Climate change impacts on thermal characteristics of freshwater fish habitats in a regulated river system

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Abstract

River temperature is projected to increase in the southeastern United States (SEUS) due to climate change, exacerbating the invasion of warm-water species and reducing suitable habitats for cold- and cool-water species. However, the response of river thermal regimes to climate change is also influenced by human activities, especially dam construction and operation. Large dams impound deep reservoirs, expand water surface area and prolong water residence time, modifying the interaction of surface meteorology with river systems. During warm seasons, surface energy fluxes can only heat the top layer (epilimnion) in deep reservoirs with bottom layer (hypolimnion) remaining cold. This vertical temperature gradient is called thermal stratification. Cold hypolimnetic releases from stratified reservoirs changes downstream thermal regimes that can expel indigenous warm-water species yet provide an ideal habitat for introduced cold-water species. For example, multiple species of trout (Family: Salmonidae) have been introduced to tailwaters downstream of multiple dams operated by the Tennessee Valley Authority, which has become a popular and lucrative recreational fishing location in the SEUS. Previous research has shown that reservoir thermal stratification will be retained under climate change, but stronger surface energy fluxes warm downstream river temperature, suggesting there will be a future decline in cold-water species habitat and a corresponding increase in local warm-water species habitat. In this study, we used a physically-based modeling method to simulate river temperatures, explicitly considering the impact of thermal stratification. The SEUS has a highly regulated river system and diverse freshwater fish species. We mapped the suitable habitats for selected cold-water and warm-water fish species by comparing the simulated river temperature against their physiological constraints. Model experiments were designed to quantify the impacts of dam operation by simulating river temperature for both regulated and unregulated scenarios. Potential ecological consequences under climate change were analyzed through projected changes in river thermal regimes, e.g., shrinking habitats for cold-water species and restoring local warm-water species.

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Southeast United States (SEUS)

#AquaticBiodiversity

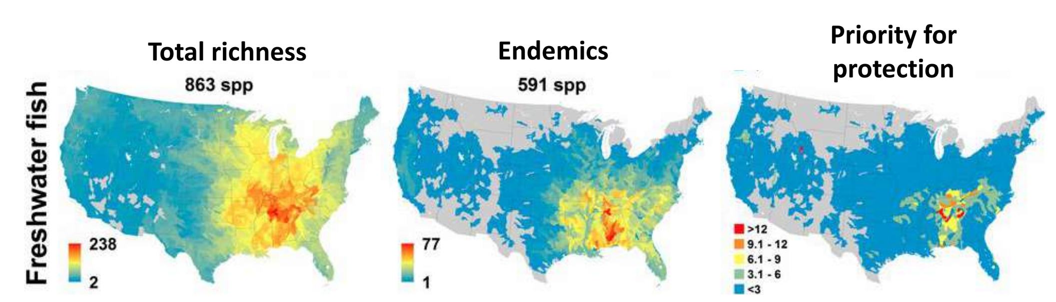


Figure source: Jenkins et al., 2015, PNAS

#Dams

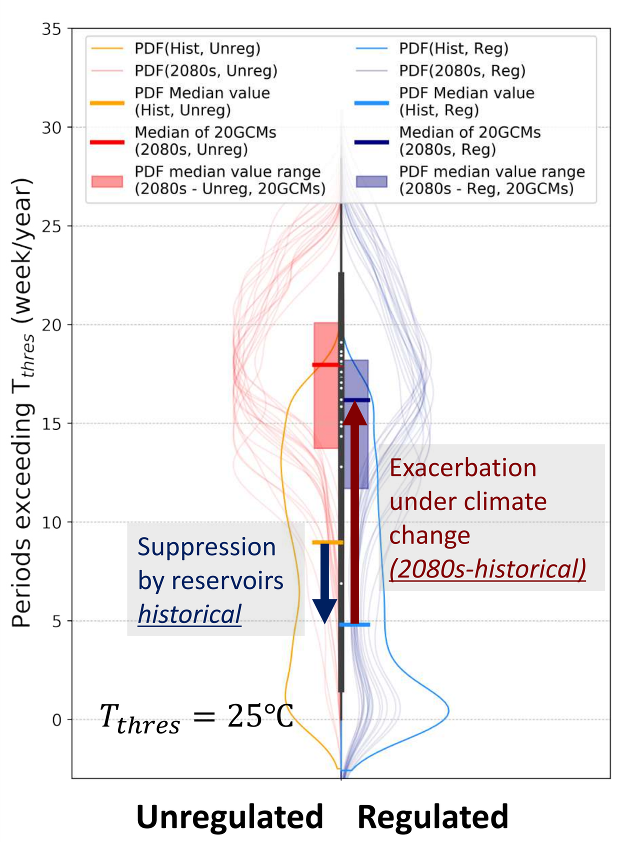
Over ***300*** major dams were constructed during the past century. Cold releases from reservoir hypolimnion change river thermal regimes and hence fish thermal habitats in the SEUS.

#ClimateChange

River temperature is projected to increase 4°C in SEUS by the 2080s under RCP8.5. During warm seasons, reservoirs can still release cold water downstream, but the cooling impacts dissipate faster.

River temperature

One of the leading physical drivers of ecosystem health and species persistence



- A physically-based modeling chain was established to simulate regulated river temperature, explicitly considering thermal stratification (*Cheng et al., Water Resources Research, in revision*)
- Calculate ***heat extremes*** as the periods that exceed a ***threshold temperature*** (T_{thres}), calculated based on the maximum weekly lethal temperature of three trout species)
- Downstream of large reservoirs, cold hypolimnetic releases suppress the extreme heat events.
- Under climate change, heat extremes will be exacerbated

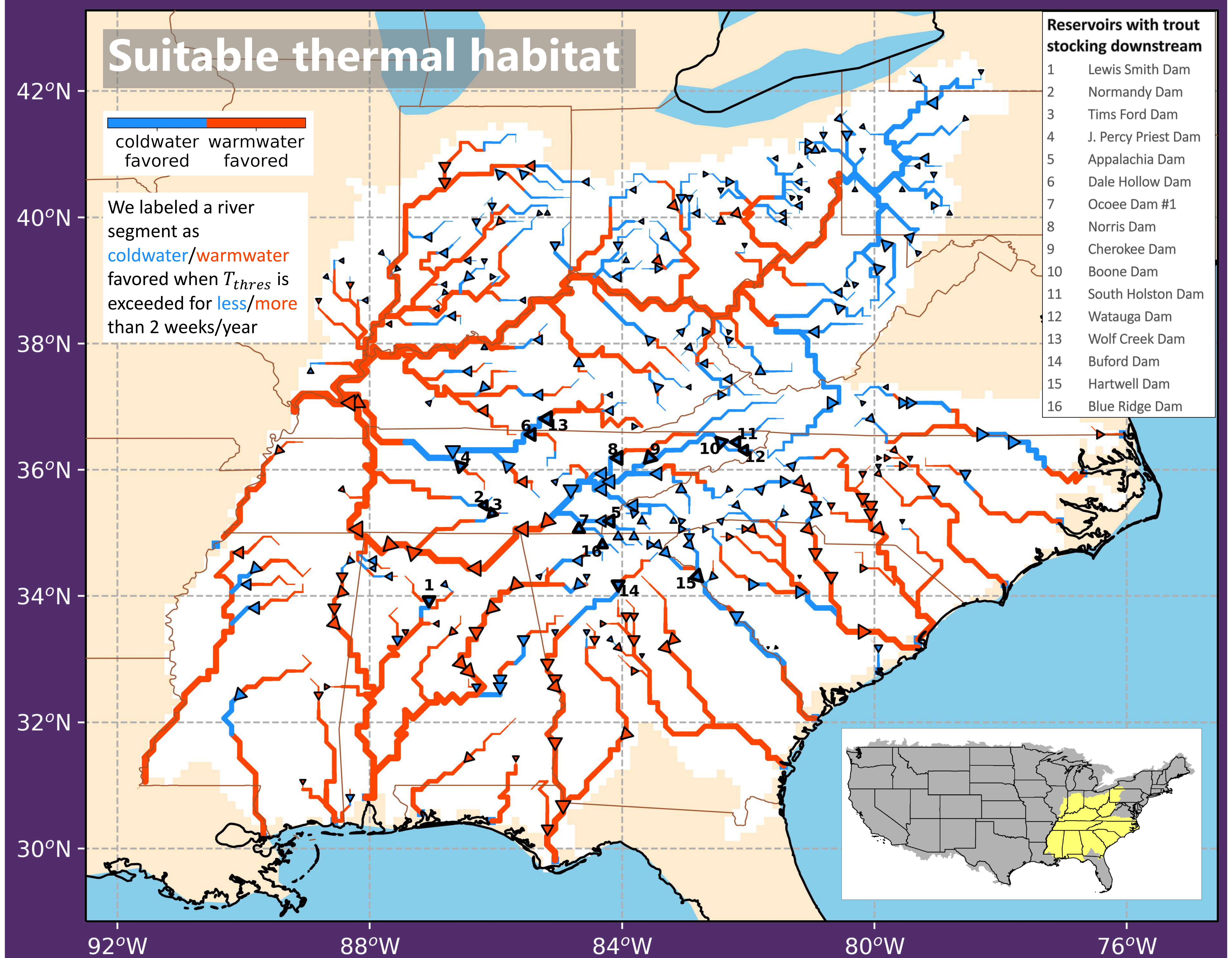
Dam-induced thermal regime alteration forces species redistribution

Pre-dam

- Southeastern United States is a place of great aquatic biodiversity, e.g., ***62*** percent of U.S. fish species and ***91*** percent of U.S. mussel species.
- Most of them are warmwater species and endemic.
- Coldwater species, e.g., rainbow and brown trout, only existed in the Appalachians and small headwater streams.

Post-dam

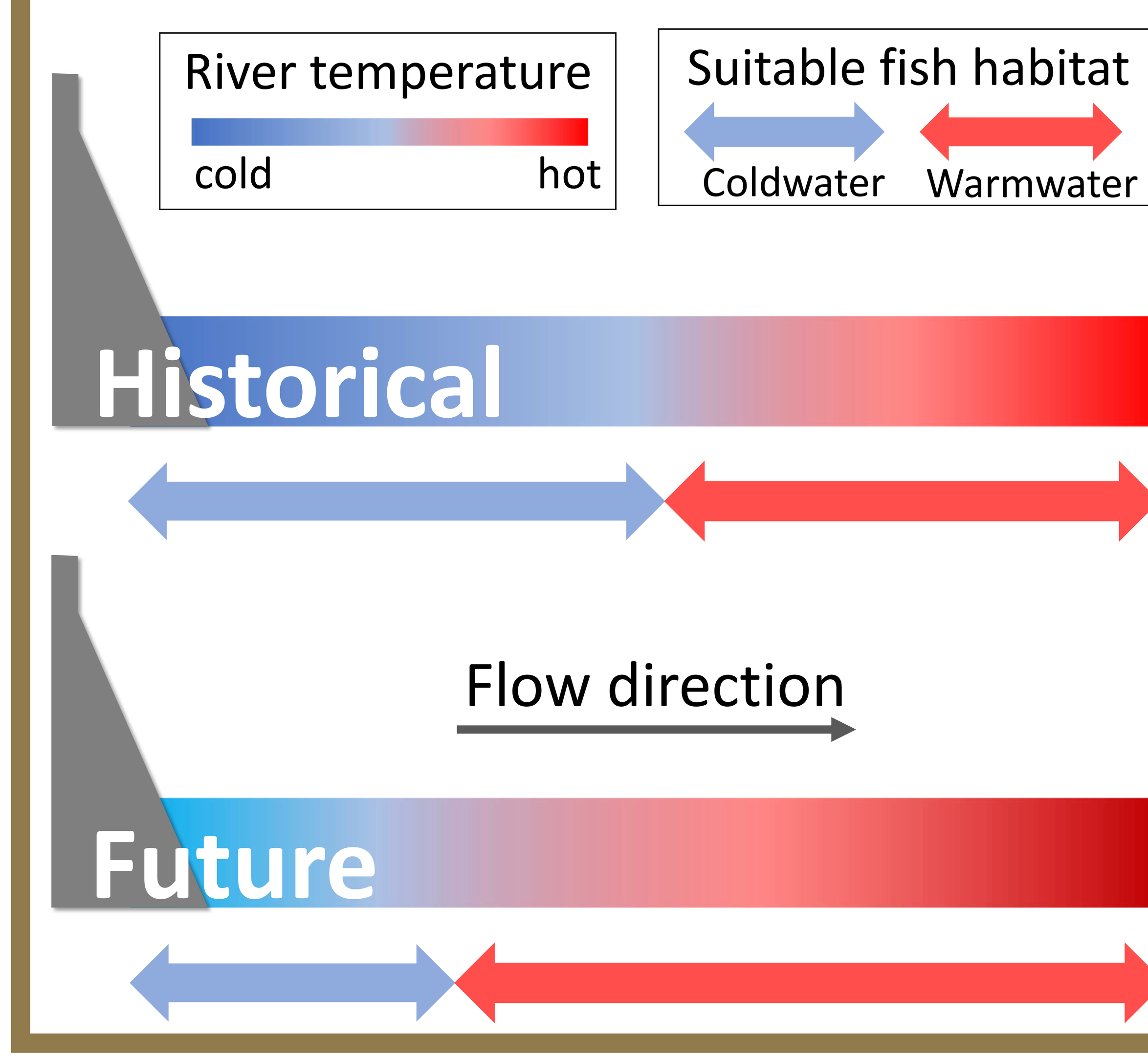
- Downstream of large reservoirs, cold hypolimnetic releases during warm seasons wipe out indigenous warmwater species. *Suitable habitats for warmwater species shrink.*
- However, the cold releases provide an ideal habitat for imported coldwater species downstream of reservoirs. At multiple dams, especially those operated by the Tennessee Valley Authority, trout are hatched and stocked downstream, bringing in significant economic benefits.



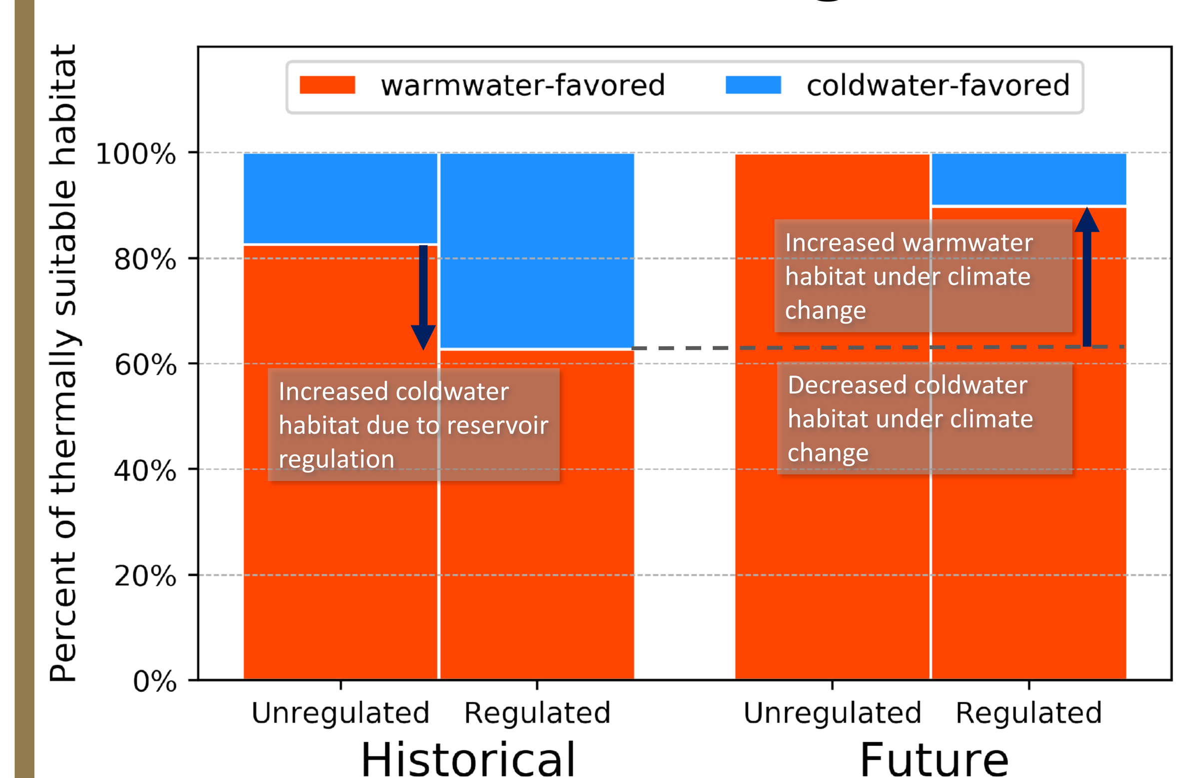
Main Takeaway

- In the SEUS, cold hypolimnetic releases from thermally stratified reservoirs provide an ideal habitat downstream of reservoirs for imported coldwater fish species, i.e., trout.
- Under climate change, as river temperature increases, suitable habitat for the lucrative and recreational trout fishing will shrink while suitable habitat for indigenous warmwater fish species will increase, which might help restore the freshwater biodiversity in the SEUS.

Projected change in fish thermal habitats



Decreasing trout habitat under climate change



- Historically, reservoirs in the SEUS convert 20% of regulated river segments from warmwater to coldwater favored.
- Under climate change, as river temperature increases, suitable habitat for coldwater species, i.e., trout, decreases from 37% to 10% while suitable habitat for warmwater species increases by 27%.

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