Warming rivers in the Atlantic coast; Is this the end of Atlantic salmon (*Salmo salar*)?

IYS Synthesis symposium

October 5, 2022

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INteractions in **T**omorrow's **E**nvironment **L**aboratory (UNB-INTEL)

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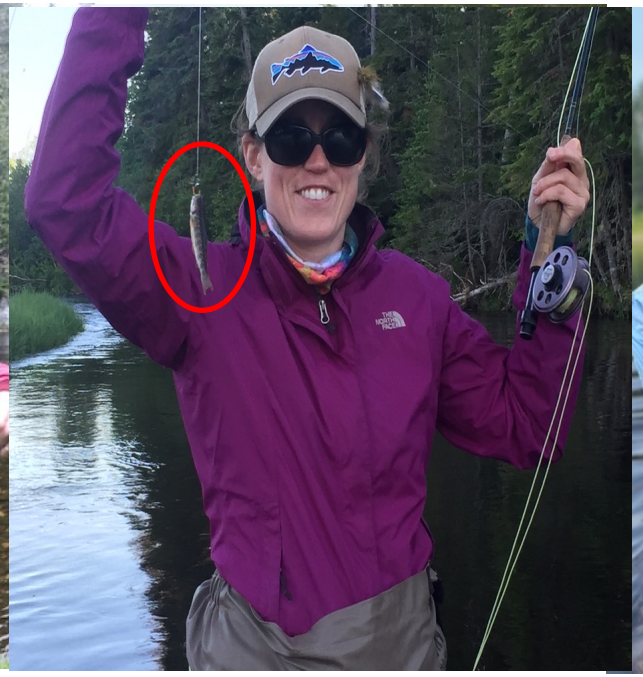
Dr. Cunjak

Dr. Curry



Dr. Corey

Effects on juveniles

Dr. O'Sullivan

Large-scale distributions
Physical habitat minutia
Threshold models

R. Carrow

Adult salmon refugia use

Work conducted in the Cunjak, Curry and then Linnansaari lab over last >15 y

… by people much smarter than the "enablers"

Atlantic salmon in warming water

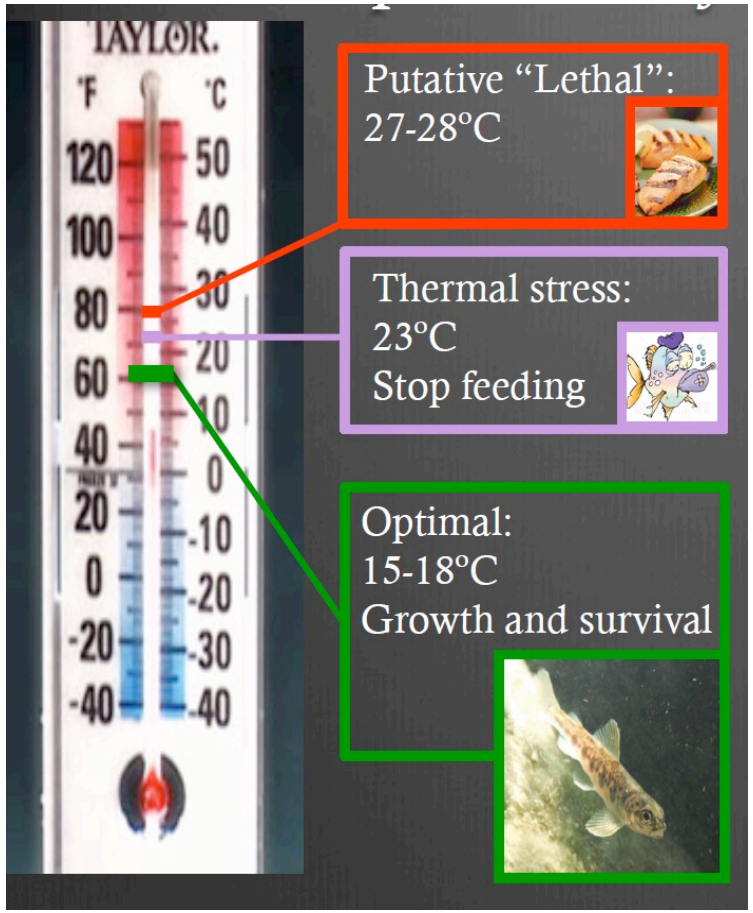
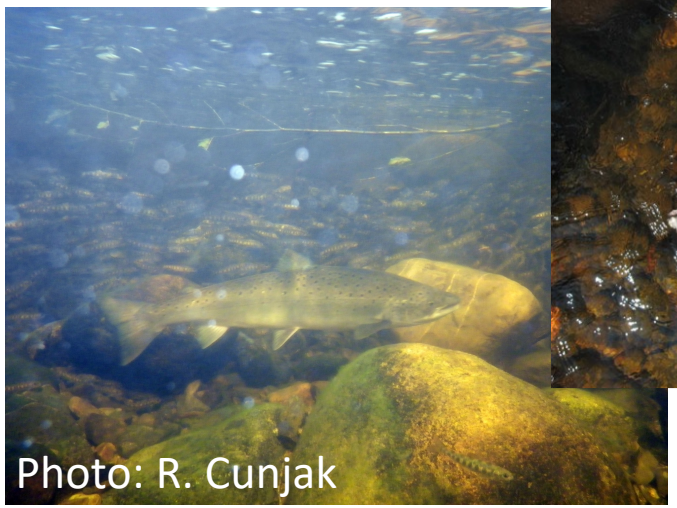


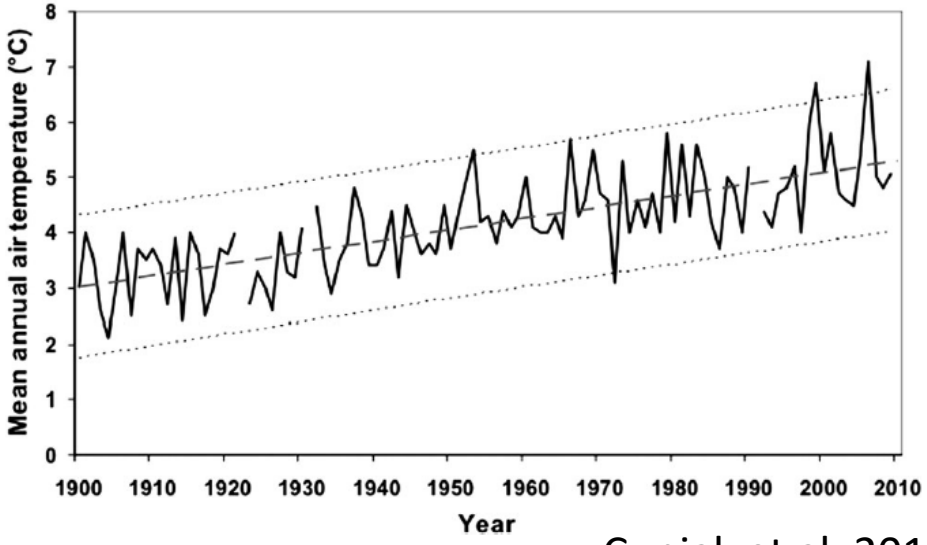
Table 1. Observed onset temperature for behavioral thermoregulation in Atlantic salmon and brook trout (adults and parr) in the Miramichi catchment.

Species	Life stage	Threshold	Source
Atlantic salmon (*Salmo salar*)	Adult	20°C Threshold based on observations in the Miramichi River	R. Carrow and T. Linnansaari (*unpublished data*)
	Parr	23°C Lower boundary at which behavioral thermoregulation has been observed in the Miramichi River	Breau et al. (2007)
		27°C Threshold at which behavioral thermoregulation is almost certain to occur in the Miramichi River	Corey et al. (2020)
Brook trout (*Salvelinus fontinalis*)	Adults and juveniles	20°C Threshold based on observations in the Miramichi River	Wilbur et al. (2020)

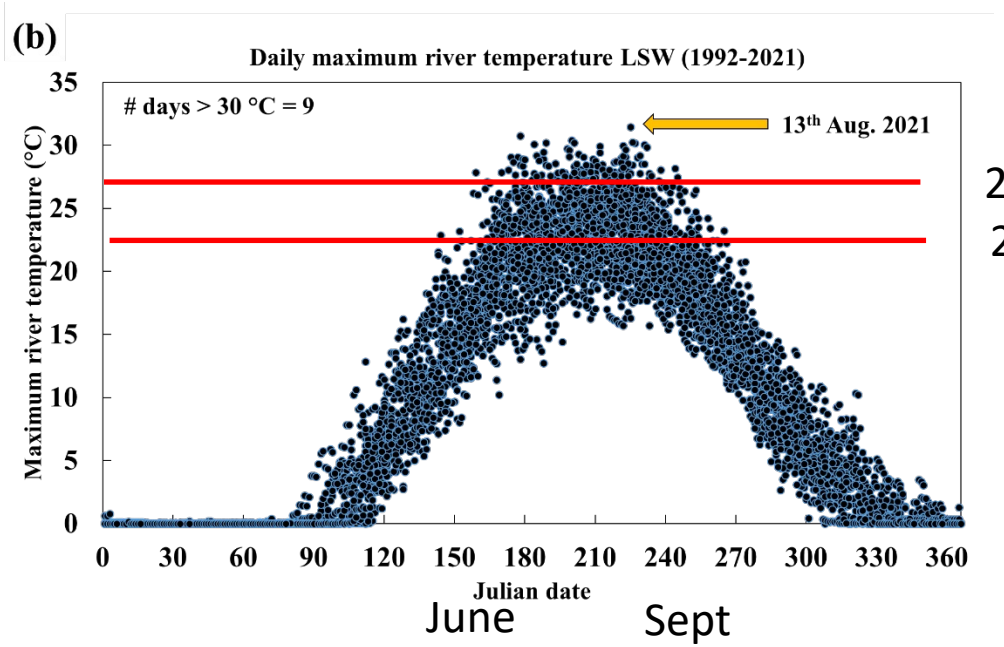
Note: Juvenile Atlantic salmon behavioral thermoregulation is examined for two thermal regimes: >23°C (as per Breau et al. 2007), and >27°C (as per Corey et al. 2020).



Miramichi River, NB, Canada



Cunjak et al. 2013



27 °C

23 °C

June Sept

Data: DFO @ D. Caissie; Graph: A.O. Sullivan

Miramichi River…future for salmon…"big picture"?

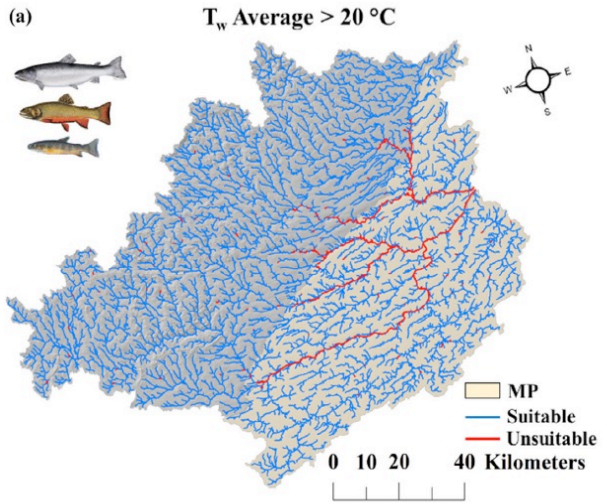
esa ECOSPHERE

FRESHWATER ECOLOGY

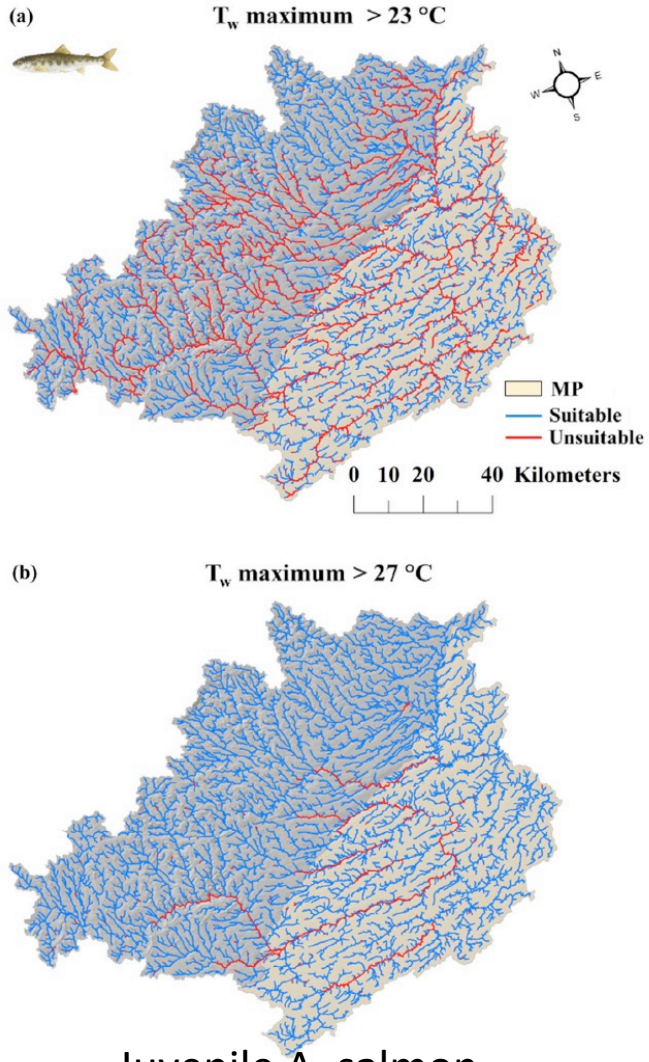
Salmonid thermal habitat contraction in a hydrogeologically complex setting

Antóin M. O'Sullivan[1,2,†], Emily Corey[1,3], Richard A. Cunjak[1,2,3], Tommi Linnansaari[1,2,3] and R. Allen Curry[1,2,3]

- Statistical river network model vs Random forest model
- August max. H2O temps modeled
  - "temporary loss"
- Adult A. salmon: ~ 80 % unsuitable
- Juv. A. salmon:
  - ~ 27.7 % @23 °C unsuitable
  - ~ 4.9 % @ 27 °C unsuitable



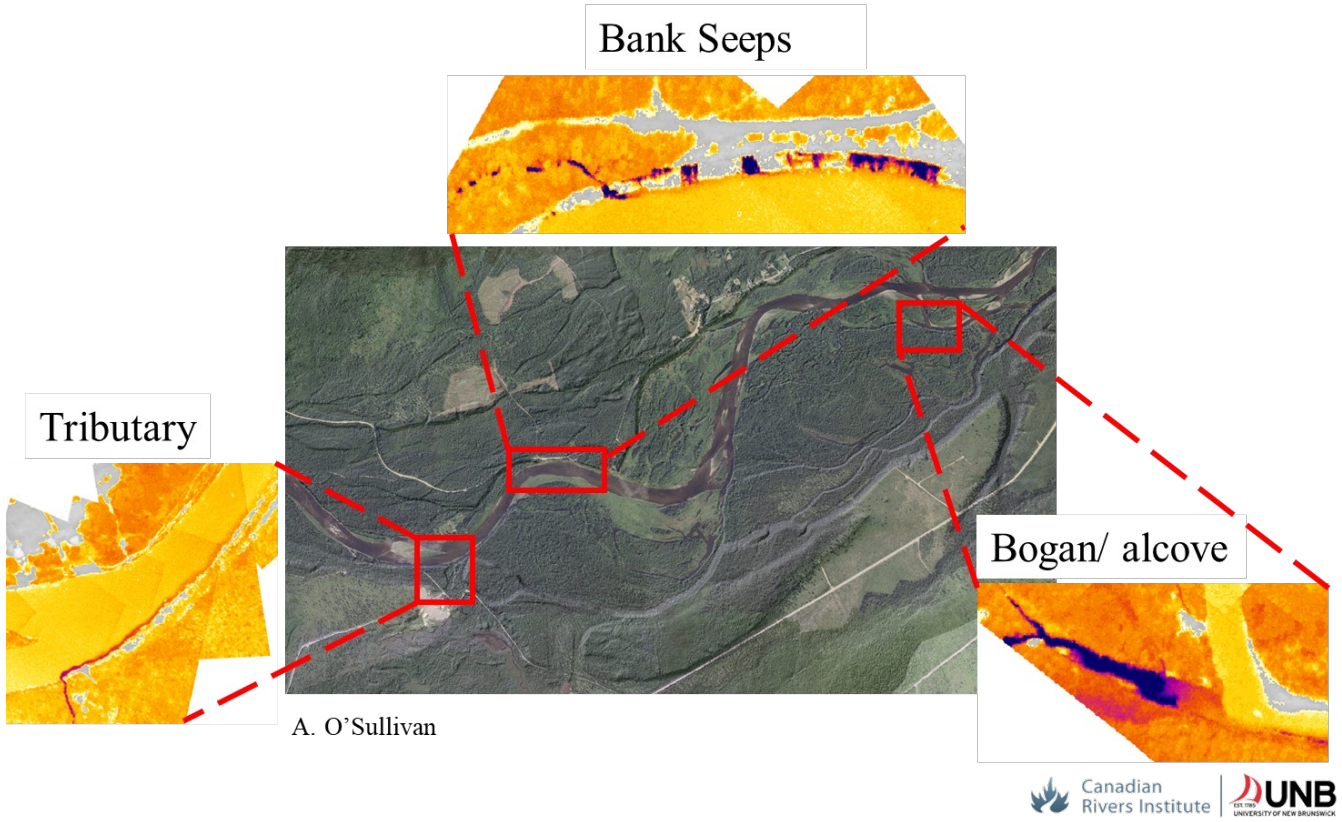
Adult A. salmon



Juvenile A. salmon

Devil is in the detail…salmon response

- "Painting" a river red (unsuitable) is not completely accurate
  - Fish use thermal refugia; mosaic of crucial microhabitat



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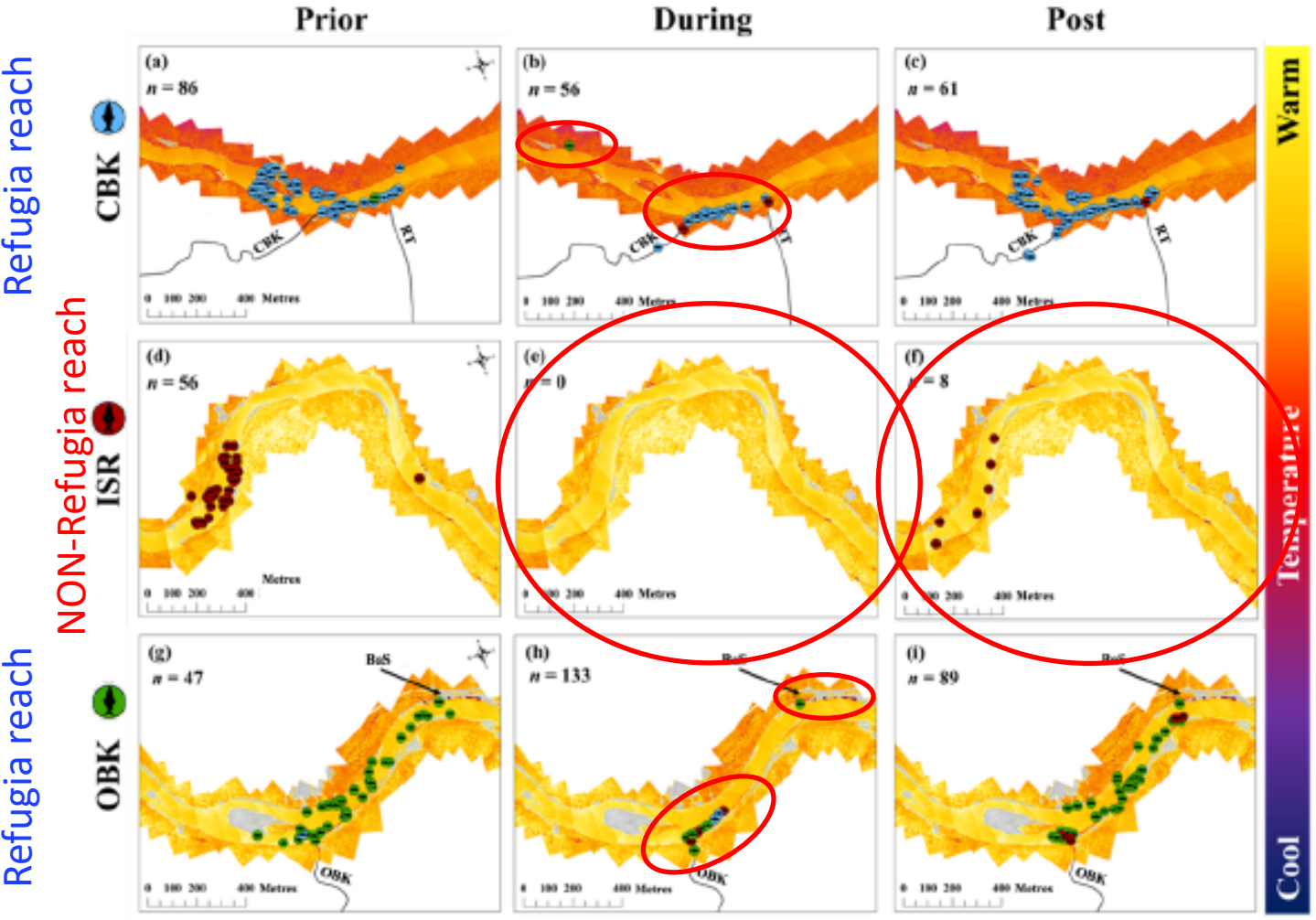
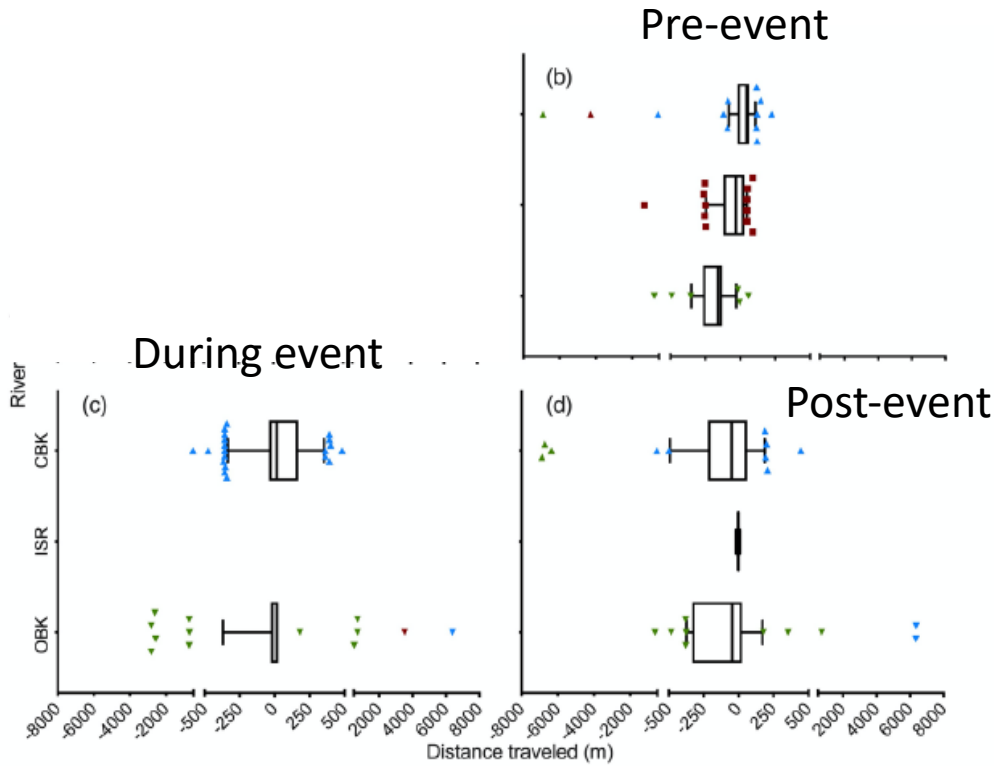
Juvenile salmon; response

- 1000's of juveniles aggregate
- Multi-km movements in temps > 27 °C
- Parr not returning to non-refugia reaches

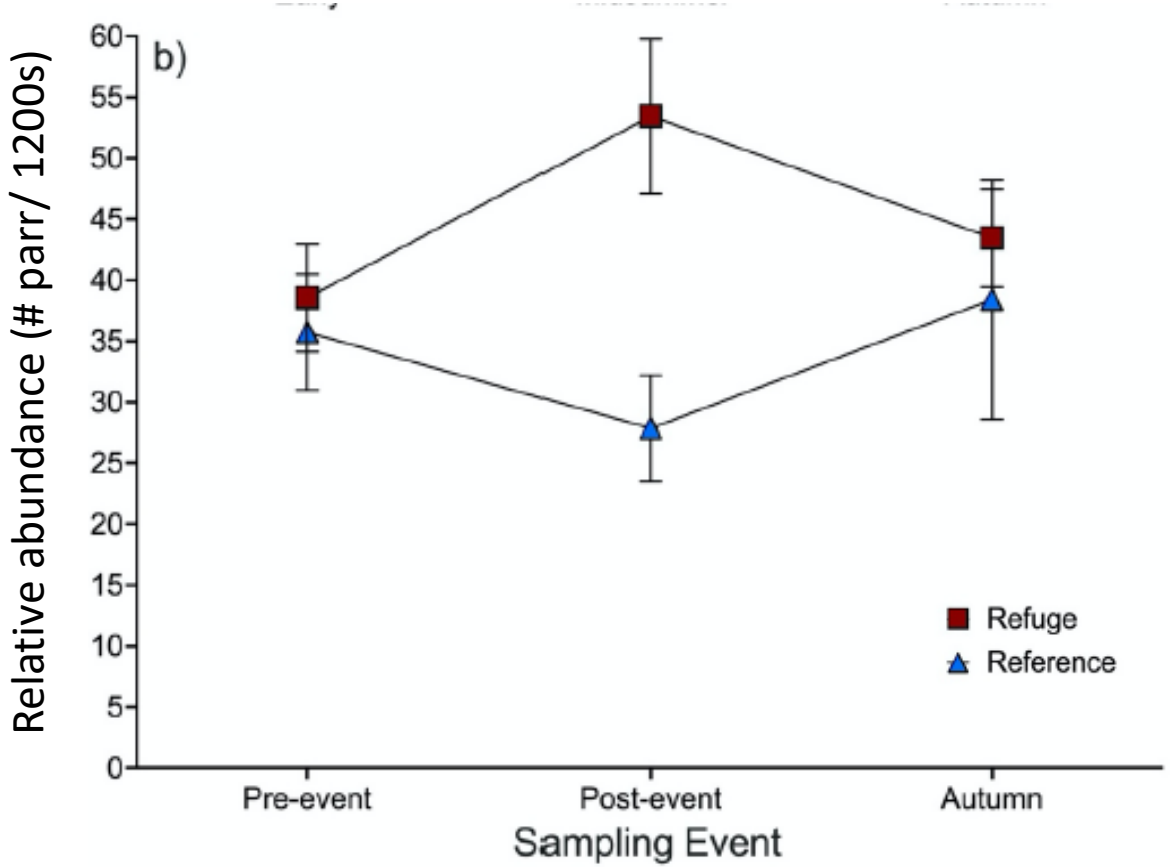




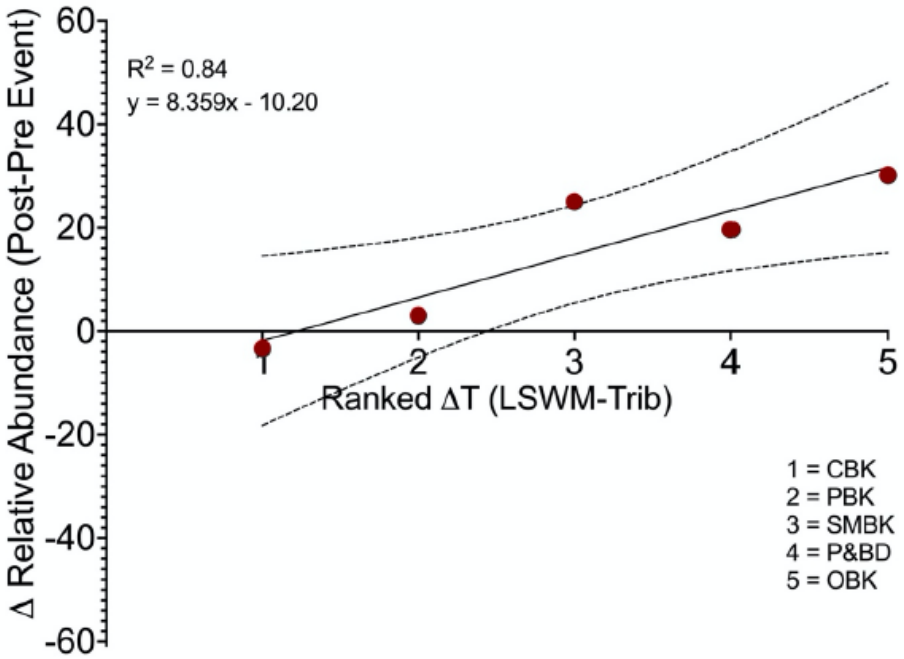
Corey et al. 2021a

What areas are “hot (cold) spots” and how long?

- Parr distribution “reset” AFTER tangible risk for further thermal events for the season is over



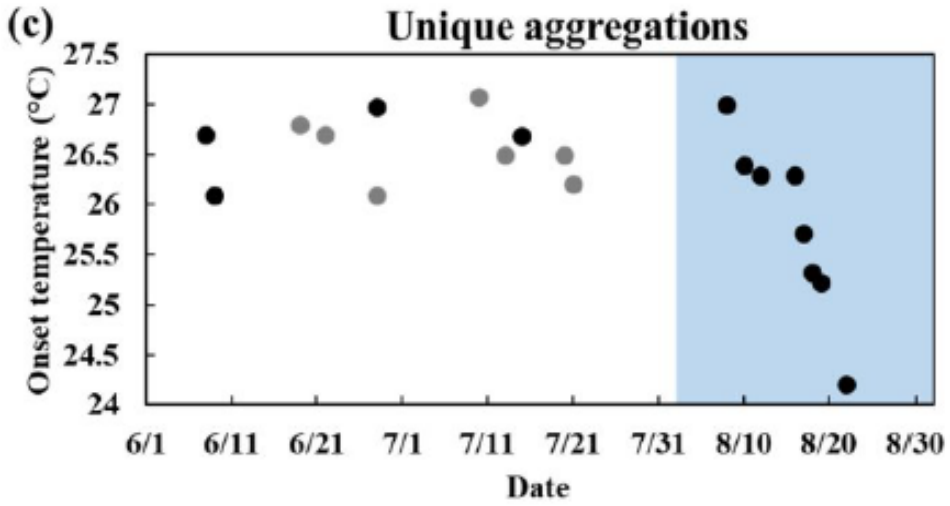
- “Clumping” more prevalent in the coldest sites



Corey et al. 2021b

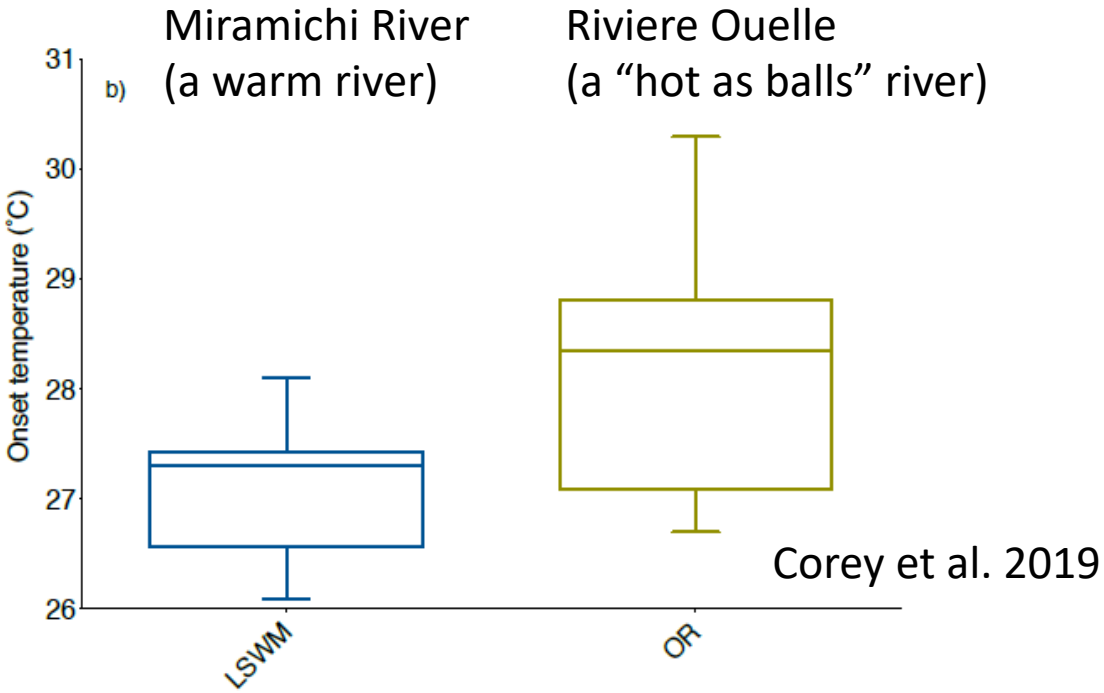
When do A. salmon respond to temperature?

- Is there a universal “threshold” within and between populations?



O’Sullivan et al. (in press)

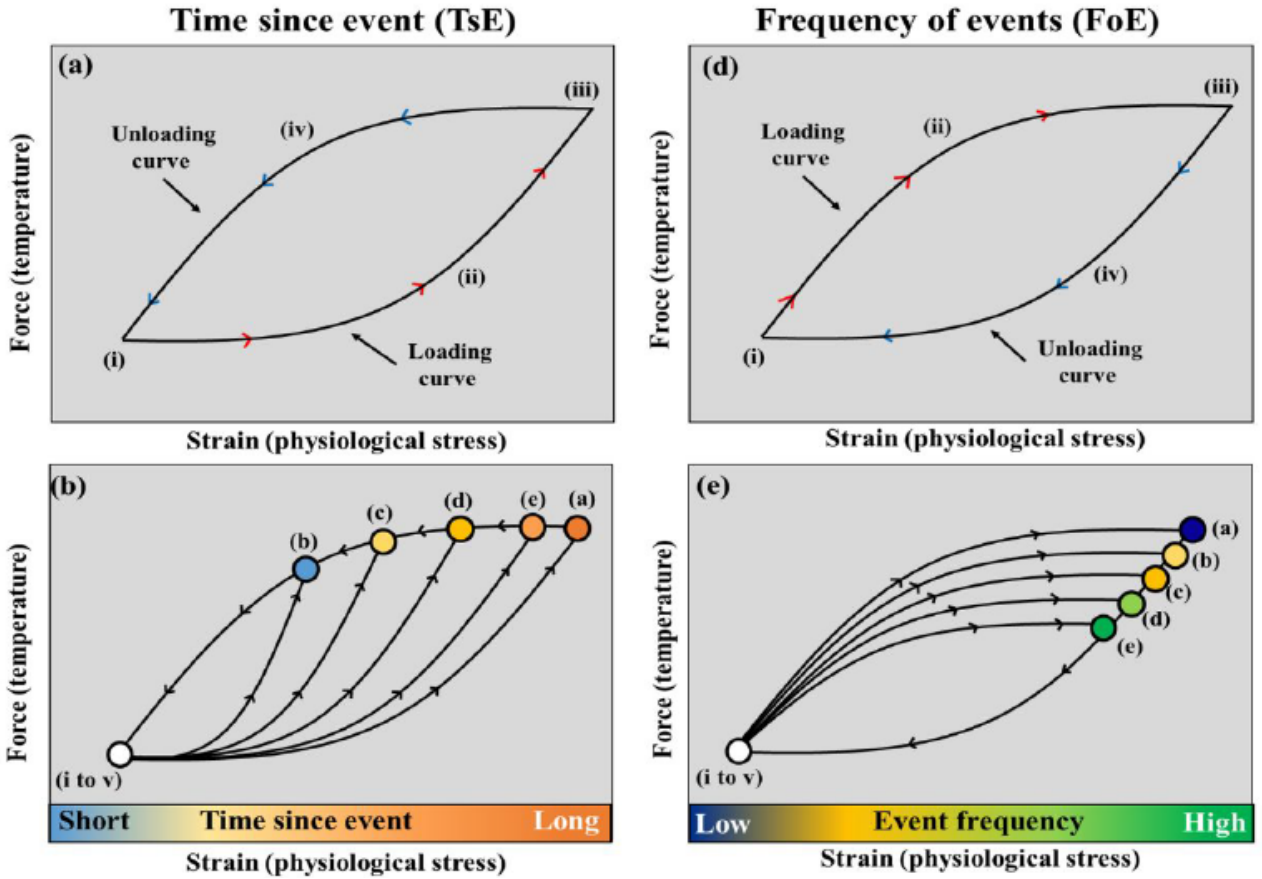
Within population: threshold is NOT universal



Corey et al. 2019

Between population: The relatively “warmer” river has higher threshold than relatively colder

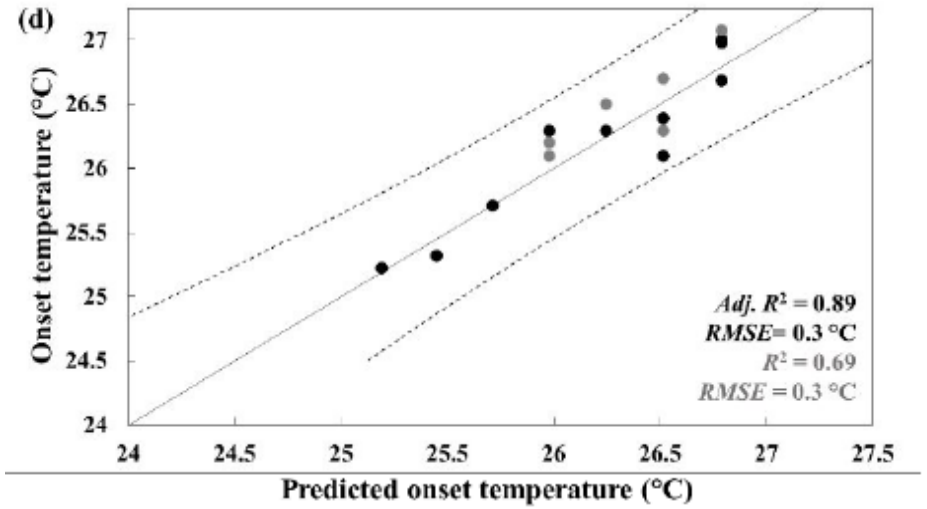
Why is there variability in aggregation thresholds?



$$T_{integrated} = a \times \log \lambda + b + ce^{d\frac{\sigma}{T}}$$

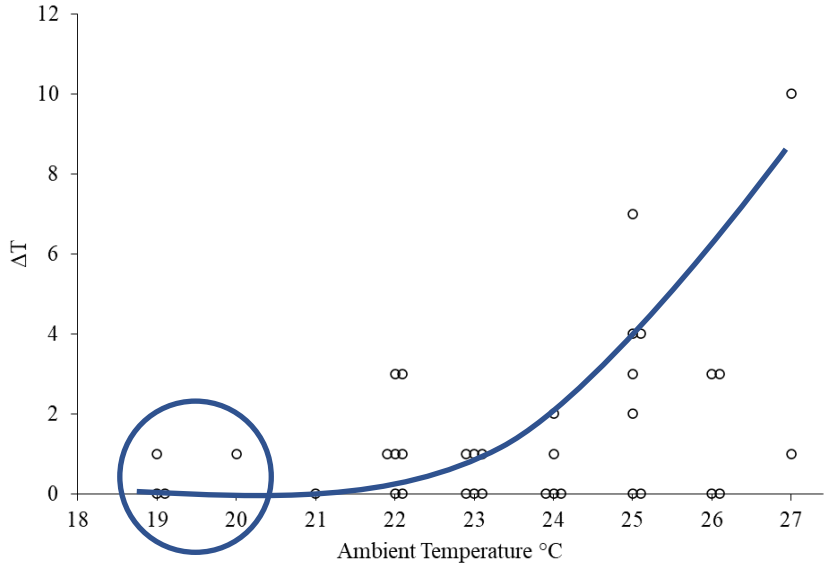
O'Sullivan et al. (in press)

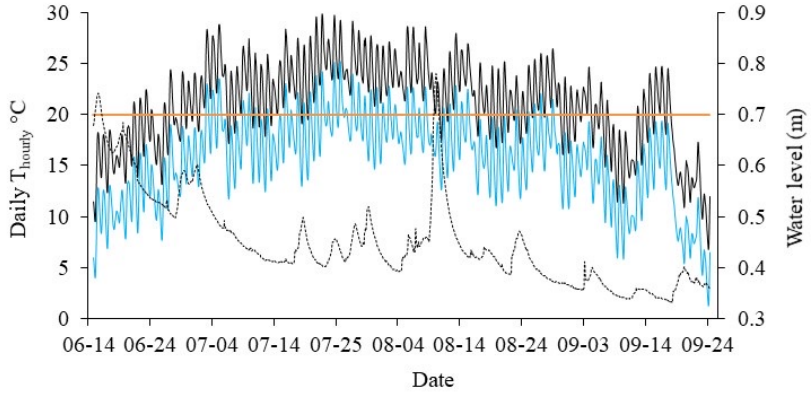
- Concept of thermal hysteresis
  - **Time since** and **frequency of** thermal events drive thermal "hysteria"
    - Training set: r2=0.90, RMSE = 0.29 °C
    - Test set: r2 = 0.82, RMSE = 0.22 °C
  - Physiological "thermal baggage"

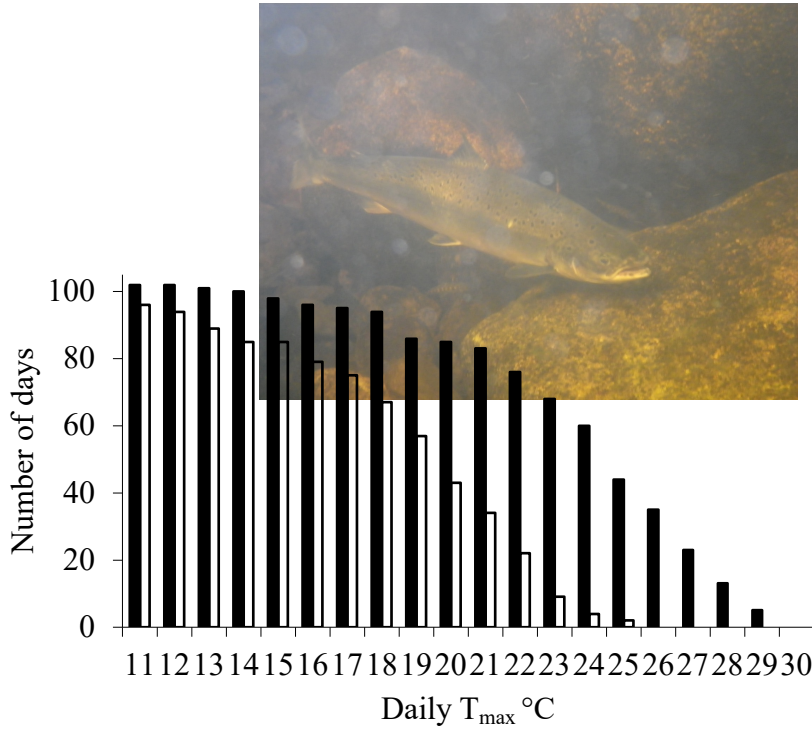


0.77 AICc weight of all assessed models in the modeled set

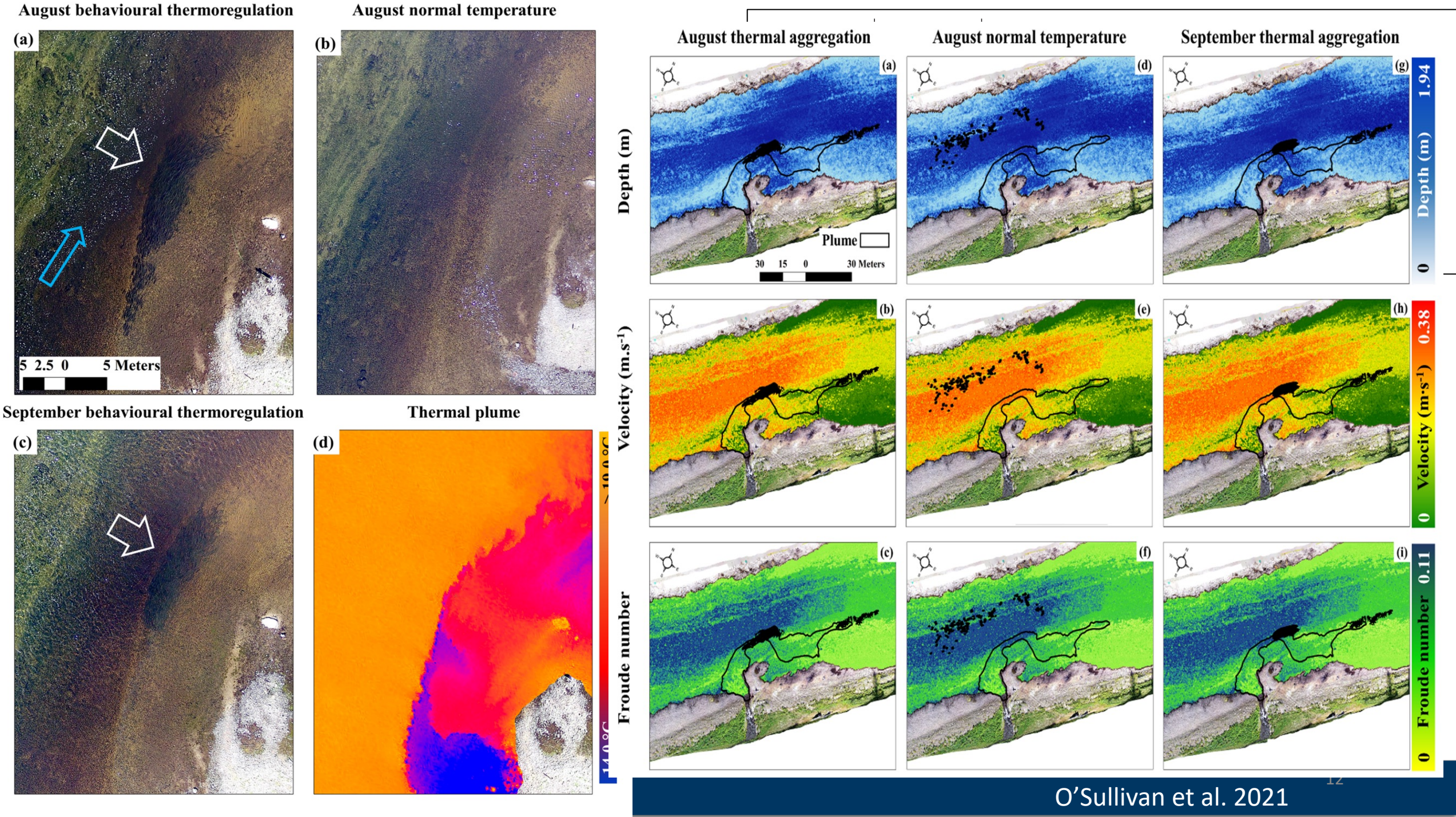
How about the adult A. salmon?





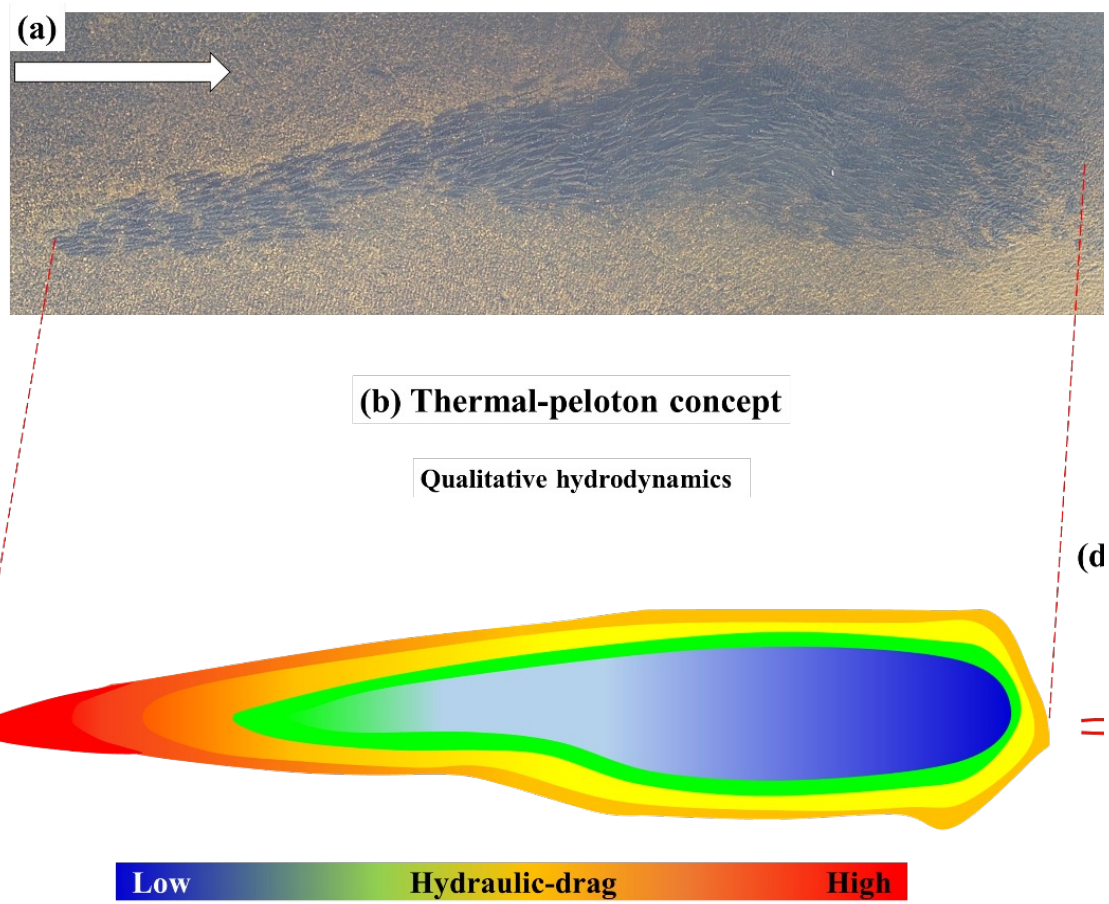


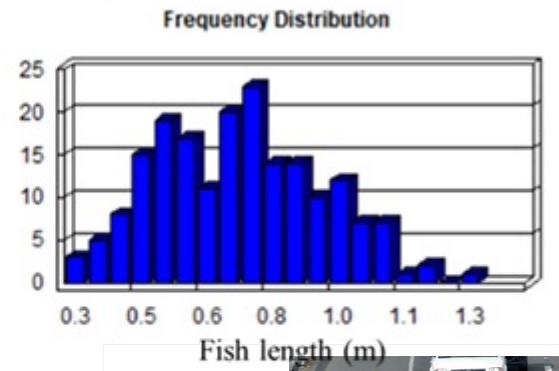
- Reasons for refugia use for adults more complicated: non-territorial
  - Facultative vs obligate use of refugia
  - Starts > 19 °C
  - ΔT increases with warmer ambient H2O temps
- Upstream migration largely dictated by H2O temps
  - Move fast to generally cold-water reaches

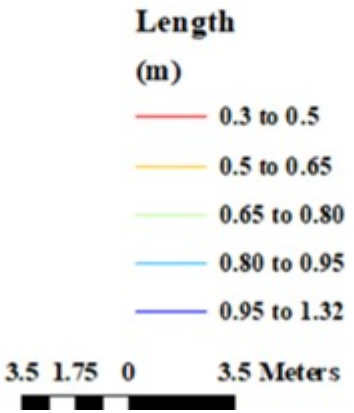


O'Sullivan et al. 2021

Thermal “peloton” for energy conservation

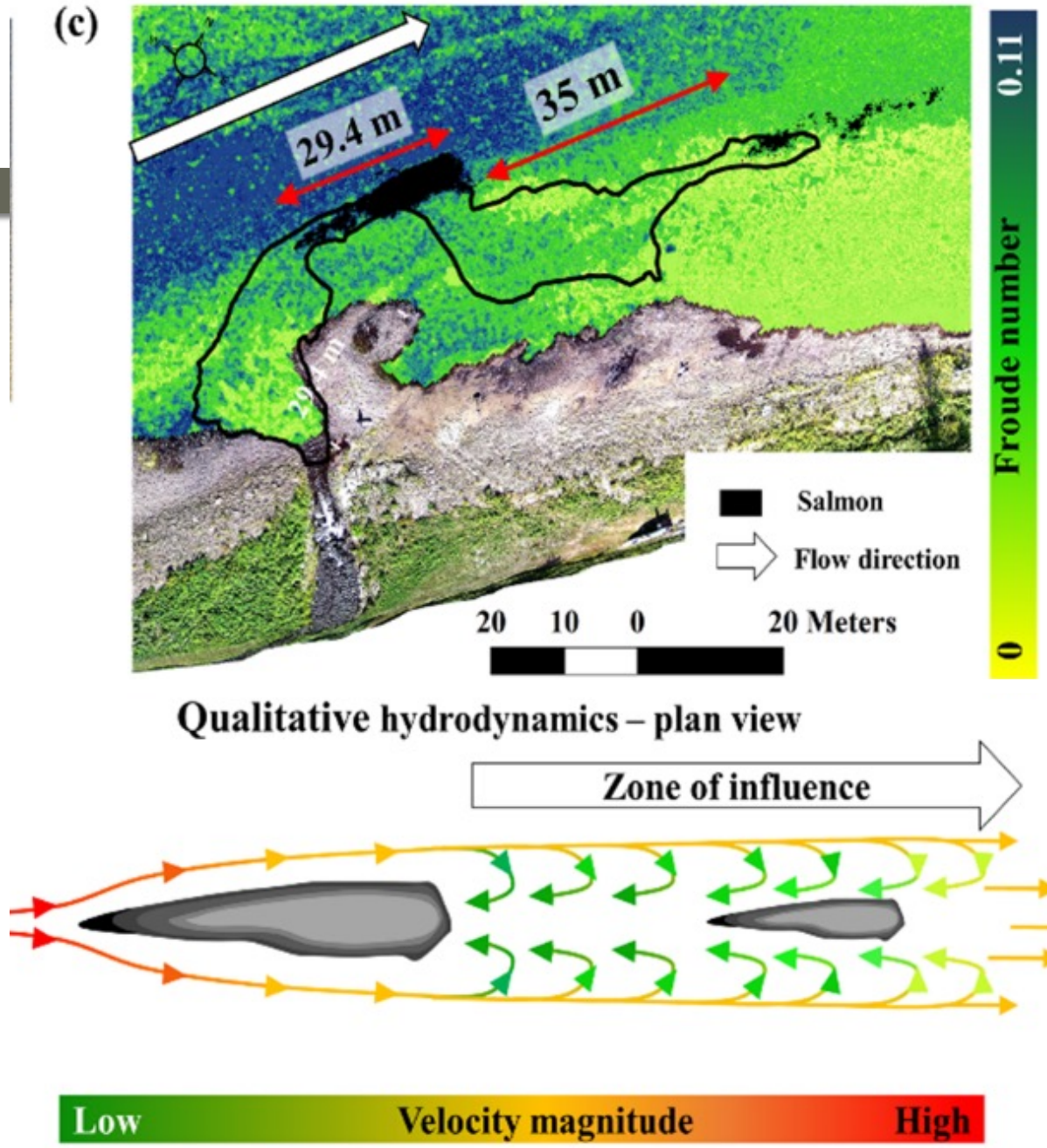


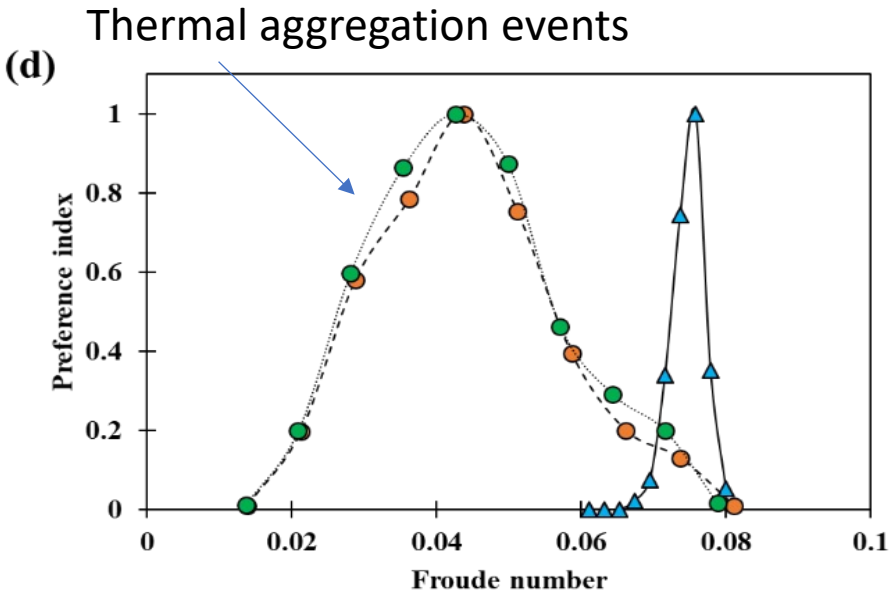




O’Sullivan et al. 2021

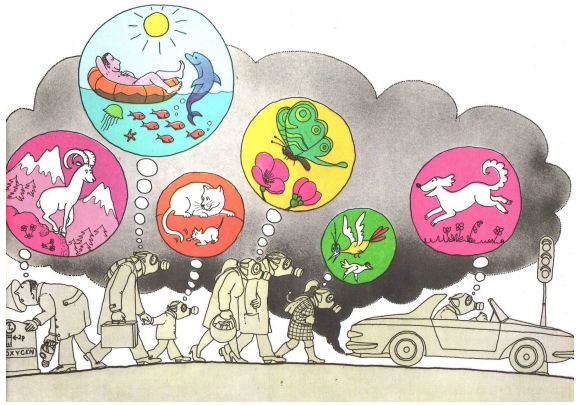
O’Sullivan & Linnansaari; unpubl.

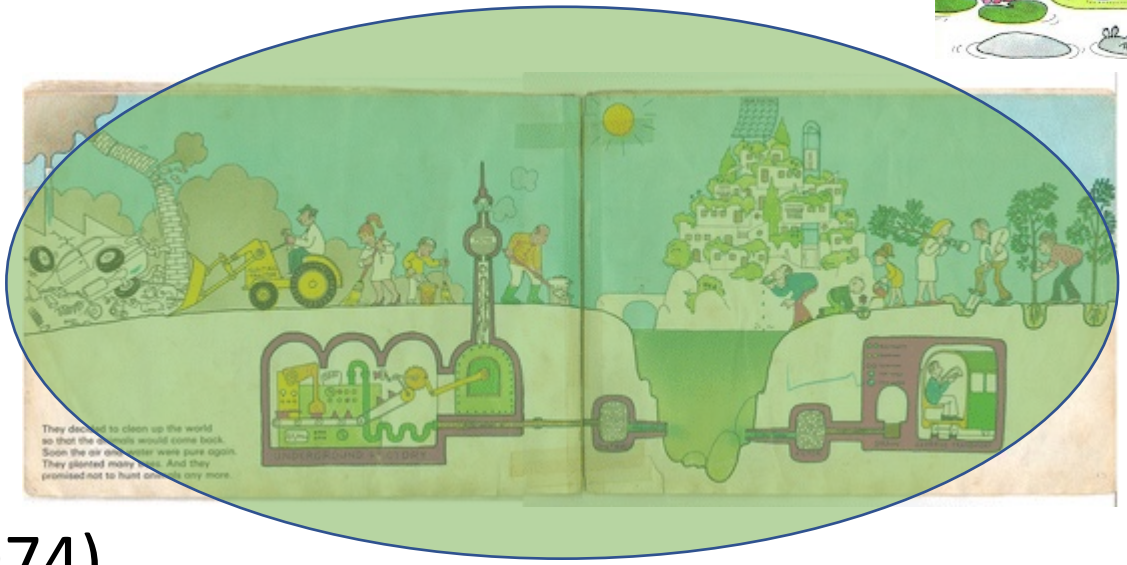




- Distribution of adults within refugia dictated by energy conservation, NOT coldest water
  - Salmon select for cool water
  - **Formations, or schooling strategies, that decrease energetic costs**
  - **Bio-derived hydraulic refuges**

So things are warming…is this the end?





To combat warming by climate change, this is the solution

- Barbababa's Ark (1974)

Cold-water protection and landscape activities

- No to forestry? No to clear-cuts?
  - NB forest cover 6.1 mill. ha (of 7.3 mill ha total : 83.6 %)
  - $1.7 billion annual economic impact
  - 1 in 14 jobs in NB linked to forestry
- Are A. salmon's problems **because of** forestry?
  - Are they because of warming? Role of climate change?
  - Are they because of warming at Atlantic Ocean?
  - Are they because of "other issues" at sea? (IUU fishery?)
- If landscape activities have **something** to do with decline, then what?

Landscape activity effect is context specific

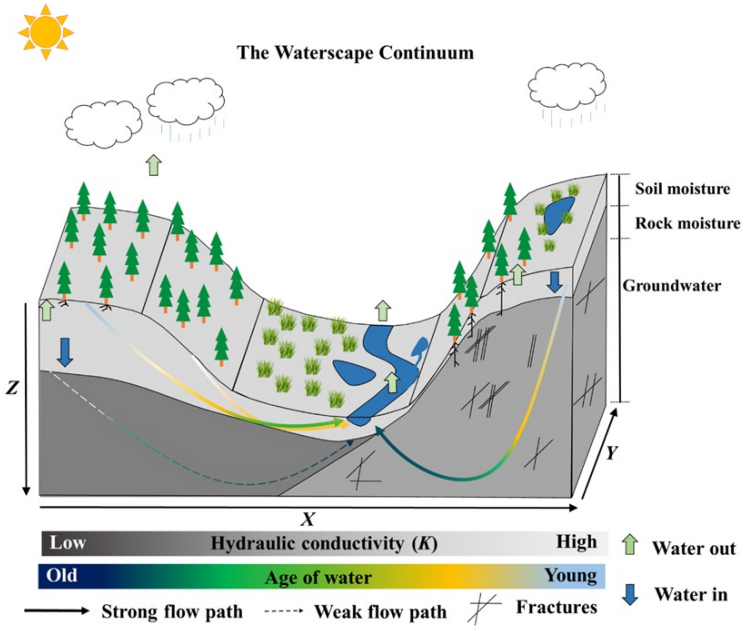
- Generic “buffer zone width must be XX m” are nonsensical
  - One size does **NOT** fit all
  - **MUST** identify **RESILIENT** and **SENSITIVE** streams by hydrological response area and apply different mitigation (and/or protect sensitive areas)

PERSPECTIVE

WIREs WATER WILEY

The waterscape continuum concept: Rethinking boundaries in ecosystems

Antóin M. O'Sullivan[1,2] | Kevin J. Devito[1,3] | Loïc D'Orangeville[2] | R. Allen Curry[1,2,4]



O’Sullivan et al. 2021

Final words: Times will be tough → BUT THERE IS HOPE!

Restoration:	Smart refugia, ensure success by post-monitoring
Fish management:	Dynamic, responsive closures
Land management:	Identify sensitive vs resilient areas, and manage accordingly

Acknowledgements

Funding and support:

The Atlantic Salmon Conservation Foundation / La fondation pour la conservation du saumon atlantique

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10’s of summer students, technicians, volunteers and colleagues