Physical and biological constraints on the capacity for life-history expression of anadromous salmonids: an Eel River, California, case study

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ARTICLE

Physical and biological constraints on the capacity for life-history expression of anadromous salmonids: an Eel River, California, case study

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Abstract: Recovery of anadromous salmonid populations is complicated by their complex life histories. We examined the spatiotemporal interplay of stream temperature, geomorphic features, and a species' thermal sensitivity mediated by biological interactions in a case study of steelhead trout (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*) in California's Eel River watershed. We estimated habitat suitability and fish capacity for each salmonid run and freshwater life stage during average, cool, and warm years in each of the watershed's subbasins, including a historically occupied high-elevation subbasin upstream of an impassable dam. Our estimates varied depending on whether we accounted for exposure to the Sacramento pikeminnow (*Ptychocheilus grandis*), an introduced predator and competitor. Our results indicate that the dammed subbasin has substantial salmonid capacity relative to the rest of the watershed and could provide an important cool-water refuge during warm years and from pikeminnow, potentially improving the productivity and resilience of multiple anadromous salmonid populations. Our approach can be applied in any setting where spatially explicit habitat metrics can be estimated and population-specific and life-stage-specific habitat criteria can be specified.

Résumé : La complexité des cycles biologiques des salmonidés anadromes complique le rétablissement de leurs populations. Nous examinons l'interaction spatiotemporelle de la température du cours d'eau, d'éléments géomorphologiques et de la sensibilité thermique des espèces modulée par des interactions biologiques dans une étude de cas de la truite arc-en-ciel anadrome (*Oncorhynchus mykiss*) et du saumon chinook (*Oncorhynchus tshawytscha*) dans le bassin versant de la rivière Eel, en Californie. Nous estimons la qualité des habitats et la capacité de charge de poissons pour les différentes étapes de migration et de vie en eau douce de ces salmonidés durant des années moyennes, froides et chaudes dans chacun des sous-bassins du bassin versant, dont un sous-bassin de haute altitude occupé par le passé situé en amont d'un barrage infranchissable. Nos estimations varient selon que nous tenons compte ou non de l'exposition à la sauvagesse du Sacramento (*Ptychocheilus grandis*), un prédateur et concurrent introduit. Nos résultats indiquent que le sous-bassin endigué présente une capacité de charge de salmonidés considérable comparativement au reste du bassin versant et pourrait offrir un important refuge d'eau froide durant des années chaudes et contre la sauvagesse, améliorant potentiellement la productivité et la résilience de plusieurs populations de salmonidés anadromes. Notre approche peut s'appliquer à tout contexte où des paramètres spatialement explicites de l'habitat peuvent être estimés et des critères relatifs à l'habitat peuvent être spécifiés pour des populations et étapes du cycle biologique précises. [Traduit par la Rédaction]

Introduction

Recovery of anadromous salmonid populations is complicated by the fact that these fish have complex life histories, exposing them to a variety of climatic, physical, and biological impacts throughout their life cycle. A useful framework for sorting through this complexity emphasizes how abundance and productivity (i.e., population growth rate), mediated by a population's interactions with habitat via spatial structure and diversity, impact a population's long-term viability (McElhany et al. 2000). Conceptually, the most straightforward way to apply these ideas has been through quantitative life-cycle models that estimate survival across successive life stages under various climatic and hydrologic conditions. But life-cycle models usually require detailed data on stage-specific survival and abundance over many years (e.g., Scheuerell et al. 2006; Zeug et al. 2012; Crozier et al. 2021), which tends to bias their application to highly impacted populations where collection of such data are mandated. To assess recovery scenarios for understudied or extirpated populations, an alternative approach is to

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Co-authors

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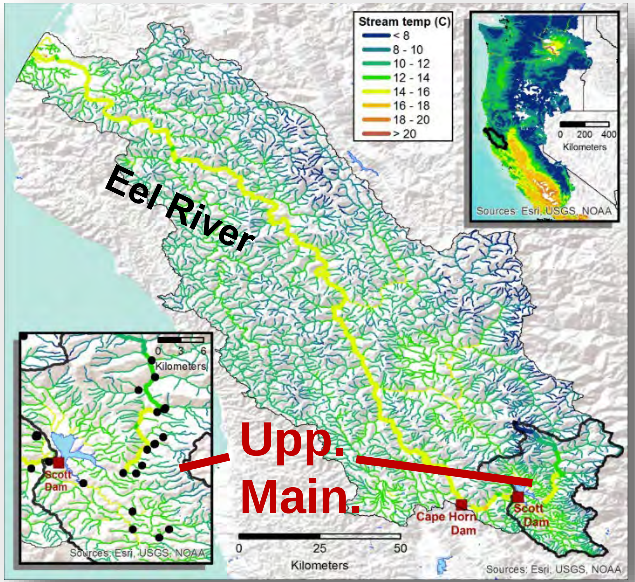
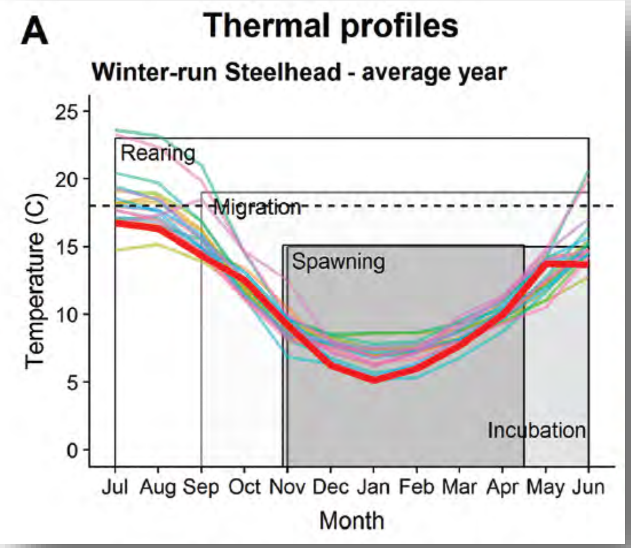
Dam blocks habitat in Eel River Basin

- Eel River Basin
  - Large, diverse stream system
    - ~10,000 river kilometers
    - Historically hosted robust run sizes (~1 million) of salmonids
      - Contains several threatened salmonid ESUs
    - 3rd largest salmonid watershed in CA
- Potter Valley hydroelectric project
  - Scott Dam (1922) blocks access to ~12% of river km in the Basin
- **Upp. Main.** is relatively cool





Approaches

Is the blocked Upper Mainstem Eel River subbasin important for salmonid recovery? How important?

1) Threshold approach
   - How much suitable habitat does the **Upp. Main.** have?
     - River km
     - Applied qualitative scores of channel type productivity and thermal conditions to estimate amount of suitable habitat

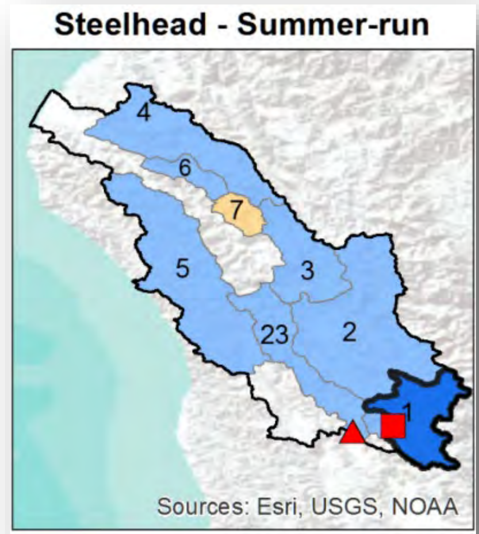
2) Capacity approach
   - How many parr and spawners can the **Upp. Main.** sustain?
     - Number
     - Applied Unit Characteristic Method, a capacity estimation statistical model

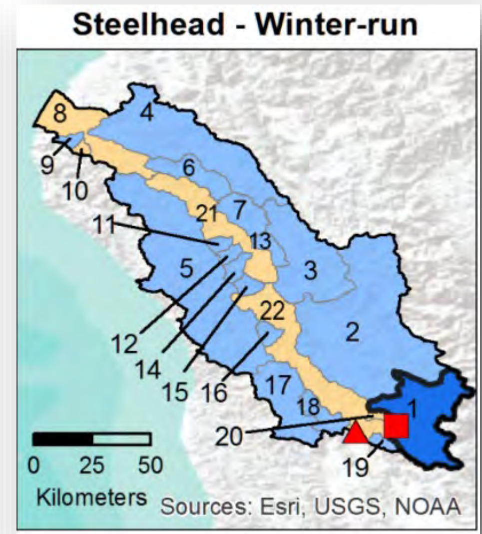
Methodological Approach 1

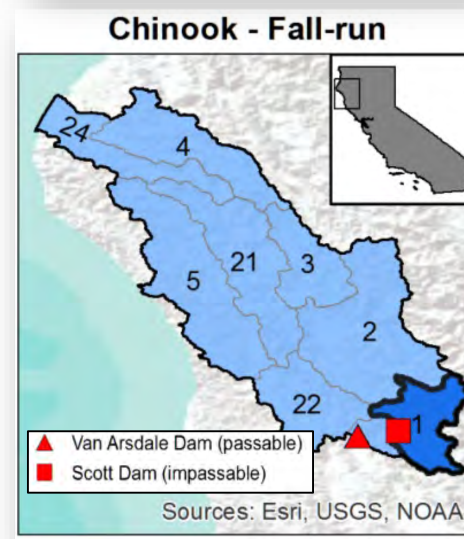
For each reach:

1) Accessible?
2) Productive habitat?
3) Thermally suitable?

- Assessed suitability for:
  - 3 ecotypes
  - 4 or 5 life stages (adult migration, pre-spawn holding, incubation, rearing, juvenile outmigration)
  - 3 year types (average, cool, warm)
  - Each subbasin
    - Subbasin: historical population boundaries defined from salmonid biogeographic breaks (Bjorkstedt et al. 2005, Spence et al. 2008)



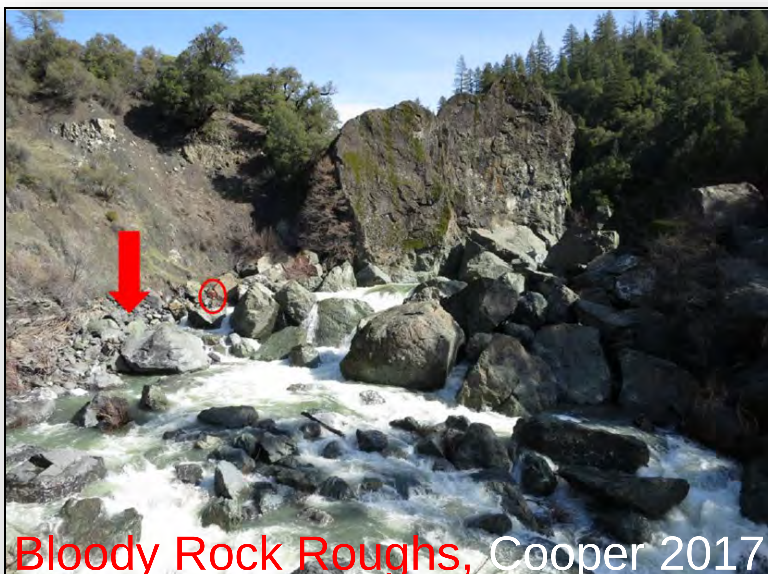




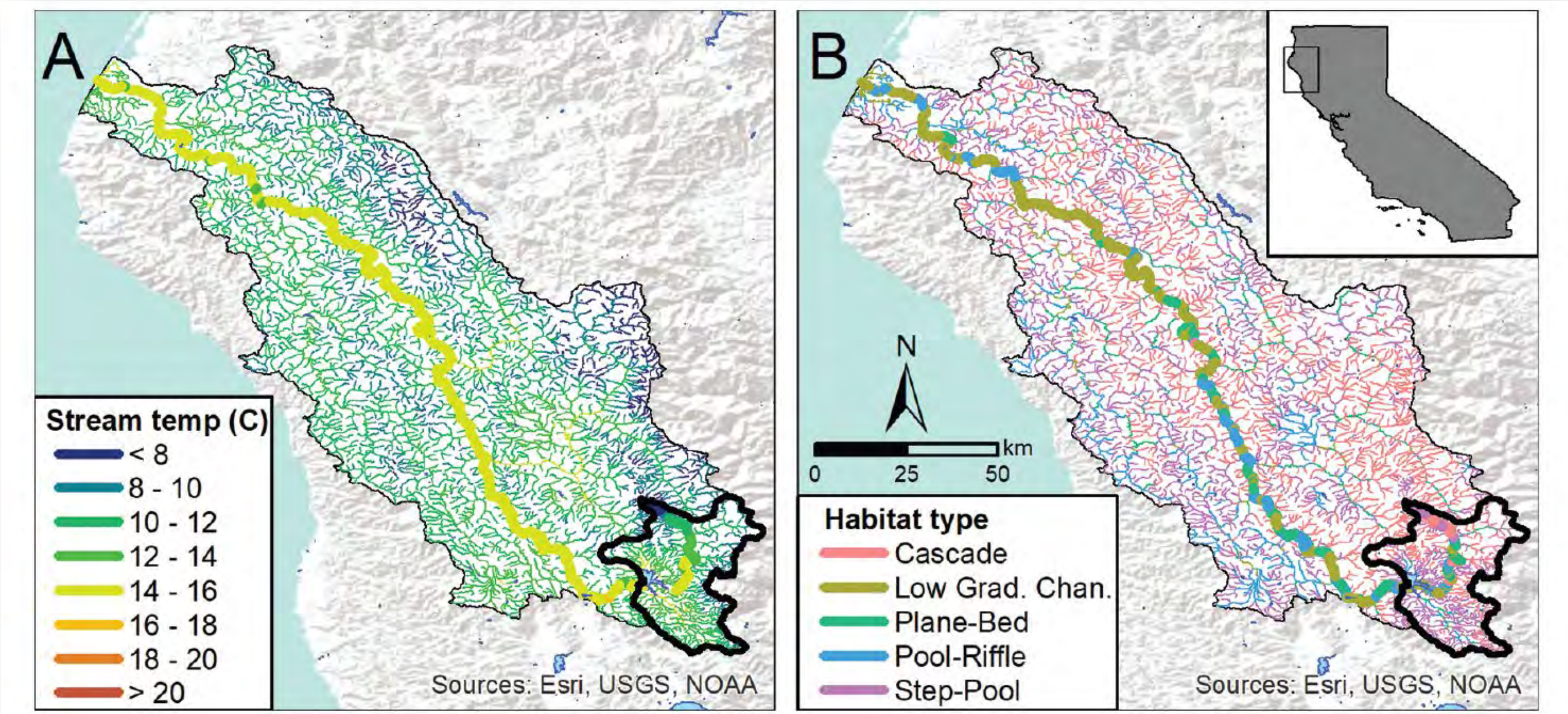
Accessible? | Productive habitat? | Thermally suitable?

- Accessibility limits: upstream of physical impassable barriers (e.g., large waterfalls) or upstream of species-specific barriers inferred from stream gradient

- Steelhead
  - ~5,000 km potentially accessible
  - **584 km blocked in Upp. Main. (12%)**
- Chinook salmon
  - ~2,500 km potentially accessible
  - **144 km blocked in Upp. Main. (6%)**



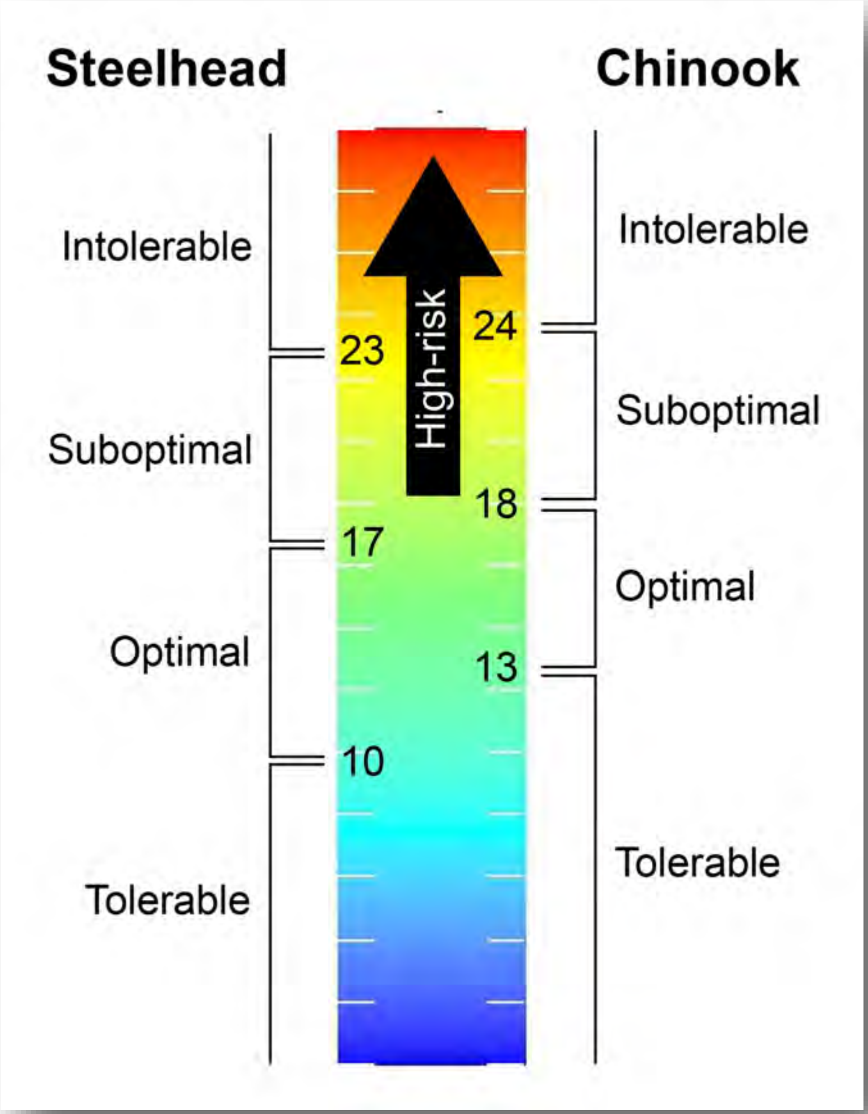
Accessible?	Productive habitat?	Thermally suitable?



- Literature review to define productivity by geomorphic channel type and thermal tolerance
  - Per life stage
- Assigned productivity level and thermal suitability
  - Across year

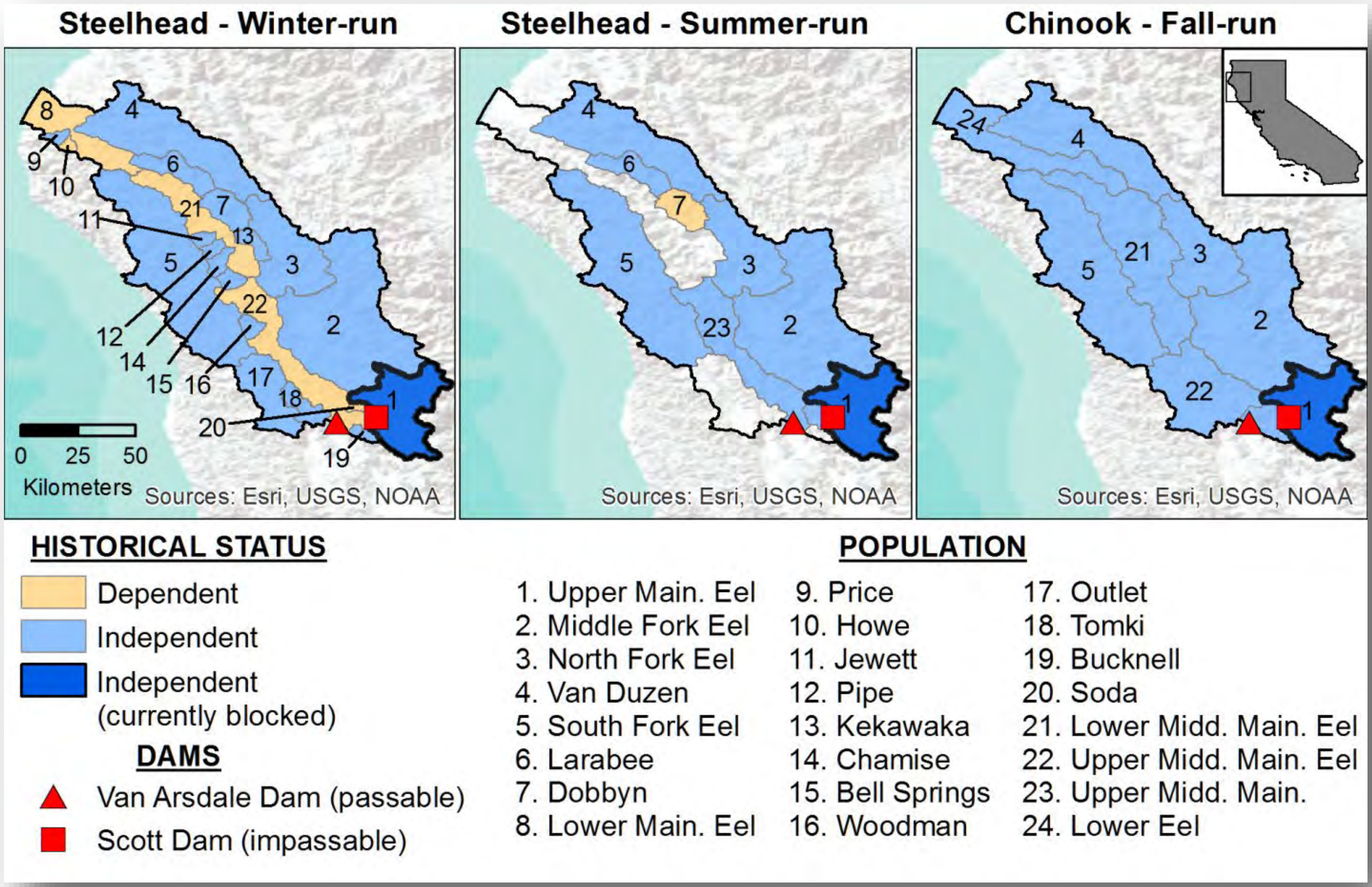
Accessible? | Productive habitat? | **Thermally suitable?**

- Additional thermal criteria needed for juveniles rearing
- Sacramento pikeminnow
  - Introduced species in Eel River Basin (ca. 1979)
  - Predator and competitor of juvenile salmonids
  - **Pikeminnow prefer temps ≥ 18°C**



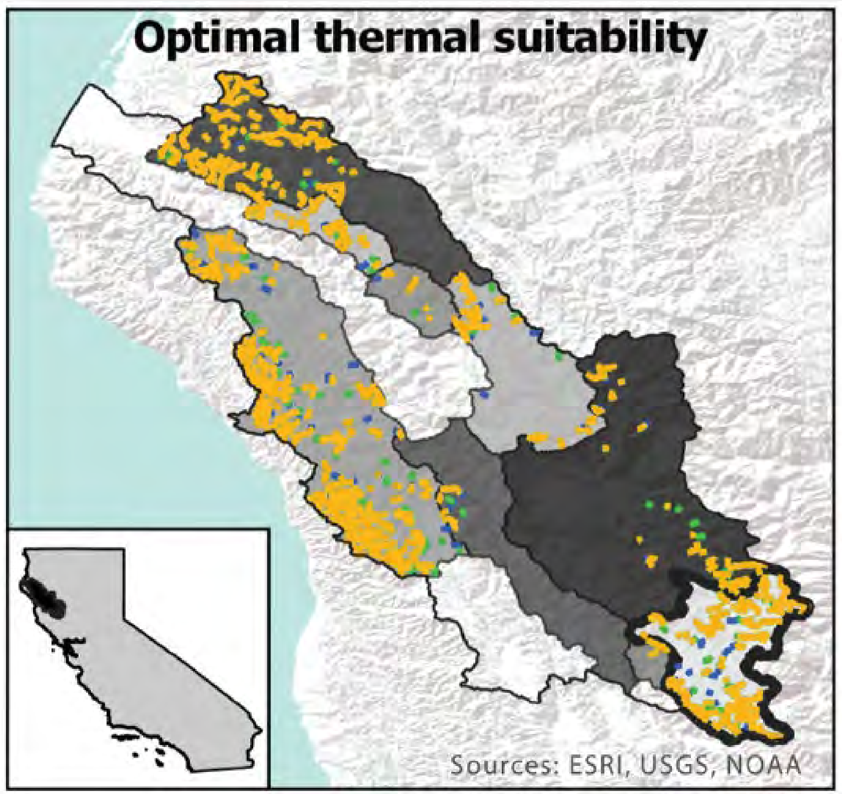
Approach 1: Results

How much suitable habitat does **Upp. Main.** have relative to other subbasins?



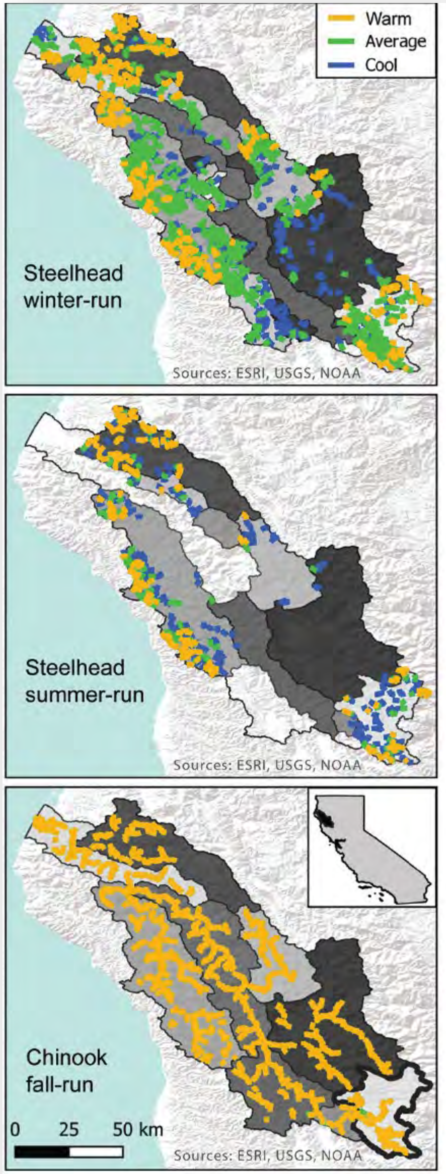
Results: Holding (STL summer only)

Figure 4. Reaches with optimal thermal suitability for holding summer-run steelhead trout in the month of August during warm years.



- Thermally optimal holding habitat present in June, greatly restricted during July and August, present in September
- Upp. Main., Van Duzen, Larabee, South Fork, had suitable cold-water habitat
- 216 km of optimal habitat in the Upp. Main., comparable to that of the Van Duzen (240 km)

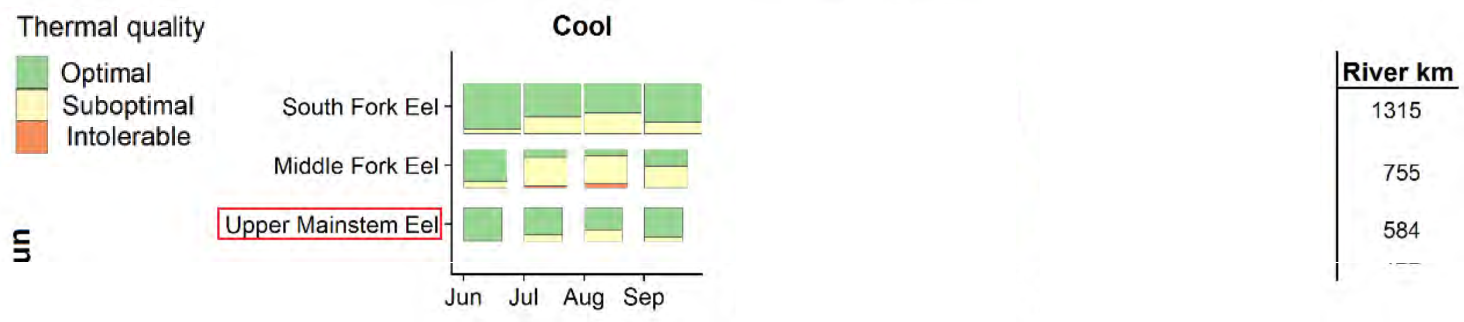
Results: Incubation



- Lots of suitable conditions during peak season (not shown)
  - **Upp. Main.** similar to Van Duzen during peak season
- Extended season – STL
  - During warm year (orange), much less suitable habitat
  - Successful spawning for fringe spawners may be precluded during drought years
- Extended season – CHK
  - Suitable throughout Basin

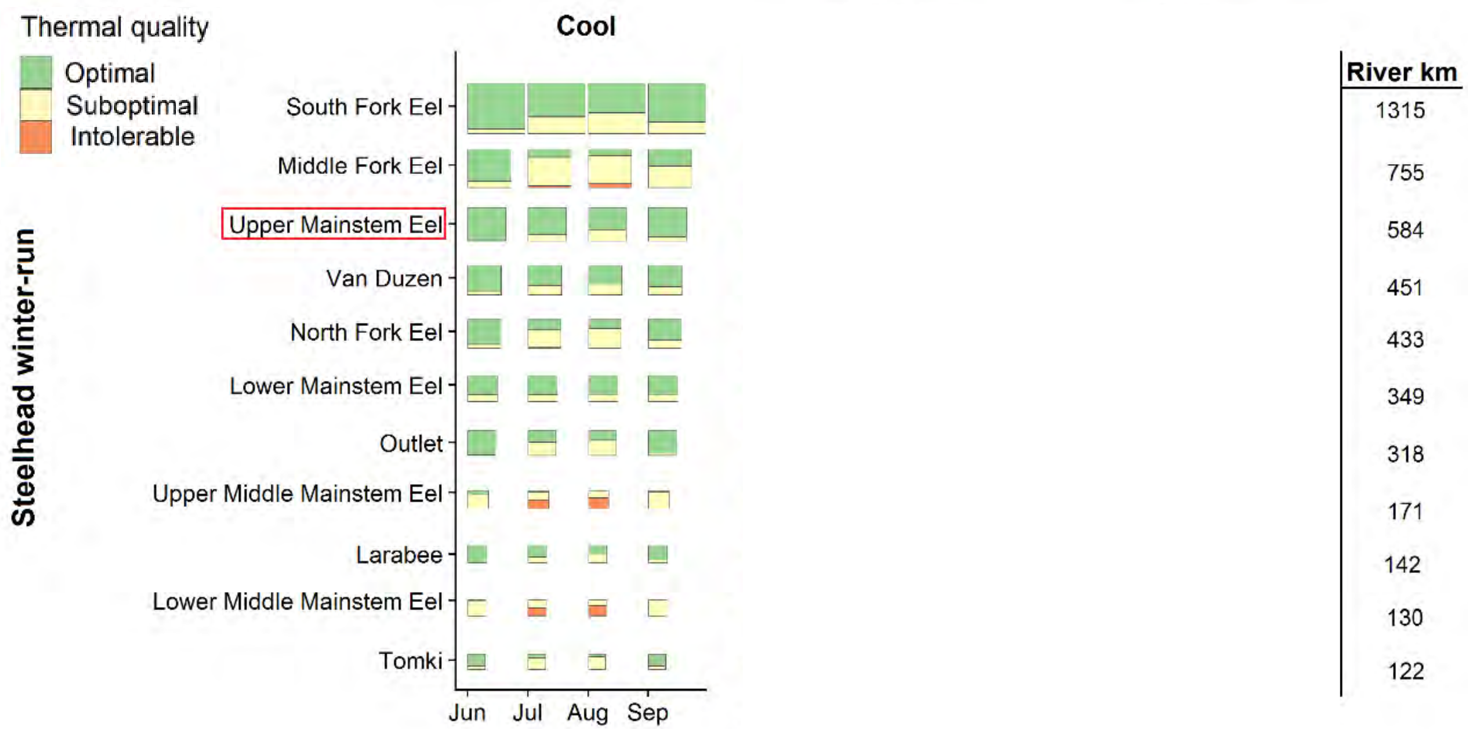
Figure 5. Suitable thermal refuges during the entire extended incubation season. Suitability is broken up by year type (colours in legend) and habitat type (left or right panels). In general, reaches suitable during the warm year were also suitable during the average year, and reaches suitable during the average year were also suitable during the cool year.

Results: Juvenile Rearing



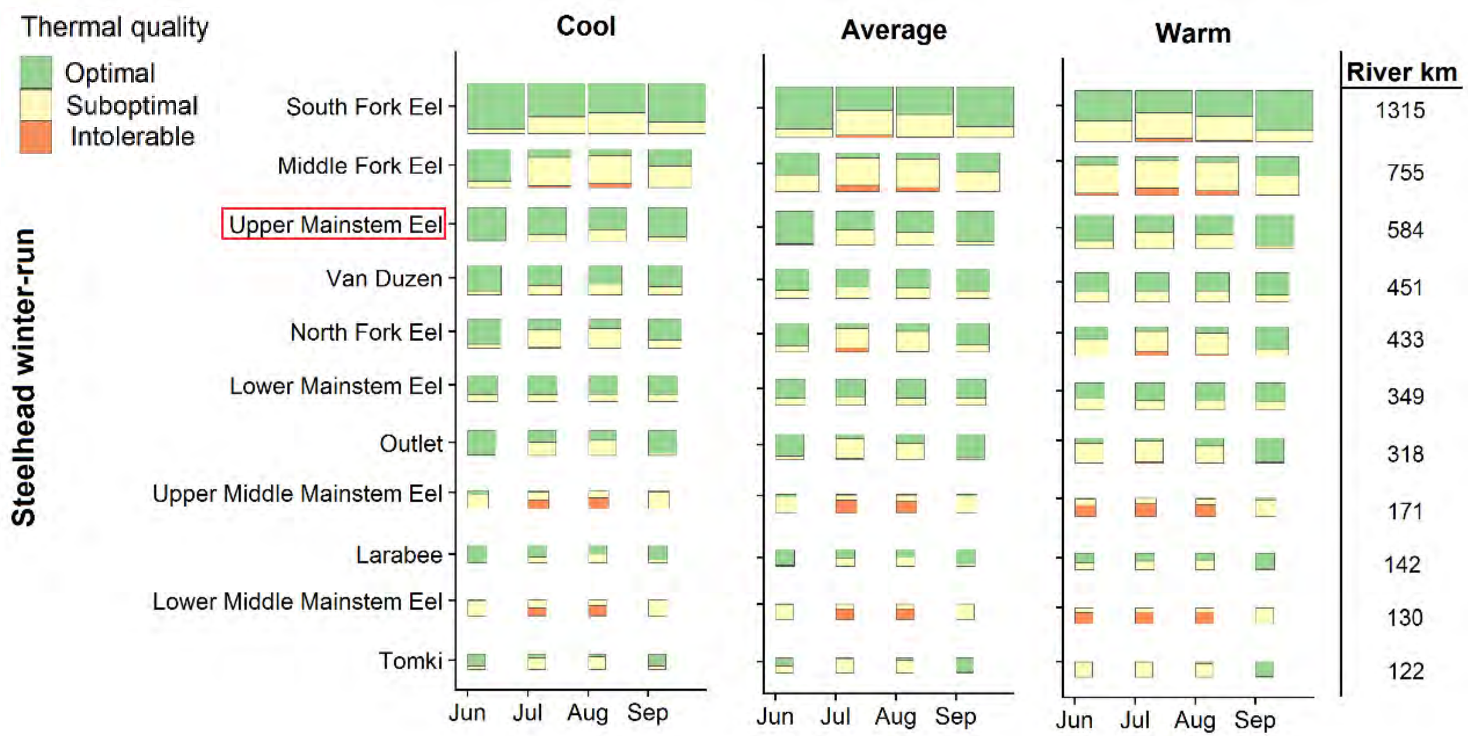
- Juveniles rear in a wide range of habitats, so temperature more restricting
- **Higher proportion green -> Good**
- Worse conditions in July & August
  - Chinook outmigrate by summer

Results: Juvenile Rearing



- Worse conditions in July & August
- Most reaches not lethal, many suboptimal -> Rearing squeezed in summer
- S. Fork had greatest amount of optimal space in July; **second was Upp. Main.**

Results: Juvenile Rearing



- Worse conditions in July & August
- Most reaches not lethal, many suboptimal -> Rearing squeezed in summer
- S. Fork had greatest amount of optimal space in July; **second was Upp. Main.**
- Better conditions in cool year, worse conditions in drought year
- **Upp. Main.** had no intolerable conditions

Summary: Approach 1

- Suitable habitat restricted during summer, warm year
  - Rearing juveniles were the most impacted, due to high temps and pikeminnow exposure
  - Late STL incubation
- **Upp. Main. had a similar or higher proportion of suitable habitat during all life stages relative to other subbasins**
  - Comparable to Van Duzen
  - STL: 169-467 km
  - CHK: 51-129 km

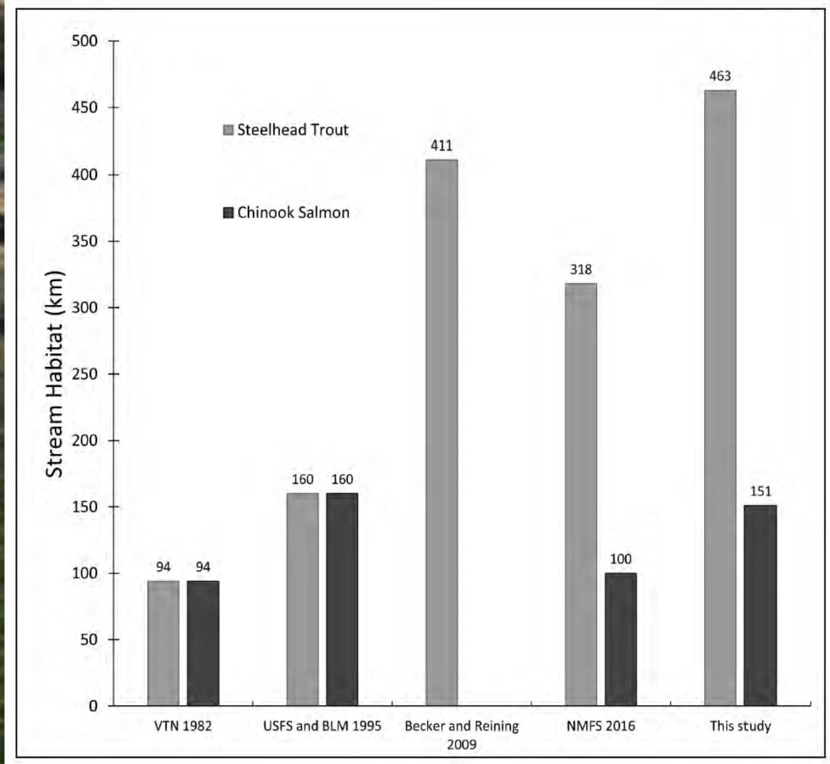


Figure 6. Quantified stream habitat (km) for steelhead trout and Chinook salmon upstream of Scott Dam from four other sources and this study (Cooper et al.).

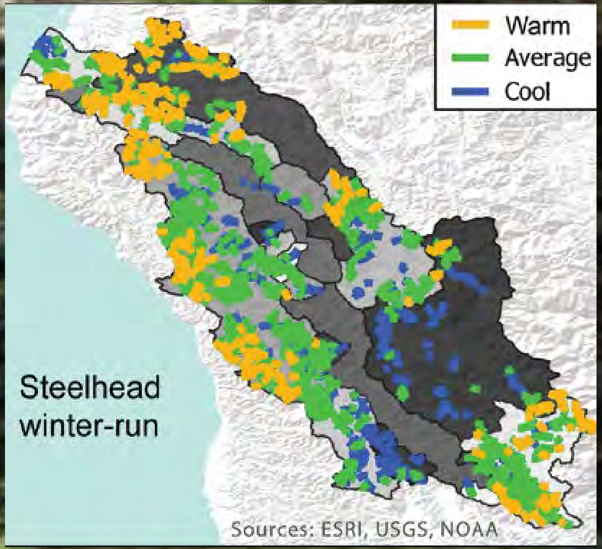
Figure 6 from Cooper et al. 2020

Bear Creek (upper) in Upp. Main. Cooper 2017

Summary: Approach 1

Opening access to **Upp. Main.** would be similar to adding a Van Duzen subbasin to Eel Basin

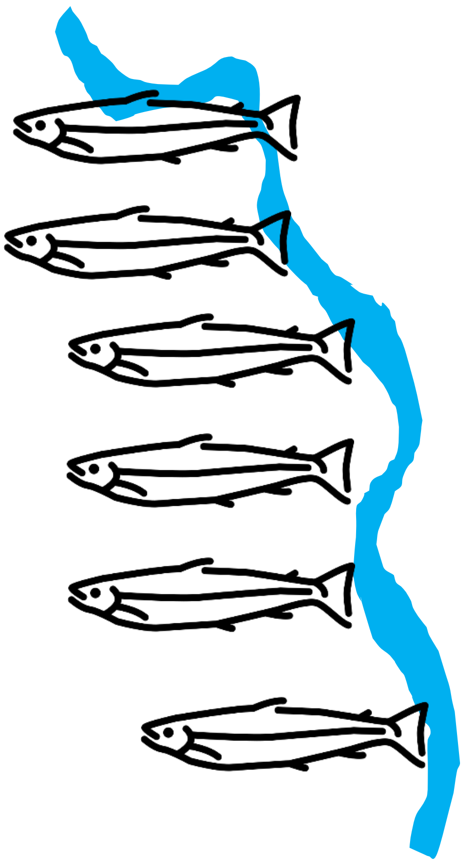
Upp. Main. could likely sustain anadromous populations, even during warm years



*How many fish could **Upp. Main.** sustain??*

Bear Creek (upper) in Upp. Main. Cooper 2017

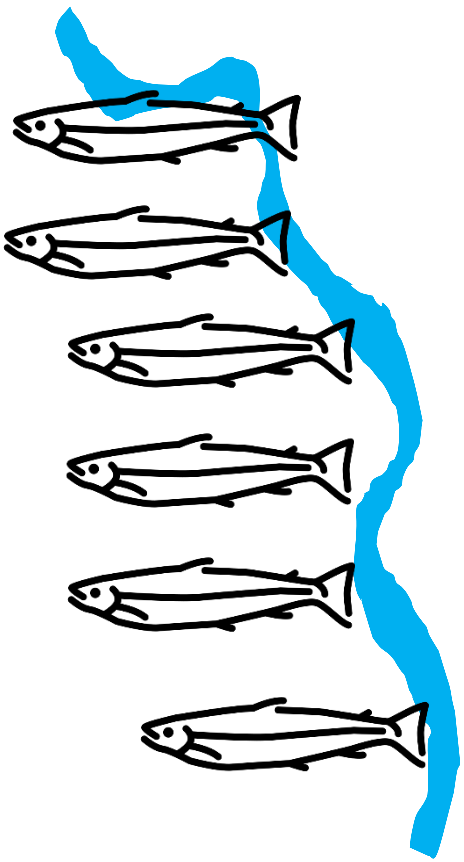
Methodological Approach 2



Baseline fish density

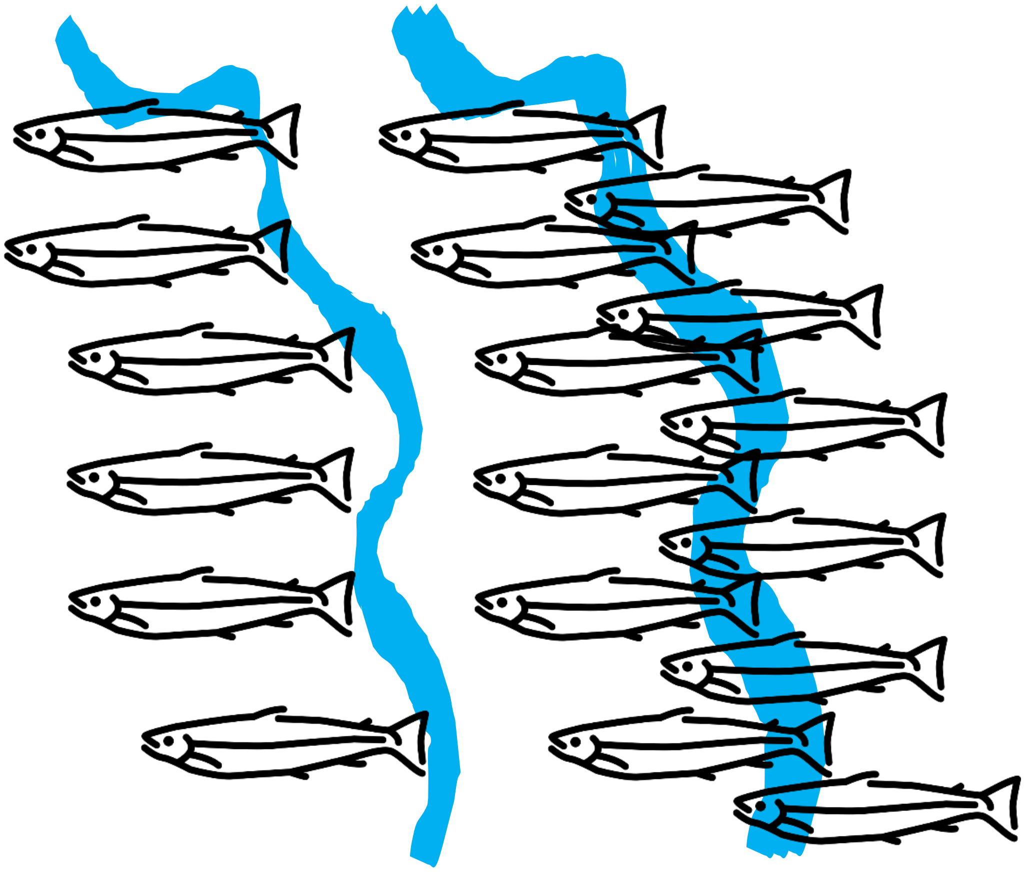
- Unit Characteristic Method (UCM) to estimate parr capacity (Cramer & Ackerman 2009)
- Multiplies baseline fish density by unit area, then adjusts the density by habitat scalar values based on parameters describing local conditions for each habitat type

Methodological Approach 2



Baseline fish density

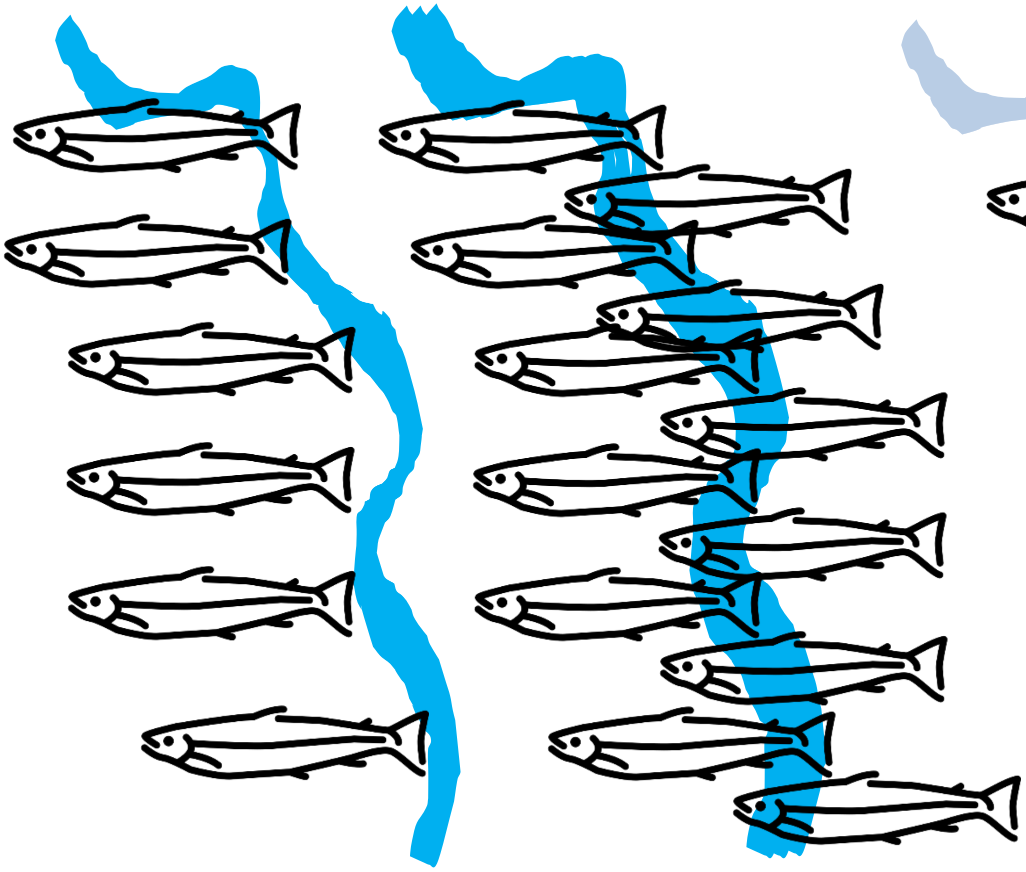
Methodological Approach 2



Baseline fish density

Larger area +
Same habitat ==
More fish

Methodological Approach 2

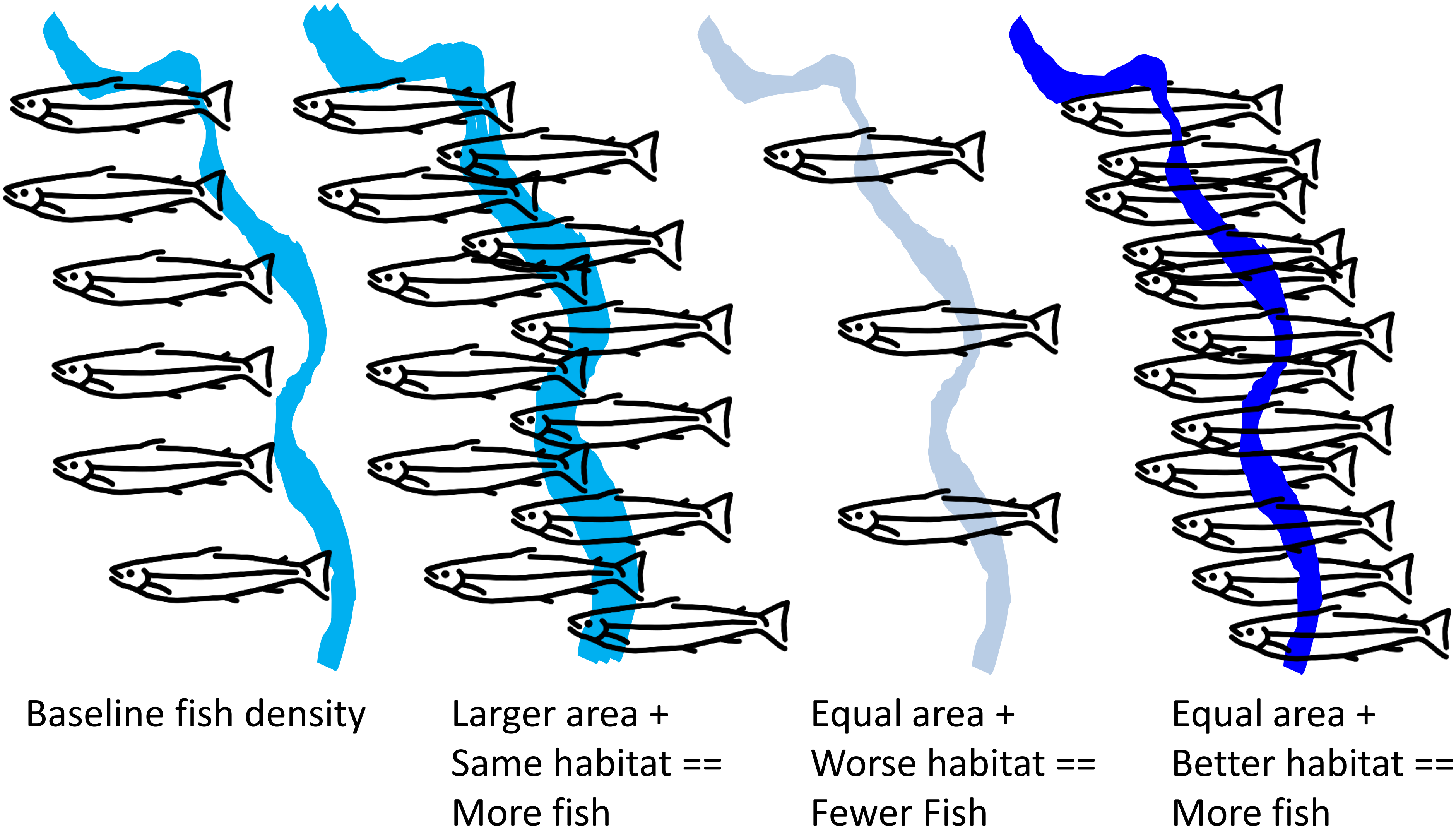


Baseline fish density

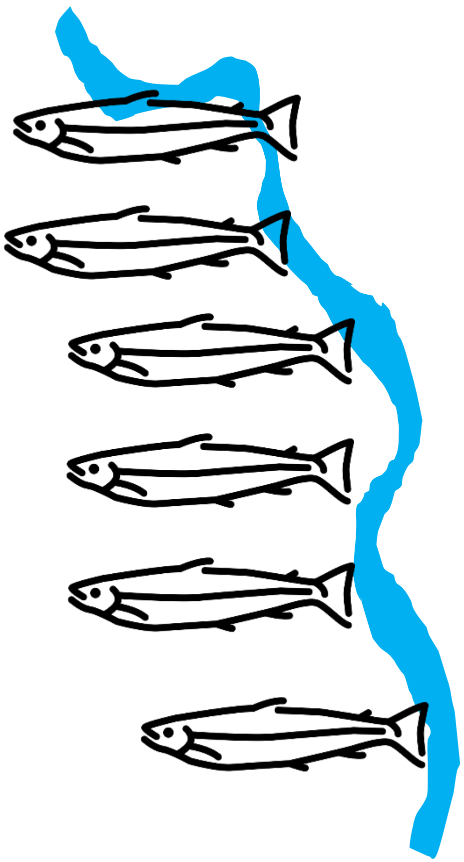
Larger area +
Same habitat ==
More fish

Equal area +
Worse habitat ==
Fewer Fish

Methodological Approach 2



Baseline Fish Density	Local Conditions	Reach Area

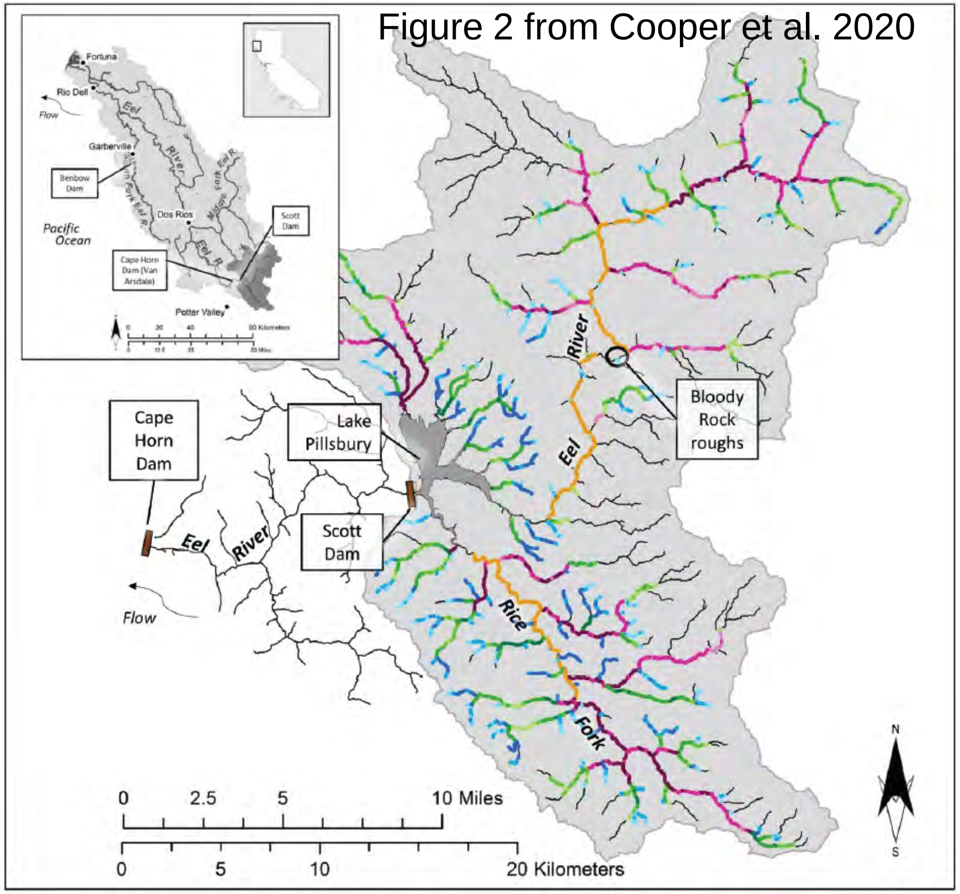


Baseline fish density

- Unit Characteristic Method (UCM) to estimate parr capacity (Cramer & Ackerman 2009)
- Multiplies baseline fish density by unit area, then adjusts the density by habitat scalar values based on parameters describing local conditions for each habitat type

- Baseline fish density -> Oregon
- Reach area (length x width)
  - Modeled wetted width by month from flow gages
- Local conditions (e.g., habitat type, cover, depth, pH, % boulders, temperature)?

Baseline Fish Density	Local Conditions	Reach Area



Drainage Area	0 - 2 km²			2 - 10 km²				10 – 100 km²			> 100 km²
Slope	0 – 2%	2 – 7%	7 – 12%	0 – 2%	2 – 7%	7 – 12%	> 12%	0 – 2%	2 – 7%	7 – 12%	0 – 2%
RT	2.1	3.1	4.1	1.2	2.2	3.2	4.2	1.3	2.3	3.3	1.4

Figure 2. Study area streams were classified and coded into Reach Types (RT) by categories of drainage area (color) and slope (steeper slopes in lighter shades) for data collection and extrapolation. Bloody Rock roughs is a partial barrier and thin black streams upstream of Scott Dam are inaccessible to anadromous salmonids.

Salmonid Habitat and Population Capacity Estimates for Steelhead Trout and Chinook Salmon Upstream of Scott Dam in the Eel River, California

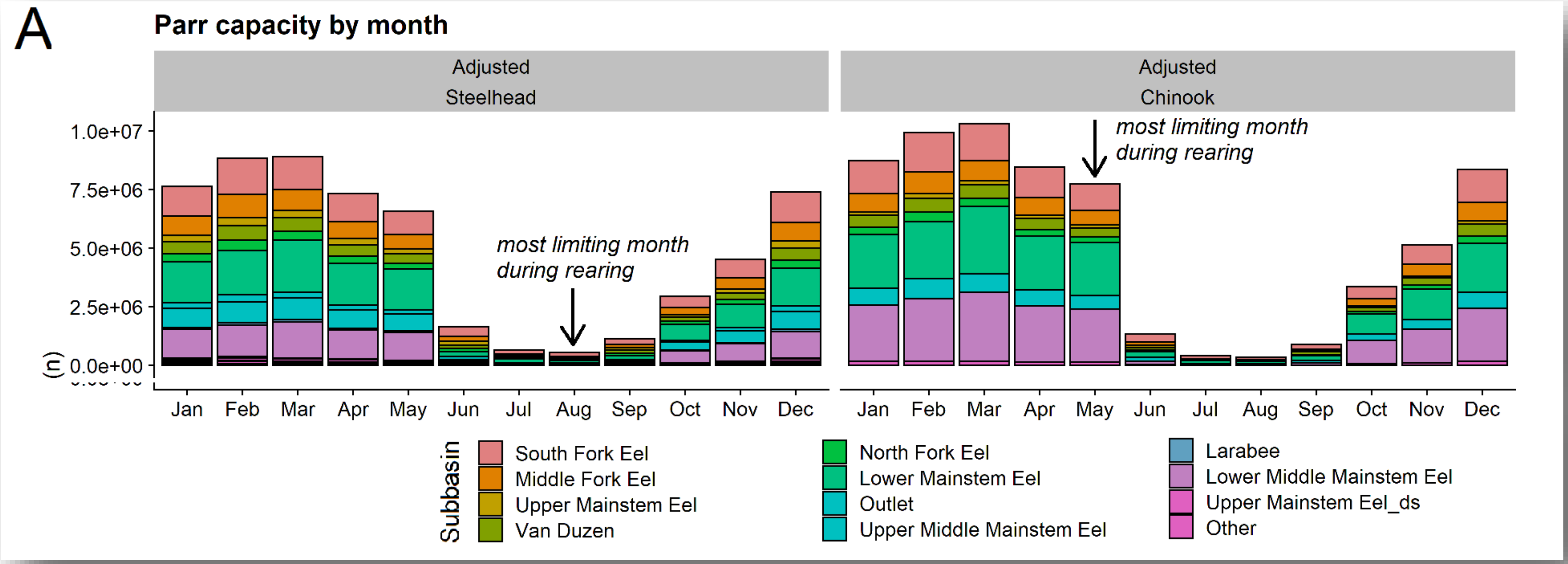
Emily J. Cooper, Alison P. O'Dowd, James J. Graham, Darren W. Mierau, William J. Trush, Ross Taylor

Author Affiliations +

Northwest Science, 94(1):70-96 (2020). https://doi.org/10.3955/046.094.0106

- Cooper (2017), Cooper et al. (2020)
- Extrapolated local conditions based on Reach Type
- **Assumed that local conditions in Upp. Main. are representative of other subbasins**

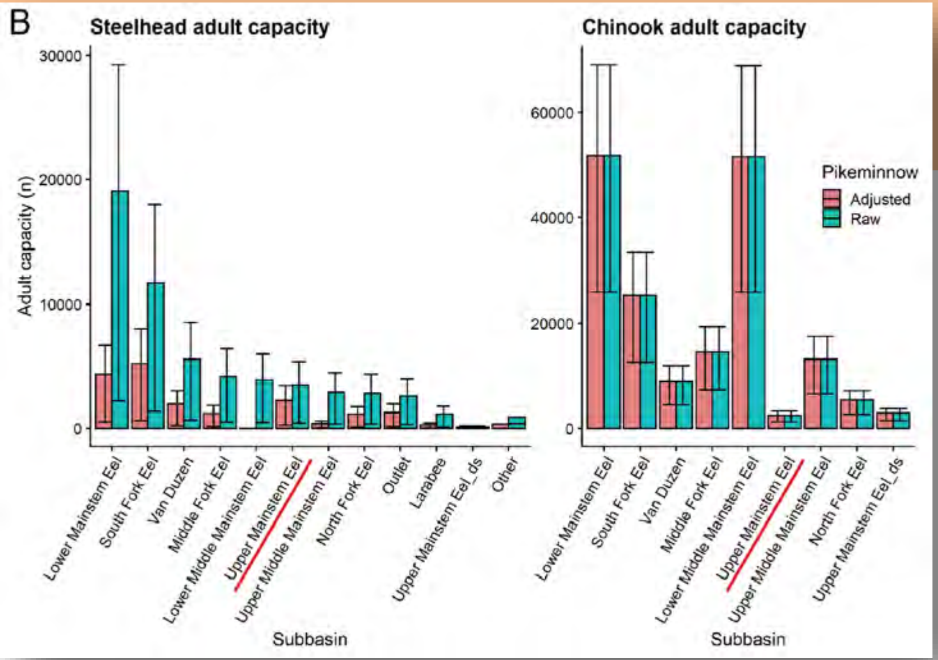
Results: Parr capacity by month



- **Steelhead**
  - 11.5% of the parr capacity in **Upp. Main.**
    - Similar to the Van Duzen
  - If unadjusted for pikeminnow, 5.8% of parr capacity in the **Upp. Main.**
- **Chinook salmon**
  - 1.4% of the parr capacity in **Upp. Main.**
  - Not adjusted for pikeminnow because temperature too cool in May

Results: Spawner capacity

- Converted parr to spawner capacity using parr-adult survival model and 3 different ocean survival models
- Large range in capacity estimates
  - STL: 256-5,370
  - CHK: 1,242-3,314
  - 3 different survival models
  - parr estimates were adjusted for pikeminnow exposure
- CHK capacity estimates overlap with previous estimates
- STL capacity estimates overlap when applying the moderate or high ocean survival model
  - Previous studies did not account for pikeminnow



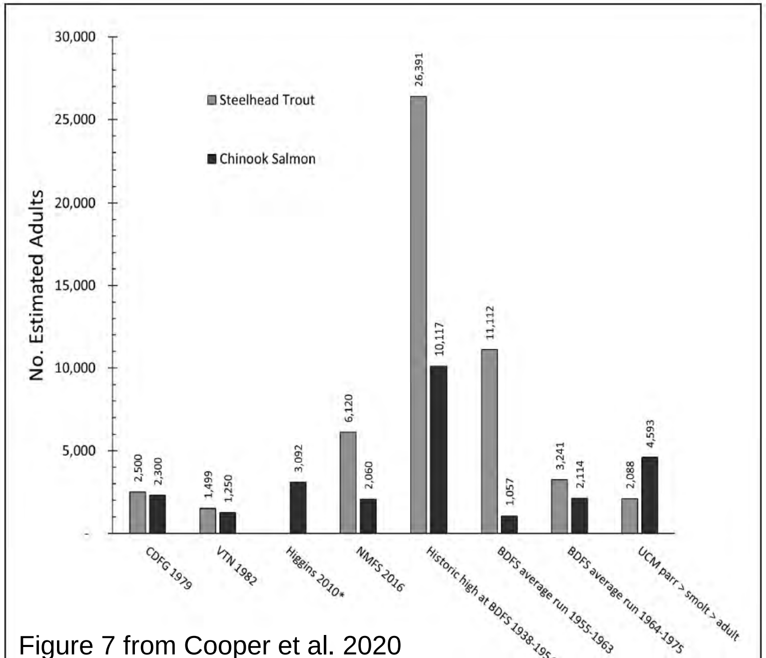


Figure 7 from Cooper et al. 2020

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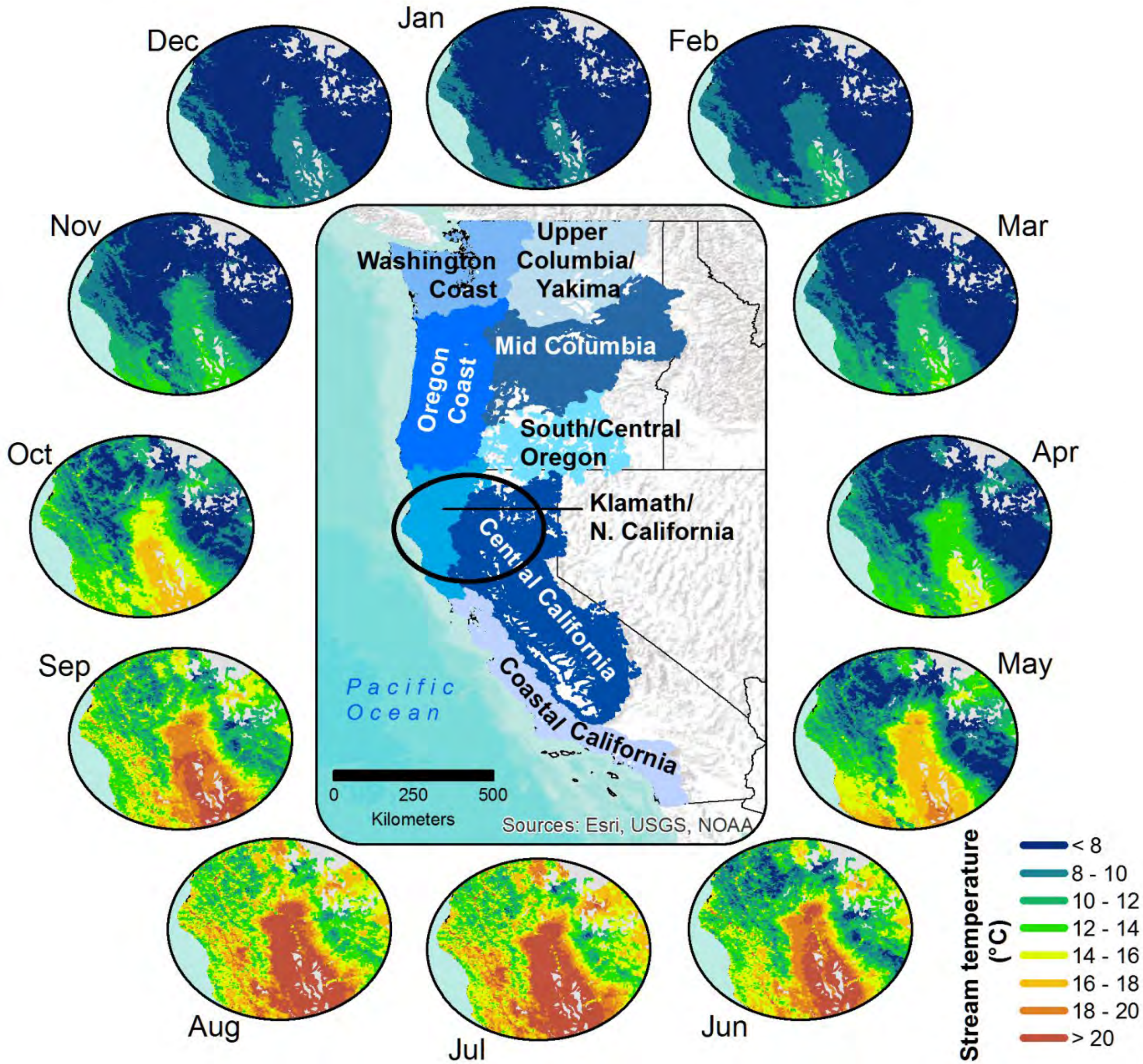
Conclusions

- Eel River Basin is particularly dynamic, with lots of spatial and temporal heterogeneity
- **Upp. Main.** harbors a large amount of thermally suitable, productive habitat types
  - Cool-water refuge during summer, warm years
  - **Upp. Main.** similar to Van Duzen
- Capacity estimates are wide, but generally overlap with other estimates
- **Upp. Main.** could sustain populations of anadromous salmonids

Cooper 2016

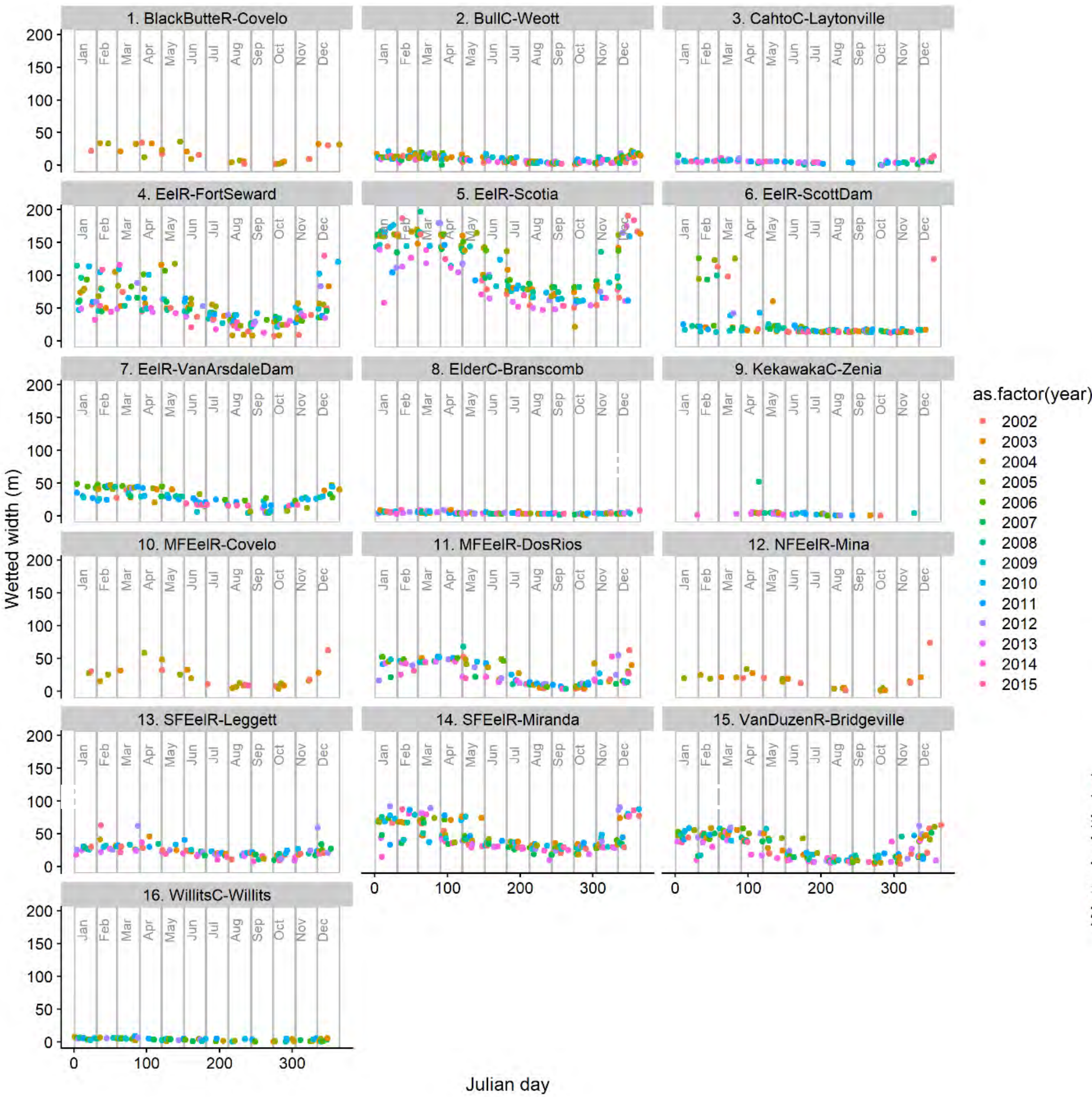
EXTRA

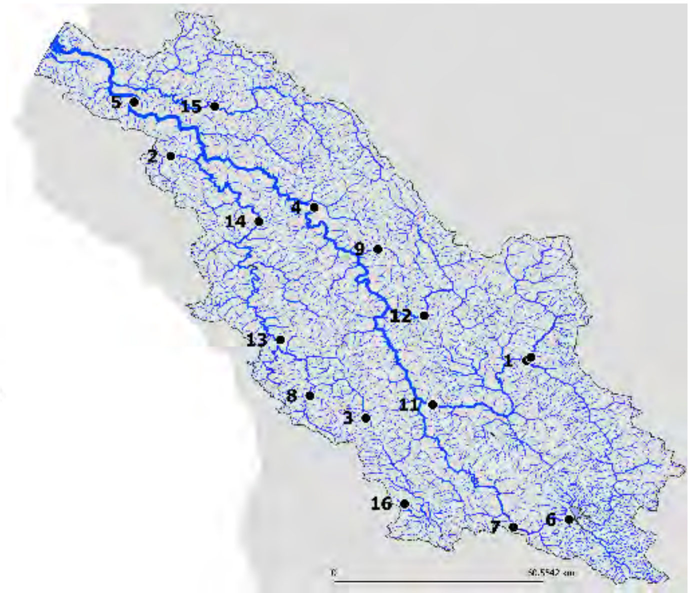
Accessibility | Channel productivity | **Thermal suitability**

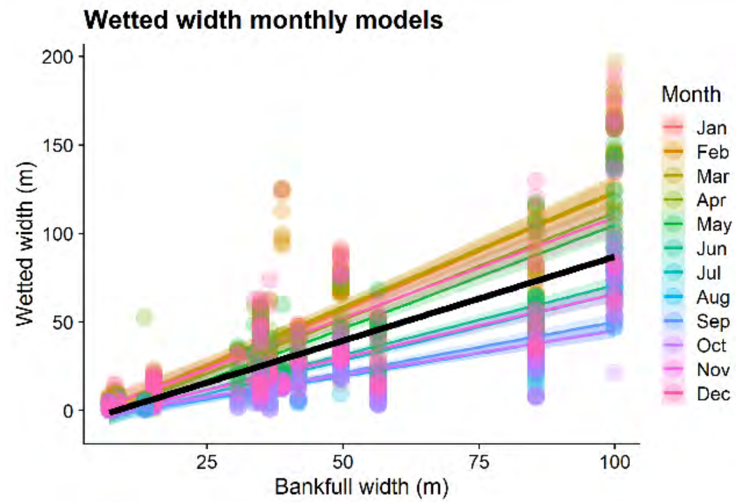


- Expanded a pre-existing spatial stream network (SSN) model
  - https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html
- Mean monthly stream temperature predictions for ~380,000 stream km in western U.S., across 8 major watershed units
- $r^2 = 0.925$
- Error ~ 1°C

Baseline Fish Density | Local Conditions | **Reach Area**







Results: Spawner capacity

- To convert from parr to spawner capacity:

- **Steelhead**
- Parr-adult survival model
  - 28% survival
- Ocean survival models
  - 1.5%
  - 13%
  - 20%

- **Chinook salmon**
- Parr-adult survival model
  - 76% survival
- Ocean survival models
  - 1.5%
  - 3.0%
  - 4.0%