Understanding and recovering the drivers of salmon productivity and resilience in the South Fork Eel River

Figure from Dralle et al. (2022) *in review*

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What does a healthy South Fork Eel River look like?

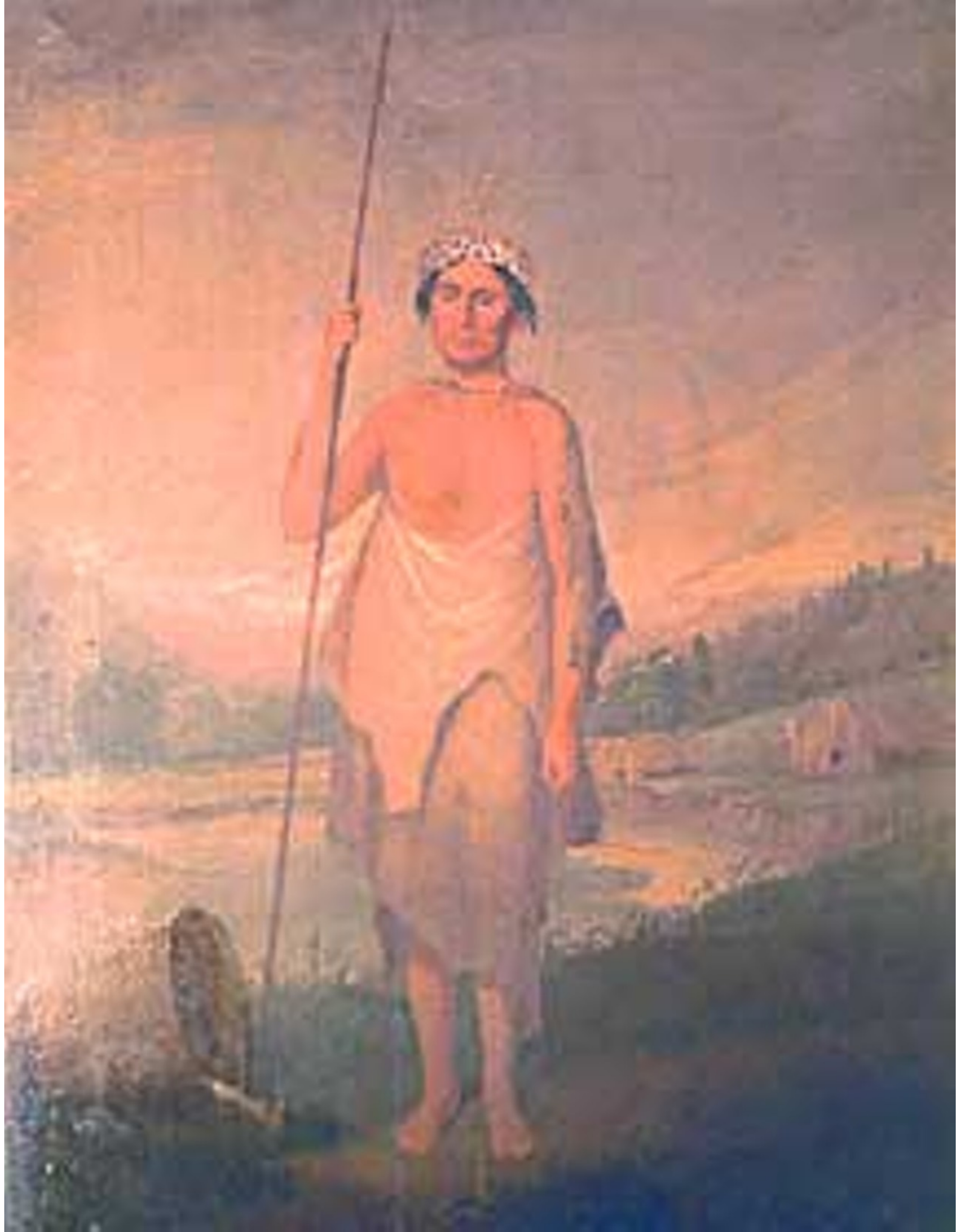
Four themes salmon productivity and resilience

- Juvenile Salmonid Life History Diversity and “ghosts of life histories past”
- The Salmonid and the Subsurface (Dralle, Dralle, Dralle!)
- Altered Foodscapes
- Lost Species Interactions

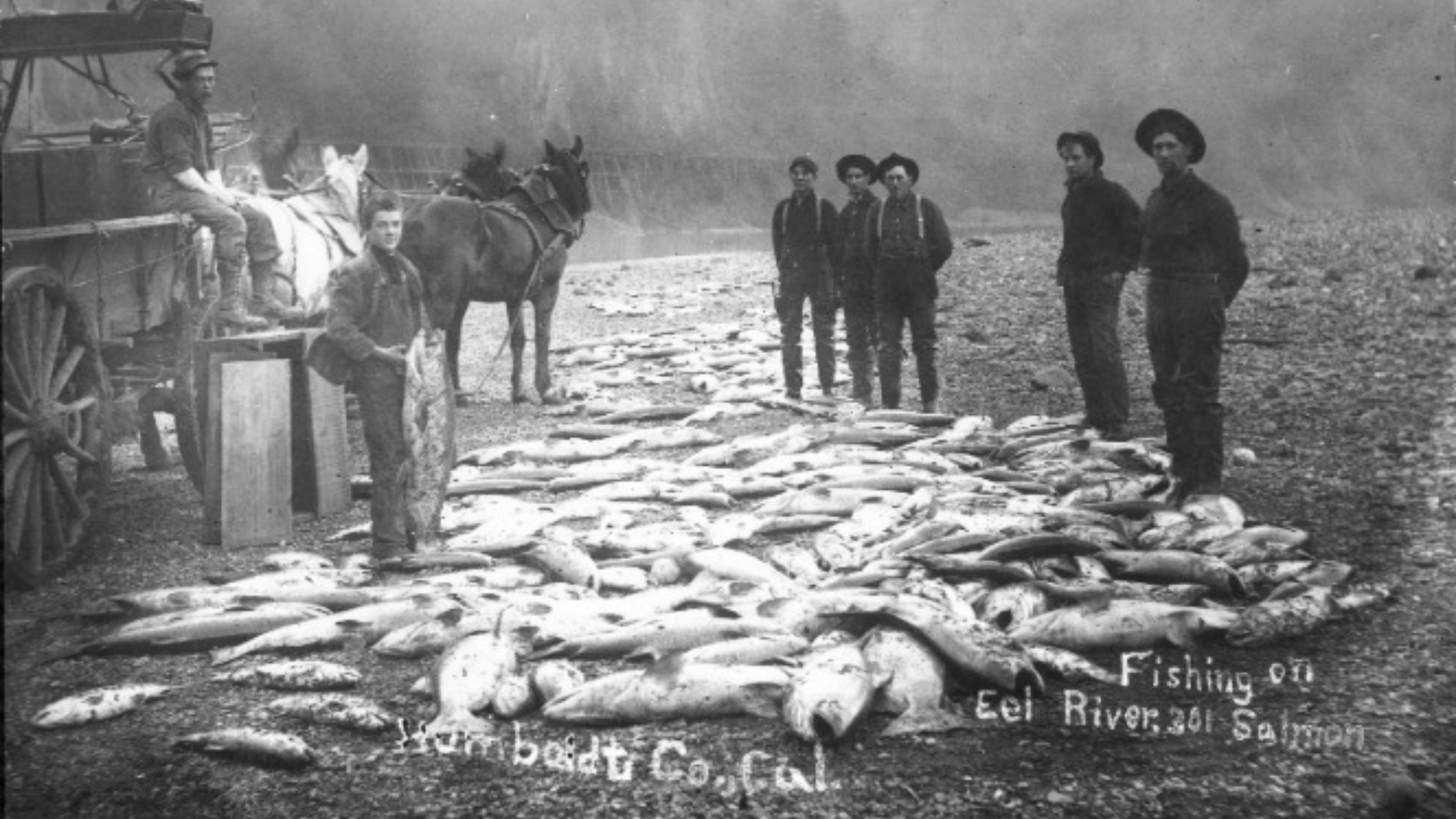
With these themes in mind let’s explore:

How might this river changed in the last 165 years? How might it not have changed? How can we look forward?

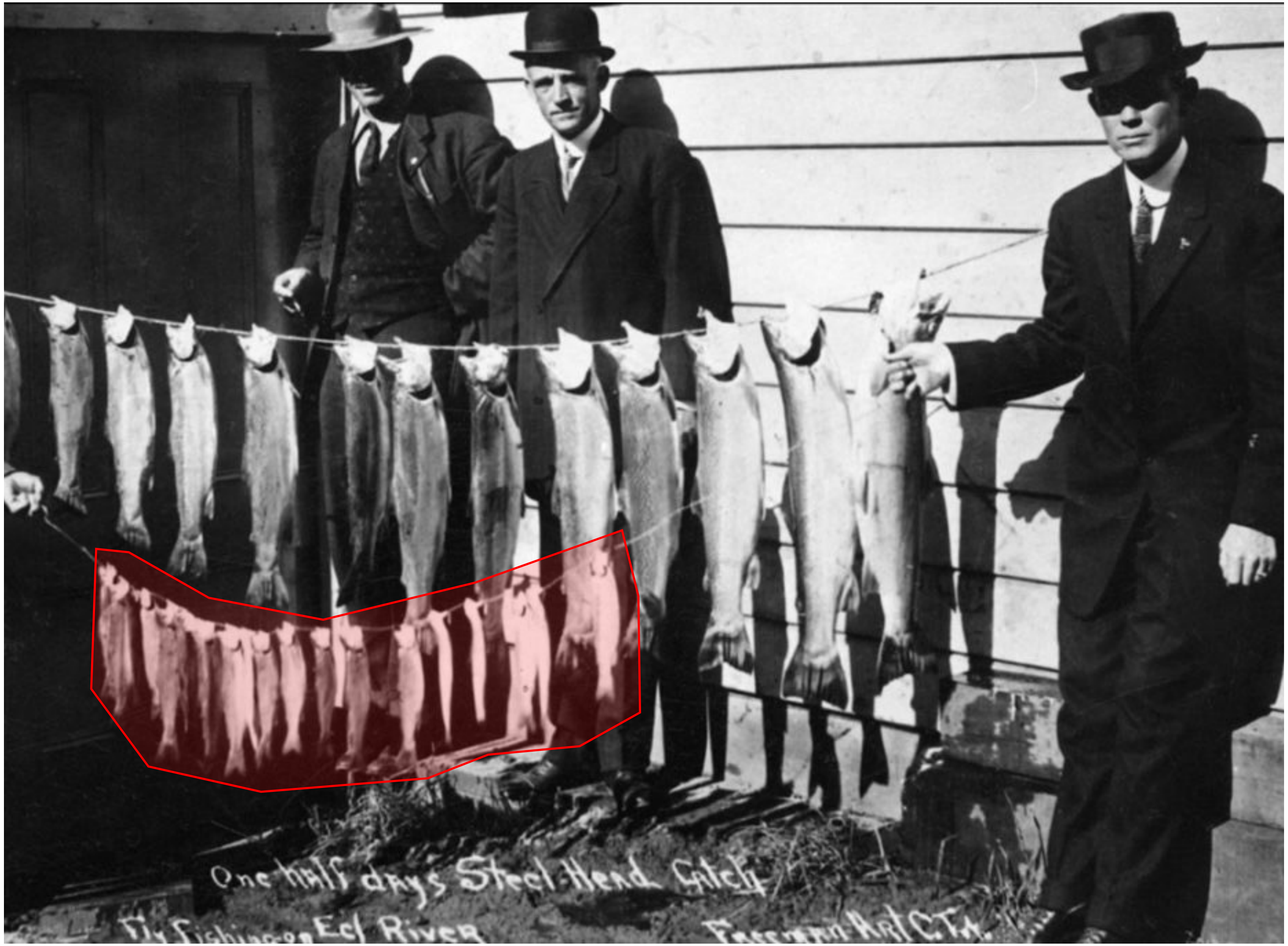
(1) a shady tributary which stays cold all year; (2) a sunny tributary with high growth potential for salmon in spring but warm intermittent flow in late-summer; (3 and 4) the canyon-bound mainstem river, (5) a newly restored estuarine slough near Cannibal Island (showing unrestored pasture land beyond) and; (6) the open estuary of the Eel River



Painting of Wiyot Elder Ki-we-lah-tah


Fishing on
Eel River, 361 Salmon
Humboldt Co., Cal.

Cannery at Port Kenyon [Crop of an image from the Palmquist Collection in the Humboldt Room of HSU]



John Snyder's first description in 1925 of the "half-pounder" steelhead life history type in the Eel and Klamath rivers. A half-pounder is an immature steelhead that returns to freshwater within about four months of entering the ocean, and is primarily found in rivers in Northern California and Southern Oregon.

The synergy of doom: Mechanized Logging Boom + 1955 & 1964 Floods (and other floods)

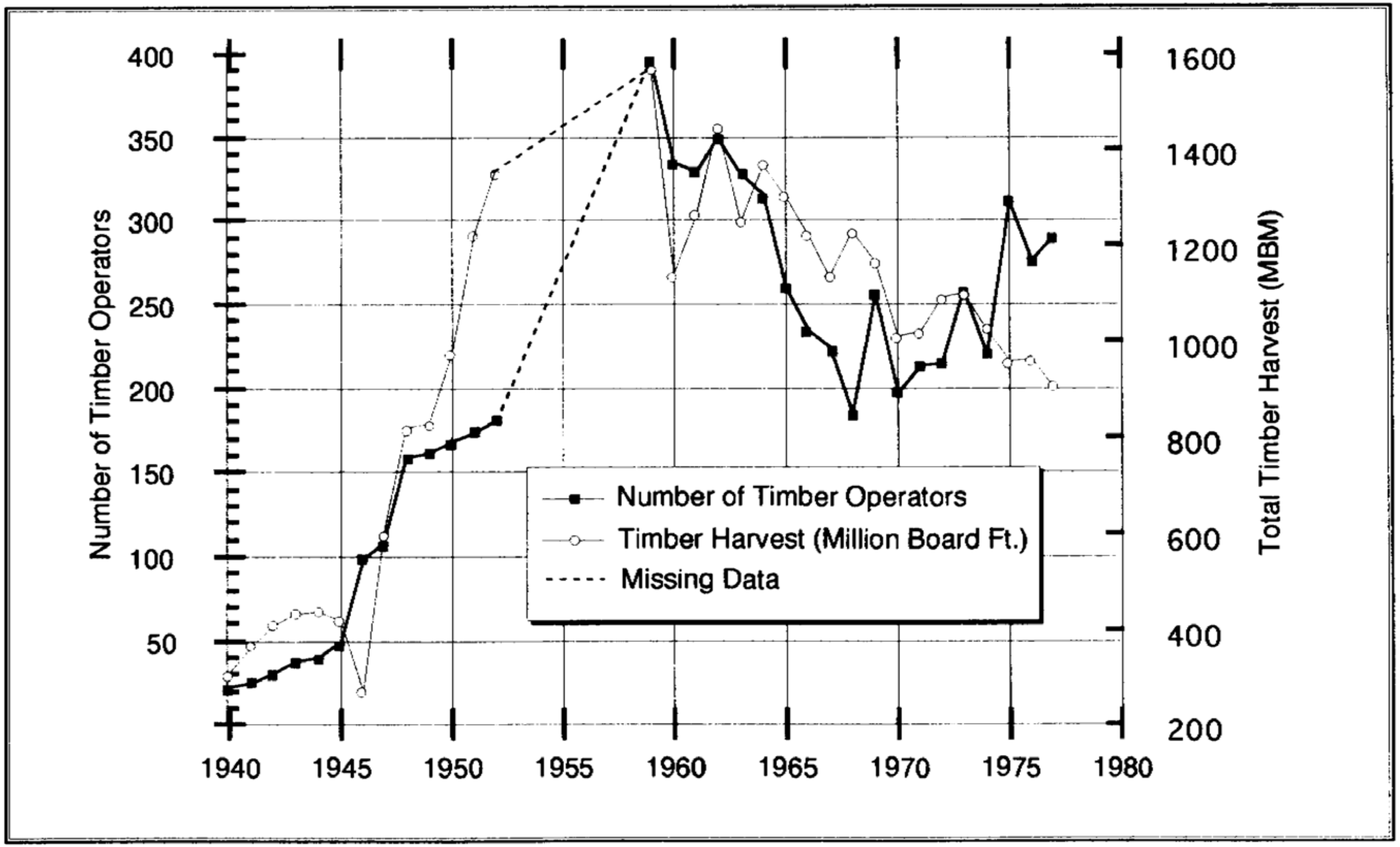
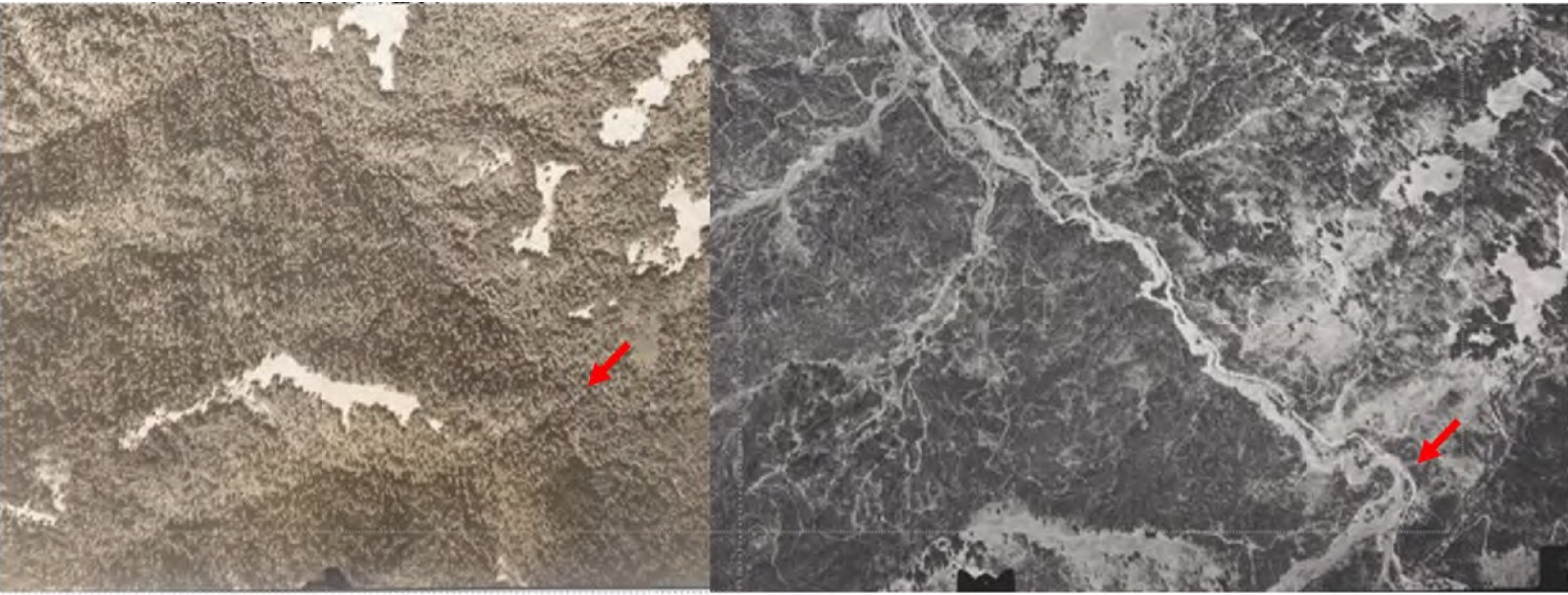


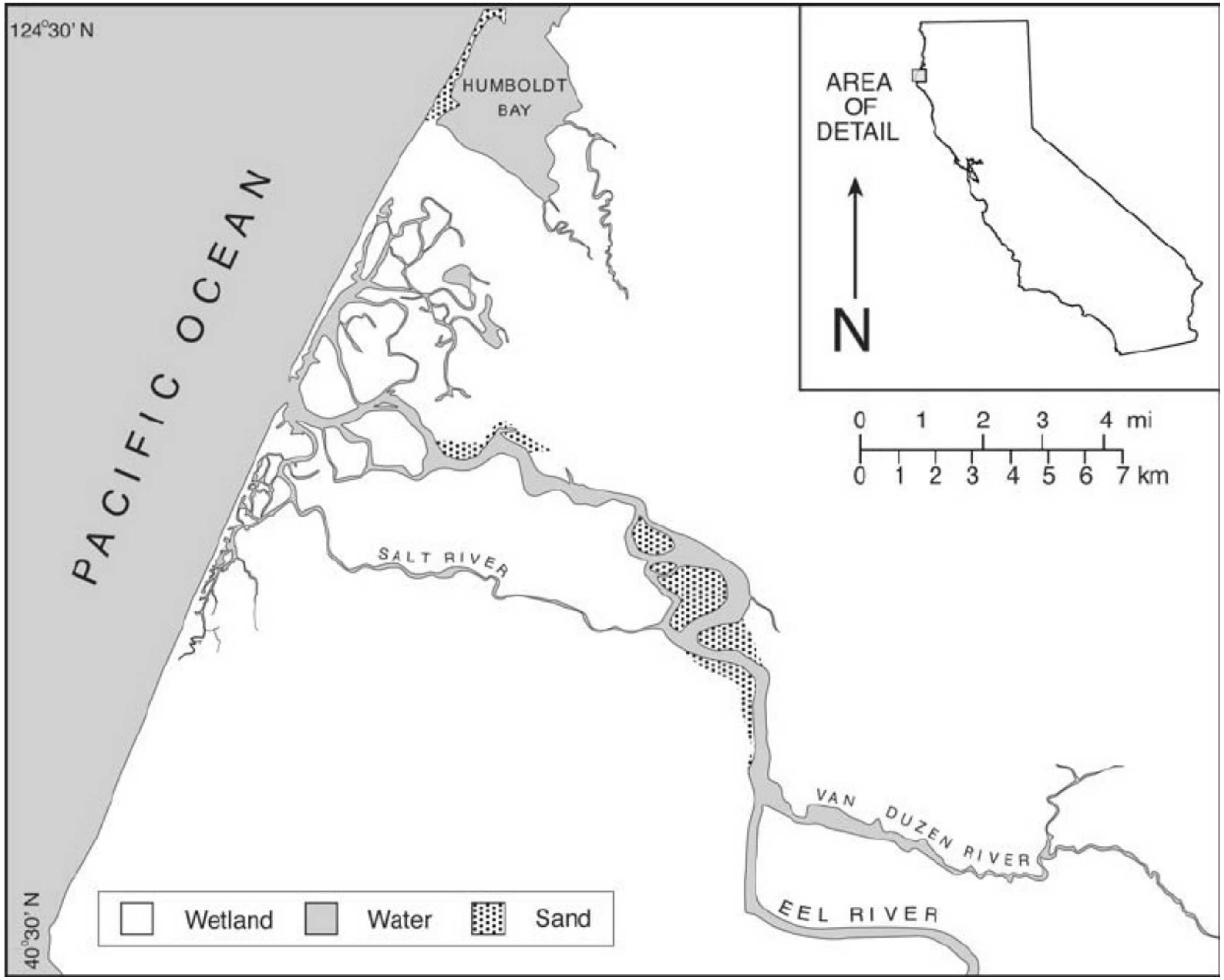
Figure 18. Number of Timber Operators and Total Timber Harvest: Humboldt County, 1940-1977. (Henry J. Vaux, An Economic Appraisal of Forest Resources and Industries in Humboldt County, California. 1954.; State Forest Notes 1961-1979).

Figure 6. Yarder Operation. (HSU Library Photograph, Gerald Partain Collection, PAR 68).



Upper Bull Creek from Slide Creek to Panther Creek from 1942 (left) to 1965 (right). The extensive upland road networks, deforestation, and flood damage are shown in stark contrast to the nearly unaltered 1942 landscape. The red arrows indicate the confluence of Panther Creek and Bull Creek. From *South Fork Eel River SHaRP Collaborative. 2021*.

FIGURE 20.—Paul Mudgett Memorial Bridge on U.S. Highway 101 over the Eel River at Rio Dell, 28 miles south of Eureka, Calif., destroyed by rampaging floodwaters, December 23, 1964. Photograph by Eureka Newspapers, Inc.



Channel widening from extensive bank erosion was the dominant geomorphic change along the lower Eel River during major floods. As a result of the 1964 flood, the largest amount of widening was 195 m and represented an 80% change in channel width (Sloan et al. 2001).

Excessive **sediment deposition from headwaters to estuary.** In the lower river in combination with levees and tidegates, **reduced tidal prism** in the Eel River Estuary up to 3 miles and reduced the total volume of tidewater by approximately 40% since 1900 (SCS 1989).

Loss of deep pools in the lower Eel (especially between Van Duzen and Fernbridge)

A review of bathymetry maps produced in 1869 showed that depths near the river mouth were 10 ft to 16 ft (3.05 m to 4.9 m) and the North Bay and lower portions of McNulty Slough ranged between 9 ft to 13 ft (2.7 m to 3.96 m). The North Bay channel ranged from 10 ft to 14 ft (3.05 m to 4.3 m) in depth, and the river thalweg and pools around Cock Robin Island were from 25 ft to 31 ft (7.6 m to 9.4 m) in depth

Speaking of the fisheries, I will here say that the salmon fisheries of Eel river are an important branch of commerce, and they cannot be carried on without the assistance of Indians. The river bed is generally full of snags, which must be removed before seines can be hauled, and none but an Indian can go down **in from three to six fathoms of water** and attach the necessary rigging for hoisting them out. -- Humboldt Times July 1869)

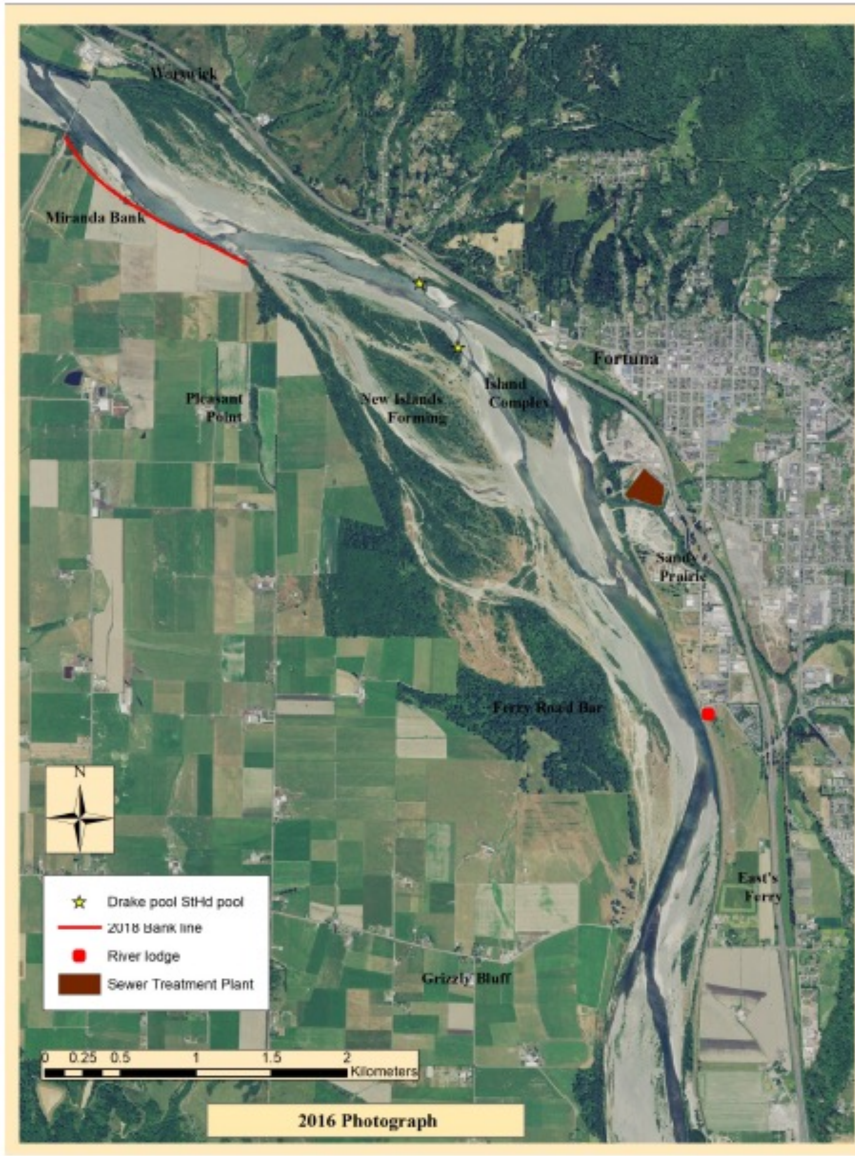
WHT (11 Aug. 1877) Rohnerville, August 6, 1877, Editor Times--...More than one hundred large sturgeon have been killed **in one deep place in Eel River, near the mouth of Van Duzen**, in the last month.

In this way the fish can be dragged… **out [of] the deep holes at the head of tide water** where they are often forced to lie and wait for enough water to allow them to ascend the river. Humboldt Times 1910

"Local anglers anticipate an old time fishing season here this year as **the Weymouth pool is very deep** and in the condition of several years ago when it furnished the best of fishing. The river between the **Weymouth and Van Duzen pools** is again in one channel, which will give the fish an opportunity to get over the riffles."

FE (5 Jan. 1917) Thousands of Salmon on Spawning Grounds--Before the recent heavy rains which have swelled the waters of Eel river considerably, **the deep pools in the river between Fortuna and Shively** were literally filled with salmon which had succeeded in passing the gillnets of the commercial fishermen at the mouth of the river.

Levees and Lower River



Levees, tide gates, dikes, and berms have been installed to reduce tide-water volume, to reclaim wetlands for agricultural conversion, and to better control high water events. The network of levees and tide gates in the Eel River estuary has, in places, blocked the ebb and flow of the ocean tides and has reduced the volume of water that is exchanged during a tidal cycle. In 1870, the tidal area was estimated to be 6,525 acres. By 1970, the estuary, inclusive of sloughs and side channels, was reduced to 2,200 acres, or 3.4 square miles (DFG –ERSSAP 97' pg 4). SALT RIVER EIR

Sacramento Pikeminnow *Ptychocheilus grandis*,

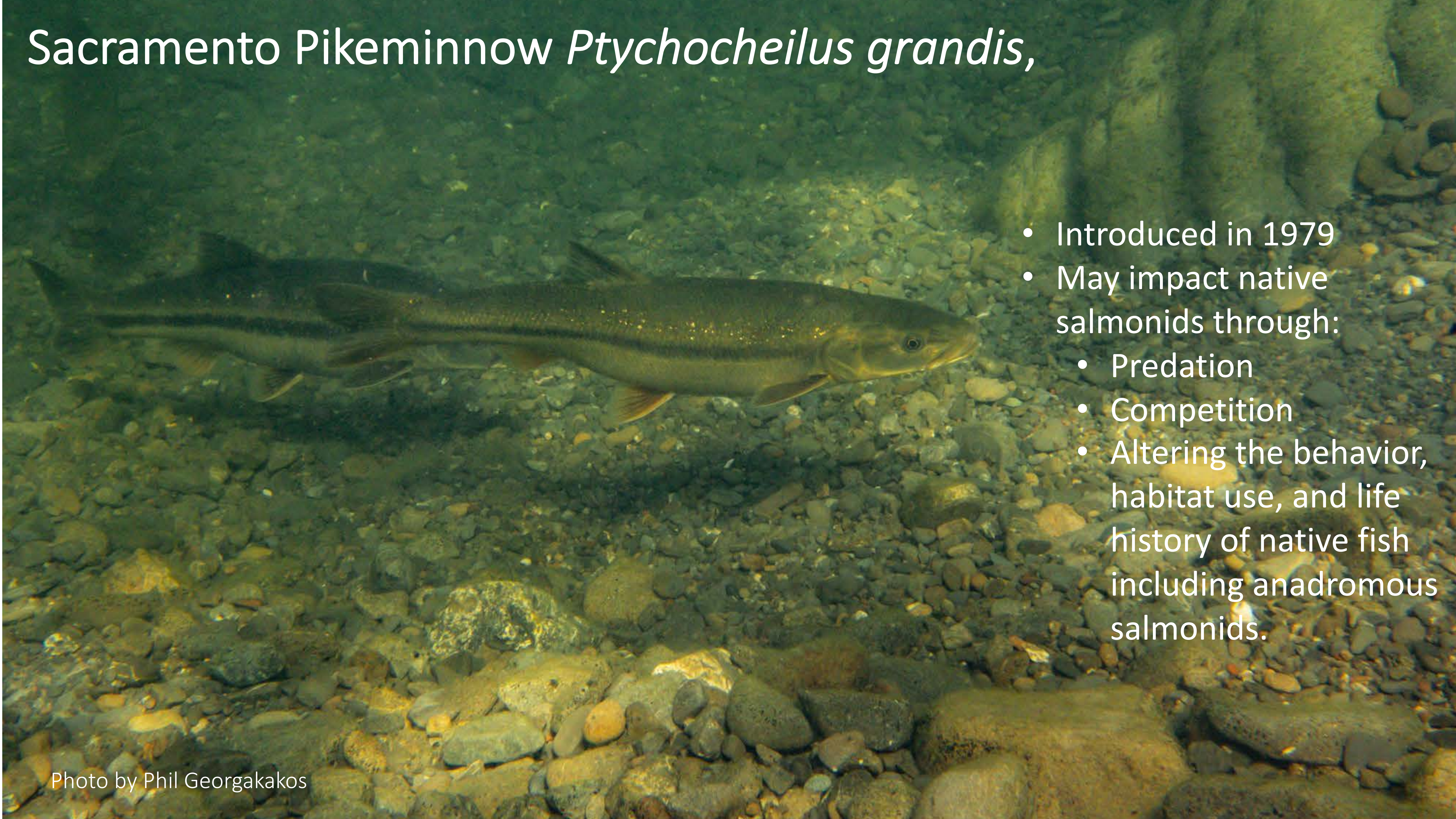


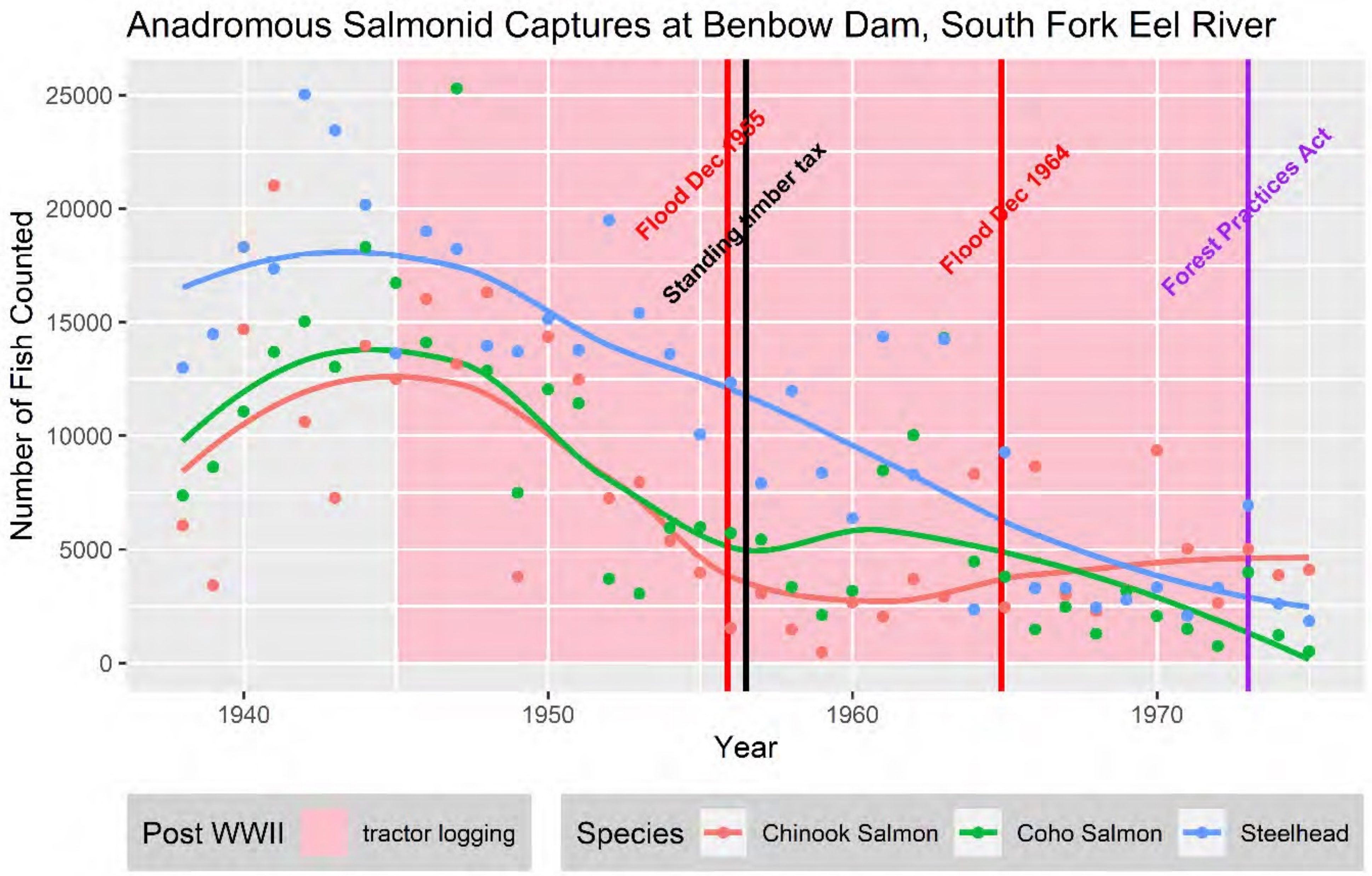
Photo by Phil Georgakakos

- Introduced in 1979
- May impact native salmonids through:
  - Predation
  - Competition
  - Altering the behavior, habitat use, and life history of native fish including anadromous salmonids.

Other important factors in Eel River salmon decline that we’re not discussing right now

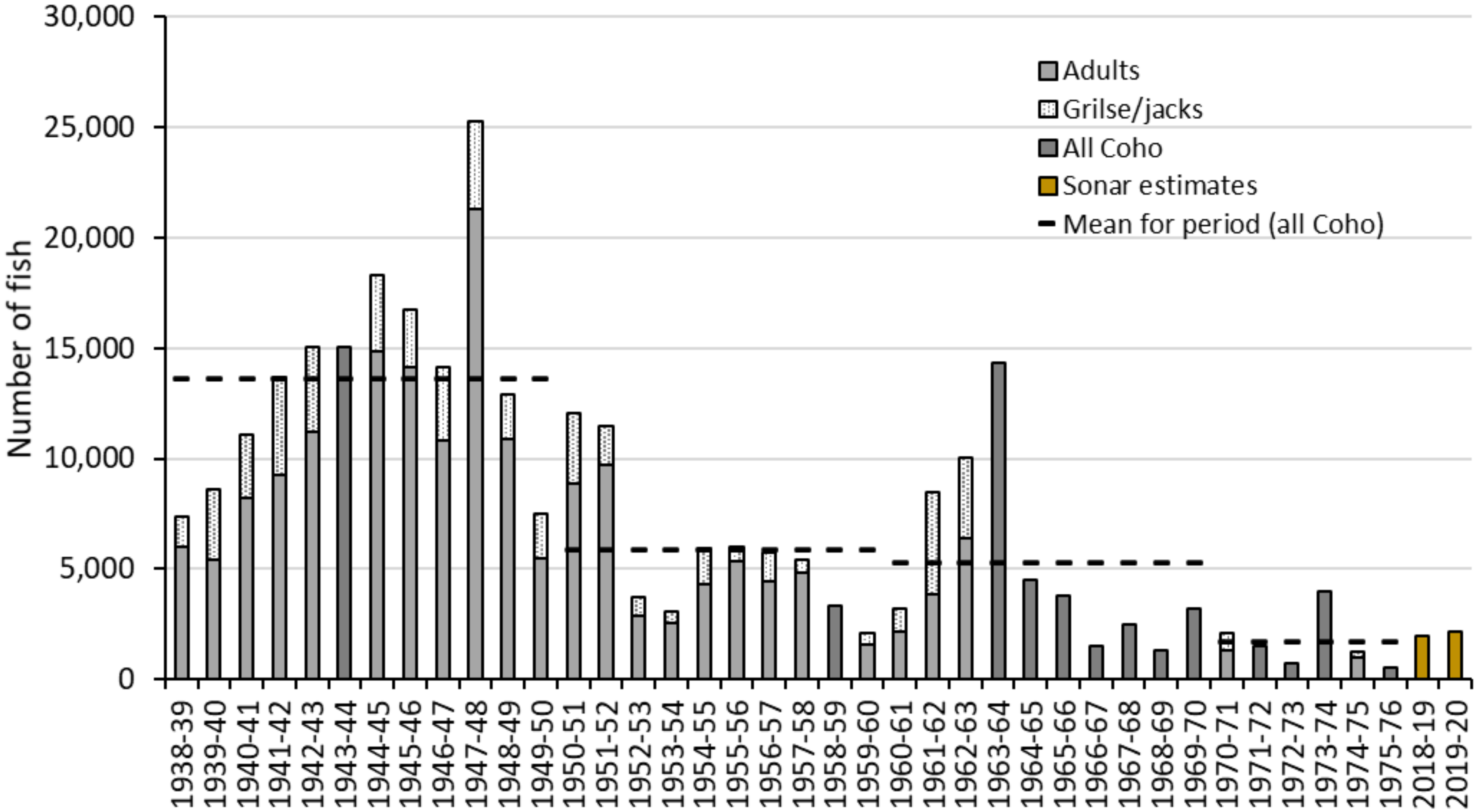
- Climate Change
- Marijuana boom of the mid 2000s
- Changes in Forest Structure Indigenous Burning
- The 1906 earthquake
- Agricultural runoff
- Potter Valley Project

1938 through 1976



Pikeminnow Introduced 1979

From *South Fork Eel River SHaRP Collaborative. 2021*



Historical counts of adult Coho Salmon at Benbow Dam in run-years 1938–39 through 1975–76 and estimates from recent sonar counts conducted by CalTrout in 2018–19 and 2019–20. Dashed horizontal lines represent means for 1930s/40s, 1950s, 1960s, and 1970s. Figure From Stillwater 2022.

What Else Might Have Changed That We Aren’t Focusing On?

Life history diversity and abundance of juvenile salmonids.

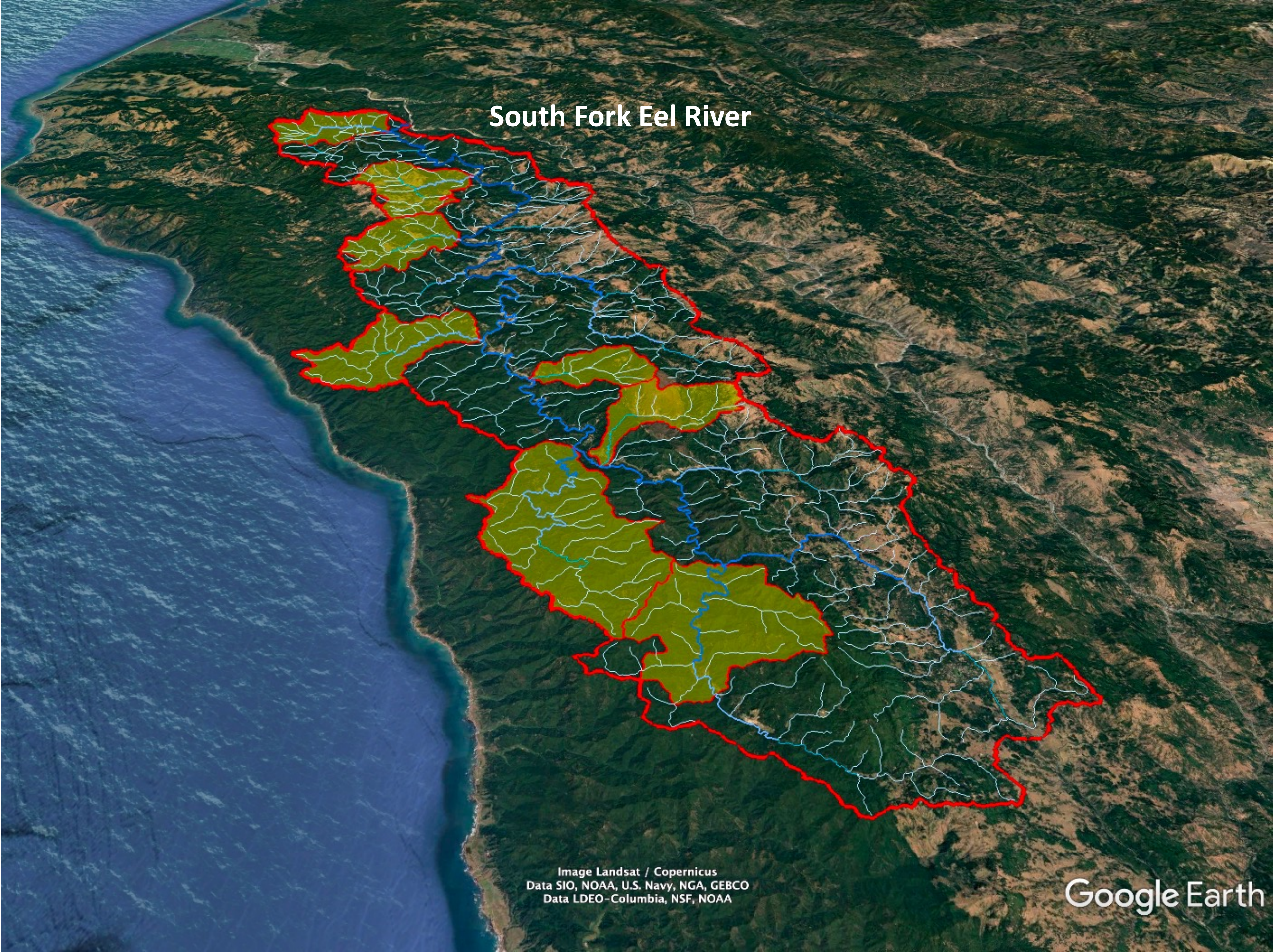
- What are the “ghosts of life histories past?”
- What characteristics of the Eel might give rise to salmon life history diversity?
- How might we have simplified or reduced life history diversity and how can we recover it?

South Fork Eel River

The ghosts of life histories past…

683 miles of stream channel in the South Fork Eel River; but less then 150* miles of cold, perennial, rearing habitat for over summering salmonids.

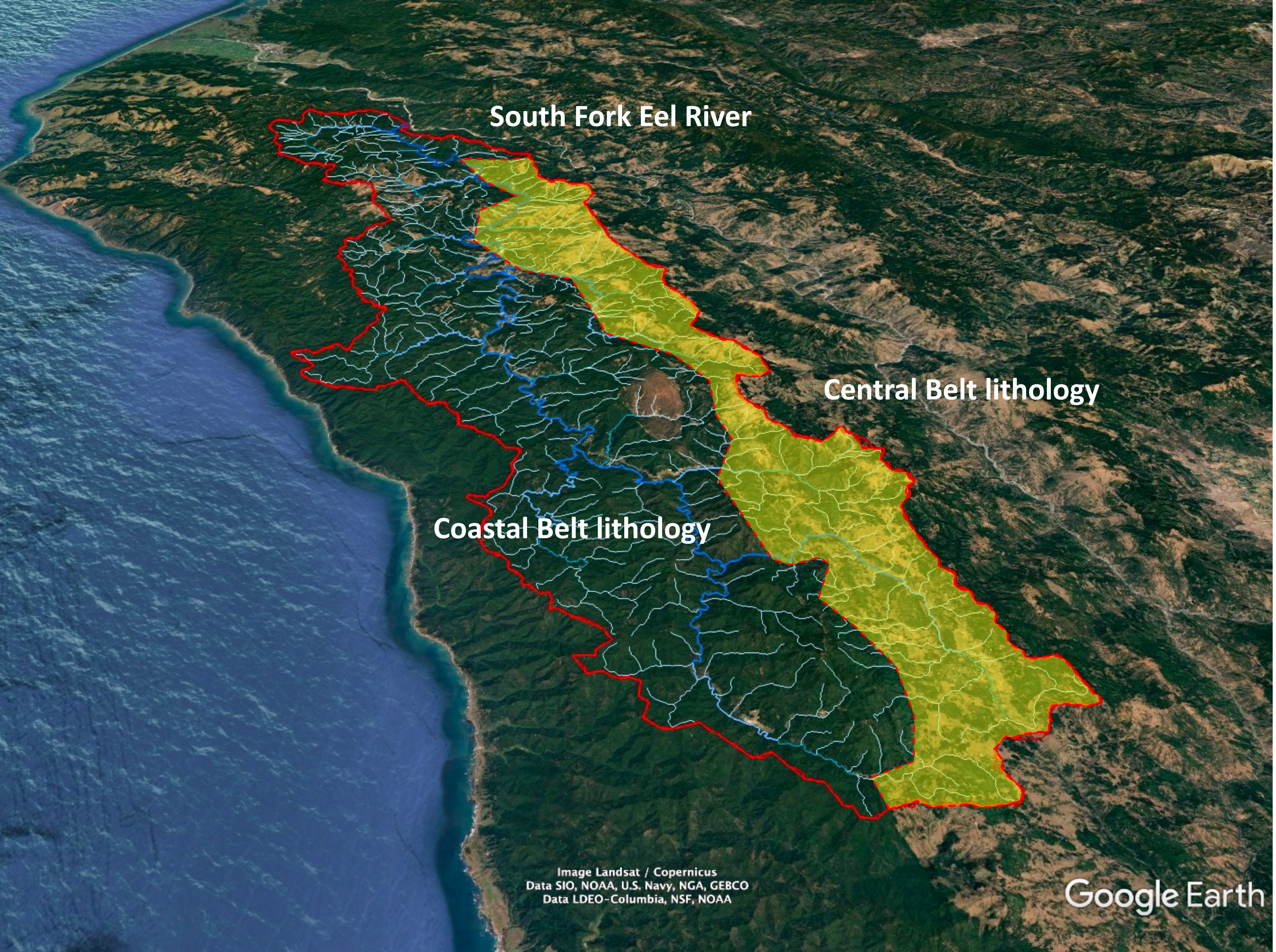
Based on SF Eel SHaRP 2021 Report



How many adult fish could these “ideal” rearing stream produce?

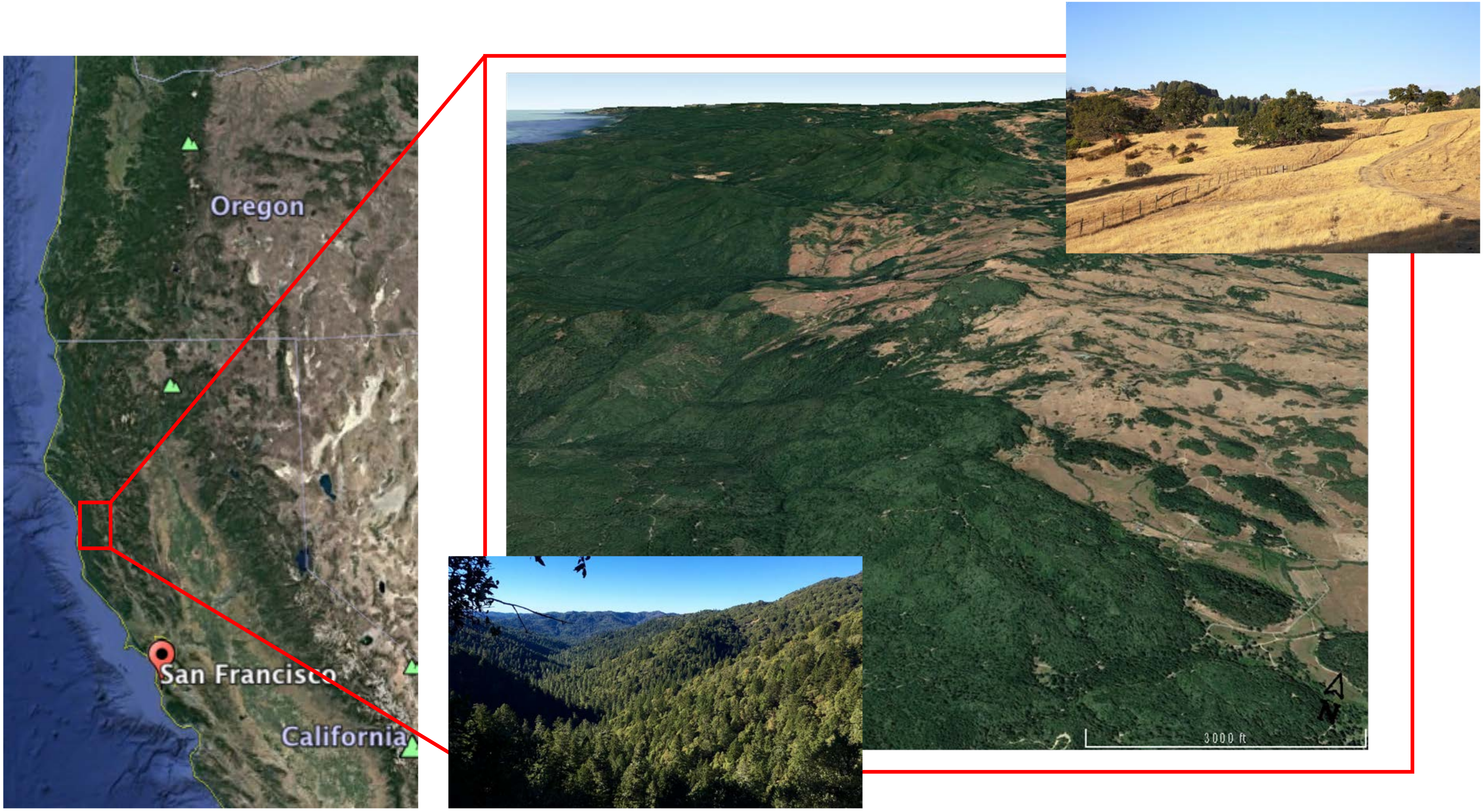
“Silly math for steelhead”
(very inflated density and survival numbers!)

~150 miles of stream;
2000 smolts per mile;
5% SAR
=
<u>300,000 smolts</u>
<u>15,000 adults</u>

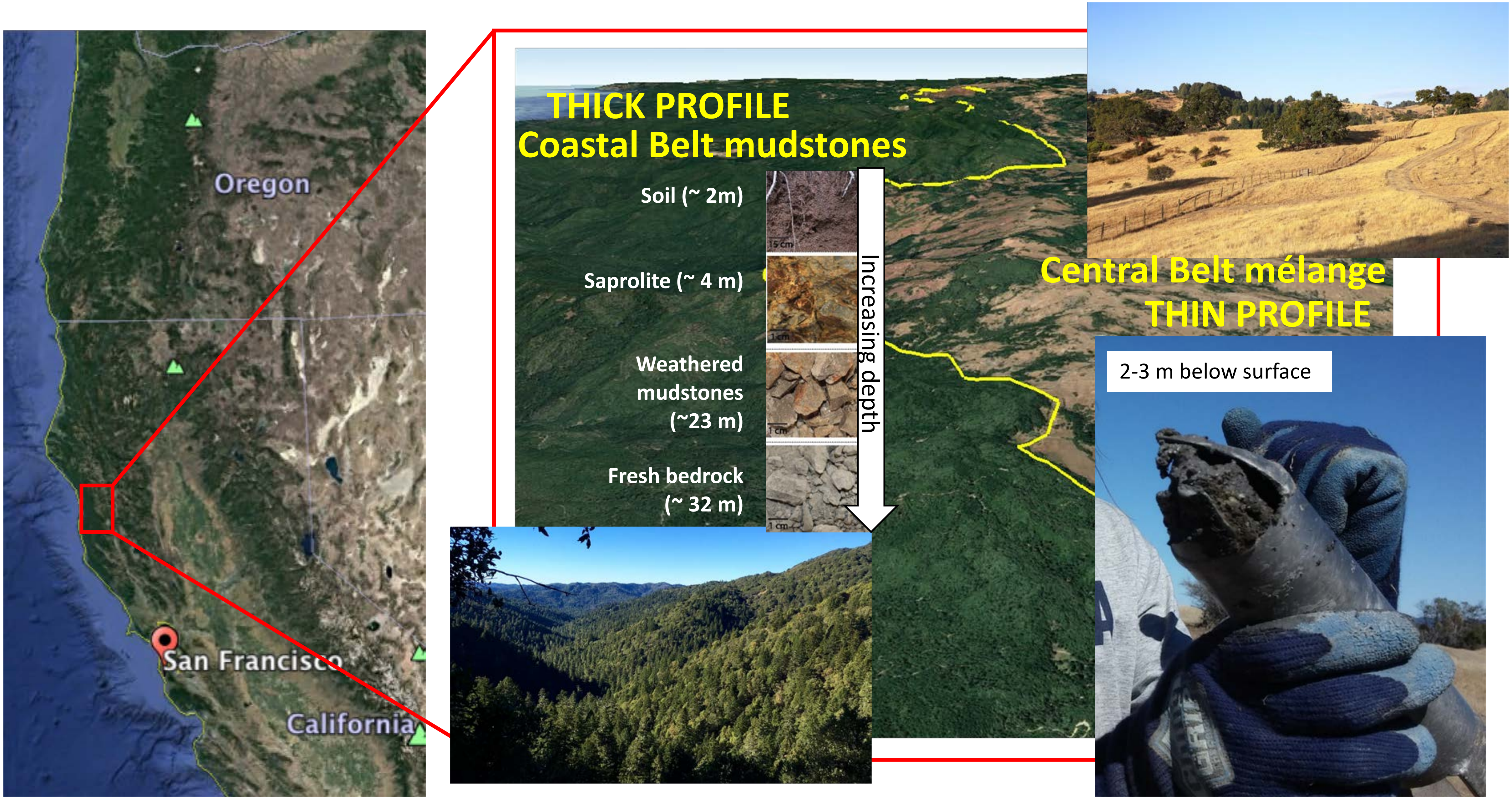


But estimates are that the SF Eel River produced **3X this number of adult fish!** Where did they come from? How did they do it?

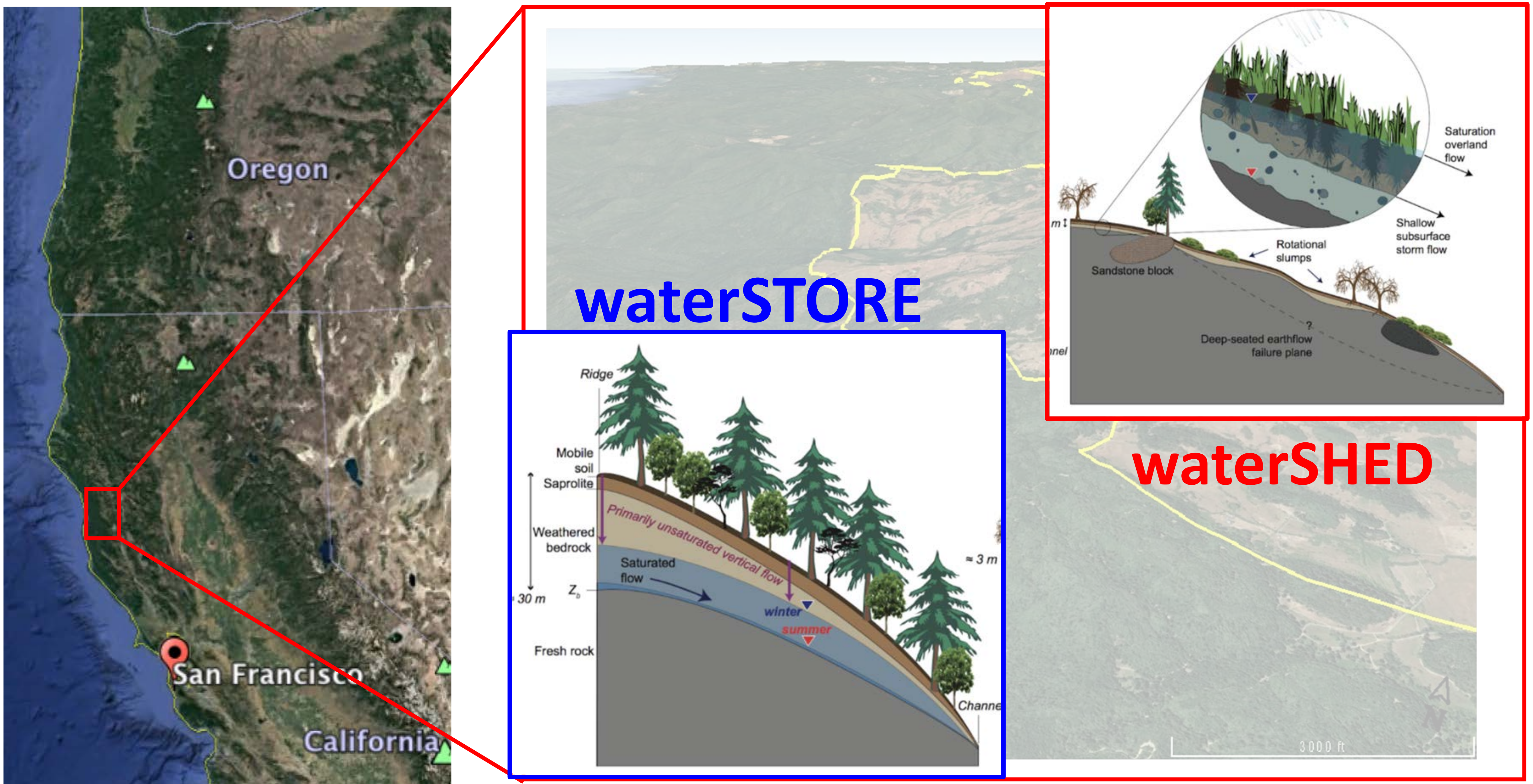
Hypothesis 1: They reared in, and occupied habitats that were only seasonally profitable and migrated to non-natal habitat through an array of life histories that have been either extirpated or massively reduced. Tracking landscape scale growth potential.



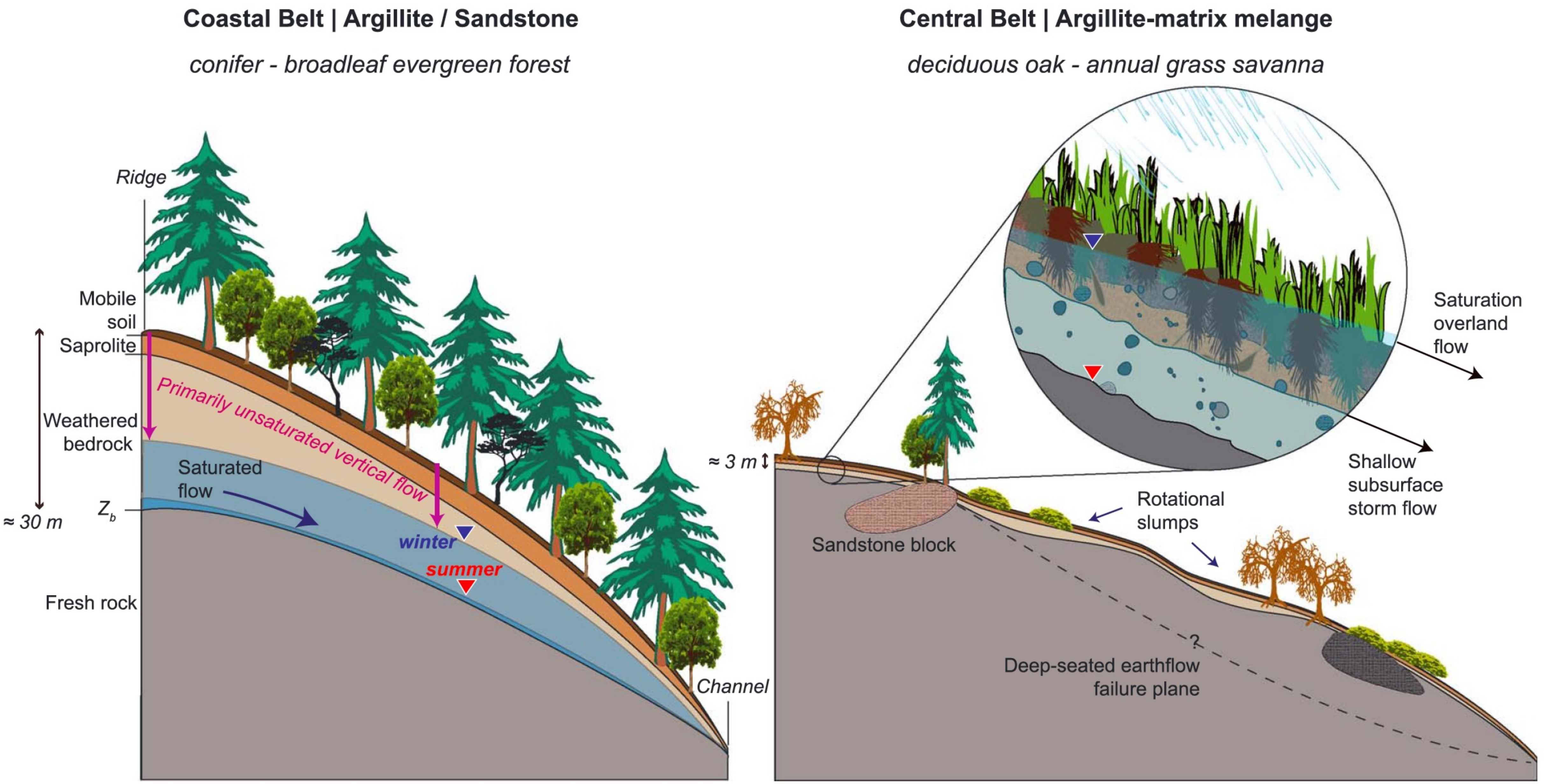
Oregon
San Francisco
California
N
3000 ft



Hahm et al, *WRR, 2019;* Dralle et al, *HP, 2018*;



Hahm et al, 2019



Hahm, Rempe, Dralle, et al,. Water Resources Research, 2019

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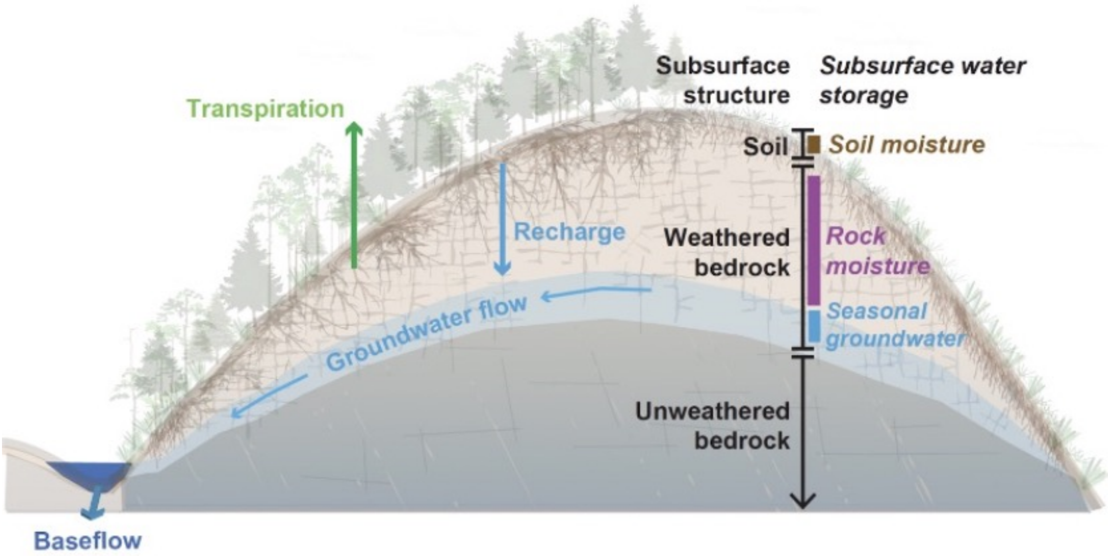
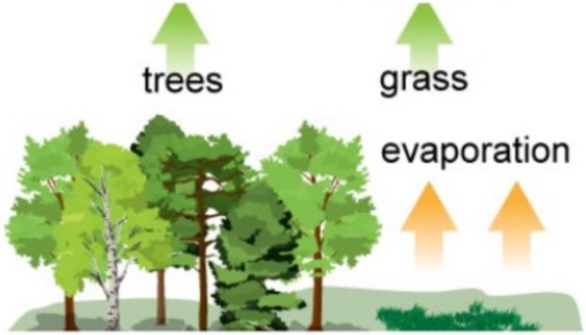
Wisdom of the sponge

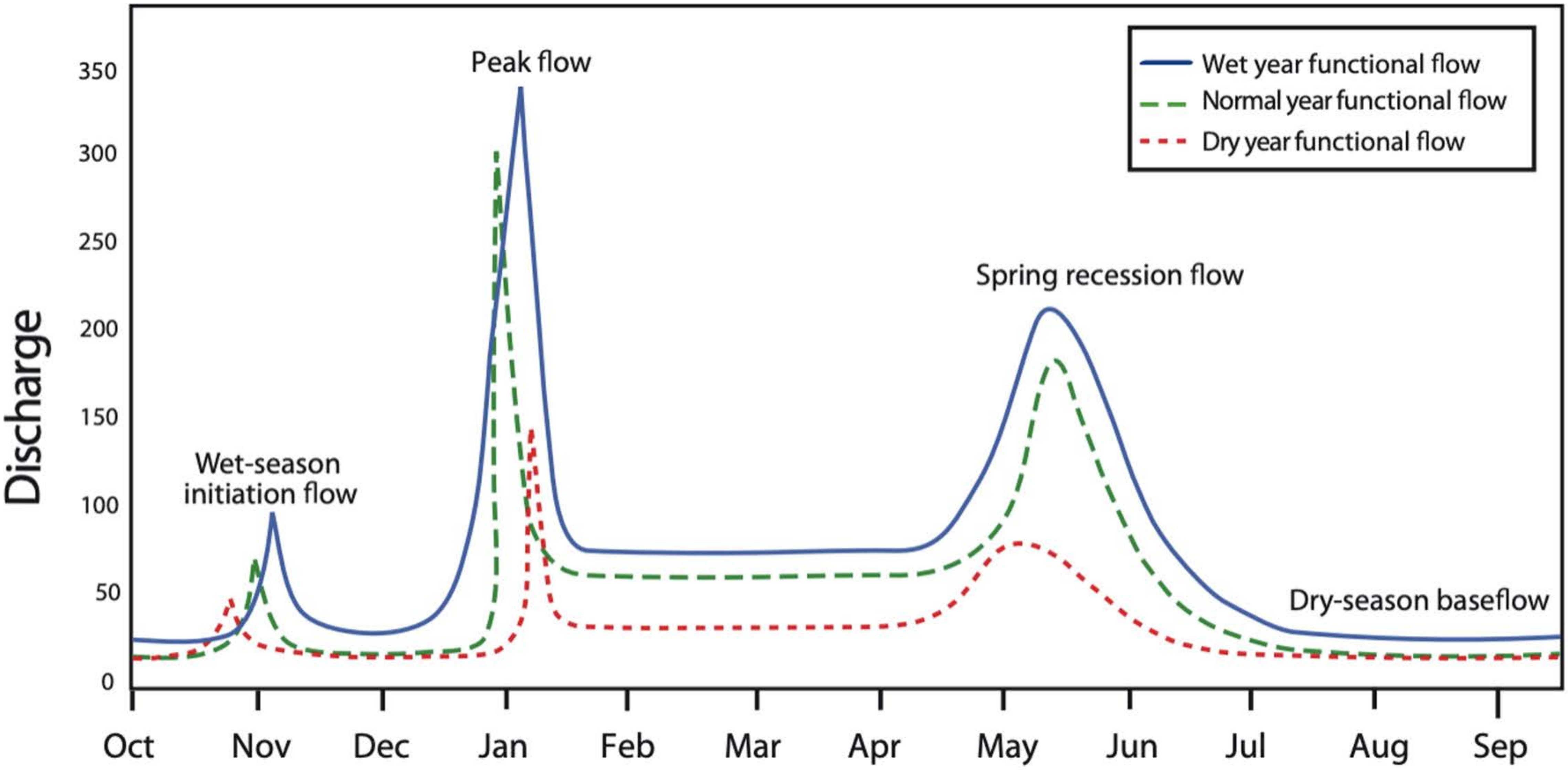
Wet sponge drips excess water, and stays wet



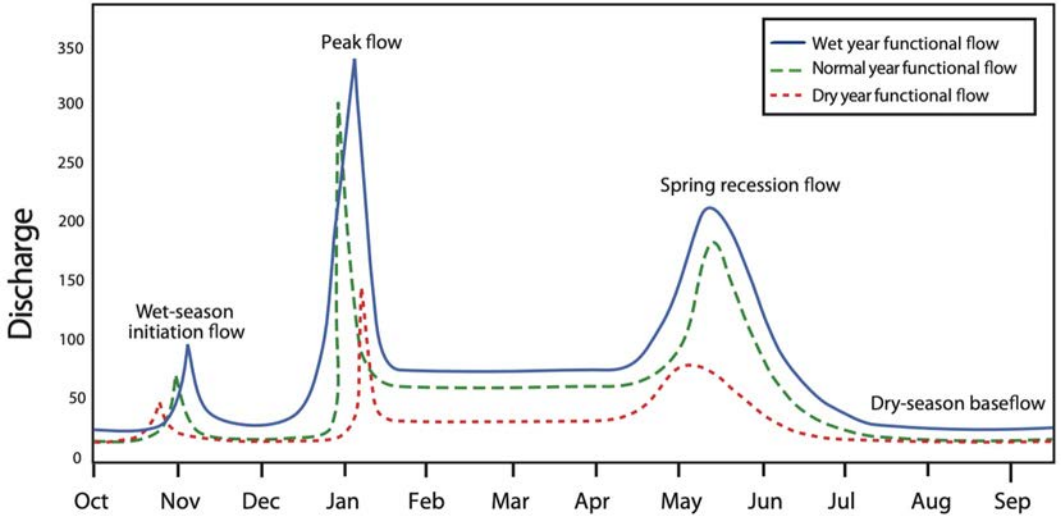
Evaporation fully dries the wet sponge



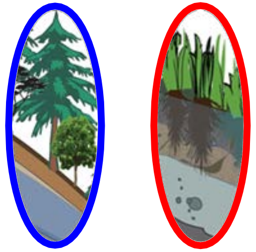
"Functional" flows

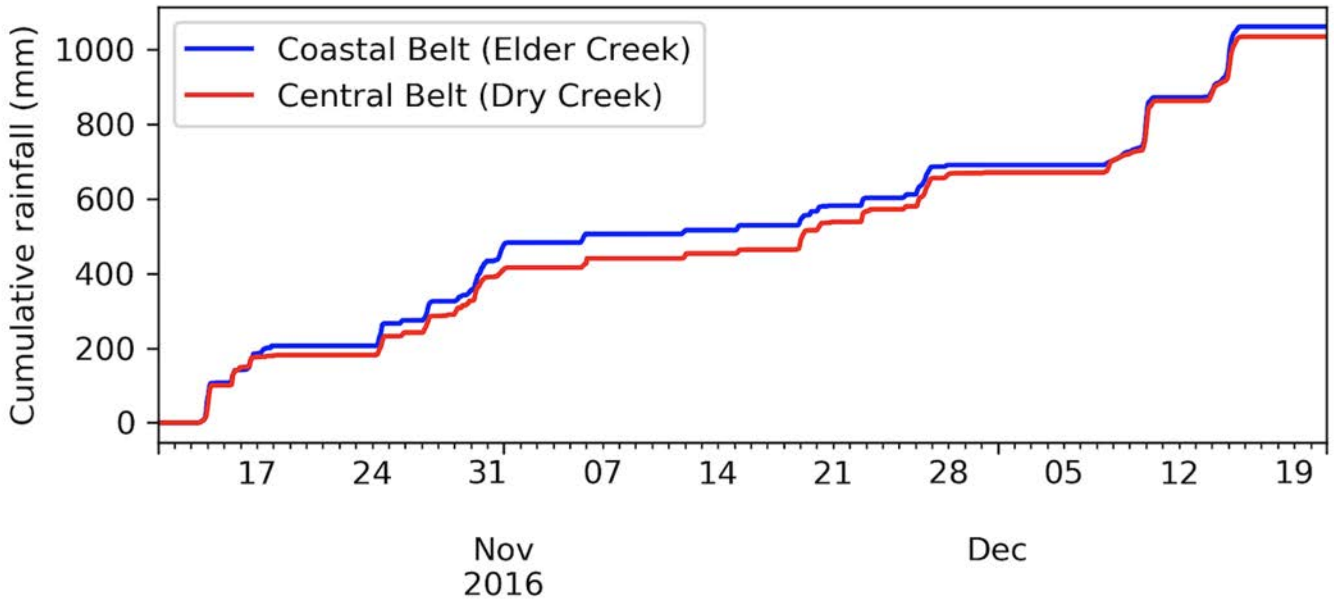


Yarnell et al, 2015

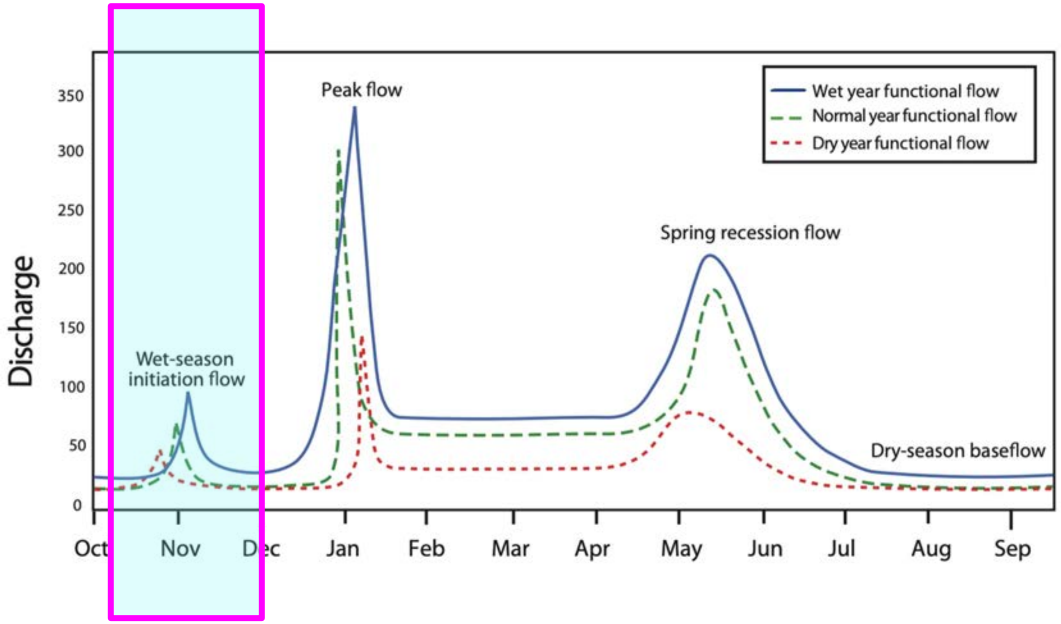


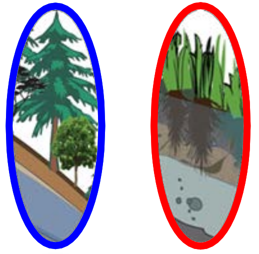
Peak flow
Wet year functional flow
Normal year functional flow
Dry year functional flow
Spring recession flow
Wet-season initiation flow
Dry-season baseflow
Discharge
350
300
250
200
150
100
50
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

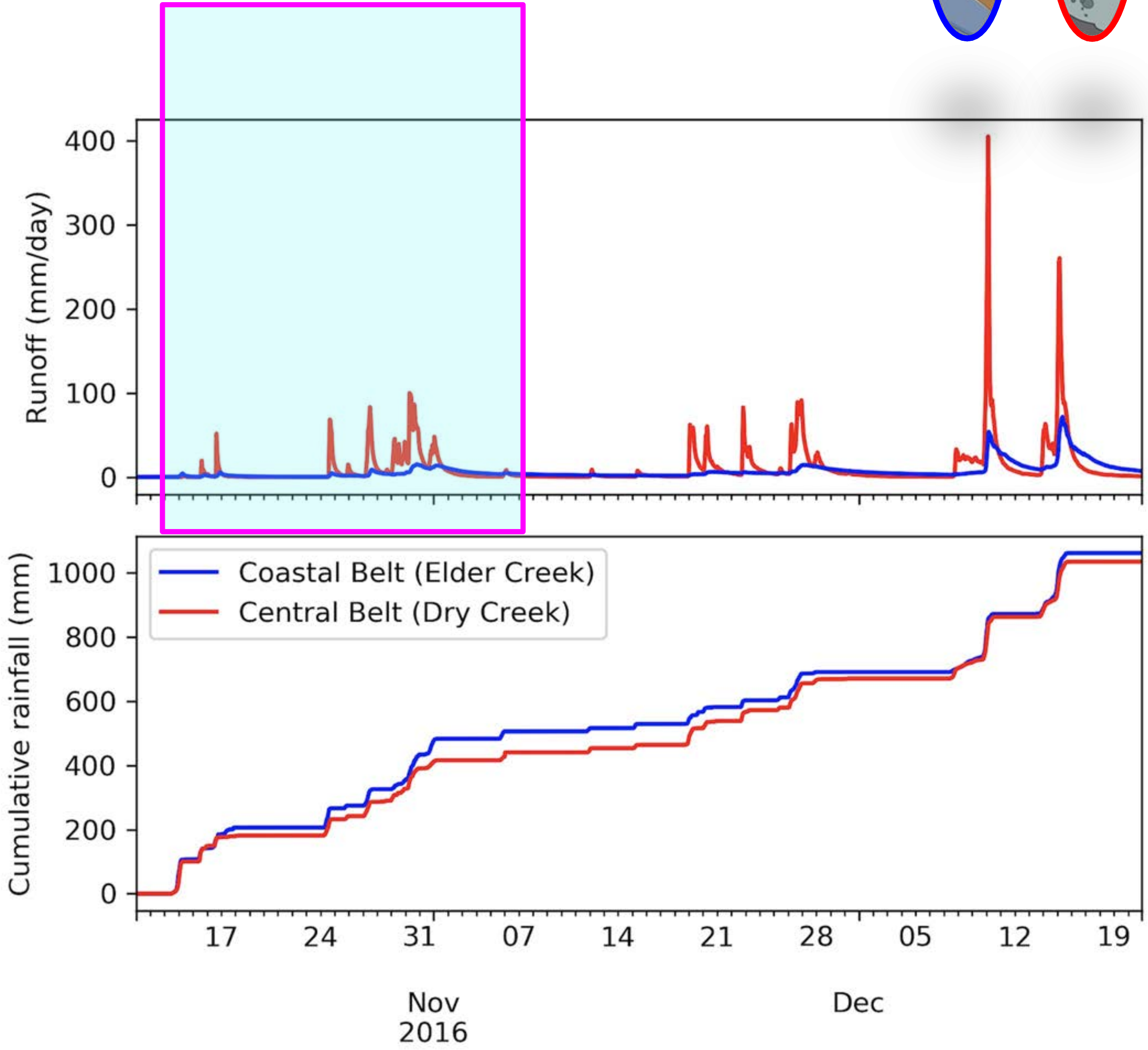




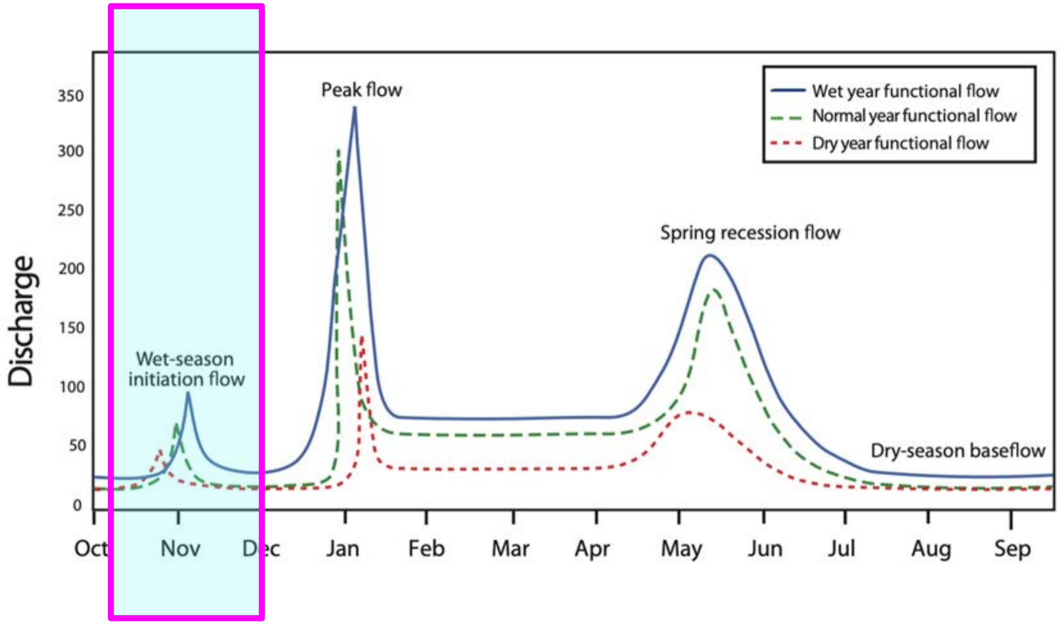
Coastal Belt (Elder Creek)
Central Belt (Dry Creek)
Cumulative rainfall (mm)
1000
800
600
400
200
0
17
24
31
07
14
21
28
05
12
19
Nov
2016
Dec

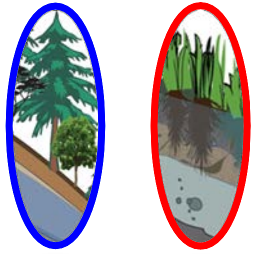




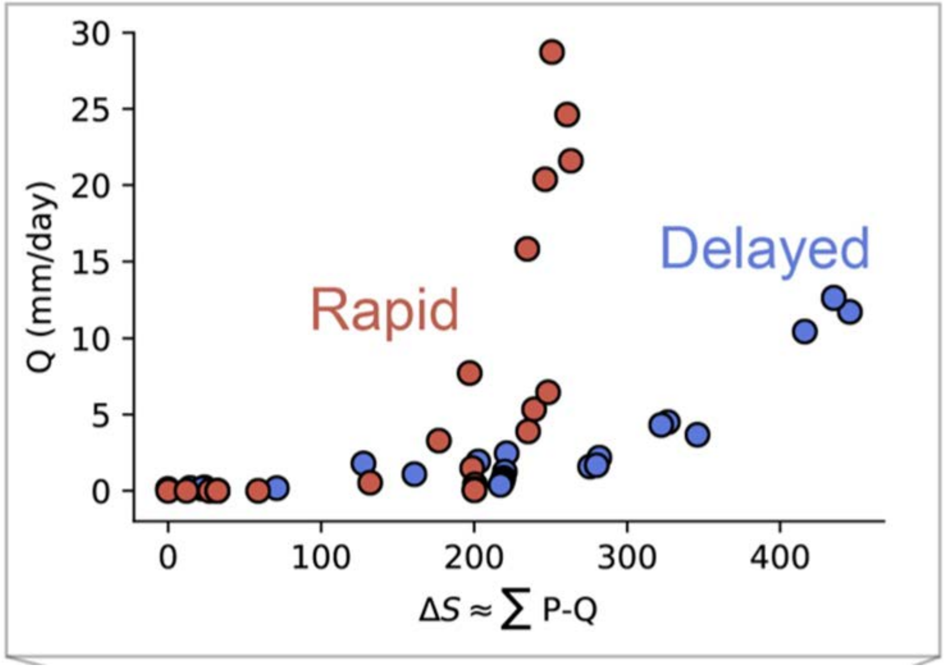


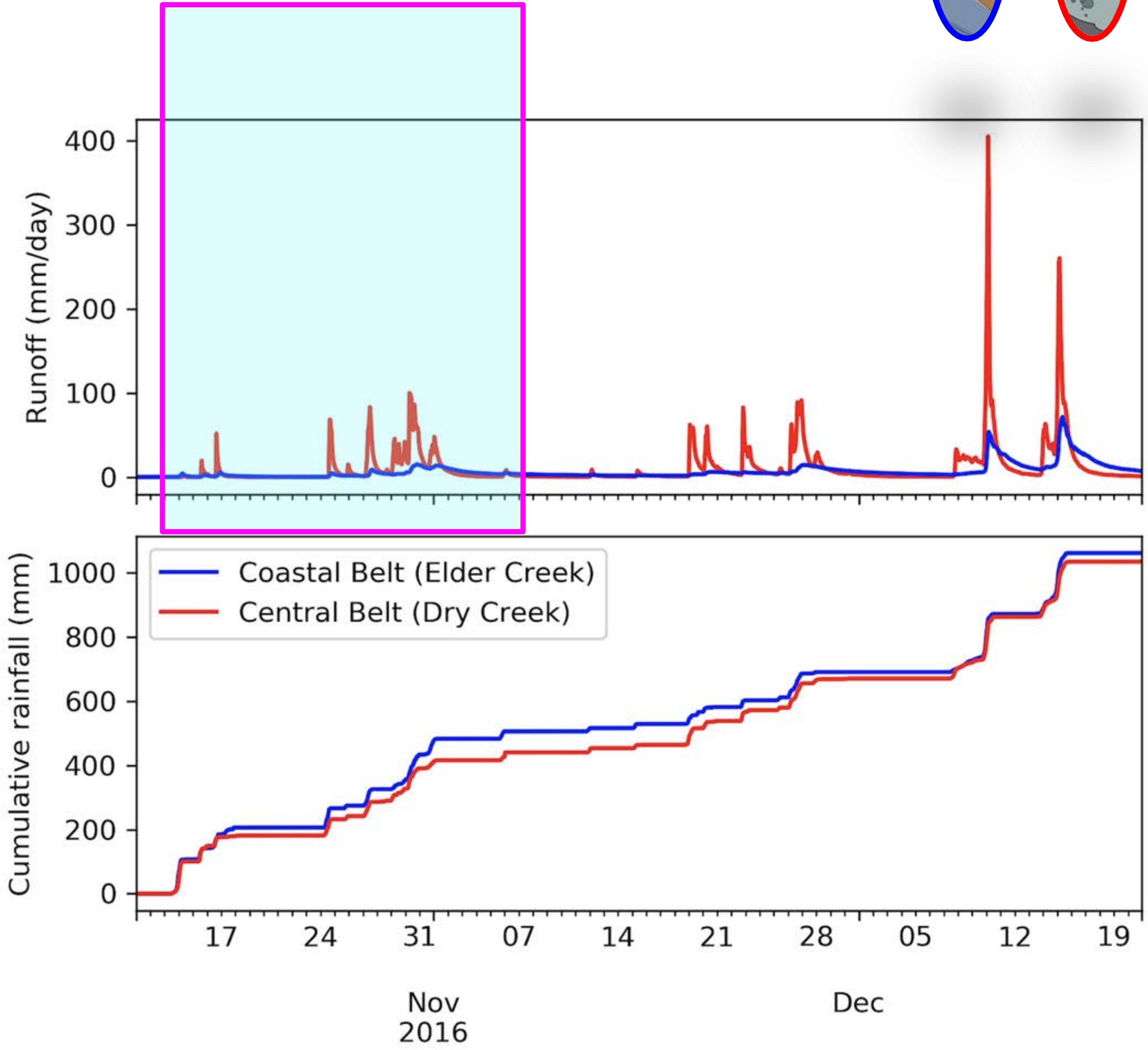
Large root-zone water storage deficits in Elder Creek must be “refilled” before significant streamflow initiation

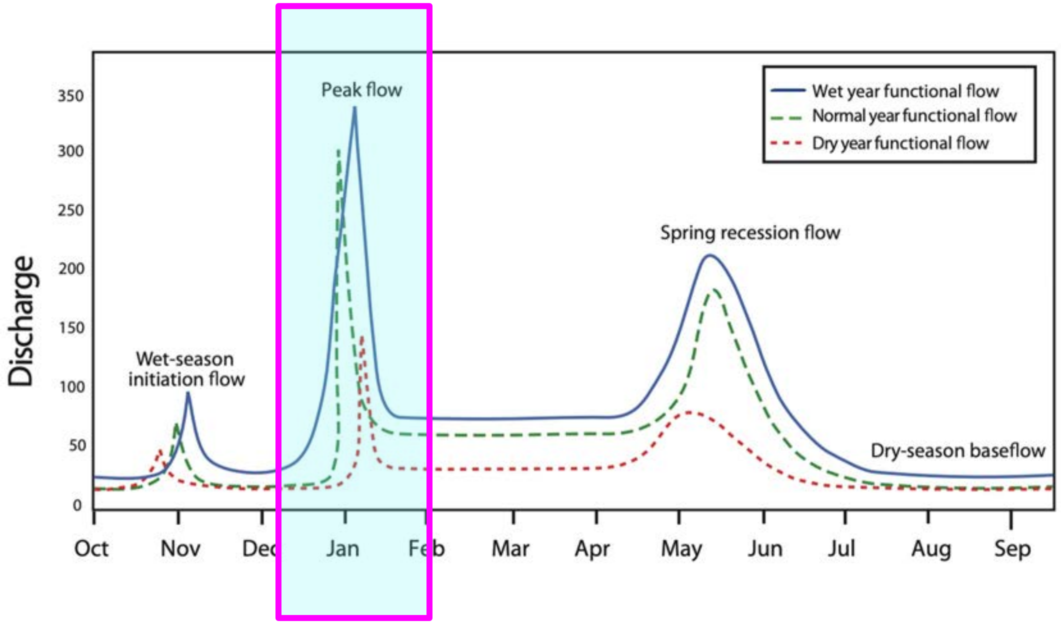


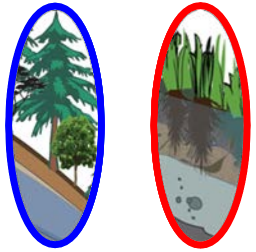


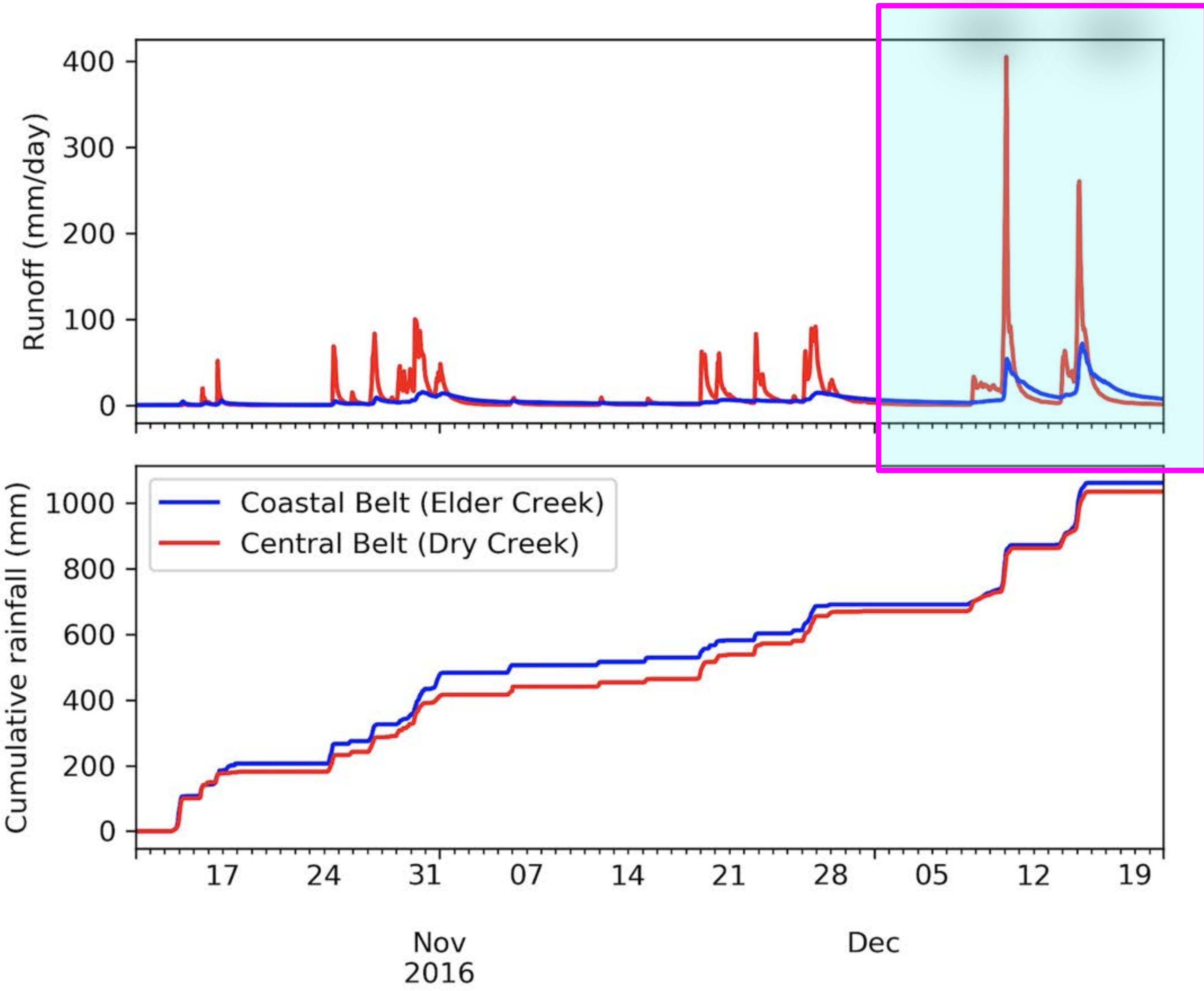
I. Wet-season flow activation



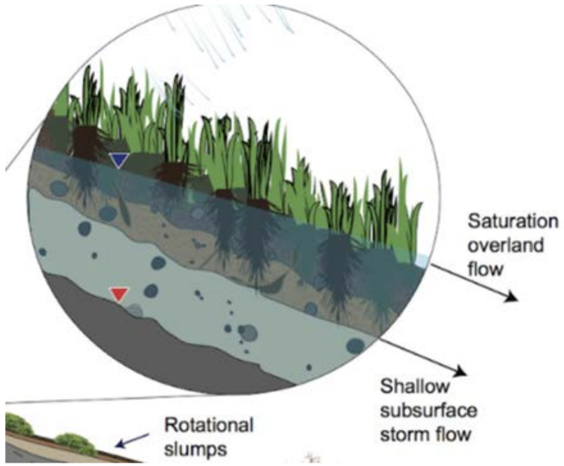


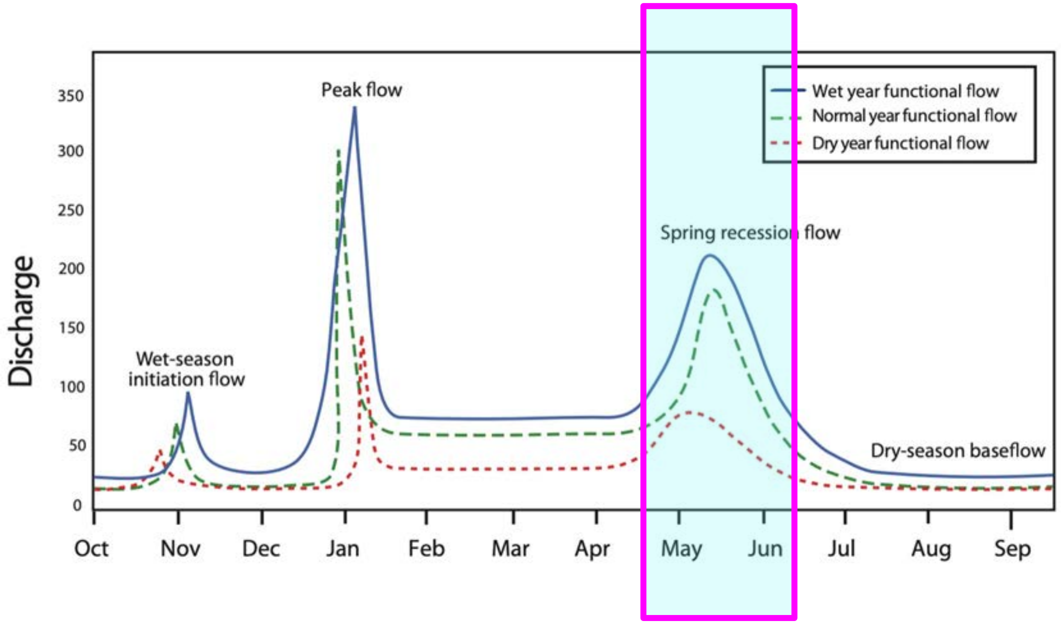


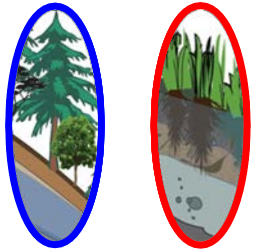


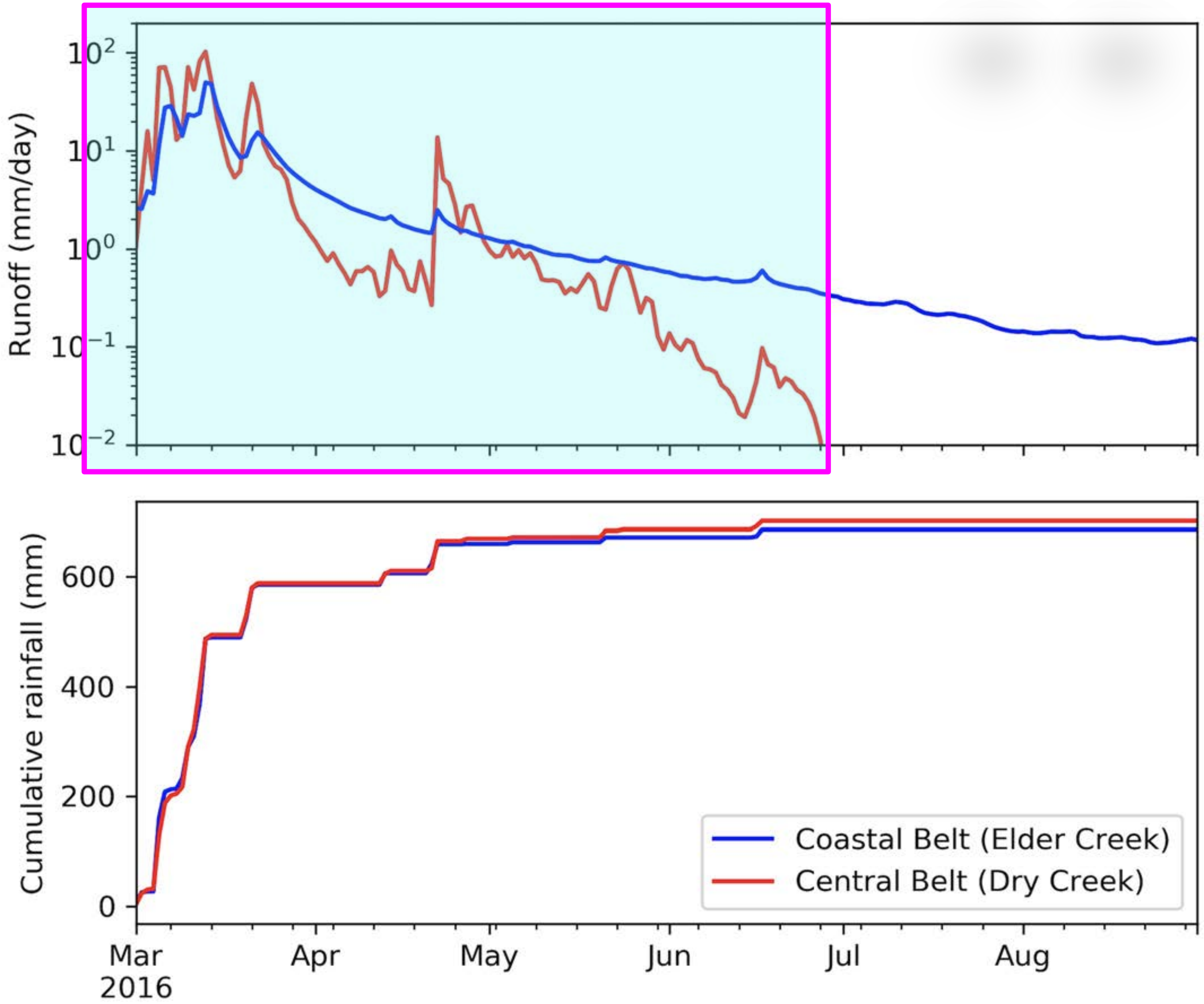


Full saturation of the subsurface in the melange catchment

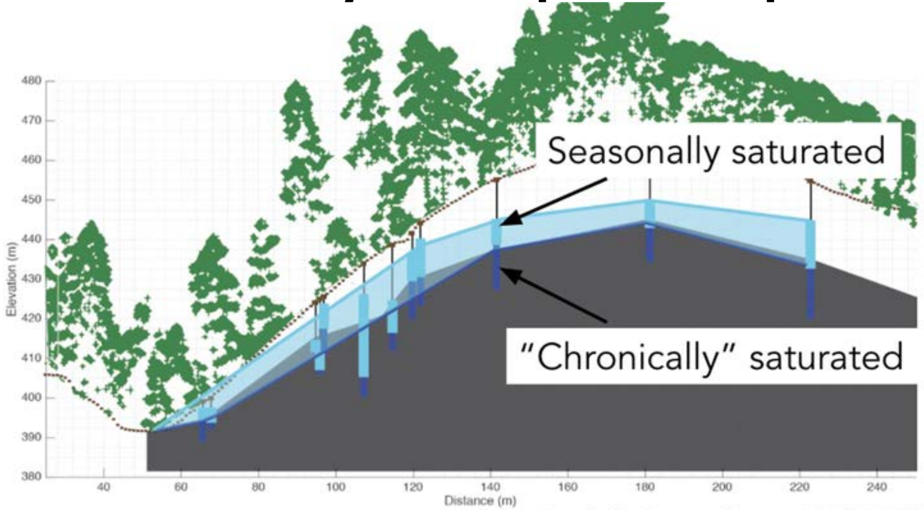




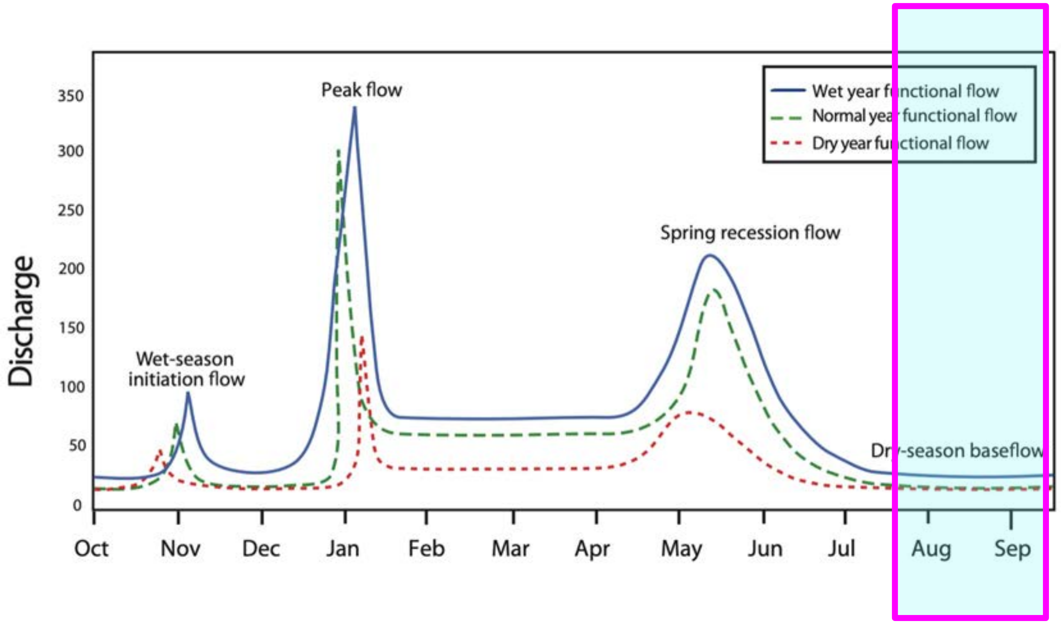


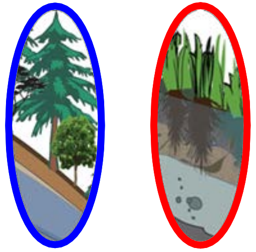


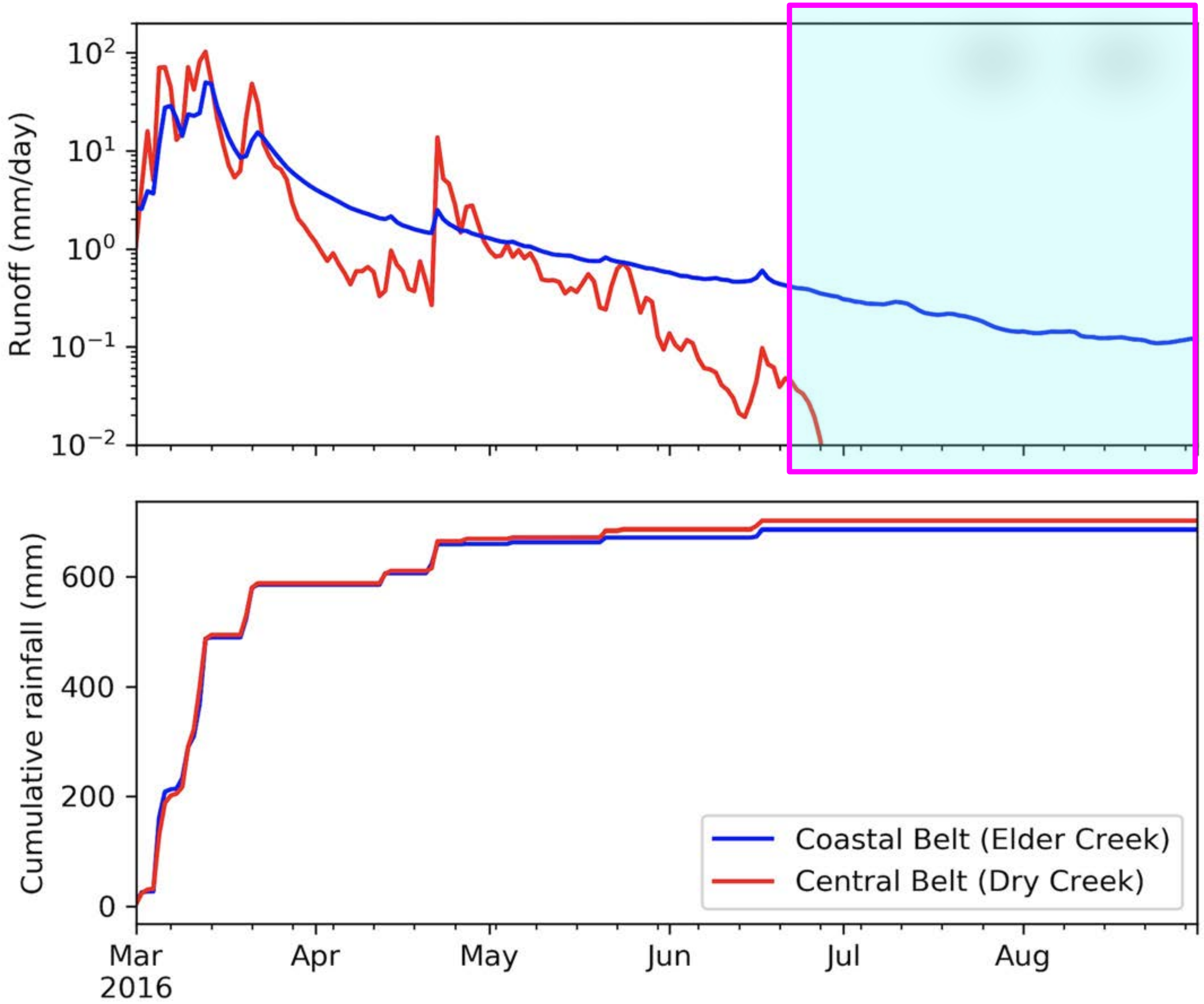
Coastal Belt, slow recession driven by deep flowpaths



Daniella Rempe figure, NCALM Lidar

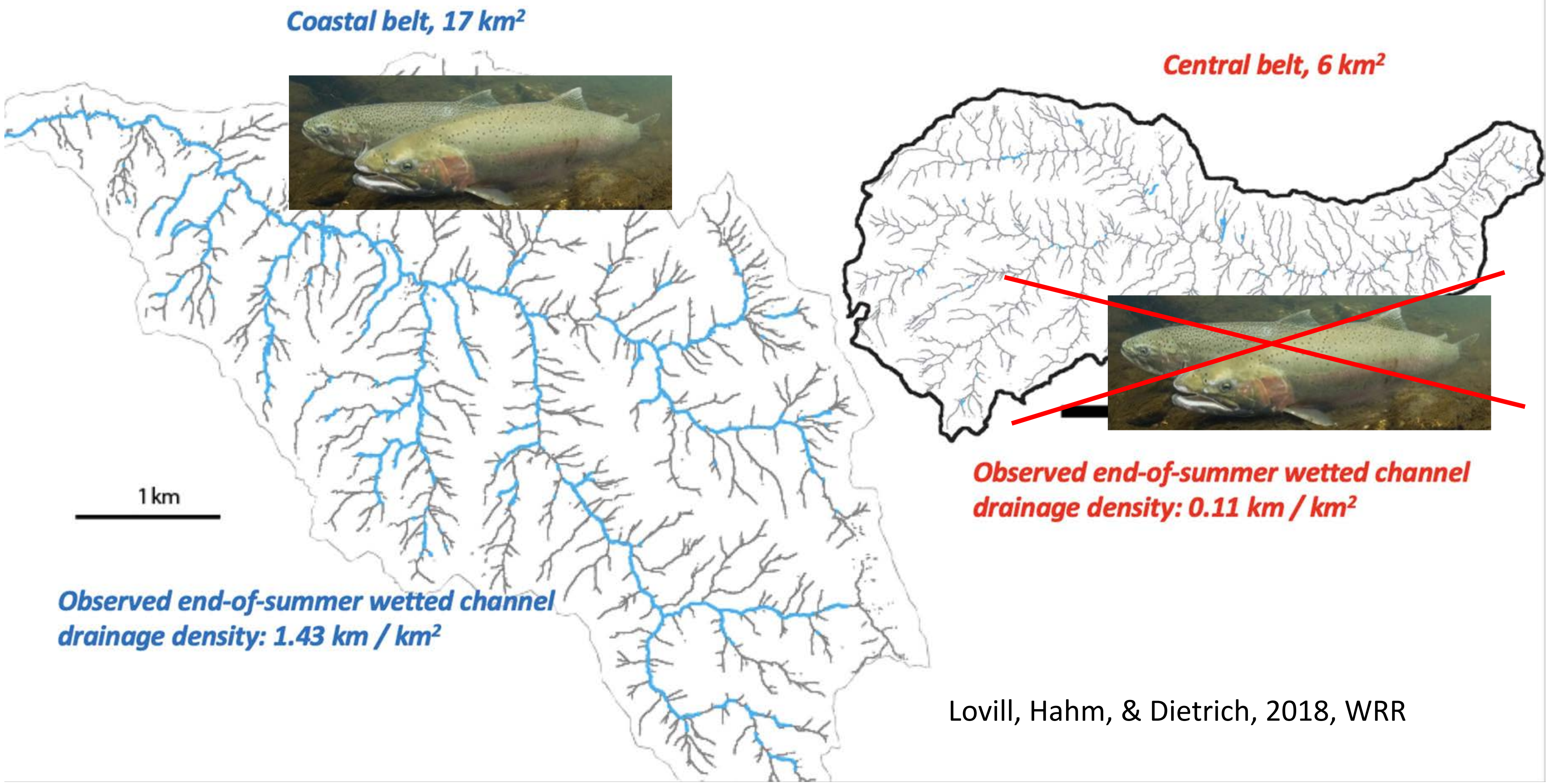






In melange, rapidly draining shallow flowpaths => streams go dry, contrasted with sustained perennial flow in Coastal Belt

Habitat extent: wetted channel dynamics

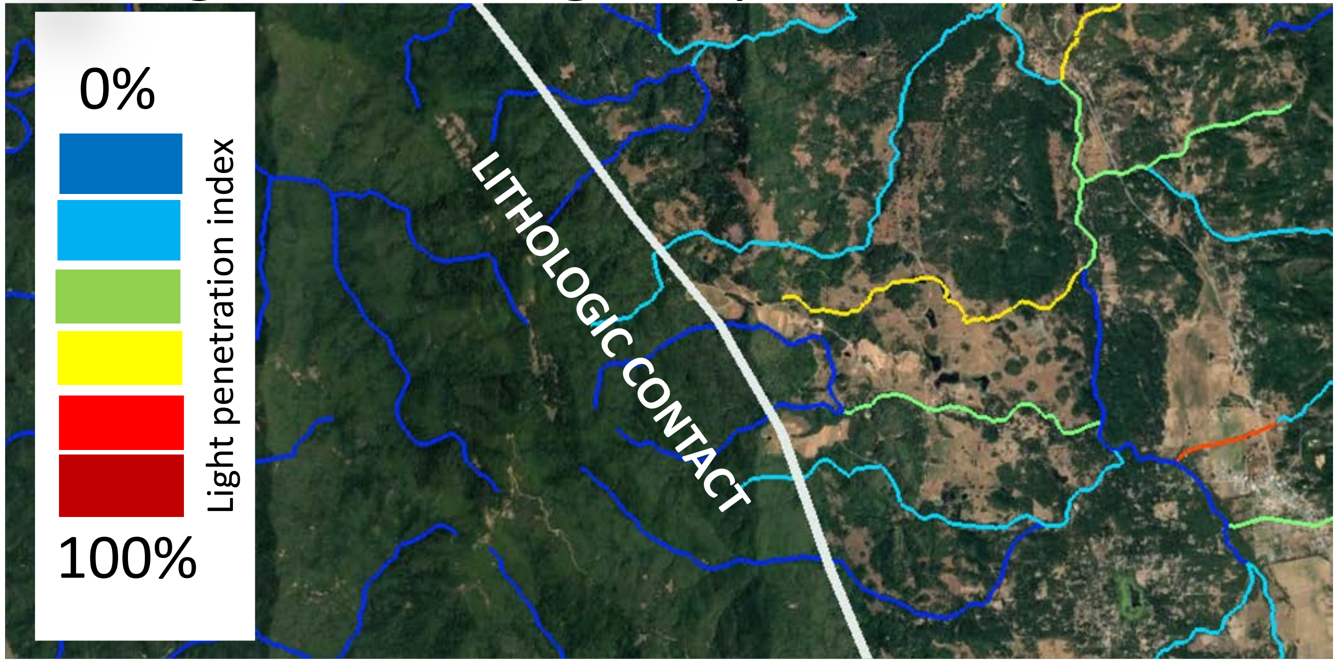


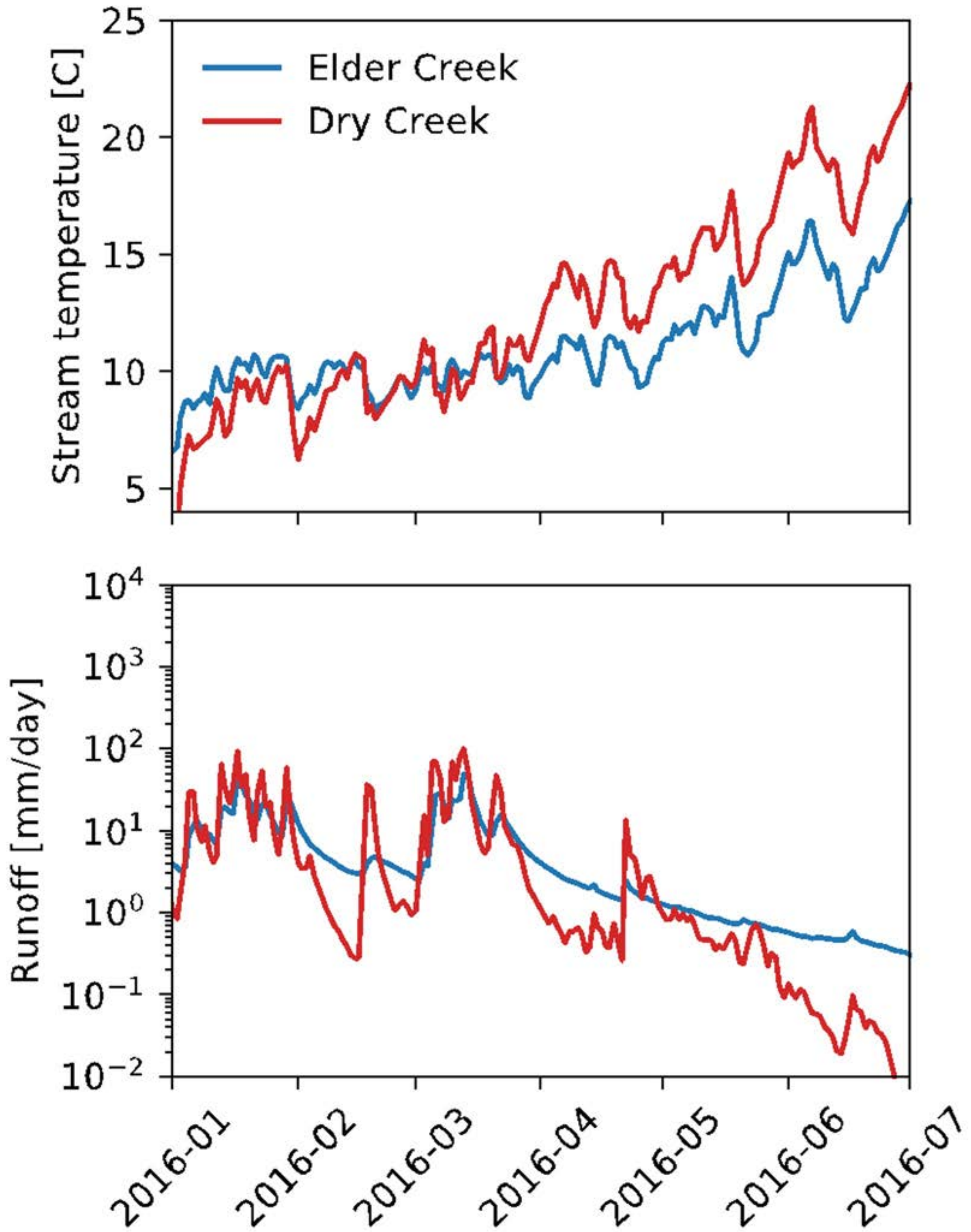
Lovill, Hahm, & Dietrich, 2018, WRR

Habitat quality: stream temperature

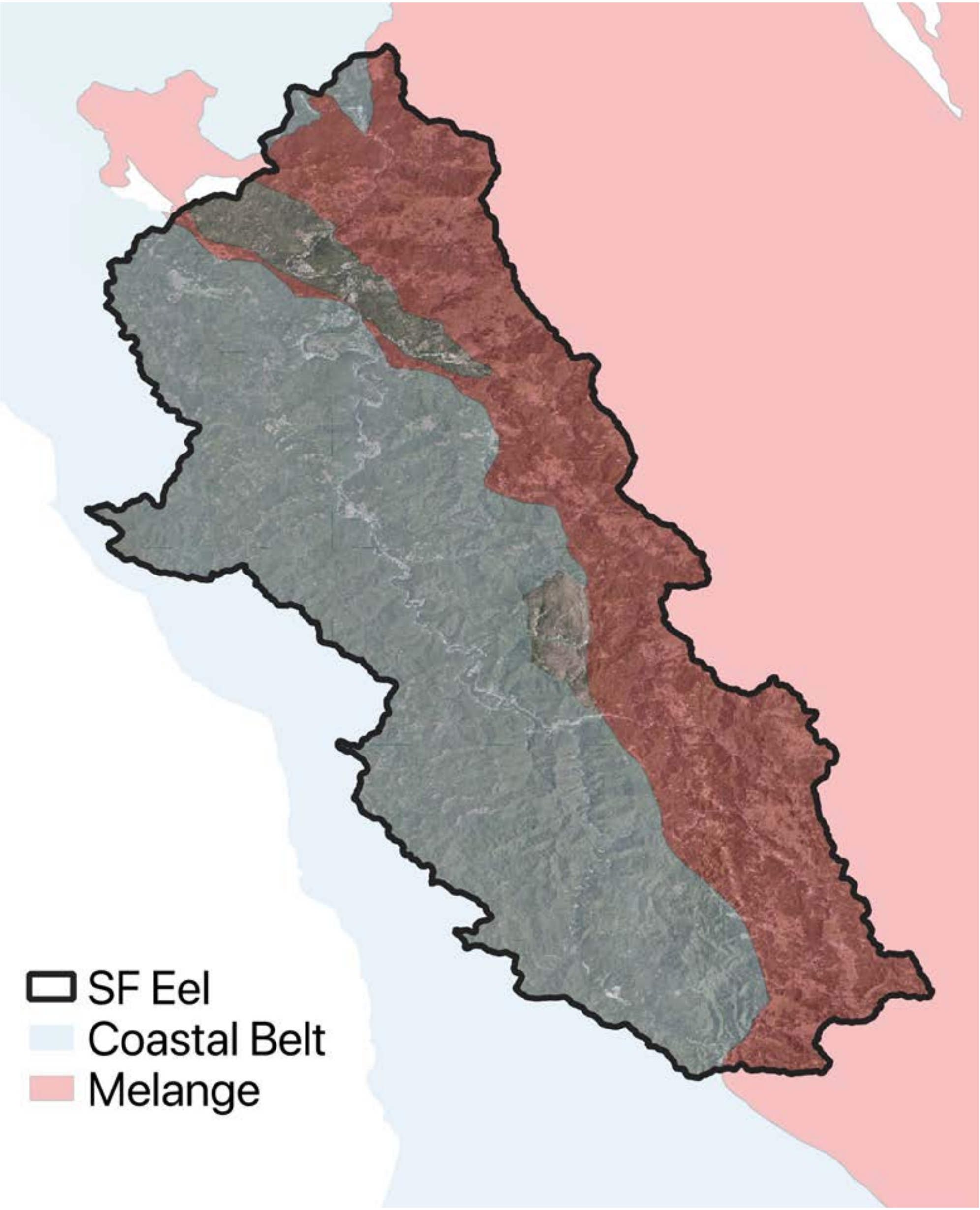
Structure impacts runoff pathways

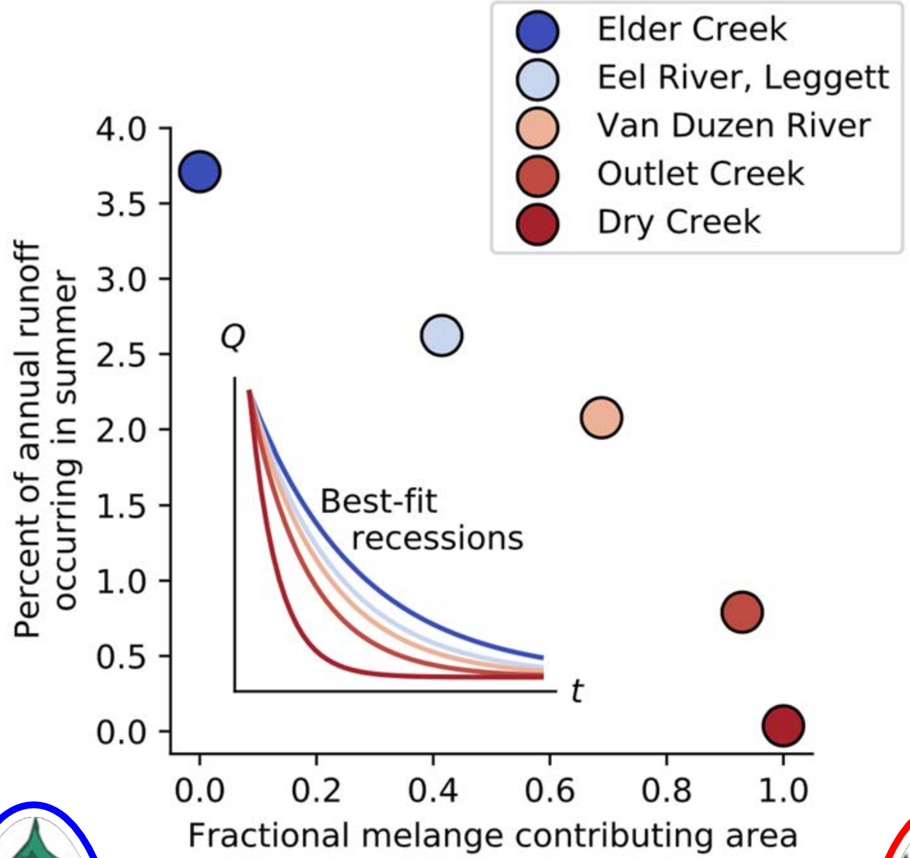
Storage affects veg -> riparian environment

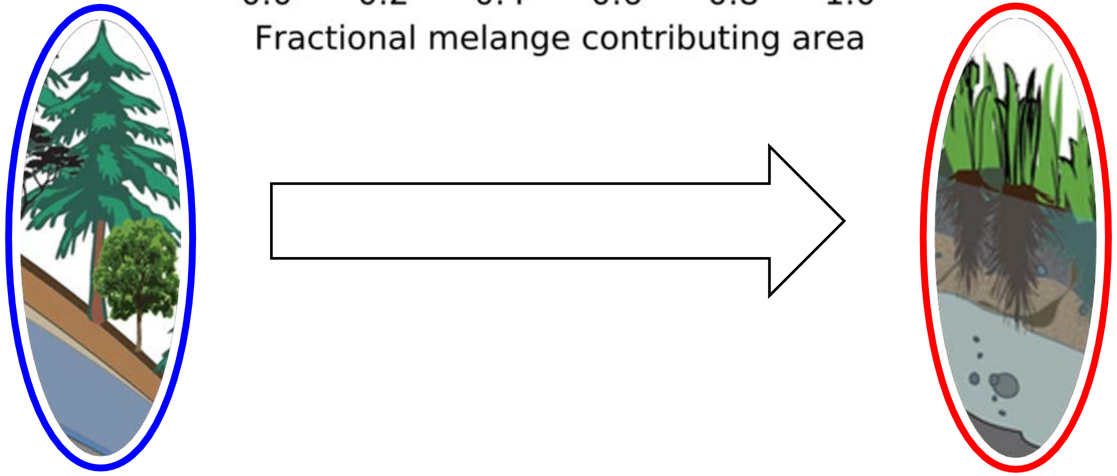




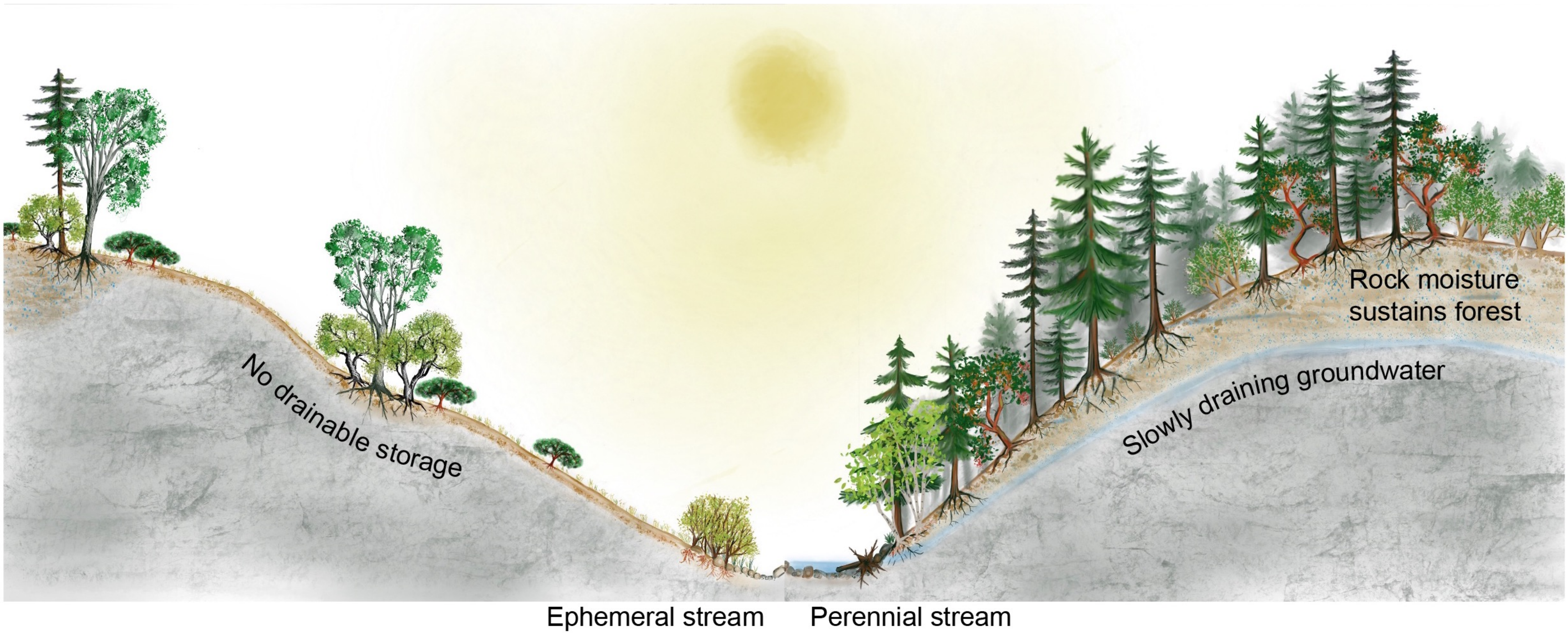
Habitat across scales: from “unit-hillslope” to “watershed”





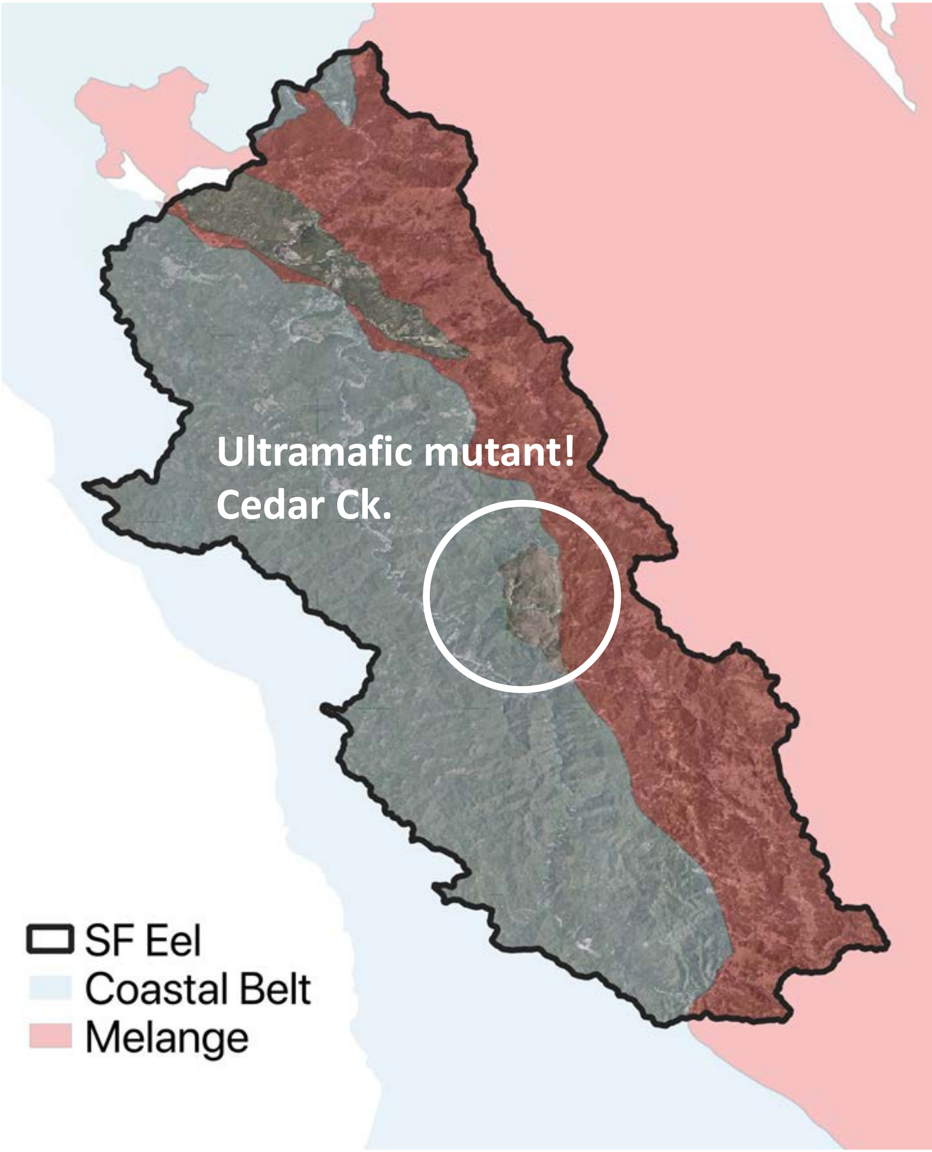


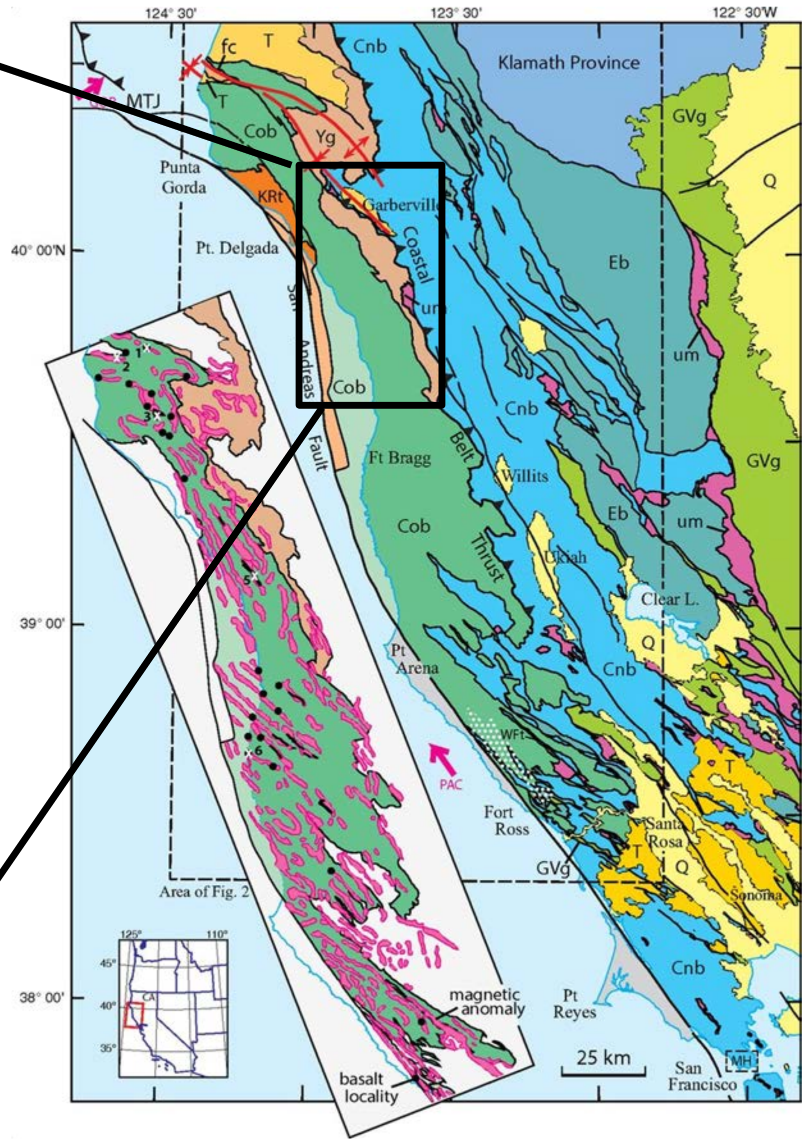
The Salmonid and the Subsurface



Dralle et al. 2022 *in review*

Of course, there are more than two geologies…





Even in the geologies we know…

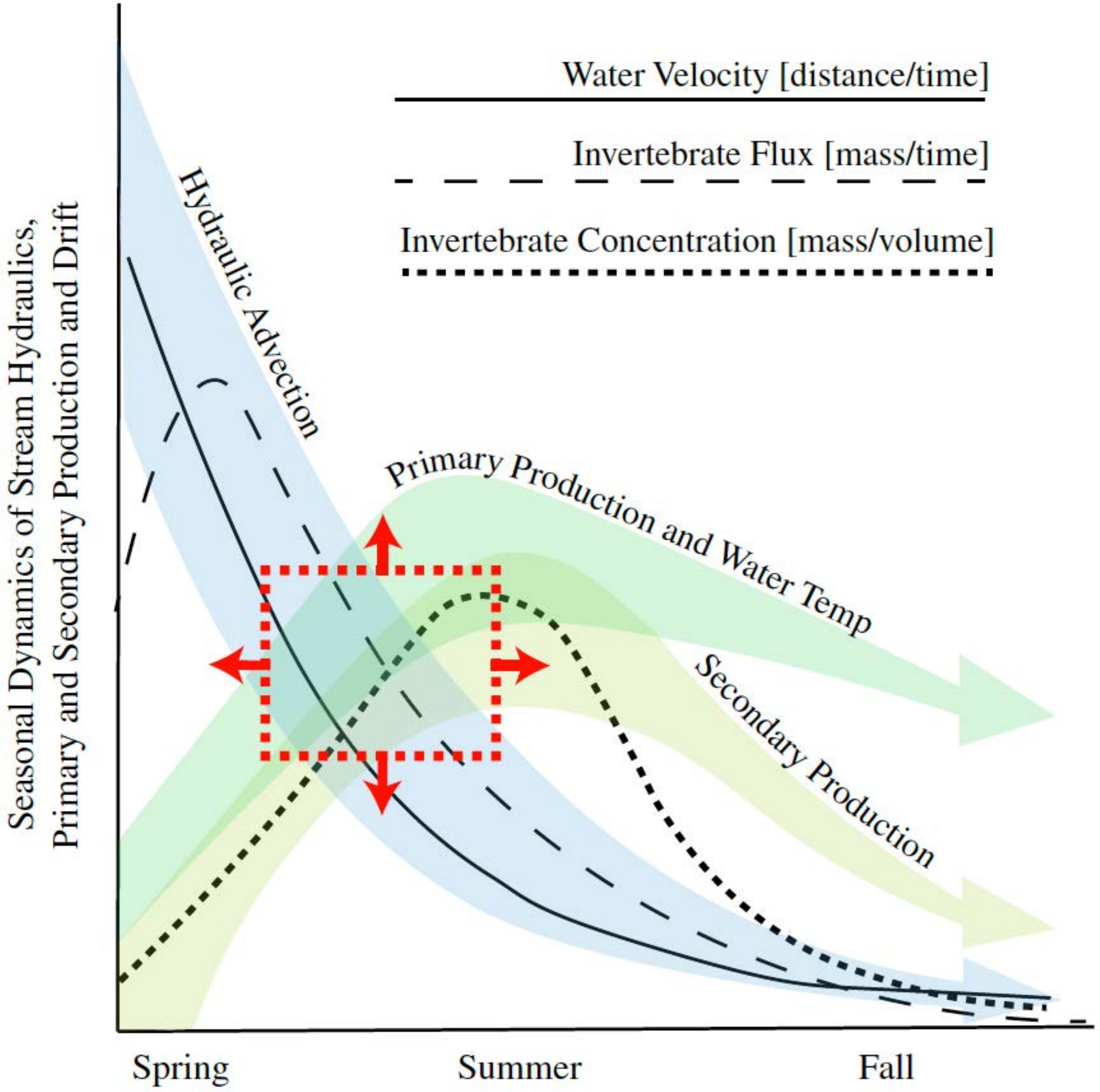
- Groundwater feeds our streams, but the extent to which trees rely on this groundwater, and how this ultimately impacts flow generation, is *very* poorly understood (e.g. doug firification)

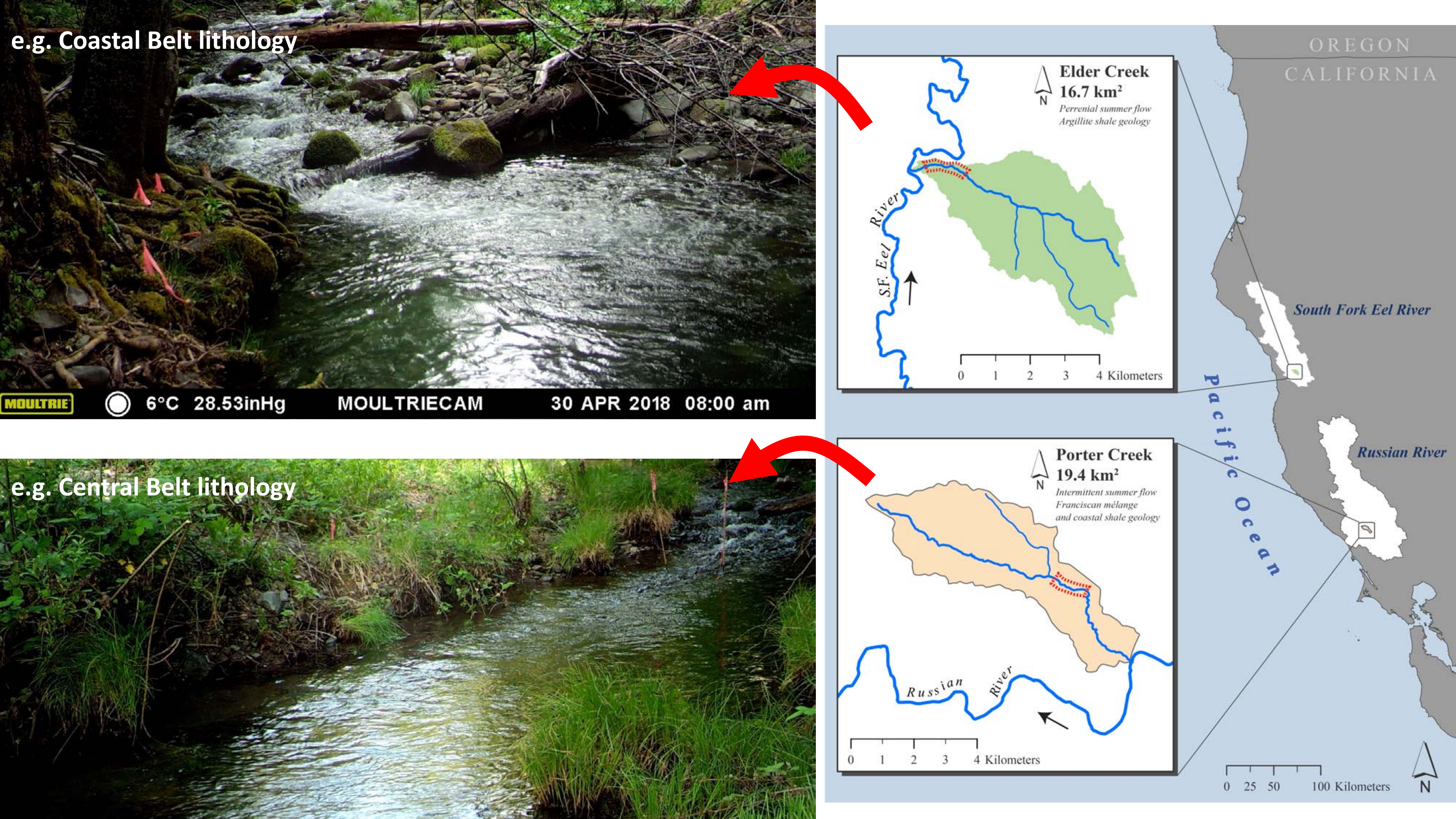
- What hydrogeomorphic variables control whether a reach is wet or dry, and how can we measure these variables at scale?

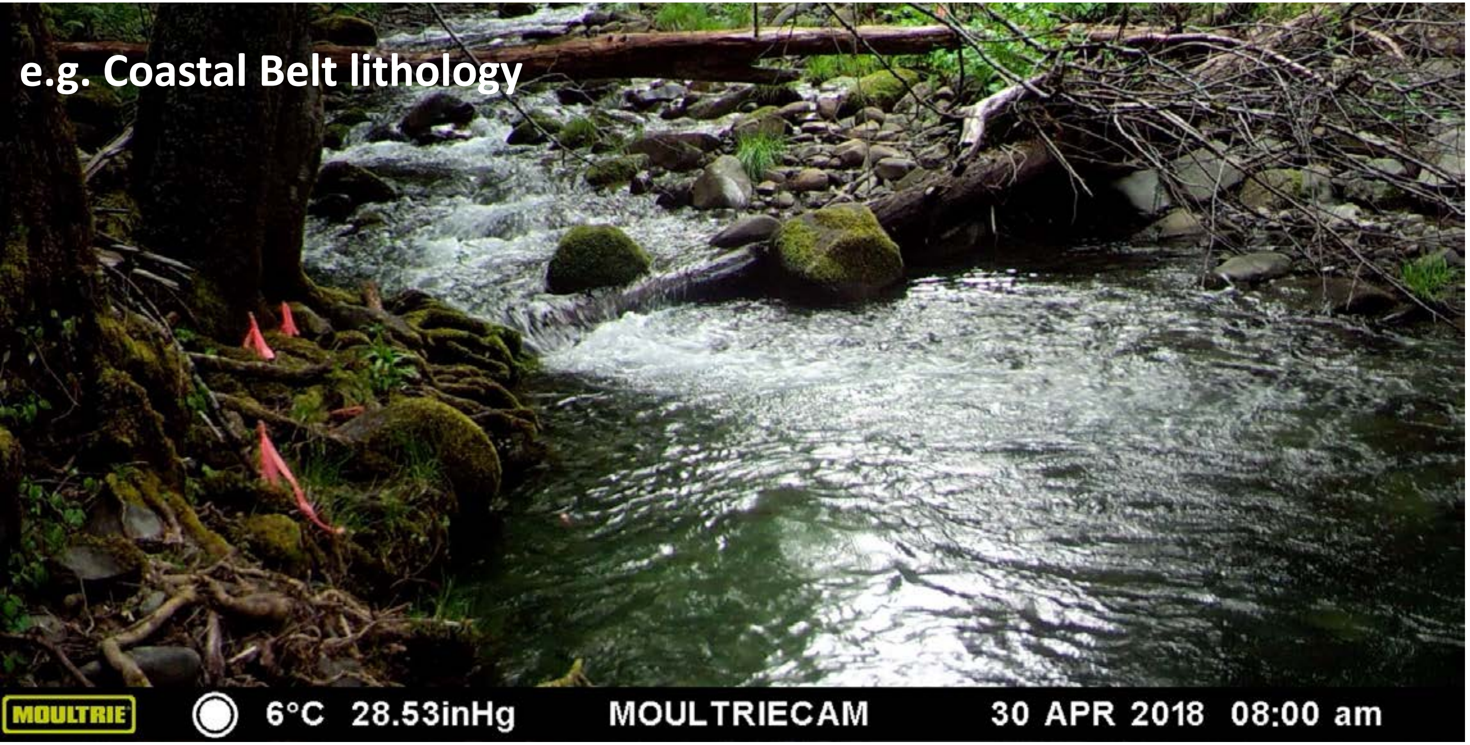
- We still need appropriately complex, process-informed tools to estimate how human activity will impact flows (e.g. numerous, distributed users pumping hillslope groundwater for irrigation)

The subsurface may impact:

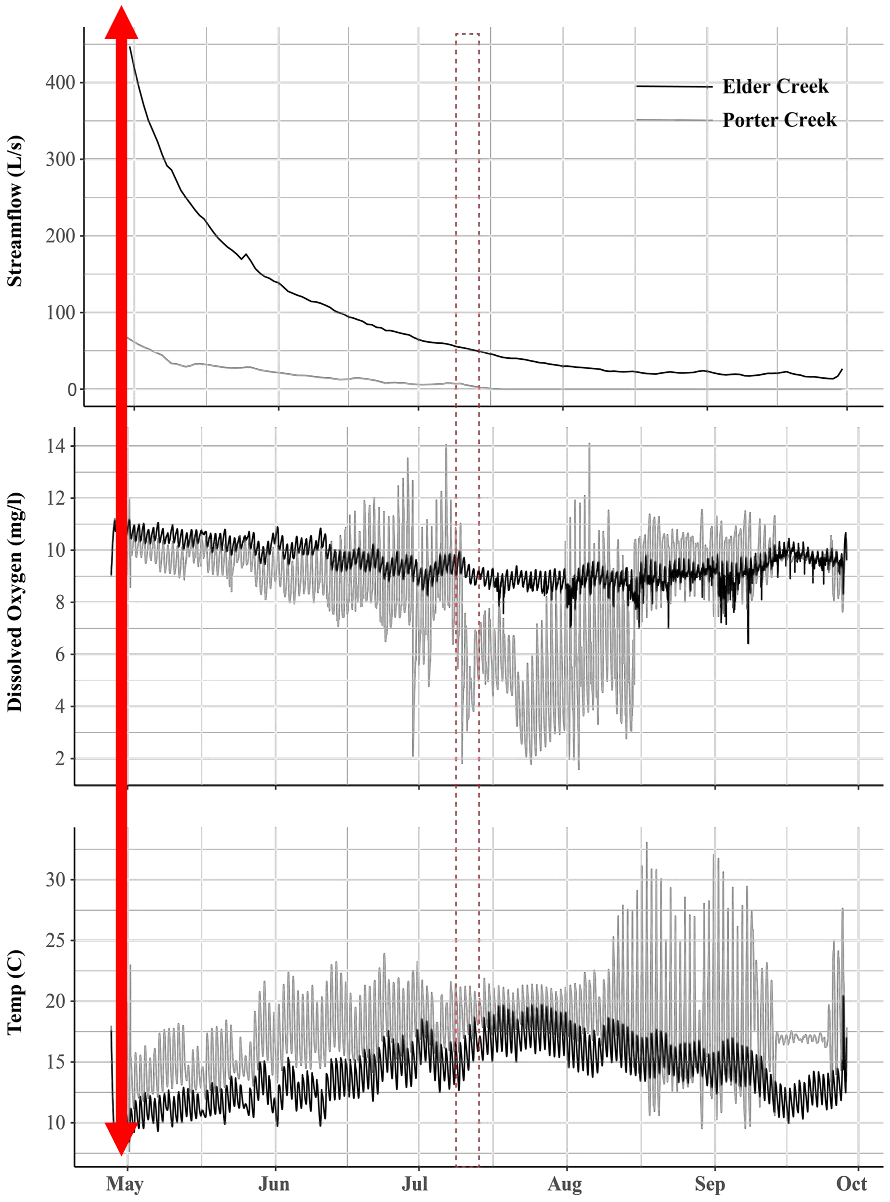
- Adult Migration and Spawning
  - flow activation, winter recession characteristics and baseflow
- Egg Incubation
  - water temperature, scour, desiccation risk
- Juvenile Growth Phenology
  - Spring hydrograph recession timing relative to primary and secondary production
- Summer Survival
  - Intermittency, water temperature, dissolved oxygen
- Life history syndromes


Water Velocity [distance/time]
Invertebrate Flux [mass/time]
Invertebrate Concentration [mass/volume]
Hydraulic Advection
Primary Production and Water Temp
Secondary Production
Seasonal Dynamics of Stream Hydraulics, Primary and Secondary Production and Drift
Spring
Summer
Fall

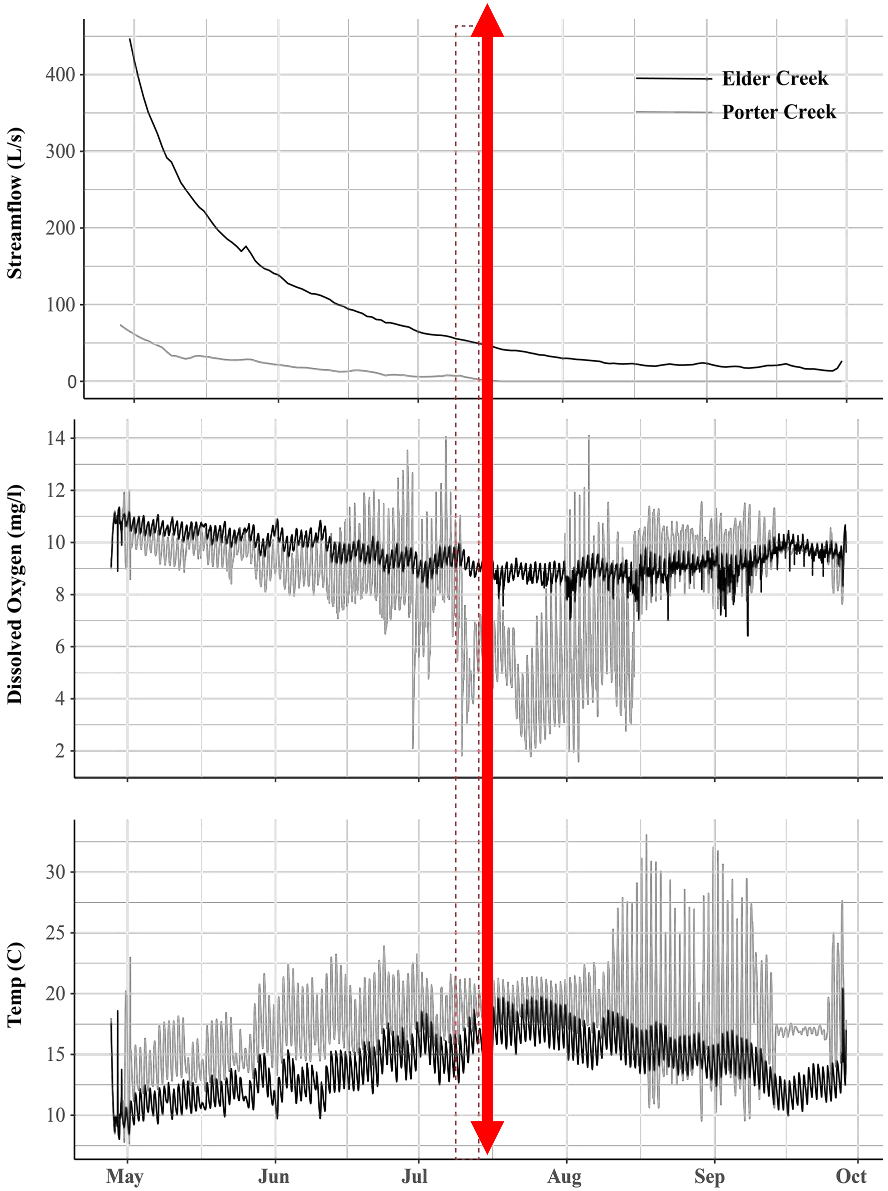

e.g. Coastal Belt lithology
MOULTRIE
6°C 28.53inHg
MOULTRIECAM
30 APR 2018 08:00 am
e.g. Central Belt lithology
OREGON
CALIFORNIA
Elder Creek
16.7 km²
Perrenial summer flow
Argillite shale geology
S.F. Eel River
0 1 2 3 4 Kilometers
South Fork Eel River
Pacific Ocean
Porter Creek
19.4 km²
Intermittent summer flow
Franciscan mélange
and coastal shale geology
Russian River
0 1 2 3 4 Kilometers
Russian River
0 25 50 100 Kilometers
N



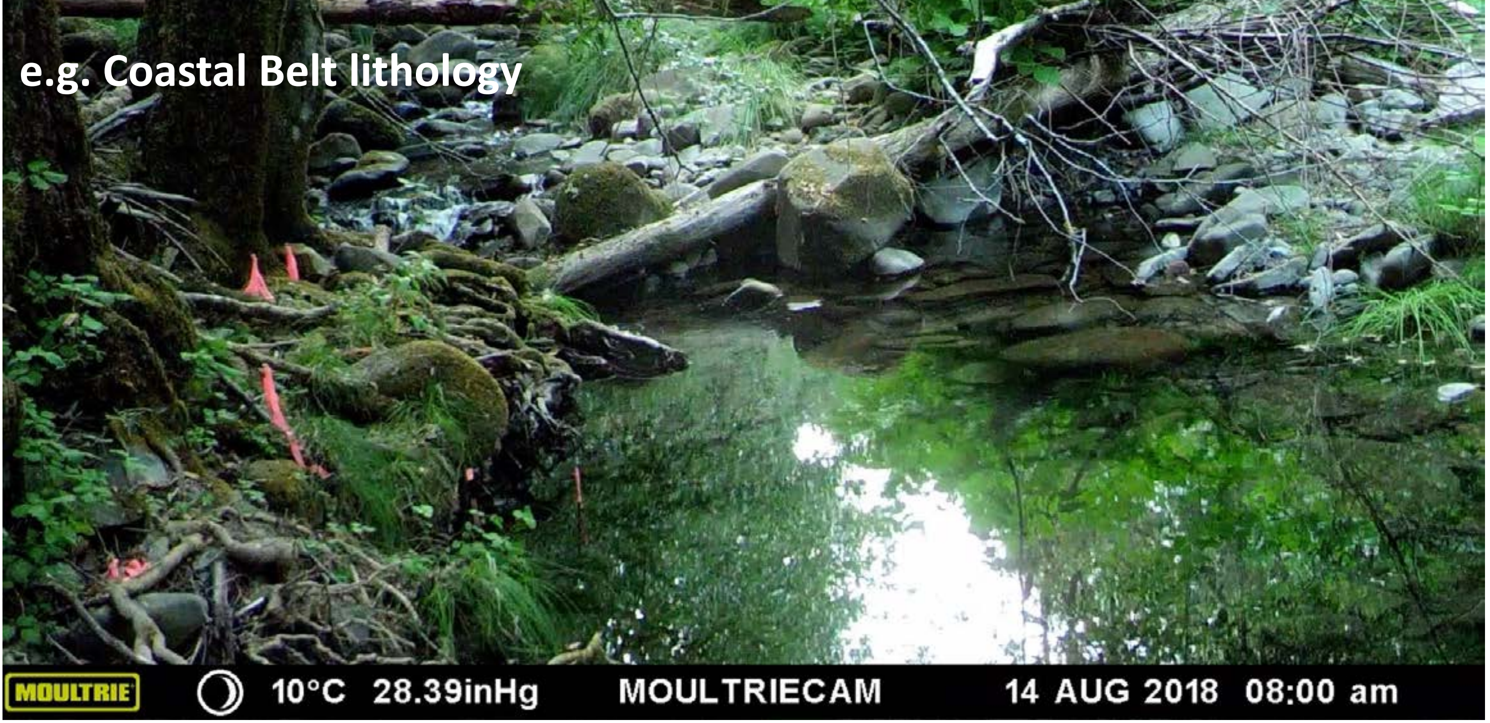
April 30th 2018

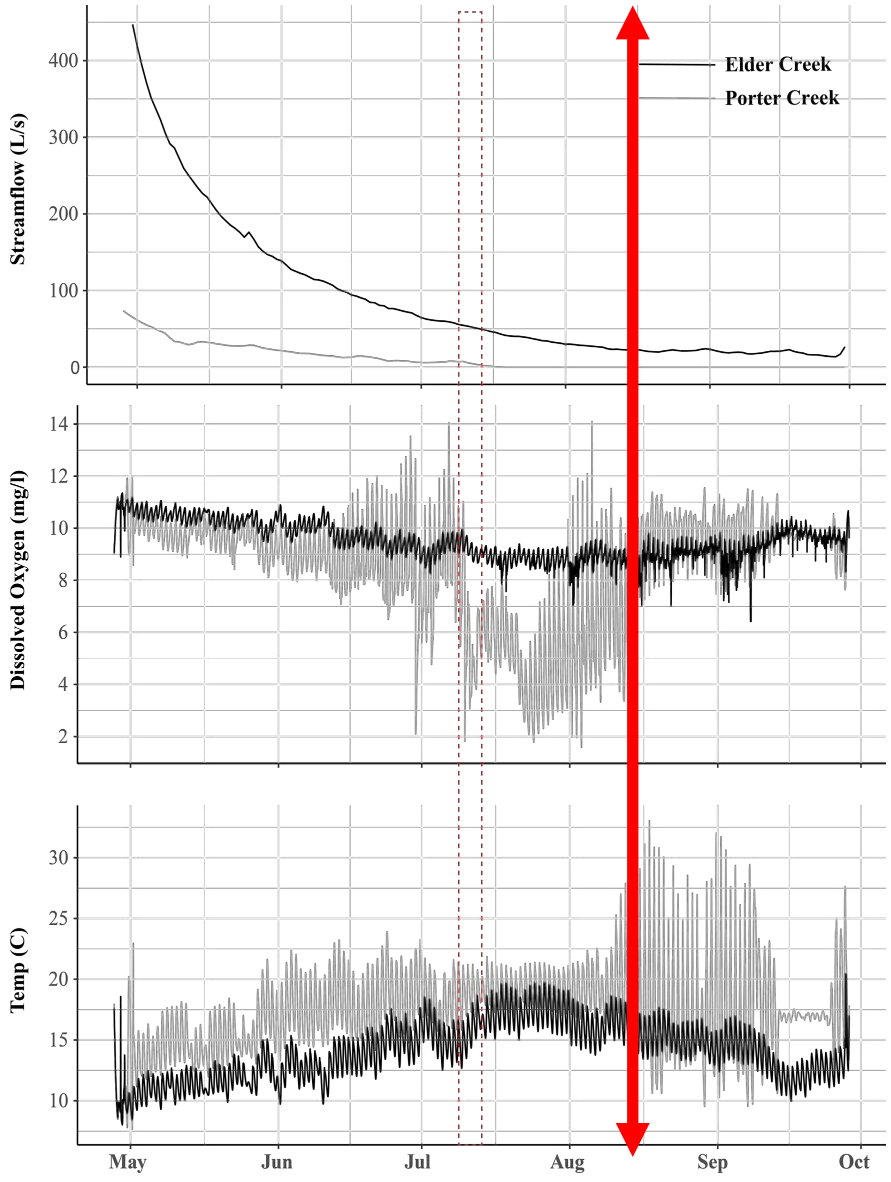


July 15th 2018

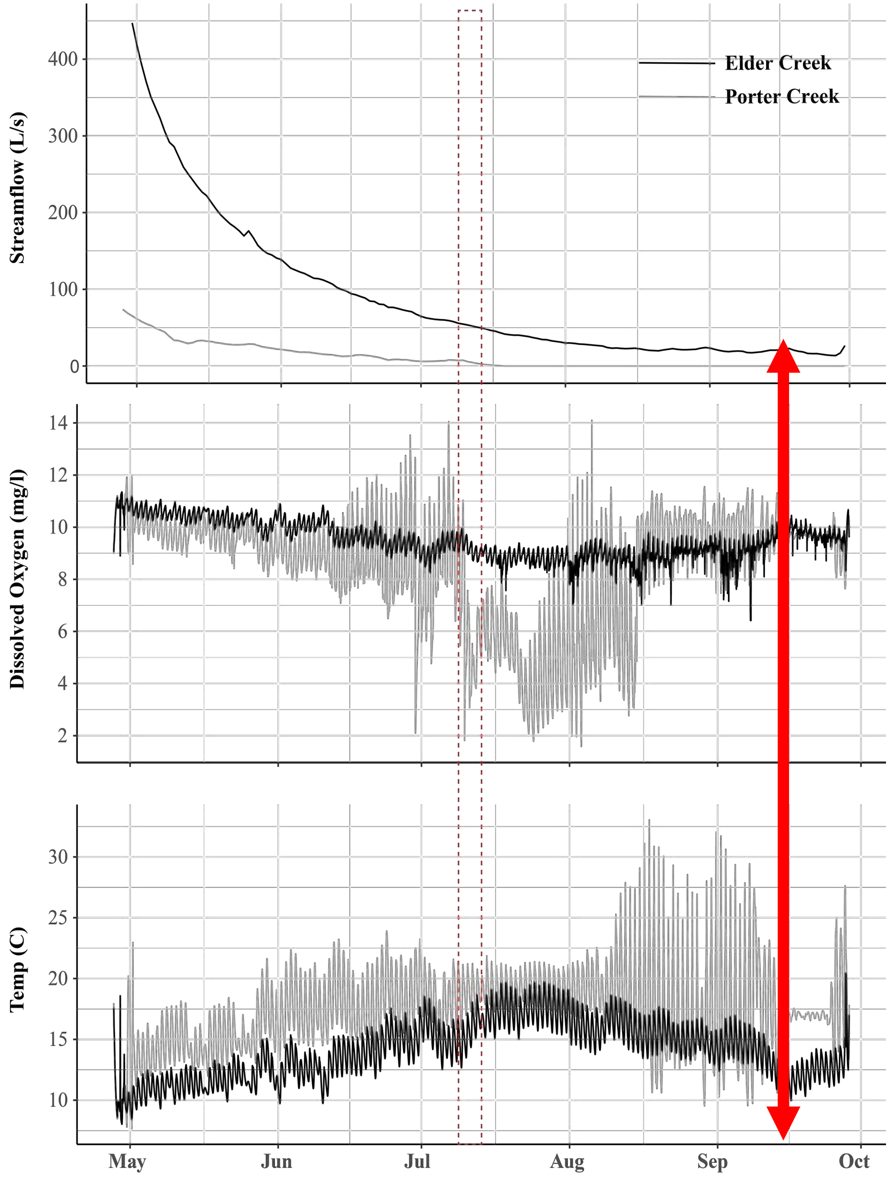


August 14th 2018





September 9th 2018

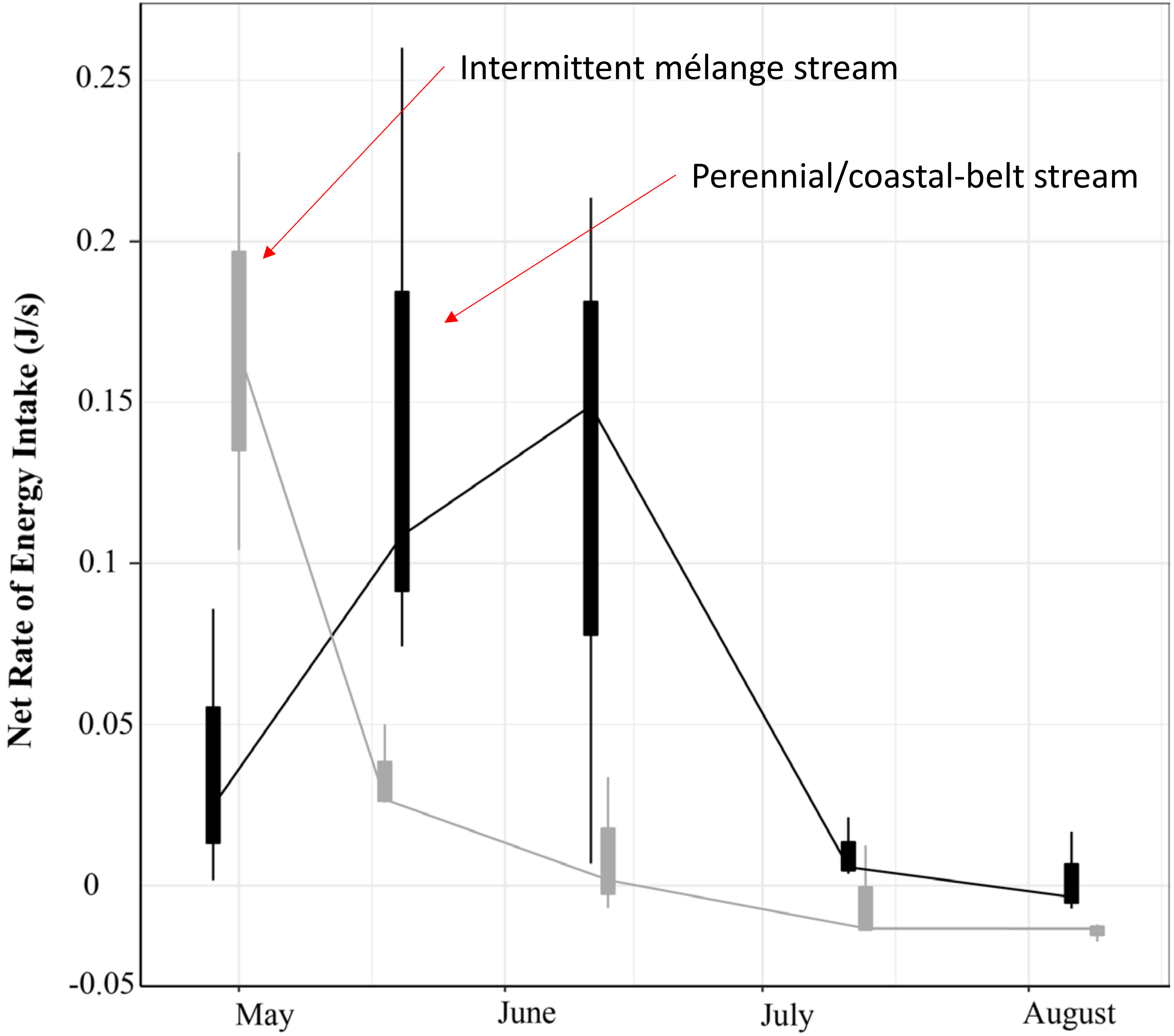


Elder Creek Pool in April


MOULTRIE
14°C 28.45inHg
MOULTRIECAM
15 JUL 2018 08:00 am
Elder Creek Pool in July
Reference Rock


Porter Creek Pool in April
Reference Rock


Porter Creek Pool in July
Reference Rock



Adapted from Rossi et al. 2022

Mainstem Occupancy, growth, transit times, survival.

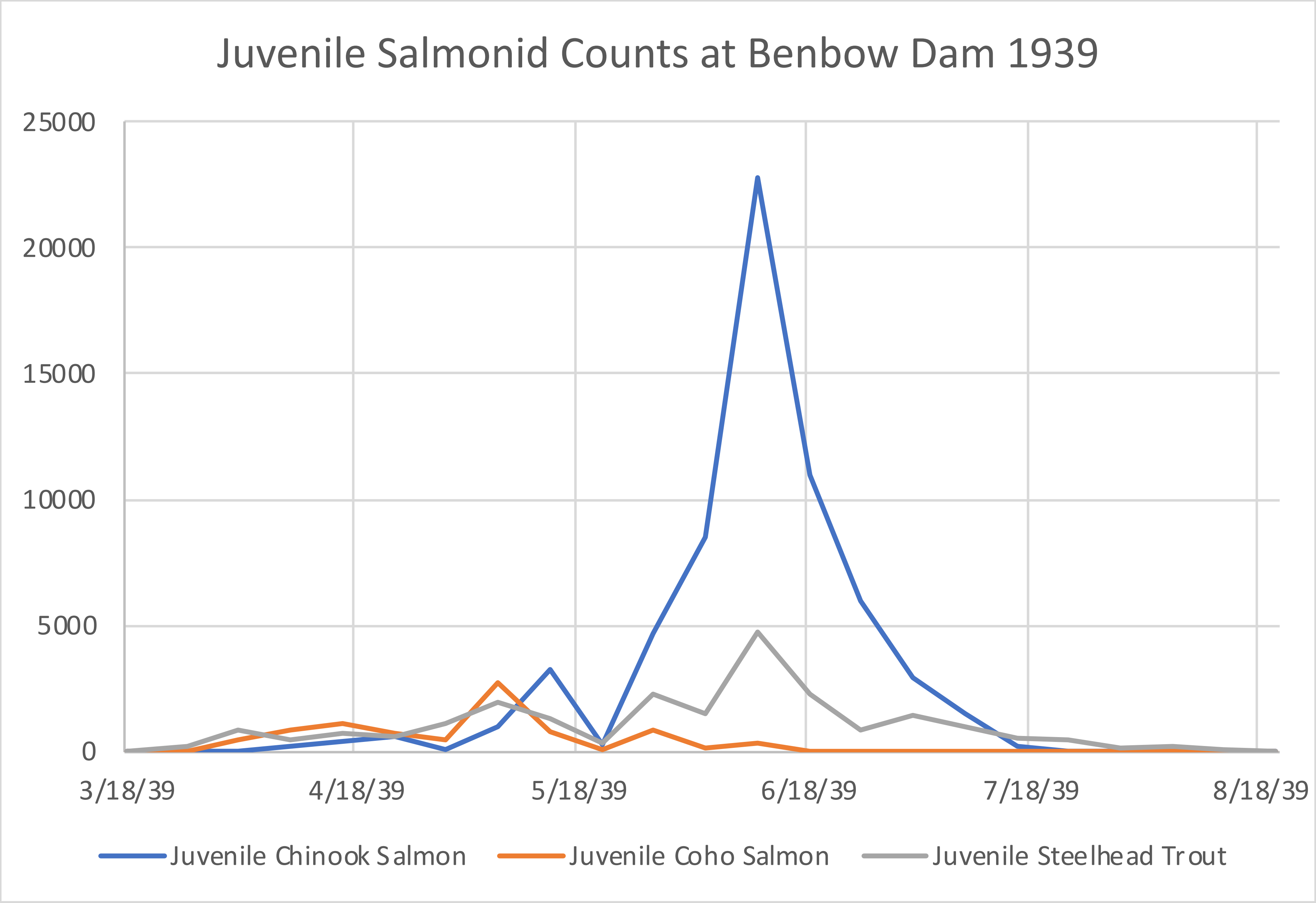


Figure From Stillwater 2022.

Total Counts

Chinook Salmon	= **63,574**
Steelhead	= **23226**
Coho Salmon	= **8696**

True numbers of Chinook were probably **2-3 million this year** (2%-3% capture) (Dewitt and Murphy 1950).

Using the same math (shady!) the steelhead run would have been ~900,000 juveniles and the Coho run would have been ~340,000 juveniles

In 1939 Shapovalov (1940) studied the downstream migration of king salmon at Benbow Dam. He installed a trap in the fishway and re-leased a known number of marked fish above the dam. From the ratio of marked to unmarked fish the total migration was estimated at 2 to 3 million fish. Migrants were taken from April 1 to July 9, 1939, but the bulks of the migrants passed the dan during the period June 1 to June 28. Dewitt and Murphy 1950

Mainstem Occupancy, growth, transit times, survival.

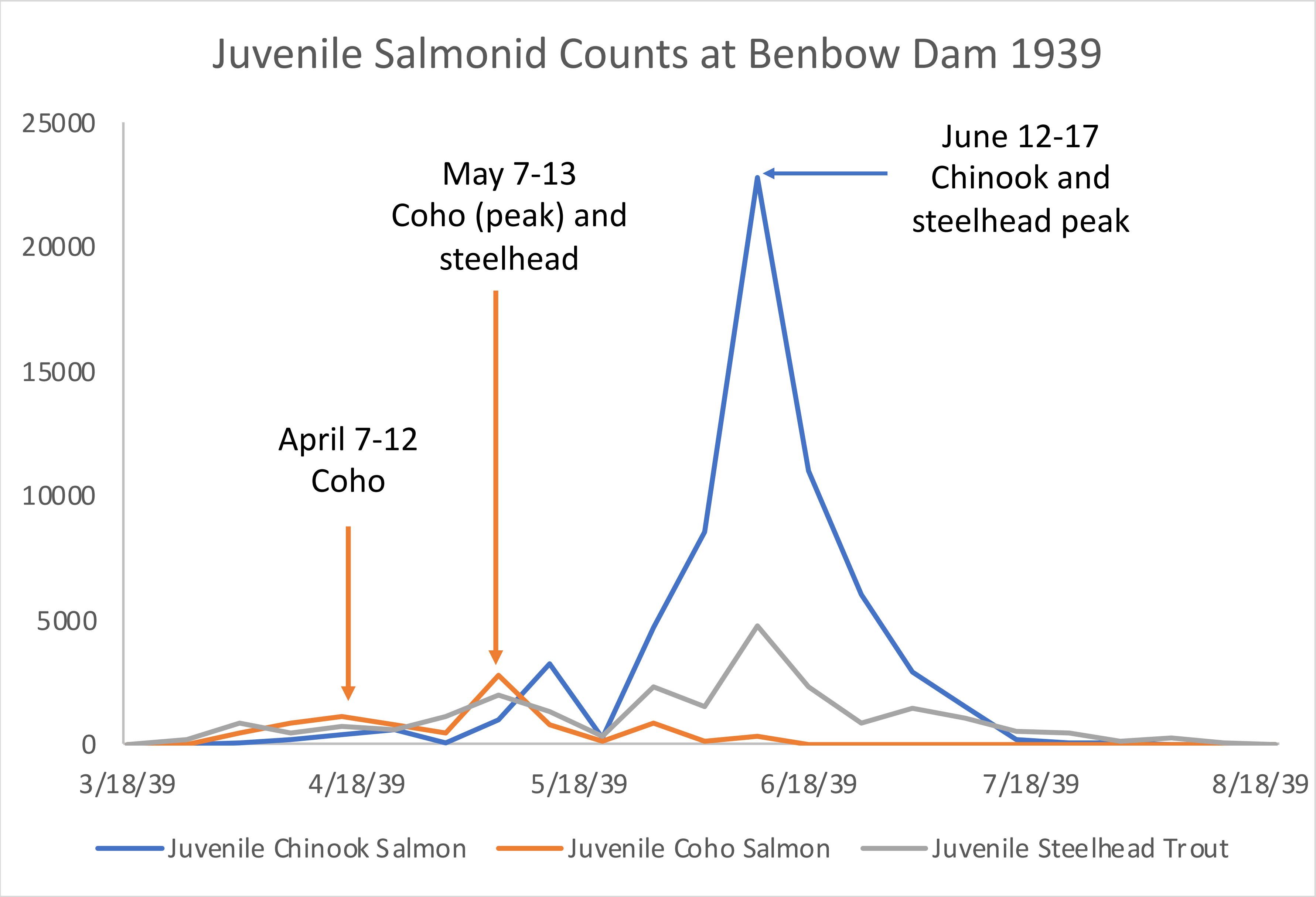


Figure From Stillwater 2022.

TABLE 22

LENGTH FREQUENCY AND AGE[1] COMPOSITION OF JUVENILE STEELHEAD MEASURED IN THE EEL RIVER SYSTEM

Length (mm)	Van Duzen River	Tenmile Creek (South Fork Eel)	Redwood Creek (South Fork Eel)	Eel River-Dos Rios	Eel River-McCann	Van Duzen River	Tenmile Creek	Redwood Creek	Dos Rios	McCann	Van Duzen River	Tenmile Creek	Redwood Creek	Dos Rios	McCann	Middle Fork Eel River near Black Butte River	Van Duzen River	Tenmile Creek	Redwood Creek	Dos Rios	McCann	Middle Fork Eel	Van Duzen River	Tenmile Creek	Redwood Creek	Dos Rios	McCann	Middle Fork Eel	Tenmile Creek	Redwood Creek	Dos Rios	McCann	Middle Fork Eel	McCann	Middle Fork Eel	McCann	McCann
	MARCH					APRIL					MAY						JUNE						JULY						AUGUST					SEPT.		OCT.	NOV.
20-29							2	47	1		5	22	27		9	26				2											1						
30-39							6	23	11		11	168	55	18	35	26	11		22	2	2	46		2	1	4	1	22		1	2		1				
40-49	AGE +								44		7	66	29	106	16	20	45		47	14	12	70		21	38	31	9	90		2	40	12	6	3	1		
50-59		8	1				4	7	10		6	8	14	42	18	3	35		9	21	9	3		41	49	21	89	42		1	107	25	5	5	9		
60-69		33	2	1			18	46	6			2	5		12		45		4	8				19	15	17	85	15		3	83	33	2	1	20		
70-79		9	9				21	70	9				8		1		25		2	2				5	1	26	28	5		1	85	14	3	1	10		
80-89	1	1	3			2	10	50	1			1	13				1		2	1		1		4		3	12				33	1	1		2	1	
90-99			1			1	4	20	3			1	17						1							5	5				7	5	1	1	2		
100-109							1	6	1				7						2			2				1	3				14	3			1		
110-119								4					5						1	1		1				2	2	2			11				3		2
120-129	AGE 1							1					5		1											3	2	2			14				2		
130-139			1																				1			4	2				4				6		
140-149				1				1					1															1			9				1		
150-159			1	1					1				2													1					4						
160-169			1	1					1																						3				1		
Over-170	AGE 2		2										1																					1			

[1] Ages were determined using age-length relationship from Shapovalov and Taft (1954)

March April Outmigration peak (1+)

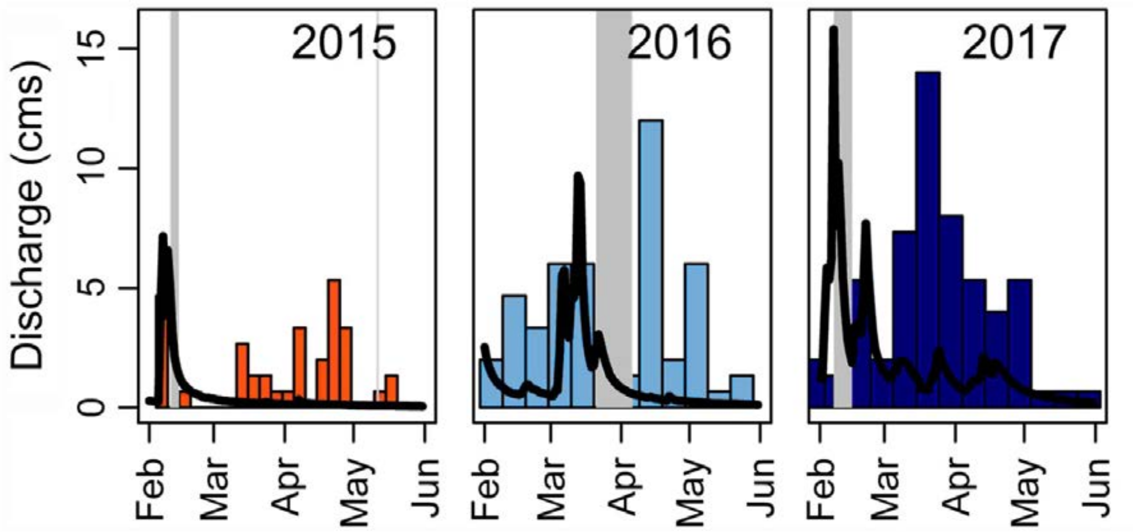


Figure 6 from Kelson et al. 2019

Mid-June peak (all ages)

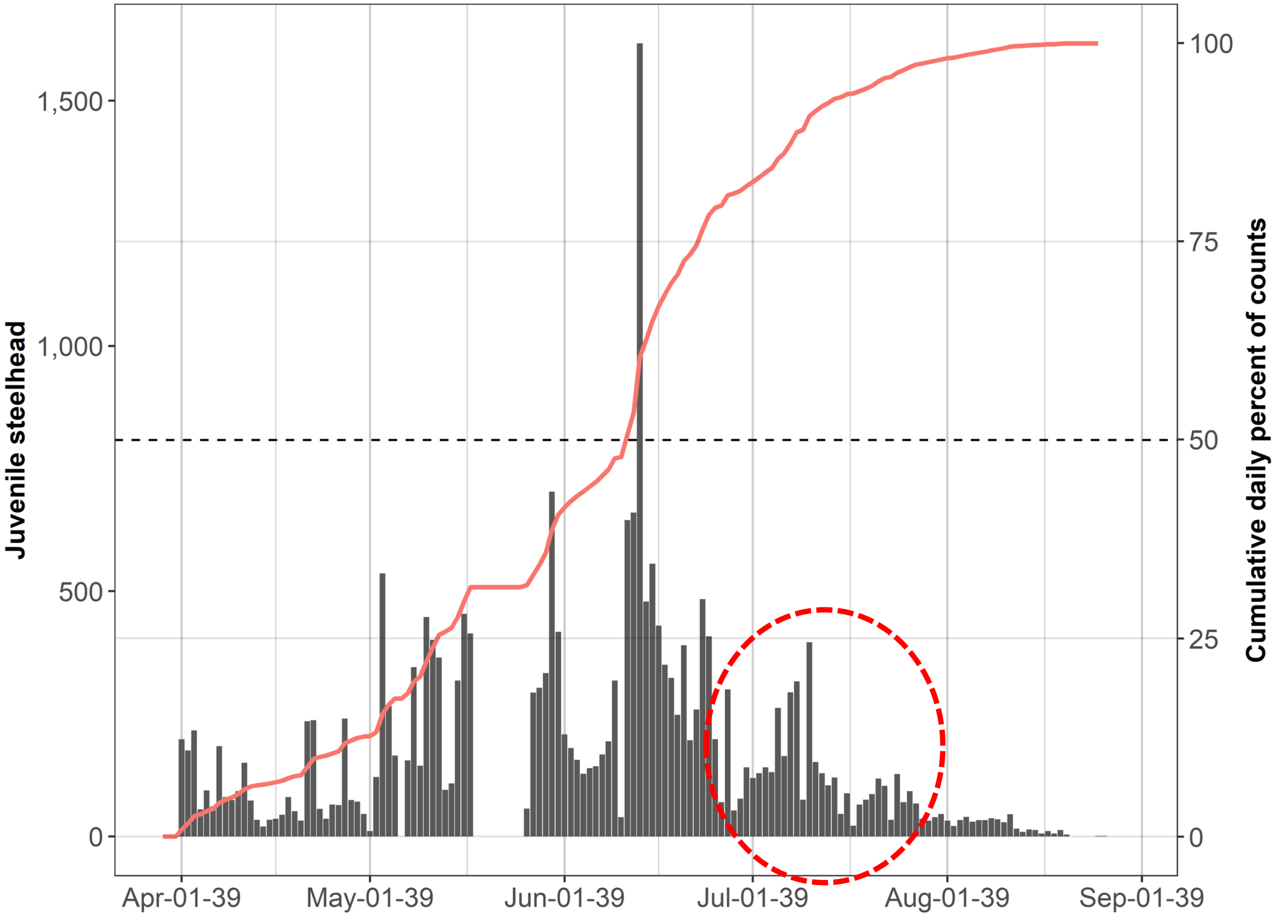
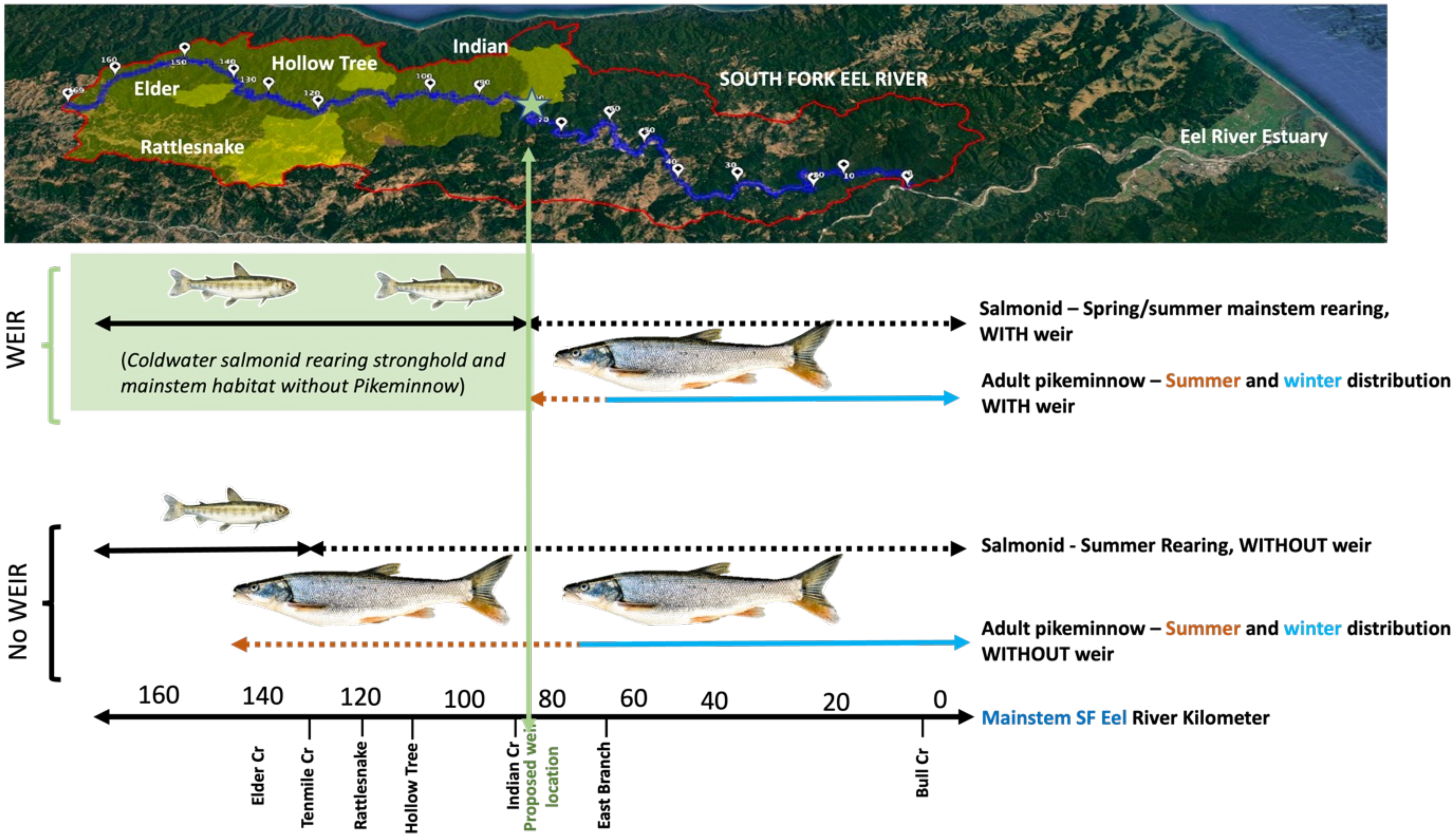


Figure From Stillwater 2022.



Indian
Hollow Tree
Elder
Rattlesnake
SOUTH FORK EEL RIVER
Eel River Estuary
WEIR
(Coldwater salmonid rearing stronghold and mainstem habitat without Pikeminnow)
Salmonid – Spring/summer mainstem rearing, WITH weir
Adult pikeminnow – Summer and winter distribution WITH weir
No WEIR
Salmonid - Summer Rearing, WITHOUT weir
Adult pikeminnow – Summer and winter distribution WITHOUT weir
160
140
120
100
80
60
40
20
0
Mainstem SF Eel River Kilometer
Elder Cr
Tenmile Cr
Rattlesnake
Hollow Tree
Indian Cr
Proposed weir location
East Branch
Bull Cr

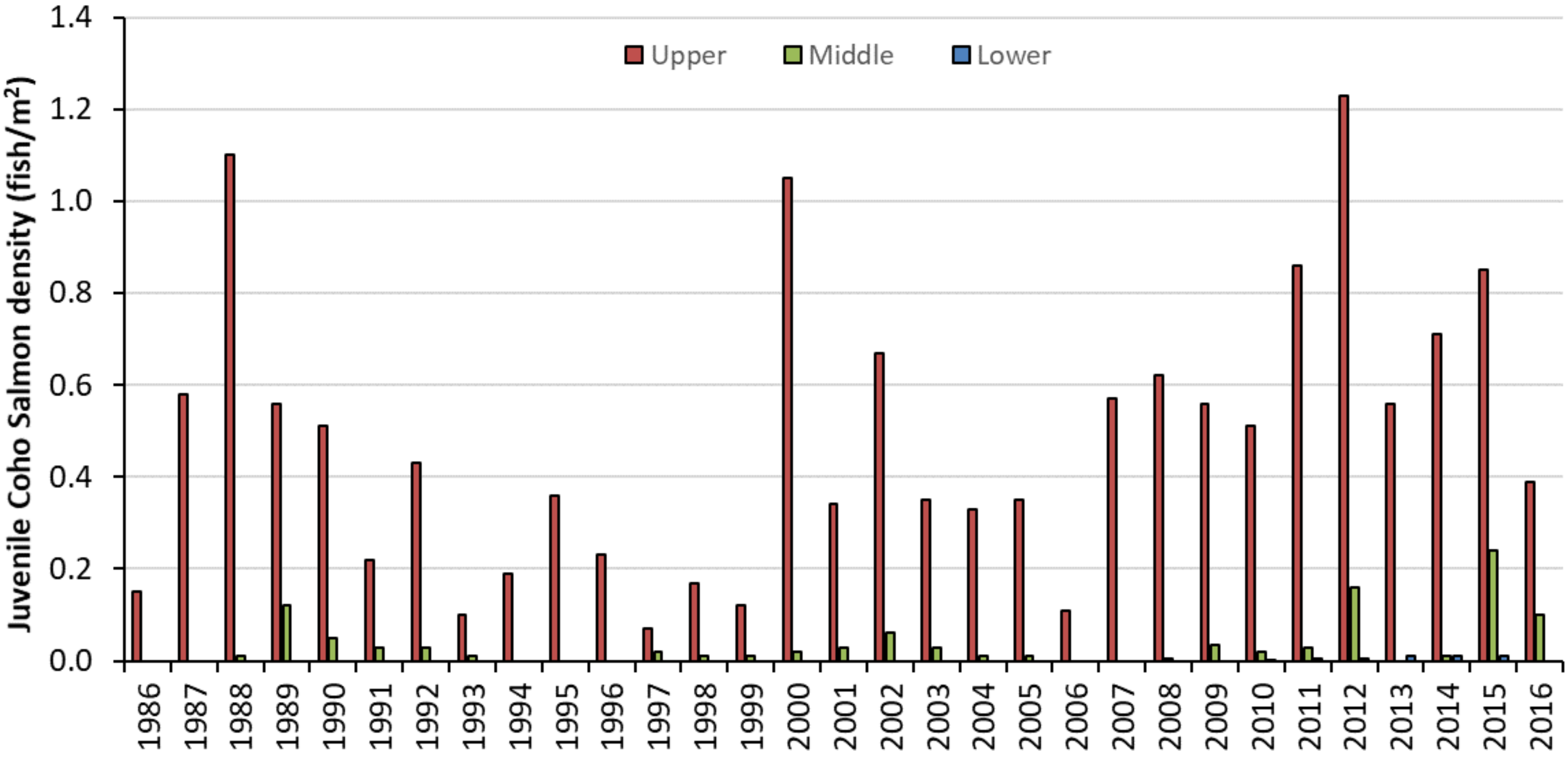
Location Code	Live Chinook	Known Chinook Redds	Live Coho	Known Coho Redds	Live Steelhead	Known Steelhead Redds	Live Unidentified	Unidentified Redds
105 S.F Eel River	0	0	6	2	0	0	0	1
113 S.F Eel River	2	1	0	0	0	0	0	3
118 Bull Creek	0	0	0	0	0	0	0	2
135 Subreach to 118	0	0	0	0	0	0	0	0
124 Bull Creek	1	0	0	0	0	0	0	0
126 Bull Creek	4	0	0	0	0	0	0	16
143 Squaw Creek	0	0	3	0	1	0	1	0
155 Mill Creek	0	0	0	0	0	0	0	0
434 Seely Creek	0	0	1	0	0	0	0	1
528 Trib to Little Sproul	0	0	0	0	2	1	0	1
728 Durphy Creek	0	0	0	0	0	0	0	0
747 Indian Creek	17	3	0	0	0	0	0	18
754 Indian Creek	11	3	0	0	0	0	0	26
779 Subreach to 754	0	0	0	0	0	0	0	0
764 Jones Creek	0	0	0	0	0	0	0	0
780 Sebbas Creek	0	0	1	0	0	0	0	2
781 Sebbas Creek	0	0	20	4	0	0	0	17
784 Subreach to 781	0	0	0	0	0	0	0	0
787 Coulborn Creek	0	0	14	2	0	0	7	6
790 Subreach to 787	0	0	3	2	0	0	0	3
793 Subreach to 787	0	0	0	0	0	0	0	0
798 Anderson Creek	6	0	19	7	0	0	1	33
799 Anderson Creek	0	0	2	1	0	0	0	3
820 Piercy Creek	0	0	4	0	0	0	0	0
826 Standley Creek	0	0	0	0	0	0	0	2
829 Standley Creek	0	0	0	0	0	0	0	0
893 Wildcat Creek	0	0	0	0	0	0	0	2
941.5 Hollow Tree Creek	7	0	6	0	0	0	0	27
965 Subreach to 941.5	0	0	0	0	0	0	0	3
950.3 Hollow Tree Creek	1	0	12	1	1	0	1	23
980 Bear Creek	0	0	0	0	0	0	0	0
984 S.F Redwood Creek	0	0	0	0	0	0	0	5
986 Subreach to 984	0	0	0	0	0	0	0	0
991 Bond Creek	0	0	1	1	0	0	0	12
992 Bond Cr eek	0	0	0	0	0	0	0	0
996 Michaels Creek	2	0	2	0	0	0	0	21
998 Subreach to 996	0	0	0	0	0	0	0	0
999 Subreach to 998	0	0	0	0	0	0	0	0
1000 Subreach to 996	0	0	0	0	0	0	0	0
1007 Huckleberry Creek	0	0	21	3	2	0	0	9
1010 Subreach to 1007	0	0	0	0	0	0	0	0
1017 Cedar Creek	32	5	0	0	1	0	1	17
1132 Tenmile Creek	22	5	0	0	0	0	1	10
1196 Subreach to 1132	0	0	0	0	0	0	0	0
1228 Little Case Creek	9	1	2	0	0	0	0	9
1229 Little Case Creek	0	0	0	0	0	0	0	0
1248 Cahto Creek	0	0	0	0	0	0	0	6
1254 Subreach to 1248	0	0	0	0	0	0	0	1
1306 Dutch Charlie Creek	0	0	25	8	1	0	2	23
1327 Kenny Creek	0	0	2	0	0	0	1	5
Total:	114	17	144	31	8	0	15	307

Major Coho producing streams in the South Fork Eel.

- Sproul Creek (South Fork and West Fork)
- Hollow Tree Creek (Huckleberry Creek)
- Indian Creek (Sebbas, Coulbrun, Anderson Creek)
- Upper South Fork (Dutch Charlie and above)

Was this always the case? What about tributaries where a 0+ or fall redistribution life history may have been viable historically but is no longer viable?

Coho Salmon in South Fork Sproul Creek



Late summer densities of juvenile coho salmon in three index sites of Hollow Tree Creek from 1986–2016. Estimated from multi-pass electrofishing surveys. Source: Stillwater 2020 Draft SWRCB report

Available estimates of age-1 juvenile coho salmon production from spring outmigrant trapping in South Fork Eel River tributaries. Source: Sproul Creek data from Vaughn (2007) and Hollow Tree Creek data from MRC (2002). Counts across both streams ranged from 42,000 to 14,000 1+ individuals.

Year	Estimated number of juvenile coho salmon (age-1 only)			
	West Fork Sproul Cr	South Fork Sproul Cr	Sproul Cr Total	Hollow Tree Creek
1999	787	366	1,153	--
2000	2,552	1,102	3,654	35,178
2001	1,962	763	2,725	35,976
2002	1,568	794	2,362	9,787
2003	100	667	767	--
2004	758	643	1,401	--
2005	1,898	2,050	3,948	--
2006	994	887	1,881	--
2007	3,066	1,962	5,028	--

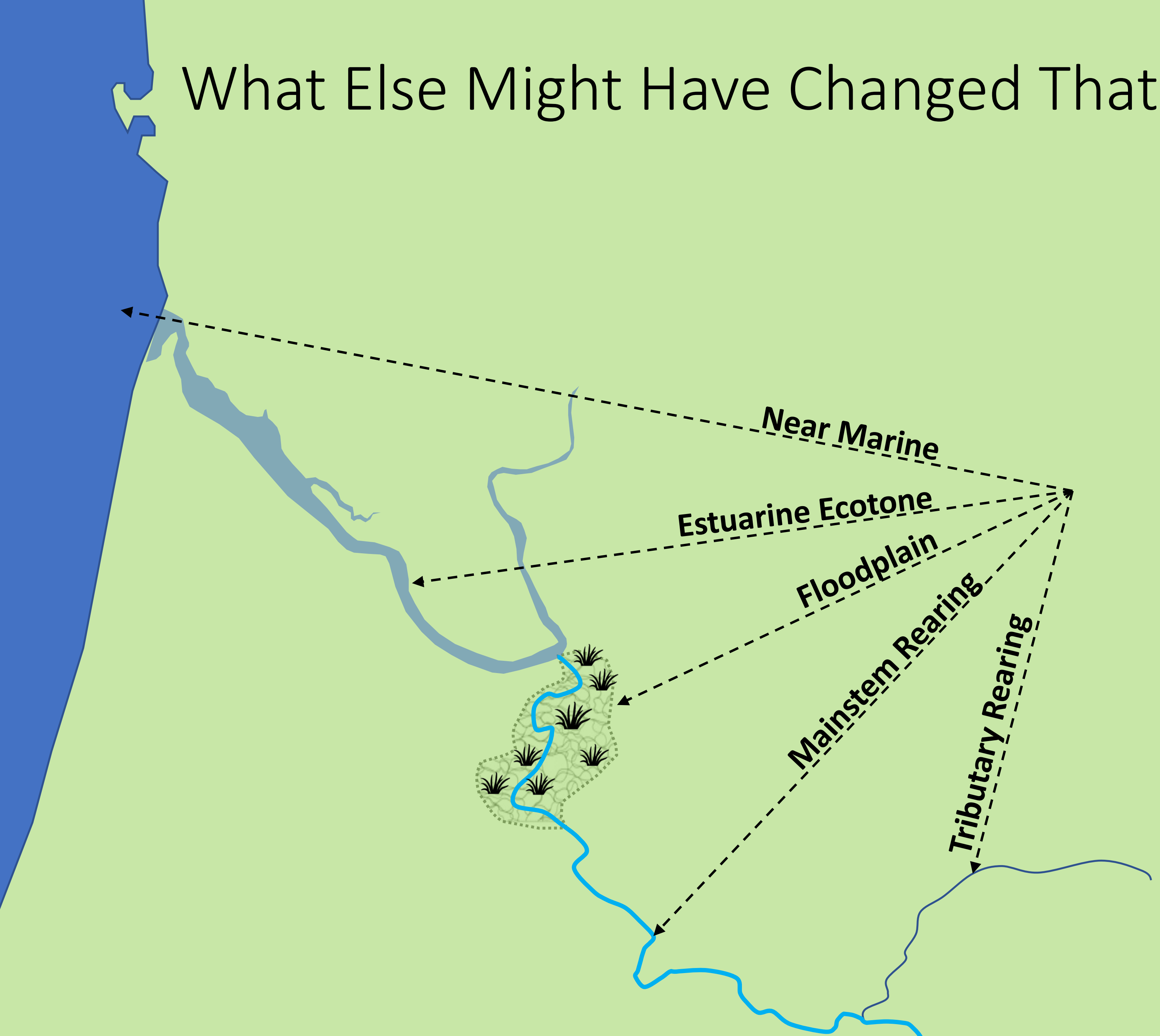
[1] Trapping effort and start date varied considerably between years in Sproul Creek and the early portion of the population may have been missed in some years.

Source: Stillwater 2020 Draft SWRCB report

Life History Summary

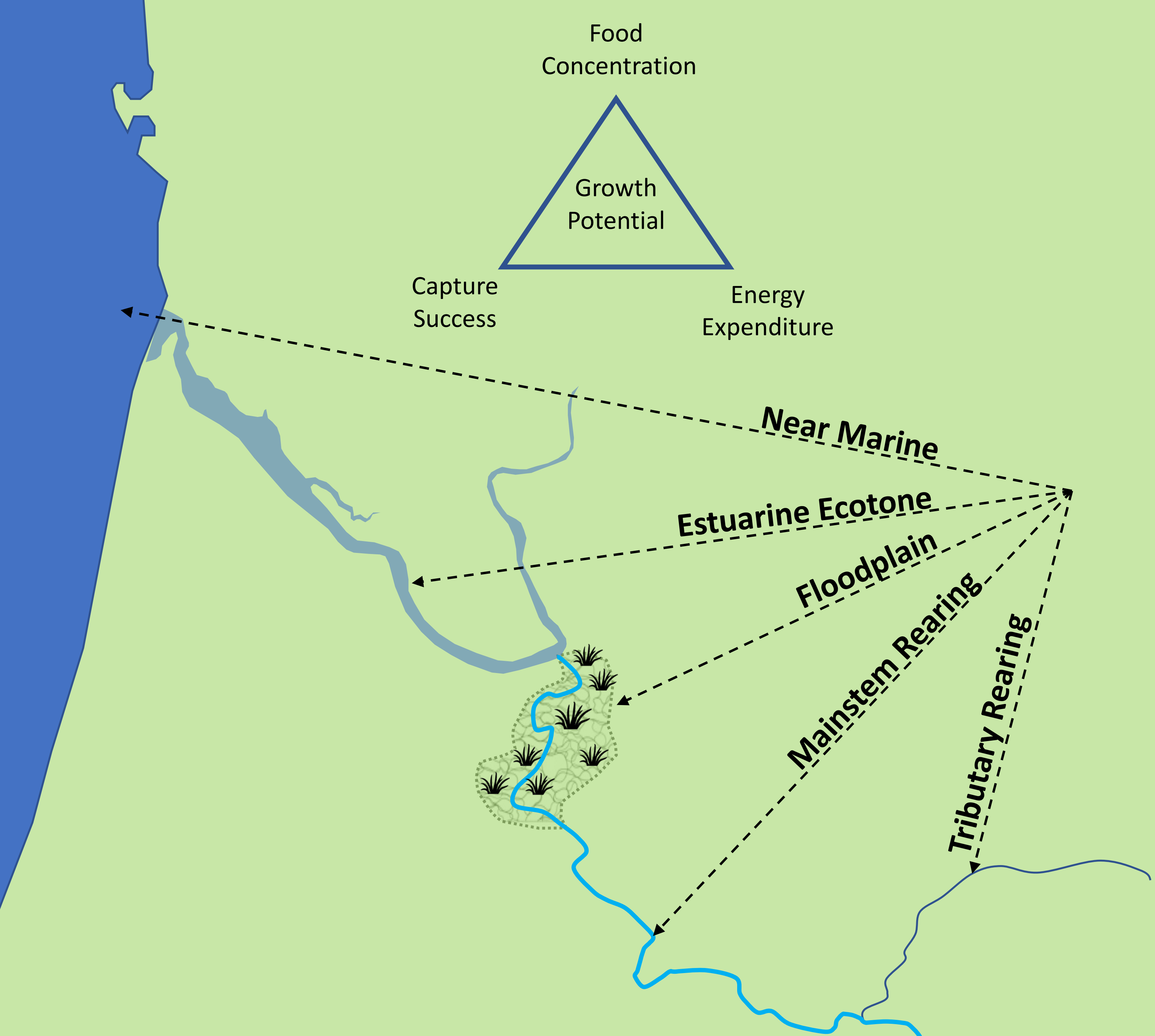
- Subsurface diversity suggest different sub-basins may exert selective pressures on traits including size, age, physiology, and timing of juvenile salmonid outmigration. This partially supported with historic trapping data (timing and age at least).
- There is evidence of large age 0+ *O. mykiss* and reason to believe in 0+ *O. kisutch* life histories outmigration but <u>*where did those animals go to finish their growth??*</u>
  - Mainstem (thermally stratified pools?)
  - Non-natal tributaries (Everest 1973) – Cedar Creek? Price Creek; Howe Creek
  - Estuarine Ecotone (deep holes between Van Duzen and Ferbridge)
  - Salt River and tributaries
  - Sloughs
- No clear trend in tributary abundance/density of Coho salmon over the last 25 years. Not enough data to estimate downstream survival and smolt-to-adult return.
- Most coho are currently produced in a few tributaries and reaches. Was that always the case? Will that always be the case?
- Was their diversity in osmoregulatory development of different runs … e.g. allowing them to use salt water in distinct times / ages? “Anticipatory process.”
- Juvenile Chinook life history and abundance in the SF Eel are very understudied

What Else Might Have Changed That We Aren't Focusing On?

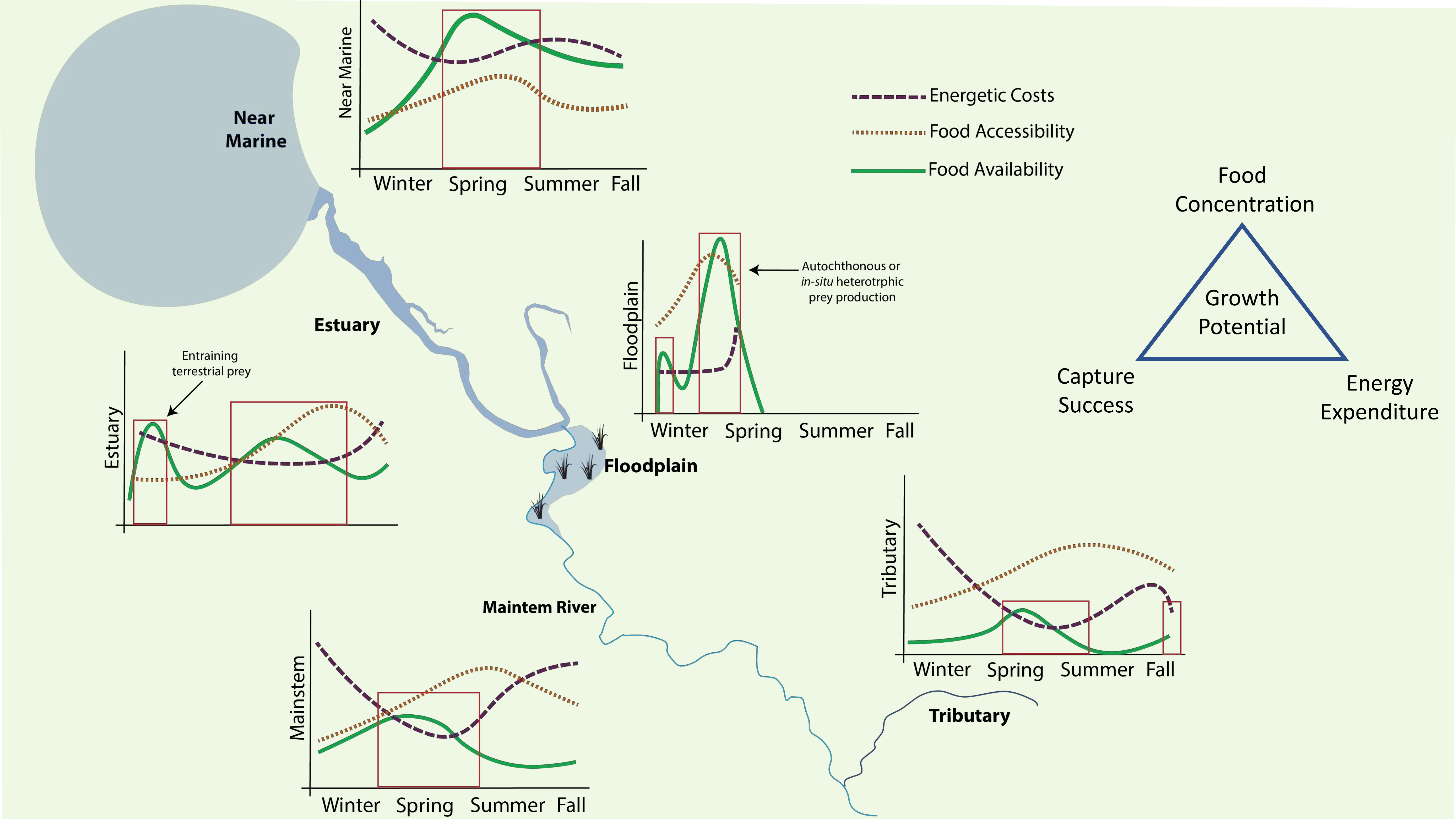


Altered Foodscapes

- What might have been the spatial temporal pattern of growth potential for juvenile salmonids in the Eel River? How has this changed in the last 165 years?



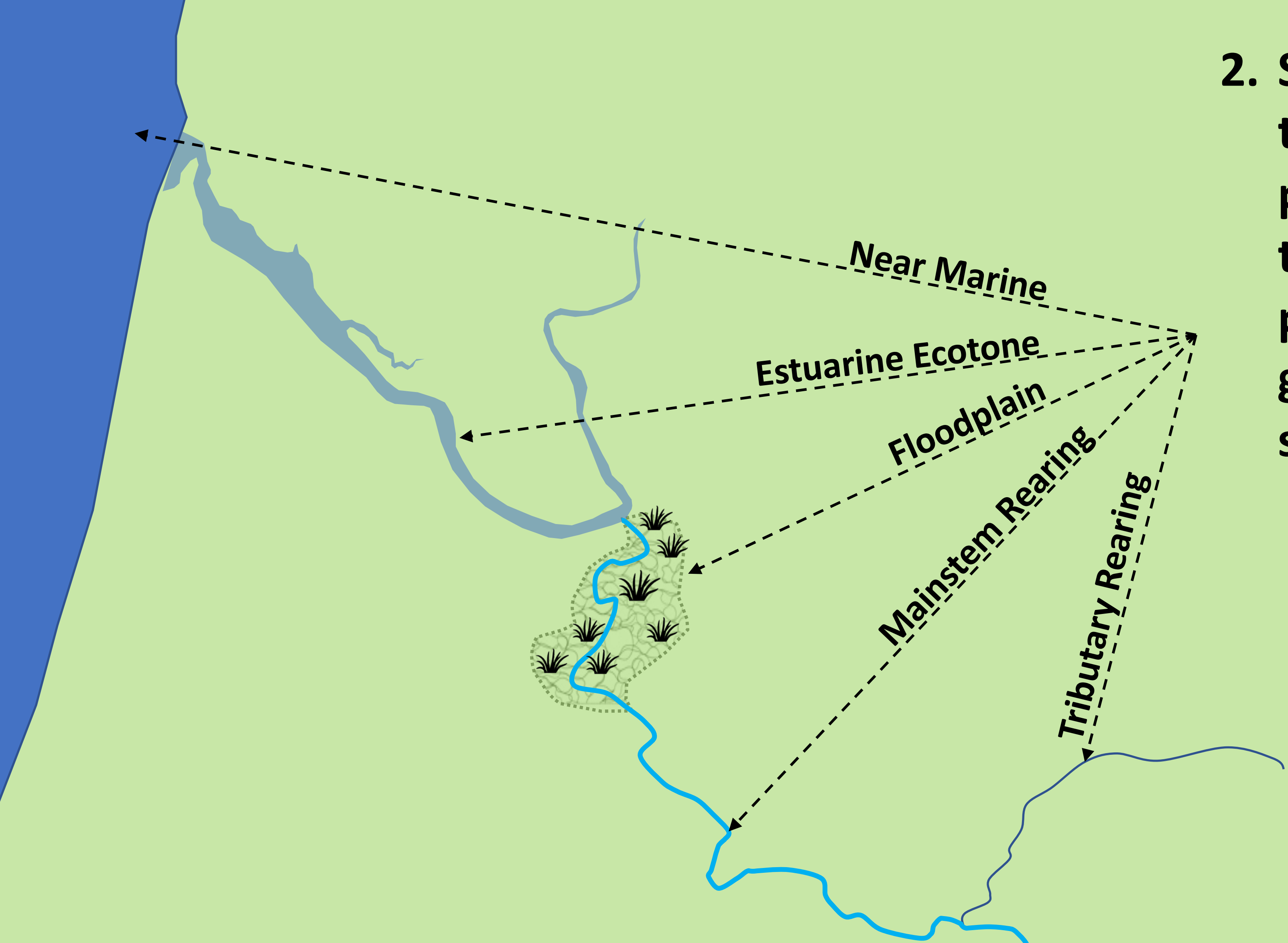
The "**foodscape**" is a mosaic of linked habitats with different growth potential phenologies that is exploited by mobile consumers and supports multiple life histories, often through asynchronies in resource availability.



Near Marine
Winter Spring Summer Fall
Energetic Costs
Food Accessibility
Food Availability
Food Concentration
Growth Potential
Capture Success
Energy Expenditure
Near Marine
Estuary
Autochthonous or in-situ heterotrphic prey production
Floodplain
Winter Spring Summer Fall
Entraining terrestrial prey
Estuary
Floodplain
Tributary
Winter Spring Summer Fall
Maintem River
Tributary
Mainstem
Winter Spring Summer Fall

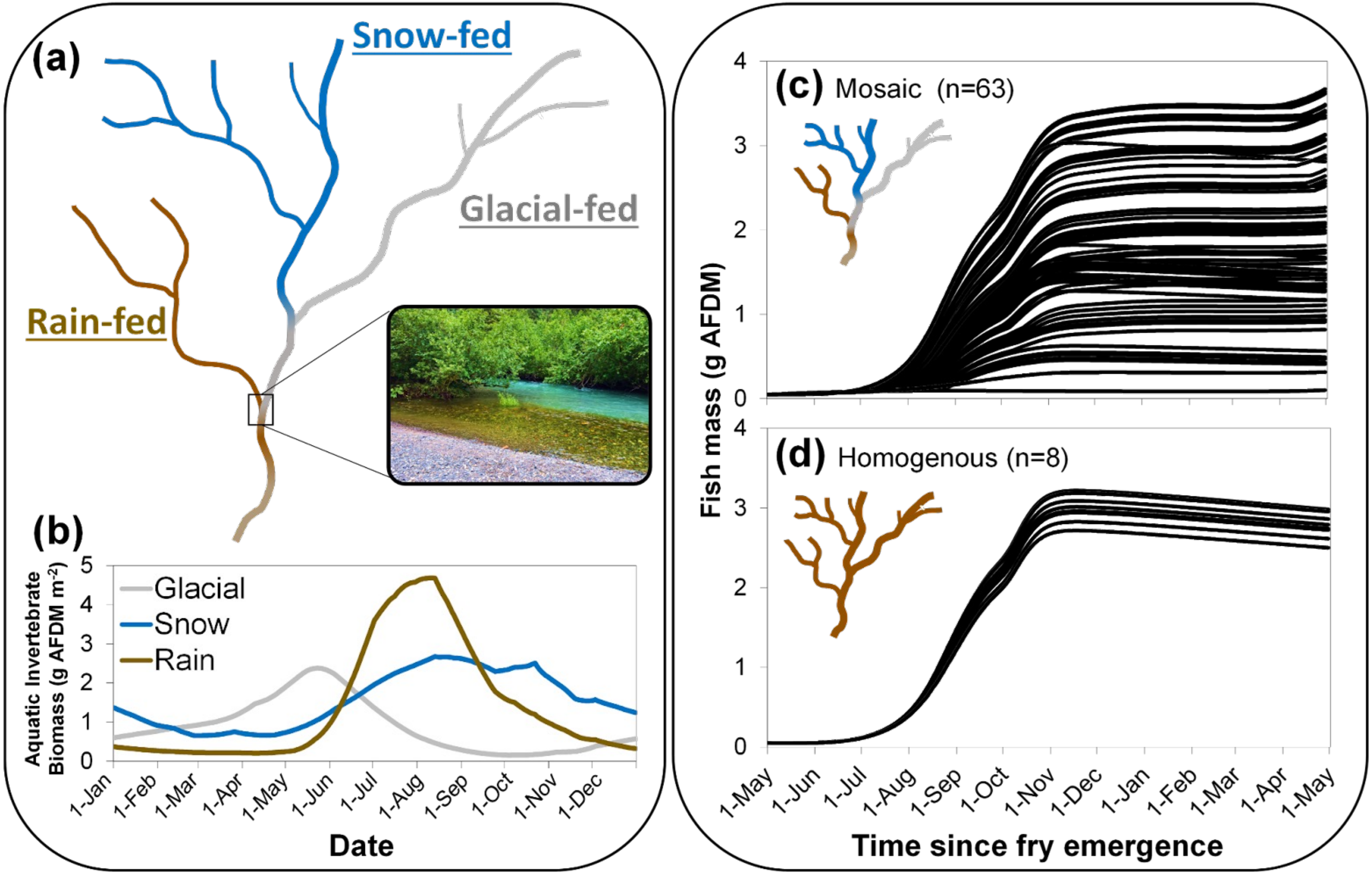
Assumptions of the Foodscape

1. Juvenile salmon use the whole watershed, and they do so through multiple, co-occurring life histories.

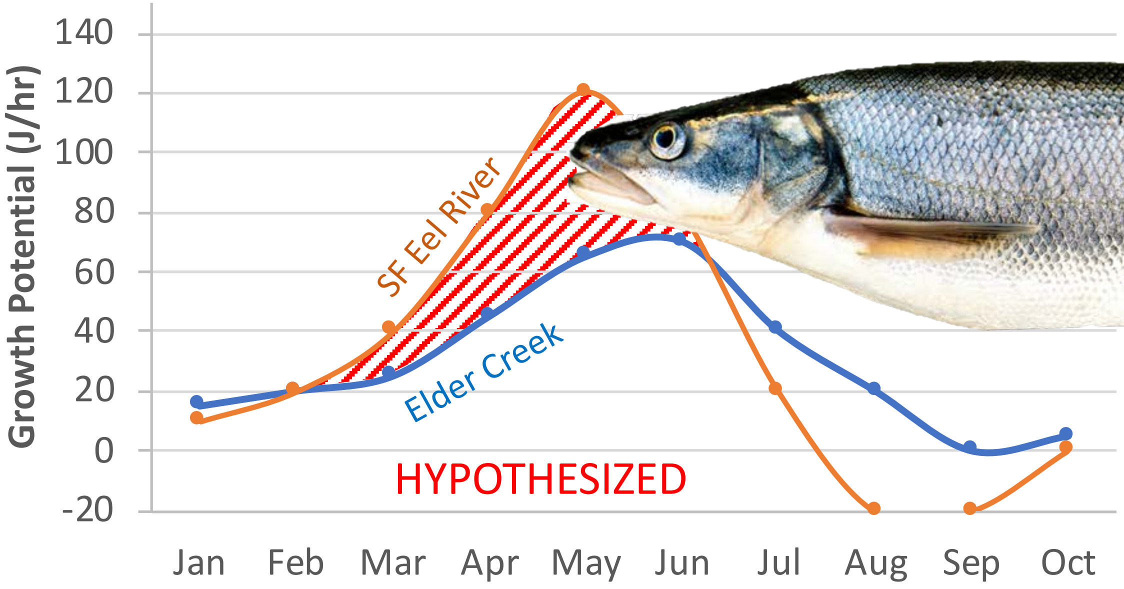


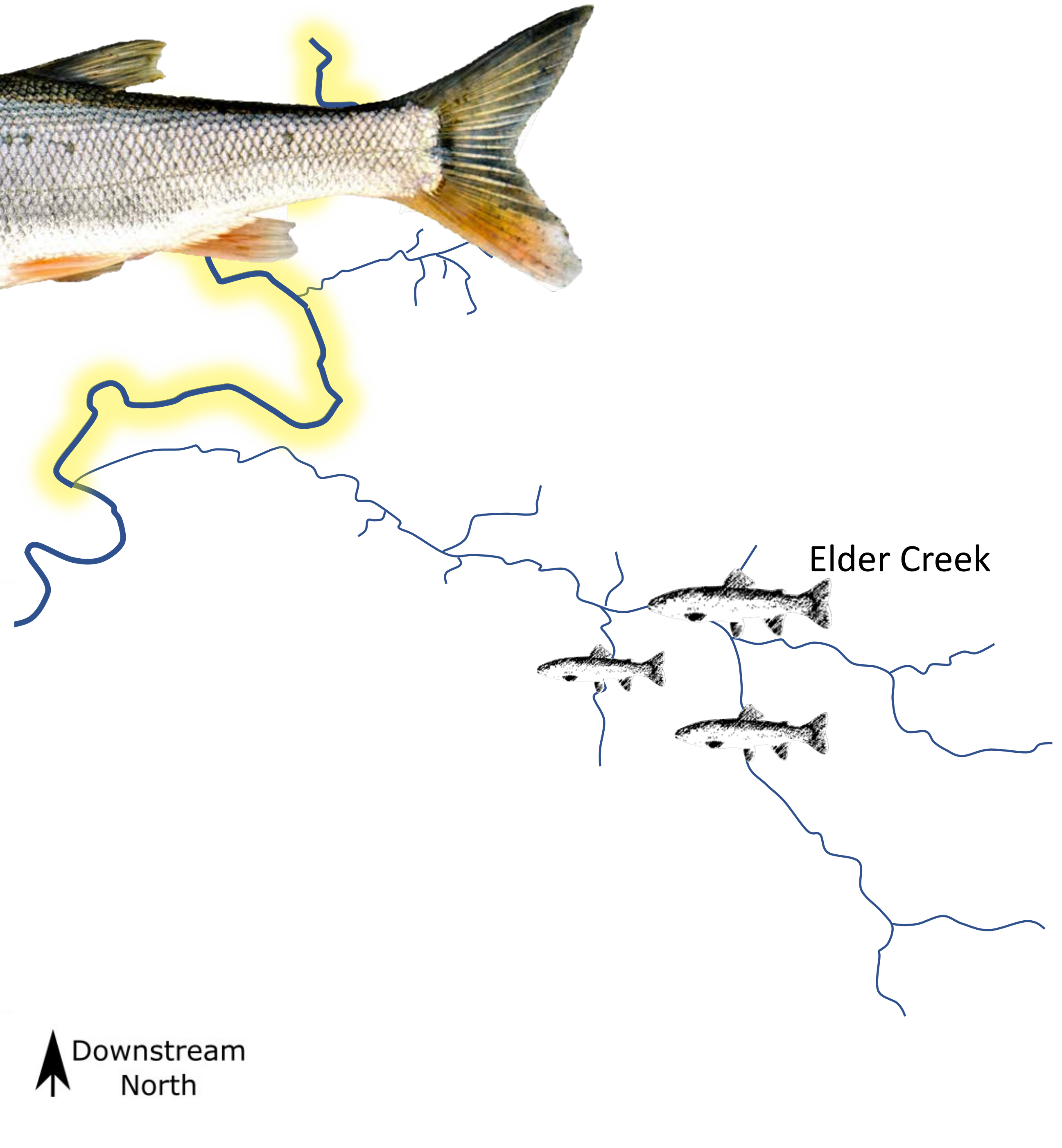
2. Salmon are fed by different trophic pathways in different parts of the watershed. And these different pathways produce asynchronous pulses of growth potential for juvenile salmonids in time, and space.

3. Salmon life histories are adapted to capitalize on the asynchronous pulses of growth that are unique to each watershed and perhaps water year.



Bellmore et al. 2022. Global Change Biology





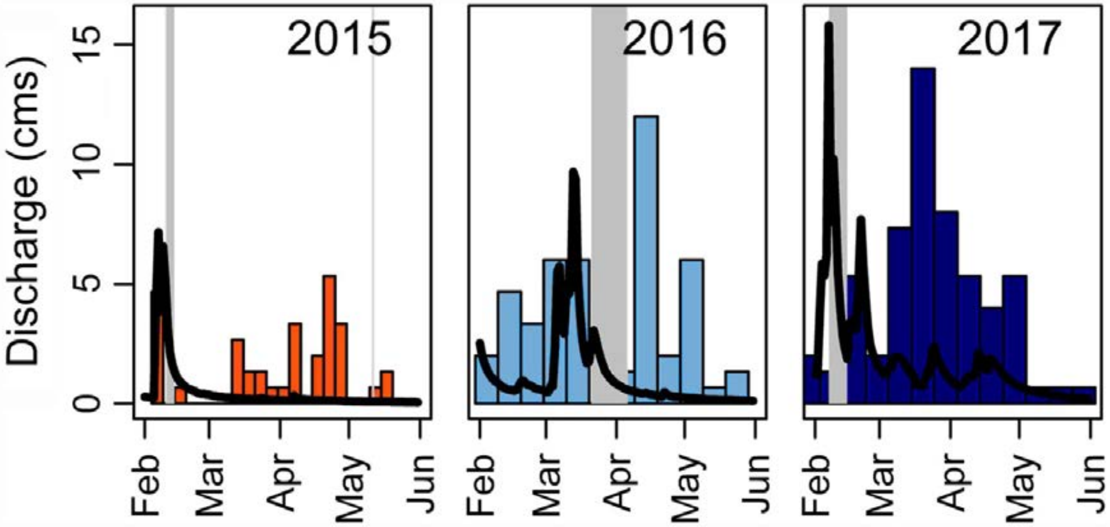
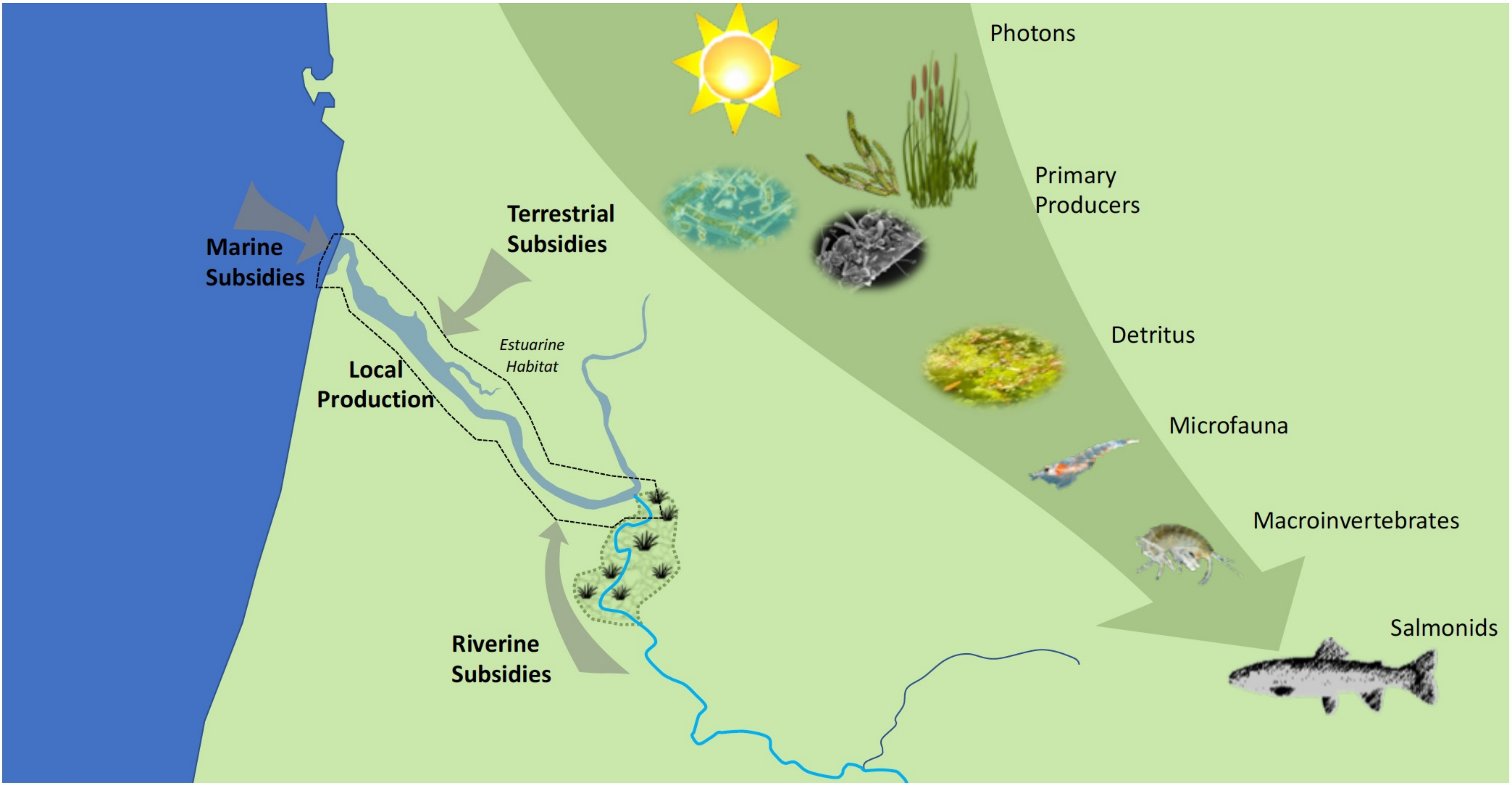


Figure 6 from Kelson et al. 2019

Altered Estuarine Foodscapes

Adapted from Sopjes Report 2018


Photons
Primary Producers
Detritus
Microfauna
Macroinvertebrates
Salmonids
Marine Subsidies
Terrestrial Subsidies
Estuarine Habitat
Local Production
Riverine Subsidies

The importance of the Estuarine Ecotone:

Salinity heterogeneity and isotonic water:

- Reduced energy costs
- Supports any state of osmoregulation

Estuarine food production

Fog belt water temperatures

Can by used by multiple life histories simultaneously

North Bay and Cannibal Island sloughs

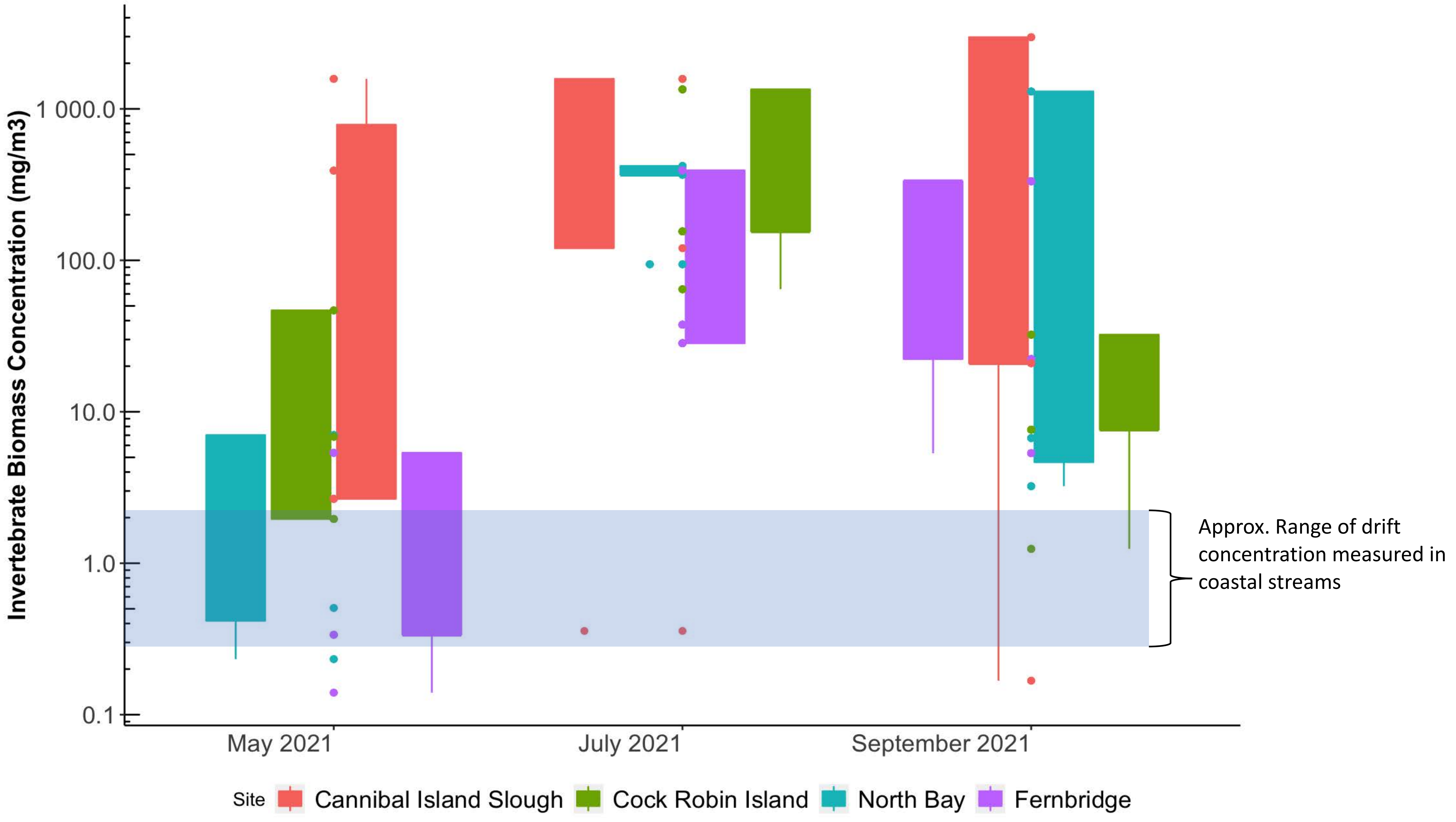

Cannibal Island slough

The crew processing algae at Cock Robin Island. The samples were often clogged with algae and filtering out the invertebrates was a technical challenge

A big handful of nutritious (at least for bugs) *Ulva* and *Enteromorpha* (marine derived green algaes)

Americorophium spinicorne

Eogammarus confervicolus



Invertebrate Biomass Concentration (mg/m3)
1 000.0
100.0
10.0
1.0
0.1
May 2021
July 2021
September 2021
Approx. Range of drift concentration measured in coastal streams
Site
Cannibal Island Slough
Cock Robin Island
North Bay
Fernbridge

Altered Foodscape Summary

- Juvenile salmon (all species) use the whole watershed, and they do so through multiple, co-occurring life histories. Salmon are fed by different trophic pathways in different parts of the watershed. And these different pathways produce asynchronous pulses of growth potential for juvenile salmonids in time, and space. This supports multiple life histories.
- How might the historic over-harvest; the synergy of doom, and the physical alteration of the lower river have severed the capacity of fish to access growth potential?
  - Loss of ecotone habitat (due to aggradation, levee and diking).
  - Loss of non-natal habitat (pool filling)
  - Loss resource subsidies (ocean, terrestrial, or riverine)
  - Impacts to salmon prey species?
- How might the rise of pikeminnow have severed the capacity of fish to access growth potential?
  - Loss of non-natal habitat (pre-estuarine tributaries)
  - The importance of mainstem rearing for density dependance
  - The importance of accessing estuarine and ecotone habitats
  - The movement and timing patterns of juvenile salmonids in the mainstem.
  - Predation on salmon facilitators?

What Else Might Have Changed That We Aren't Focusing On?

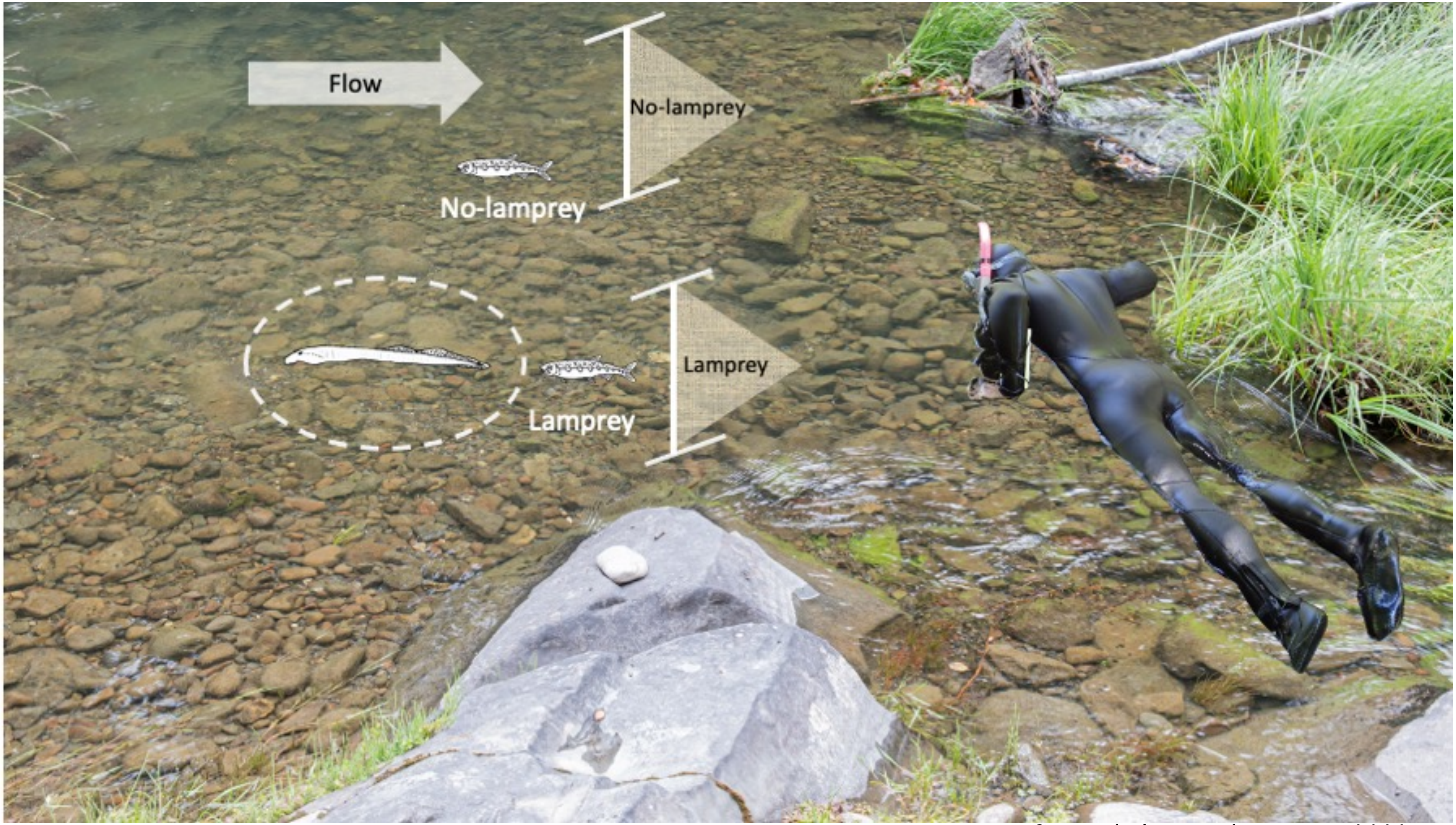
Lost Interactions

"And the other is Gary Nabhan's idea. In one of his books he says that animals don't go extinct because someone shoots the last one, or a bulldozer scrapes away the last habitat. They go extinct because the web of relationships that sustain them unravels. He then put it in anthropomorphic terms and said, they go extinct because of a lack of ecological companionship."

Jim Lichatowitch (2013)

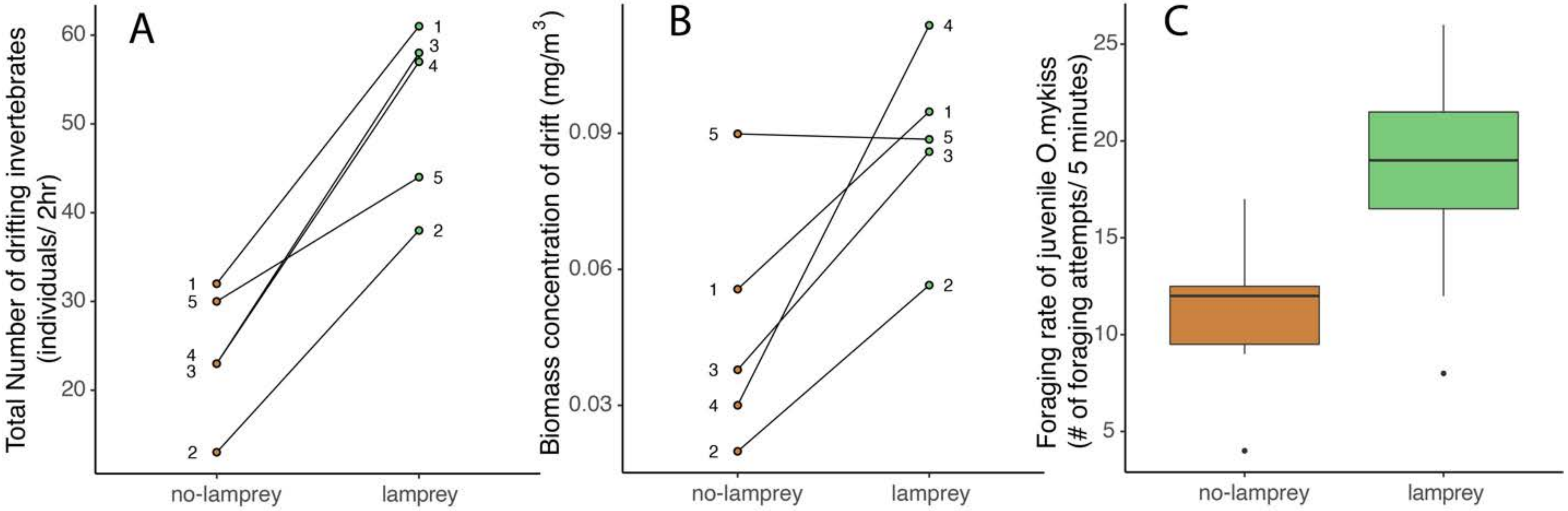
Pacific Lamprey facilitate juvenile salmonids
Georgakakos et al. *in prep*

From Georgakakos et al. *in prep, 2022*



From Georgakakos et al. *in prep, 2022*

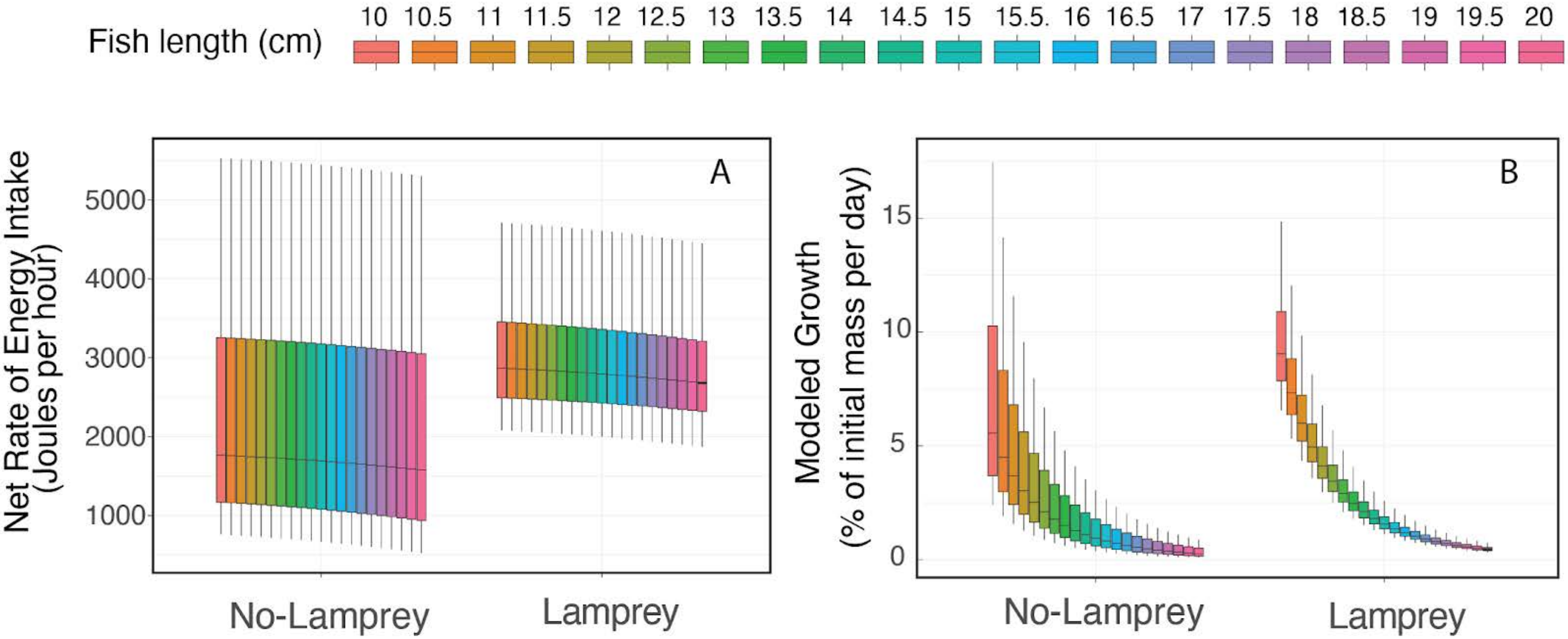
More bugs and more foraging



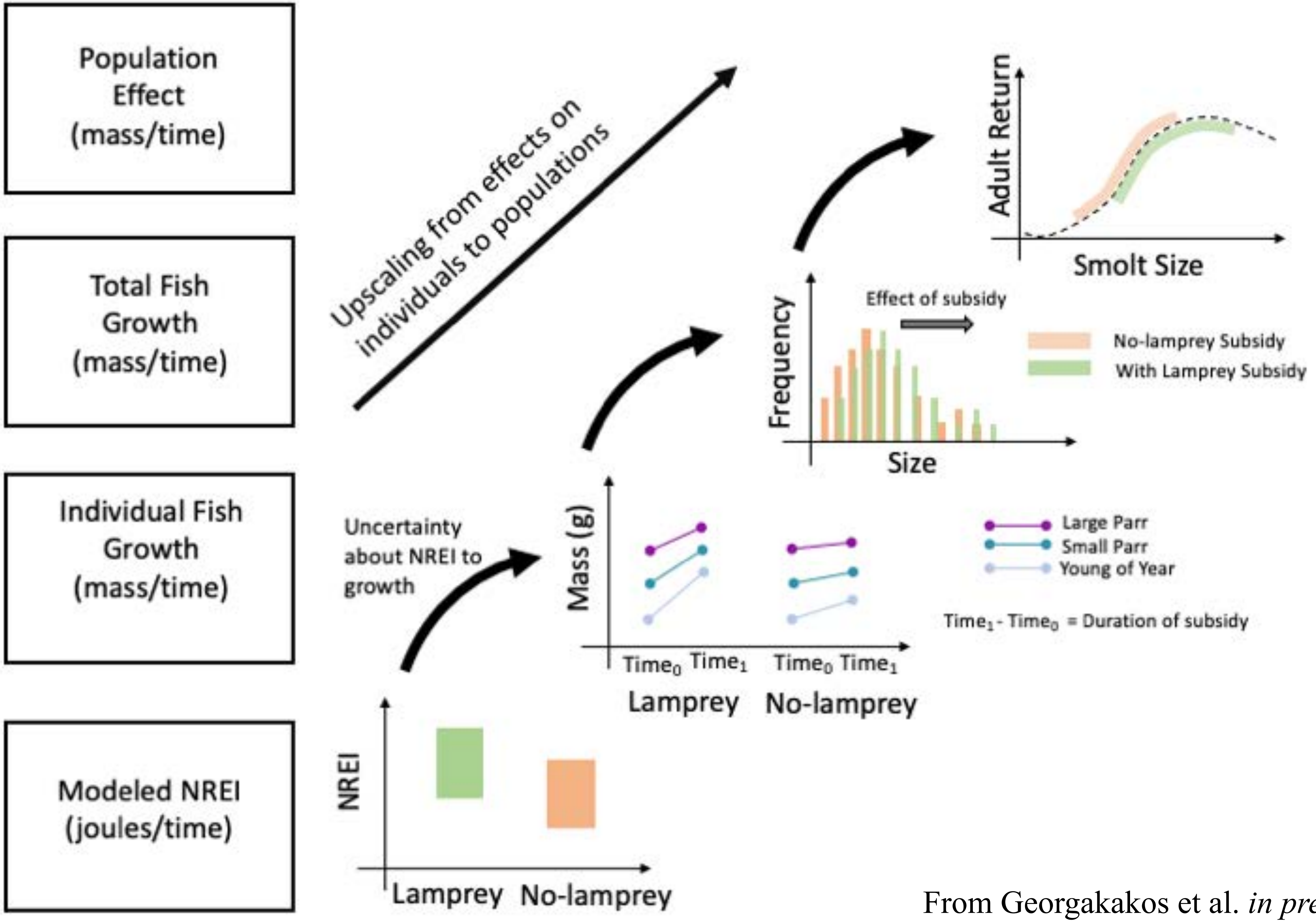
Lines connect paired samples for no-lamprey (brown) and lamprey (green) treatments. **A.** Number of invertebrates collected in drift samples. Significantly more invertebrates were sampled in lamprey treatments (GLMM, N = 5, p <.0001) **B.** Biomass concentration of drifting invertebrates (mg/m3) from drift samples. Significantly more biomass in lamprey treatment (GLMM, N = 5, p = 0.38) **C.** foraging attempts by juvenile steelhead more foraging behind lamprey (paired t-test, p = 2.76e-05)

From Georgakakos et al. *in prep, 2022*

Higher potential for growth



From Georgakakos et al. *in prep, 2022*



From Georgakakos et al. *in prep, 2022*

Hmmm… what just happened?

Understanding and recovering the “ghosts of life histories past.”

Understanding the linkage between subsurface dynamics and ecological response… and their role in population diversity.

How/where have those historic life histories been severed from riverscape-scale growth potential? How can they be re-connected?

What species interactions might be critical to recovering native salmonids?

How can we address these and other questions as a community?

Acknowledgements

- **California Trout**
- **UC Natural Reserve System**
- **Rangjung Yeshe Gomde**

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Questions?