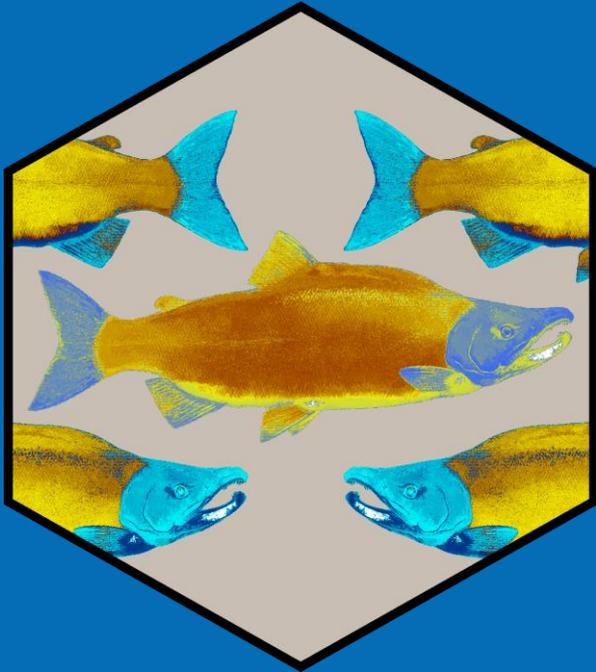


Tough places and safe spaces: can refuges save salmon from a warming climate?



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Matt Keefer⁴, Randy Comeleo¹, Allen Brookes¹, Jonathan Halama⁵,
Peter Leinenbach⁷, John Palmer⁷

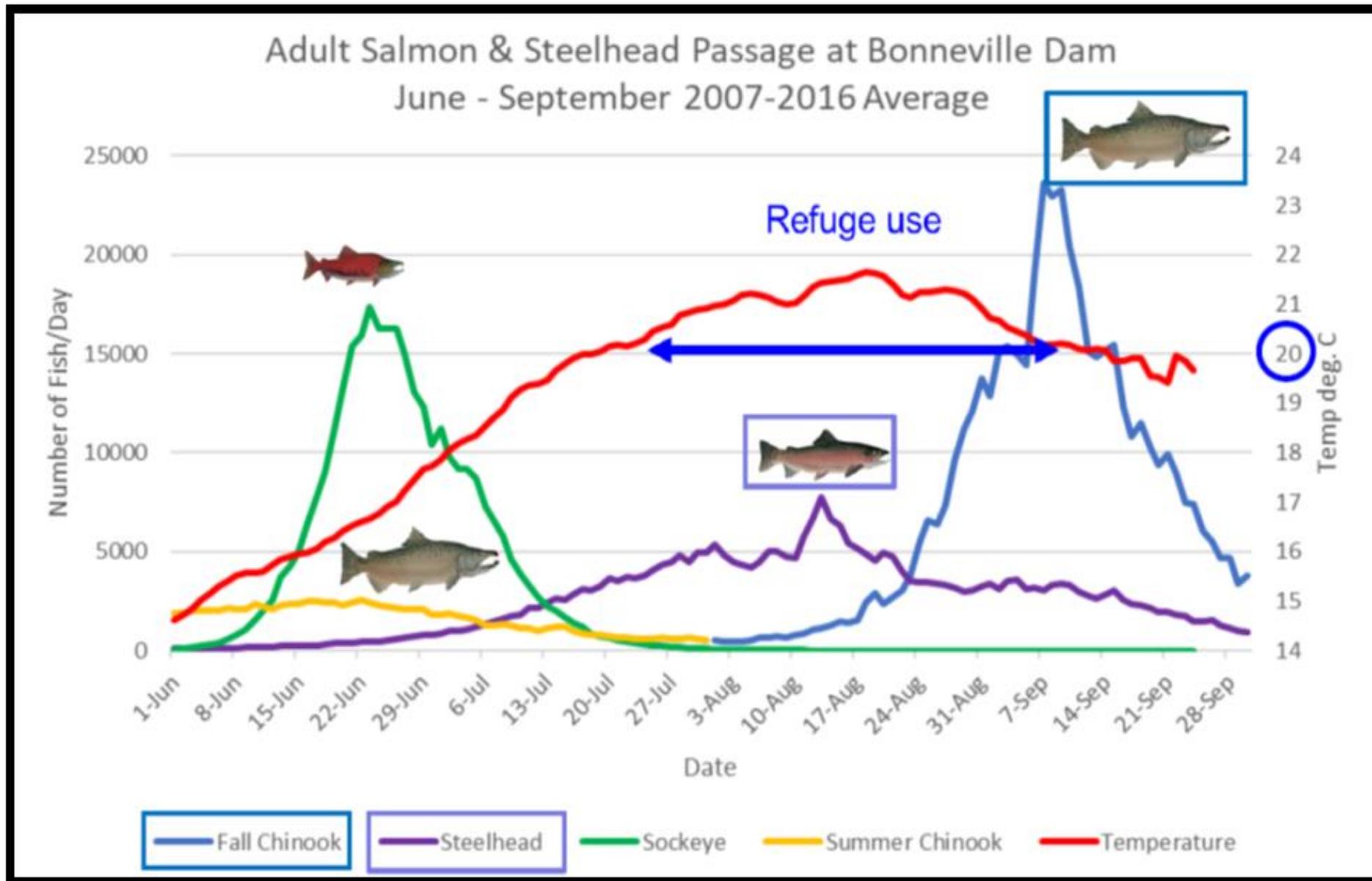
1. *US EPA, Pacific Ecological Systems Division, Corvallis, OR*
2. *Oregon State University, College of Forestry, Corvallis, OR*
3. *USGS Forest and Rangeland Ecosystem Science Center, Corvallis OR*
4. *University of Idaho, Moscow ID*
5. *Oak Ridge Institute for Science and Education*
6. *US EPA Region 10, Seattle WA*

Thermal refuge use

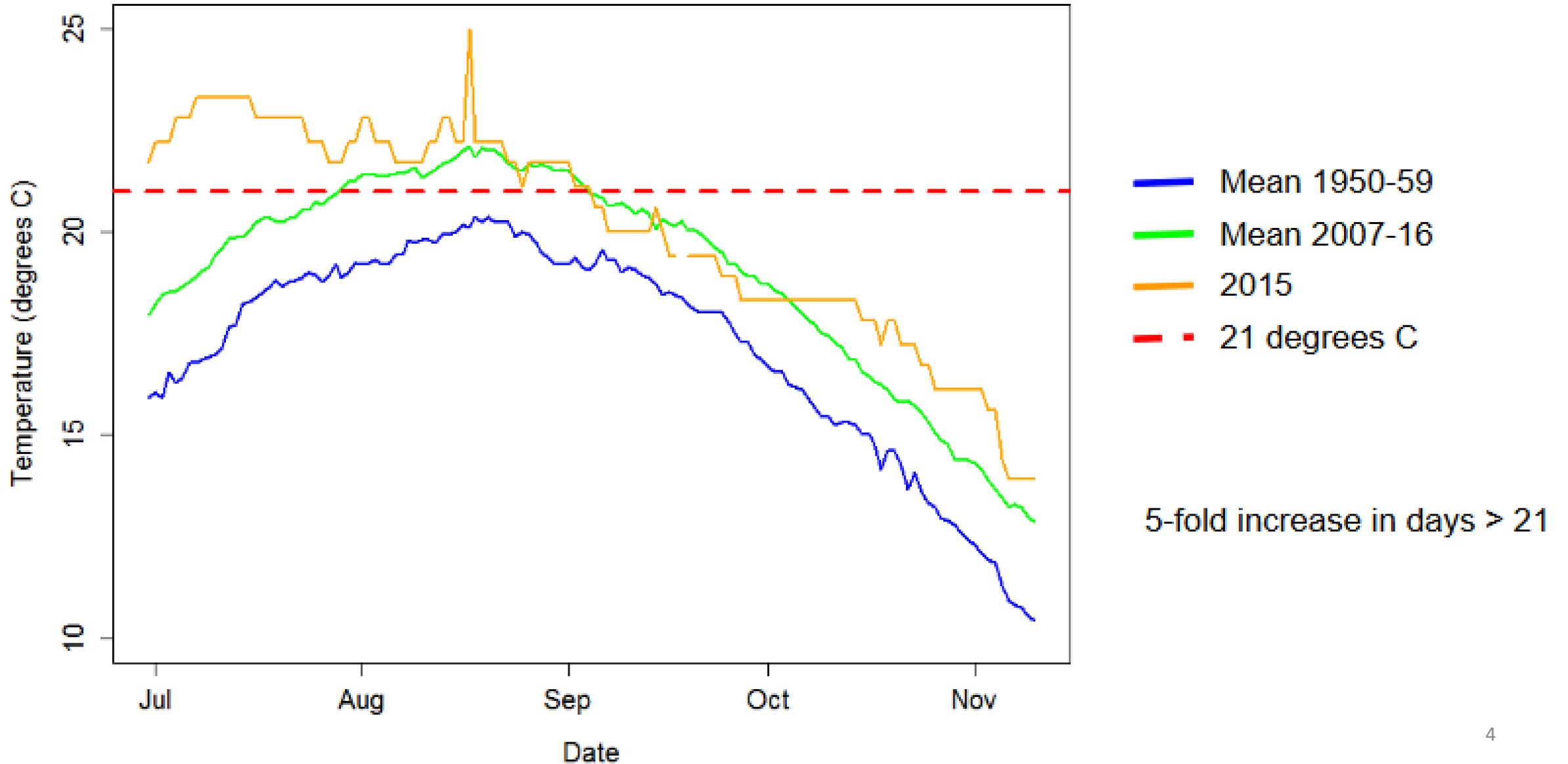


Discover Crystal River

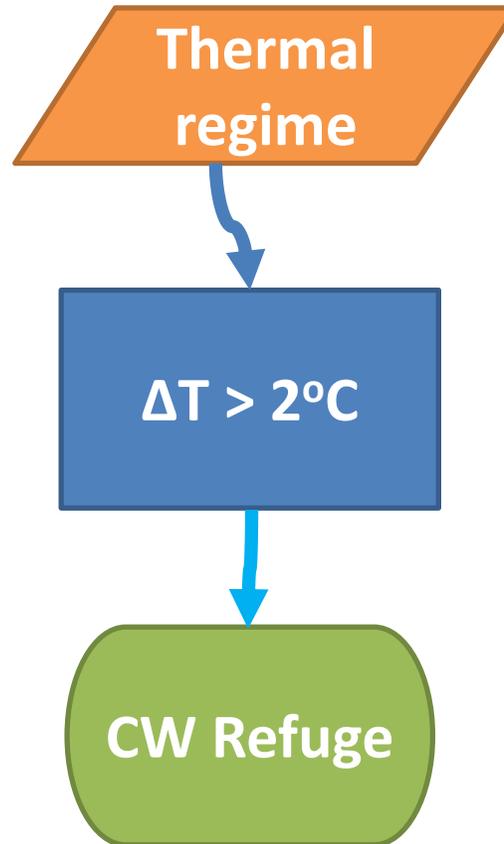
Run timing and Columbia River temperature



Warming water temperature



Cold water refuge



... "those portions of a water body where, or times during the diel cycle when, the water temperature is at least 2° C colder than the daily maximum temperature of the adjacent well mixed flow of the water body" - Oregon DEQ

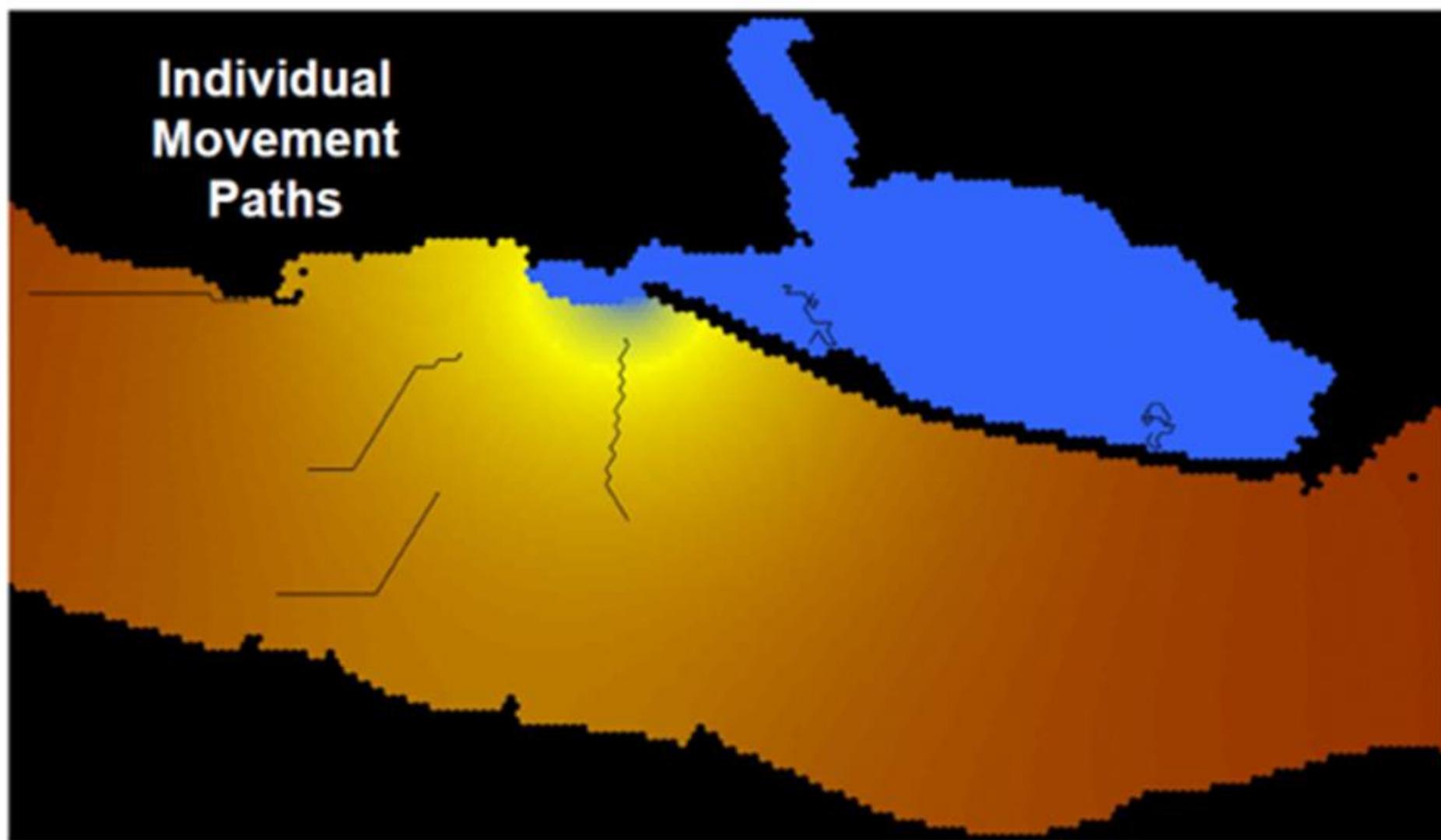
Consequences of refuge use

- Refuge use has many benefits, but also presents some risks.
- Quantifying consequences (good or bad) of refuge use is difficult.
- Our model allows us to find out which migration strategies are advantageous.

Cold water refuges along the Columbia River migration corridor

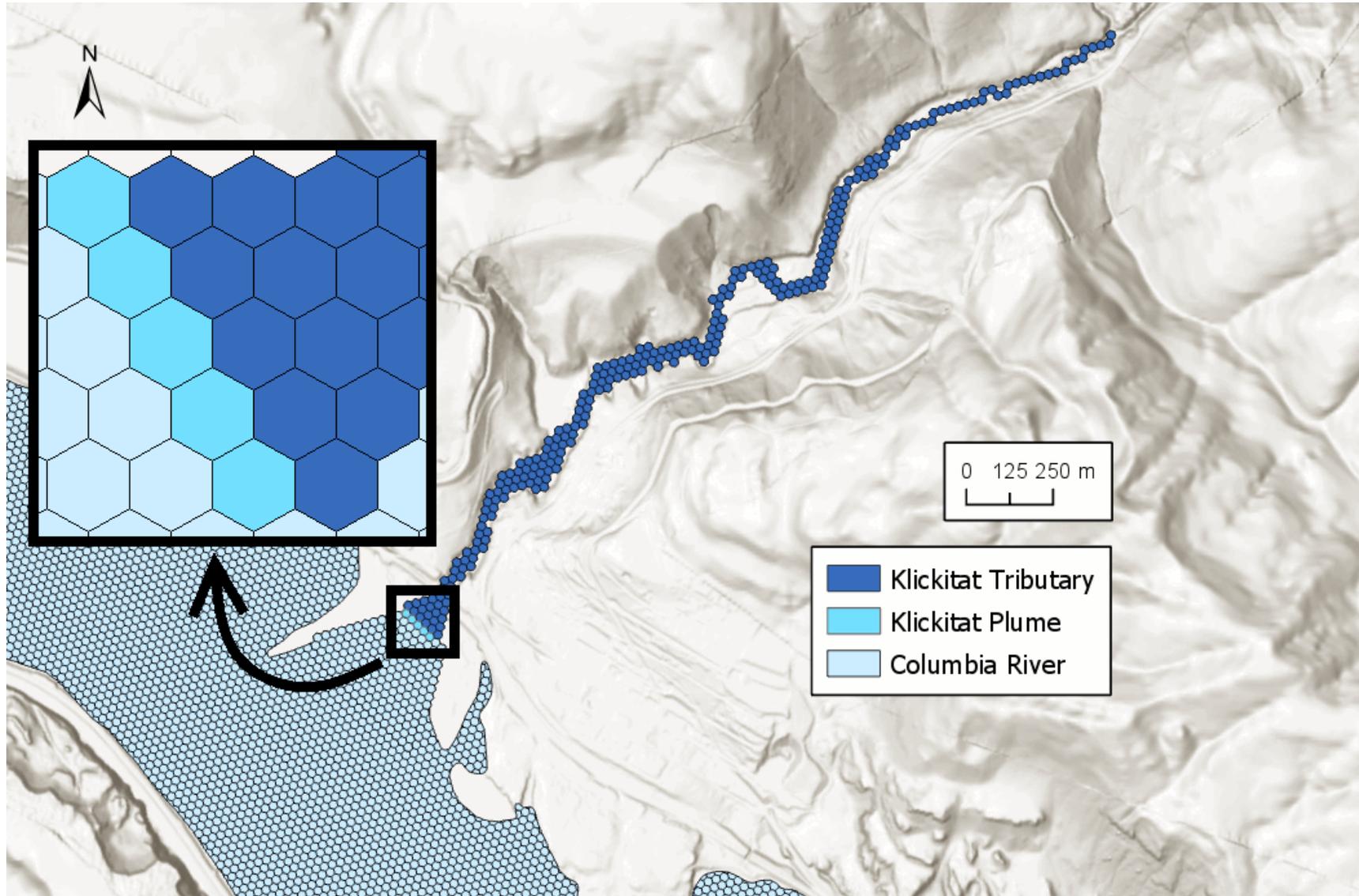


HexSim

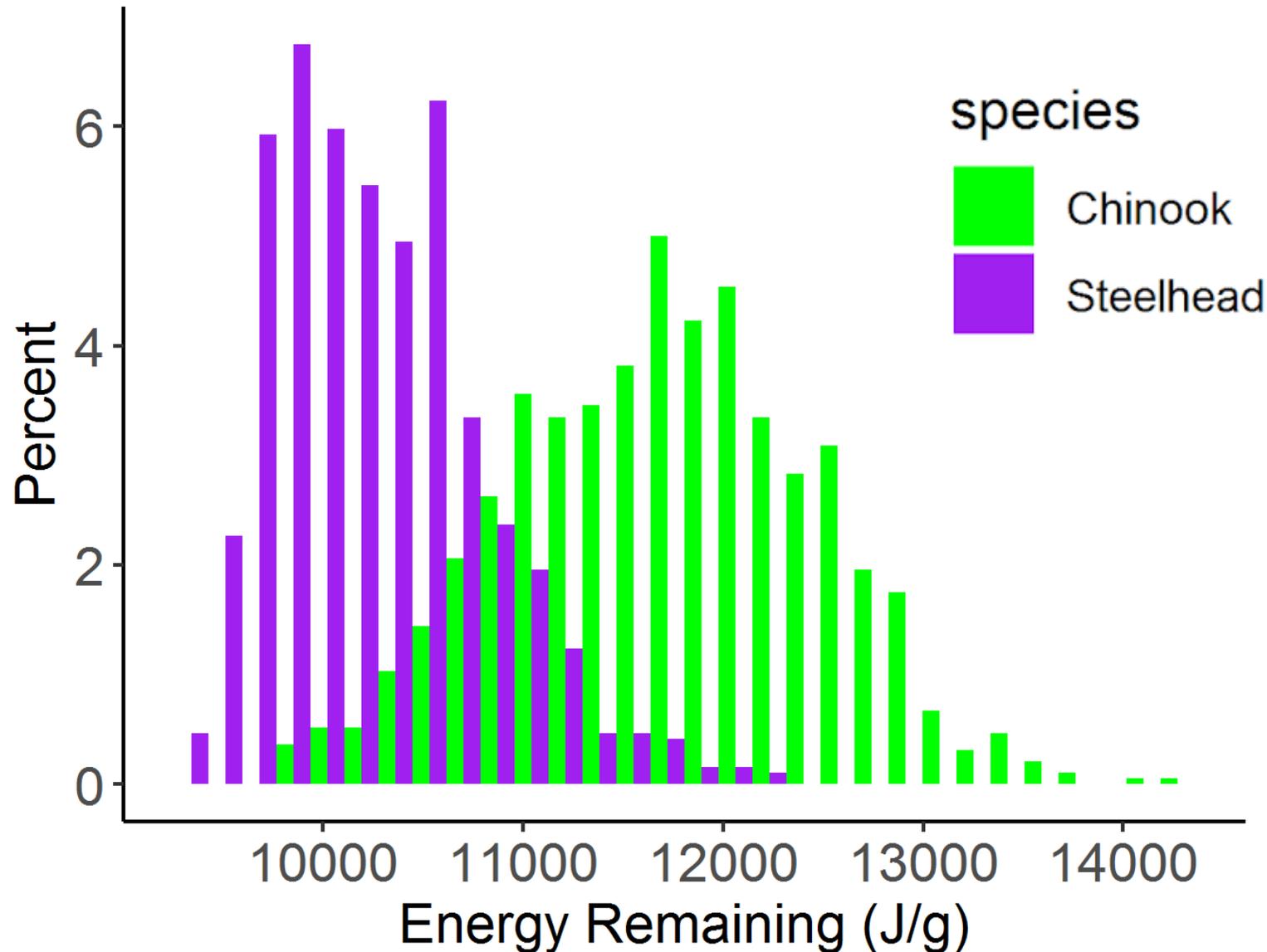


- **Spatially explicit modelling platform**
- **Individuals modelled in HexSim have associated traits.**
- **Life cycle flexibility**

Model thermalscape



Simulation outcomes



Cold water refuge sufficiency can be evaluated using model outcomes:

- survival rates
- energy status
- cause of mortality
- cumulative degree days
- passage timing

Scenarios

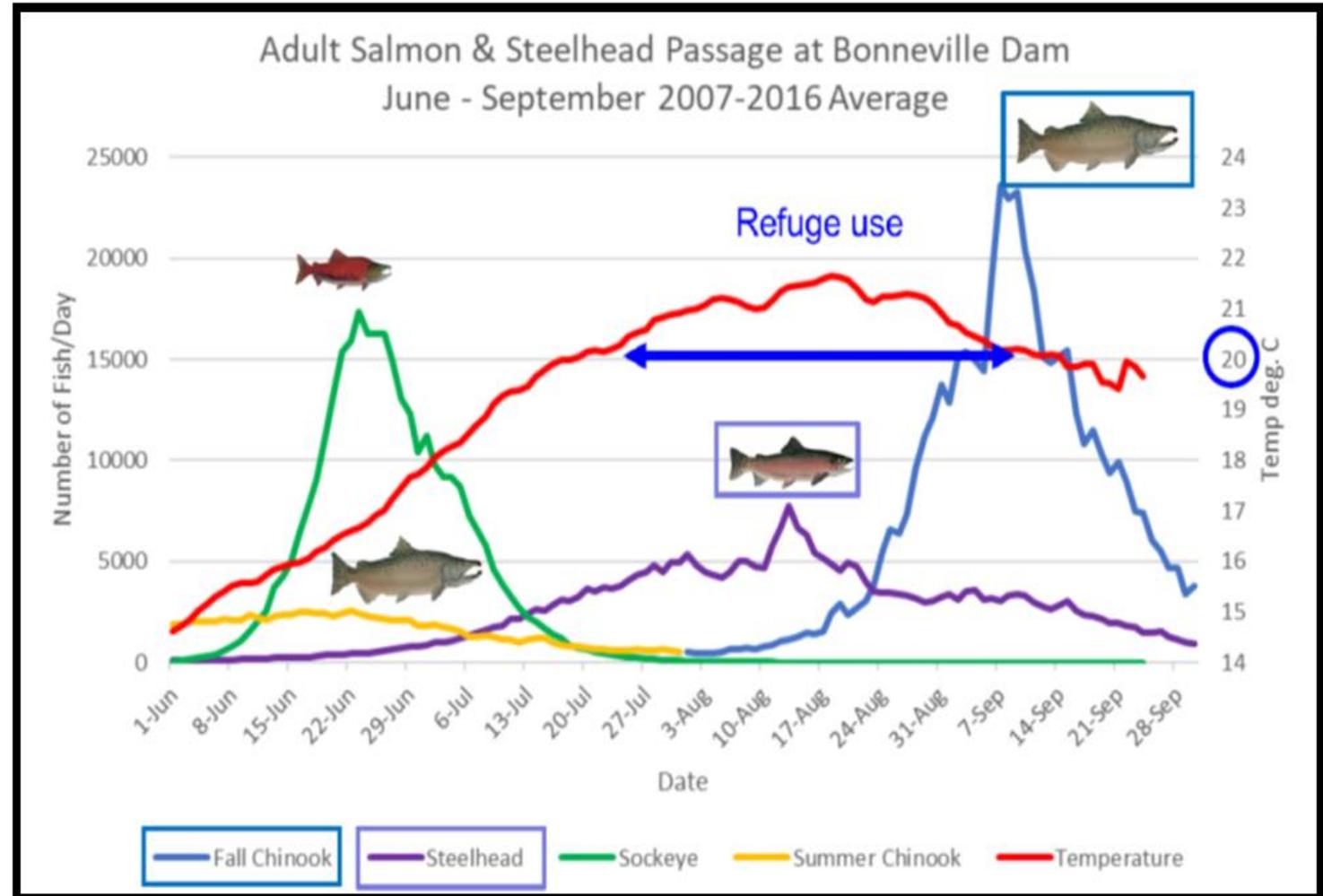
4 thermascapes and 2 populations:

Thermascapes

- Current with coldwater refuges
- Current without coldwater refuges
- Future with coldwater refuges
- Future without coldwater refuges

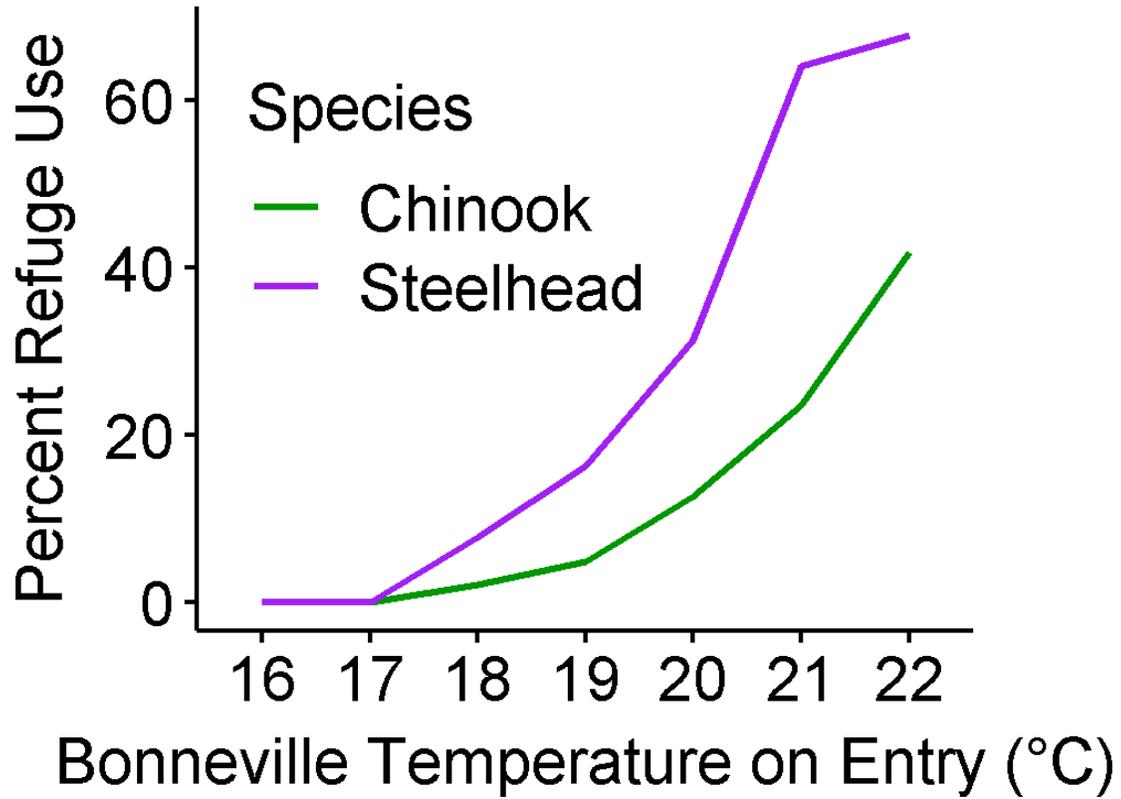
Populations

- Grande Ronde River summer steelhead
- Snake River fall Chinook salmon

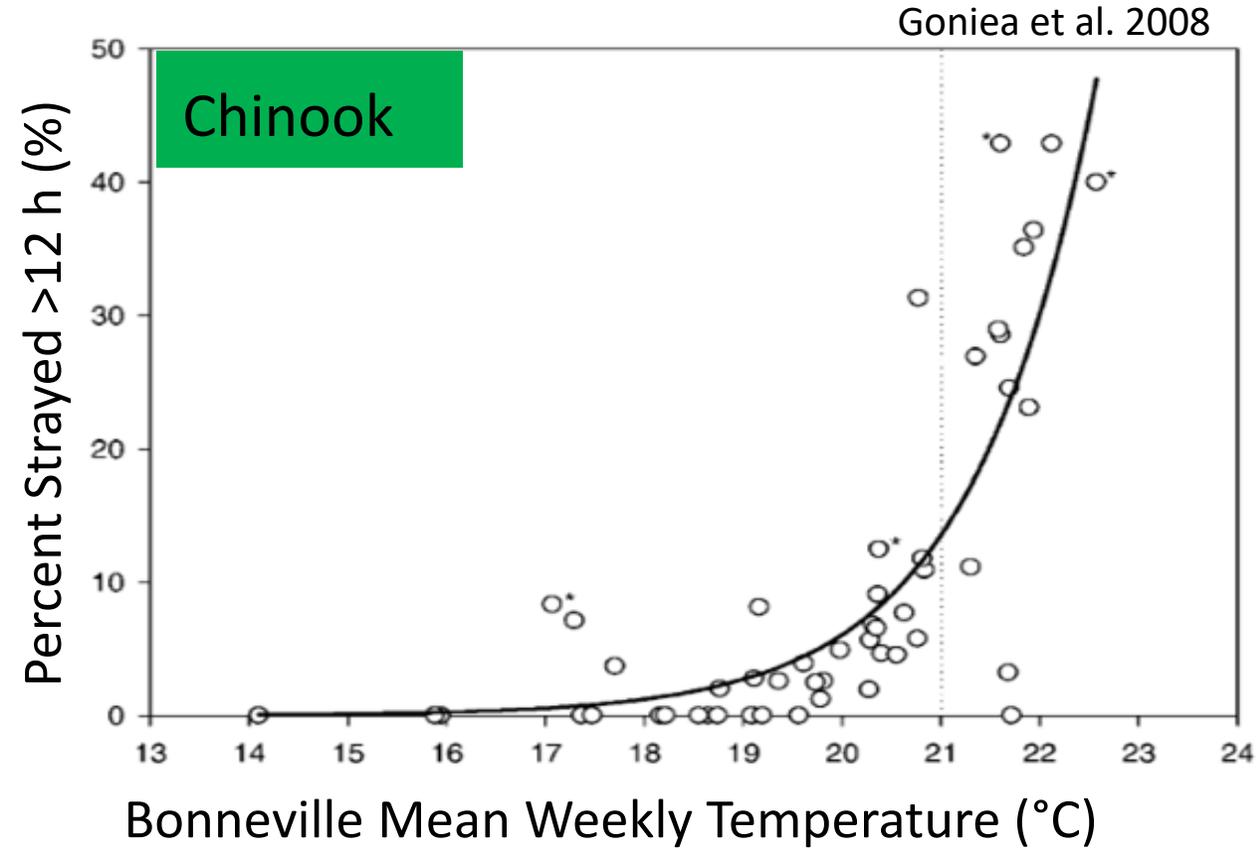


Results: % of individuals holding in refuges

Modelled

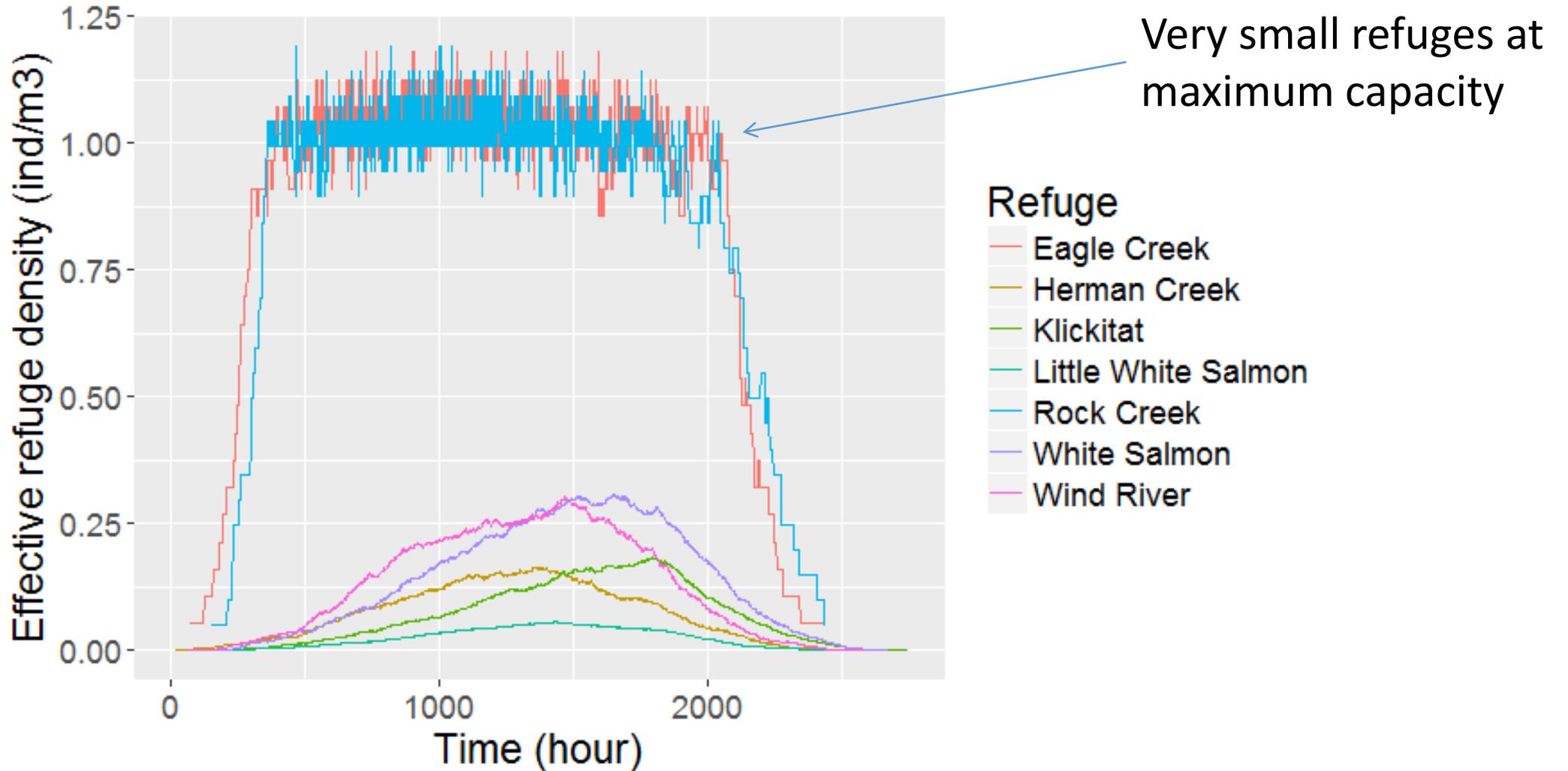


Observed



Percentage of individuals occupying refuges versus the temperature at Bonneville on date of entry.

How much cold water is enough?

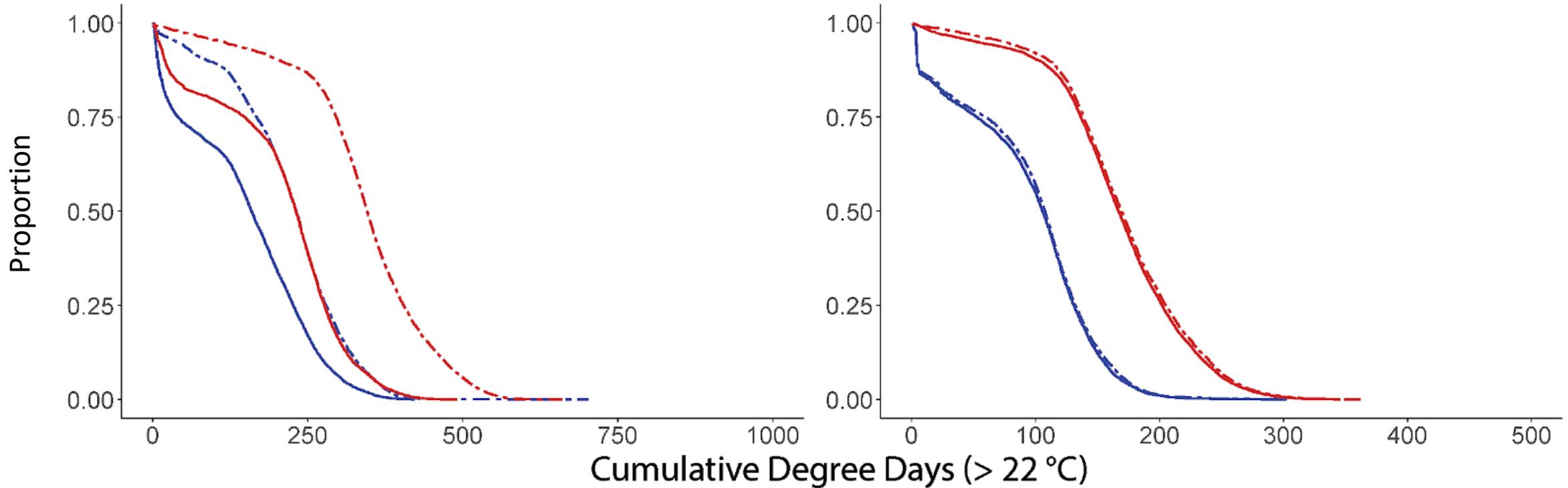


Effective density per refuge through time for steelhead and Chinook salmon combined.

Results: Accumulated Thermal Exposure

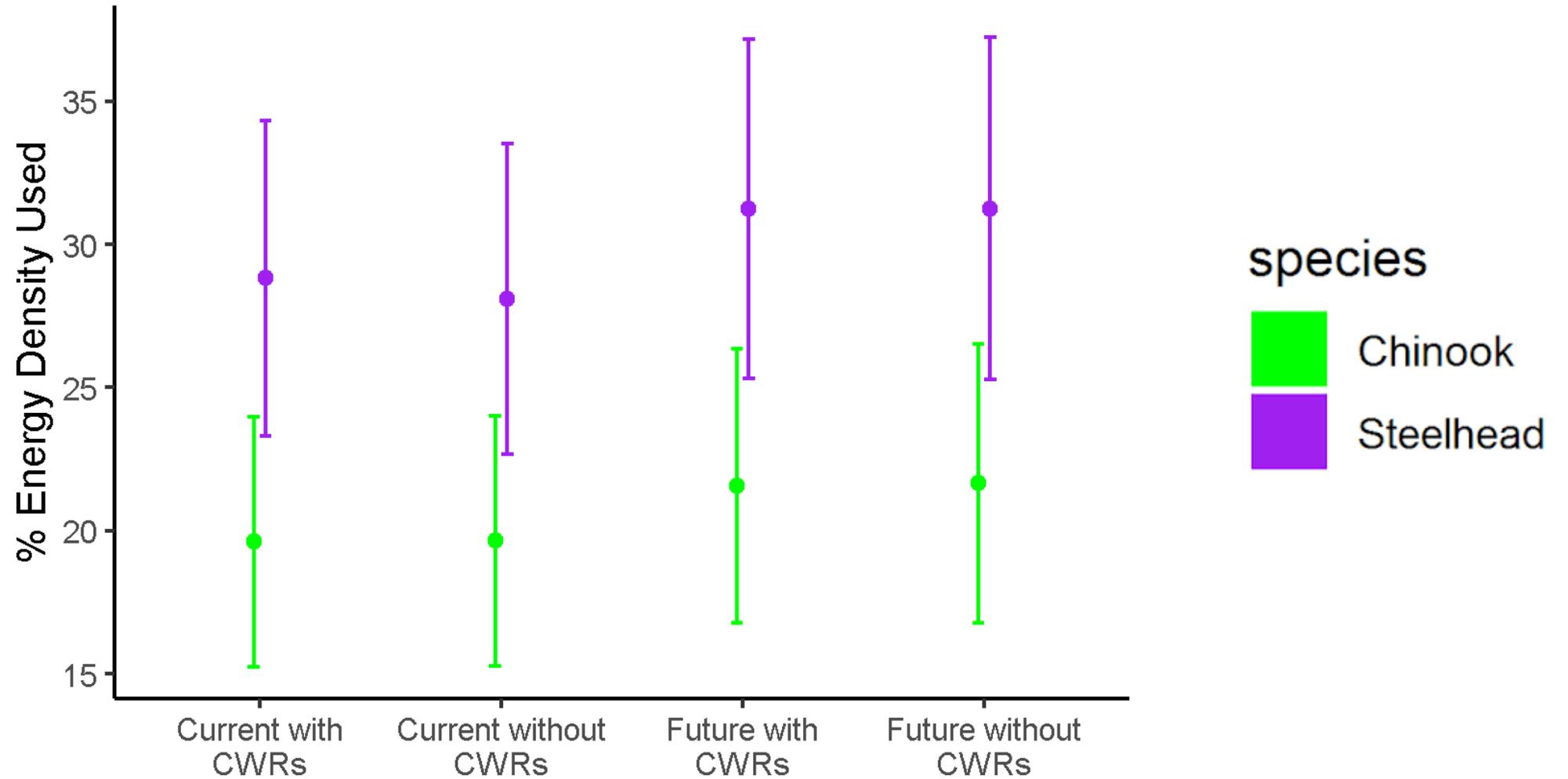
Grande Ronde River Summer steelhead

Snake River fall Chinook salmon

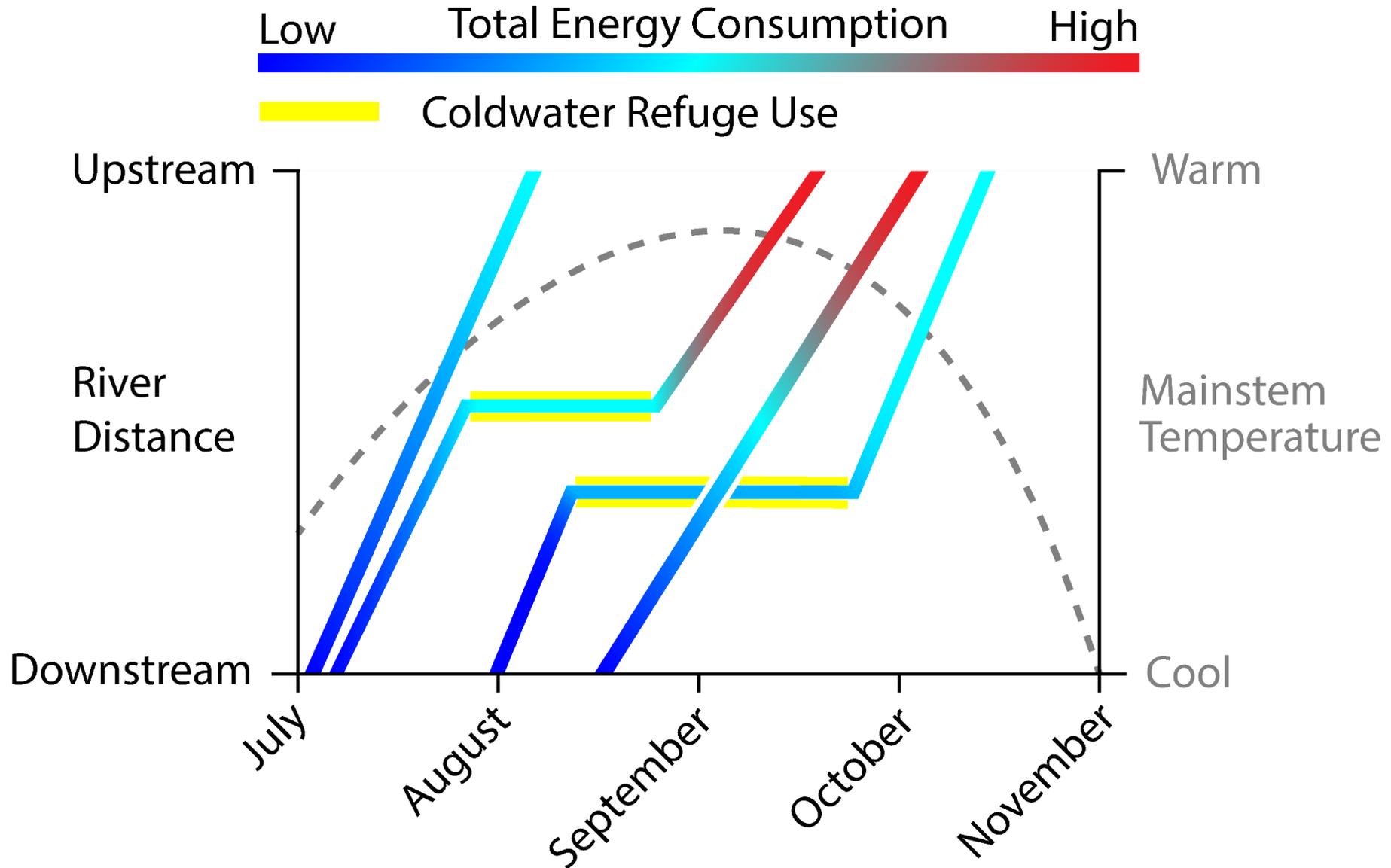


— Current with CWRs - - - Current without CWRs — Future with CWRs - - - Future without CWRs

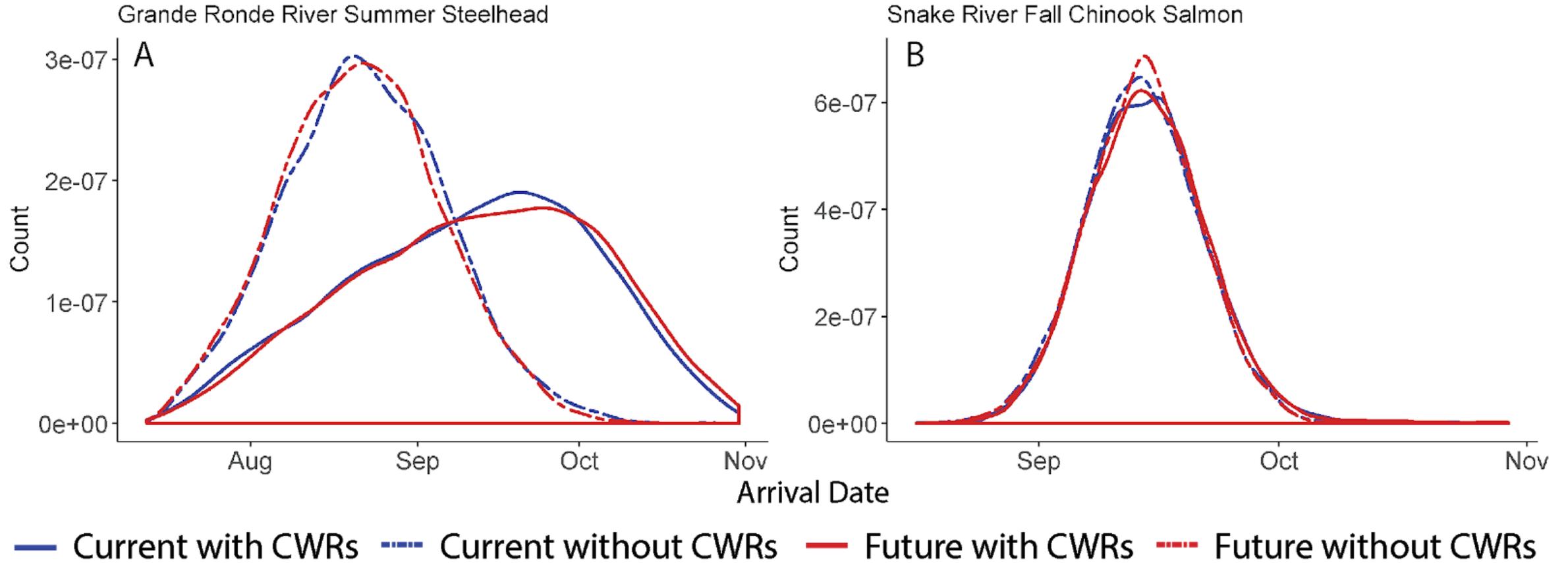
Results: Energy Use



Consequences of refuge use



Results: Behavioral Phenotypes



Conclusions

- Energy use is influenced by temperature of the Columbia River more so than the use of CWRs.
- Acute temperature stress is not high but depending on timing of use, CWRs can decrease the cumulative exposure to stressful temperatures.
- CWR use extends migration duration, which may increase or decrease cumulative thermal exposure depending on timing. Increasing migration duration delays mean arrival dates at the Snake River and/or increasing the range in dates of arrival for a given entry date

University of Idaho
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Disclaimer: The opinions expressed here are those of the authors and do not reflect opinions or policy of the Environmental Protection Agency.

Thank you!