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
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).
The use of railroad “inlines” made steam yarding on extremely steep slopes possible. The top of this incline is visible to the left of the yarder.

Figure 6. Yarde 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)
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, 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*,

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

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

~150 miles of stream;
2000 smolts per mile;
5% SAR
= 300,000 smolts
15,000 adults
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.
Coastal Belt mudstones
Central Belt mélange

THICK PROFILE
Coastal Belt mudstones

- Soil (~2 m)
- Saprolite (~4 m)
- Weathered mudstones (~23 m)
- Fresh bedrock (~32 m)

THIN PROFILE

- 2-3 m below surface

Increasing depth

waterSTORE

Hahm et al, 2019
Wisdom of the sponge

Wet sponge drips excess water, and stays wet

Evaporation fully dries the wet sponge
“Functional” flows

Yarnell et al., 2015
Large root-zone water storage deficits in Elder Creek must be "refilled" before significant streamflow initiation.
I. Wet-season flow activation

\[\Delta S \approx \sum P - Q\]

\[Q (\text{mm/day})\]

Rapid

Delayed

Runoff (mm/day)

Cumulative rainfall (mm)

Coastal Belt (Elder Creek)

Central Belt (Dry Creek)

Nov 2016

Dec
Full saturation of the subsurface in the melange catchment
Coastal Belt, slow recession driven by deep flowpaths
In melange, rapidly draining shallow flowpaths => streams go dry, contrasted with sustained perennial flow in Coastal Belt.
Habitat extent: wetted channel dynamics

Coastal belt, 17 km²

Central belt, 6 km²

Observed end-of-summer wetted channel drainage density: 0.11 km / km²

Observed end-of-summer wetted channel drainage density: 1.43 km / km²

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...

Ultramafic mutant!
Cedar Ck.
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
Seasonal Dynamics of Stream Hydraulics, Primary and Secondary Production and Drift
e.g. Coastal Belt lithology

e.g. Central Belt lithology
e.g. Coastal Belt lithology

April 30th 2018

e.g. Central Belt lithology
e.g. Coastal Belt lithology

July 15th 2018

- Streamflow (L/s)
- Blended Oxygen (mg/L)
- Temperature (°C)

14°C 28.45inHg  MOULTRIECAM  15 JUL 2018  08:00 am

e.g. Central Belt lithology
e.g. Coastal Belt lithology

e.g. Central Belt lithology

August 14th 2018

- Streamflow (L/s)
- Dissolved Oxygen (mg/L)
- Temperature (°C)
September 9th 2018

E.g. Central Belt lithology

E.g. Coastal Belt lithology
Elder Creek Pool in April

Reference Rock
Reference Rock

Elder Creek Pool in July
Porter Creek Pool in April

Reference Rock
Juvenile Salmonid Counts at Benbow Dam 1939

- **Chinook Salmon** = 63,574
- **Steelhead** = 23,226
- **Coho Salmon** = 8,696

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.

**Juvenile Salmonid Counts at Benbow Dam 1939**

- **May 7-13**: Coho (peak) and steelhead
- **June 12-17**: Chinook and steelhead peak
- **April 7-12**: Coho

Figure From Stillwater 2022.
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**Table 22**

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

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Ages were determined using age-length relationship from Shapovalov and Tait (1954)
Major Coho producing streams in the South Fork Eel.

- Sproul Creek (South Fork and West Fork)
- Hollow Tree Creek (Huckleberry Creek)
- Indian Creek (Sebas, 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?

### Table: Coho Salmon in South Fork Sproul Creek

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<th>Location Code</th>
<th>Live Chinook</th>
<th>Known Chinook Redds</th>
<th>Live Coho</th>
<th>Known Coho Redds</th>
<th>Live Steelhead</th>
<th>Known Steelhead Redds</th>
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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.

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<th>Year</th>
<th>Estimated number of juvenile coho salmon (age-1 only)</th>
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<tr>
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<td>2006</td>
<td>994</td>
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<td>2007</td>
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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 *where did those animals go to finish their growth??*
  - 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.
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.
Figure 6 from Kelson et al. 2019
Altered Estuarine Foodscapes

Adapted from Sopjes Report 2018
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 be 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 algae).
**Americorophium spinicorne**

**Eogammarus confervicolus**
Approx. Range of drift concentration measured in coastal streams
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?
“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
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
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

Questions?