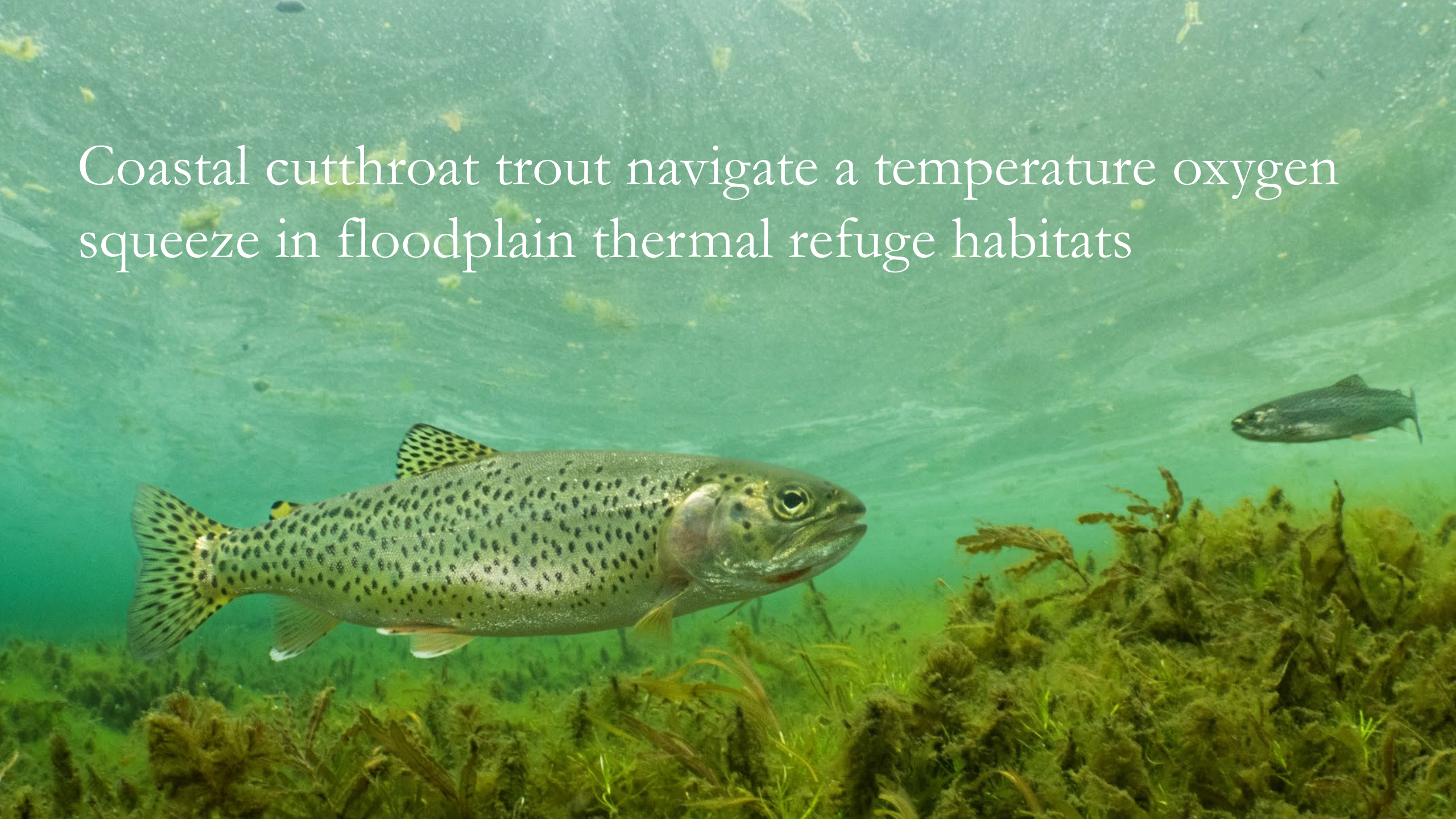
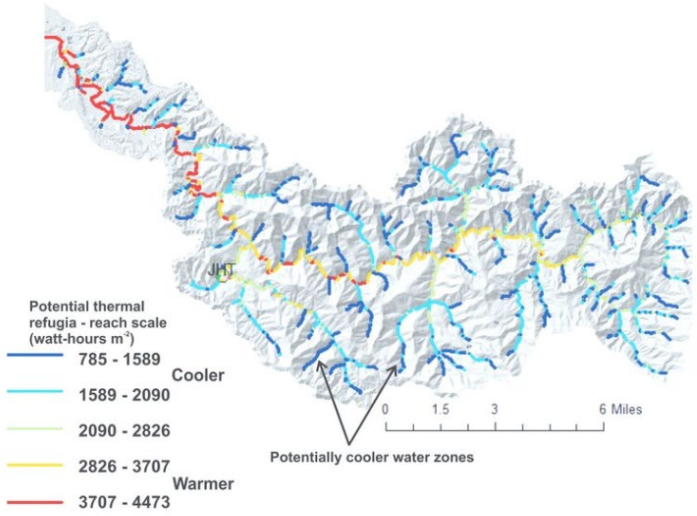
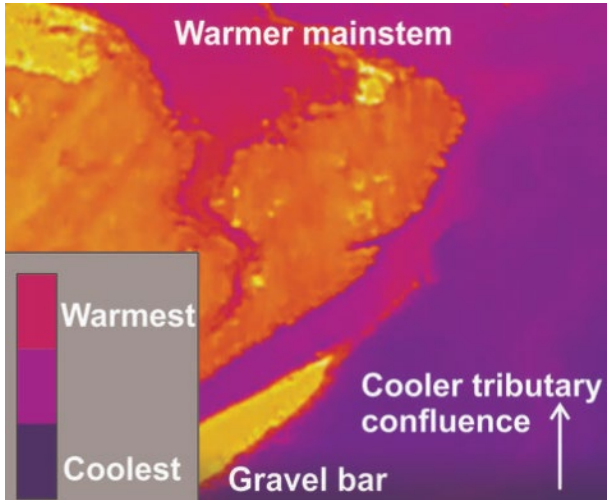
Coastal cutthroat trout navigate a temperature oxygen squeeze in floodplain thermal refuge habitats



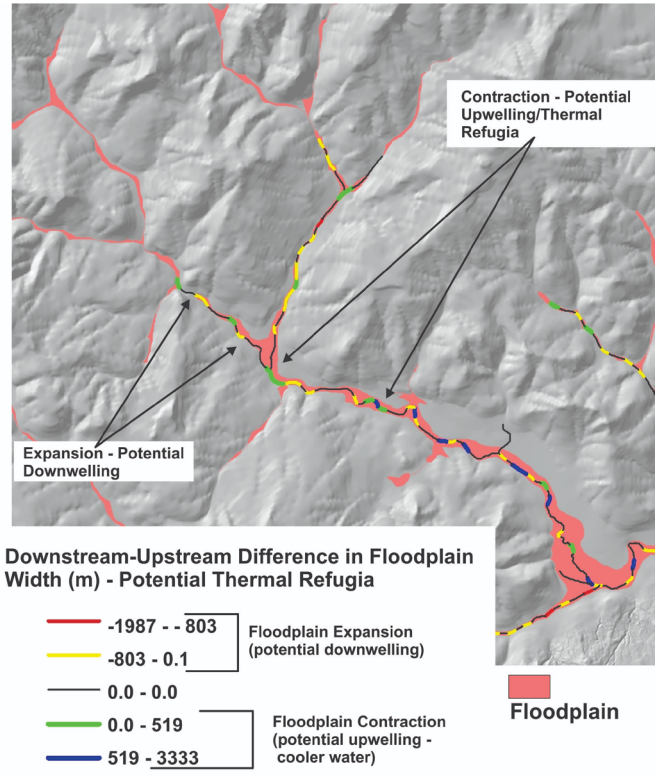
Tributary/stream-reach scale



Tributary confluence



Valley/floodplain upwelling

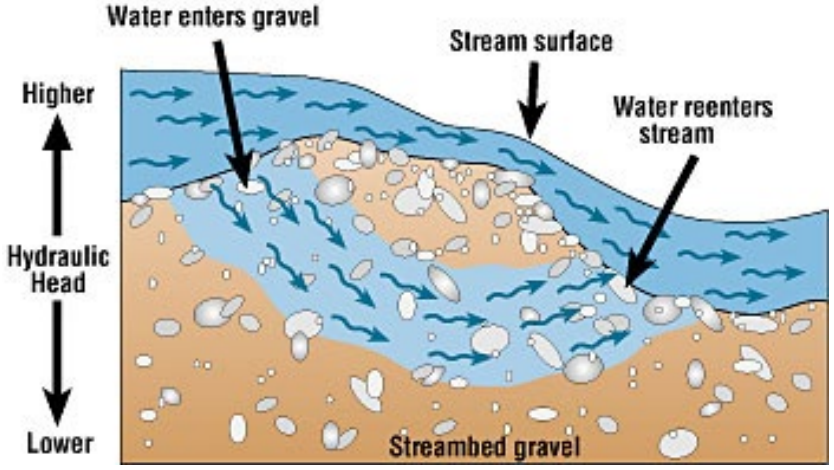


Terrainworks.com

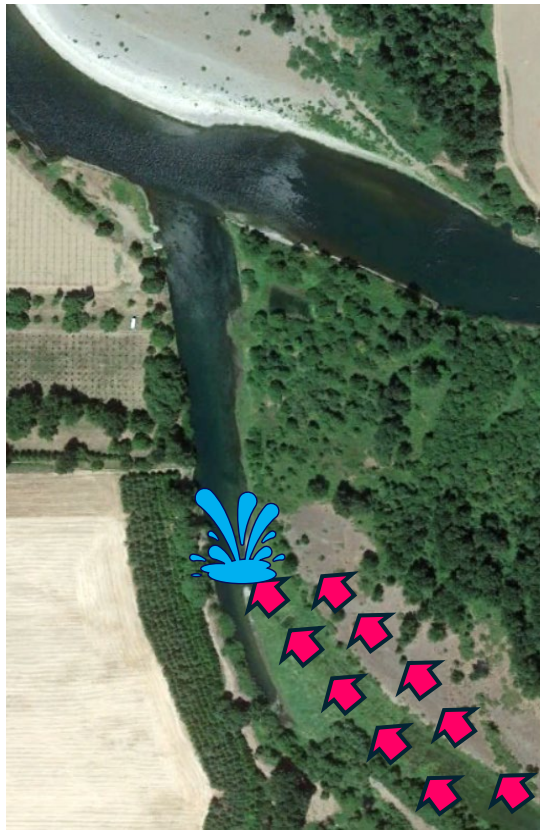
EPA **Primer for Identifying Cold-Water Refuges to Protect and Restore Thermal Diversity in Riverine Landscapes**

Torgersen, Ebersole, and Keenan, USEPA, 2012

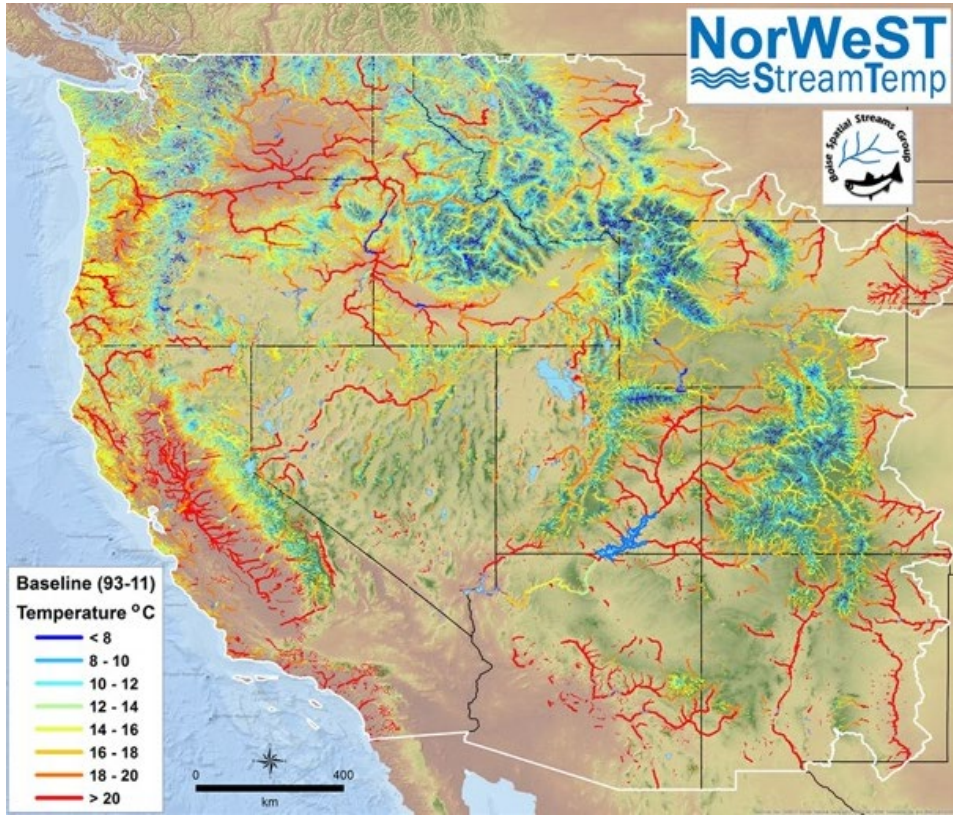
Hyporheic upwelling



naturemappingfoundation.org

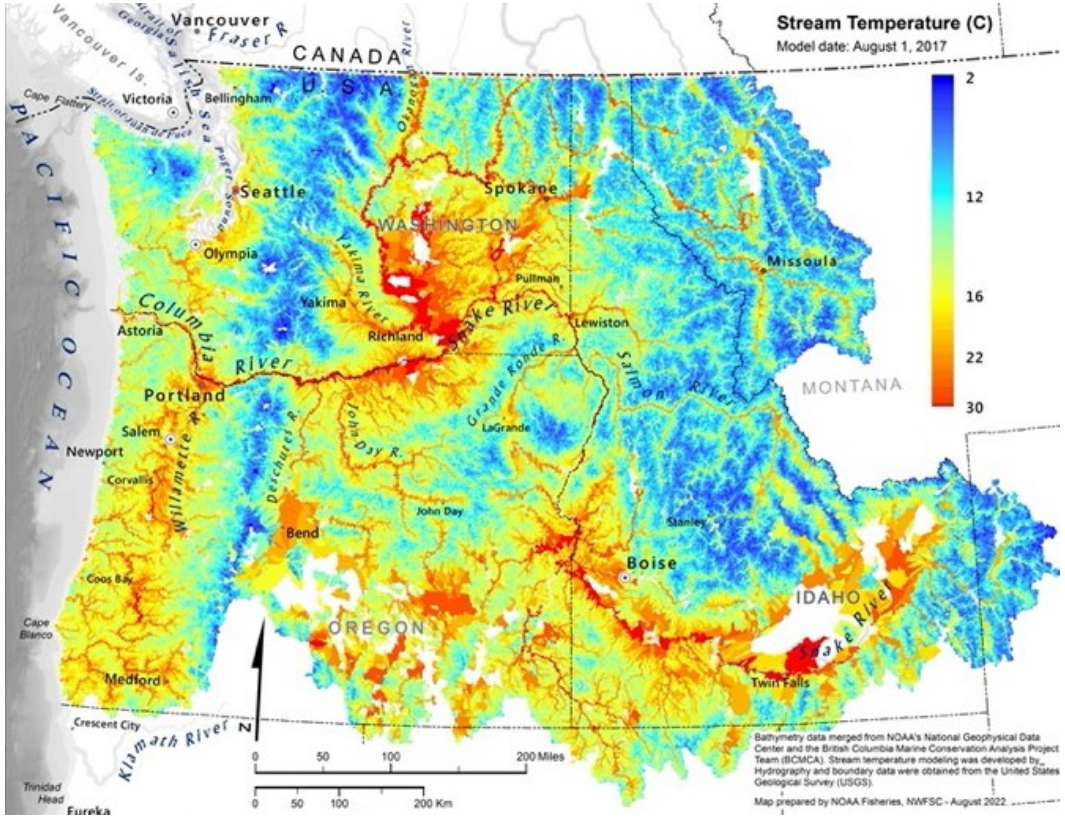


Spatial resolution 1-km



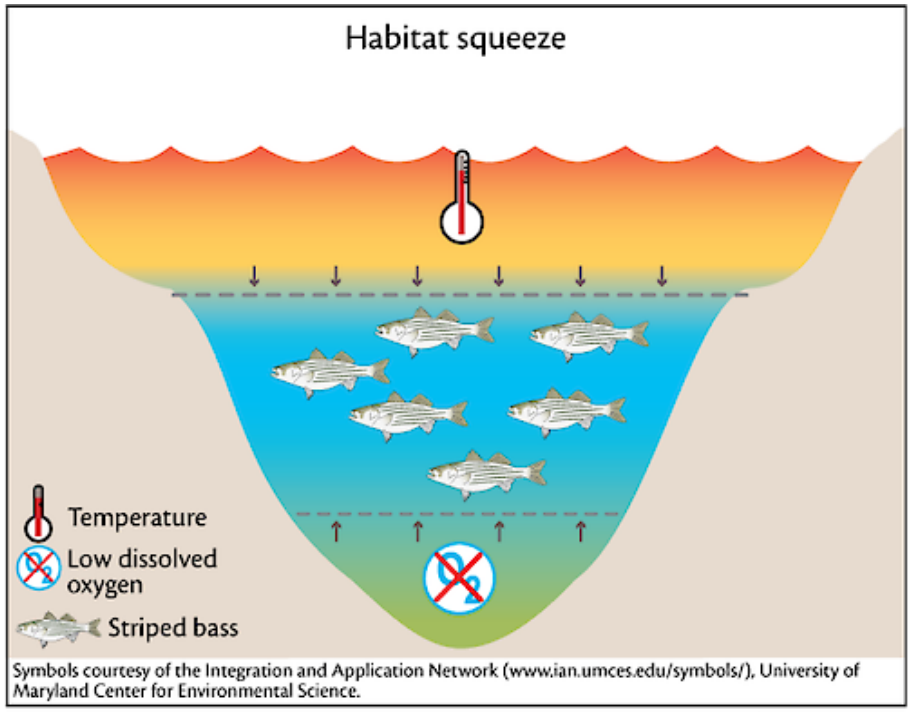
Isaak et al. 2017
Water Resources Research

Spatial resolution ~2-km

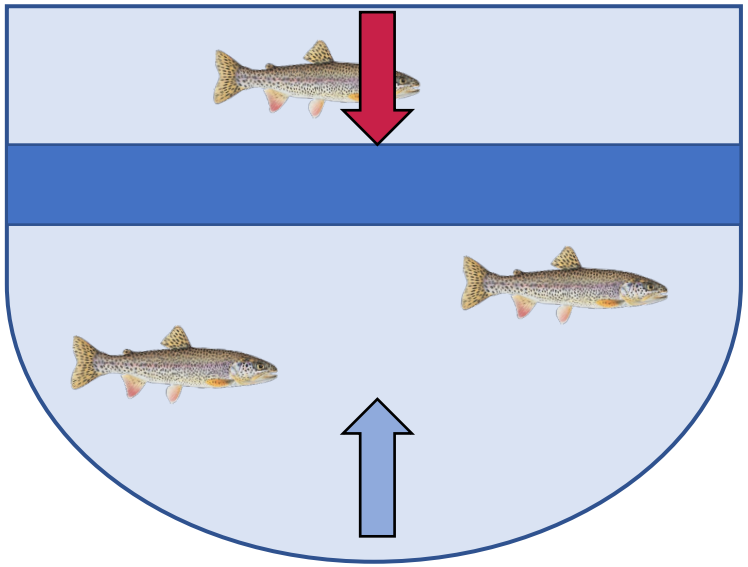


Siegel et al. 2023
Freshwater Science

Temperature oxygen squeeze



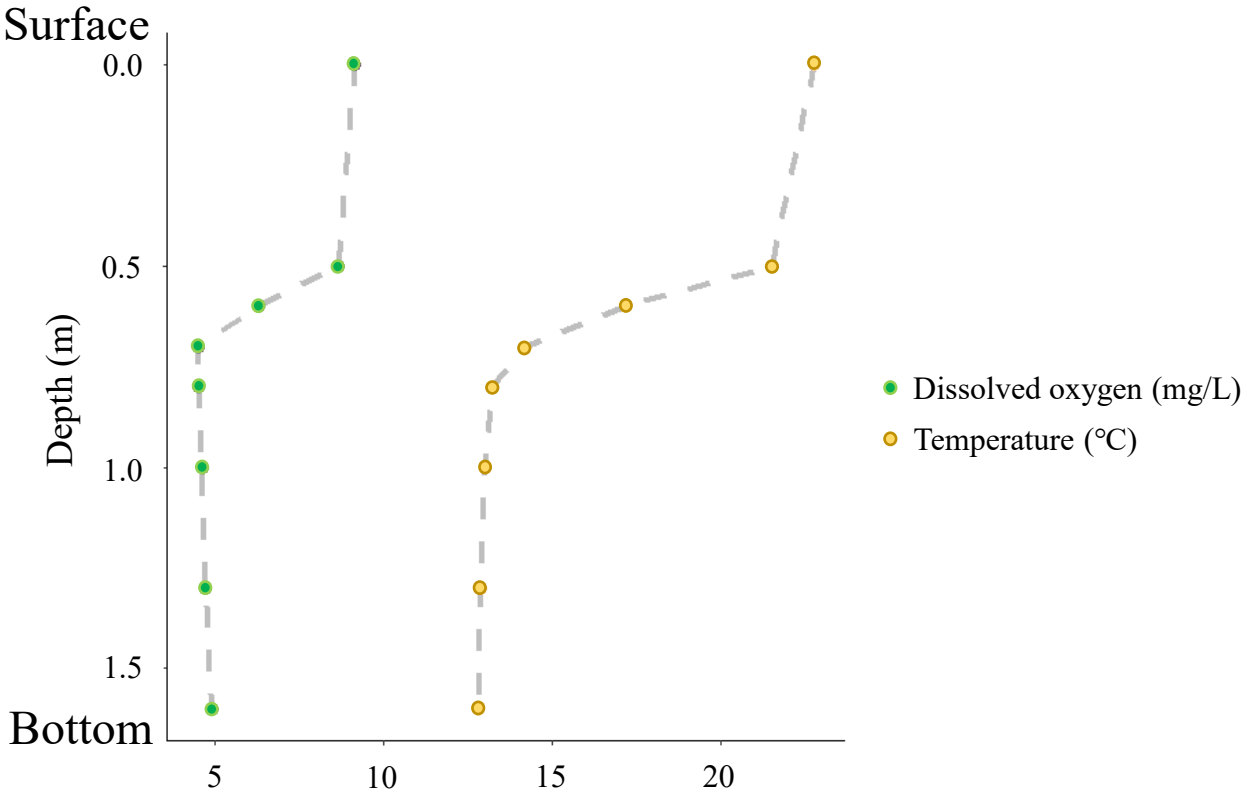
Conceptual diagram illustrating how change in a water source's oxygen and tempature can restrict the habitat of species.
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Ecocheck

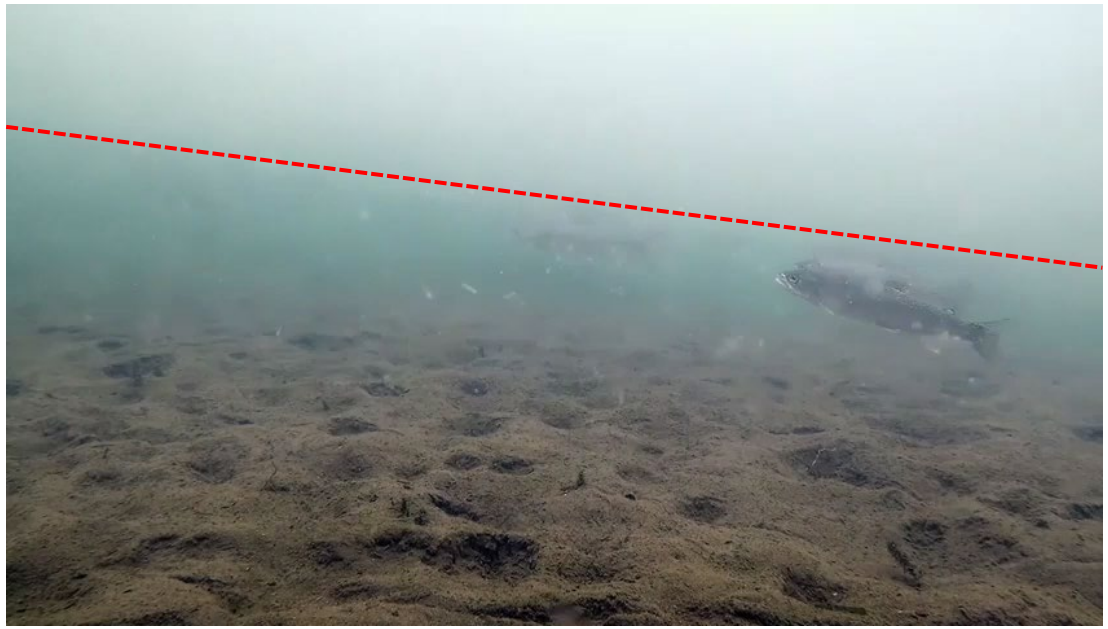


Transactions of the American Fisheries Society 114:31–61, 1985

Striped Bass, Temperature, and Dissolved Oxygen: A Speculative Hypothesis for Environmental Risk[1,2]

CHARLES C. COUTANT



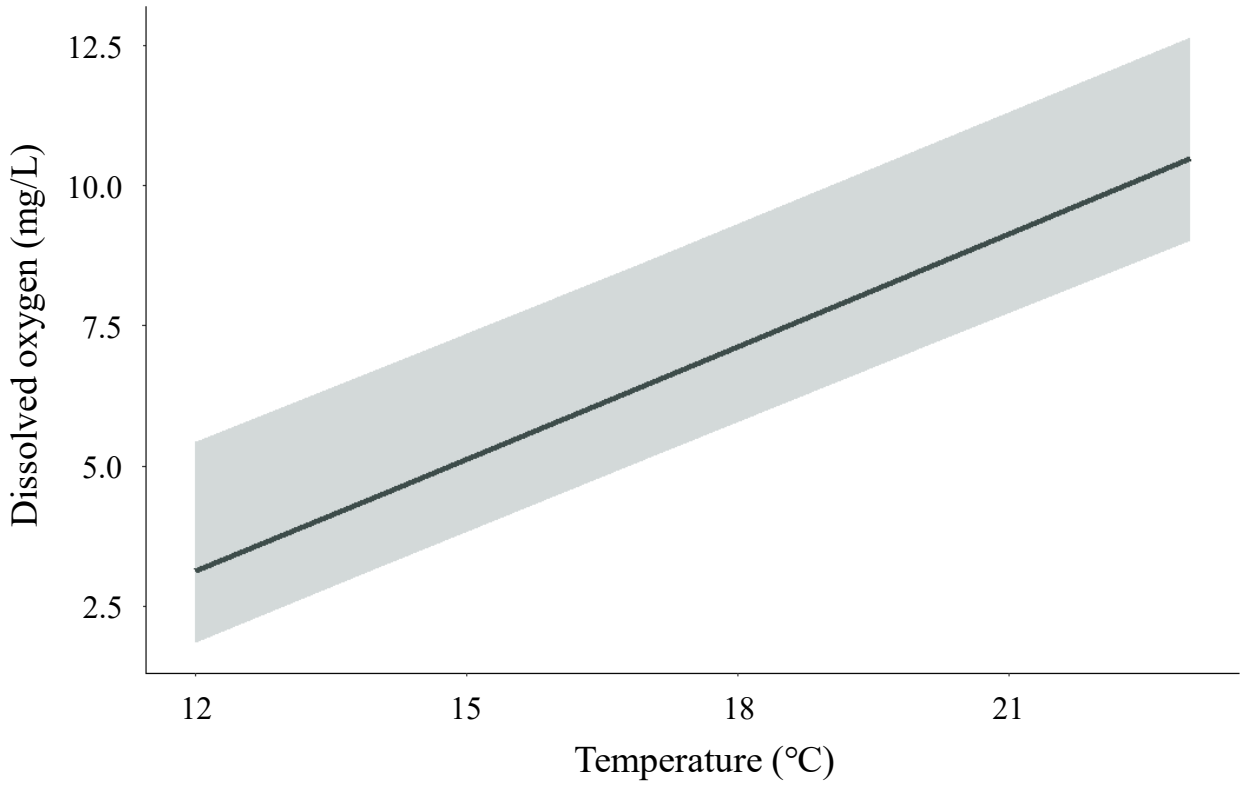


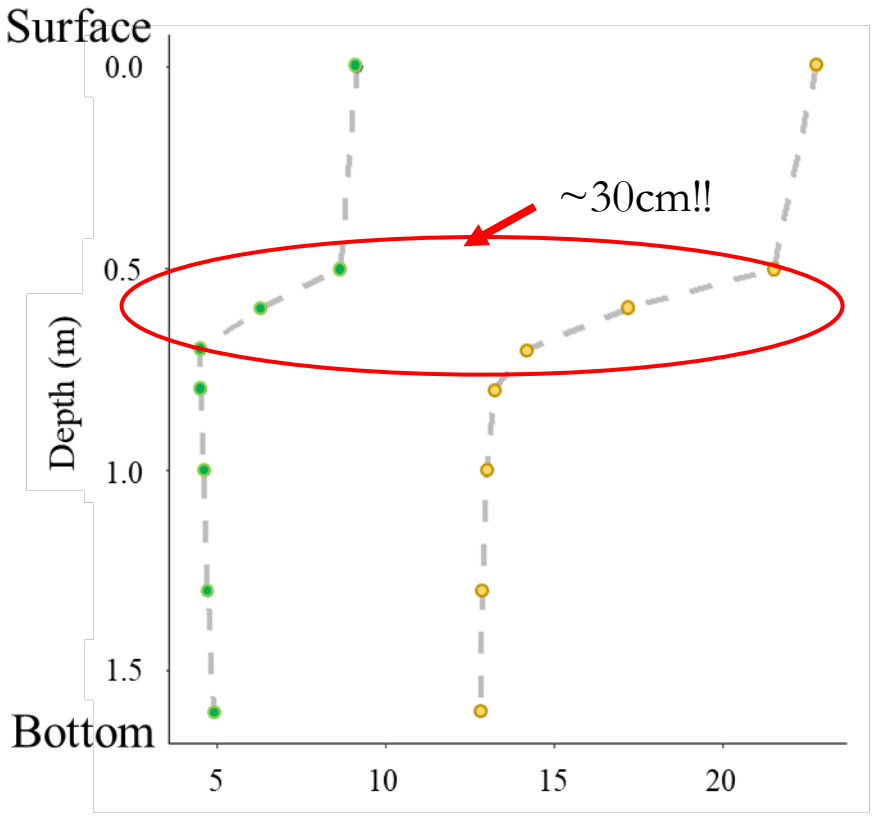
RESEARCH ARTICLE

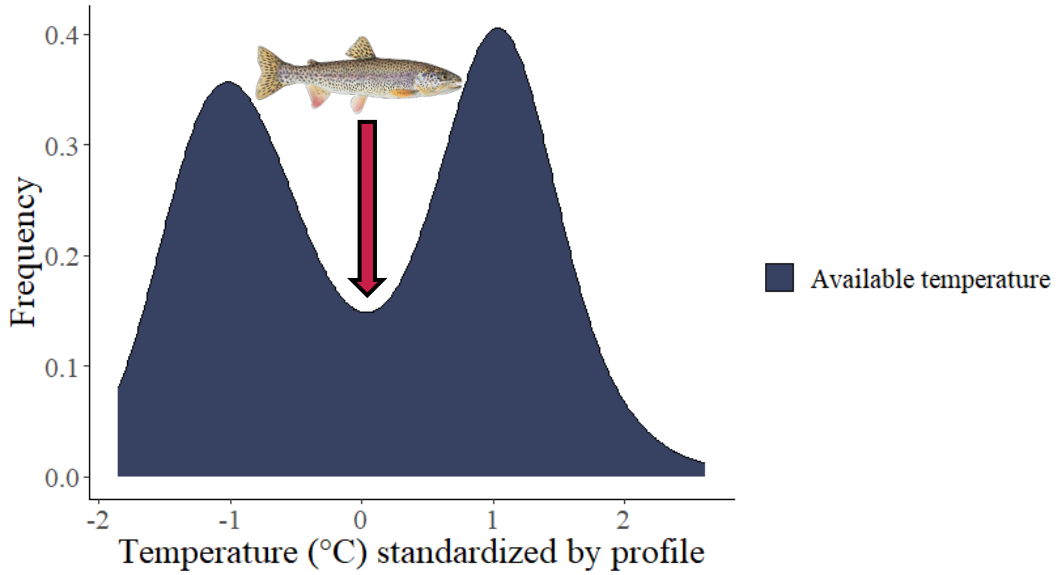
AMERICAN WATER RESOURCES ASSOCIATION JAWRA JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

Novel dimensionless index for physically based assessment of thermal refugia characterizes off-channel habitat on gravel bed river

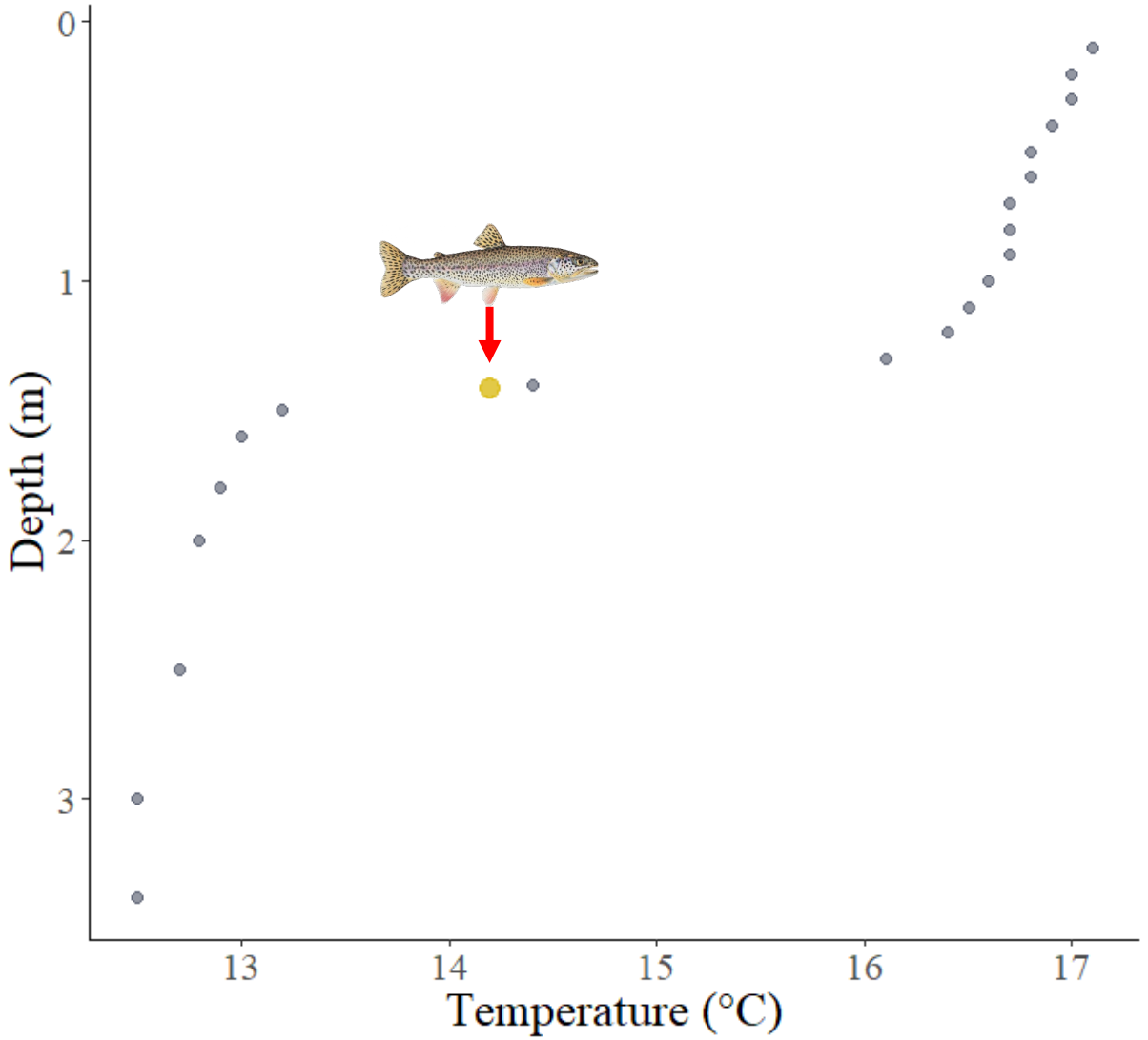
Carolyn E. Gombert[1] | Stephen T. Lancaster[2] | Gordon E. Grant[3] | Rebecca L. Flitcroft[3]

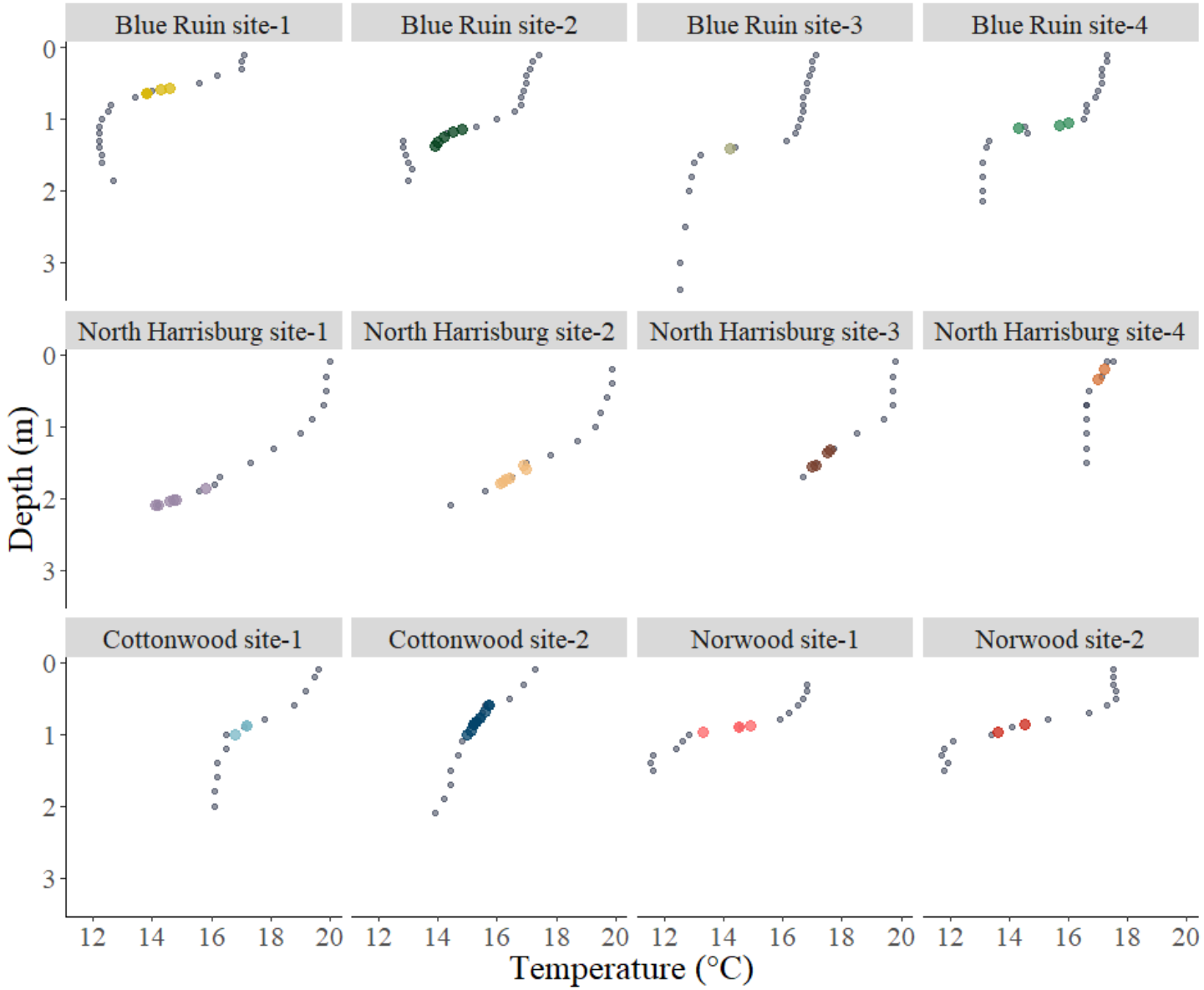

Dissolved oxygen (mg/L)
12.5
10.0
7.5
5.0
2.5
12
15
18
21
Temperature (°C)

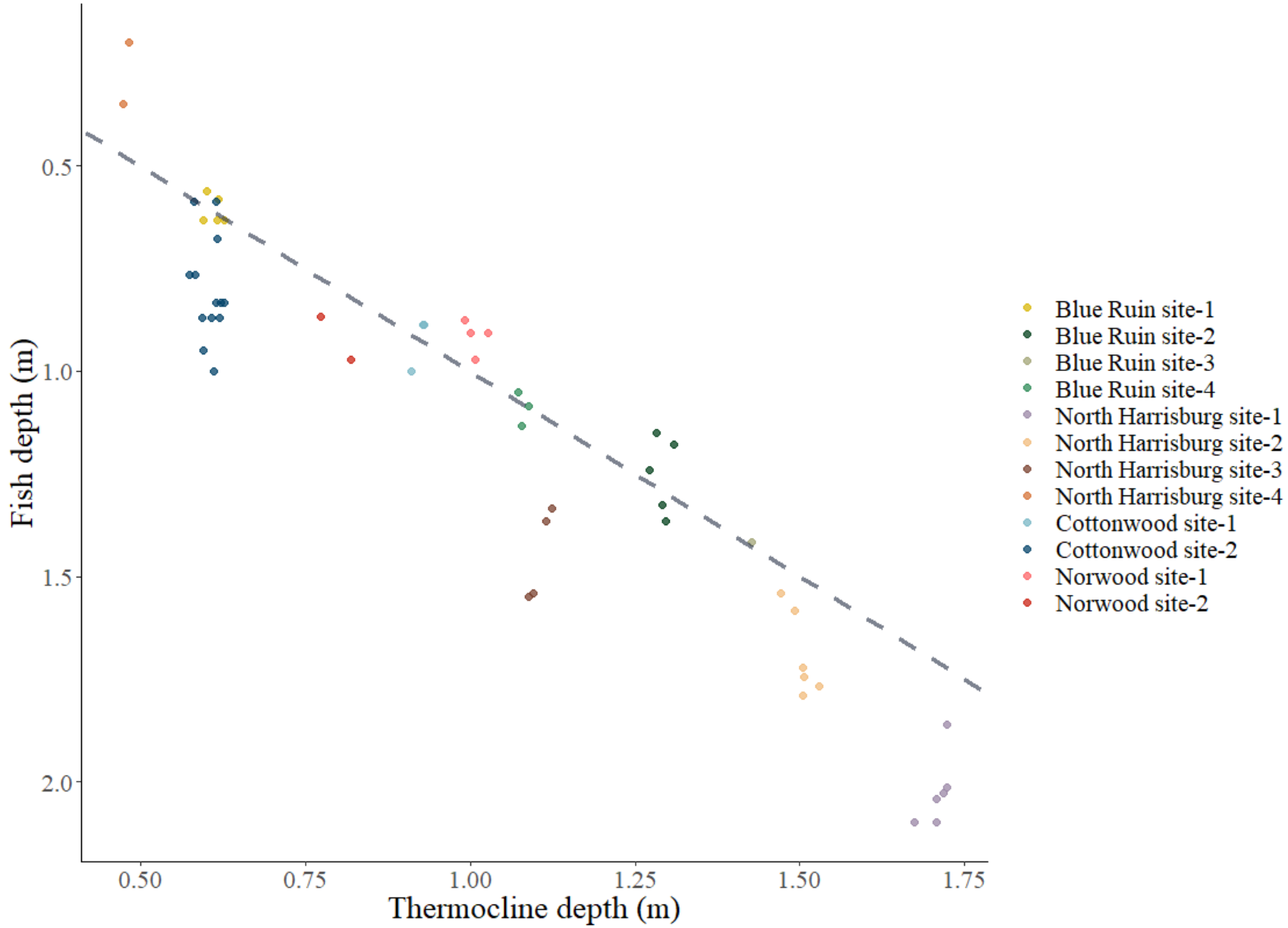

Surface
0.0
0.5
1.0
1.5
Bottom
Depth (m)
~30cm!!
5
10
15
20
Dissolved oxygen (mg/L)
Temperature (°C)


0.4
0.3
0.2
0.1
0.0
Frequency
-2
-1
0
1
2
Temperature (°C) standardized by profile
Available temperature

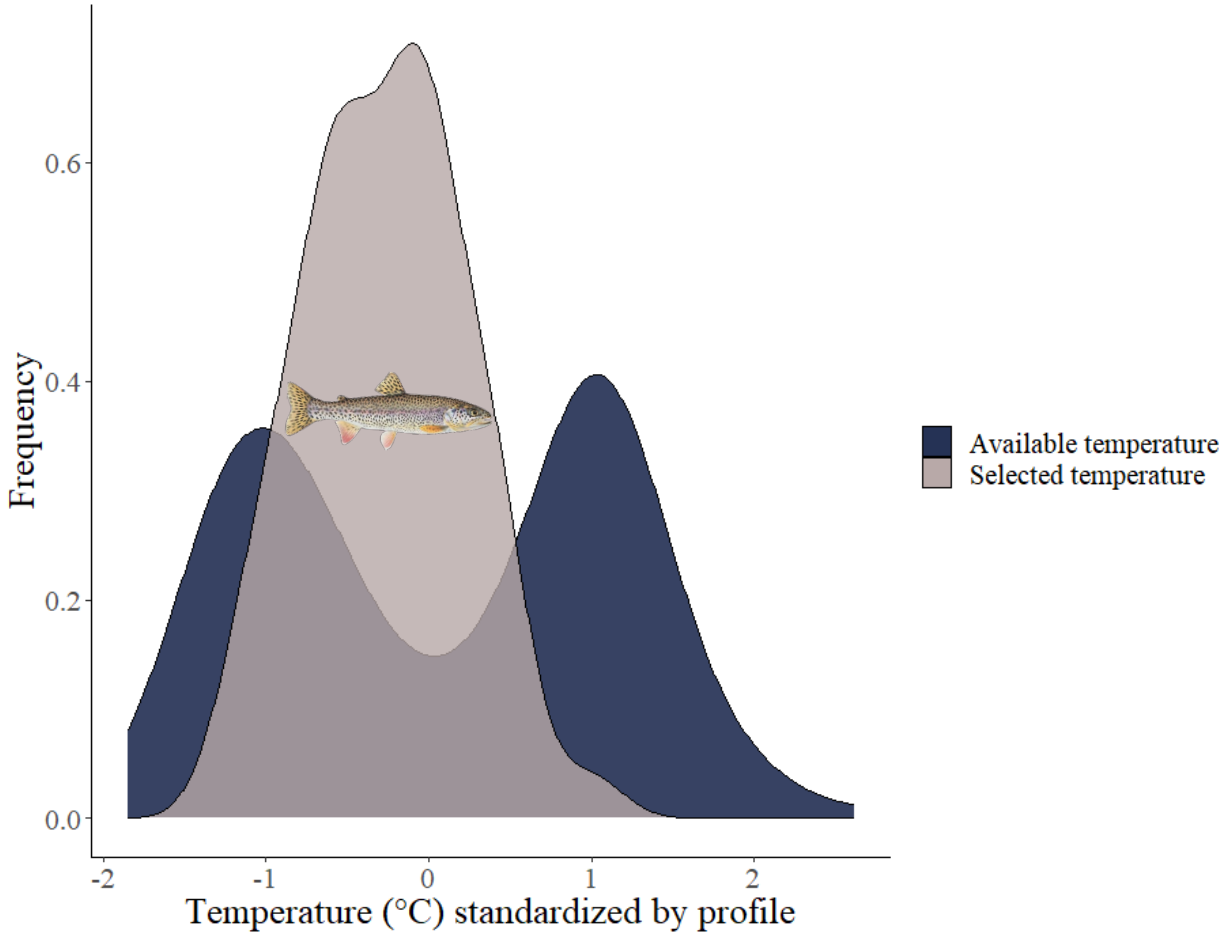
The boat-shock-meat-probe method


0
1
2
3
Depth (m)
13
14
15
16
17
Temperature (°C)


Blue Ruin site-1
Blue Ruin site-2
Blue Ruin site-3
Blue Ruin site-4
North Harrisburg site-1
North Harrisburg site-2
North Harrisburg site-3
North Harrisburg site-4
Cottonwood site-1
Cottonwood site-2
Norwood site-1
Norwood site-2
Depth (m)
0
1
2
3
12
14
16
18
20
Temperature (°C)


Fish depth (m)
0.5
1.0
1.5
2.0
0.50
0.75
1.00
1.25
1.50
1.75
Thermocline depth (m)
Blue Ruin site-1
Blue Ruin site-2
Blue Ruin site-3
Blue Ruin site-4
North Harrisburg site-1
North Harrisburg site-2
North Harrisburg site-3
North Harrisburg site-4
Cottonwood site-1
Cottonwood site-2
Norwood site-1
Norwood site-2

A small slice of the alcove offers intermediate T-DO conditions that fish select

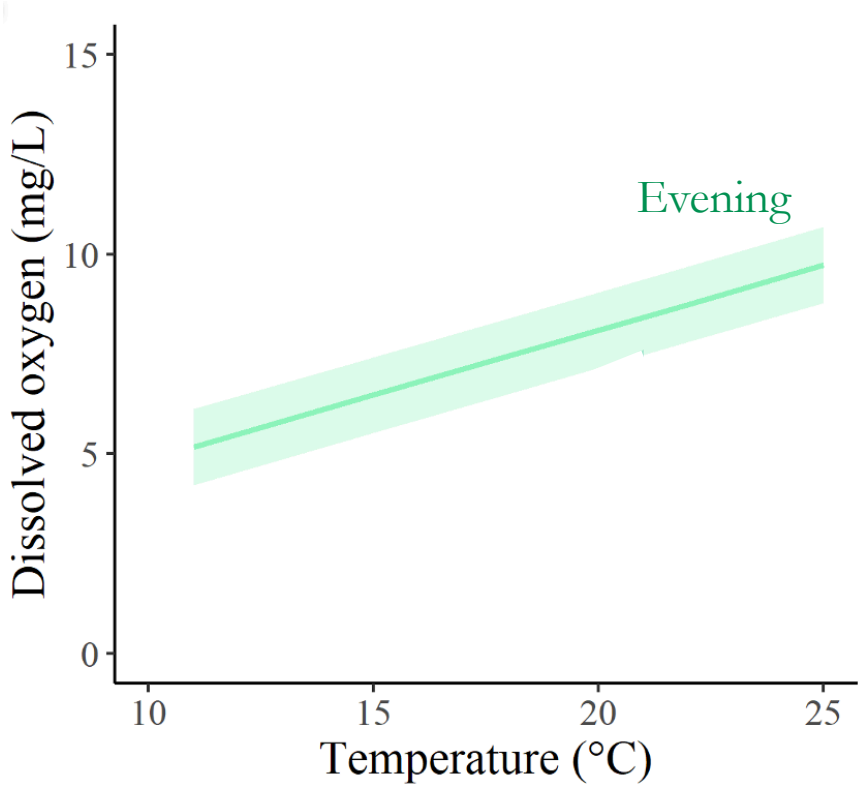


Studying fish behavior provides inference on the useable size of these alcoves.

Total alcove - large
Portion with cool water - small
Portion with cool water and high DO - very small

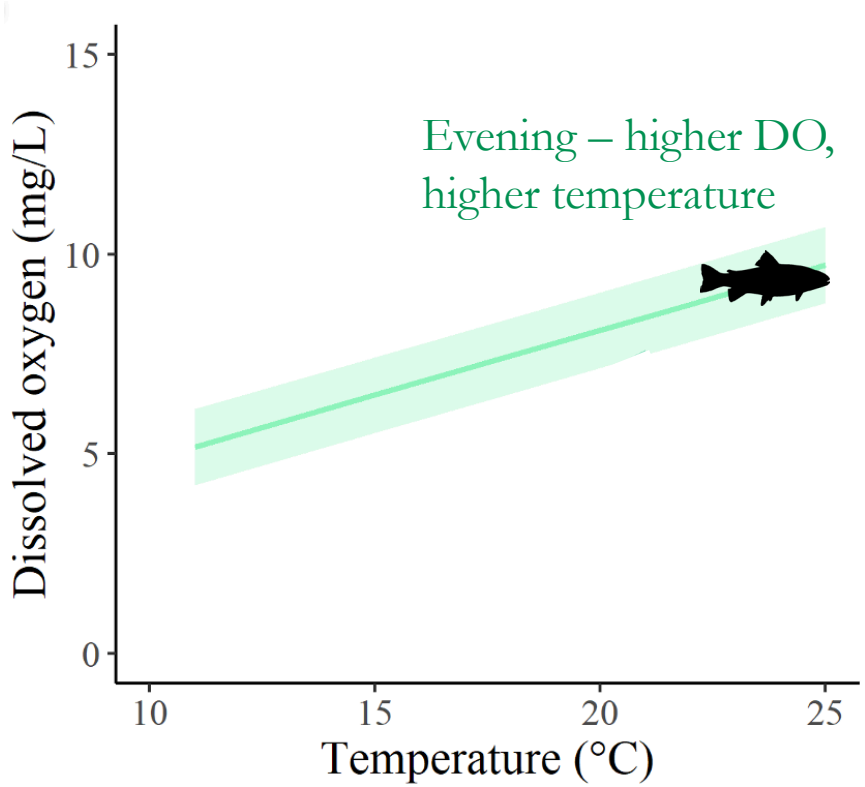
There is a shortcoming of our work so far – we've only sampled during the day…

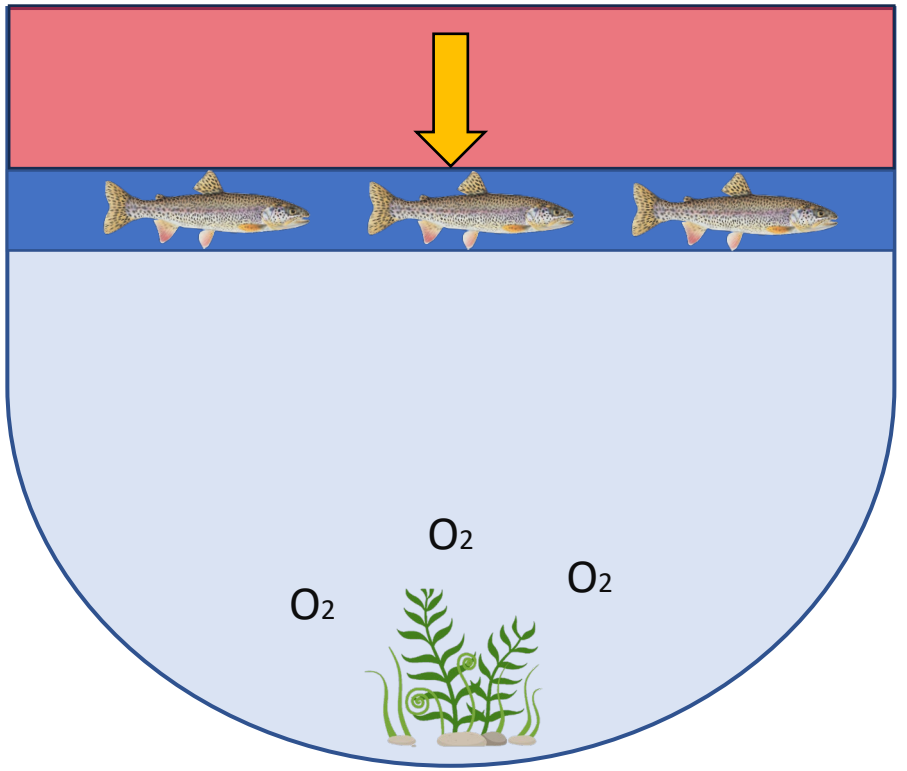
Diel variation: stressors occur asynchronously

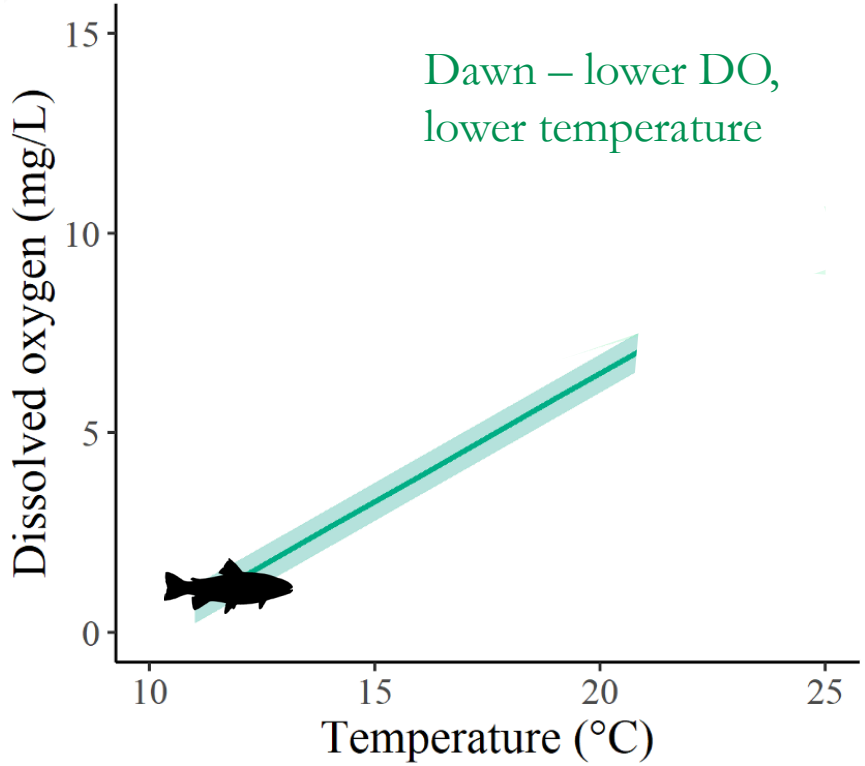


Stressors are asynchronous for fish

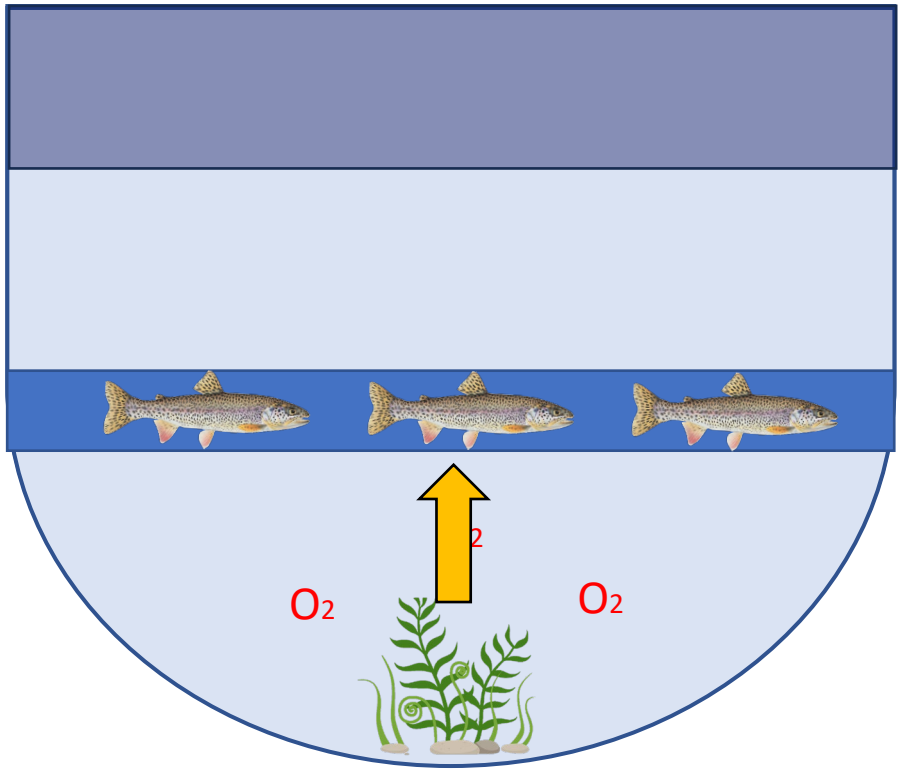
- Night
  - (+) lower temperature
  - (-) lower DO
- Day
  - (-) higher temperature
  - (+) higher DO
- Constraints are toggling – asynchrony softens trade off
- Fish can navigate these trade offs by moving
  - Fine scale diel vertical movement (DVM)

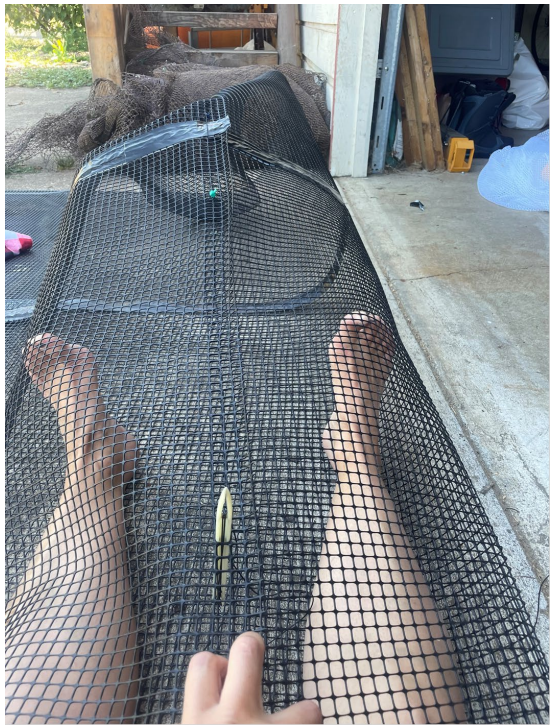

Evening – higher DO, higher temperature
Dissolved oxygen (mg/L)
15
10
5
0
10
15
20
25
Temperature (°C)

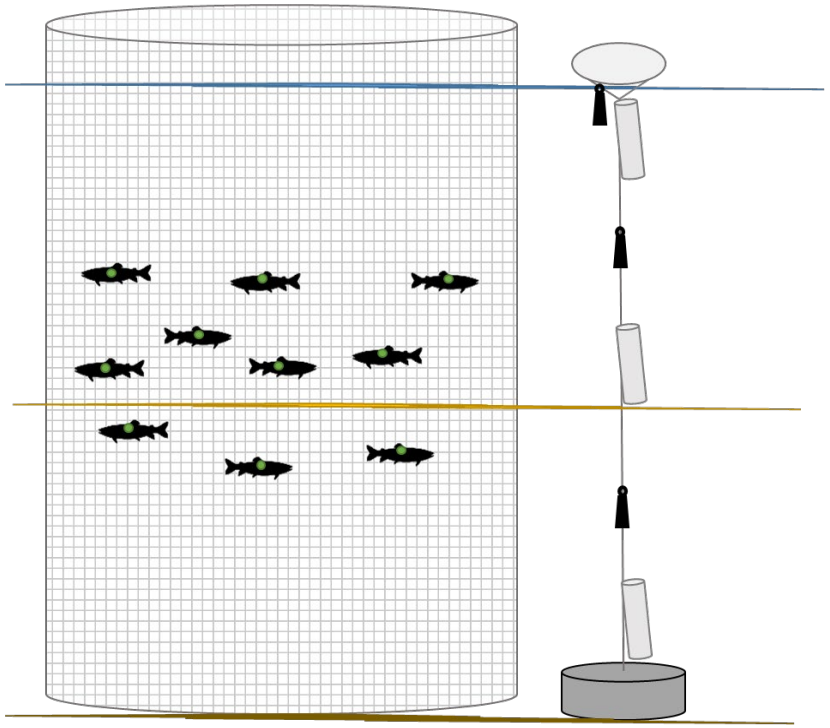

O2
O2
O2

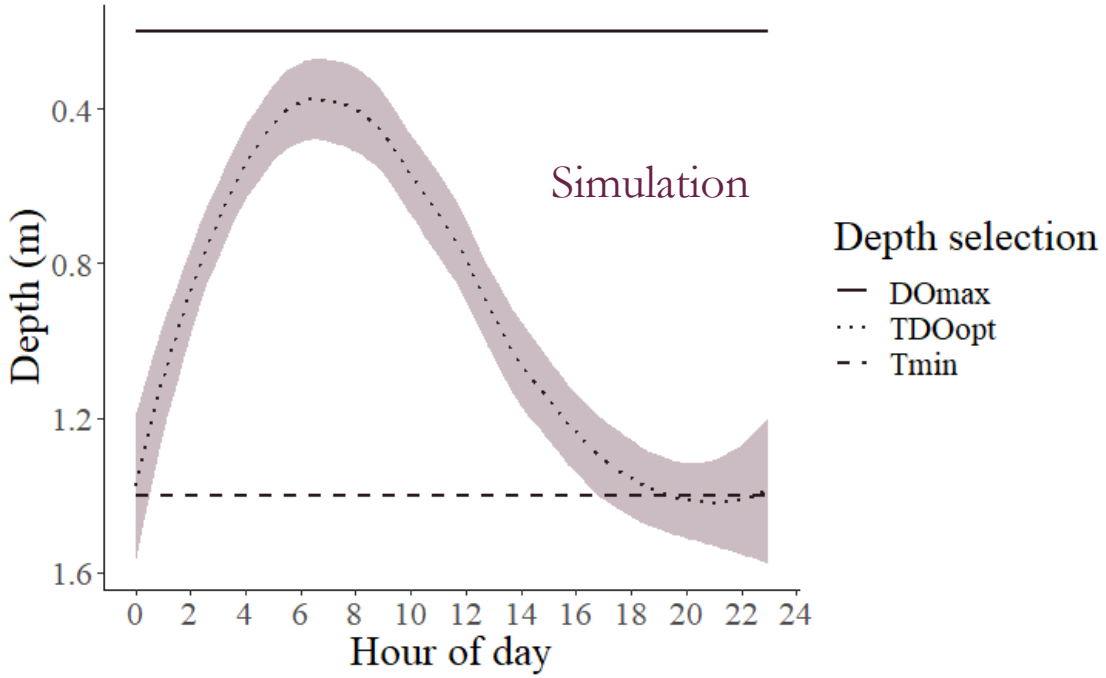


Dawn – lower DO, lower temperature

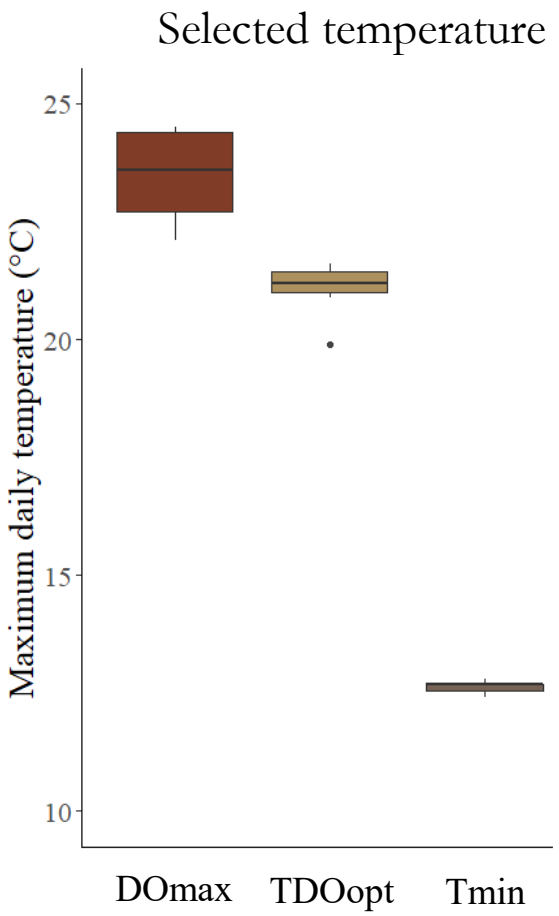


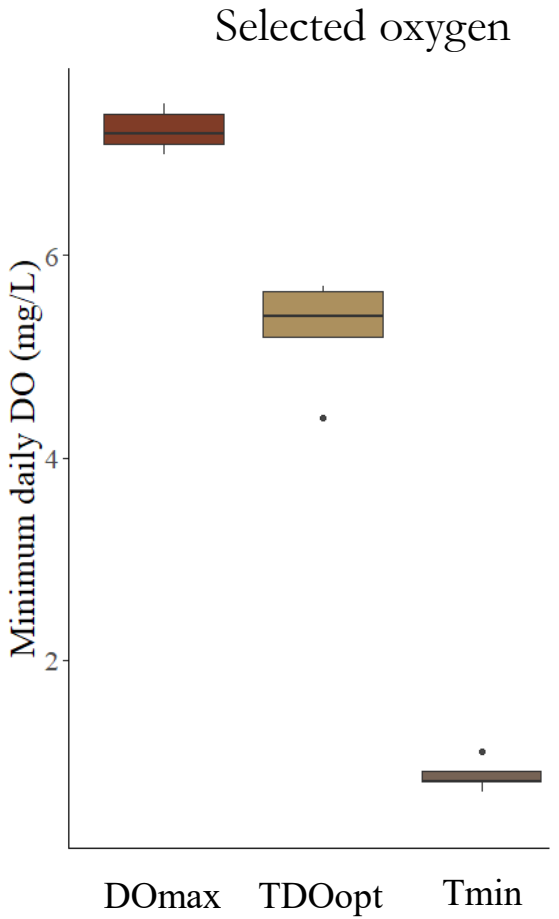





Simulation
Depth (m)
0.4
0.8
1.2
1.6
0 2 4 6 8 10 12 14 16 18 20 22 24
Hour of day
Depth selection
DOmax
TDOopt
Tmin

Tagged fish incur low DO in exchange for cold temperatures





Refuges formed by hyporheic upwelling can generate a temperature-oxygen squeeze

In stratified alcoves, intermediate conditions in temperature and oxygen existed in a relatively small boundary layer spanning as little as ~30cm of the water column.

Fish body temperatures indicate limited vertical use of habitat

Oxygen constraints on thermal refuge use may be a blind spot for climate adaptation planning of cold-water fishes – oxygen data is limited compared to temperature data.

Temperature and dissolved oxygen are critical to cold-adapted fishes, and these conditions can vary both spatially and through a 24-hour timeframe

Asynchronous threats of hypoxia and heat stress create a pronounced trade-off for fish, which became more severe at night during the oxygen minimum

Diel vertical migration is an emergent property for fish balancing these dynamic trade-offs