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RESPONSE OF SMALLMOUTH BASS AND OTHER SPECIES TO COOL MIX

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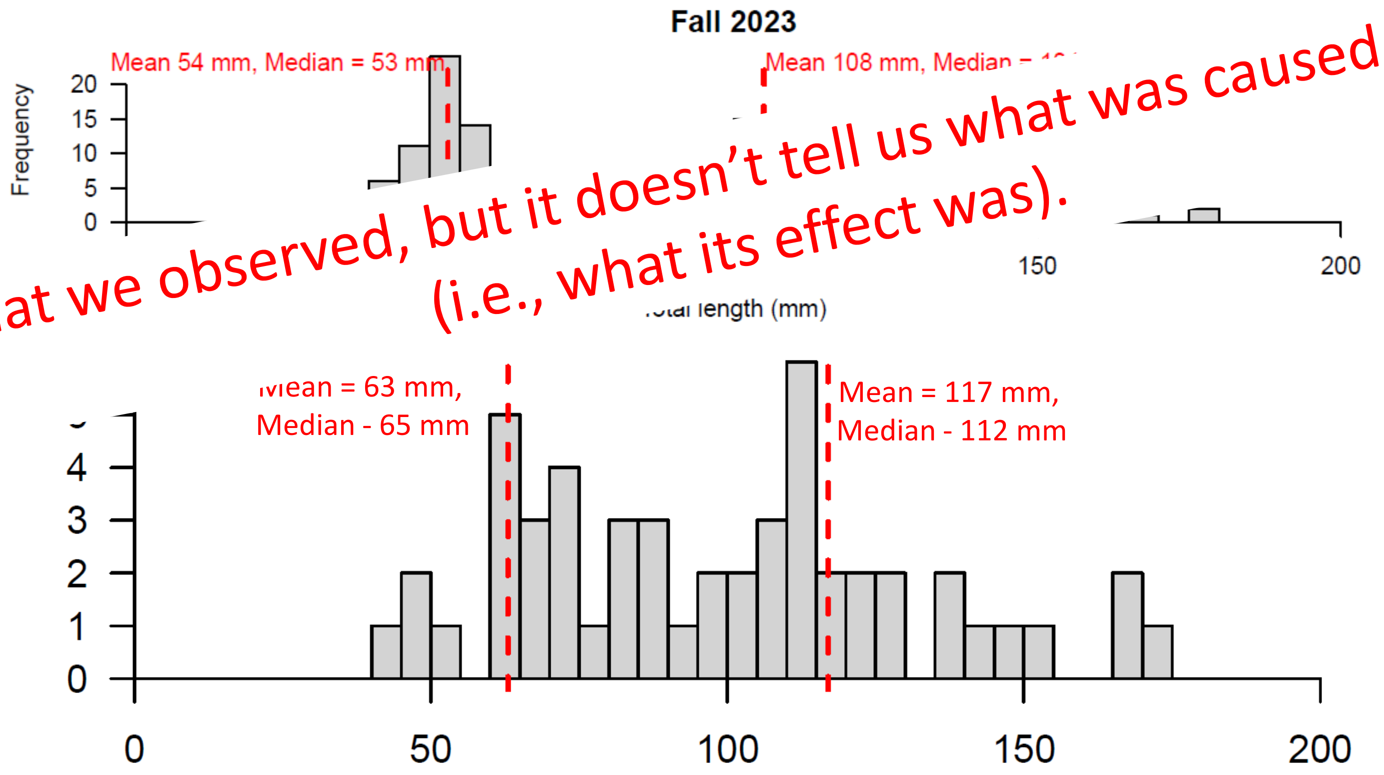
Southwest Climate Adaptation Science Center
Interagency Smallmouth Bass Taskforce
Glen Canyon Dam Adaptive Management Program

What were the effects of cool mix on various resources?

Minimal evidence of growth and no observed nests or obvious YOY



This is what we observed, but it doesn't tell us what was caused by cool mix (i.e., what its effect was).

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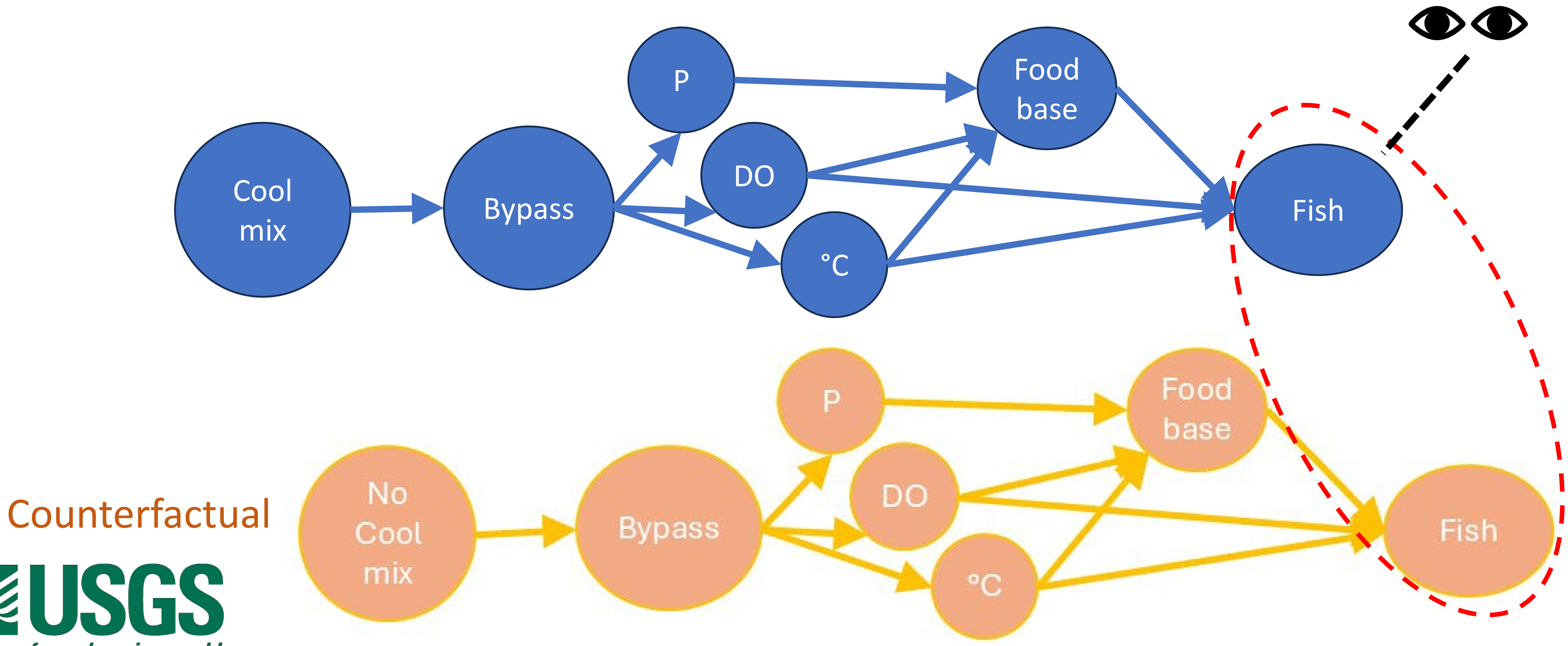
Before-After comparisons are common when evaluating environmental flows

- But uncontrolled conditions can confound assessment.
- Maybe ongoing removals lowered adult population significantly.
- Maybe temperatures would have been relatively cool without cool mix.
- Lots of maybes.
- Ideally applied science leads to models that include, and control for, important external drivers and allow for counterfactual analysis.

What were the effects of cool mix on various resources?

- A practical question that is also a question of causality.



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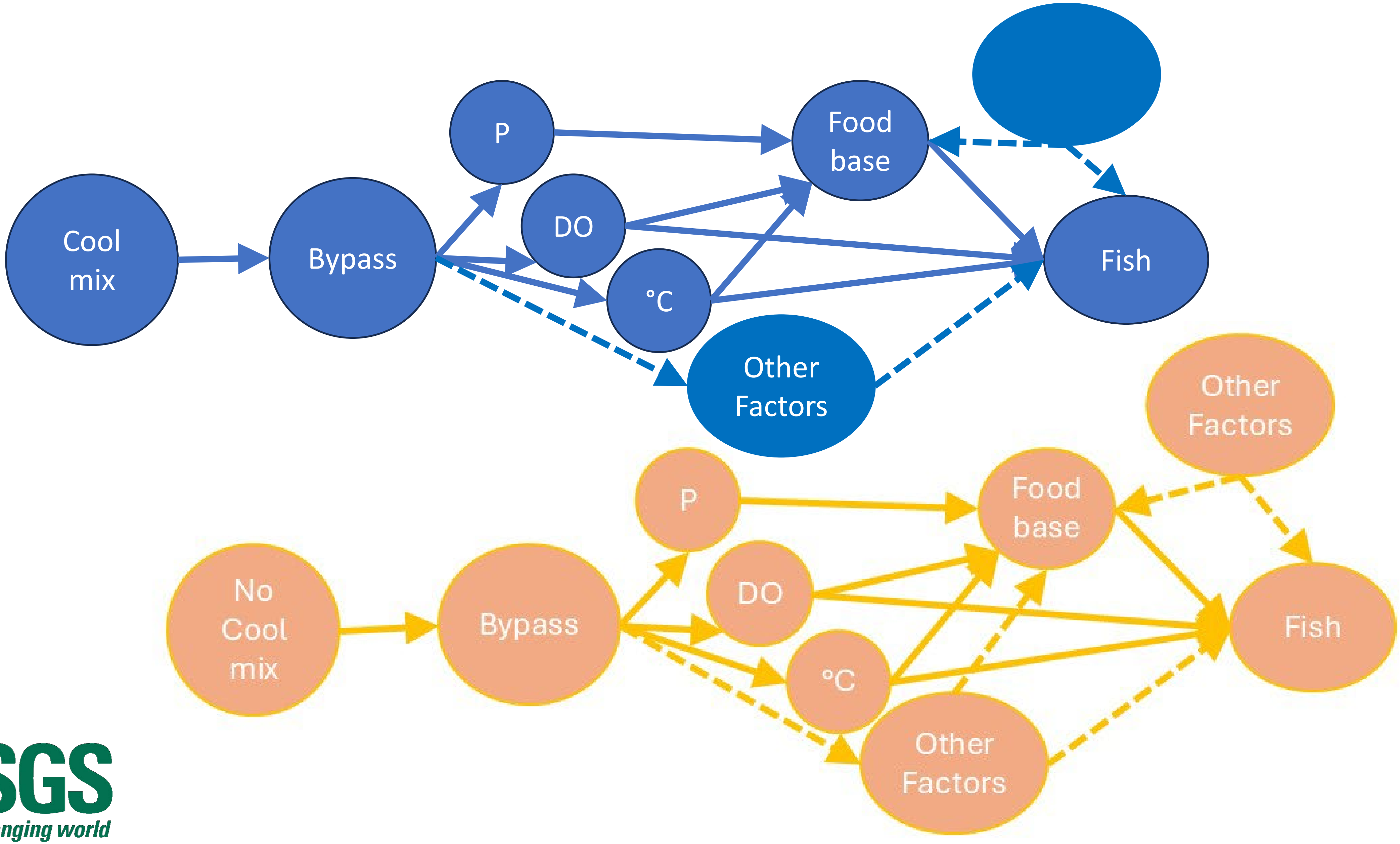
What were the effects of cool mix on various resources?



How do we deal with these other fa… Western science to try to make c… e?

- Randomized, replicated, experiments … unit you don't know the counterfactual … overall effect on a population. (often not fea… … es simplification)
- When system is hi… … stood may be able to use deterministi… … power generation).
- Som… … s to quantifying potential bias in
- … uralism – statistical associations in combination with … istic hypotheses (including sometimes experiments to test mechanisms on portions of hypothesis).

It is impossible to make causal inference without assumptions.

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Causal inference in partially observed, partially controllable systems may best be seen as existing along a spectrum.

Weaker Causal Knowledge → Stronger Causal Knowledge

- Consistent with past observations, but with little mechanistic support.
- Mechanistic support, but importance in natural system unquantified or only weakly supported.

- Consistent with past observations, with some mechanistic support, but untested on out of sample data.
- Consistent with past observation and with out of sample data, but mechanisms poorly understood.

- Consistent with past observations, with strong mechanistic support and consistent with out of sample data.

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Outline

- **<u>Temperature with and without cool mix</u>**
- Humpback Chub growth
- Rainbow Trout growth
- Smallmouth Bass growth and population response
- Ongoing work

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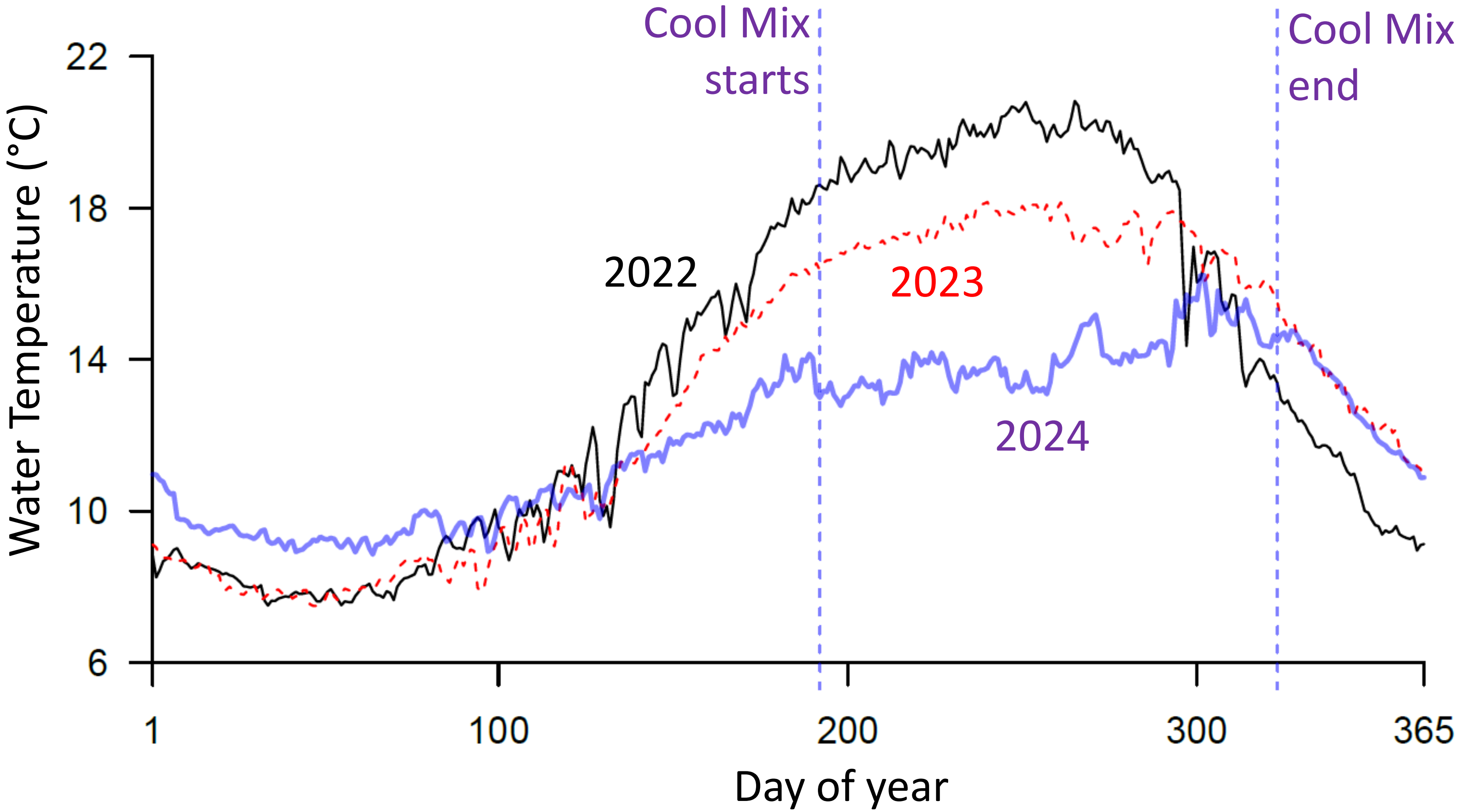
Water temperatures in 2024 in Lees Ferry were cooler than in 2022 and 2023 prior to July 9



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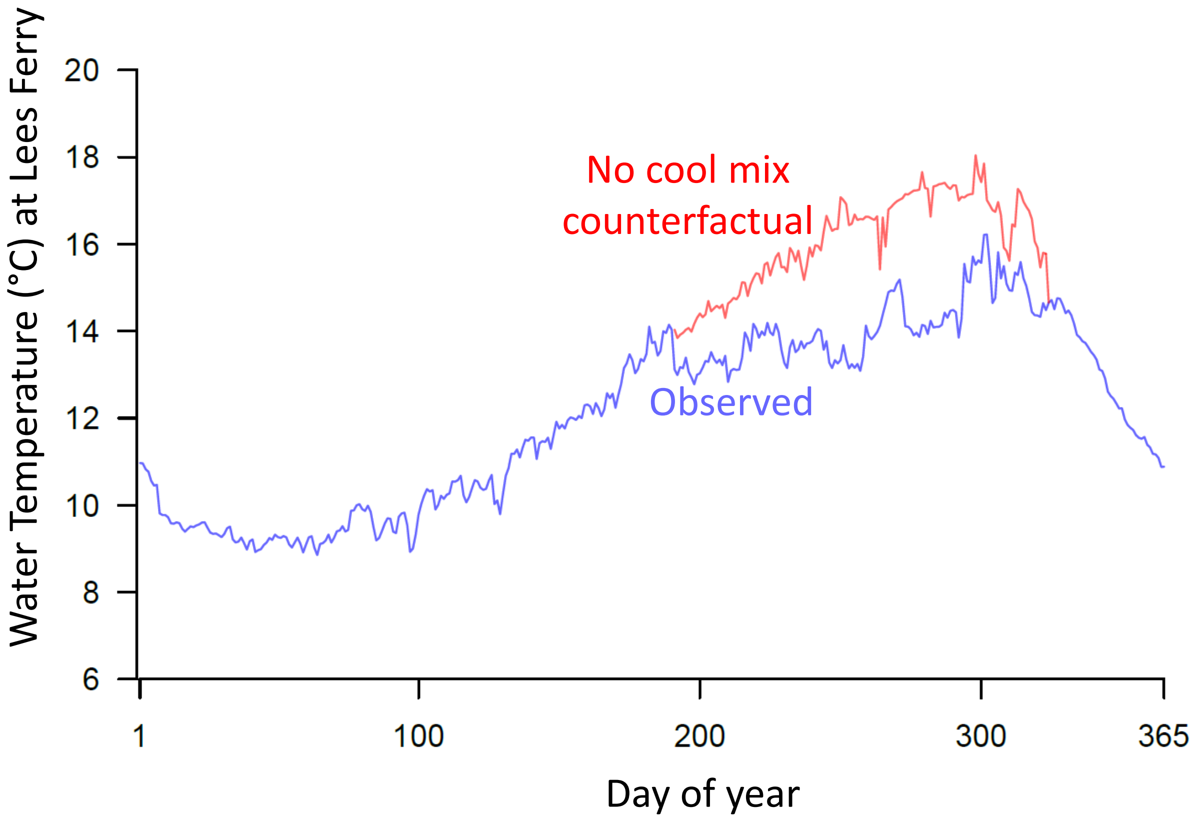
Water temperature – creating a counterfactual

- Method: Predict water temperature at Lees Ferry gage using Dibble et al. (2020) warming model and observed temperatures in hydropower tubes.
- In 2023, predictions for Lees Ferry from July 9 to November 18 were slightly warmer than observations on average but very close (mean +0.25 °C; median +0.05 °C). Similar performance at LCR.
- 2024 counterfactual temperatures during the same period were an average of 2 °C warmer than observed temperatures under cool mix.



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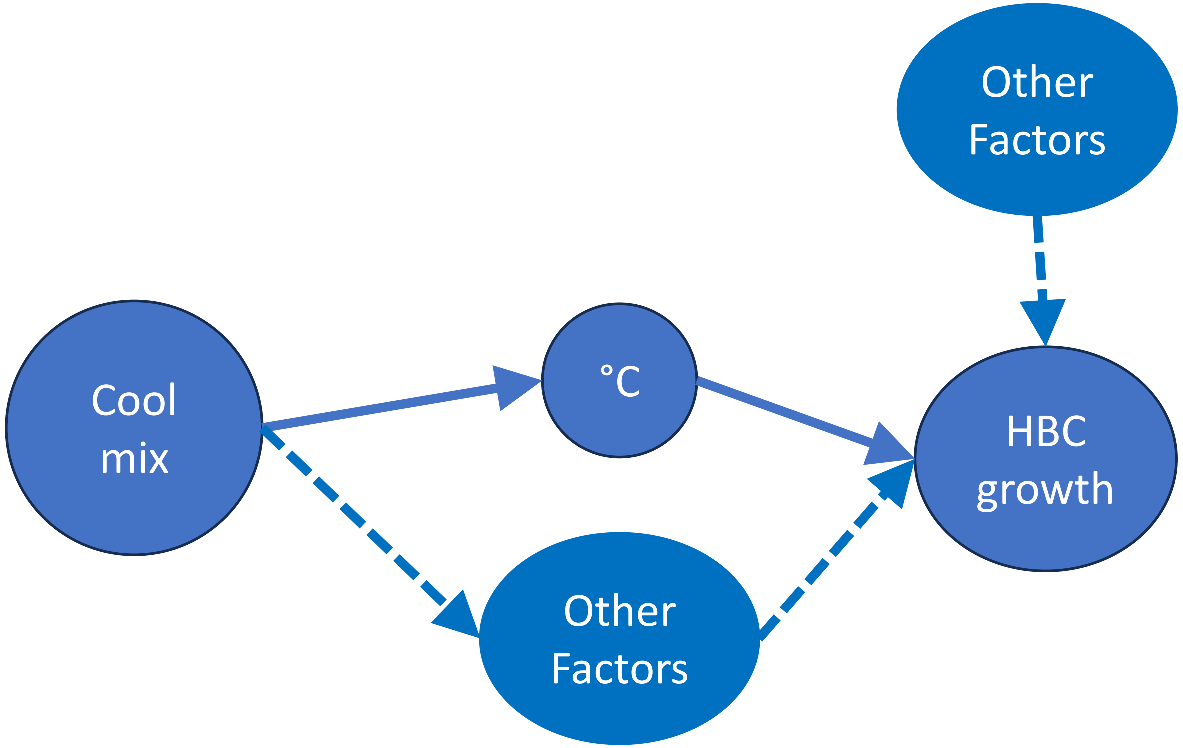
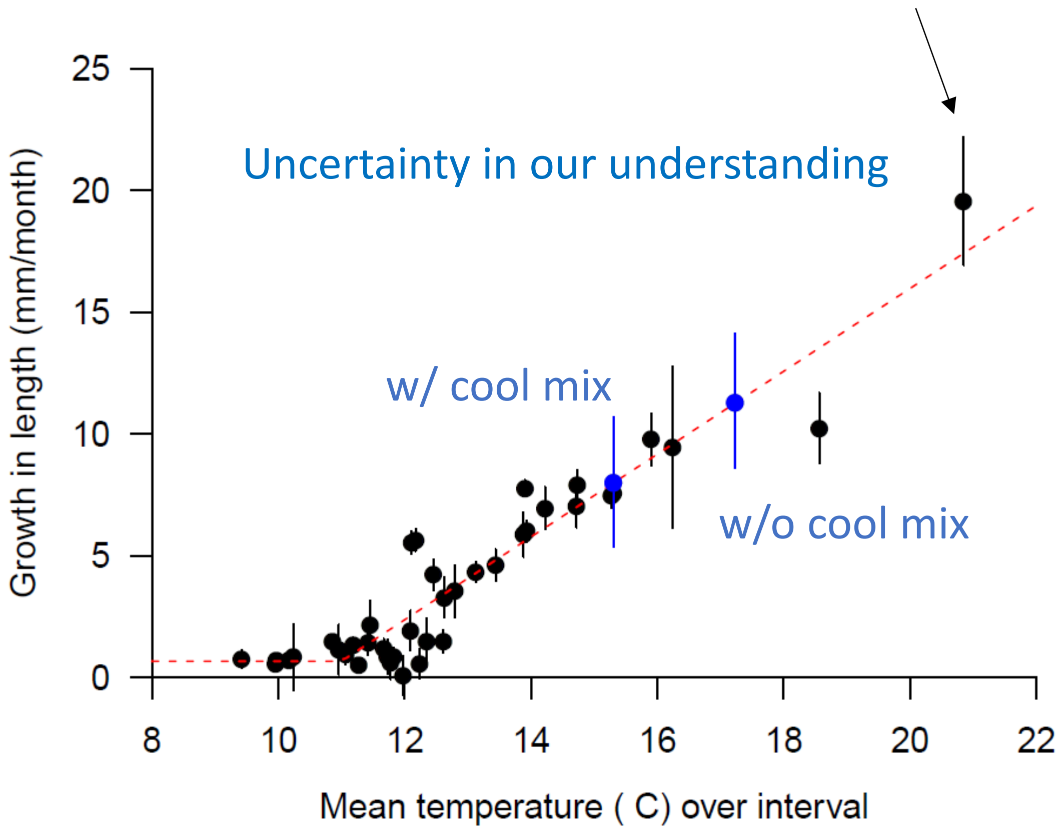


$$G = \beta_0 + \beta_1 T_{11} + \eta_t$$

Laboratory studies conducted in 1990s established that Humpback Chub growth at temperatures below ~11 to 12°C was near zero.

Uncertainty in our observations



*Use temperatures at LCR confluence averaged between JCM trips

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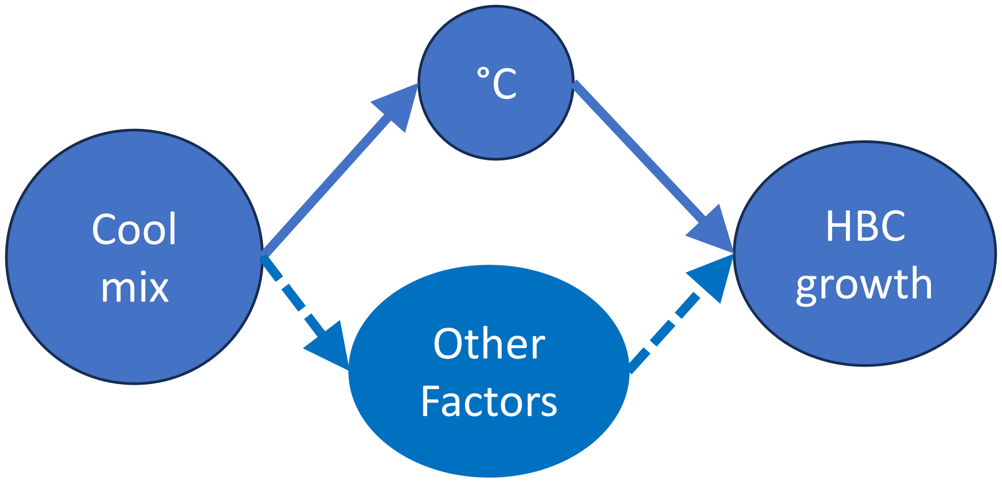
(Version 1)



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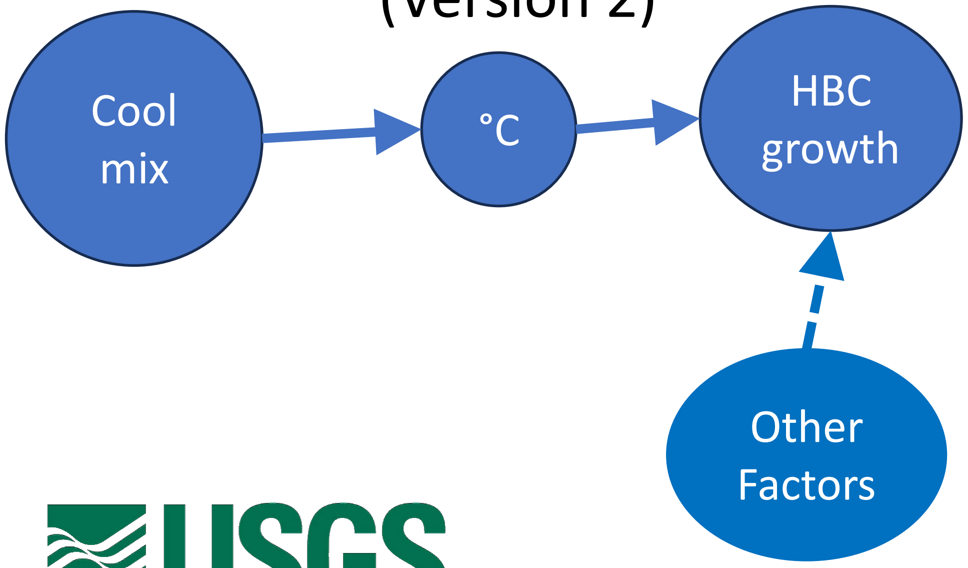

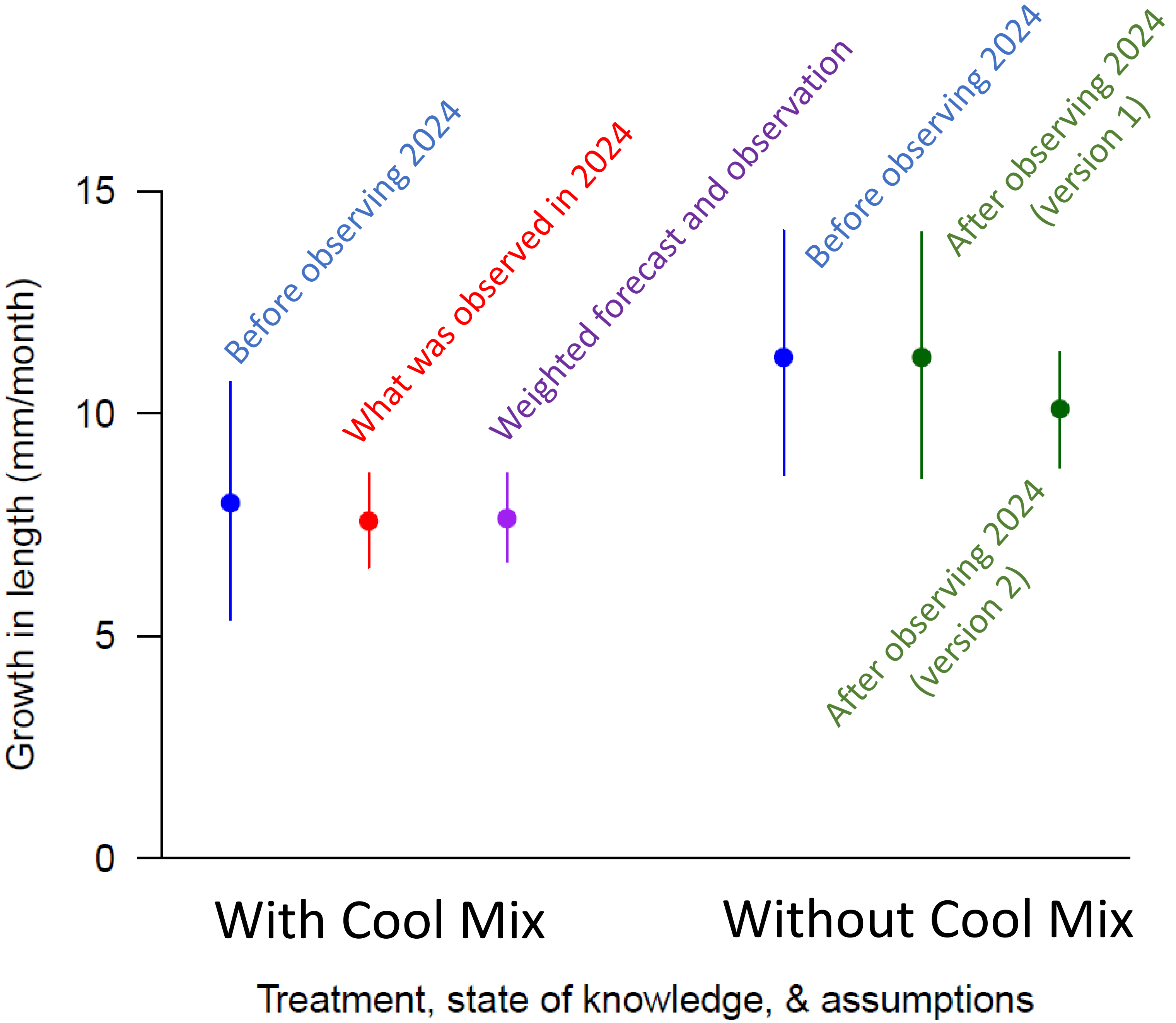

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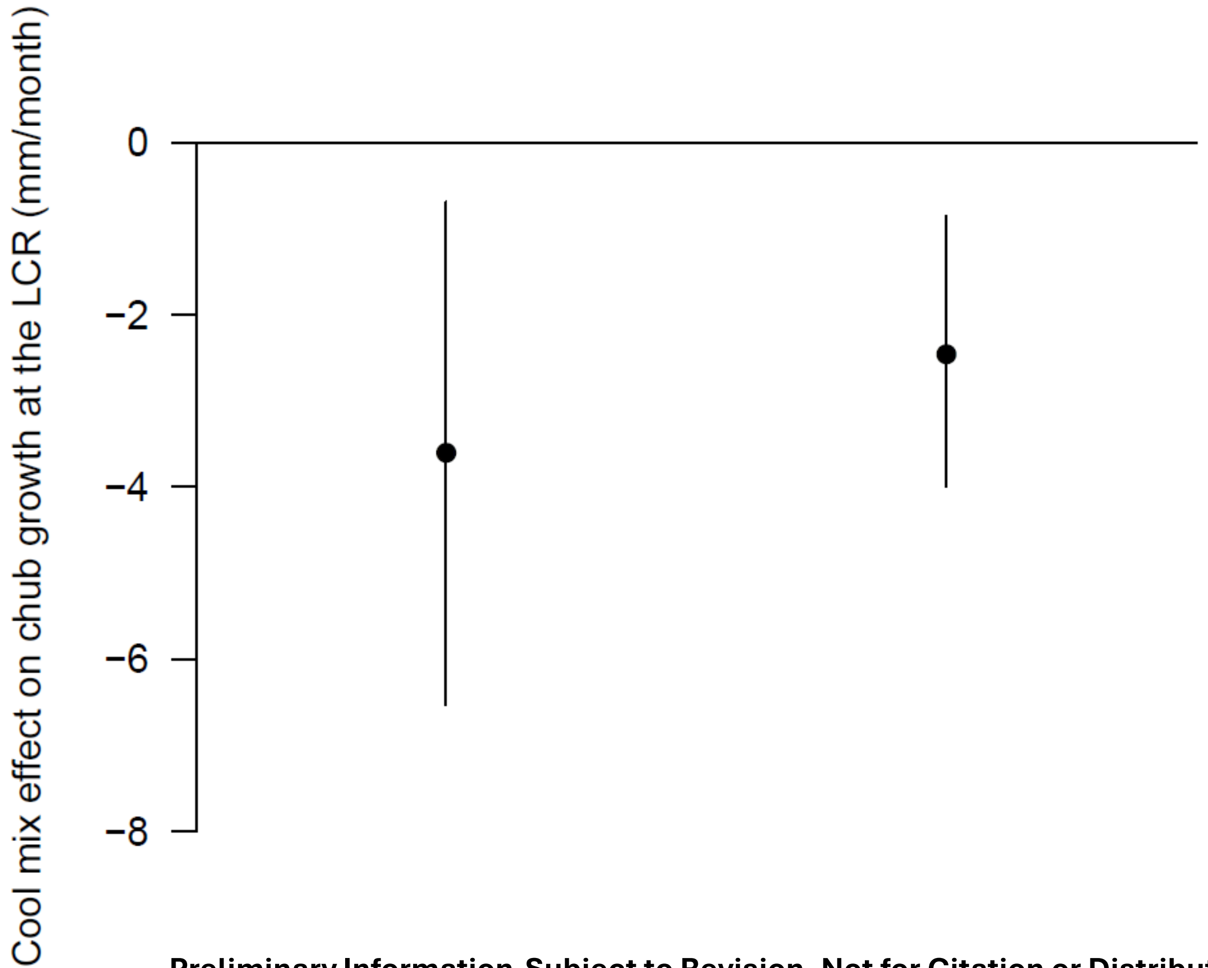
So, what was the effect of cool mix on Humpback Chub growth?

Mean value and uncertainty depend on assumptions, but under both extreme assumptions regarding other factors, the effect of cool mix was a modest decrease in Humpback Chub growth near the Little Colorado River.



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Outline

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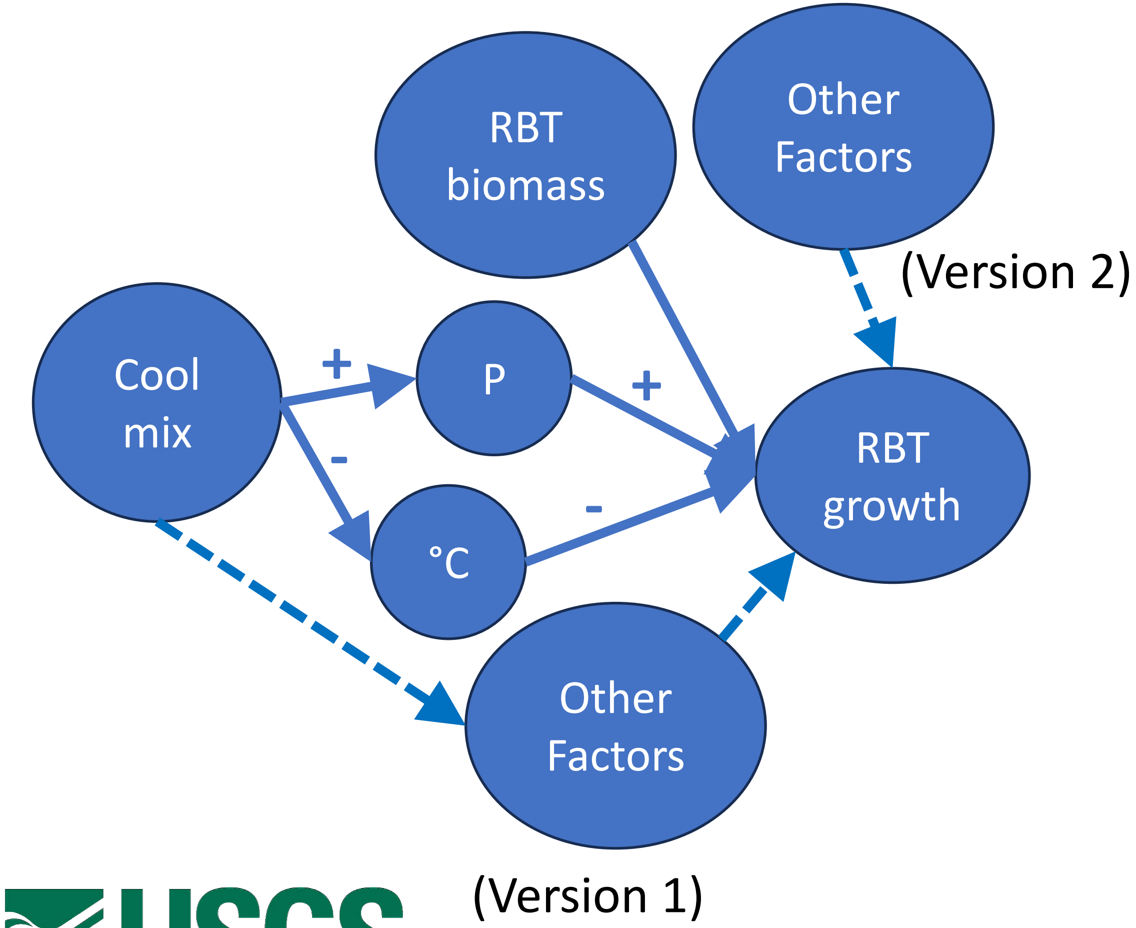
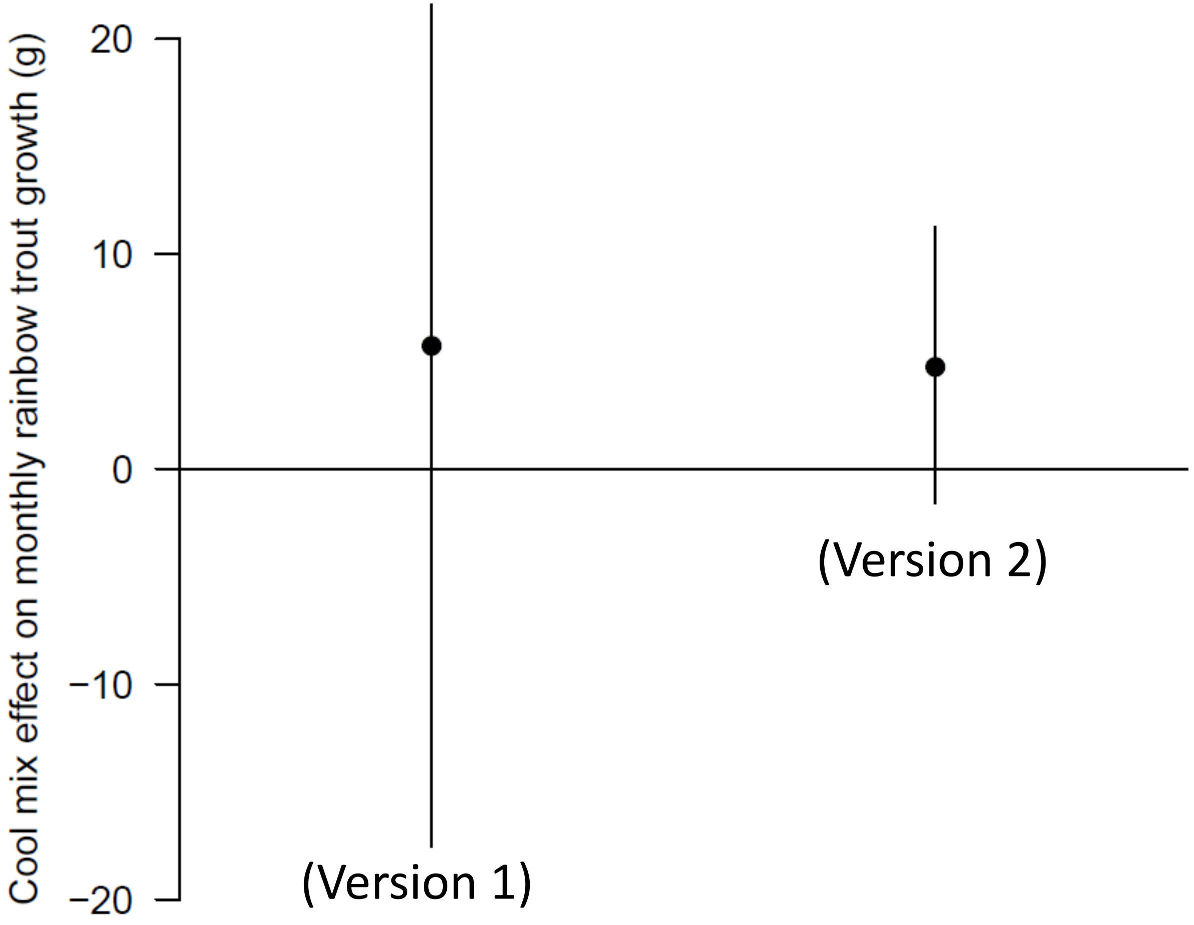
Rainbow Trout growth in weight likely positively effected by cool mix, but with more uncertainty.





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- Temperature with and without cool mix
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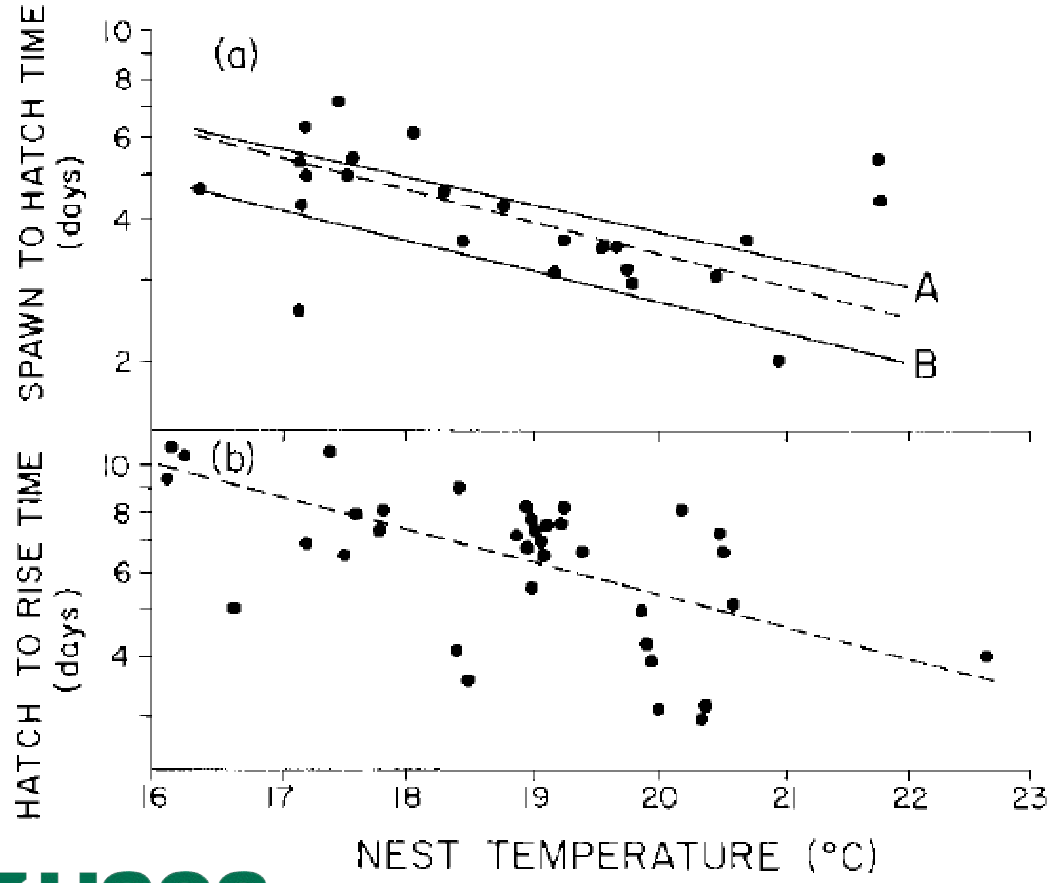
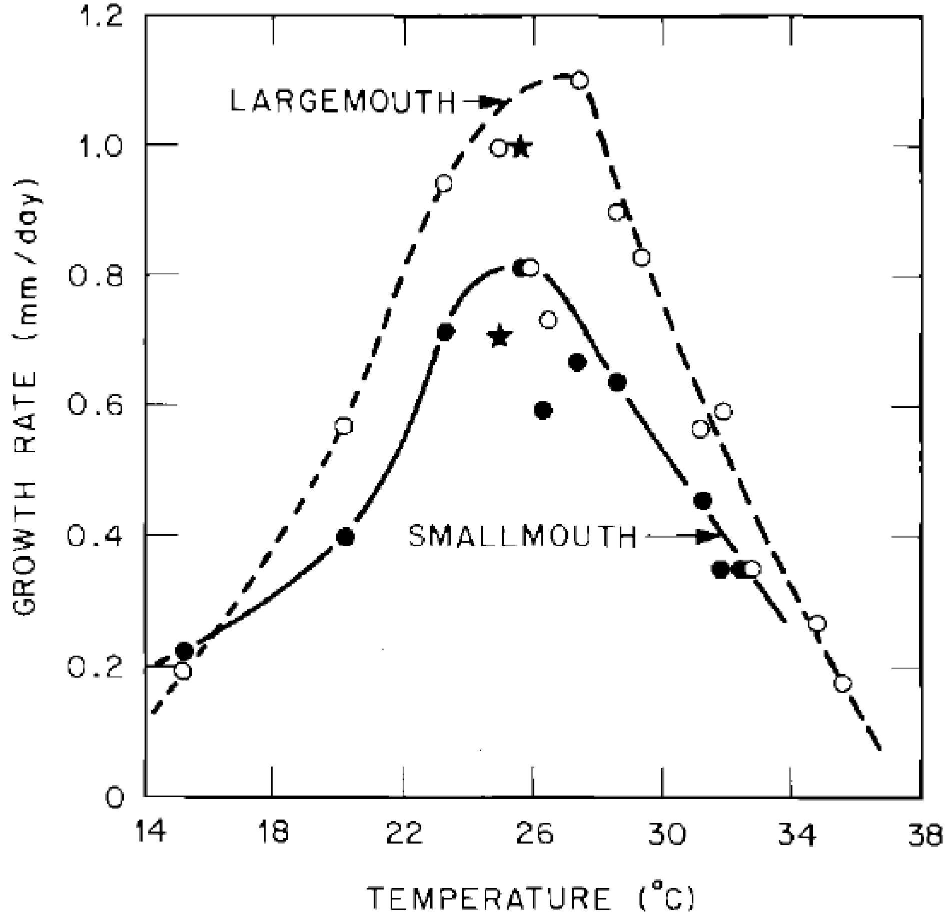
Wide variety of lab and field studies supporting the temperature dependence of Smallmouth Bass early life history development and growth.



Shuter et al. (1980)



Coutant and DeAngelis (1983)

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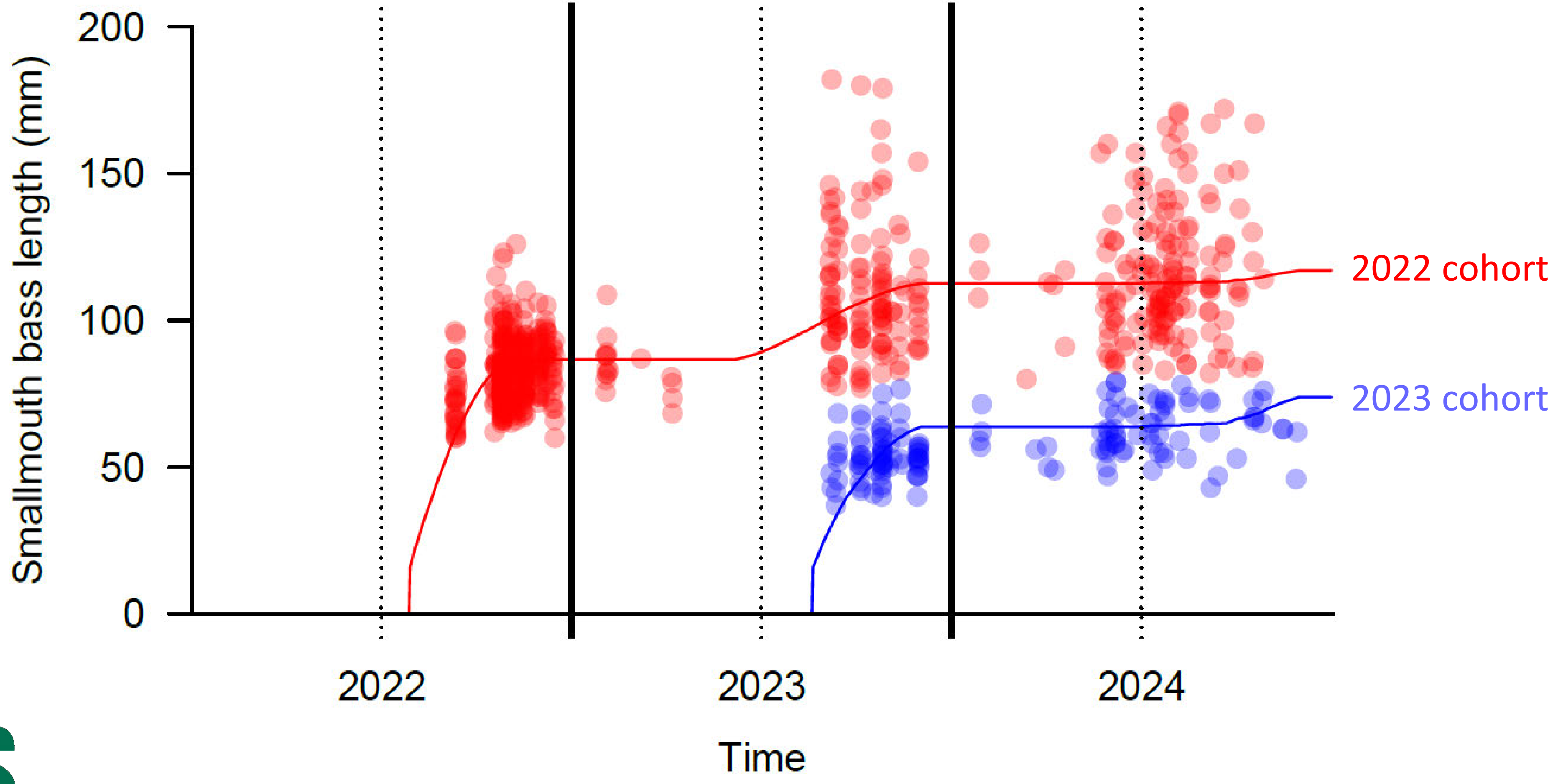
Some assumptions for Smallmouth Bass growth model

- Eggs begin to be laid 2 days after 16°C threshold is passed
- Time from hatch to juvenile based on water temperature and published laboratory studies.
- If temperature falls below 13°C during egg to swim up, cohort is lost.
- Following first successful cohort, daily cohorts spread over 30 subsequent days.
- If it takes more than 45 days to progress from egg to juvenile a cohort is lost.
- Growth from juvenile (~16 mm) onwards fitted to data from Green River, Yampa River and Grand Canyon as a function of water temperature (degrees over 14 °C) and fish size using the median hatch date.

Growth model fitted to electrofishing data from Lees Ferry and PBR reaches



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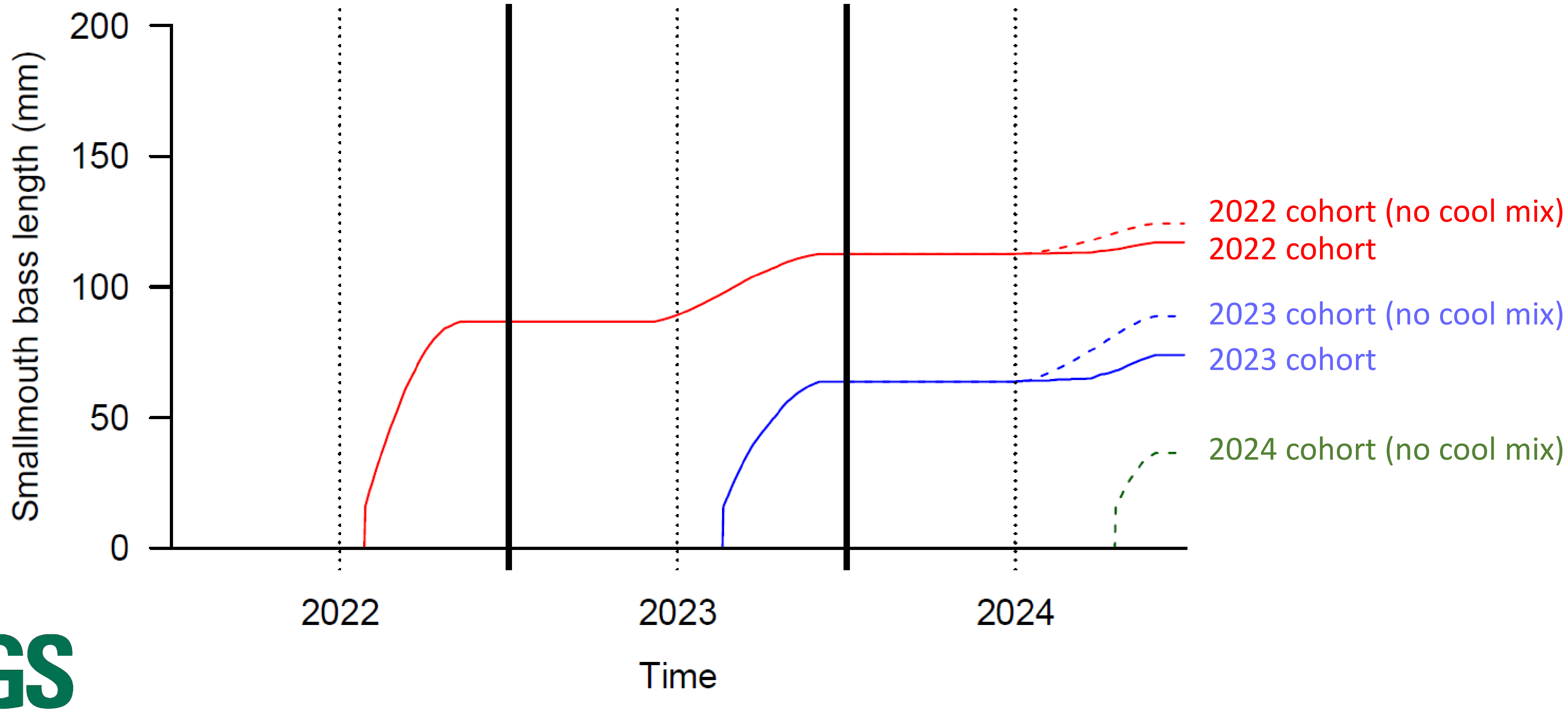
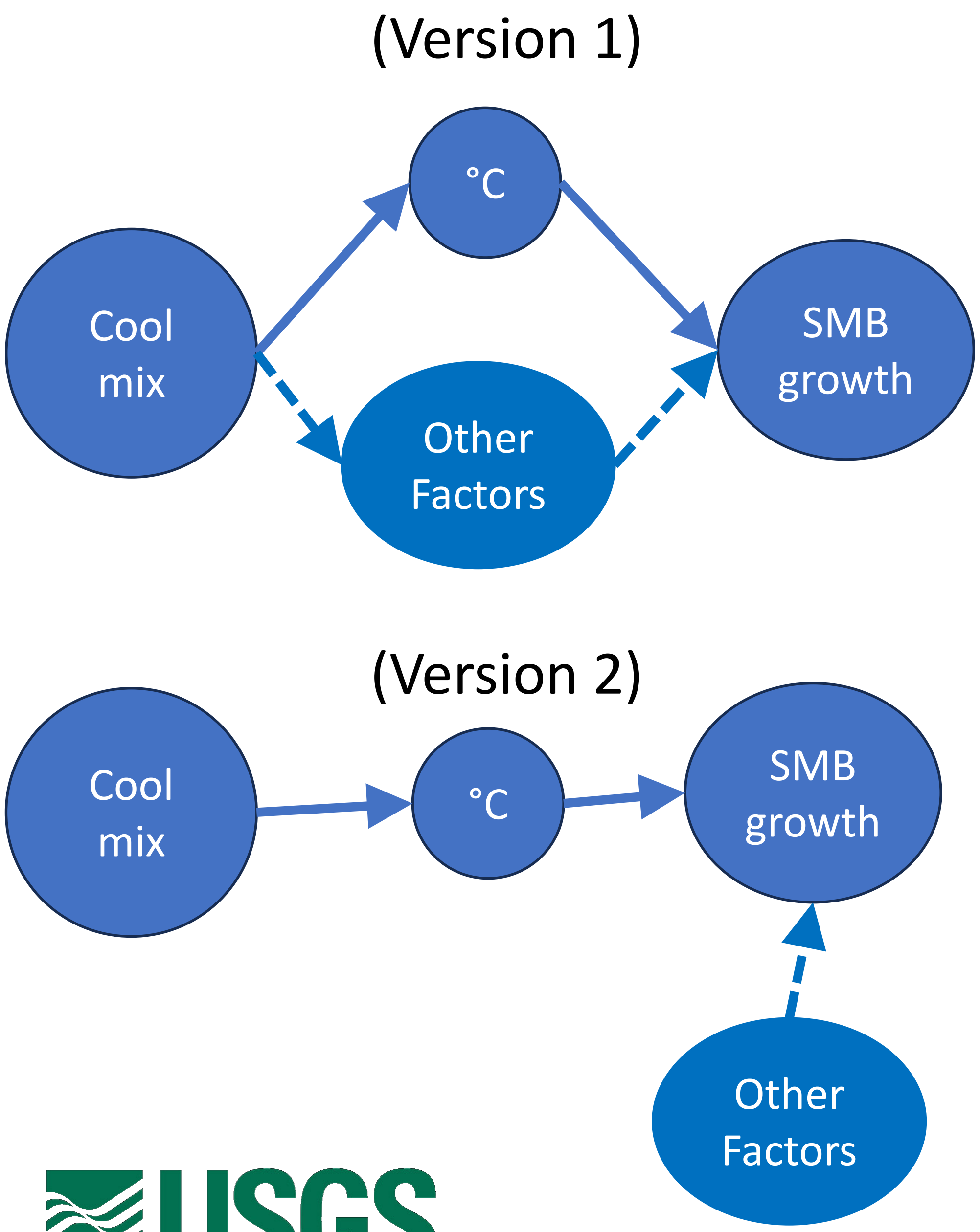
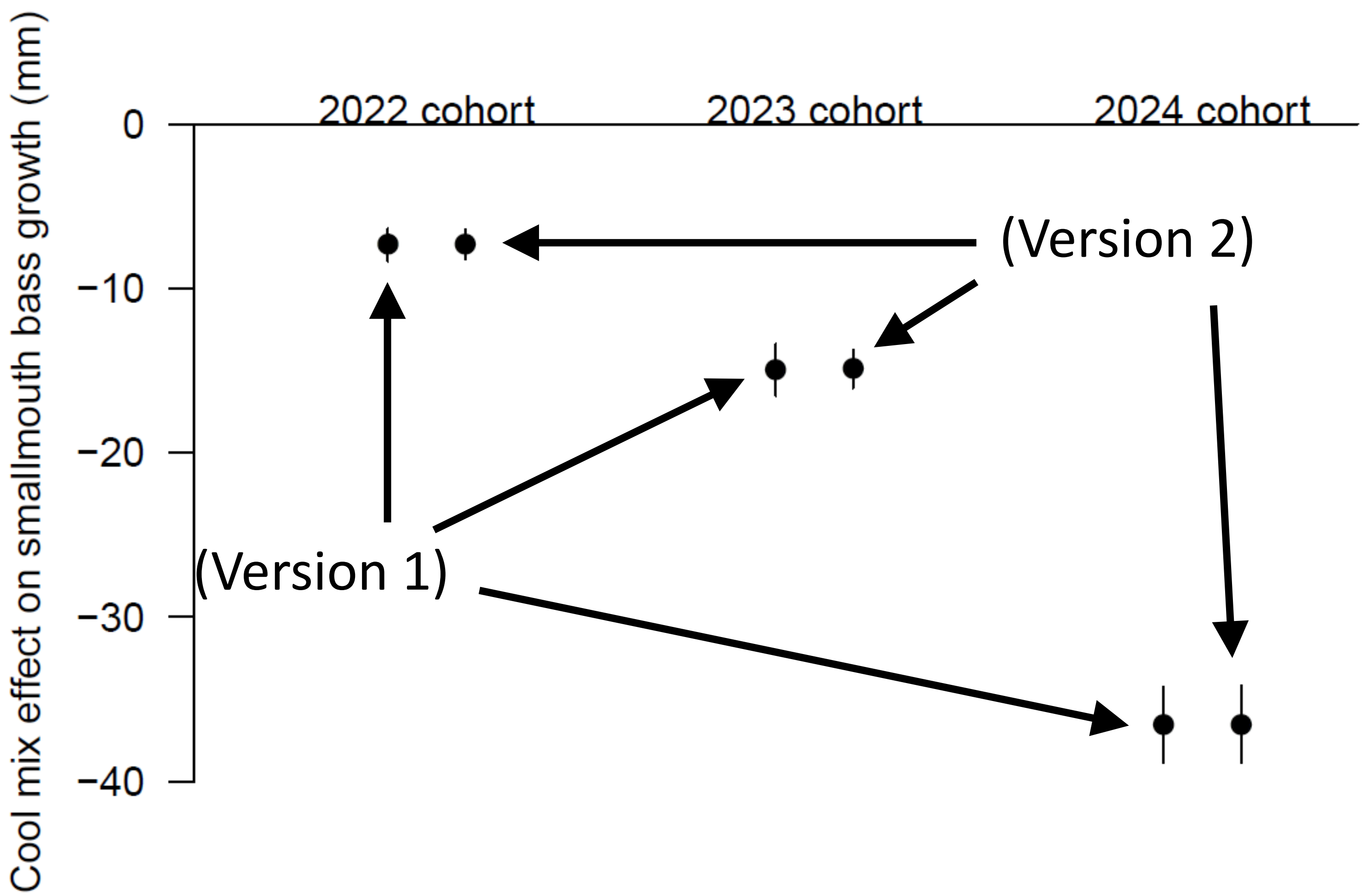
Growth model fitted to electrofishing data from Lees Ferry and PBR reaches







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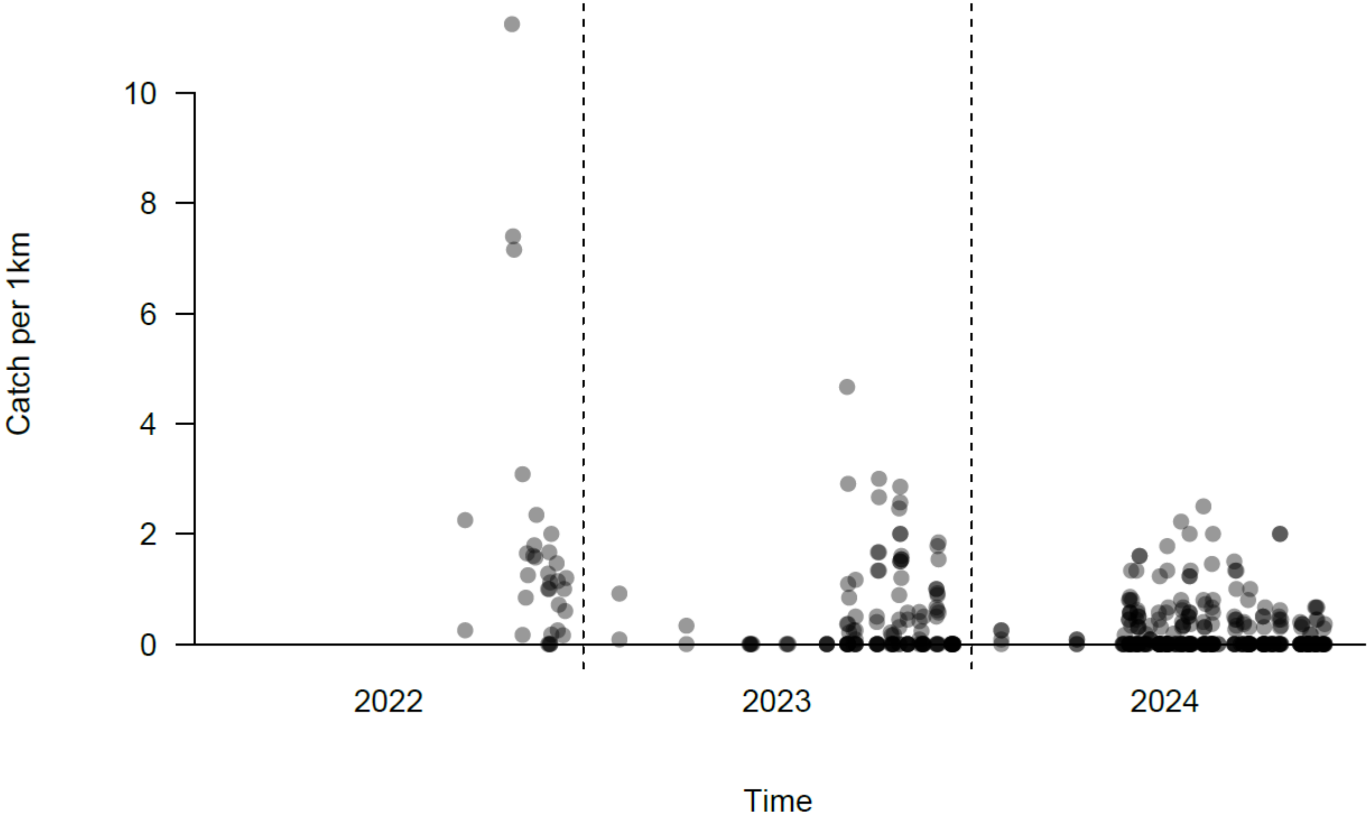
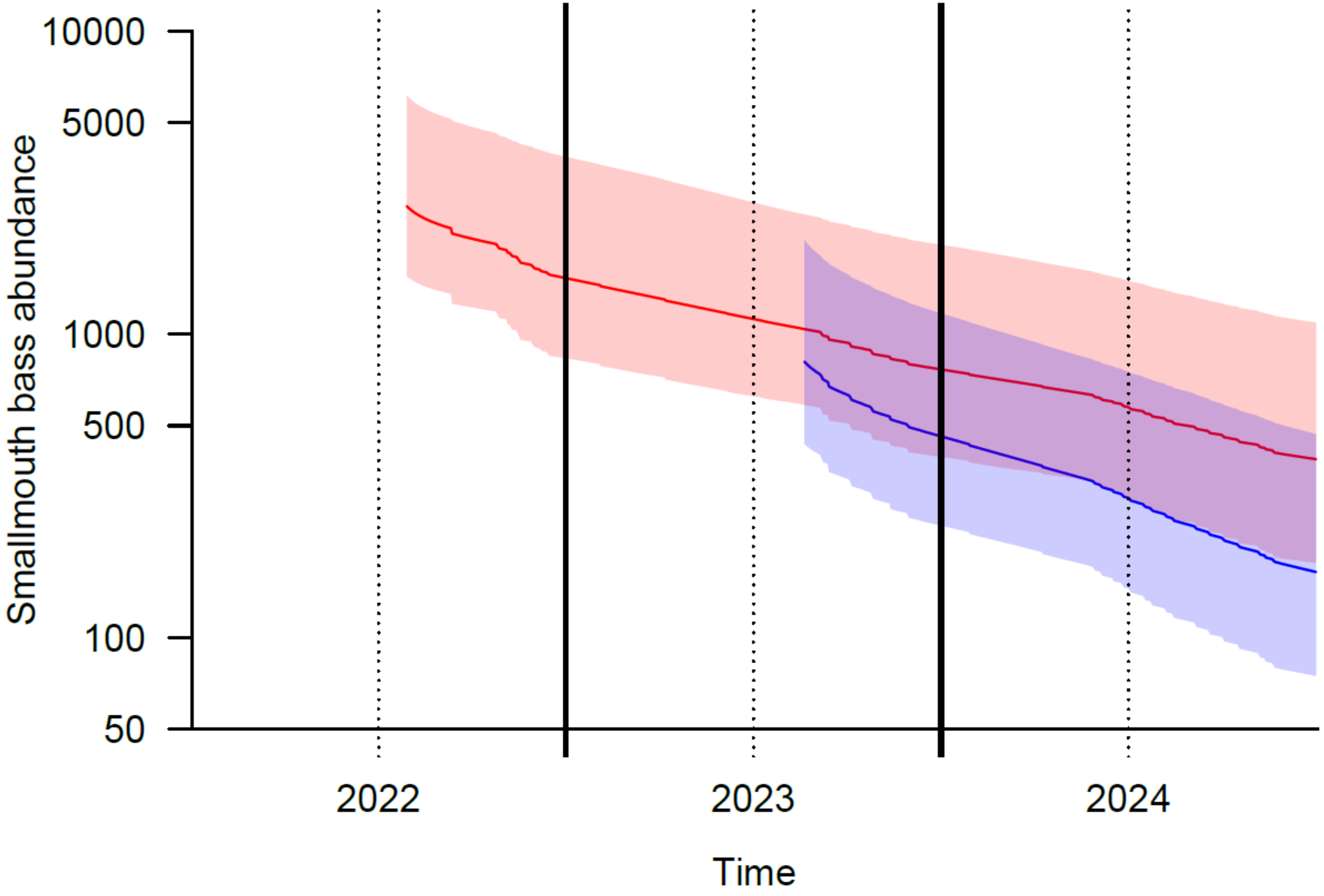
Some assumptions for SMB population model

- See assumptions in growth model, plus…
- Assume constant mortality rate during egg to juvenile stage based on published studies.
- Juvenile mortality rate is lower and decreases further for larger juveniles.
- Abundance tracked in 11 river segments and linked to all monitoring and most management electrofishing efforts.
- Assume catchability varies with water temperature.



The abundance of juvenile Smallmouth Bass associated with both 2022 and 2023 cohort declined as a function of natural mortality and removals. Cool mix was not expected to substantially lower abundance of these cohorts and counterfactual comparisons were consistent with this expectation.



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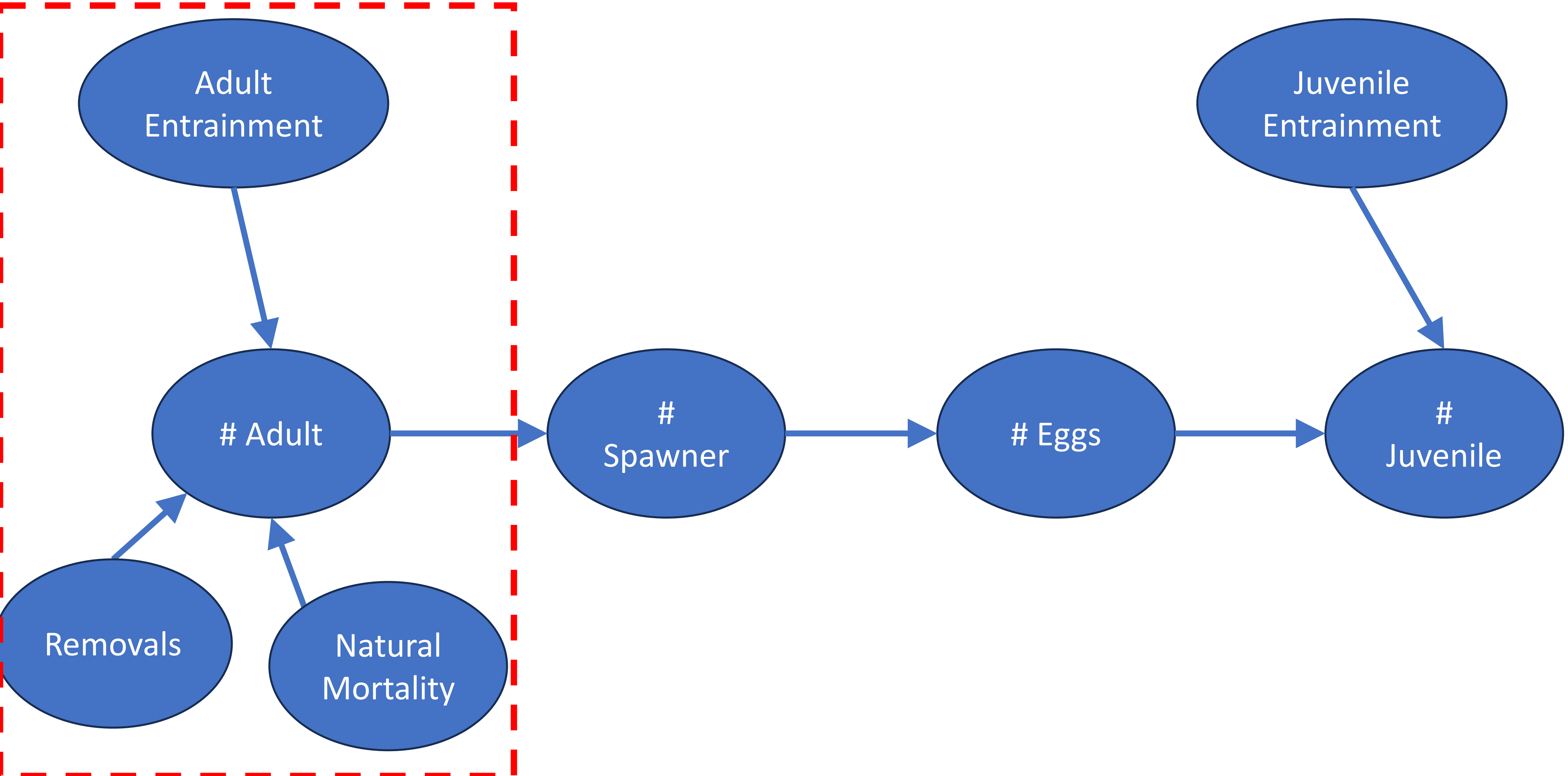
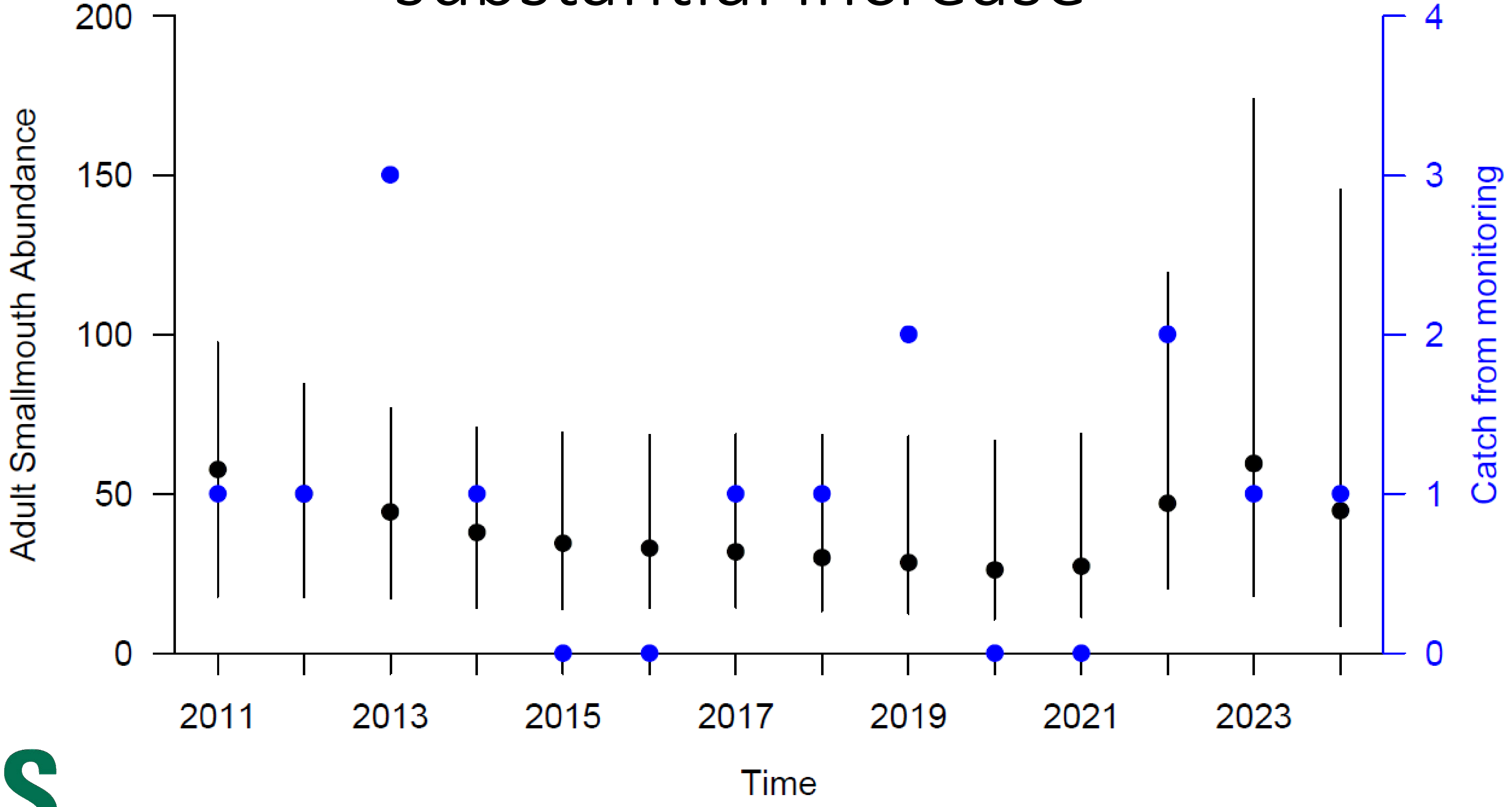
No confirmed age-0 Smallmouth Bass in 2024 (but still looking at otoliths), but how many might there have been if cool mix had not occurred?



Modest increase in estimates of adult Smallmouth Bass abundance since 2021, but little evidence for substantial increase



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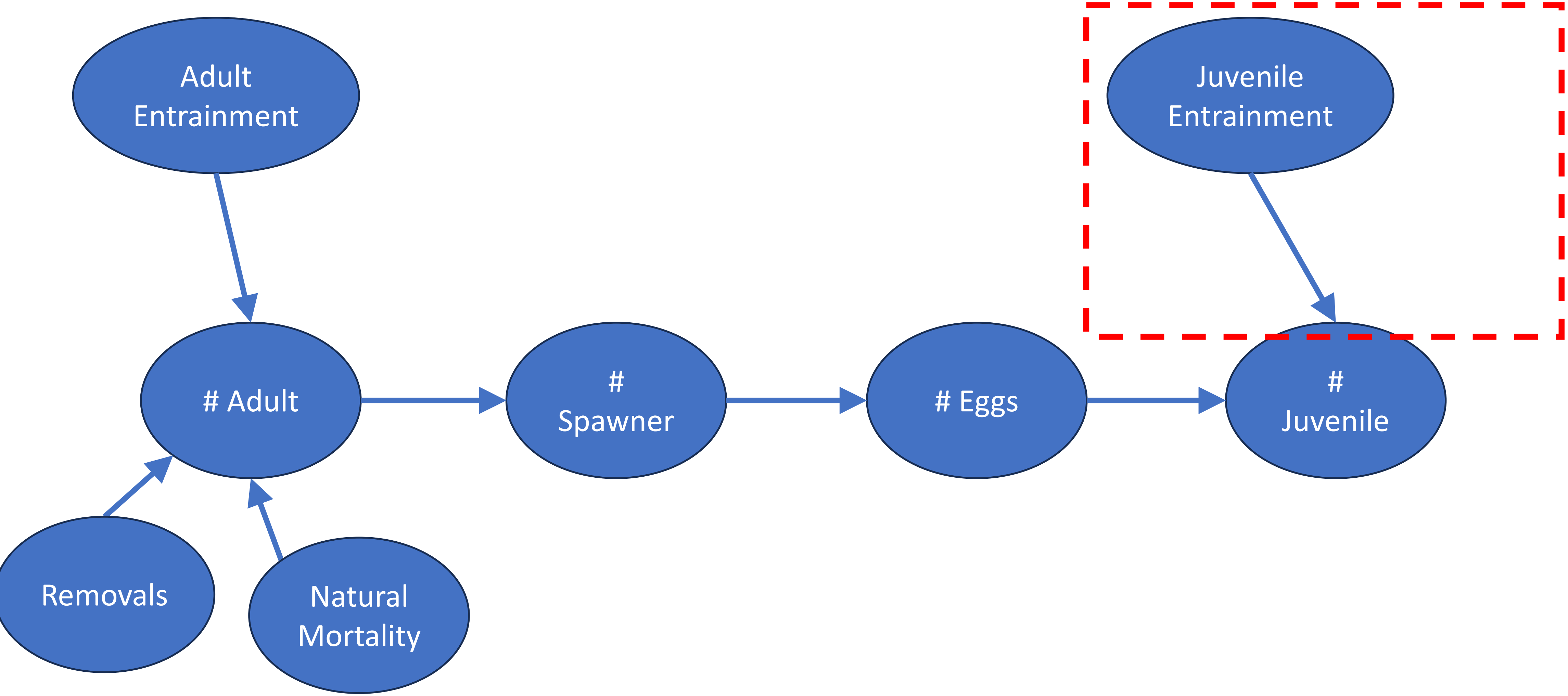
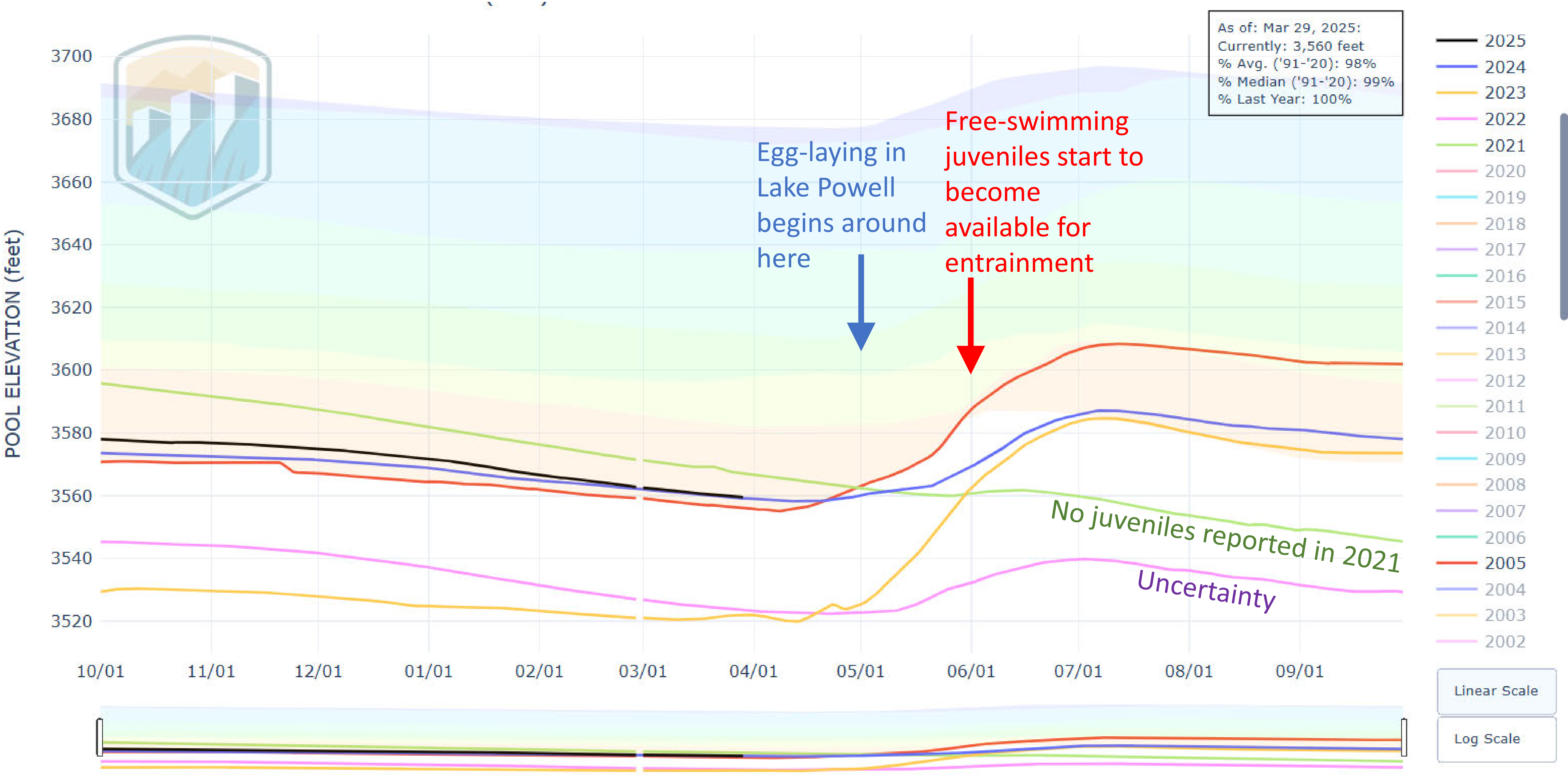
What about juvenile entrainment?
Juveniles are likely concentrated high in the water column and are only available during some months…





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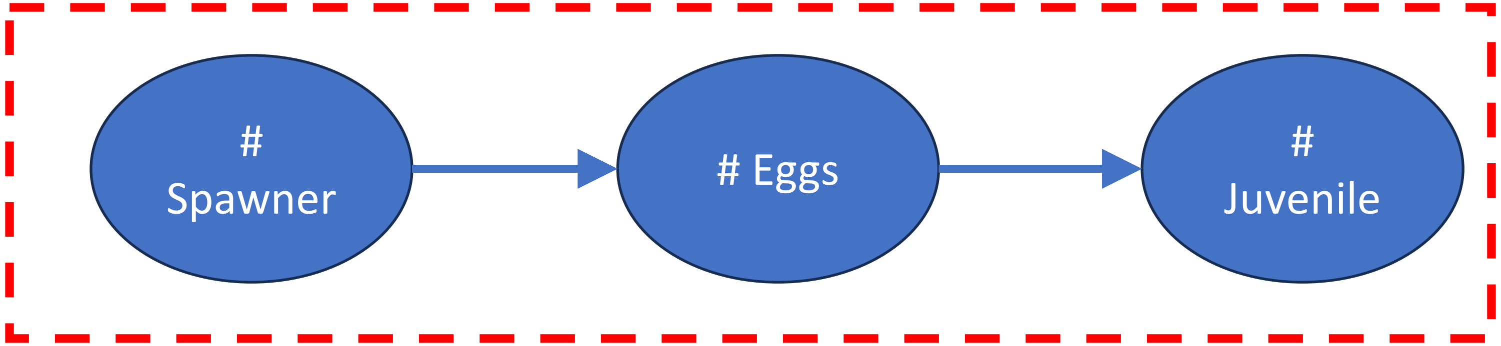
https://www.usbr.gov/uc/water/hydrodata/reservoir_data/919/dashboard.html#pool_elevation/

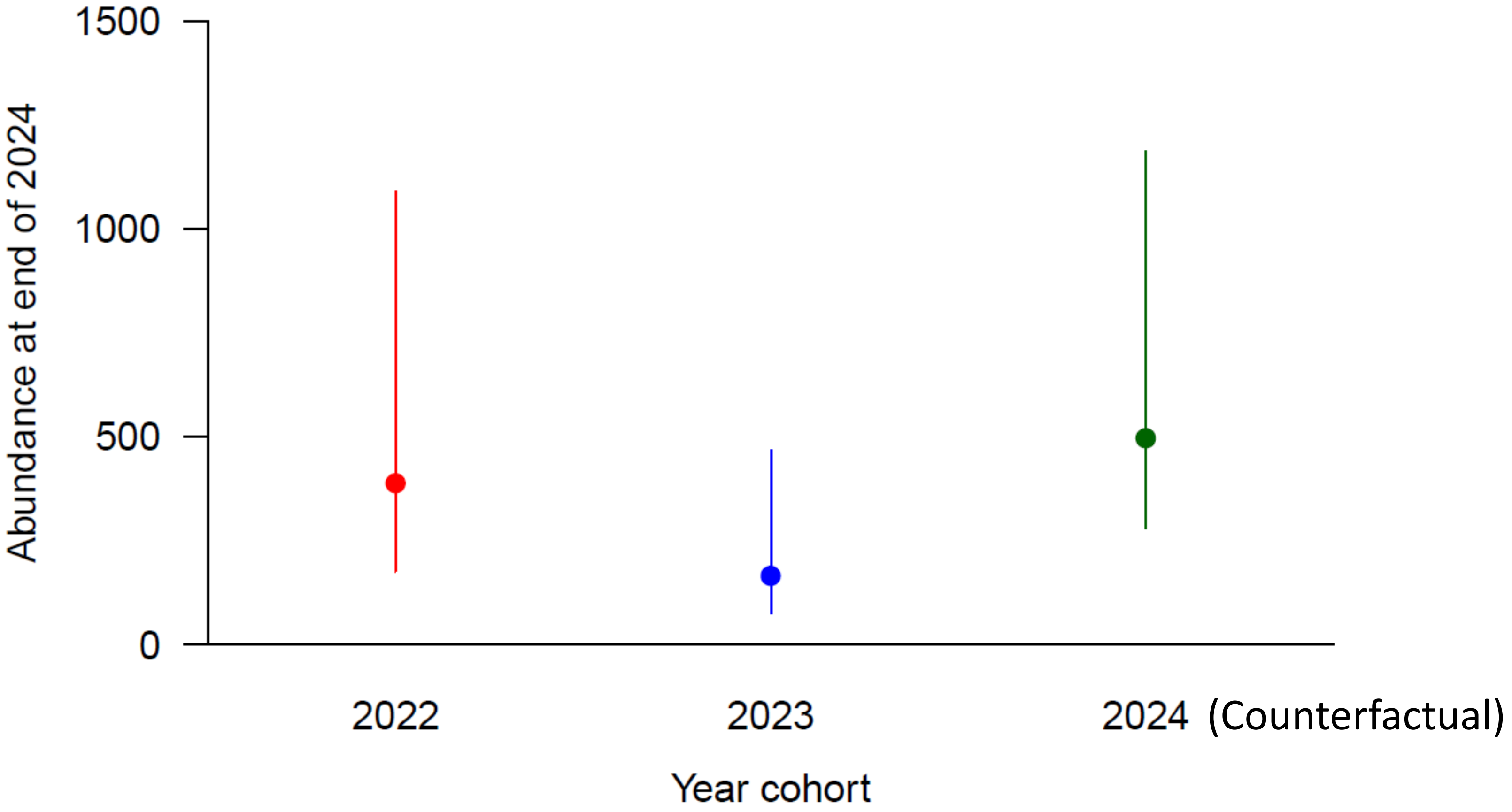
What about these relationships?



Year	Number of adults	Number of female spawners	Number of eggs	Average number of days from egg to juvenile	Number transitioning to juvenile
2022	47 (20 - 119)				2600 (1600-6100)
2023	60 (18 – 174)				800 (400-2000)
2024 (counterfactual)	45 (8 – 146)				?

Preliminary data, subject to change, do not cite

Assuming there would have been similar number of spawners in 2024 as in 2023, then we expect there would be approximately twice as many Smallmouth Bass as there currently are in the absence of cool mix.



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Take homes

- Counterfactual analysis suggests temperatures would have naturally been a little cooler in 2024 then they were in 2023.
- Without cool mix,
  - There is a high likelihood that Humpback Chub subadults near the LCR would have grown more in length.
  - A moderate likelihood that Rainbow Trout adults in the tailwater would have grown less in weight.
  - A high likelihood that Smallmouth Bass already in the system would have grown more, that a new cohort would have been produced, and that this cohort would have smaller individuals than in past years.
  - A high likelihood that this new cohort would be smaller than the 2022 cohort and a moderate likelihood it would be smaller than the 2023 cohort.

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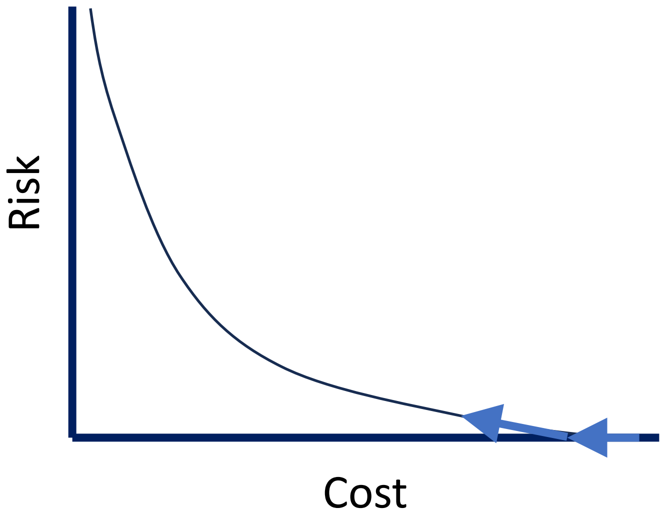
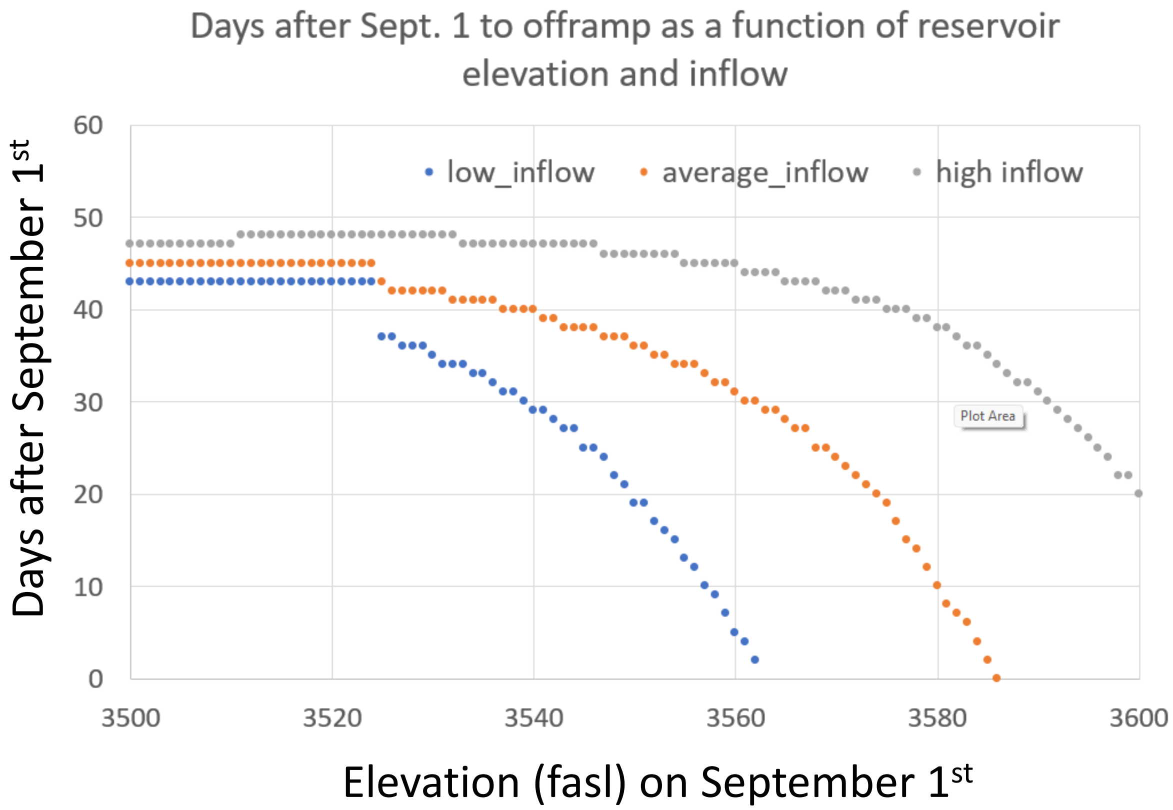
Ongoing data collection and analysis

- Currently looking for annuli in SMB collected in 2023 and 2024 to test age assignments.
- Assessing SMB diets over time.
- Hope to analyze genetics of 2023 cohort in near future for kinship and spawner abundance.
- Currently testing effects of different overwinter temperatures on SMB survival in the lab and hope to look at turbidity in the coming year.

Ongoing modeling work

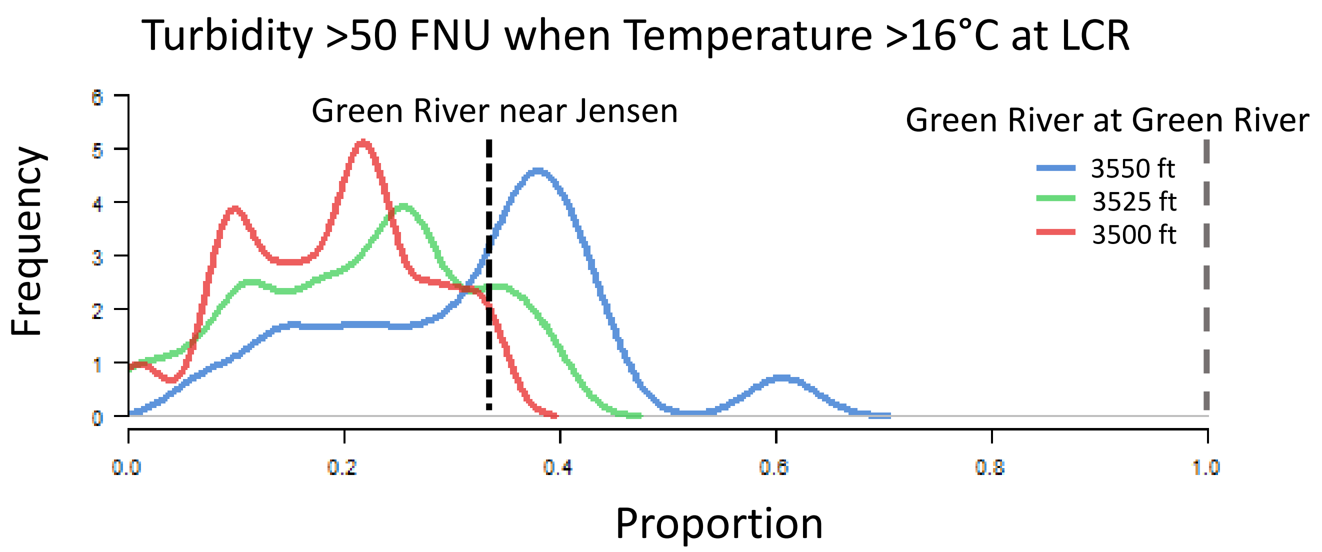
- Reducing costs to hydropower of Smallmouth Bass flows.





Ongoing modeling work

- Reducing costs to hydropower of Smallmouth Bass flows.
- Forecasting potential Smallmouth Bass abundances over CRe while accounting for critical uncertainties.



Data: USGS gages 09261000; 093150000; 09383100

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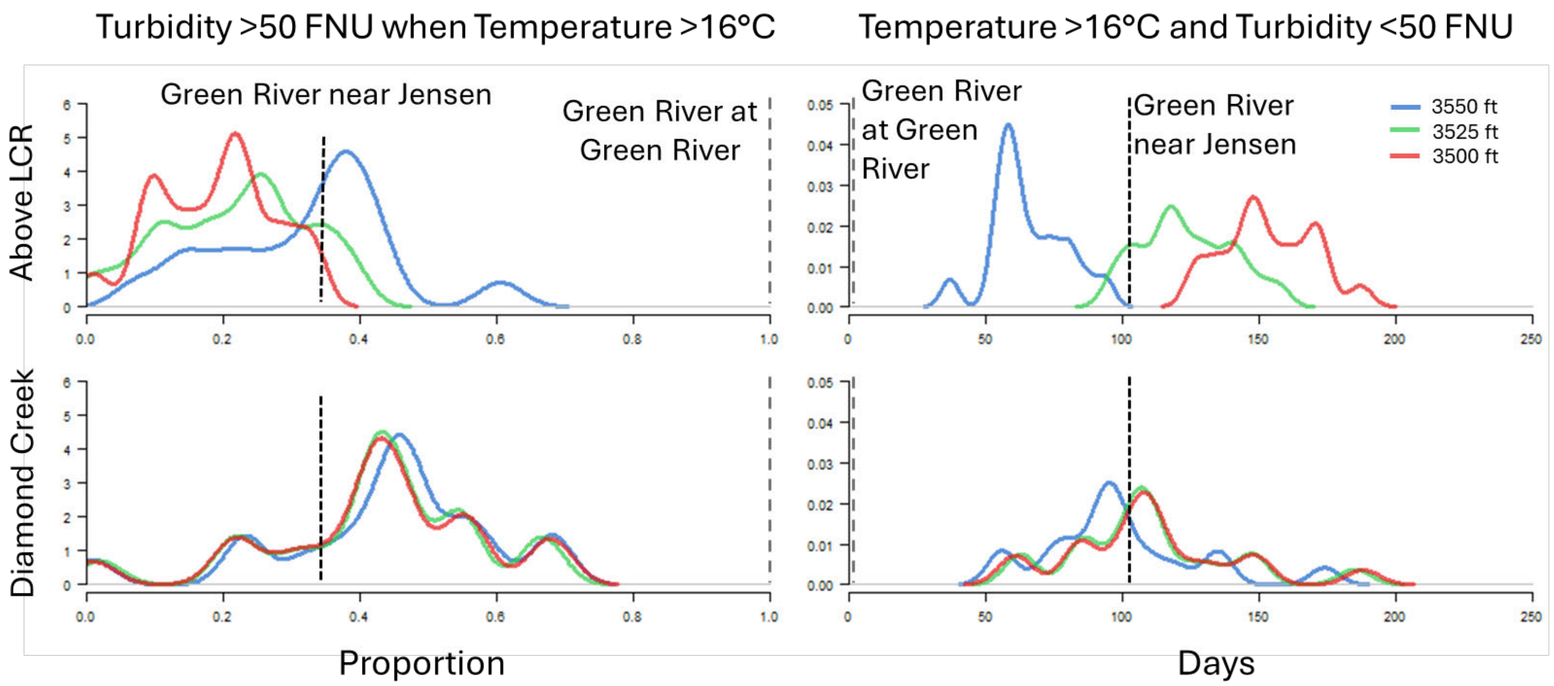

Green River near Jensen mean: 2022-2024

Green River at Green River mean: 2022-2024

Data: USGS gages 09261000; 093150000; 09383100; 09404200

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Ongoing modeling work

- Reducing costs to hydropower of Smallmouth Bass flows.
- Forecasting potential Smallmouth Bass abundances over CRe while accounting for critical uncertainties.
- Coupling Smallmouth Bass and Humpback Chub models to forecast overall effect of Smallmouth Bass (& management actions) on Humpback Chub.

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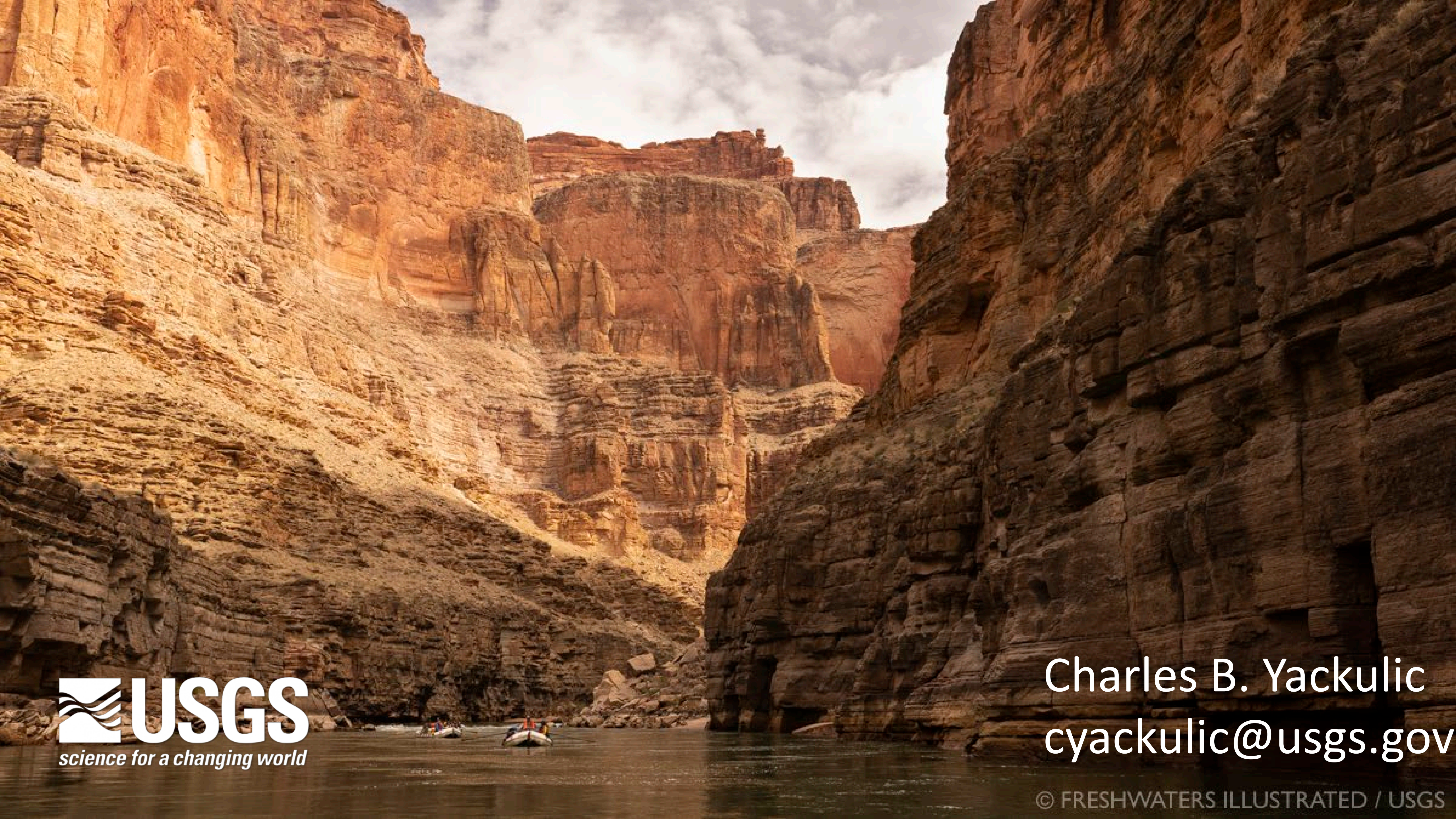
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