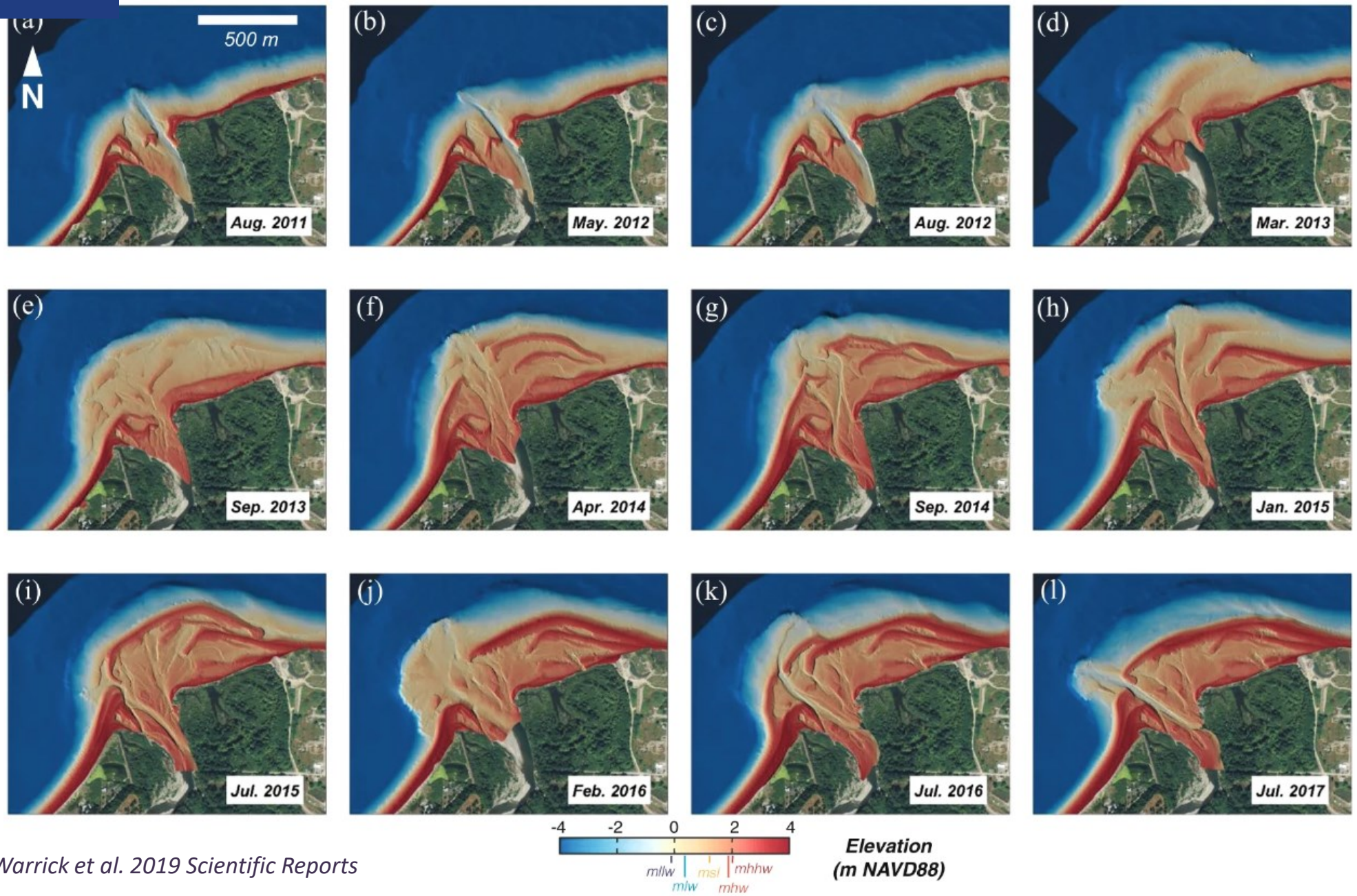


Photo: Tom Roorda

Morley et al. 2020 PloS One

USGS science for a changing world

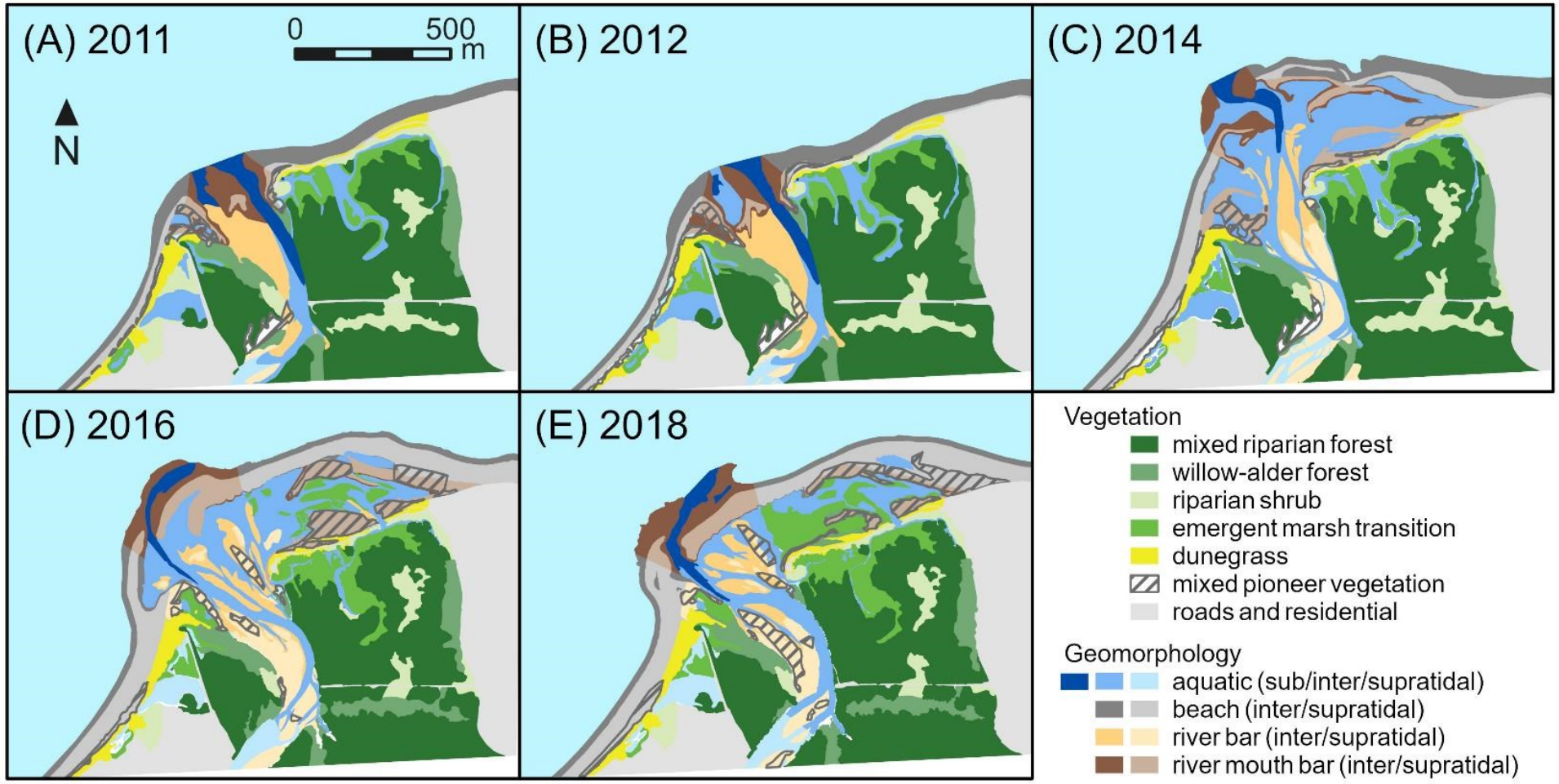
Coastal response



USGS

Warrick et al. 2019 Scientific Reports

Coastal response

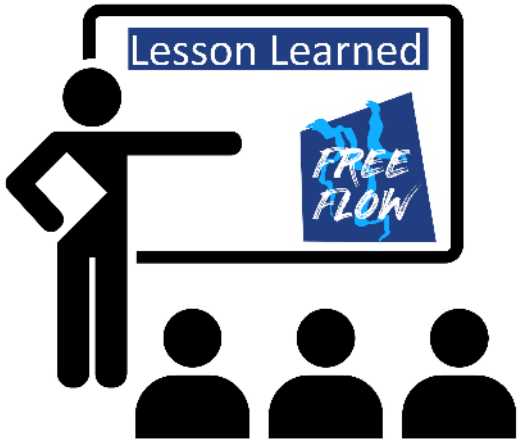


Vegetation Increase:

Marsh + 6.5 ha

Pioneer + 5.2 ha

Willow/Alder +2.6 ha



Long-term datasets are Key

USGS

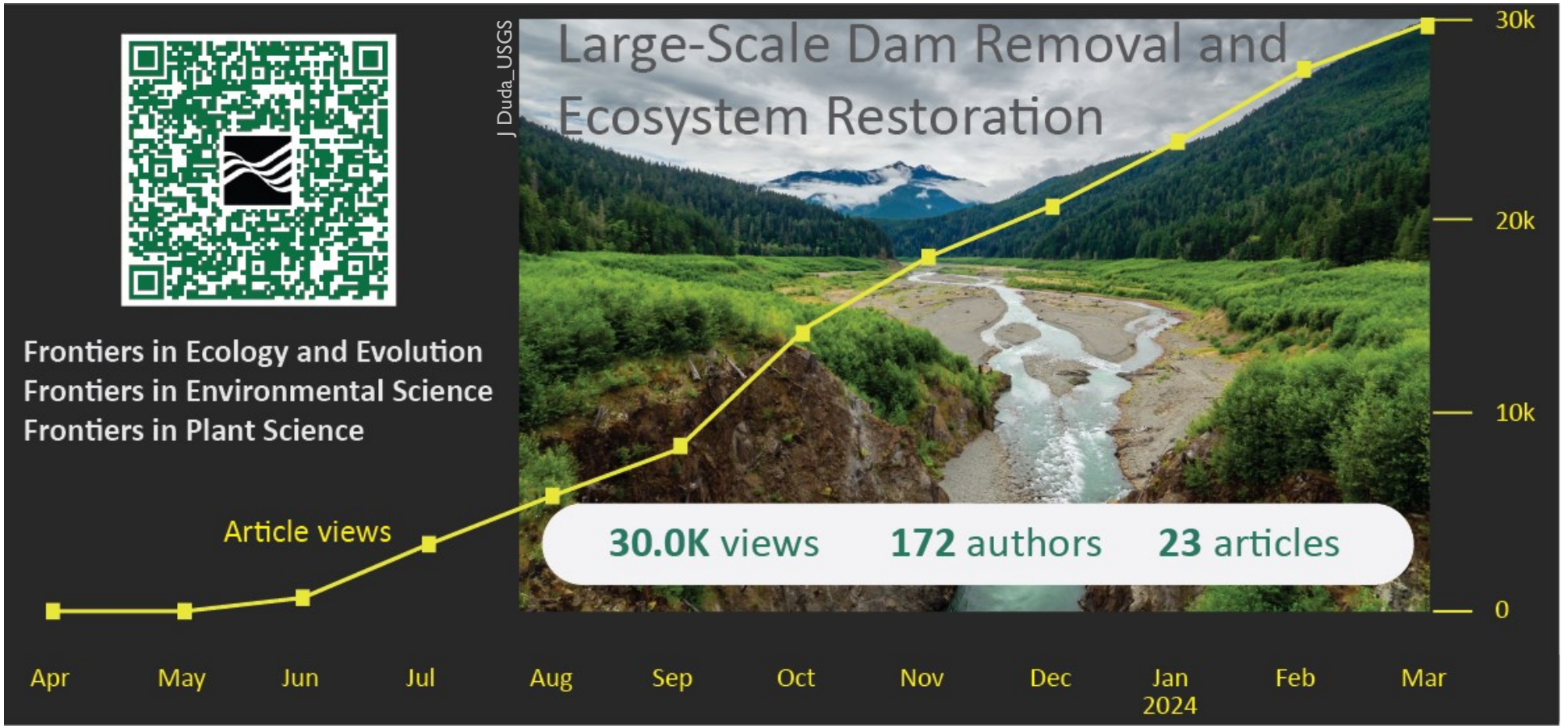
Foley et al. 2017 Ecological Monographs; Perry et al. 2023 Frontiers in Ecology and Evolution

Act III: Now and towards the future

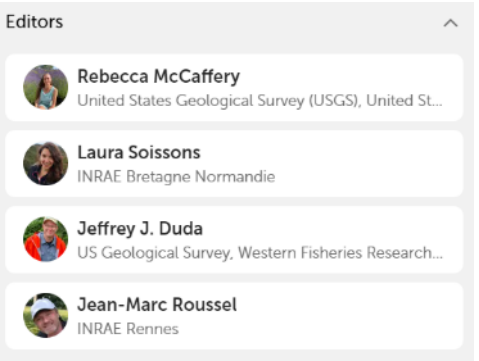
J Duda_USGS

USGS

Research collection @Frontiers: Large dam removal



Rivers featured:
Elwha
Sélune
Klamath
Penobscot

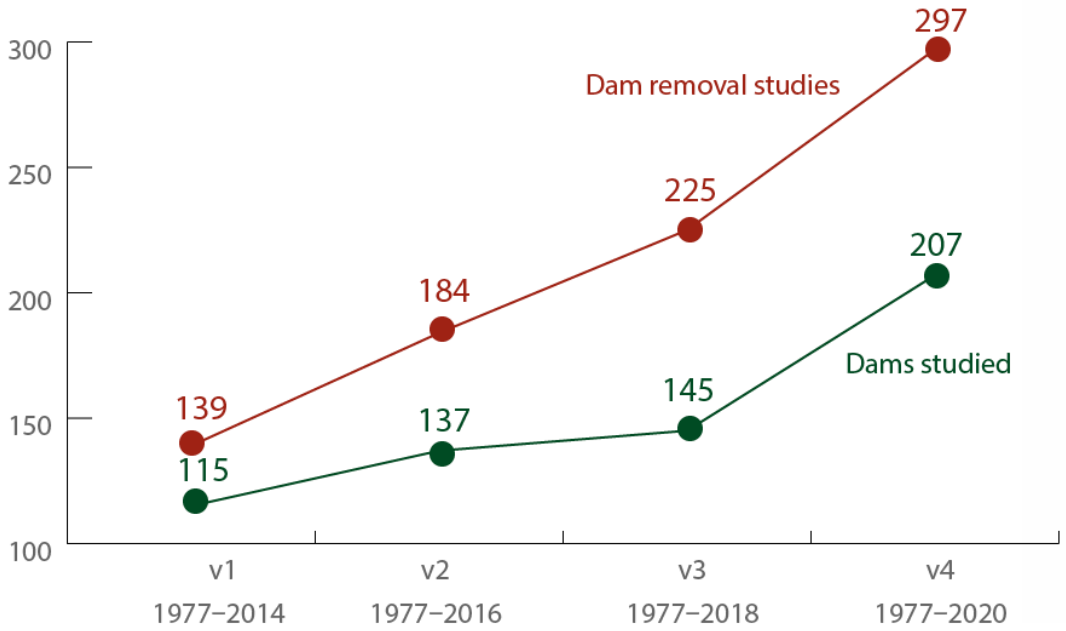


USGS

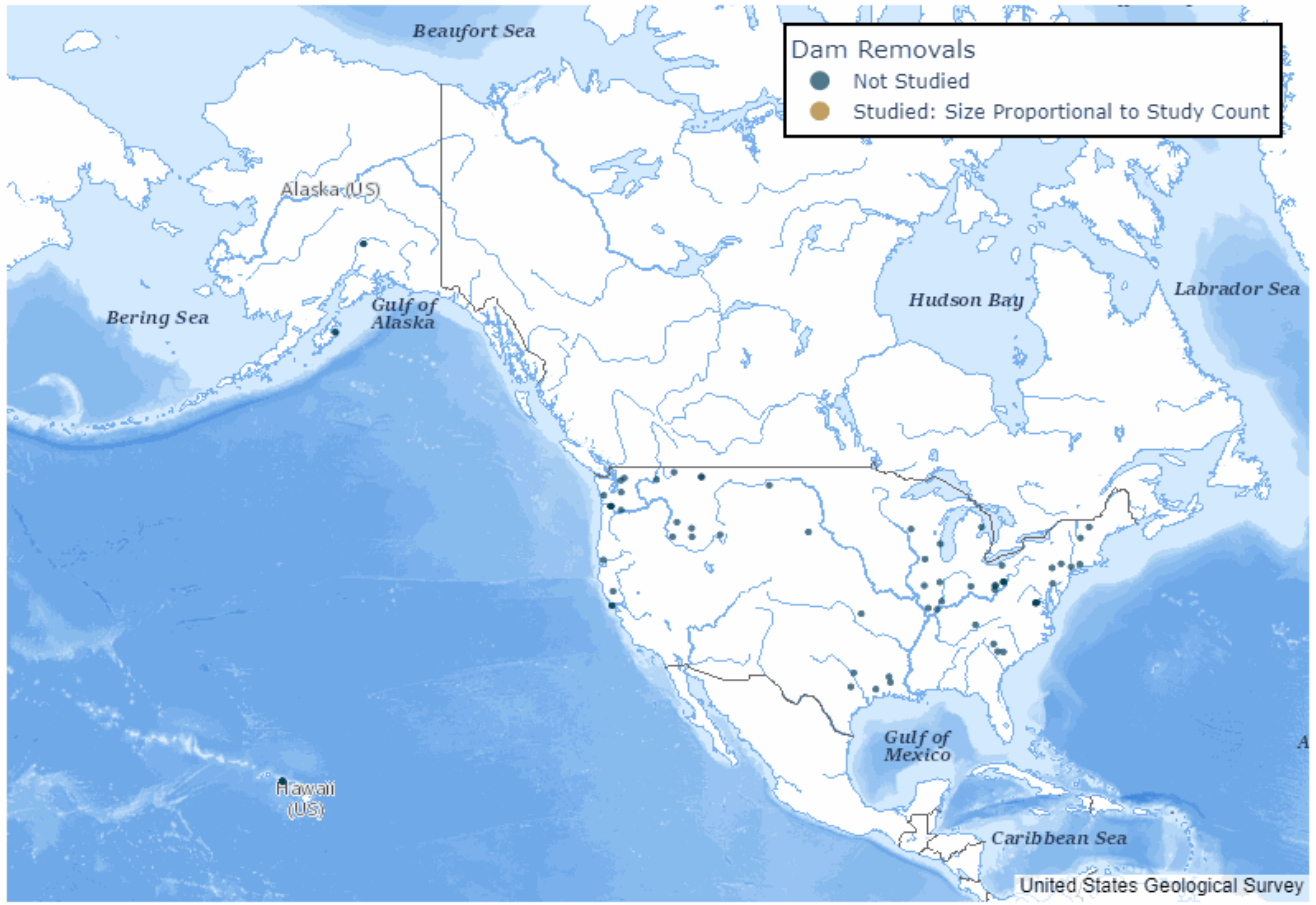
Dam removal information portal (DRIP)

https://data.usgs.gov/drip-dashboard

- A tool to explore trends about dam removal science and query scientific studies that evaluate environmental response to dam removals.
- Studies of dam removals from 13 countries (73% U.S.)



Dam Removal Studies Through Time: Unknown



Expanding DRIP: dam removal cost database

Condit Dam Removal—White Salmon River, WA, USA

National Geographic (2011)

frontiers in Ecology and Evolution

doi: 10.3389/fevo.2023.1215471

Patterns, drivers, and a predictive model of dam removal cost in the United States

Jeffrey J. Duda[1]*, Suman Jumani[2,3], Daniel J. Wieferich[4], Desiree Tullos[5], S. Kyle McKay[2], Timothy J. Randle[6], Alvin Jansen[6], Susan Bailey[2], Benjamin L. Jensen[1], Rachelle C. Johnson[1], Ella Wagner[1], Kyla Richards[4], Seth Wenger[3], Eric J. Walther[3], and Jennifer A. Bountry[6]

US Army Corps of Engineers

BUREAU OF RECLAMATION

USGS science for a changing world

Oregon State University

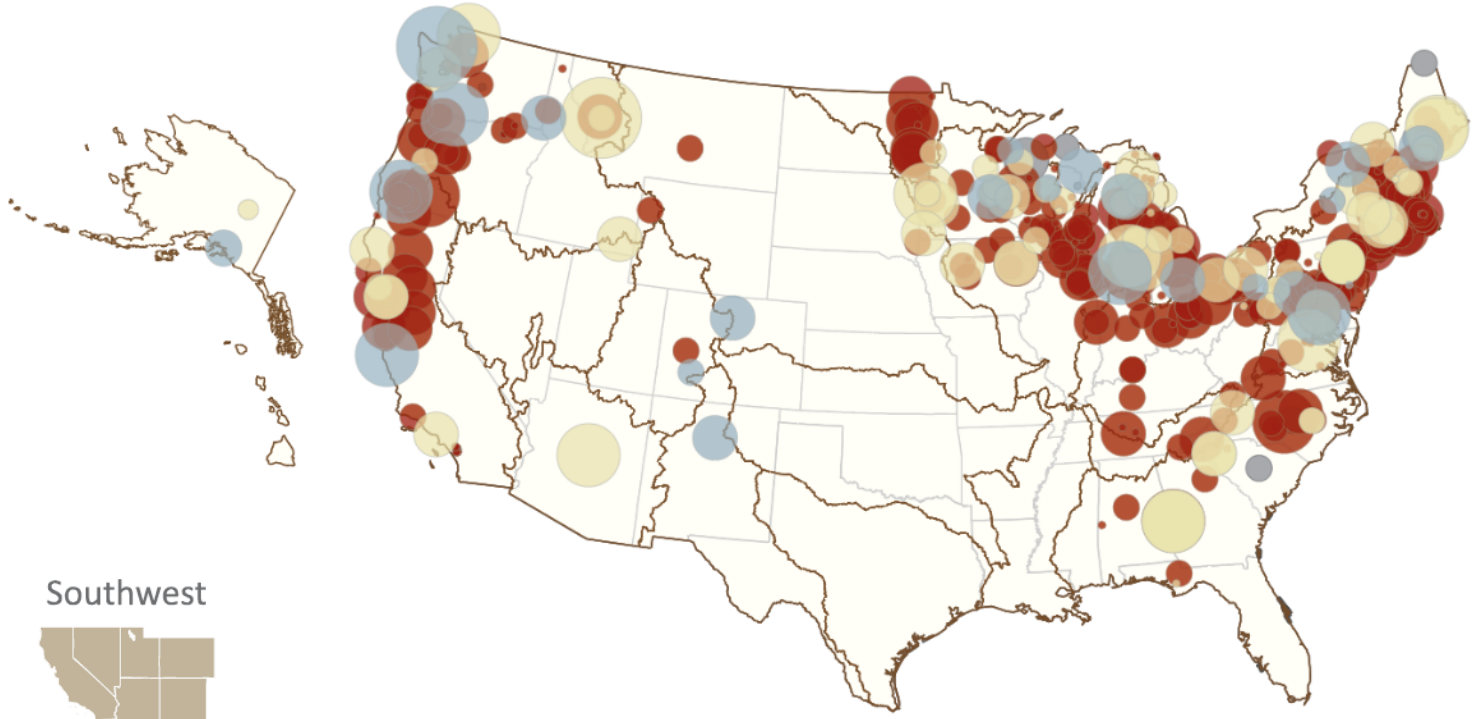
River Basin Center UNIVERSITY OF GEORGIA

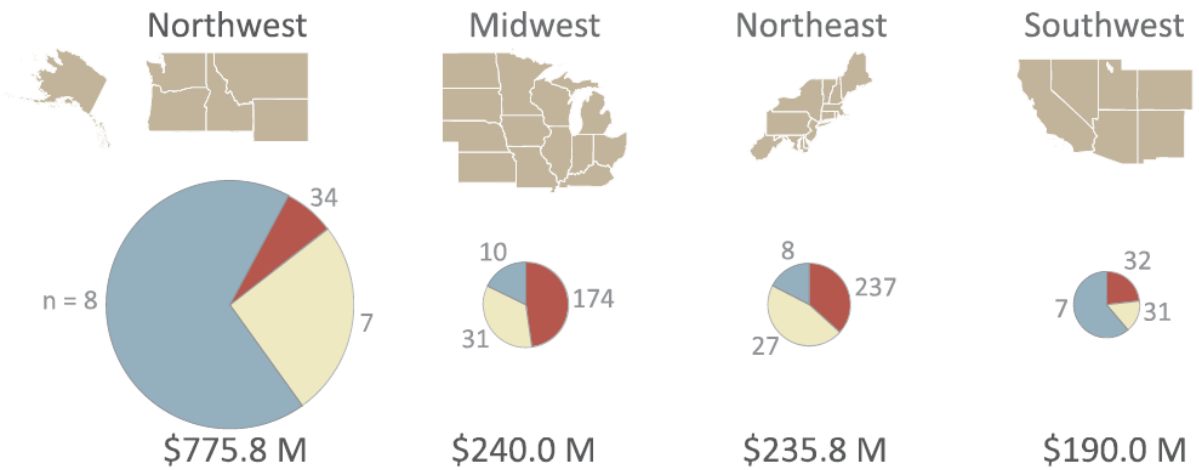
Cost of dam removal - overview

Database on dam removal cost

- Reported cost for 668 projects from 1965-2020; approximately 38% of total
- Inflation adjusted cost to 2020 $USD

- 38% dam removal costs= $1.522 Billion
- 100% dam removals = $4.366 Billion





Dam Height Category

n=542 < 5 m
77 ≥ 5 – 10 m
30 > 10 m
19 Unspecified

Removal Cost

>$100 M
$10 M – $100 M
$1 M – $10 M
$100 K – $1 M
<$100 K

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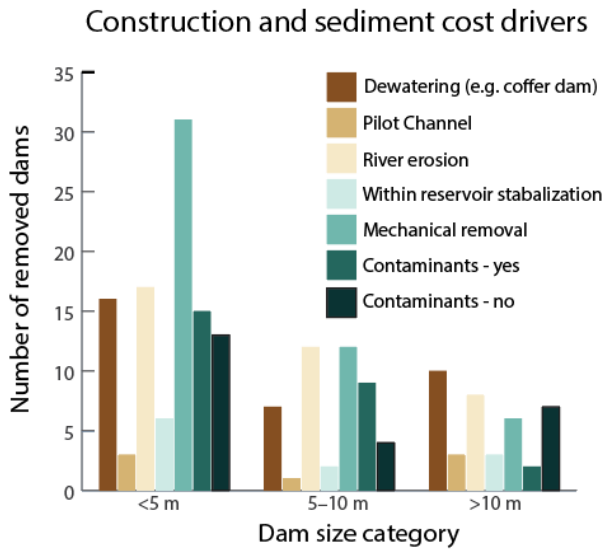
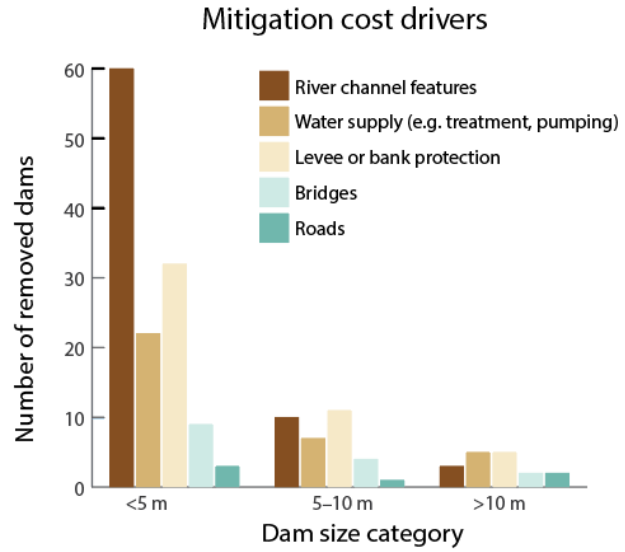
Duda et al. 2023. Frontiers in Ecology and Evolution

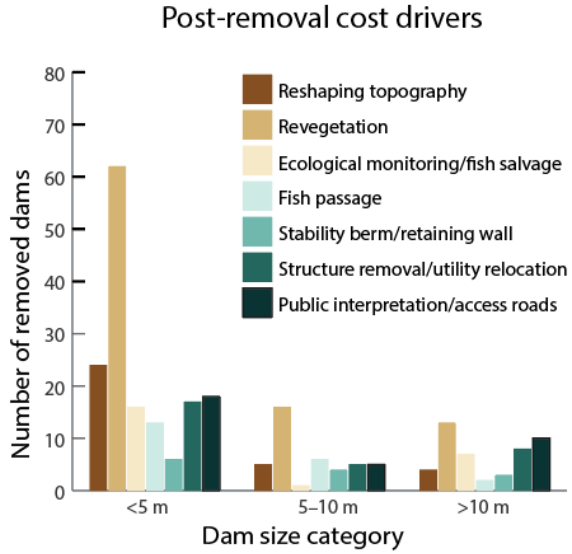
Dam removal predictive cost model

Model dam removal cost as a function of:

- **Dam attributes** – Age, height, length, material, purpose
- **Site/Watershed attributes** - Annual discharge, Watershed Area, Region, stream order
- **Cost-drivers**/Complexity
- **Goal:** Order-of-magnitude cost estimates for relevant scenarios to inform dam decisions and priortization





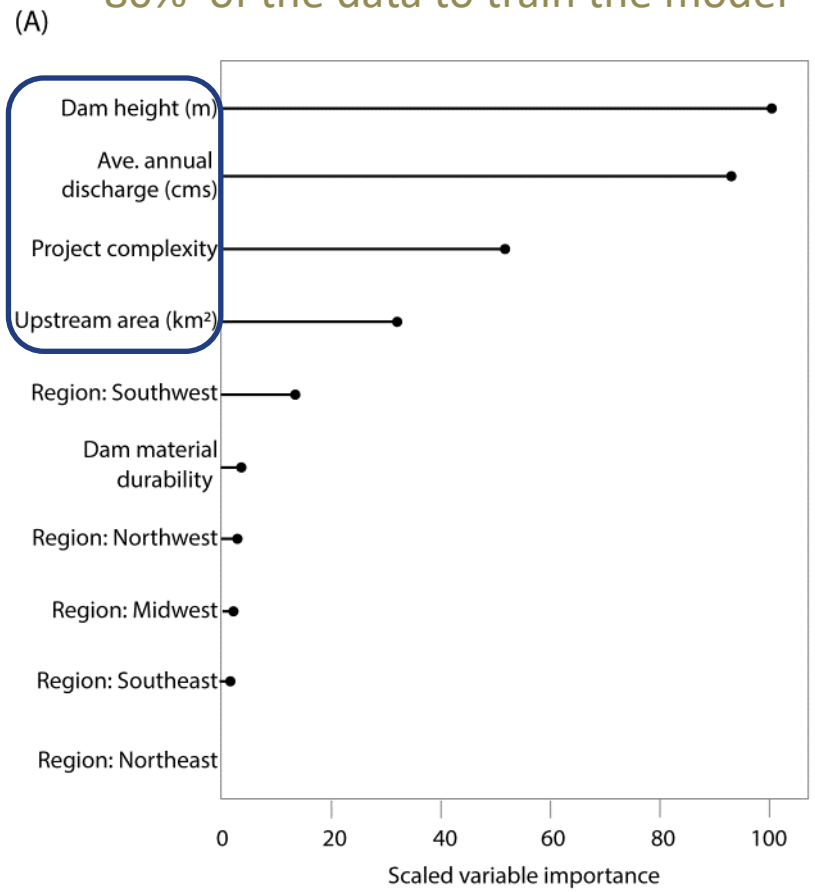


Duda et al. 2023. Frontiers in Ecology and Evolution

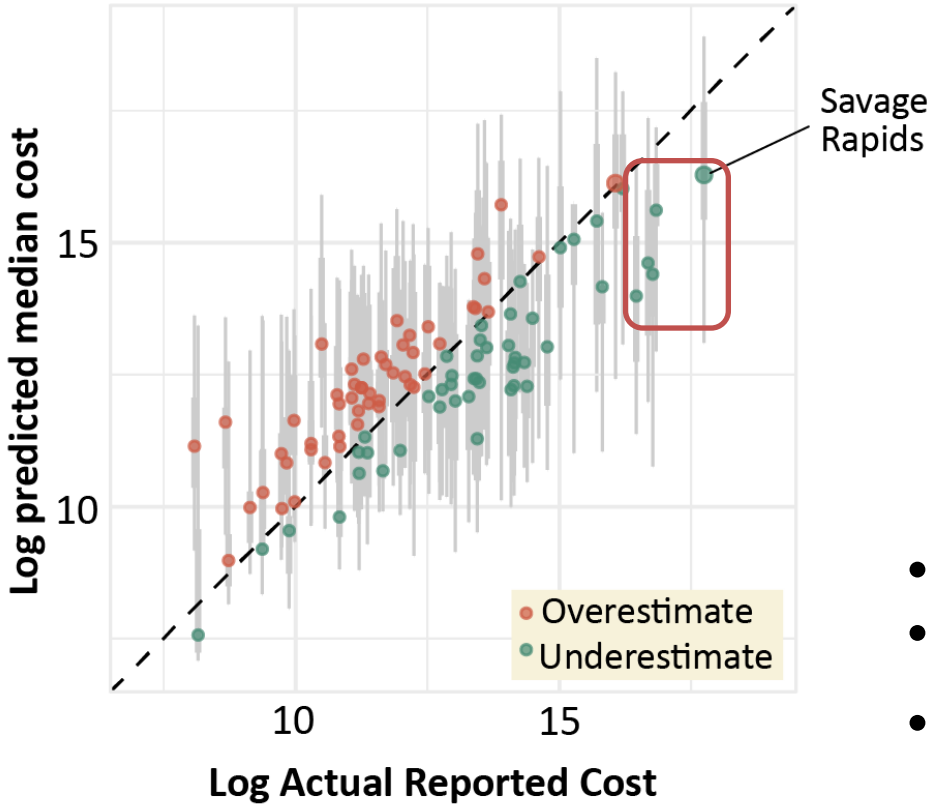
Dam removal predictive cost model

- Cost model created using both regression trees and Machine Learning (Gradient Boosted Quantile Regression)
- Model cost against predictor variables

80% of the data to train the model



20% of the data to test the model



Savage Rapids dam before (above) and after (below) removal.
Photo : ODFW

- Actual vs. Predicted:
- R^2 = 33.8% & MAE = $1.4M
- Actual costs encompassed within prediction intervals

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Dam removal cost model Shiny App

https://wrises.shinyapps.io/DamRemovalCostPredictiveModel/

Dam Removal Cost Estimator | Model | Model description | Case study: Boardman dam

Input parameters

Please provide values for the following varialbes to obtain cost predictions. Detailed explanations for each variable can be found in the introduction tab to the right.

Dam characteristics

Dam height (in meters)

11.5

Dam Material

Masonry/Concrete/Steel

Project complexity

0 0.3 0.5 1

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Hydrology

NHD COMID*

*NHDPlus V2.1

Discharge (m^3/s): 2.15

Drainage area (km^2): 170

OR

Annual avg. discharge (in m^3/s)

2.15

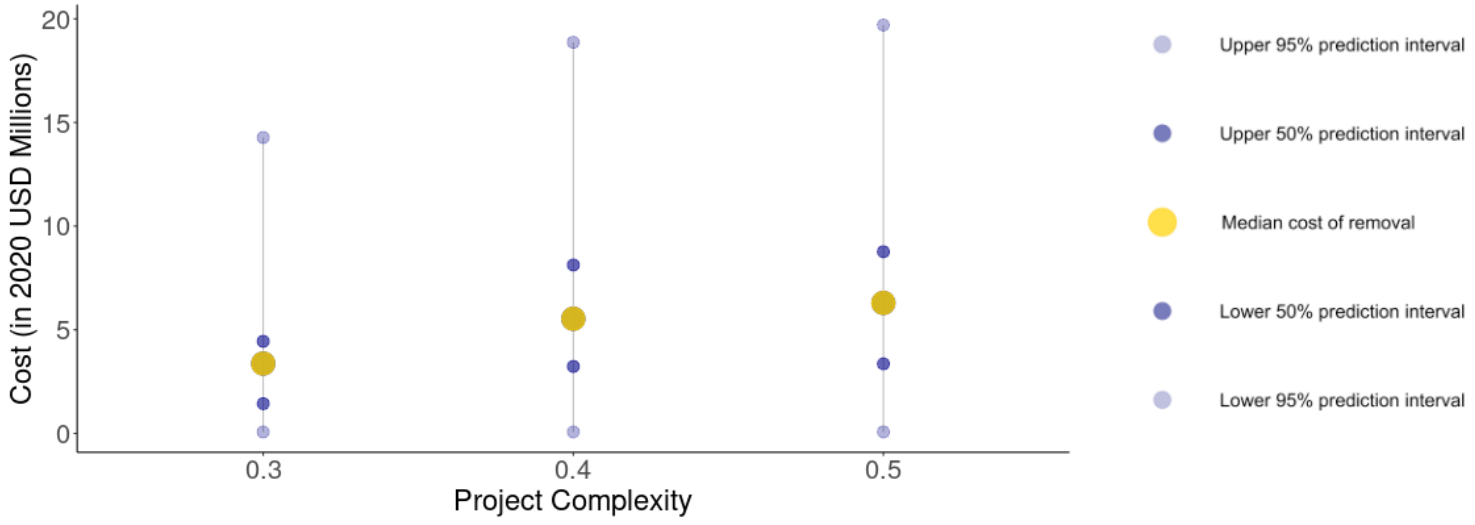
Drainage area (in km^2)

170

Please enter either a NHD reach COMID value OR discharge and draiange area values. Any entered NHD COMID will override the directly entered discharge and draiange area values. If the user wishes to directly enter hydrology data, the NHD stream code cell must be blank.

Estimated Costs (in 2020 USD)

	0.3	0.4	0.5
Median cost of removal:	$3,370,606	$5,531,313	$6,296,109
Lower 50% prediction interval:	$1,433,814	$3,230,021	$3,357,750
Upper 50% prediction interval:	$4,443,620	$8,128,144	$8,763,186
Lower 95% prediction interval:	$71,478	$71,478	$71,478
Upper 95% prediction interval:	$14,276,767	$18,870,712	$19,703,408



Duda et al. 2023. Frontiers in Ecology and Evolution.

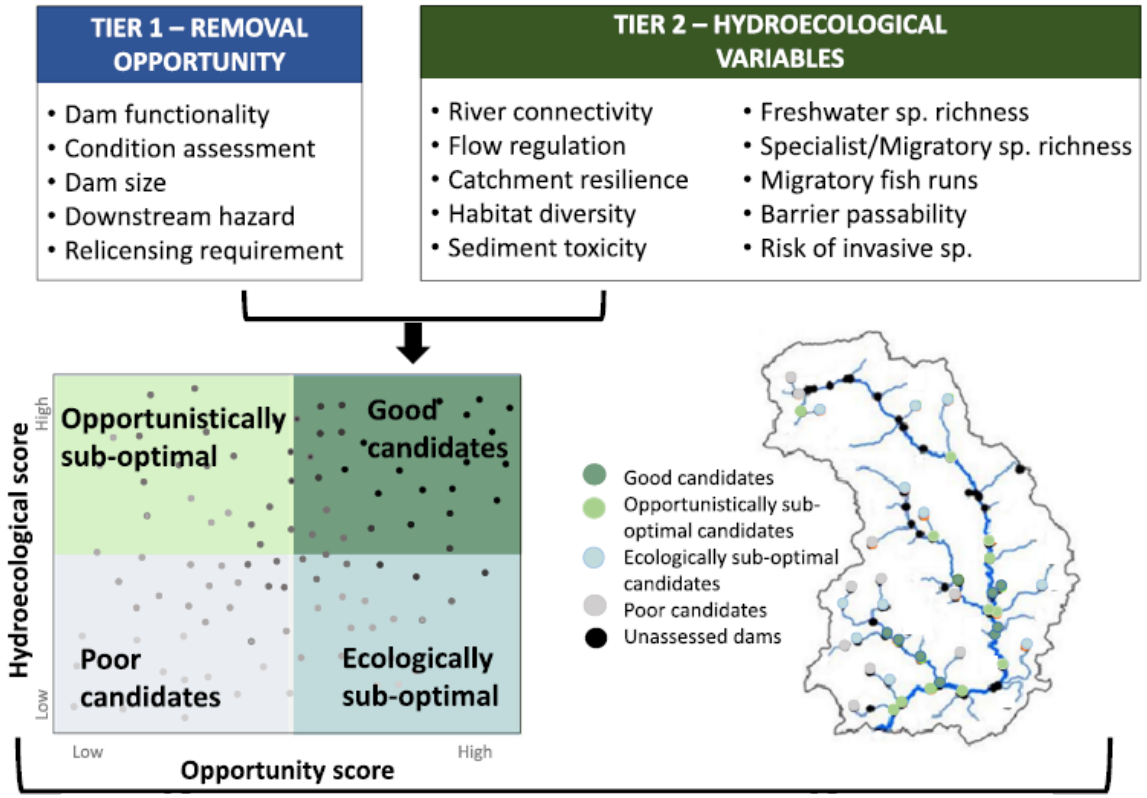
Environmental Challenges

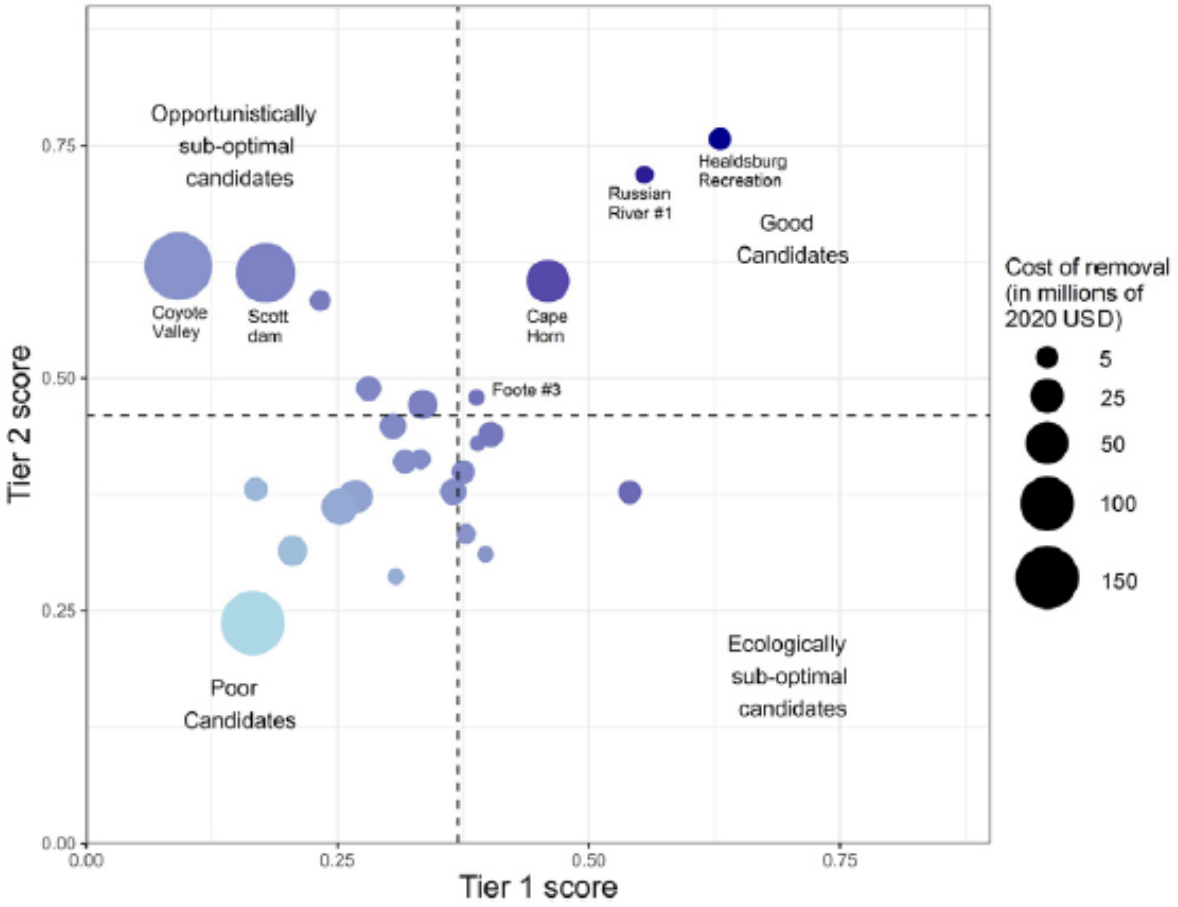
Open access

Vol 12:100731

A decision-support framework for dam removal planning and its application in northern California

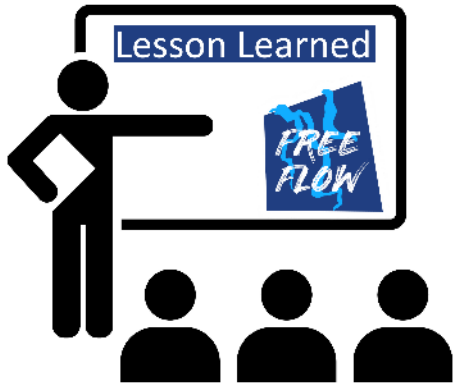
Suman Jumani[a,b*], Lucy Andrews[c], Theodore E. Grantham[c], S. Kyle McKay[d], Jeffrey Duda[e], Jeanette Howard[f]





Smith, Redwood, Mad, Eel, Russian, Cape Mendocino, Mendocino Coast, and Bodega watersheds

Big data for dam removal – an aspiration not fully realized



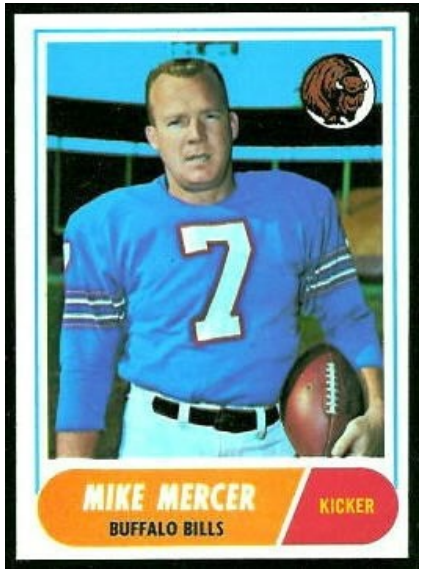
- Even “the basics” can be hard to come by
  - Who, what, where, why, and how?

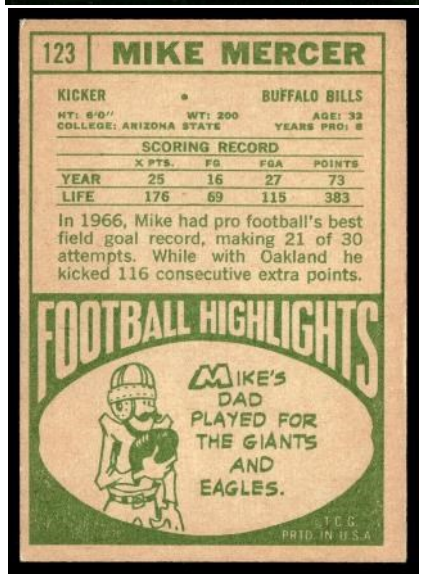
Global/continental data sets on Dam Removal are extremely valuable … but largely incomplete (aside from “maps with pins”).

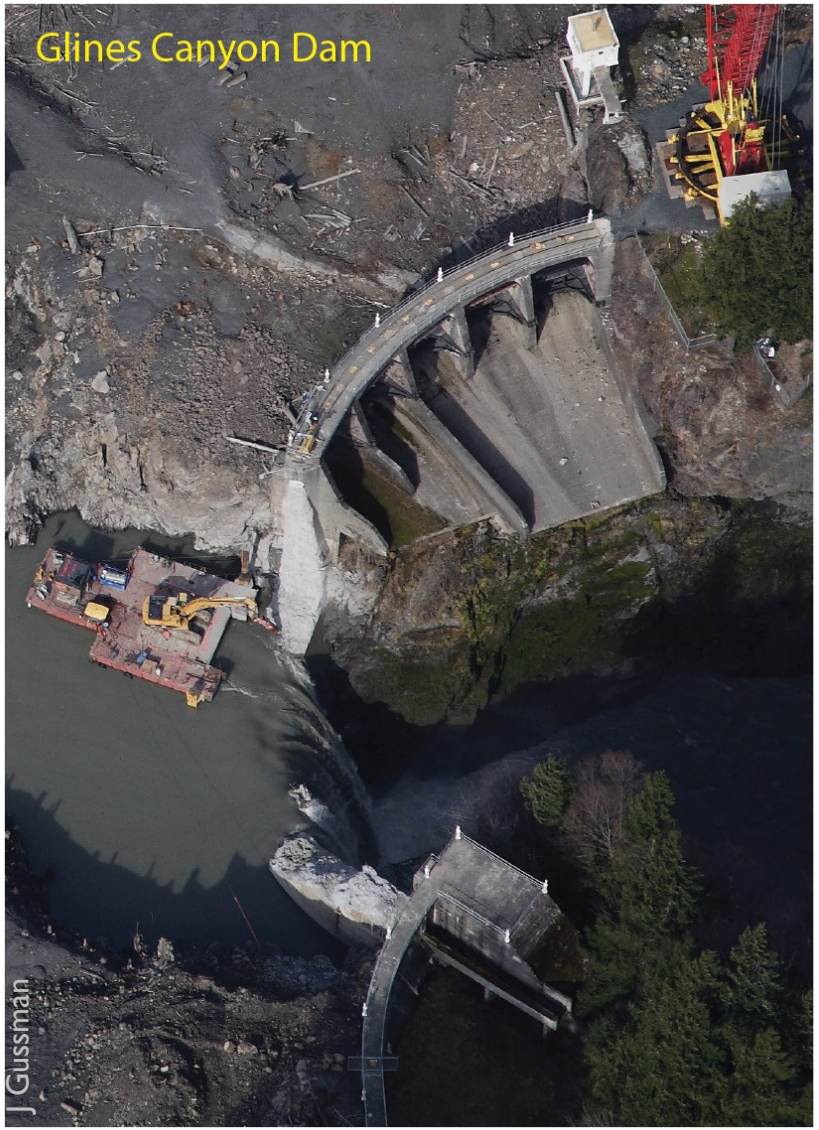
Licensed Adobe Stock

USGS

“The Basics” for each dam removal







Glines Canyon Dam

Feature ID:8b689cf1-6626-43e4-8ffc-234aaea768ad

River name: Elwha River
Location: Washington, USA
Lat: 48.002
Lon: -123.6

Height: 64 m
Material: Concrete
Year Built: 1927
Purpose: Hydroelectric

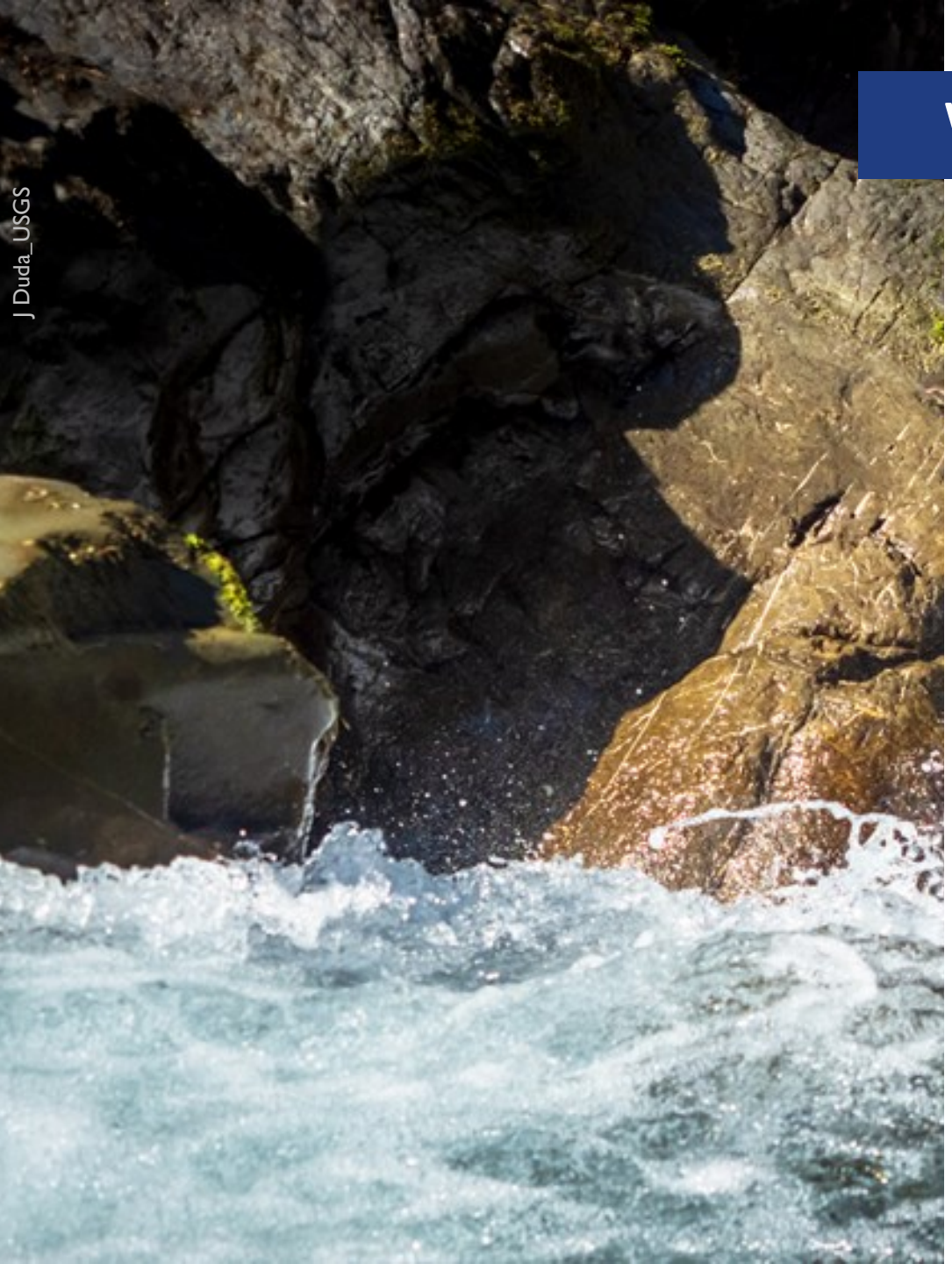
Year Removed: 2014
Reason removed: Restoration
Removal Type: Staged
Cost (est.year): $268.8 M (2014)

Sediment volume: 15.6 x 10^6 m^3

Fish species impacted: Salmon (Chinook, Chum, Pink, Coho, Sockeye, Steelhead), Bull Trout, Pacific Lamprey

Mitigation required: Yes

Cost drivers: pilot channel, , fish hatchery, levees, revegetation, water treatment



What to do when resources are limited?

- Not every project will have “Elwha” resources ($)
- Record “the basics”
- ID the most important Q’s that are locally relevant
- Citizen/Community science
- Technology
  - Drones
  - Publicly available satellite
  - eDNA
  - Long-term photo points

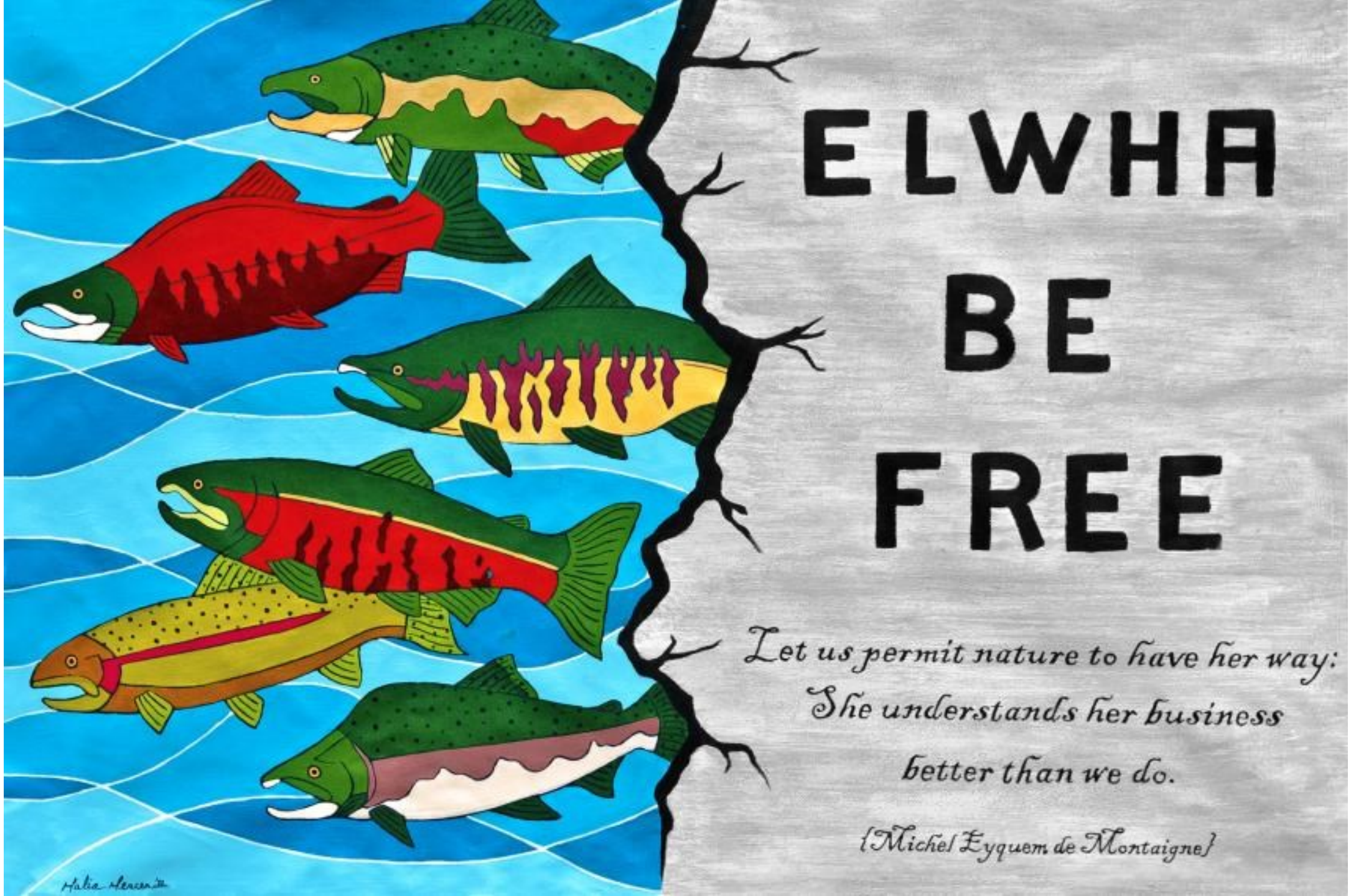
Thank you—Gracias—Merci—Grazie—Go raibh maith agat—Danke—Dankjewel—Kiitos—Obrigado—Dziękuję—Hvala—Tak—Děkuji vám—Ďakujem—Diolch—Köszönöm—Ευχαριστώ—Paldies—Vă mulțumesc

Acknowledgement

- The Lower Elwha Klallam Tribe
- National Park Service
- USGS
- The Elwha Science Community
- The Powell Center Dam Removal working Group
- American Rivers
- Dam Removal Information Portal (DRIP) developers
- Dam removal cost database developers
- Bureau of Reclamation
- Army Corps of Engineers

FREE FLOW

jduda@usgs.gov


ELWHA
BE
FREE
Let us permit nature to have her way:
She understands her business
better than we do.
{Michel Eyquem de Montaigne}

Elwha impact: inspiration and hope

Pao Fernandez-Garrido, Dam Removal Europe, 2022, at the Elwha ScienceScape conference

Source: A. Kojima, P. Pearsall, J. Gussman. Clip from USGS Geonarrative "The Elwha River: Landscapes of Recovery"
https://geonarrative.usgs.gov/elwhariverrestoration/