Foodscapes in Action- Morning Session

A Concurrent Session at the 42nd Annual Salmonid Restoration Conference
Santa Cruz, California, April 29 - May 2, 2025

Session Coordinators: Gabriel Rossi, Ph. D., Research Scientist, *UC Berkeley* and *California Trout Coastal River Ecologist*

Recent work in watersheds from Alaska to California has emphasized the central role of food in salmon resilience and recovery. A foodscape perspective expands our view of watershed management to consider the sources, phenology, and pathways of key food resources. It also focuses our attention on the conditions that allow salmon (and other mobile consumers) to track and exploit feeding opportunities across the riverscape. Like every aspect of salmon habitat, the foodscape has been (and continues to be) altered, simplified, and often severed. But unlike work on fish passage, water quality, or instream flow, we are only now beginning to realize the challenges and opportunities for recovering and maintaining healthy, functional foodscapes.

Join us as we examine “foodscapes in action” – specific projects and places where foodscape thinking is being applied to salmon conservation and recovery. This session will bring together stewards, managers, and researchers, who are developing methods to study, monitor, and restore foodscapes. We will consider foodscapes in relatively intact watersheds, which shed light on the key trophic pathways and spatiotemporal patterns of foraging and growth potential that support salmon populations. We will also consider foodscapes in heavily impacted systems, which provide a novel lens to consider how alternative restoration actions promote diverse and connected foraging and growth opportunities for fish. In both contexts, foodscape thinking reveals opportunities to find new and productive tools that can help move the needle on salmon population abundance, diversity, and resilience – opening new possibilities for watershed stewardship and bringing optimism in a time of ecological crisis.

Presentations

Recovering non-natal life histories to recover salmon (on the case of the missing life histories)

Stephanie Carlson[1], J. Ryan Bellmore[2], Mariska Obedzinski[1,3], Henry Baker[1], Rachael Ryan[1], Avi Kertesz[1], Amy Fingerle[1], Phil Georgakakos[1], Ted Grantham[1], Gabe Rossi[1]

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PERSPECTIVE

Why Aren't Salmon Responding to Habitat Restoration in the Pacific Northwest?

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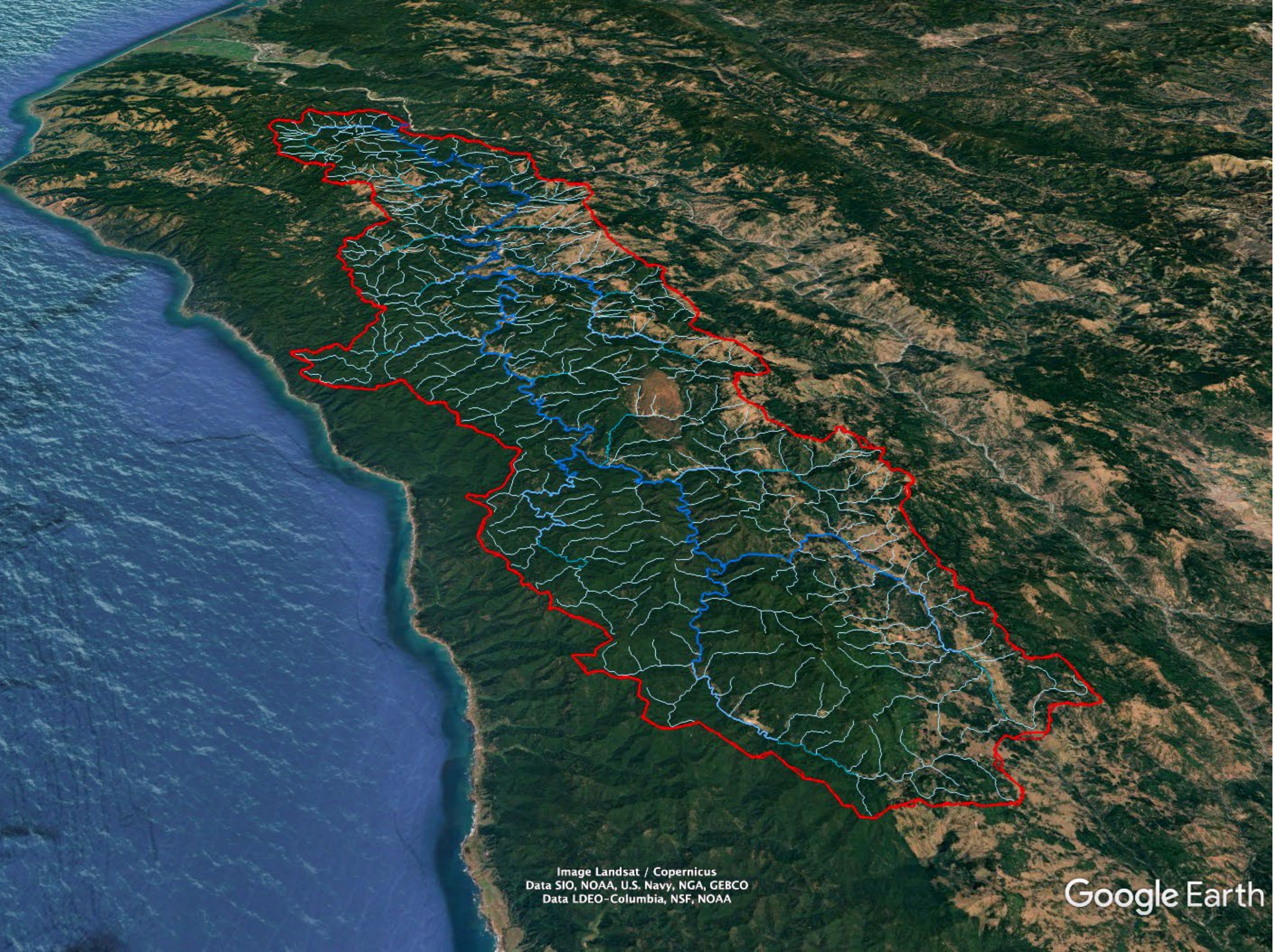
Ken P. Currens | Northwest Indian Fisheries Commission, Olympia, WA
Kurt L. Fresh | National Marine Fisheries Service, retired, Seattle, WA
Derek B. Booth | University of Washington, Seattle, WA
Robert R. Fuerstenberg | King County Dept. of Natural Resources and Parks, retired, Seattle, WA
Gino L. Lucchetti | King County Dept. of Natural Resources and Parks, retired, Seattle, WA

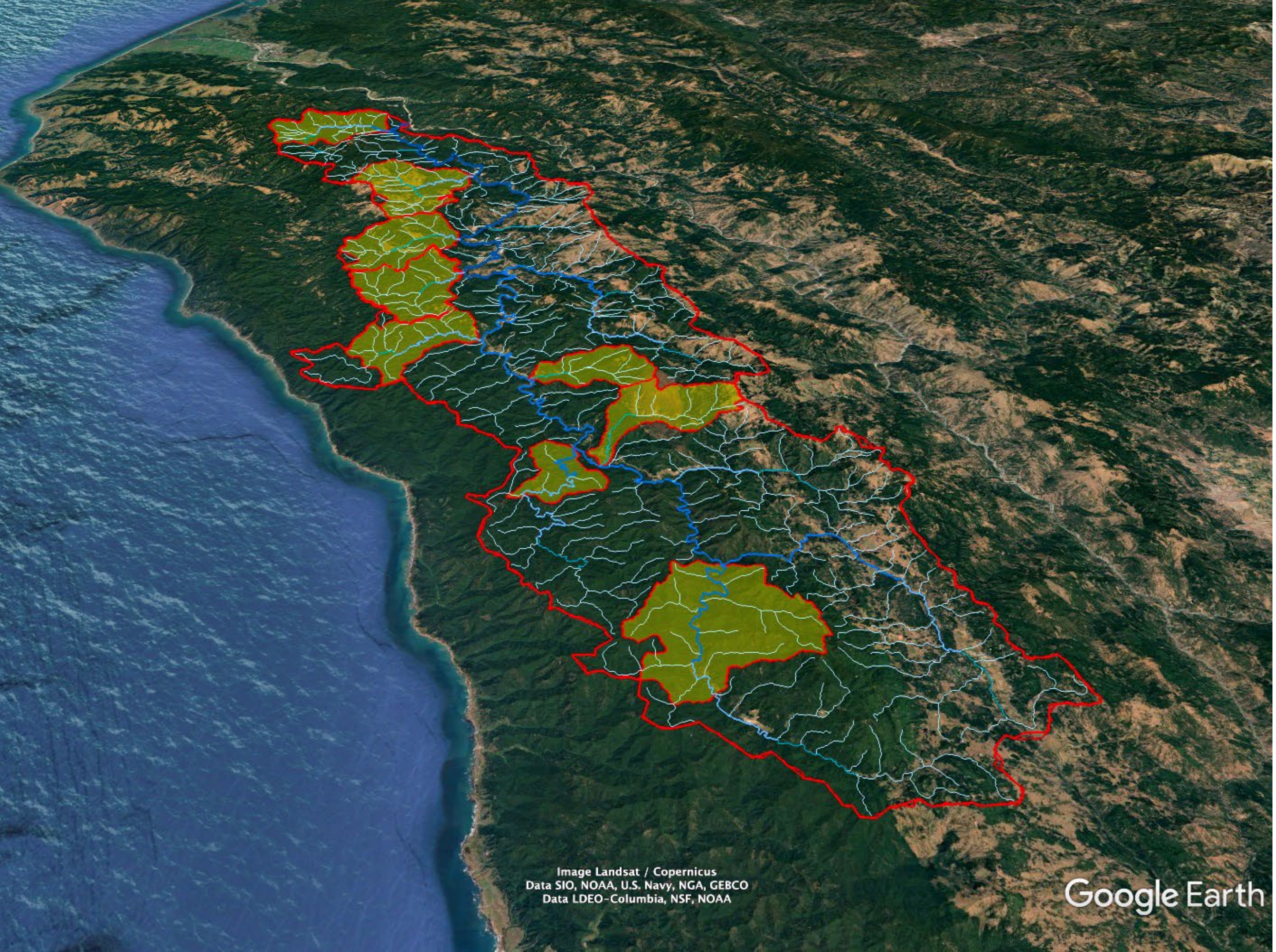
- Not enough restoration has been done
- We are not doing the right things in the right places at the right times
- Ongoing habitat restoration is offsetting restoration benefits
- Not enough time has passed
- Monitoring has been inadequate to detect changes in Pacific salmon abundance

Back of the envelope calculation reveals something is missing

- Anecdotally, we observed that many river systems in which salmon were historically abundant do not appear to have the natal-stream capacity to produce enough juvenile salmon to support the historic adult populations.
- For example, the Eel River in California, near the southern extent of Pacific Salmon, supported runs of up to 150,000 adult coho salmon and 200,000 adult steelhead – and yet cool, perennial natal habitat that these juvenile salmonids depend on is quite limited in the Eel and likely was historically (SHaRP 2021; Dralle et al. 2023).



683 miles of stream channel in the South Fork Eel River; but less than 150 miles of cold, perennial, rearing habitat for over summering salmonids (SHaRP 2021).

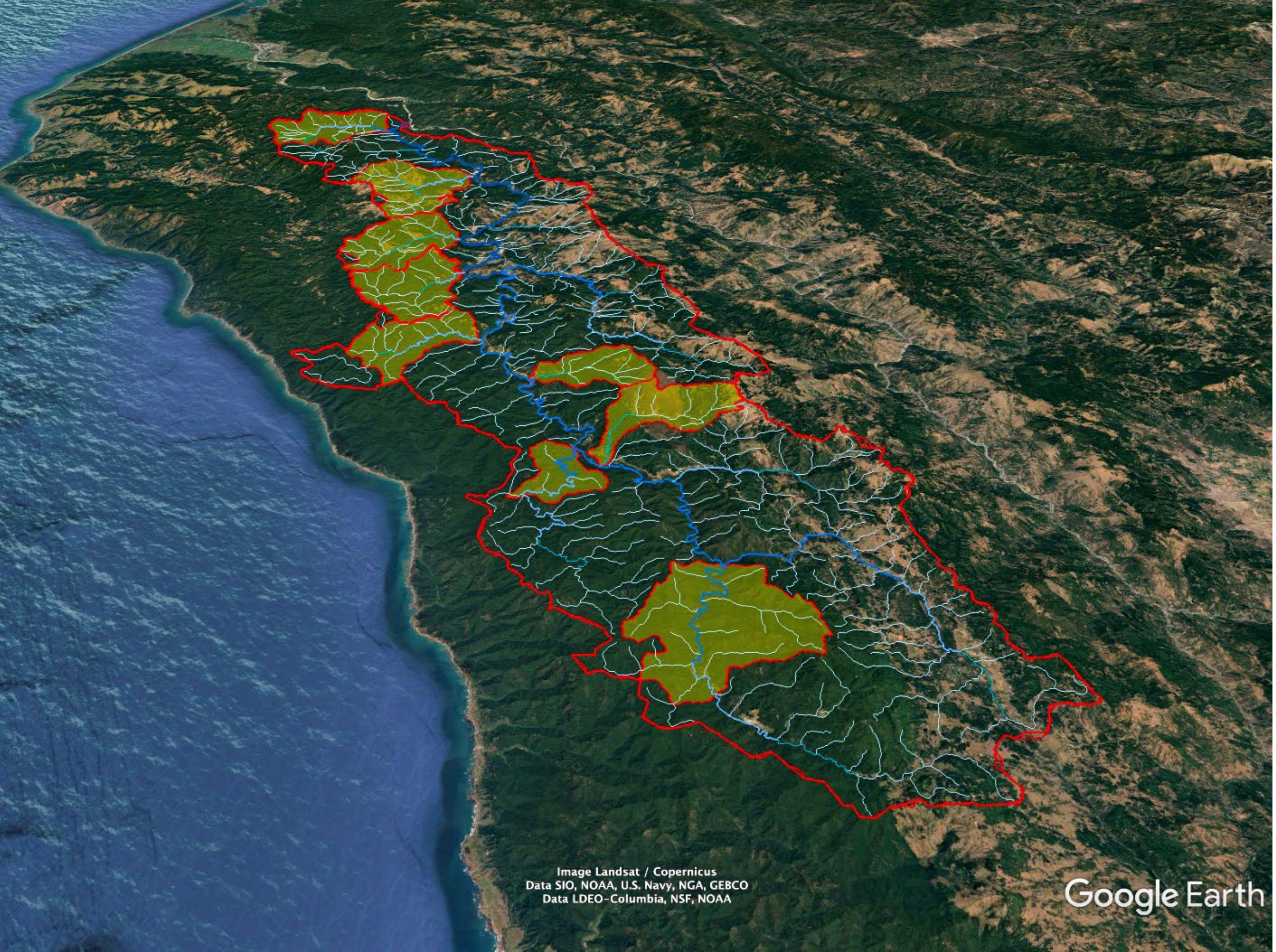


How many adult fish could these "ideal" rearing streams produce?

(inflated density and survival numbers!!)

~150 miles of stream X 1500 smolts per mile*
=**225,000 smolts**
X 5% SAR =
11,250 adults.

(based on high end of Elder Creek 1+ density, pre-smolts)



Our question:

How did they do it?

Our hypothesis

They moved to non-natal habitat through an array of life histories that are no longer supported due to disproportionate loss of productive stop-over habitats

Recovering salmon requires recovering productive stop-pver habitats and access to it to recover the missing life histories

Streams have carrying capacities which lead to density-dependent growth and survival

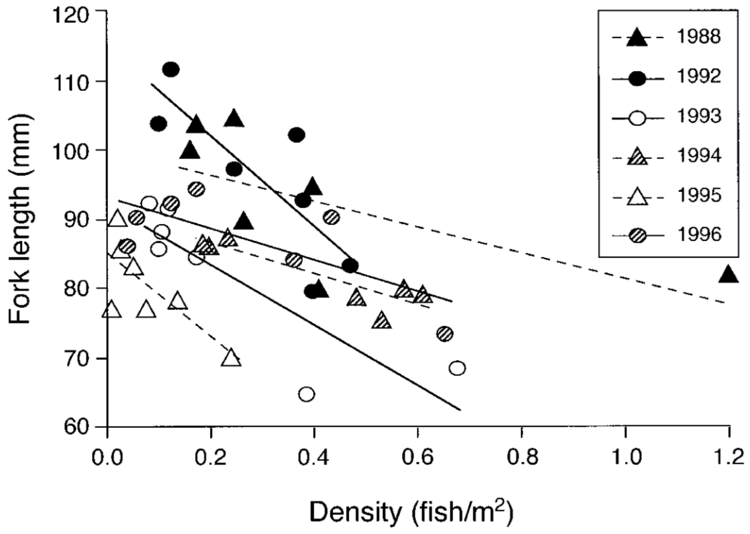


FIG. 2. Average fork length of underyearling brown trout relative to total trout density in seven sections of Mammoth Creek in 1988 and 1992–1996. Also shown are the lines of univariate linear regressions fitted to the data of each year (equations and statistics are given in Table 3A).

Jenkins et al. 1999. Effects of population density on individual growth of brown trout in streams. Ecology 80: 941- 956.

South Fork Sproul Creek steelhead emigrants (1999-2007)									
Year	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
0+ (raw)	15478	8945	1063	2316	4804	19783	2872	3260	11367
1+ expanded	1191	1166	946	800	223	988	477	458	1059
% 1+	8%	13%	89%	35%	5%	5%	17%	14%	9%

Data from Harry Vaughn, 2008

ECOLOGY AND MANAGEMENT OF SUMMER STEELHEAD IN THE ROGUE RIVER

Fred H. Everest

Fishery Research Report Number 7
Oregon State Game Commission
Corvallis, Oregon
November 1973

Documented fry migration, and postulated that migrants are offspring of late spawners, delayed emergence, and density-dependent movement

> 30,000 (!) fry migrants were captured and marked (fin clip). Recaptured fish were caught in the mainstem Rogue (near the tributary of origin), in nearby tributaries (suggesting habitat choice), and as large smolt yearlings

Downstream Movement of Rainbow Trout Fry in a Tributary of Sagehen Creek, Under Permanent and Intermittent Flow

Don C. Erman and George R. Leidy

Department of Forestry and Conservation, University of California, Berkeley, California 94720

ABSTRACT

Rainbow trout fry spawned in an intermittent stream had a diel periodicity in downstream movement that was highly correlated with discharge. Shortly after fry emerged in mid-July 1973, Kiln Meadow Tributary of Sagehen Creek began to dry up and fry began to move downstream, primarily during the day. After rains, when the water level remained high (5 to 8 liters/s) without diel fluctuations, few fry were captured in the trap.

In 1974 the tributary was permanent and fry exhibited a nocturnal downstream emigration. Many fry remained in the tributary where they were almost the only fish occupants.

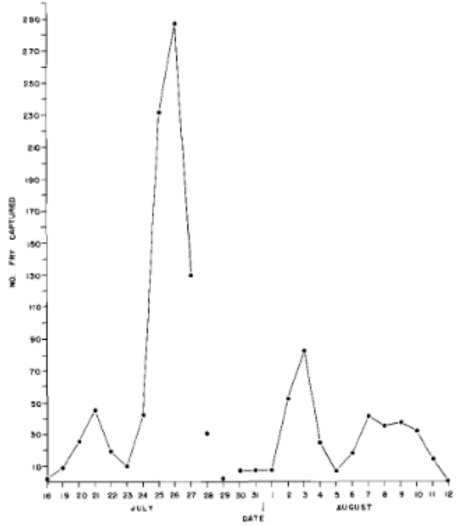
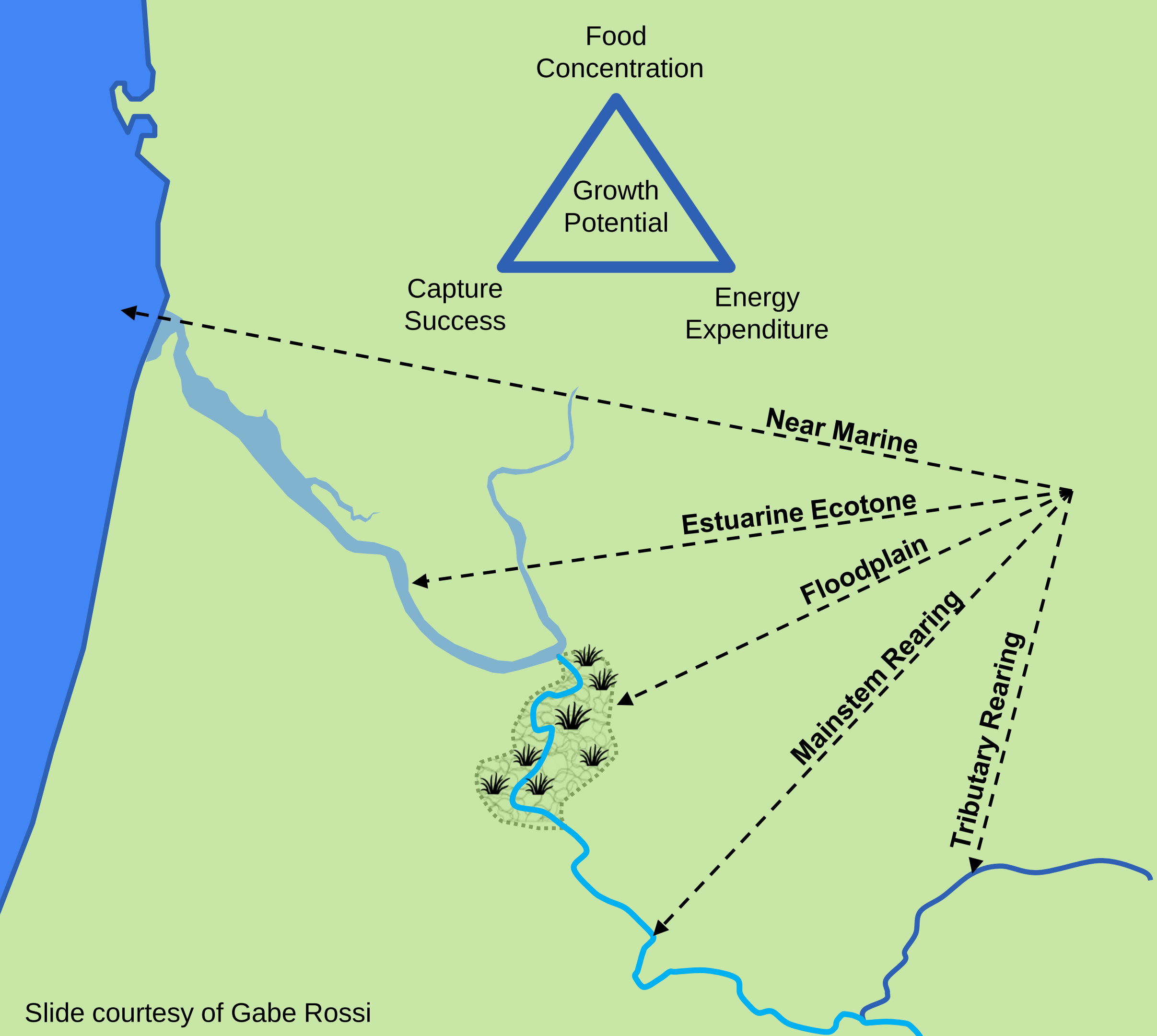


Figure 2.—*Total number of rainbow trout fry captured by date in Kiln Meadow Tributary, July 18 through August 12, 1973. A freshet displaced the fish trap on July 28 and 29, and an incomplete record was obtained.*

TRANS. AM. FISH. SOC., 1975, NO. 3

Key messages

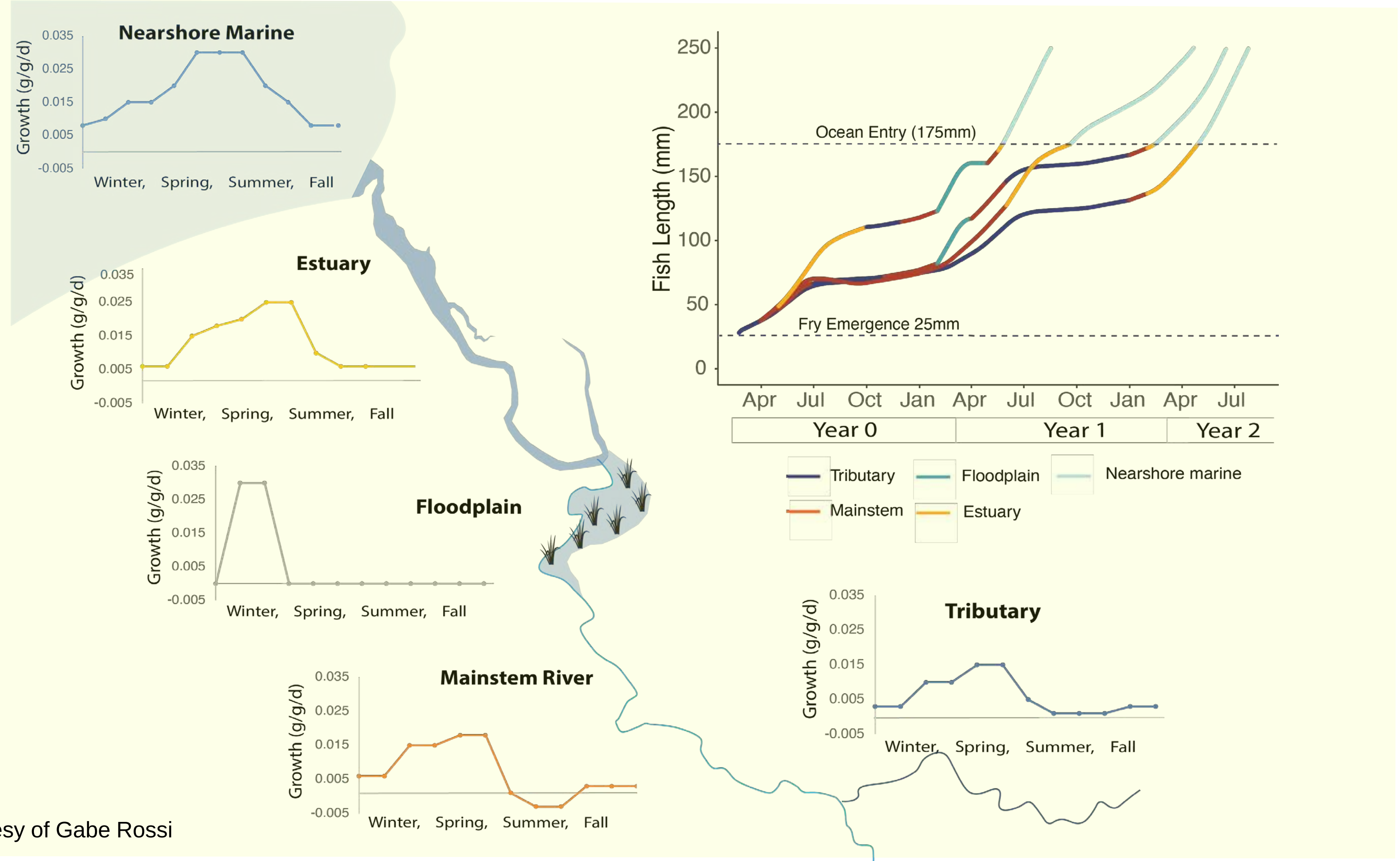
- Fish movement away from natal areas allows population to spread out on landscape **and alleviates density dependence**



Rossi et al., 2024

The “**foodscape**” is a mosaic of linked habitats with different growth potential phenologies that is exploited by mobile consumers and supports multiple life histories, often through asynchronies in resource availability.

Slide courtesy of Gabe Rossi

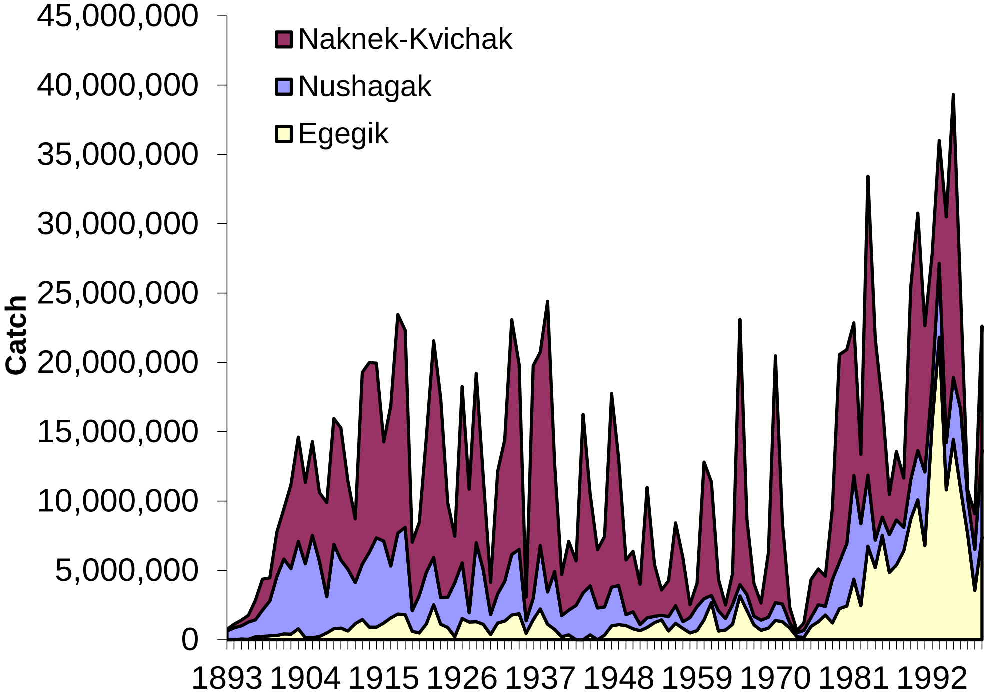


Slide courtesy of Gabe Rossi

Key messages

- Fish movement away from natal areas allows population to spread out on landscape **and alleviates density dependence**
- When habitats differ in ways that influence growth (foodscape, temperature, etc.), **individuals using different parts of the system will express different life histories**

Population diversity gives rise to a "portfolio effect"



Aggregate returns to Bristol Bay were 41-77% more stable than individual stocks

Hilborn et al. 2003. PNAS 100: 6564-6568.

Schindler et al. 2010. Nature 465: 609-612.

Key messages

- Fish movement away from natal areas allows population to spread out on landscape **and alleviates density dependence in the natal habitat**
- When habitats differ in ways that influence growth (e.g., food, temperature, density dependence, etc), **individuals using different parts of the system will express different life histories**
- Life history diversity within and among populations **increases both abundance of adults and stability** via the portfolio effect

Mounting evidence that non-natal rearers exist, and contribute to adult returns

"The downstream movement of coho salmon nomads (age 0), ***conventionally considered surplus fry****, has been an accepted characteristic of juvenile coho salmon for the past 40 to 50 yr. The fate of these nomads, however, was not known and they were assumed to perish in the ocean."* – Koski 2009

Nomads no more – life history pathways exhibited by coho salmon

“*There has been considerable research documenting the early migration of juvenile coho salmon to salt water, but until now, there has been little evidence that these fish contribute to the spawning population. In our study streams, juvenile coho exhibited a strongly bimodal emigration pattern, with a large peak in the fall/winter that contributed to nearly 37% of the adult return from 2004 to 2010…. This diversity of life history patterns essentially provides a portfolio effect to spread the risk of mortality for coho in these small streams*.”

Bennett et al. 2015. Ecology of Freshwater Fish 24: 264-275.

Examples from Russian River – after lunch

- [1:55] Mariska Obedzinski et al. "*Foodscape perspectives on salmon in the Russian River watershed*"
- [2:20] Hank Baker et al. "*Causes and consequences of variation in rearing strategies in juvenile Coho Salmon*"

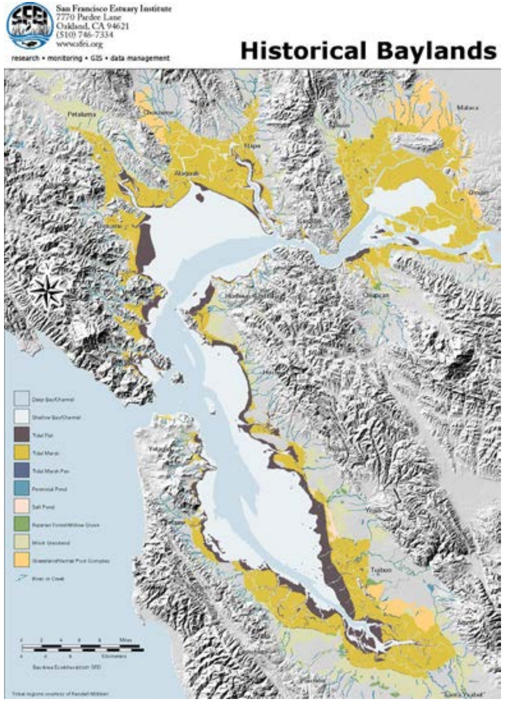
Key messages

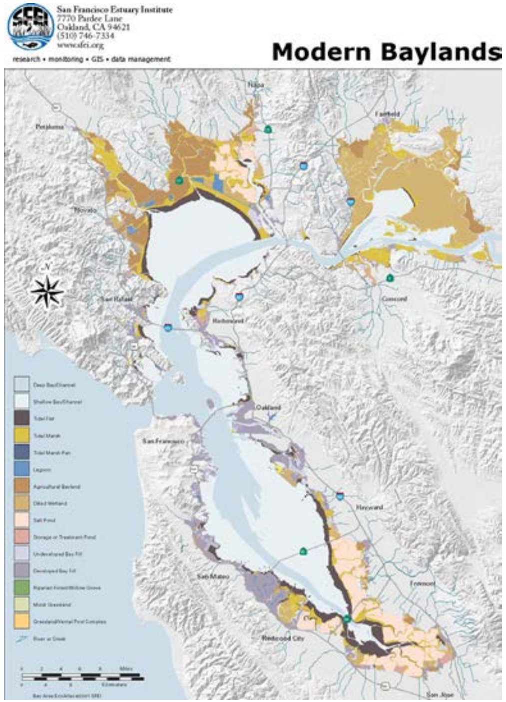
- Non-natal habitat and flow connectivity to exploit it allows population to spread out on landscape and **alleviates density dependence**
- When habitats differ in ways that influence growth (e.g., food, temperature, density dependence, etc), **individuals using different parts of the system will express different life histories**
- Life history diversity within and among populations **increases both abundance of adults and stability via the portfolio effect**
- ***Non-natal life histories linger*** *on the landscape, and when they find suitable stop-over habitat, non-natal life histories contribute to adult returns and stability*

Habitats that non-natal rearers relied/rely on have been disproportionately lost or degraded

- Key habitats have been degraded and lost (e.g., floodplains, tidal and freshwater marshes, estuaries, etc.).

Downstream habitats that supported non-natal rearers have been lost or degraded….. This limits occupancy, growth, …





Fish. Bull. 100:244–257 (2002).

Physiological ecology of juvenile chinook salmon (*Oncorhynchus tshawytscha*) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California*

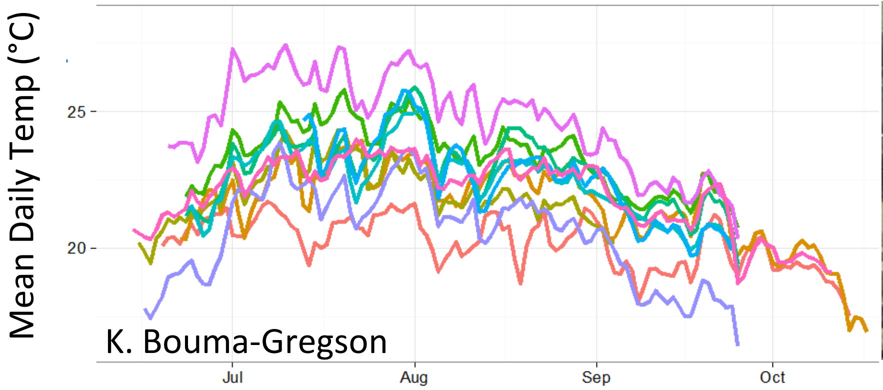
R. Bruce MacFarlane
Elizabeth C. Norton

"The relatively short period of abundance in the San Francisco Estuary and emigration rates presented here suggest that juvenile chinook from the Central Valley may derive less benefit from estuarine residence than do more northerly populations."

https://www.sfei.org/content/ecoatlas_habitats

Habitats that non-natal rearers relied/rely on have been disproportionately lost or degraded

- Key habitats have been degraded and lost (e.g., floodplains, tidal and freshwater marshes, estuaries, etc.).
- Many river mainstems are warming, prone to disease outbreaks, and invaded by piscivores



Habitats that non-natal rearers relied/rely on have been disproportionately lost or degraded

- Key habitats have been degraded and lost (e.g., floodplains, tidal and freshwater marshes, estuaries, etc.).
- Many river mainstems are warming, prone to disease outbreaks, and heavily invaded by piscivores
- Natal rearers that use non-natal habitat as a corridor (as opposed to stop-over habitat) are likely favored in the contemporary riverscape

Key messages

- Non-natal habitat and flow connectivity to exploit it allows population to spread out on landscape and **alleviates density dependence**
- When habitats differ in ways that influence growth (e.g., food, temperature, density dependence, etc), **individuals using different parts of the system will express different life histories**
- Life history diversity within and among populations **increases both abundance of adults and stability via the portfolio effect**
- **Non-natal life histories linger** on the landscape, and when they find suitable stop-over habitat, non-natal life histories contribute to adult returns and stability
- ***Degradation of mainstems and stop-over habitats limits the success of non-natal rearers***

Re-awakening the missing life histories

“Anecdotal evidence from Bear River and the Mattole are that there were deep holes in the lower rivers/estuary pre ’54 and ‘64. We trapped Bear River just above the tide for a couple springs a while back. Just as the temps rose in June, thousands of YOY steelhead bailed. I couldn’t help but go down to the estuary to see where they were rearing. Turns out they weren’t there. The majority of the estuary was less than 2m deep, hot and barren. My sense at the time was that these animals were perishing. I wonder if the emigration was the ‘ghost’ of a life history strategy that no longer works.” -- Seth Ricker CDFW personal communication 2022

Restoring stop-over habitats to re-awaken life histories

"Rehabilitation of marshes through removal of levees, structures, and fill took decades (B—years refer to the timing of marsh rehabilitation), but resulted in the recovery of approximately 70% of original estuarine marsh habitat to natural tidal inundation regimes."

Flitcroft et al. 2016. Aquatic Conservation: Marine and Freshwater Ecosystems 26: 39-59.

Expect the unexpected: place-based protections can lead to unforeseen benefits

REBECCA L. FLITCROFT[a,*], DANIEL L. BOTTOM[b], KAREN L. HABERMAN[c], KEN F. BIERLY[d], KIM K. JONES[e], CHARLES A. SIMENSTAD[f], AYESHA GRAY[g], KAMI S. ELLINGSON[h], ERIN BAUMGARTNER[c], TREVAN J. CORNWELL[e] and LANCE A. CAMPBELL[i]

“The recovery of a large area of potential rearing habitat in the Salmon River estuary enabled a study of life-history re-emergence by Chinook and coho salmon populations, including documenting previously unknown estuary specific life-history strategies in this species….

Comparisons of recent and historical data… reveal that life-history variation in both Chinook and coho salmon populations has expanded since tidal connections to most of the estuarine wetlands were re-established”

Aquatic Conservation: Marine and Freshwater Ecosystems 26 (Suppl. 1): 39–59 (2016)

Key messages

- Non-natal habitat and flow connectivity to exploit it allows population to spread out on landscape and **alleviates density dependence**
- When habitats differ in ways that influence growth (e.g., food, temperature, density dependence, etc), **individuals using different parts of the system will express different life histories**
- Access to diverse, productive, non-natal habitats **increases both abundance of adults and stability via** the portfolio effect
- **Non-natal life histories linger on the landscape**
- **Degradation of mainstems and stop-over habitats limits success of non-natal rearers; past restoration actions have tended to support natal rearers**
- ***Restoration actions at right places can re-awaken life histories and their contributions to adult returns and stability***

Modeling the Salmon Foodscape

42nd Annual Salmonid Restoration Conference,
Santa Cruz, California, 2 May 2025

J. Ryan Bellmore[1], Gabriel Rossi[2], Stephanie Carlson[2], Holly Harris[1], Aimee Fullerton[3], Avi Kertesz[2]

[1]Forest Service, Pacific Northwest Research Station, Juneau, AK
[2]University of California at Berkeley, CA
[3]NOAA Fisheries, Seattle, WA

Salmon population models

- A lot of existing models developed to examine and predict salmon population dynamics.

1596

The Shiraz model: a tool for incorporating anthropogenic effects and fish–habitat relationships in conservation planning

Mark D. Scheuerell, Ray Hilborn, Mary H. Ruckelshaus, Krista K. Bartz, Kerry M. Lagueux, Andrew D. Haas, and Kit Rawson

North American Journal of Fisheries Management 43:203–230, 2023

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10859

ARTICLE

Life Cycle Model Reveals Sensitive Life Stages and Evaluates Recovery Options for a Dwindling Pacific Salmon Population

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Thomas P. Quinn
School of Aquatic and Fishery Sciences, University of Washington, 1122 Nebraska Boat Street,
Washington 98105, USA

NOAA Contract Report NMFS-NWFSC-CR-2023-05

Habitat Assessment and Salmon Life-Cycle Models for the Chehalis Basin Aquatic Species Restoration Plan: Summary of Research Products

Contracts **WDFW#15-03970** and **RCO#17-1477**

NOAA Technical Memorandum NMFS

APRIL 2024

LIFE CYCLE MODELING FRAMEWORK FOR CHINOOK SALMON SPAWNING IN THE SACRAMENTO RIVER

Noble Hendrix[1], Ann-Marie K. Osterback[2], Sara John[2], Miles Daniels[2], Eva Dusek Jennings[3], Eric Danner[4], and Steve Lindley[4]

Salmon life cycle models

- Life cycle models are important tools for identifying population bottlenecks.

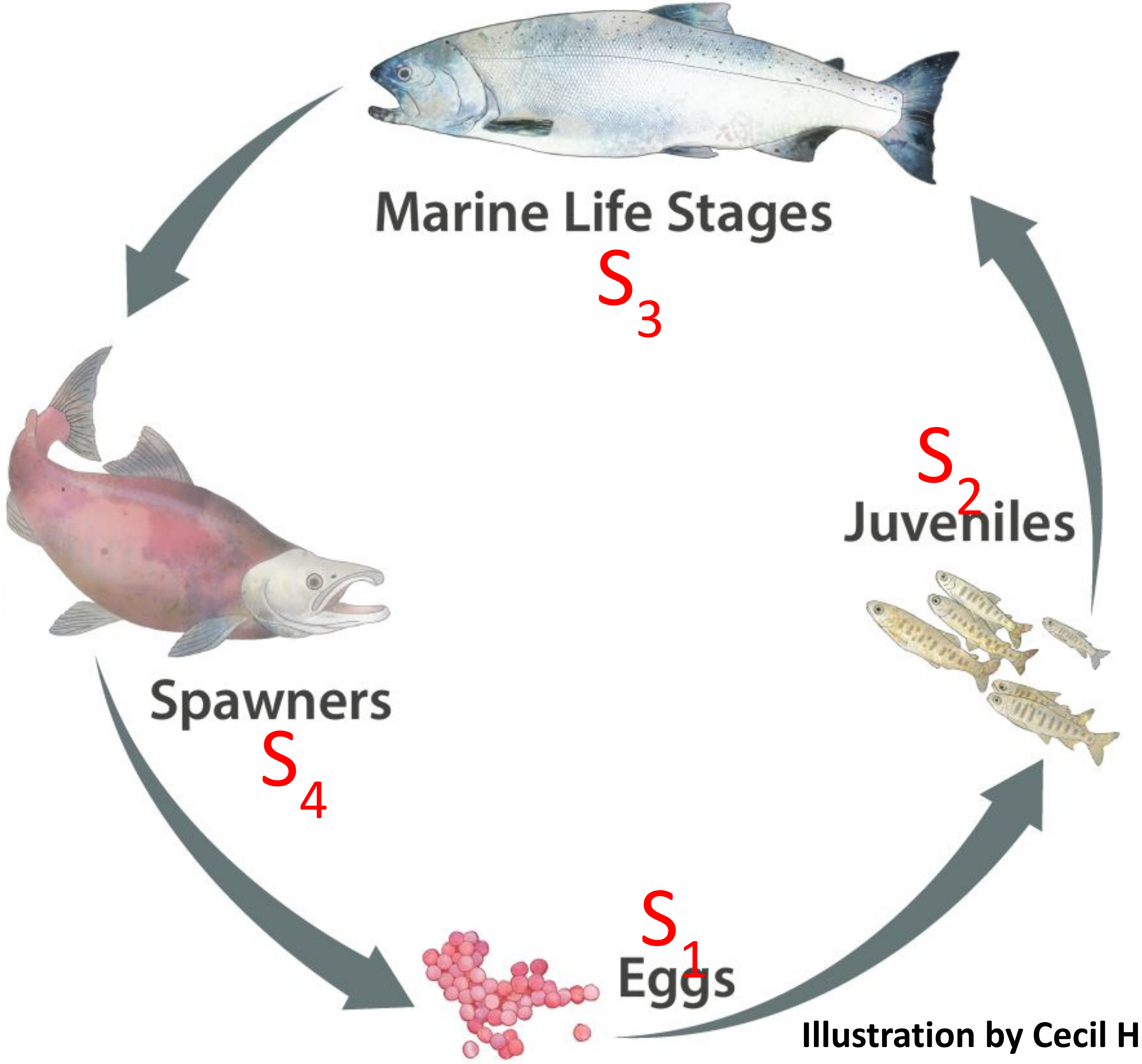

Illustration by Cecil Howe
(Bellmore et al. 2023)

Salmon life cycle models

- Relate salmon survival to the quantity and quality of physical habitat (Scheuerell et al. 2006; Jorgensen et al. 2021)
- Often identify that *natal* rearing habitat is limiting

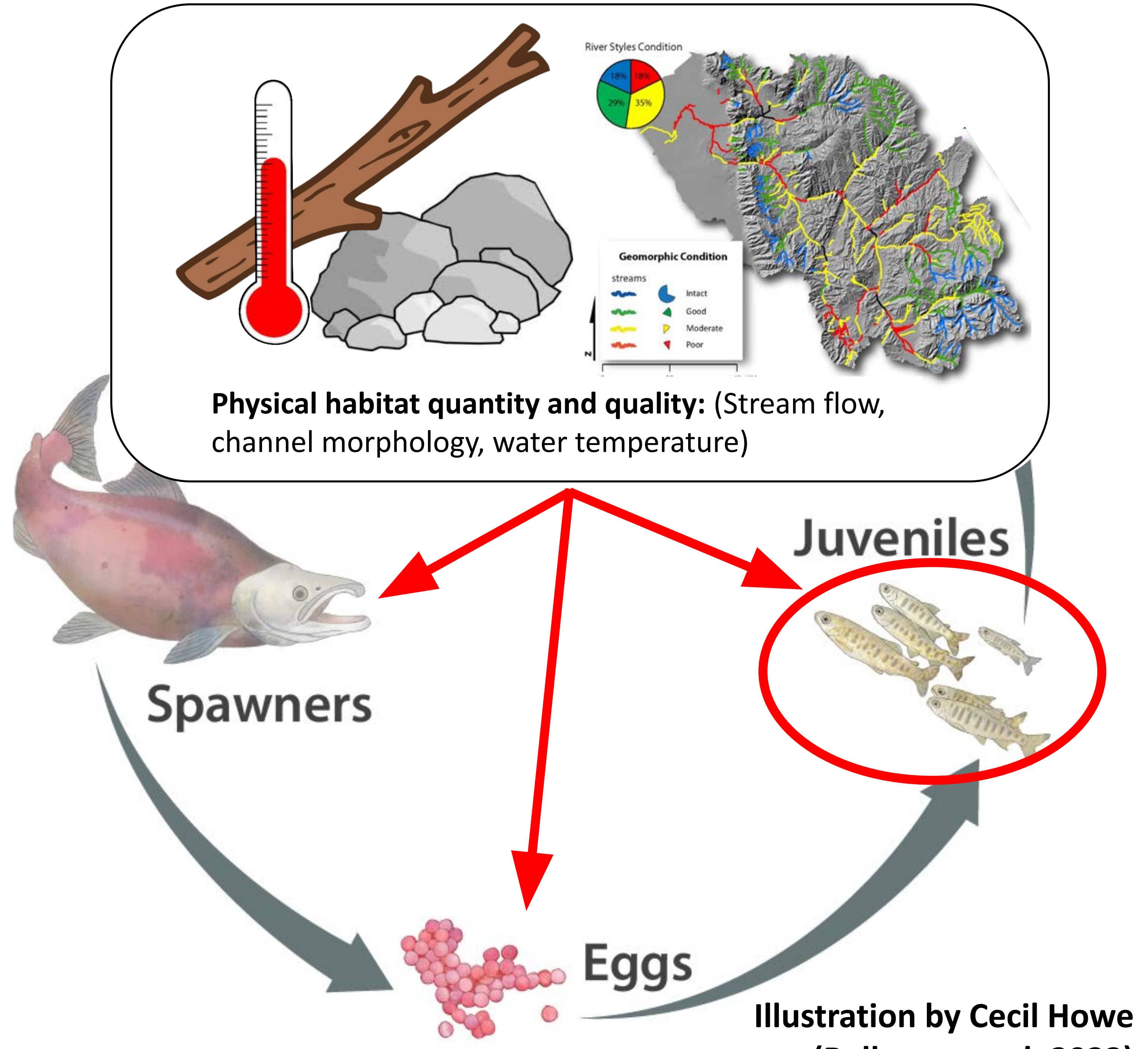

Illustration by Cecil Howe (Bellmore et al. 2023)

What they leave out...

1. Div
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2. M
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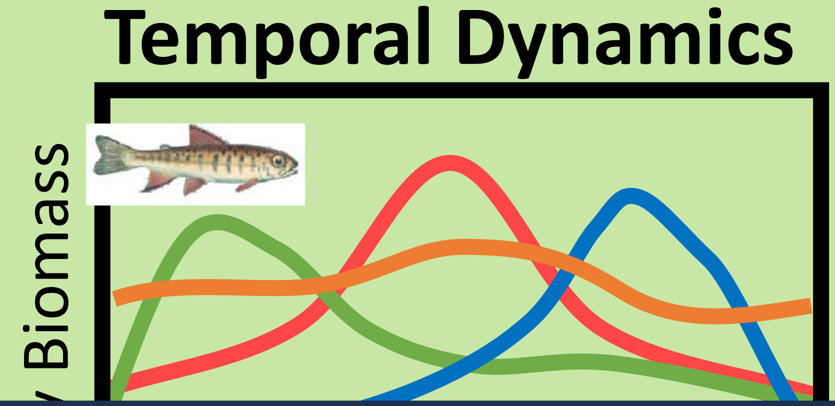
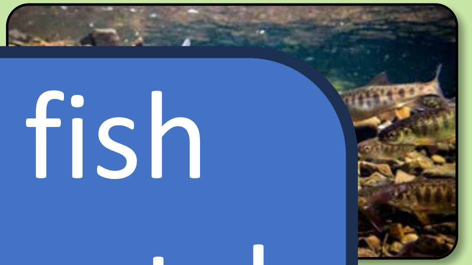
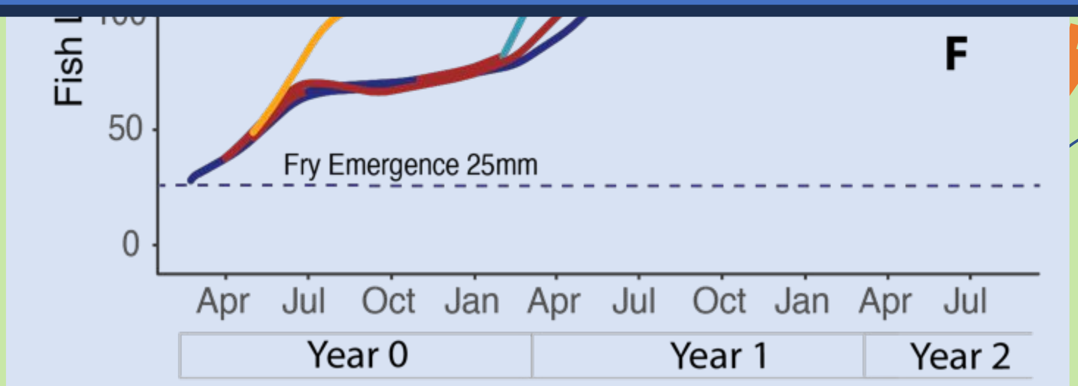
3. Diversity of life histories that this compliment of habitats supports





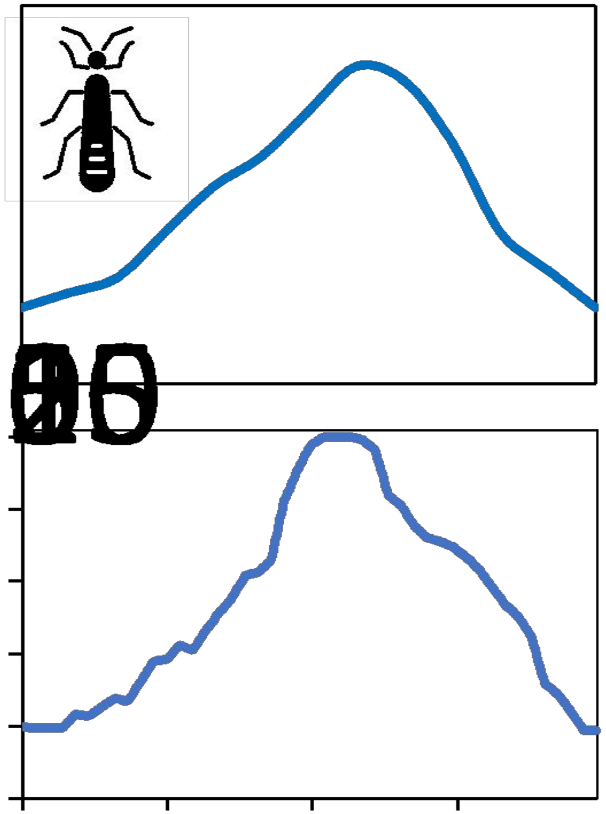
Develop a model to illustrate how fish movement between natal and non-natal habitats influences salmon life history diversity and population abundance



Model Description

Individual based model that tracks growth, movement, and survival of juvenile salmon across watersheds (*sensu* Railsback et al. InStream; Fullerton et al. 2017; Bellmore et al. 2022)

- **Growth:** function of seasonal food and temperature regimes, and competition



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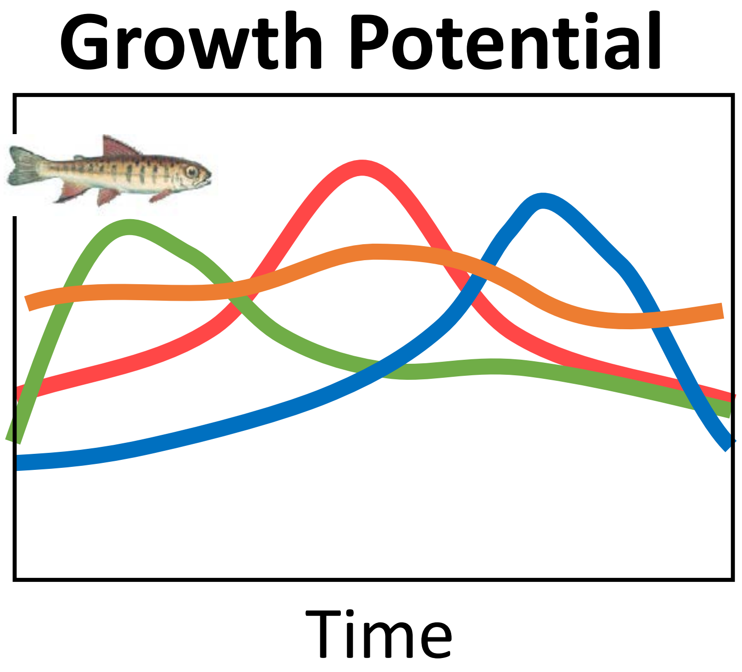
- **Growth:** function of seasonal food and temperature regimes, and competition
- **Movement:** function of difference in growth potential between connected habitats



Model Description

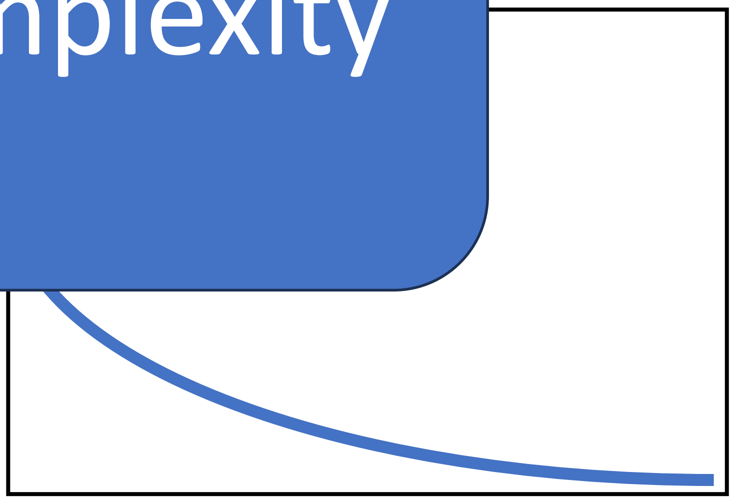
Individual based model that tracks growth, movement, and survival of juvenile salmon a

InStream; F

- **Growth:** ... y
  regimes,
- **Moveme**
  between
- **Survival:** function of fish size (more growth = greater survival)

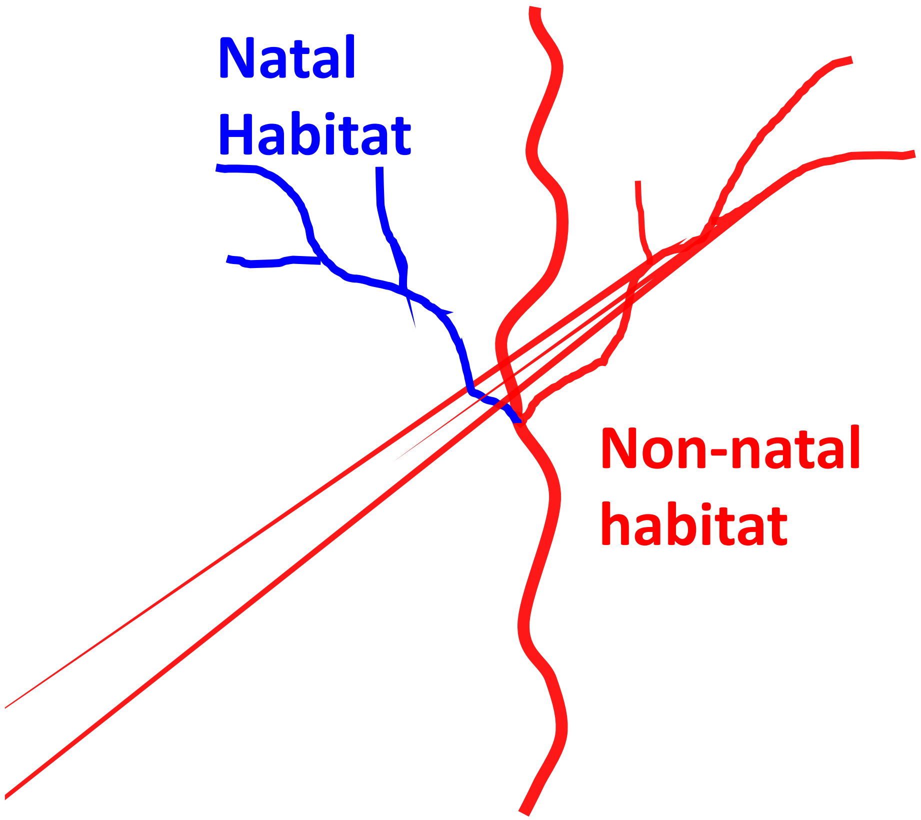
Hueristic model!

Start simple and build complexity as necessary.



Objectives

1. Examine mechanisms by which accessible and diverse non-natal habitat promotes salmon life history diversity and population abundance.



Objectives

1. Examine mechanisms by which accessible and diverse non-natal habitat promotes salmon life history diversity and population abundance.

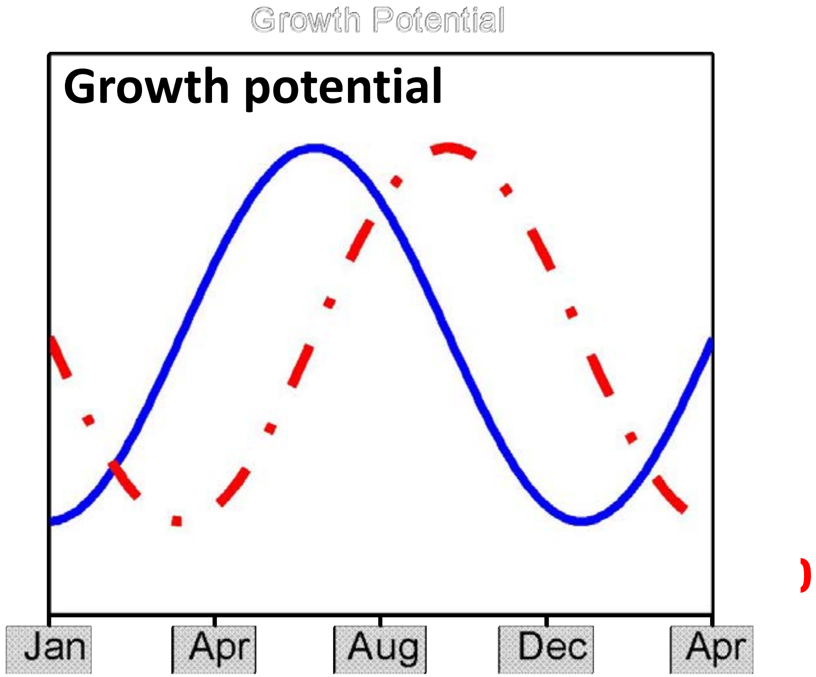
2. Illustrate how these mechanisms support healthy salmon populations in northern California coastal watersheds.

Objectives

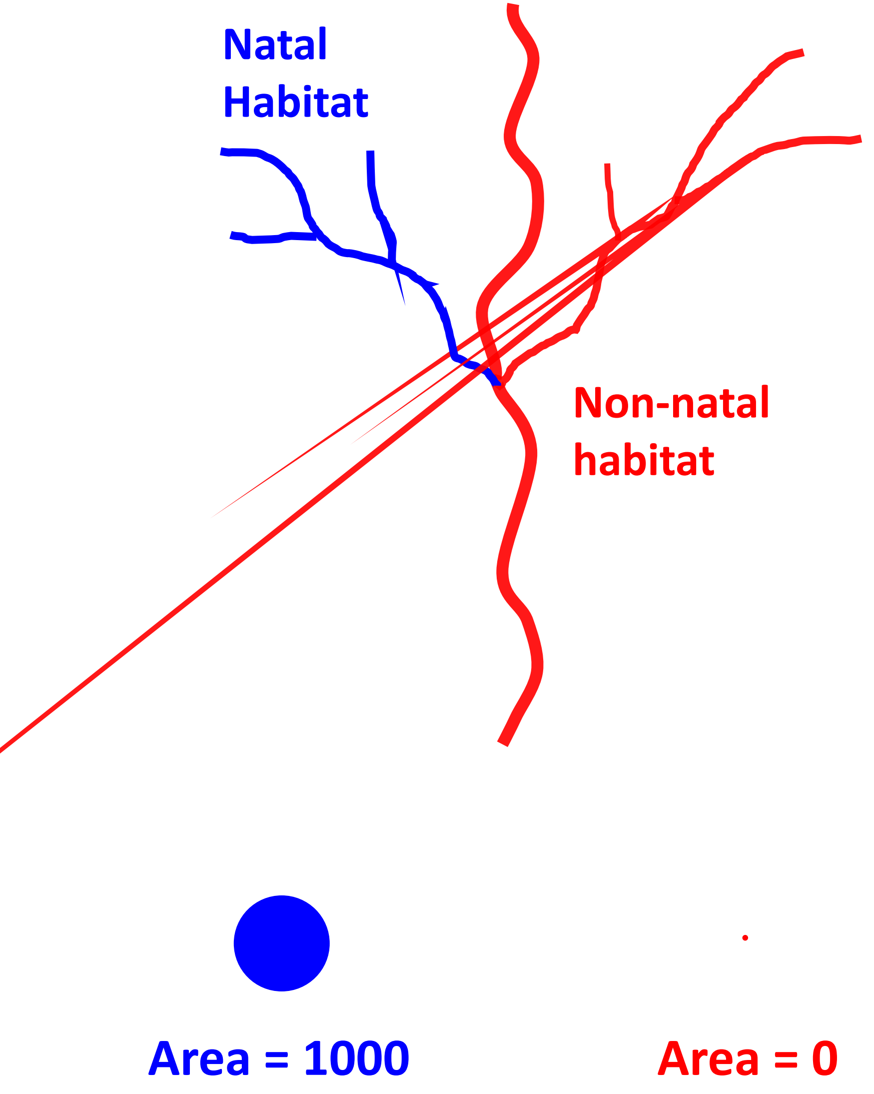
- Simple 2 patch model

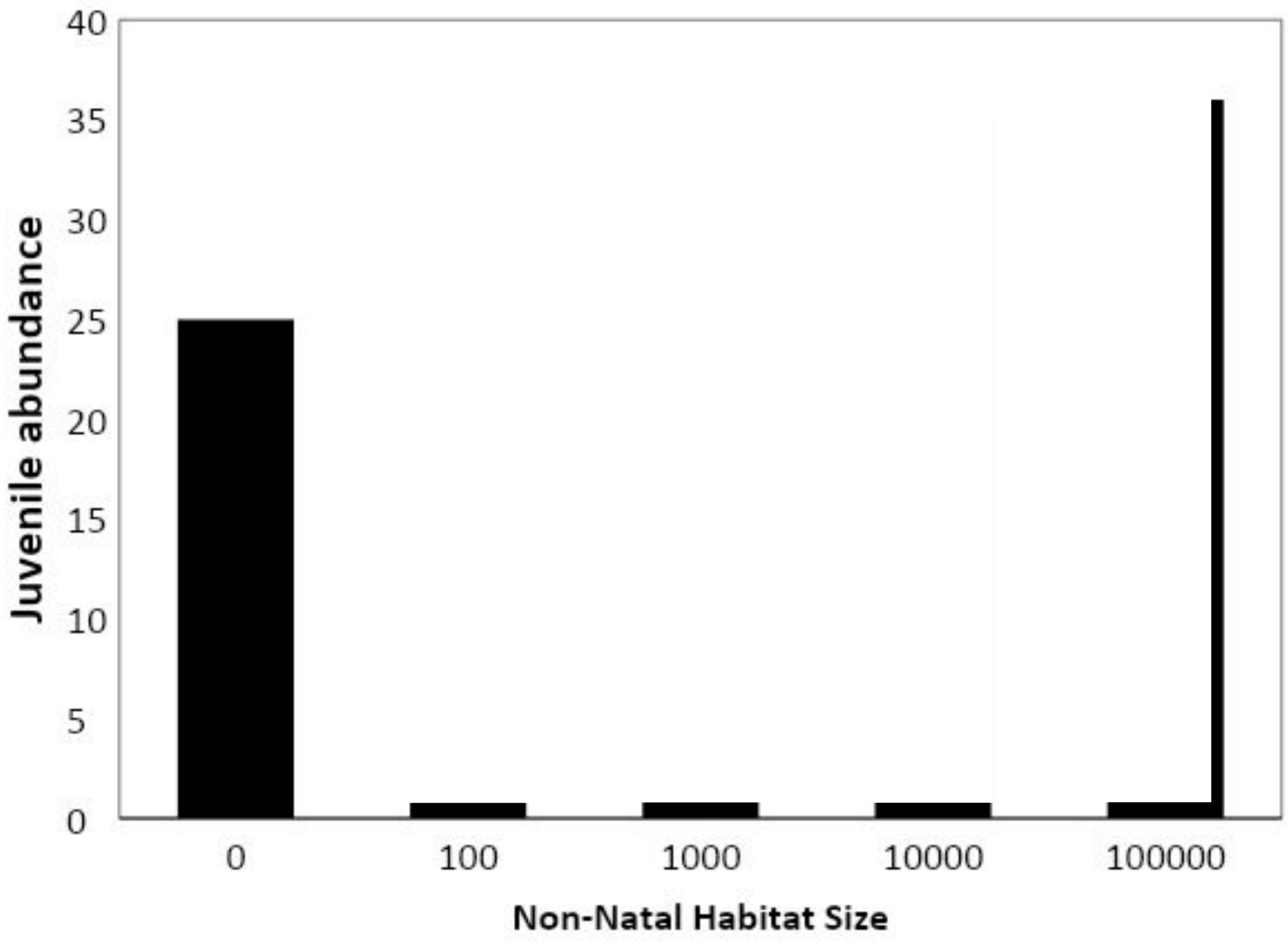
- Manipulated:
    1. Non-natal habitat size
    2. Non-natal temperature and food availability regimes

- Initialized model with 1000 fry and tracked juvenile growth and survival for 365 day



Mechanism 1: More non-natal habitat makes more fish





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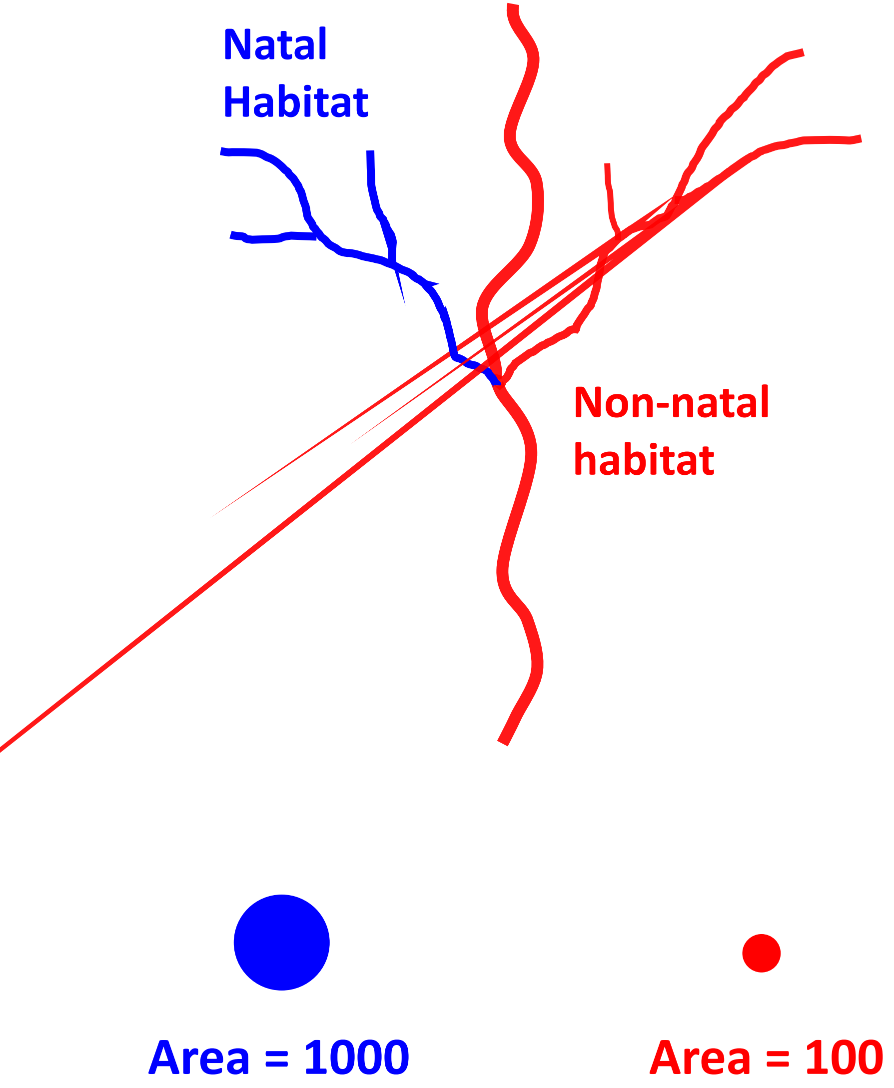

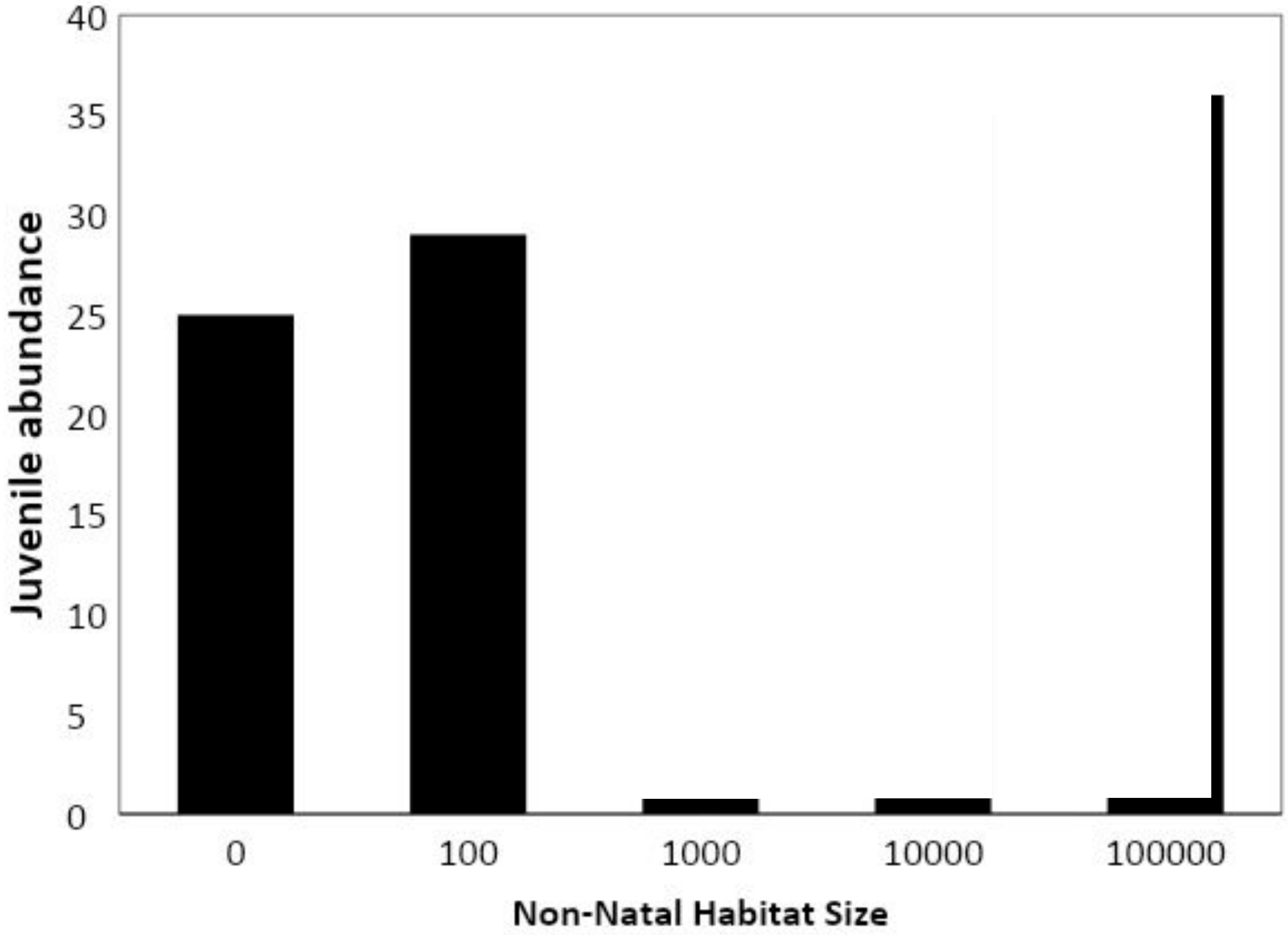

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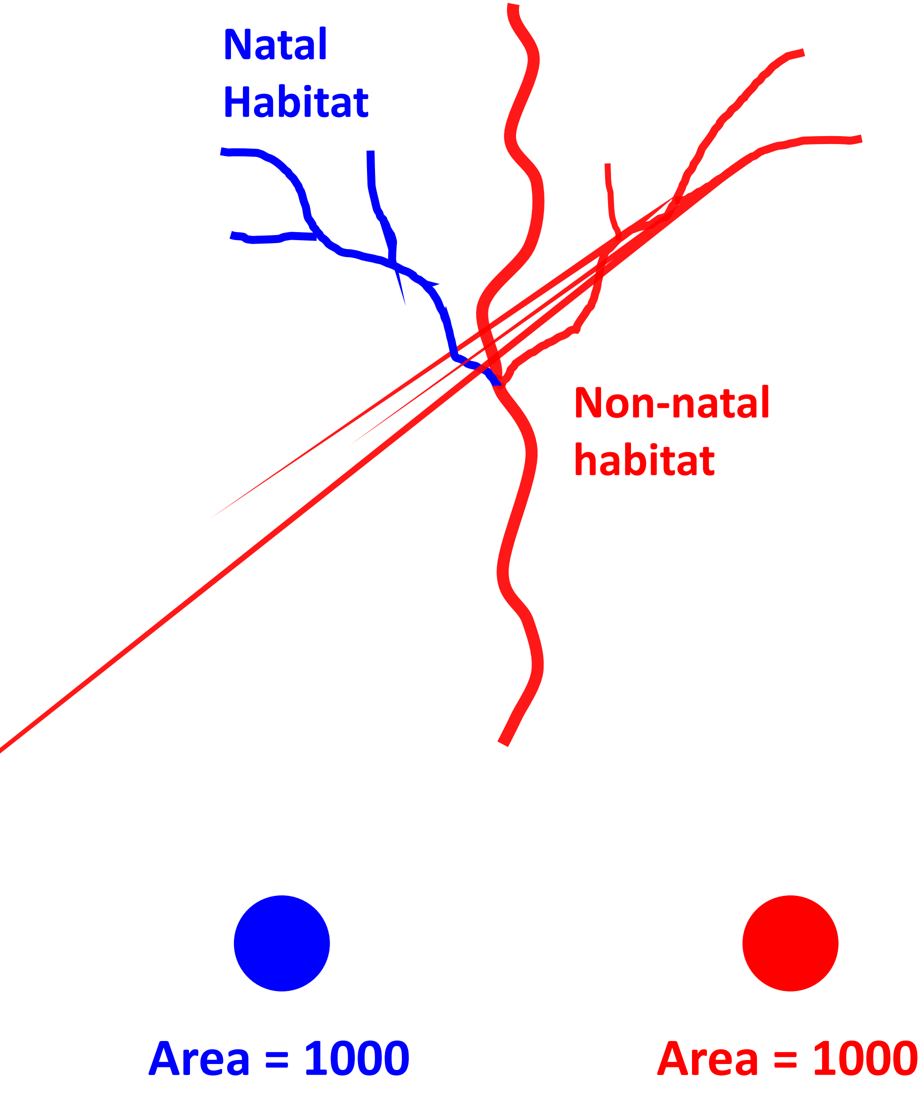

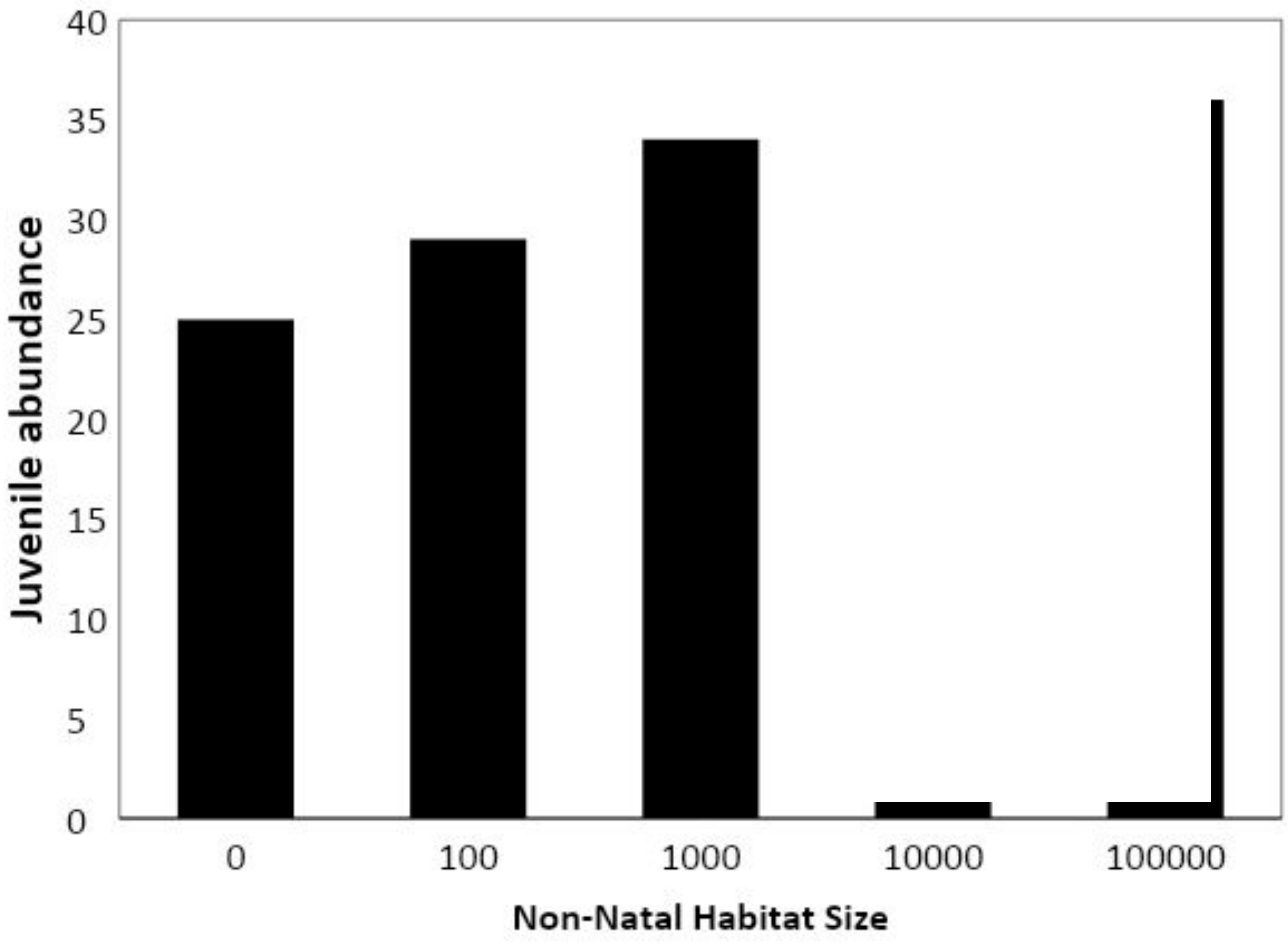

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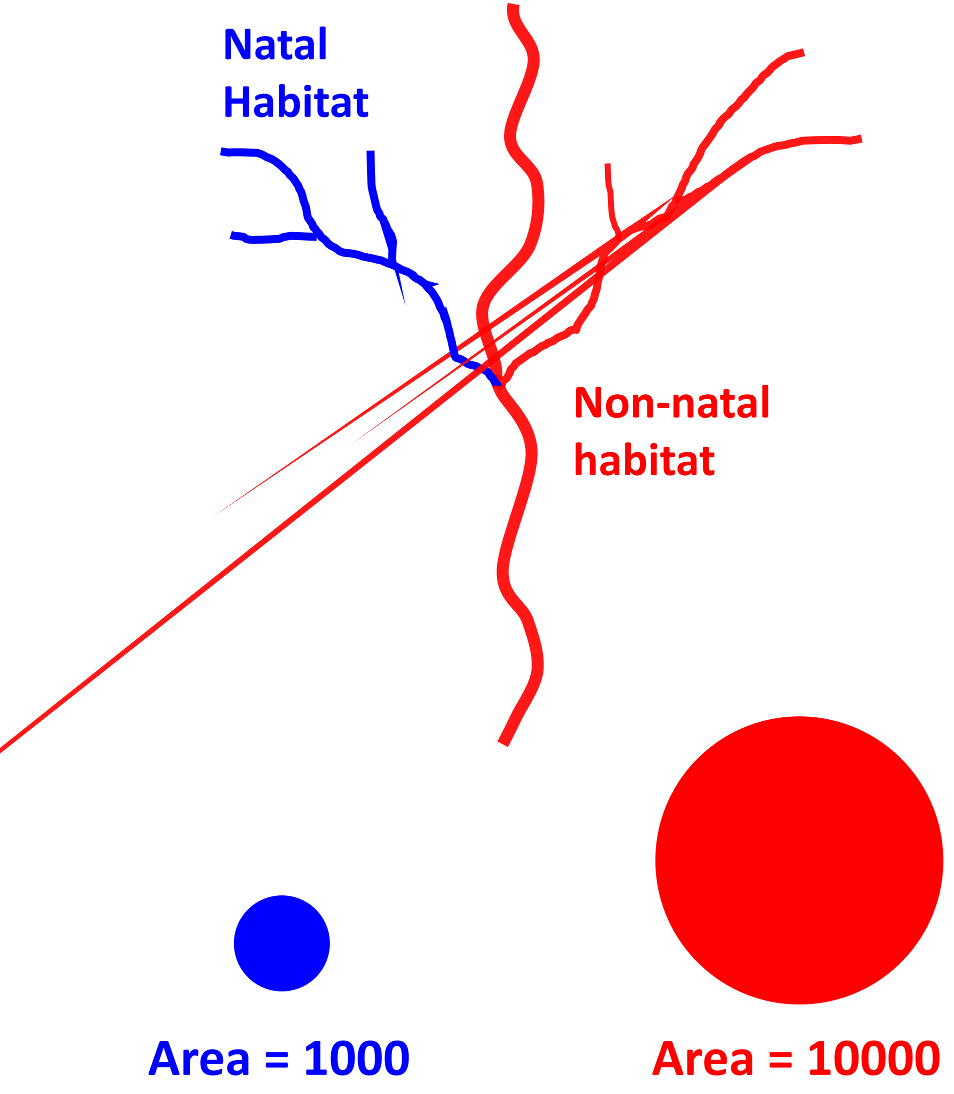
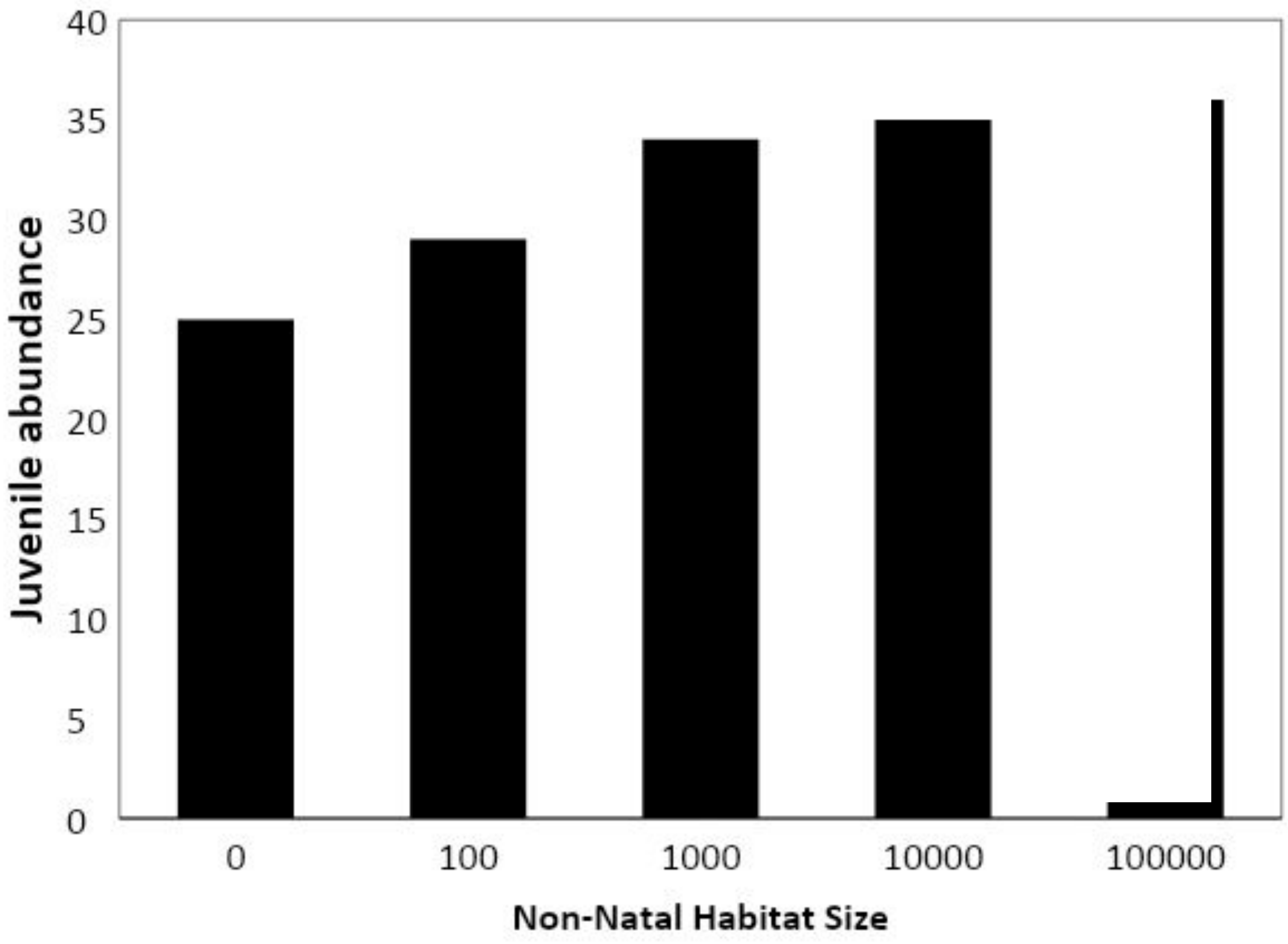
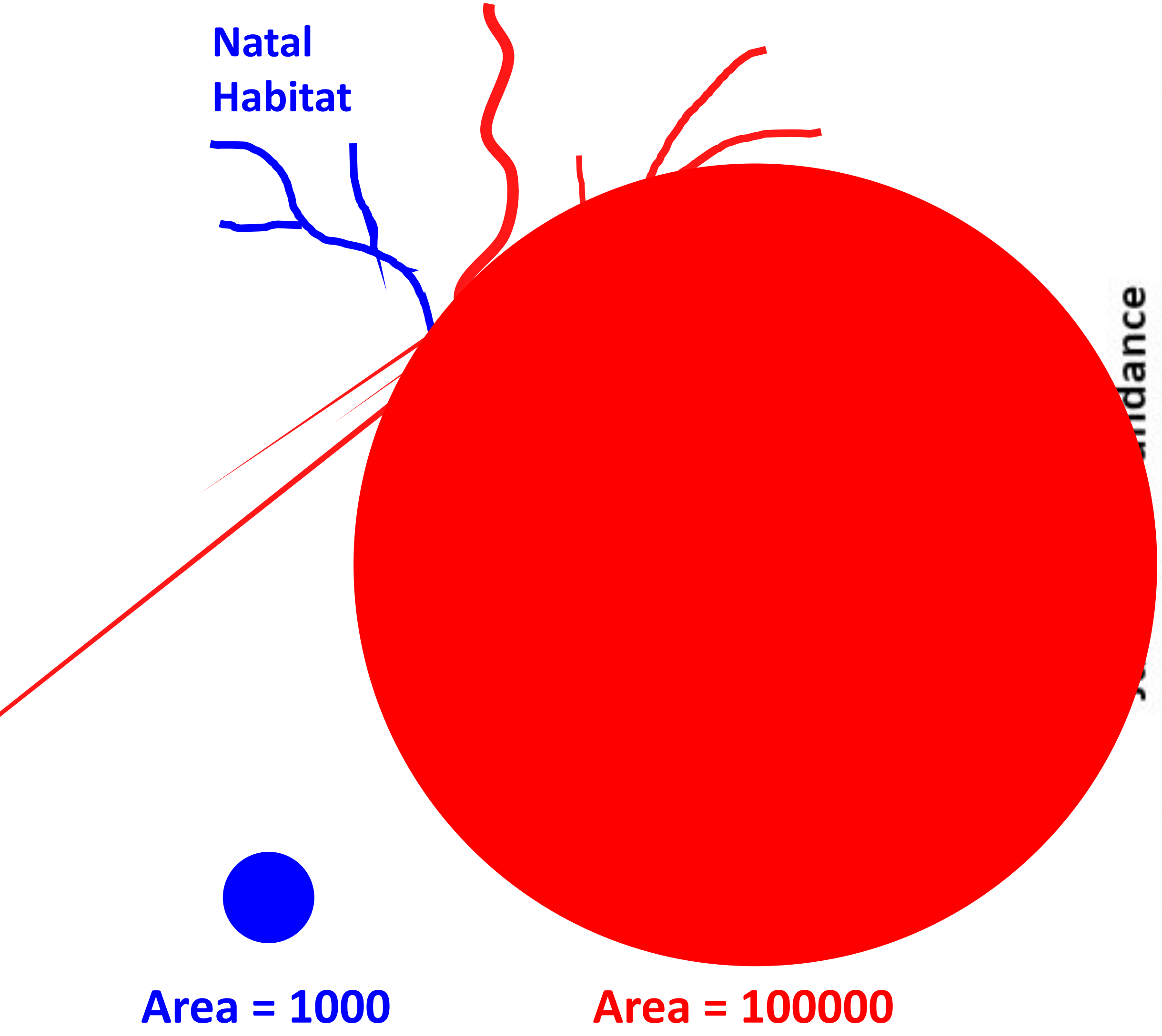
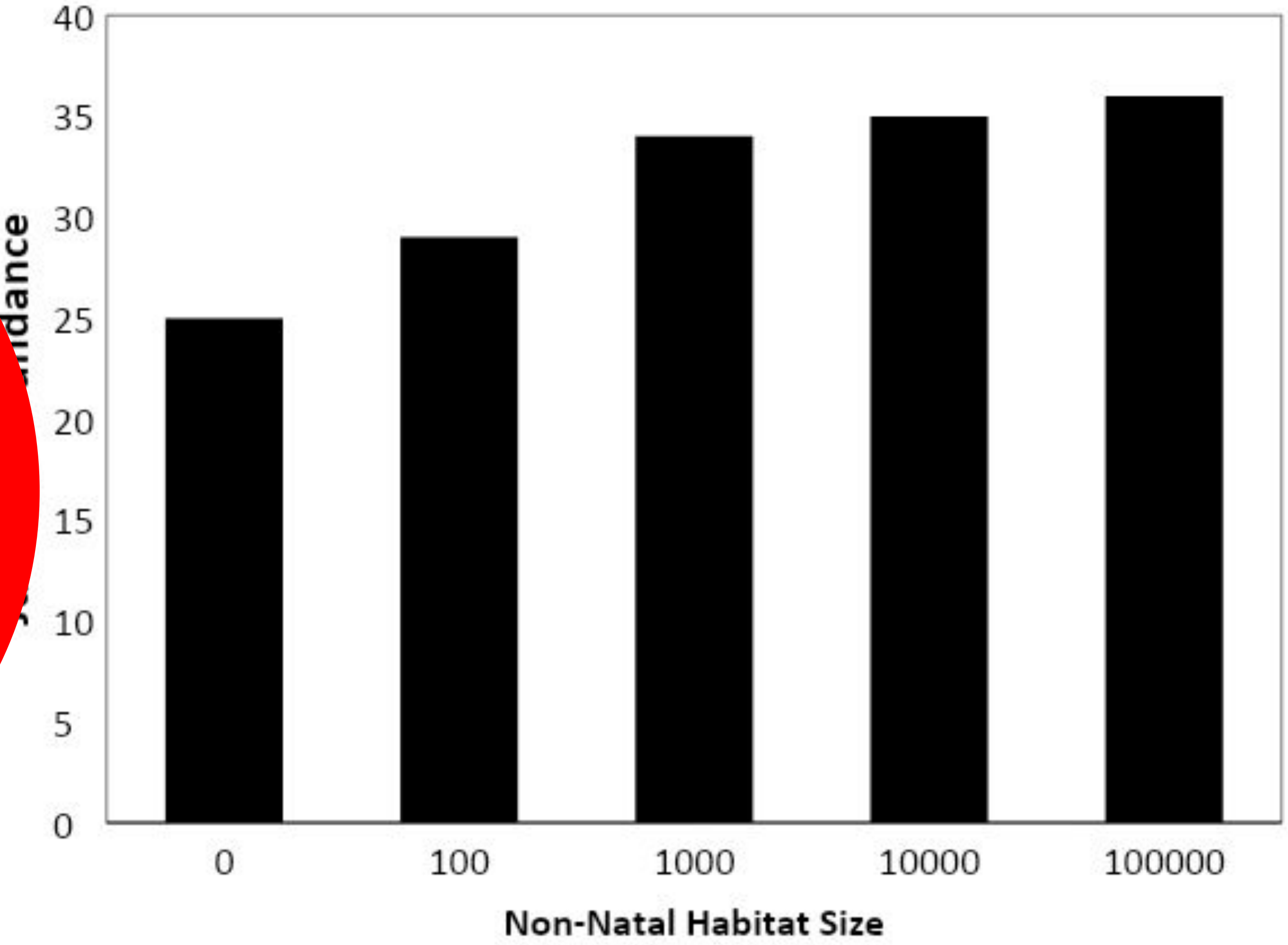




Mechanism 1: More non-natal habitat makes more fish

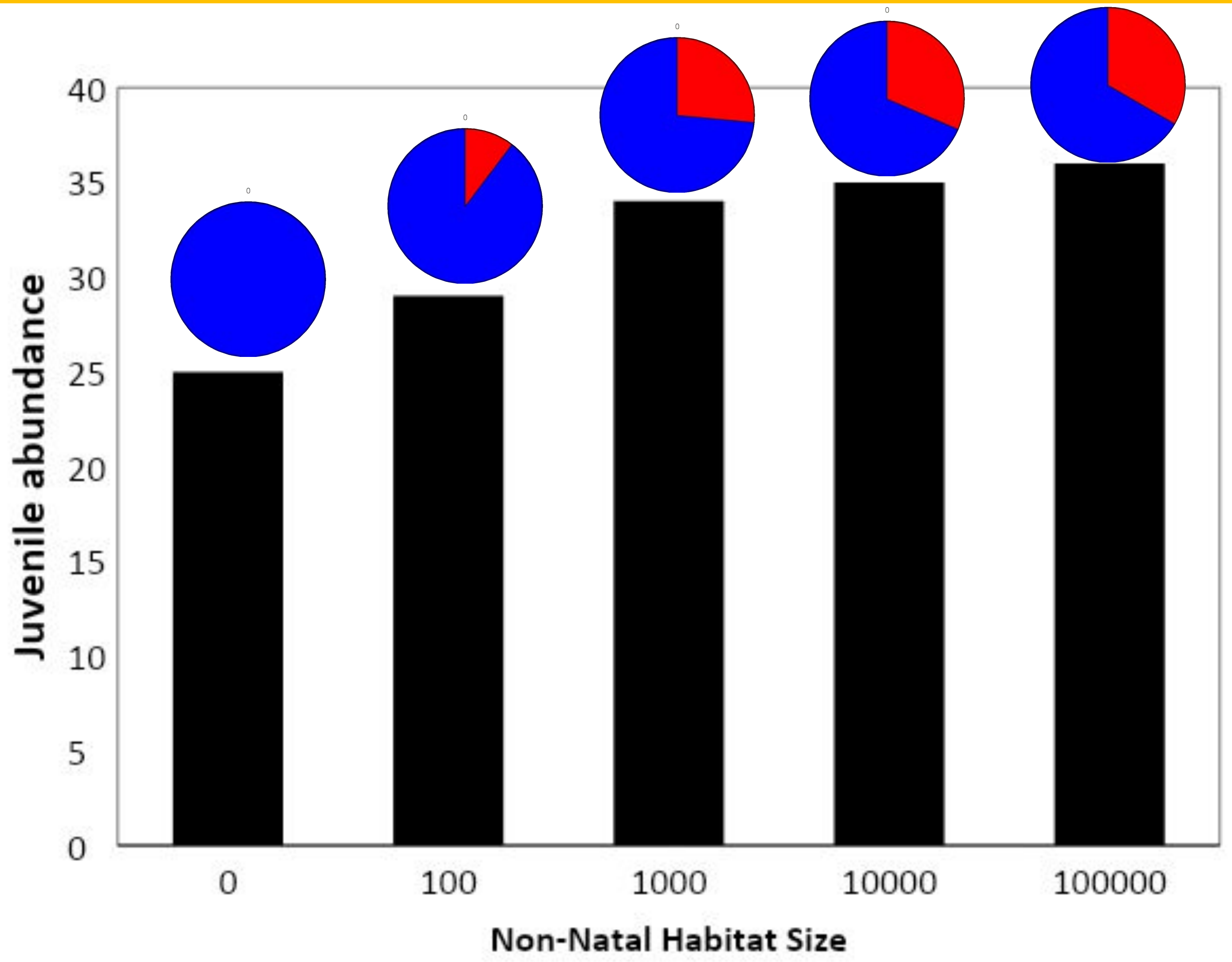




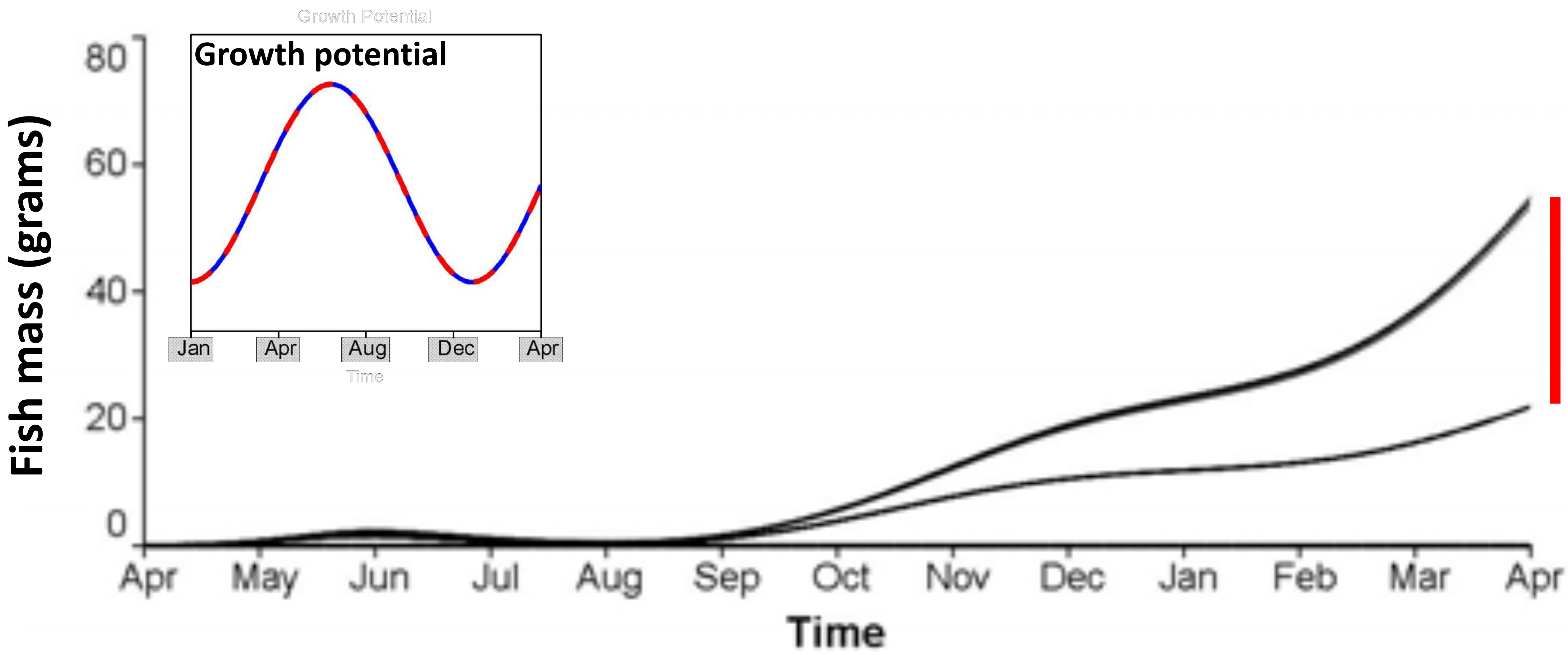
Mechanism 1: More non-natal habitat makes more fish

Mechanism: movement into non-natal habitat alleviates density dependence for fishes that move (non-natal fishes) and those that stay (natal fishes).

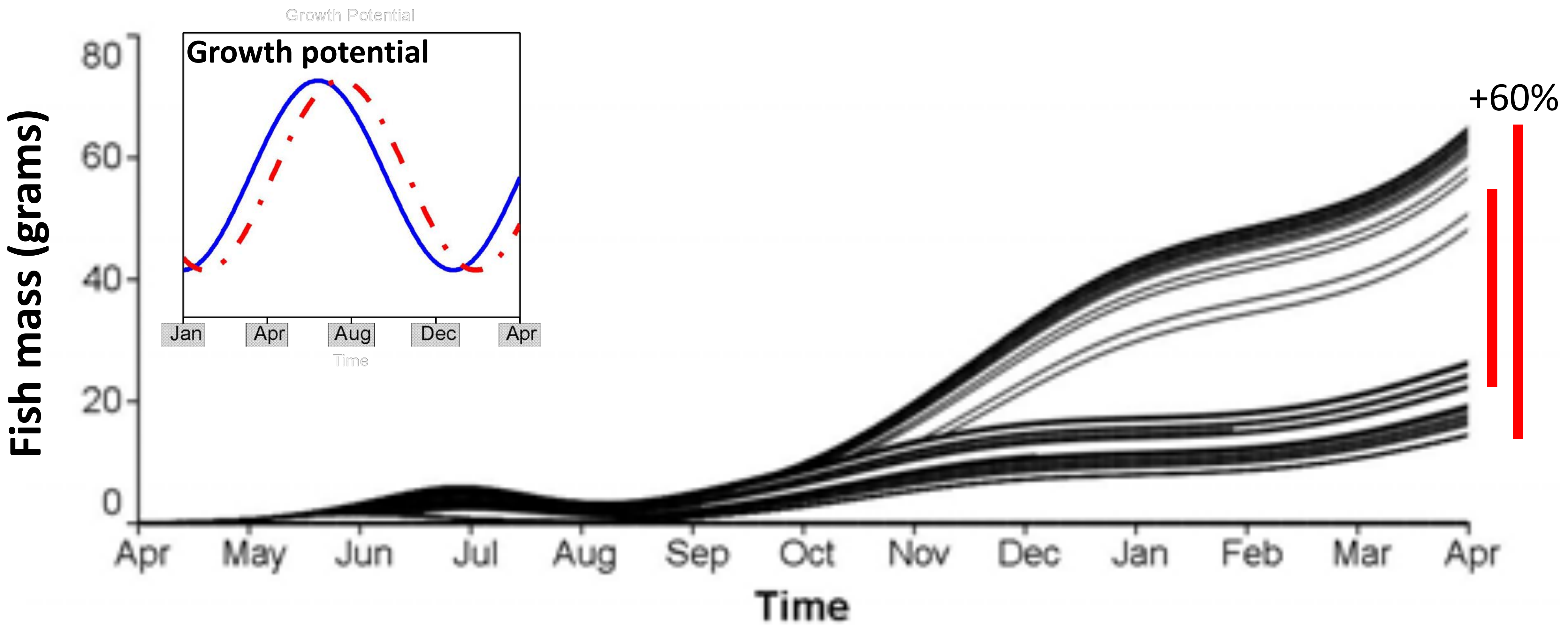
Non-natal habitats must be accessible and suitable!



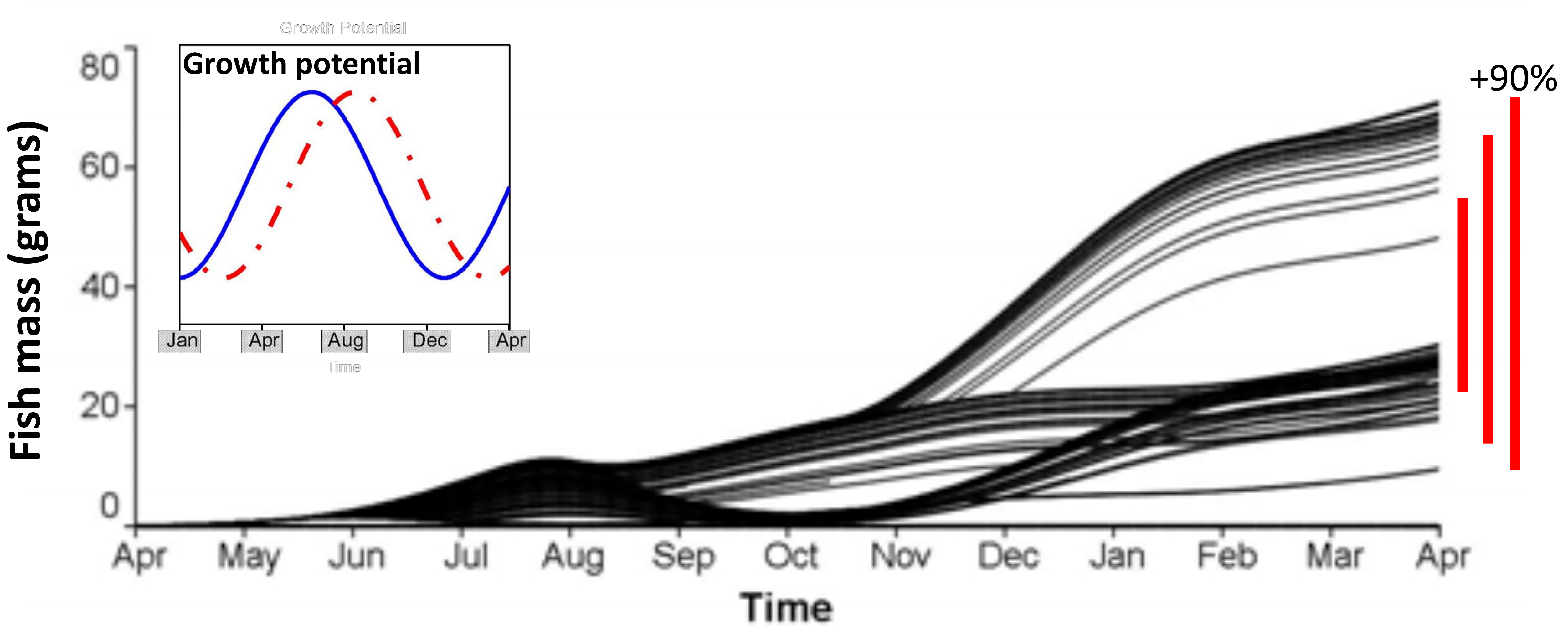
Mechanism 2: Habitat diversity promotes life history diversity



Mechanism 2: Habitat diversity promotes life history diversity

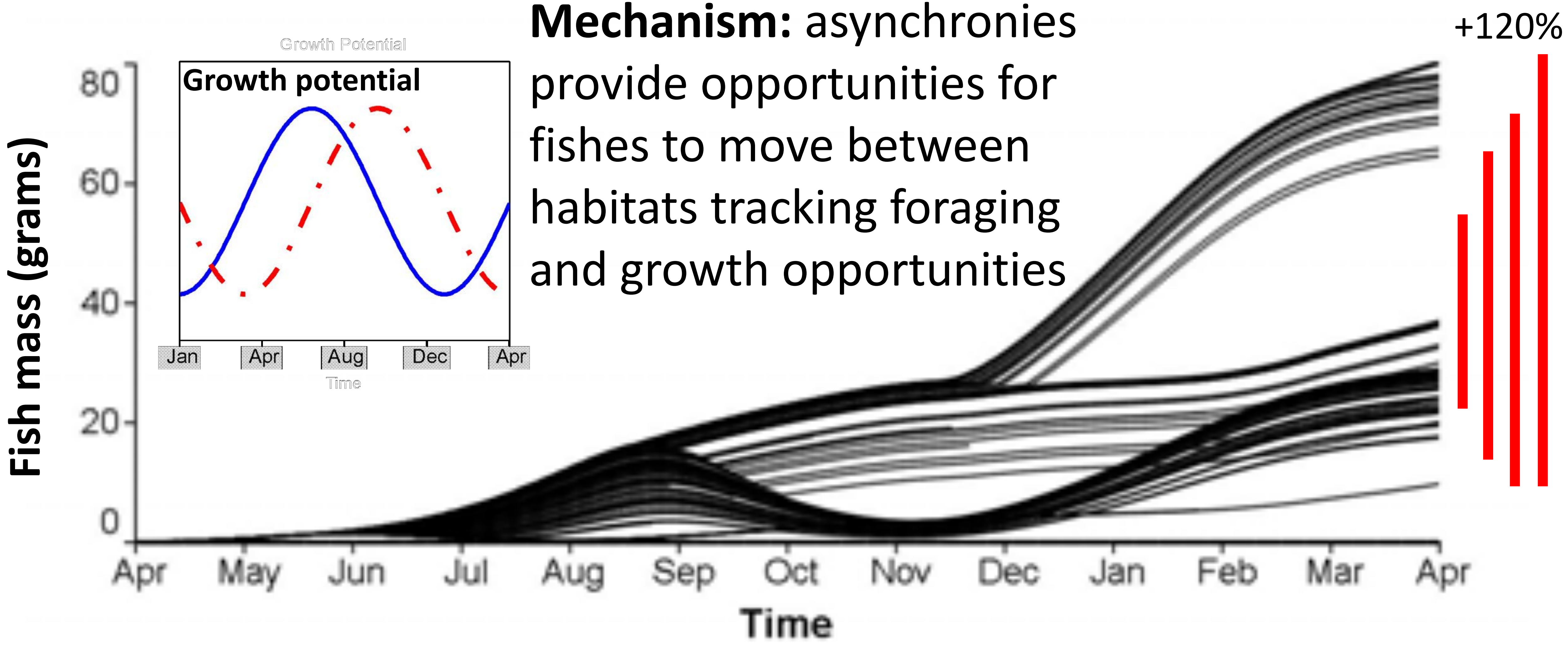


Mechanism 2: Habitat diversity promotes life history diversity

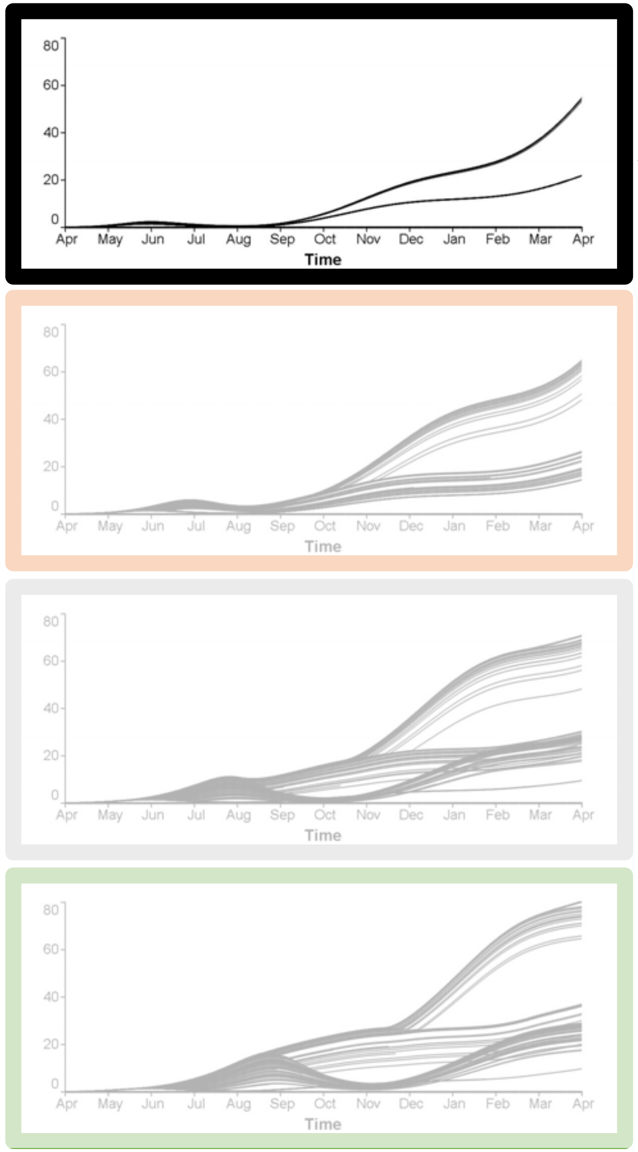


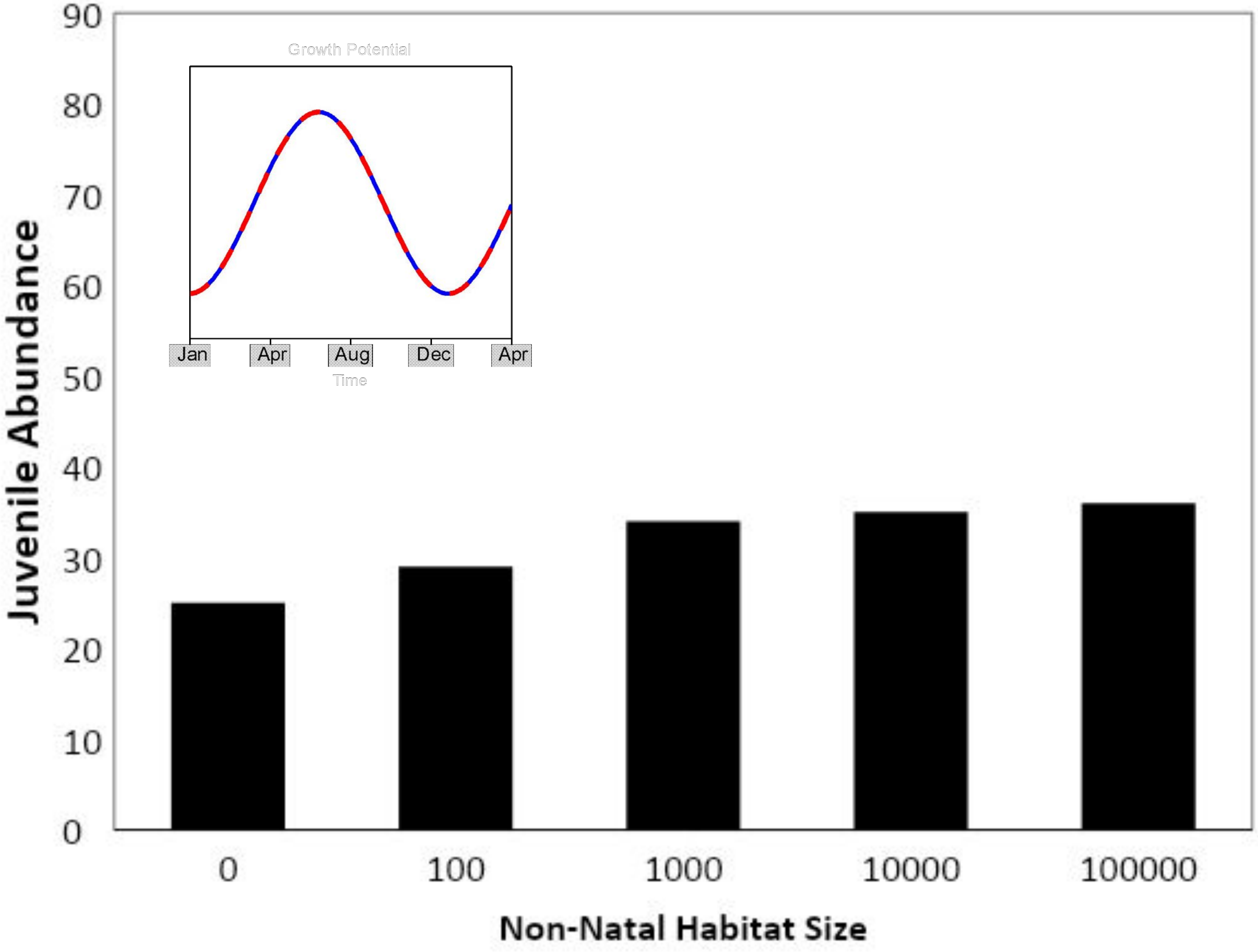
Mechanism 2: Habitat diversity promotes life history diversity

Mechanism: asynchronies provide opportunities for fishes to move between habitats tracking foraging and growth opportunities

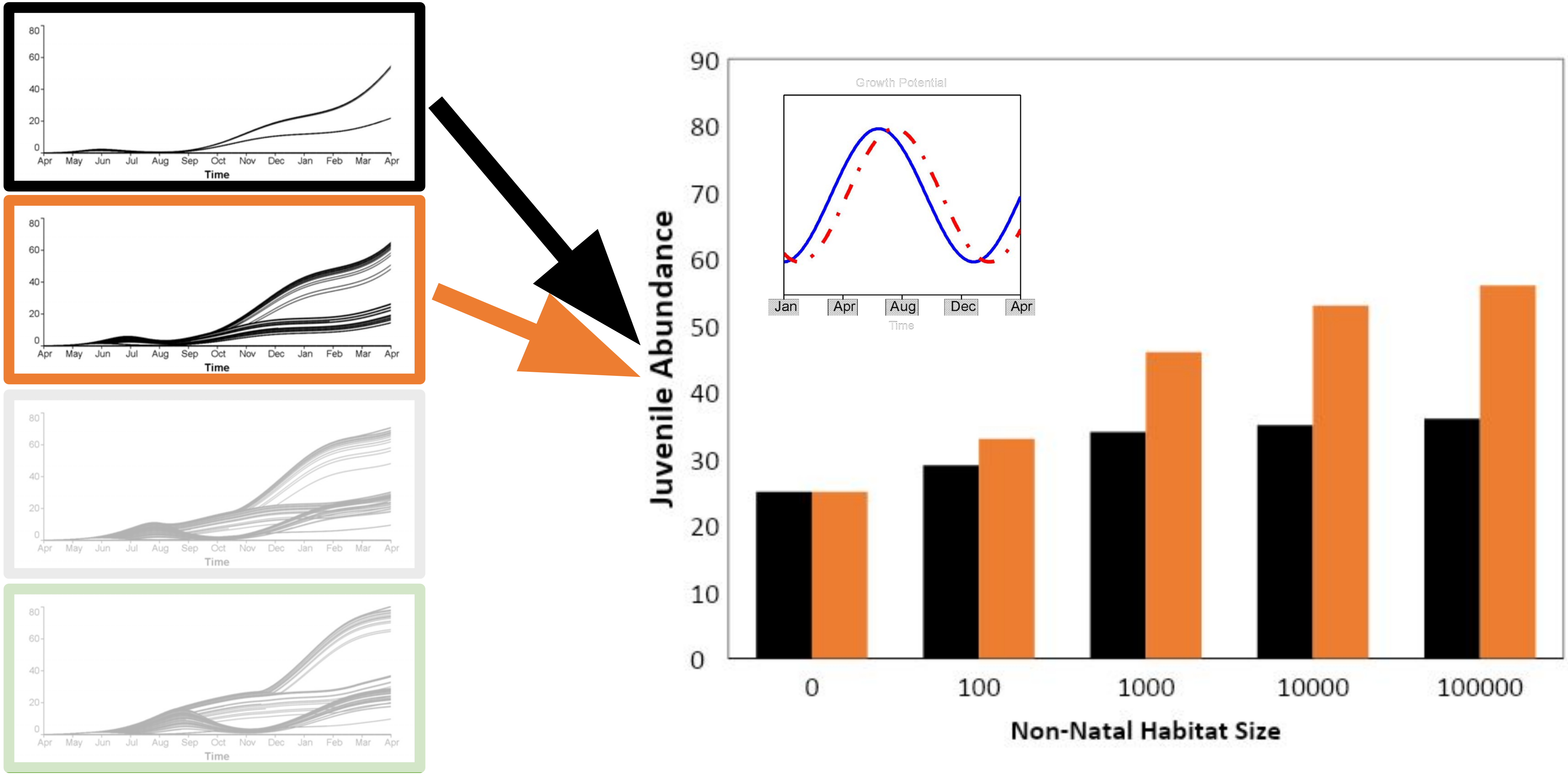


Mechanism 3: Freshwater life history diversity promotes population abundance

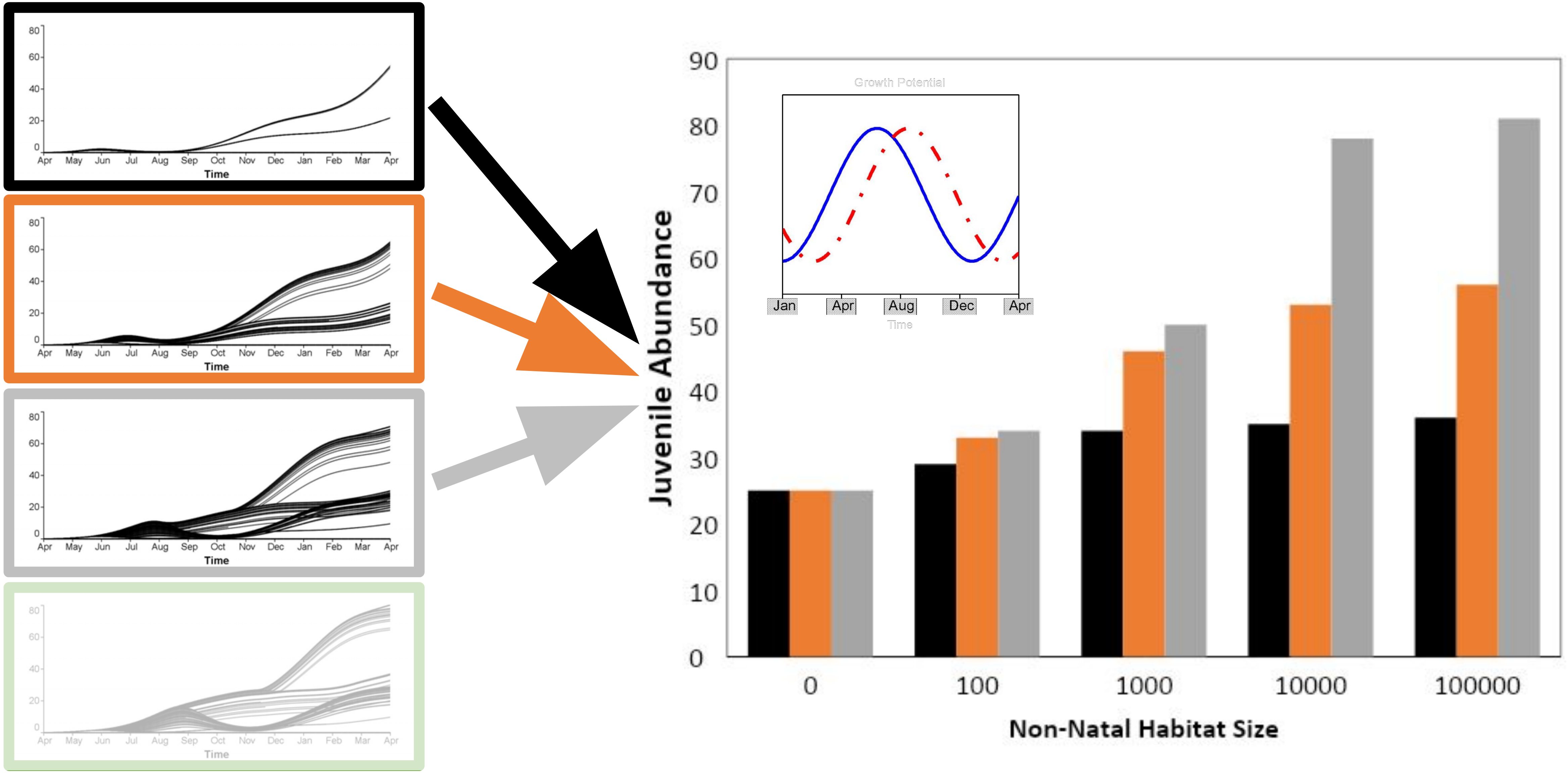




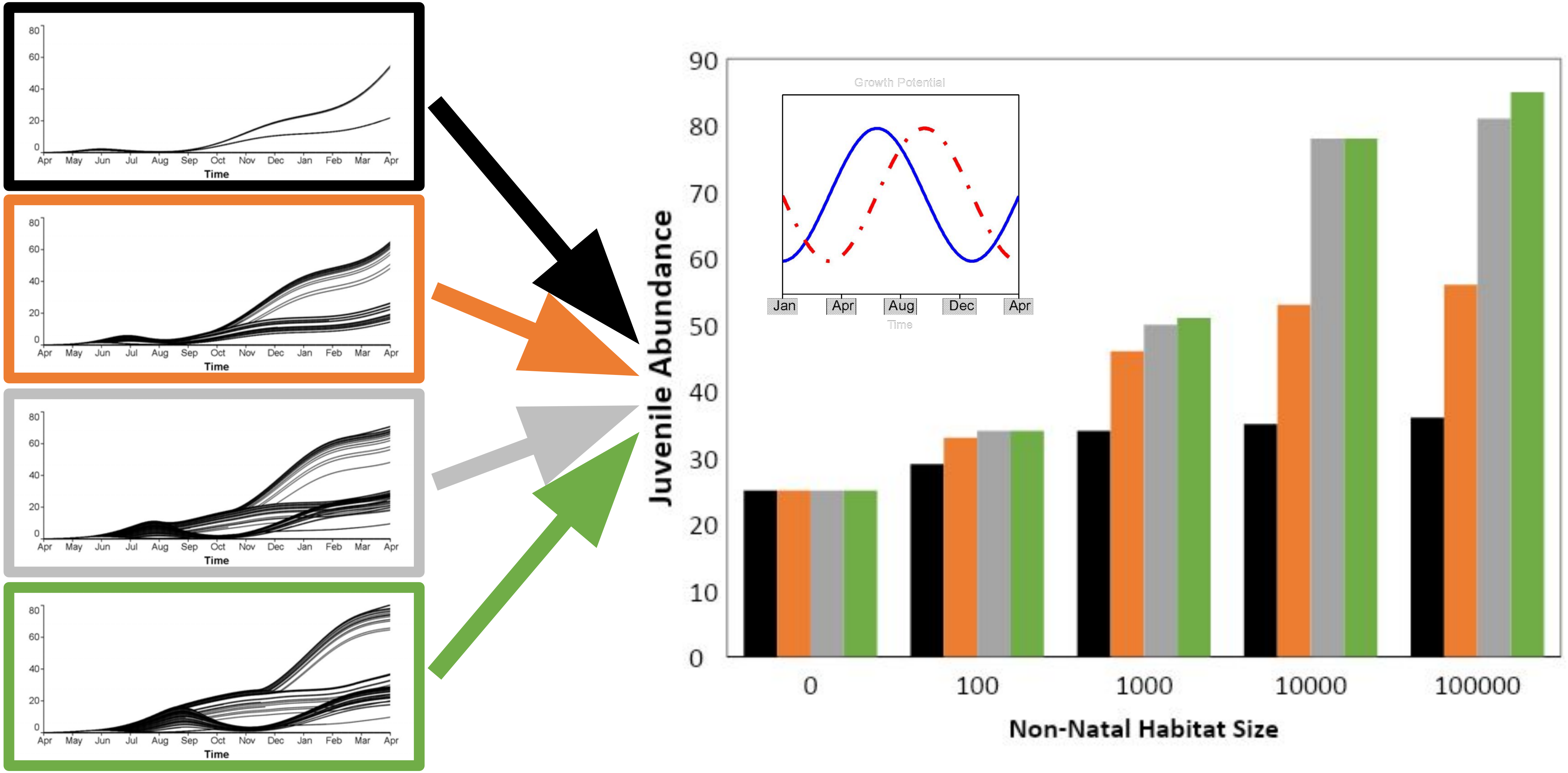
Mechanism 3: Freshwater life history diversity promotes population abundance



Mechanism 3: Freshwater life history diversity promotes population abundance



Mechanism 3: Freshwater life history diversity promotes population abundance

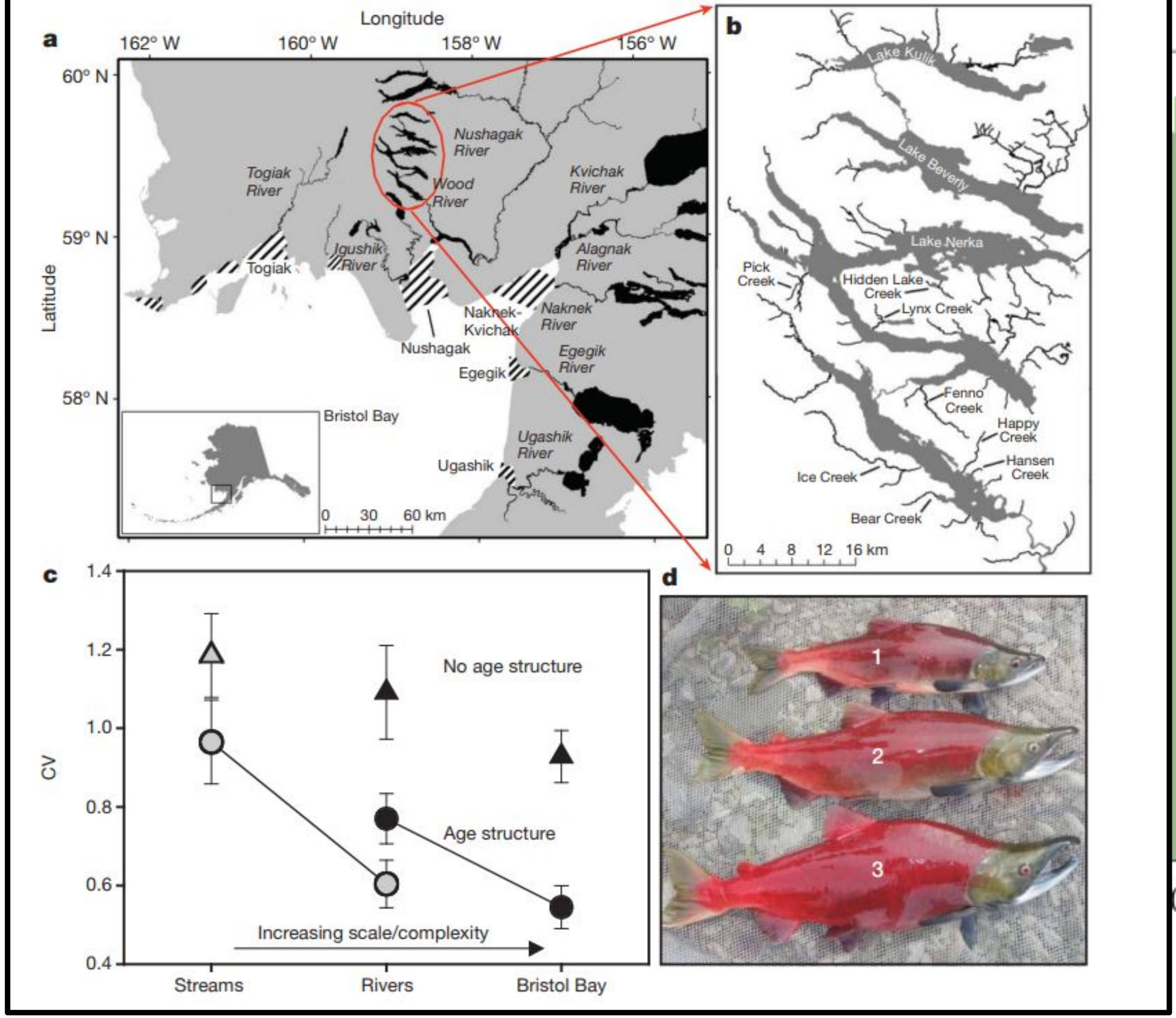


Mechanism 3: Freshwater life history diversity promotes population abundance

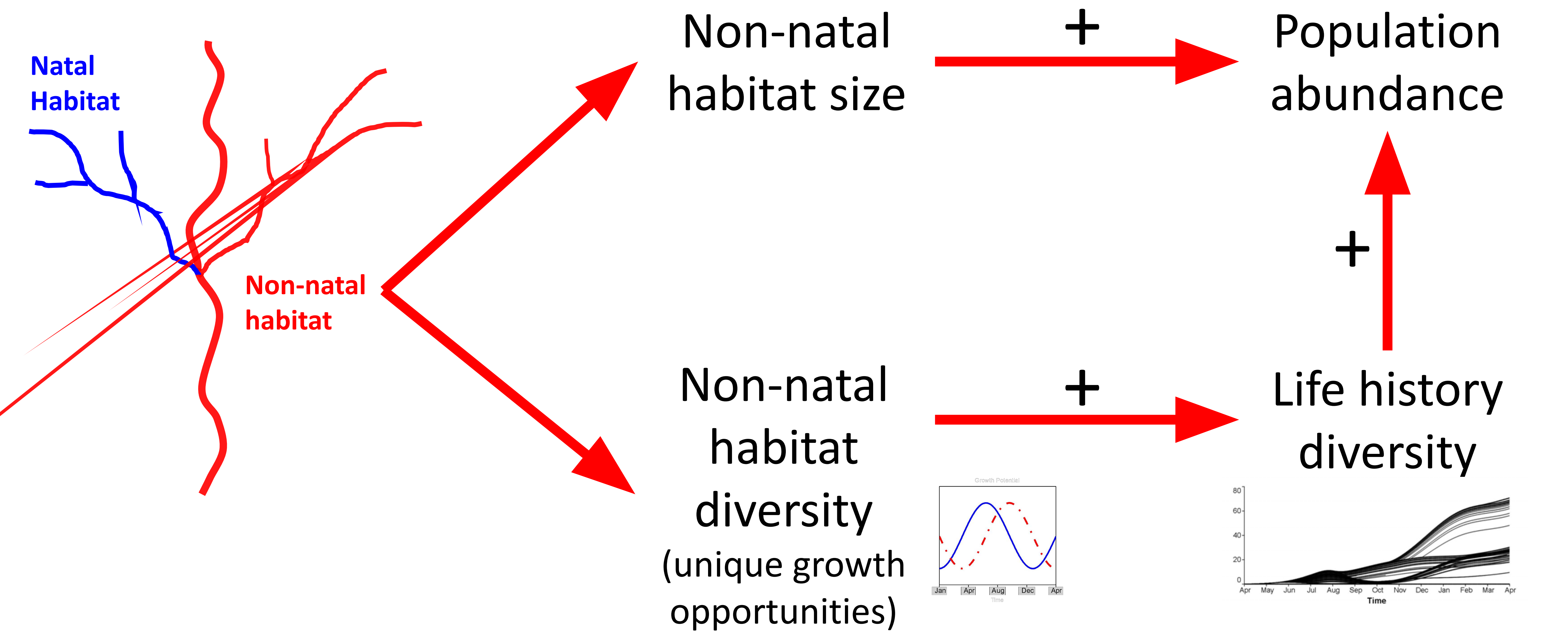
Life history diversity begets population abundance!

Mechanism: life histories that track favorable growth conditions grow larger and survive better.

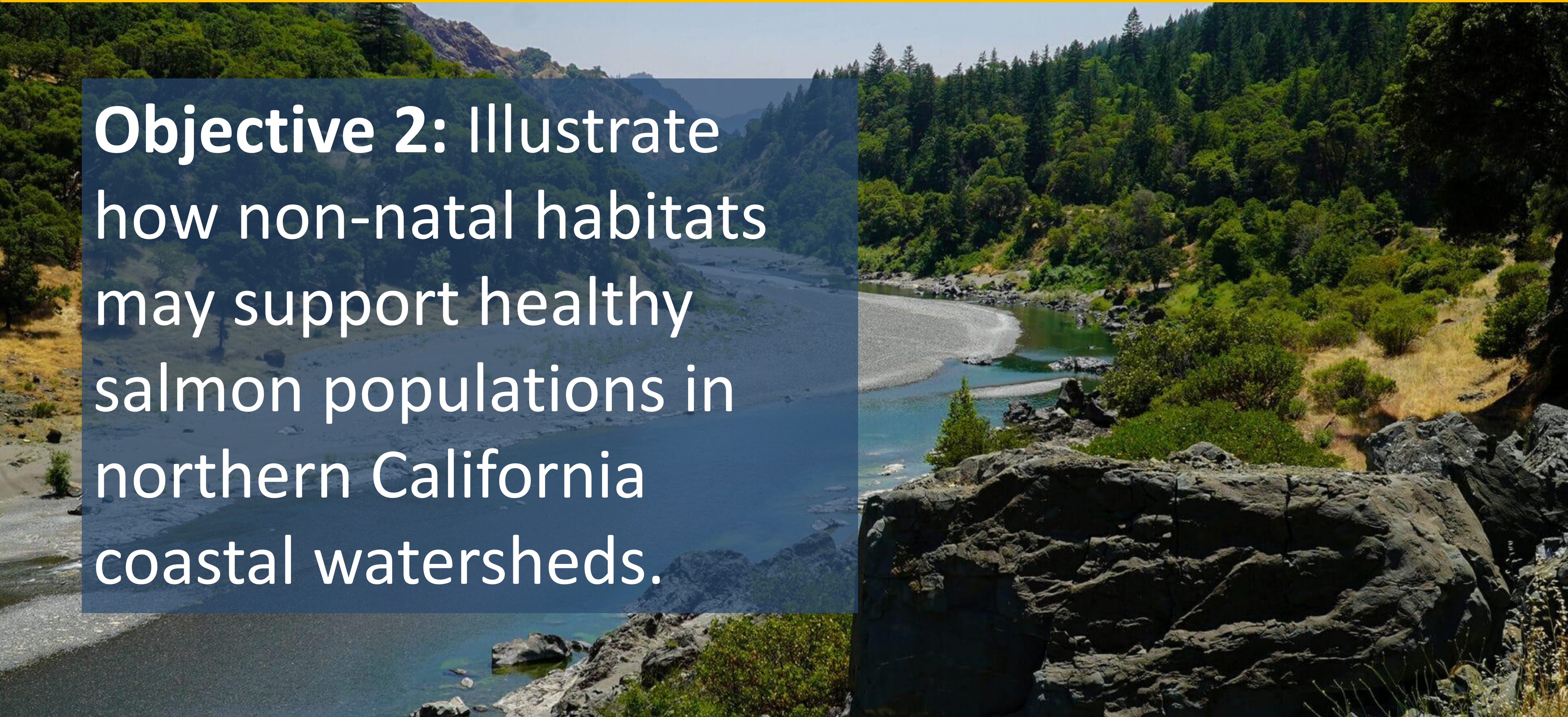
Schindler et al. 2010



Increasing the SIZE and DIVERSITY of non-natal habitats increases population abundance



Foodscape modeling in practice: A case study example



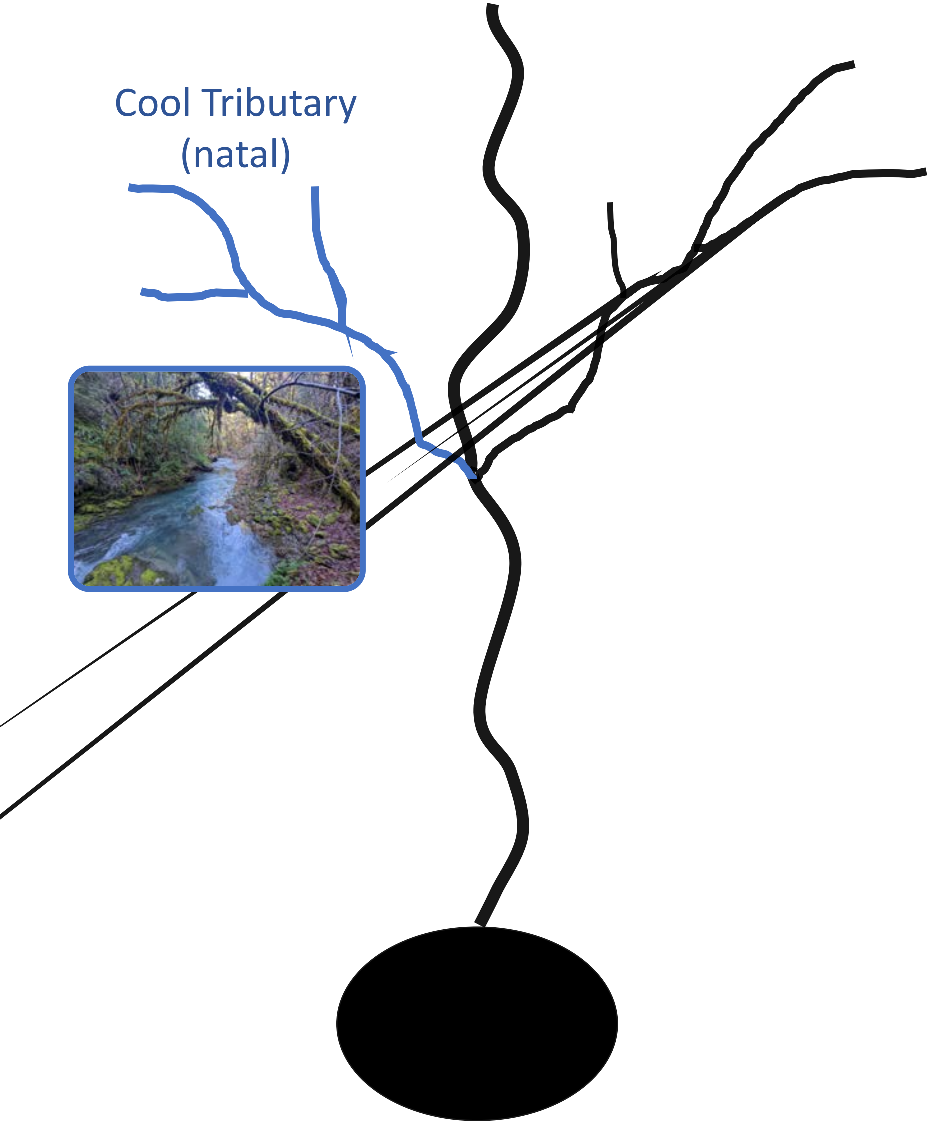
Objective 2: Illustrate how non-natal habitats may support healthy salmon populations in northern California coastal watersheds.

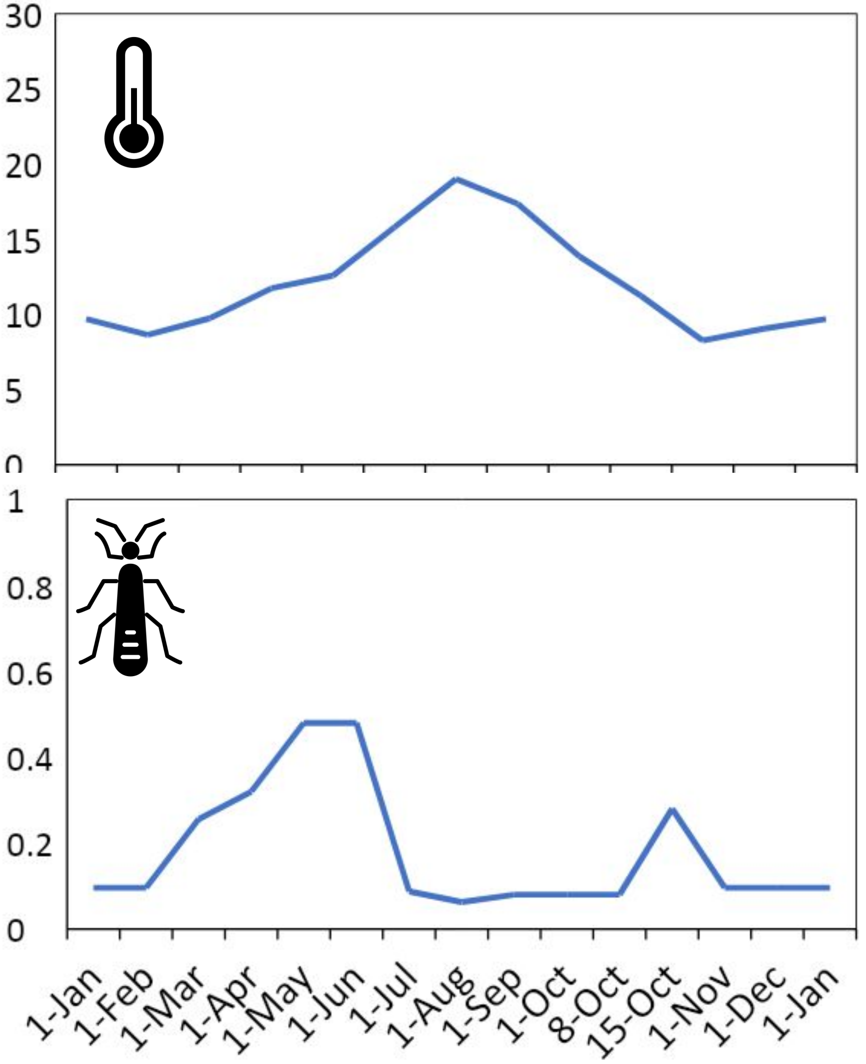
Foodscape modeling in practice: A case study example

Parameterized model with *realistic* food and temperature regimes for natal and non-natal habitats found in northern California coastal watersheds.

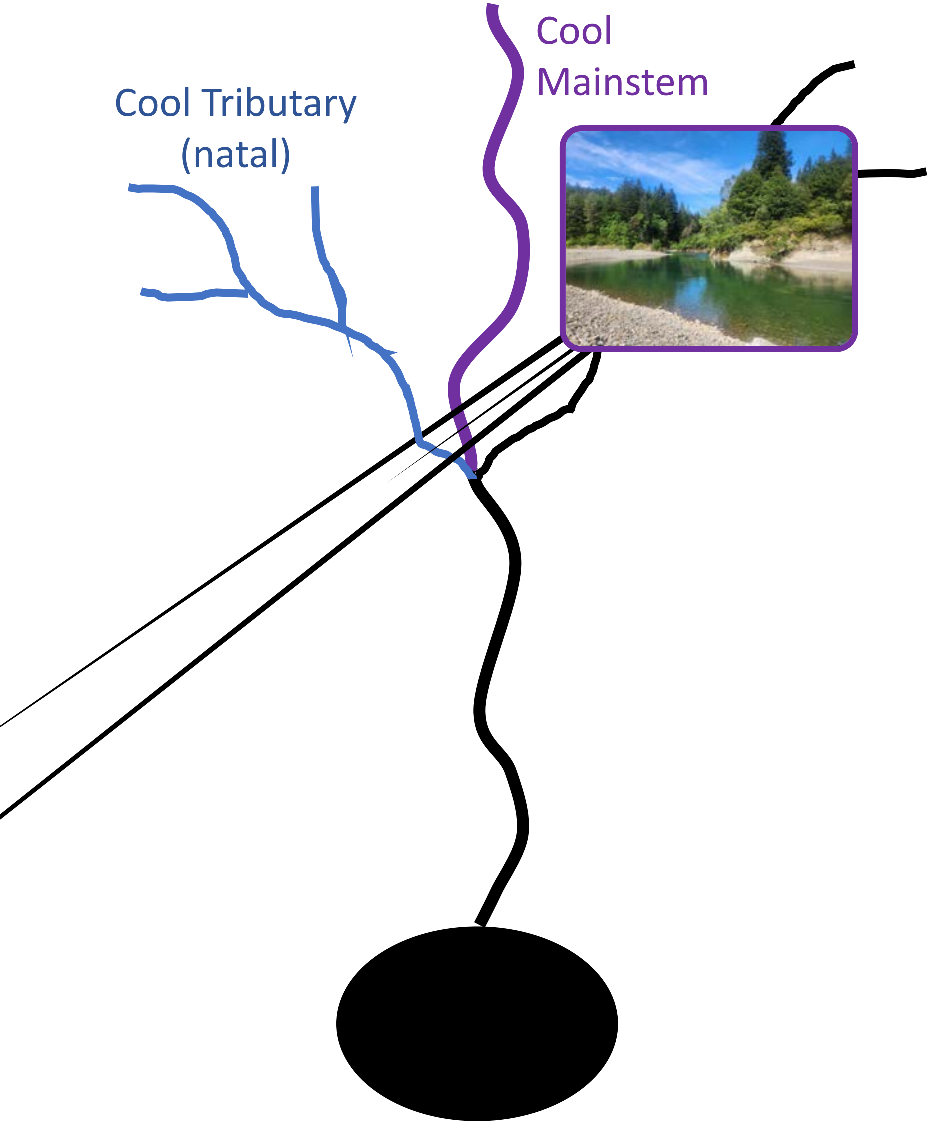
Inspired by the Eel River

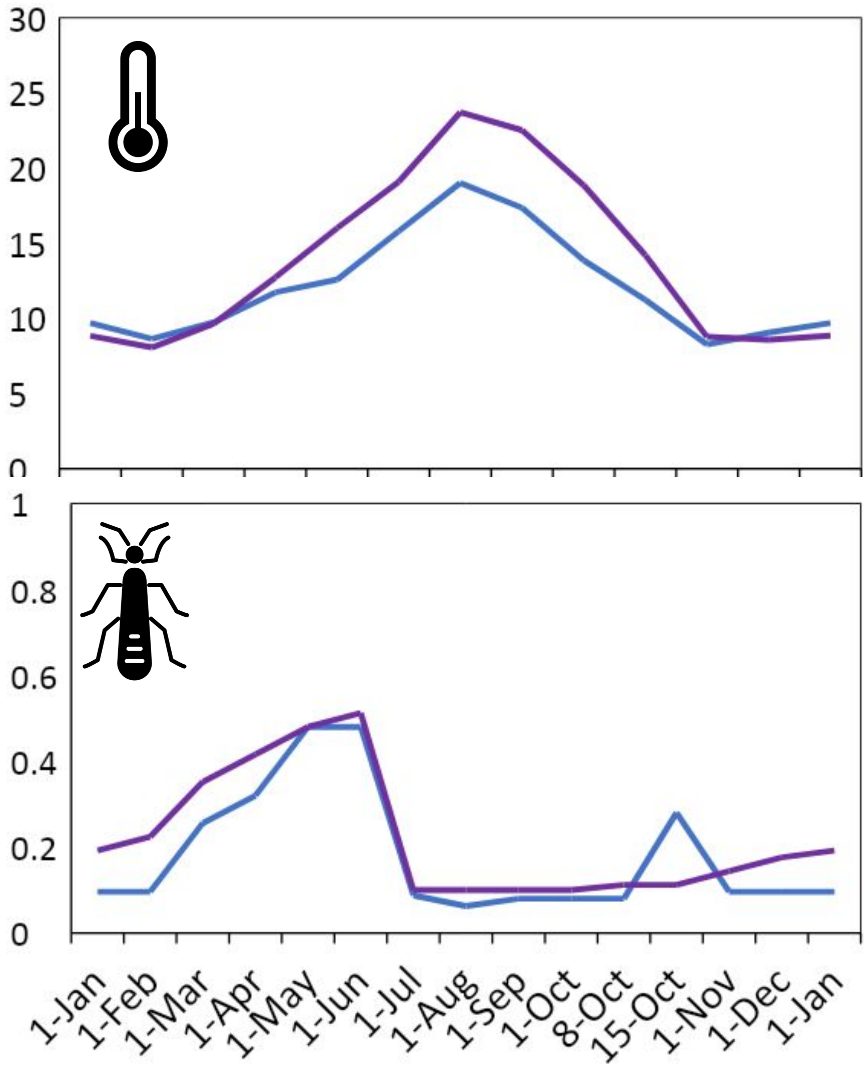
Foodscape modeling in practice: A case study example



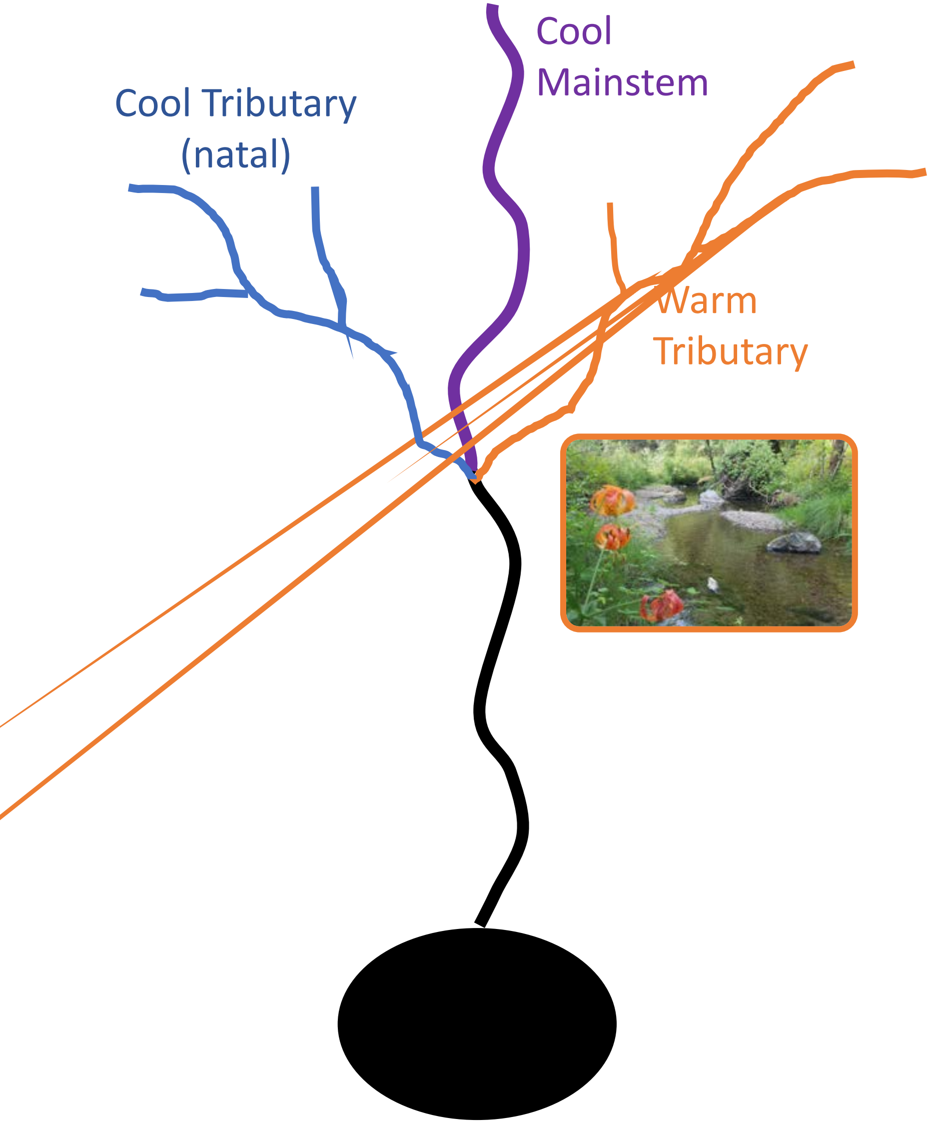


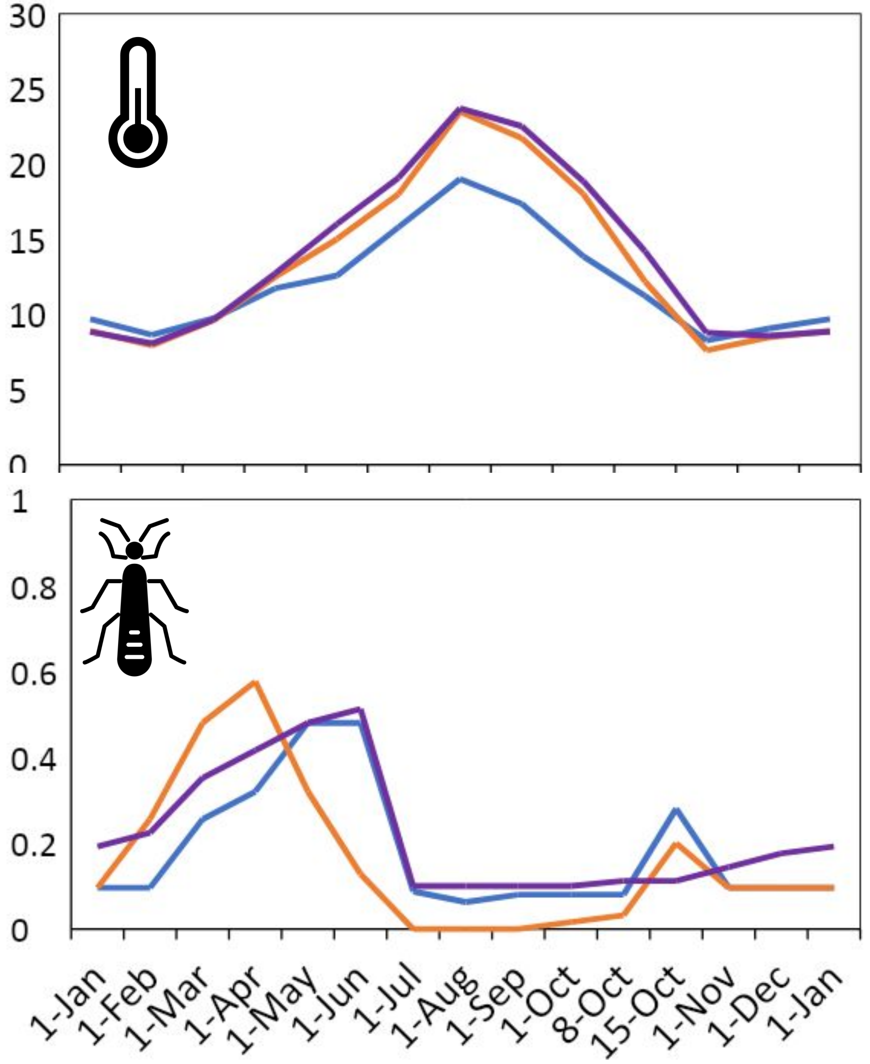
Foodscape modeling in practice: A case study example



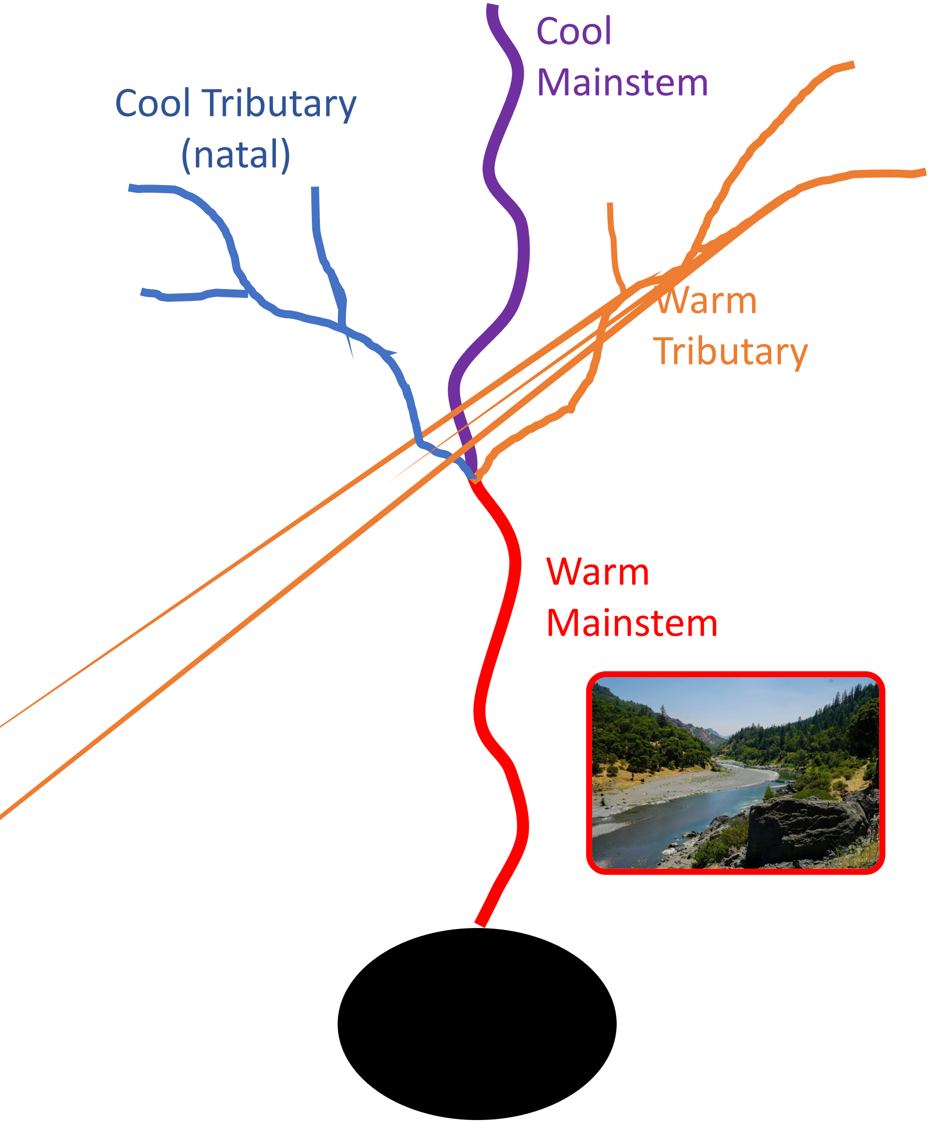


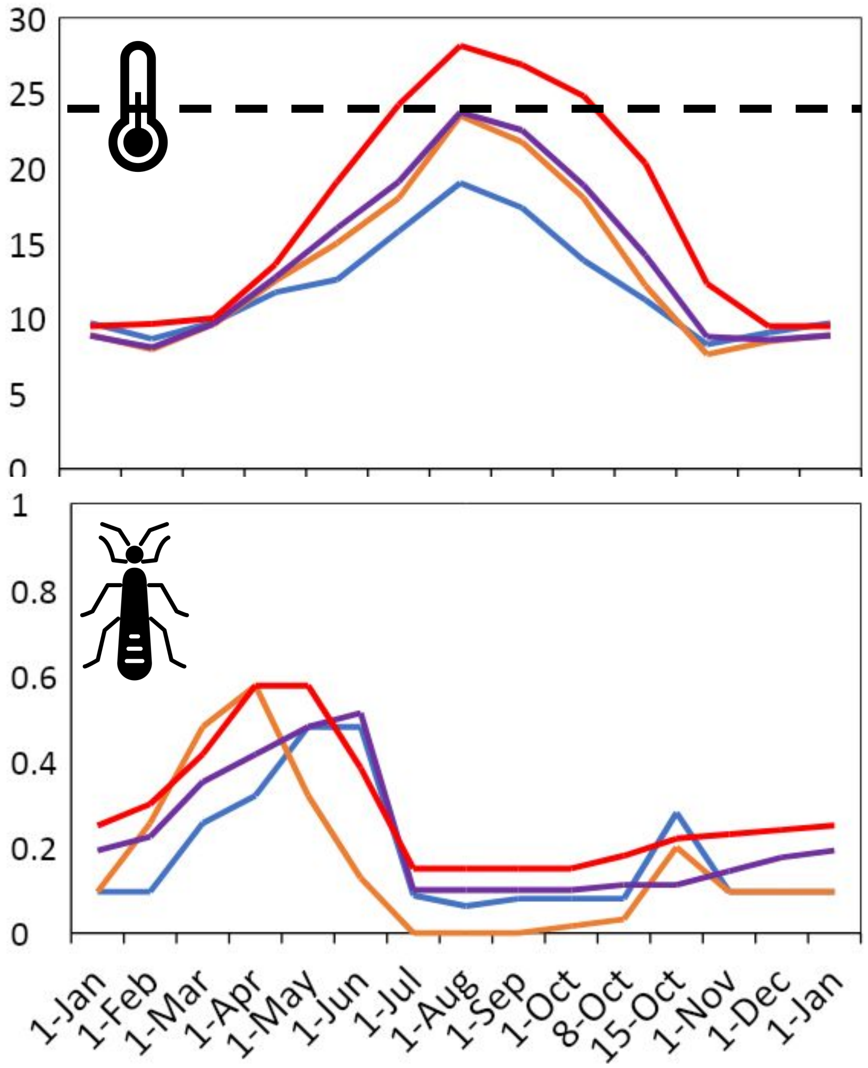
Foodscape modeling in practice: A case study example



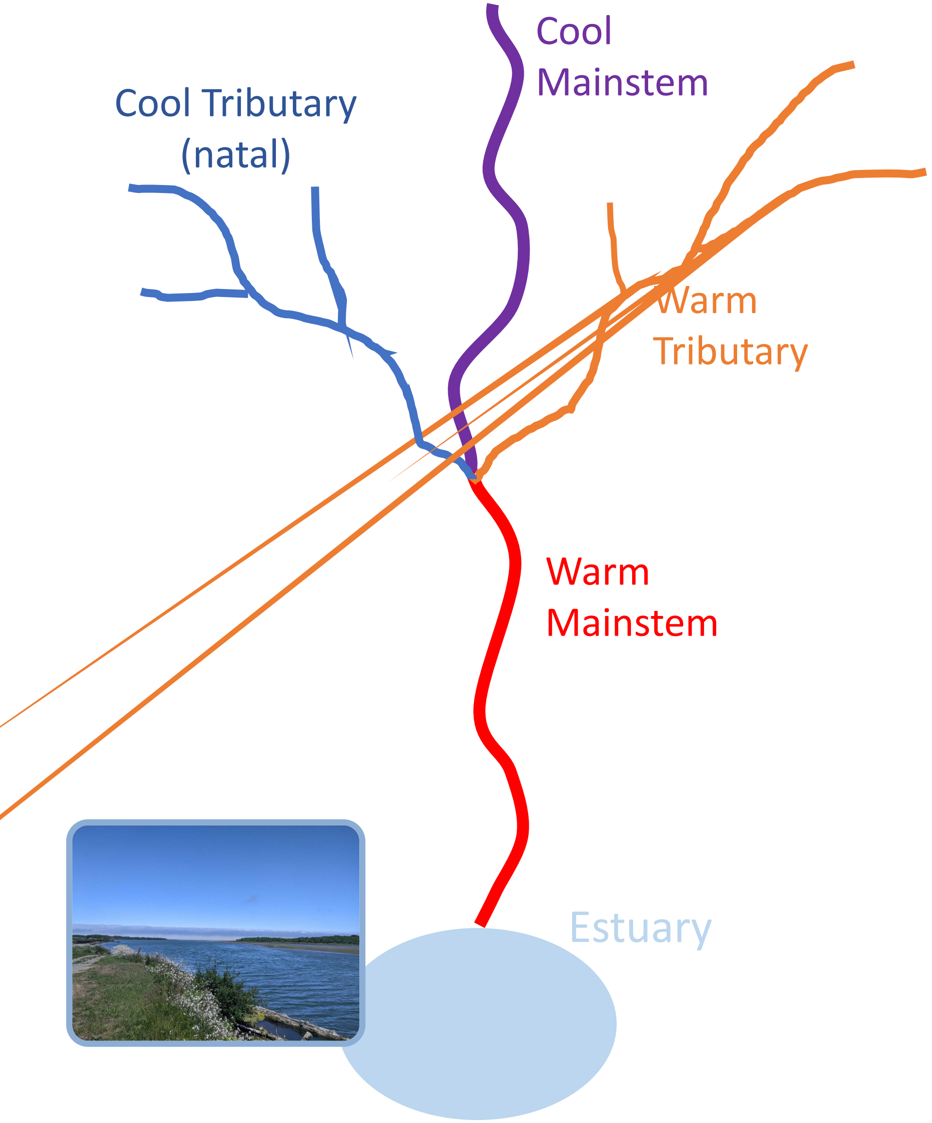


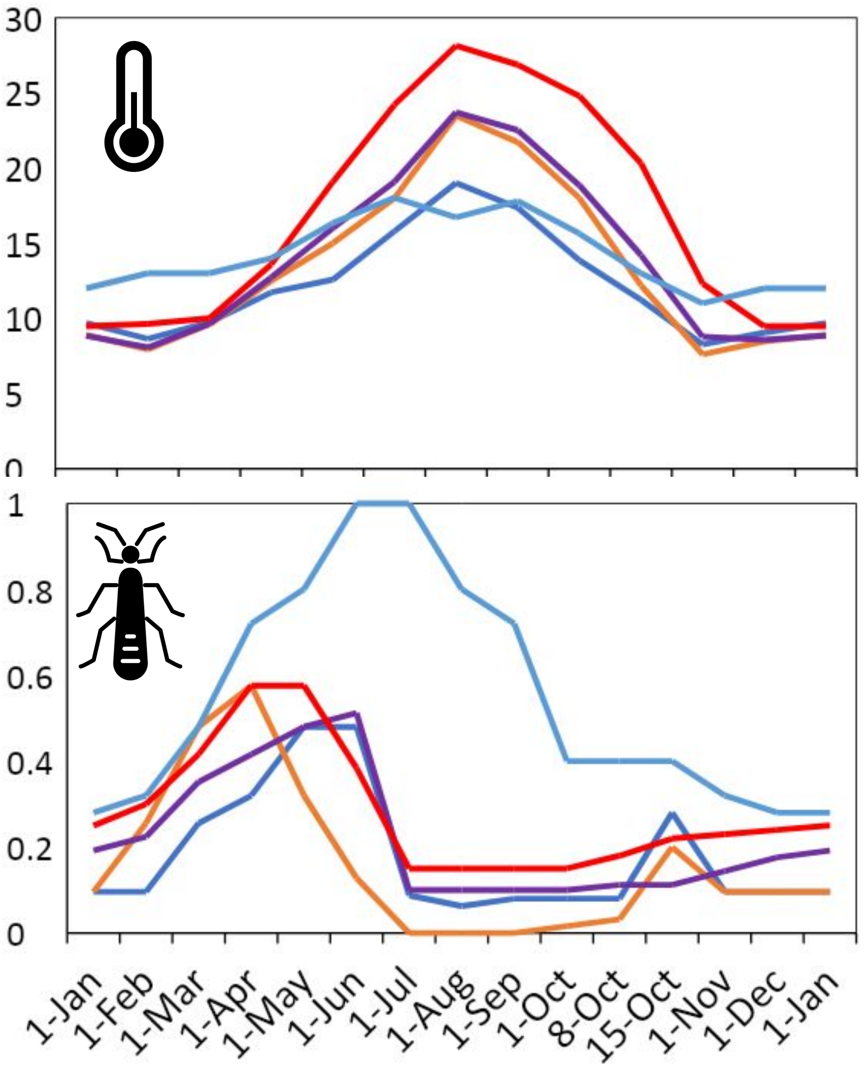
Foodscape modeling in practice: A case study example

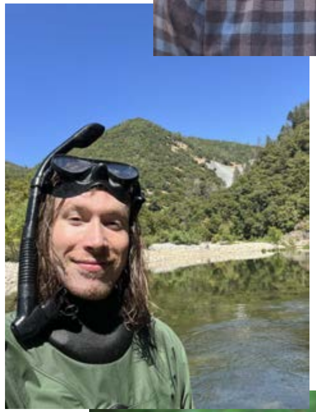




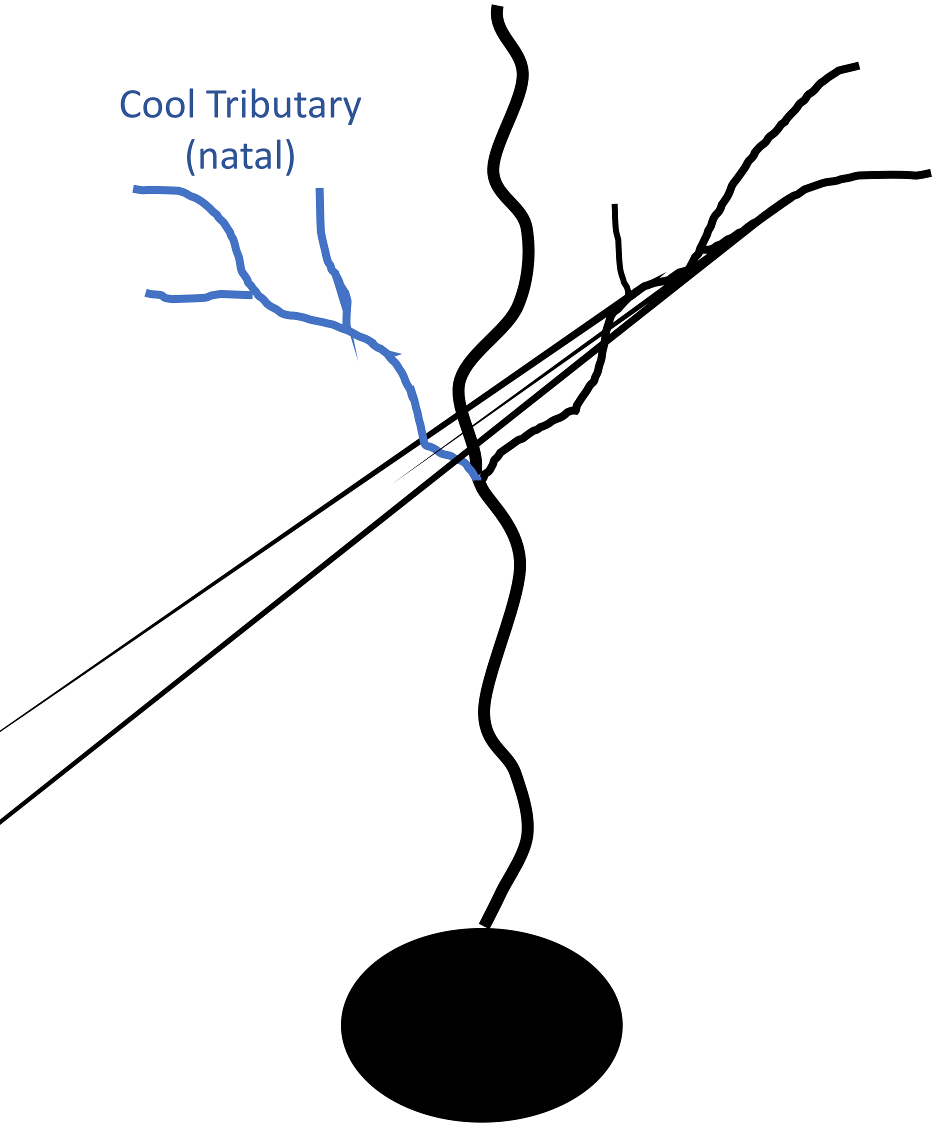
Foodscape modeling in practice: A case study example







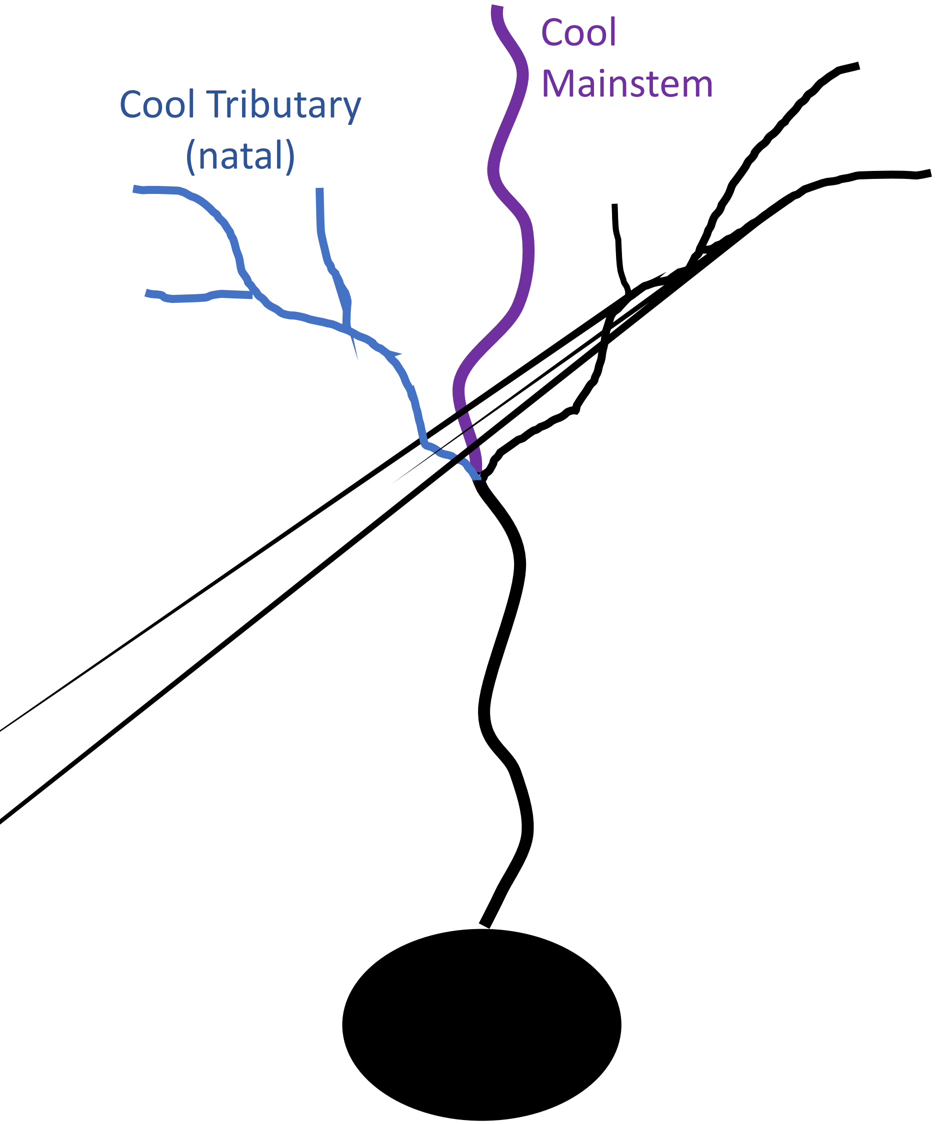
Habitat Aggregation Experiment



Cool Tributary

Life history diversity and population abundance

Habitat Aggregation Experiment



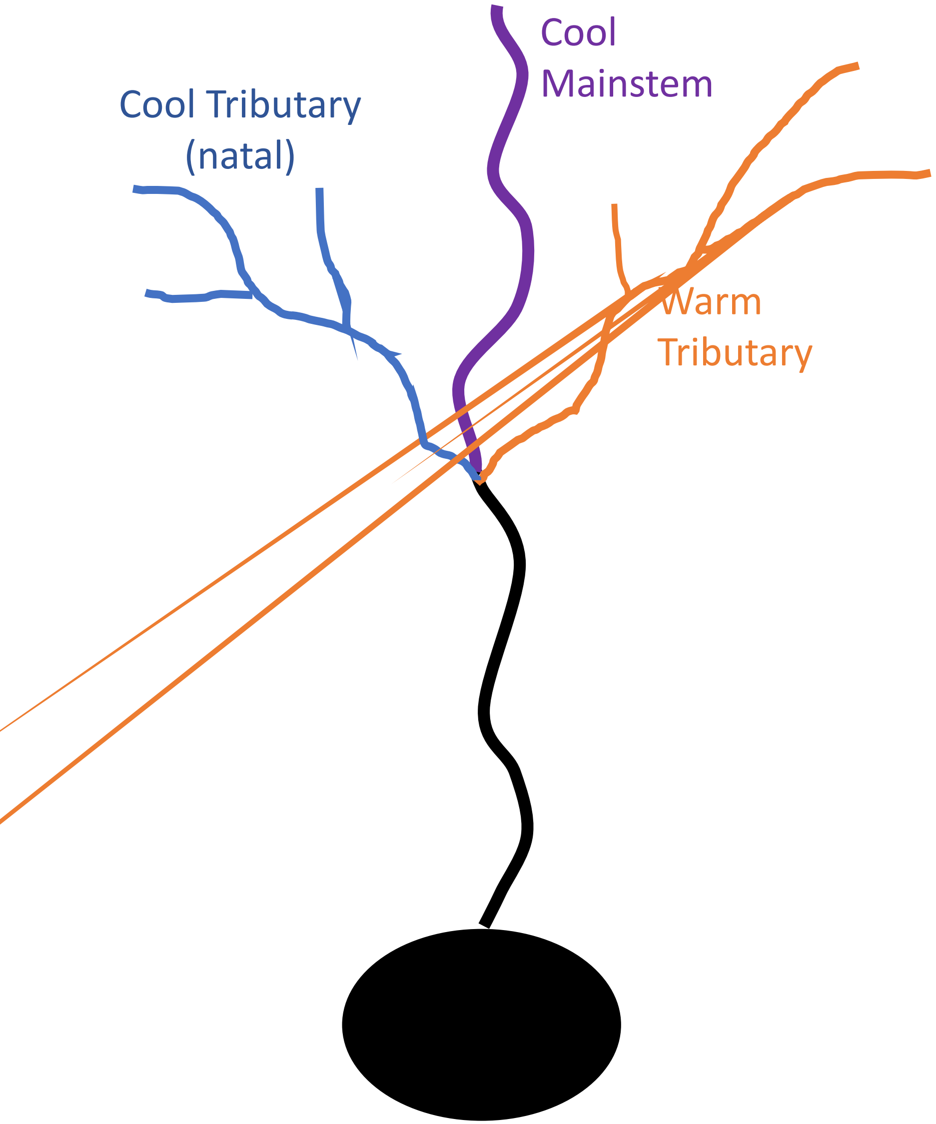
Cool Tributary

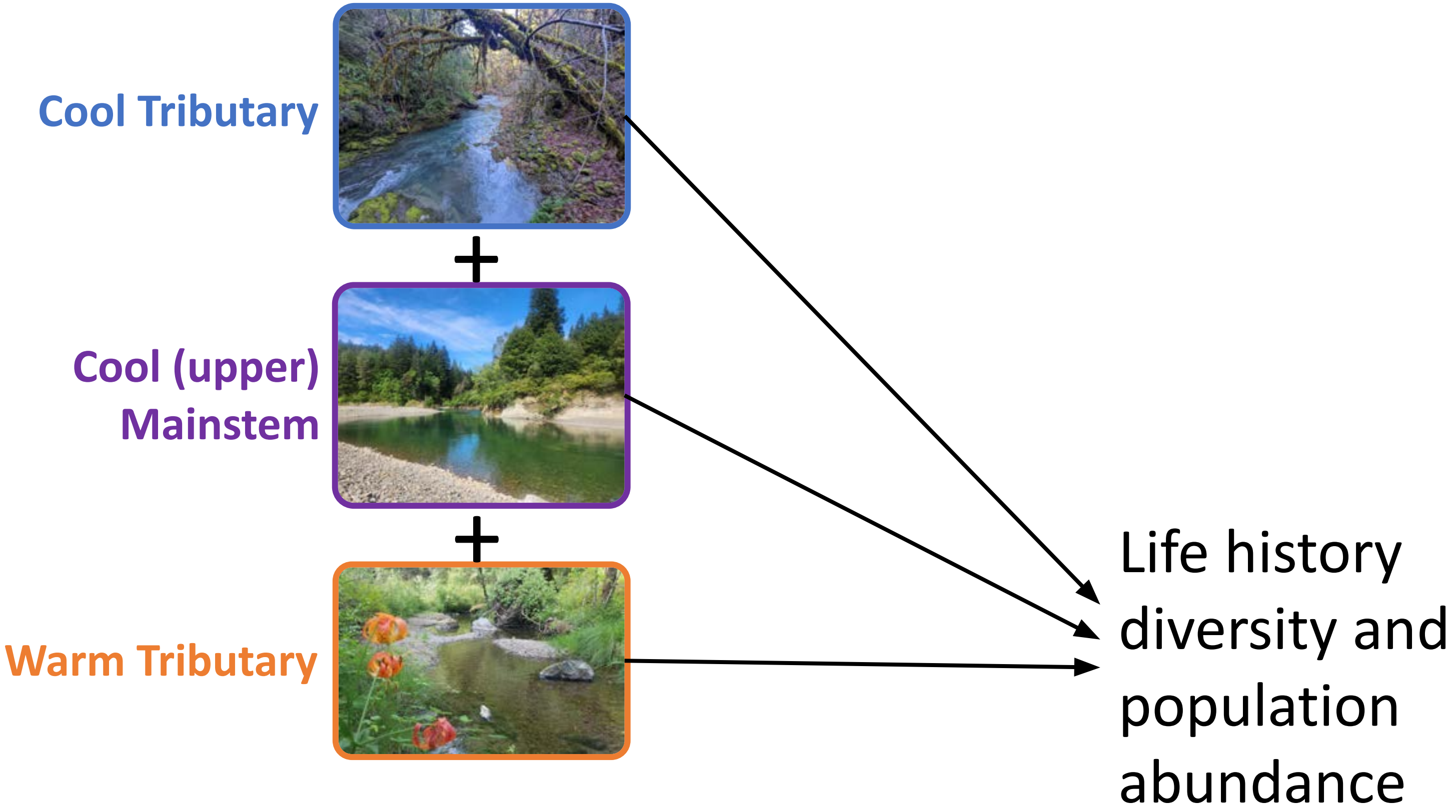
+

Cool (upper) Mainstem

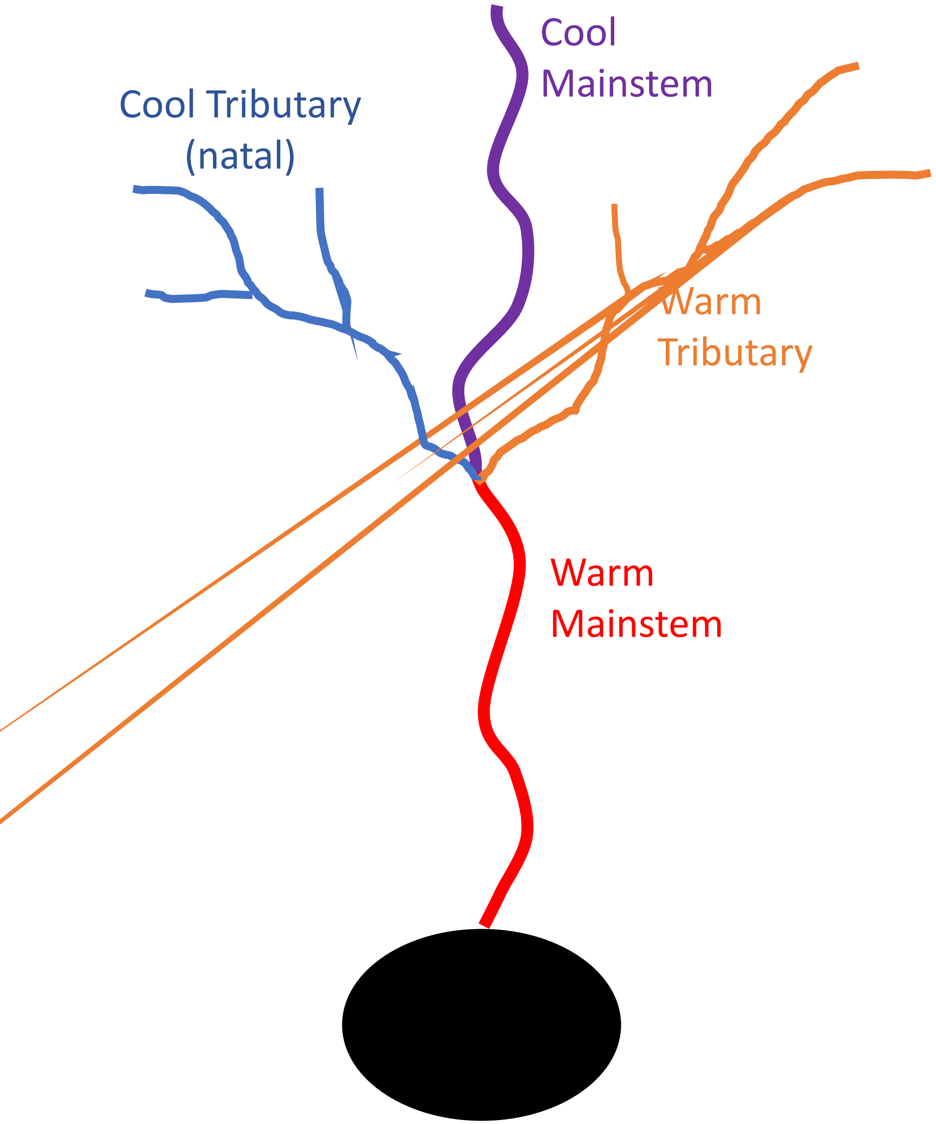
Life history diversity and population abundance

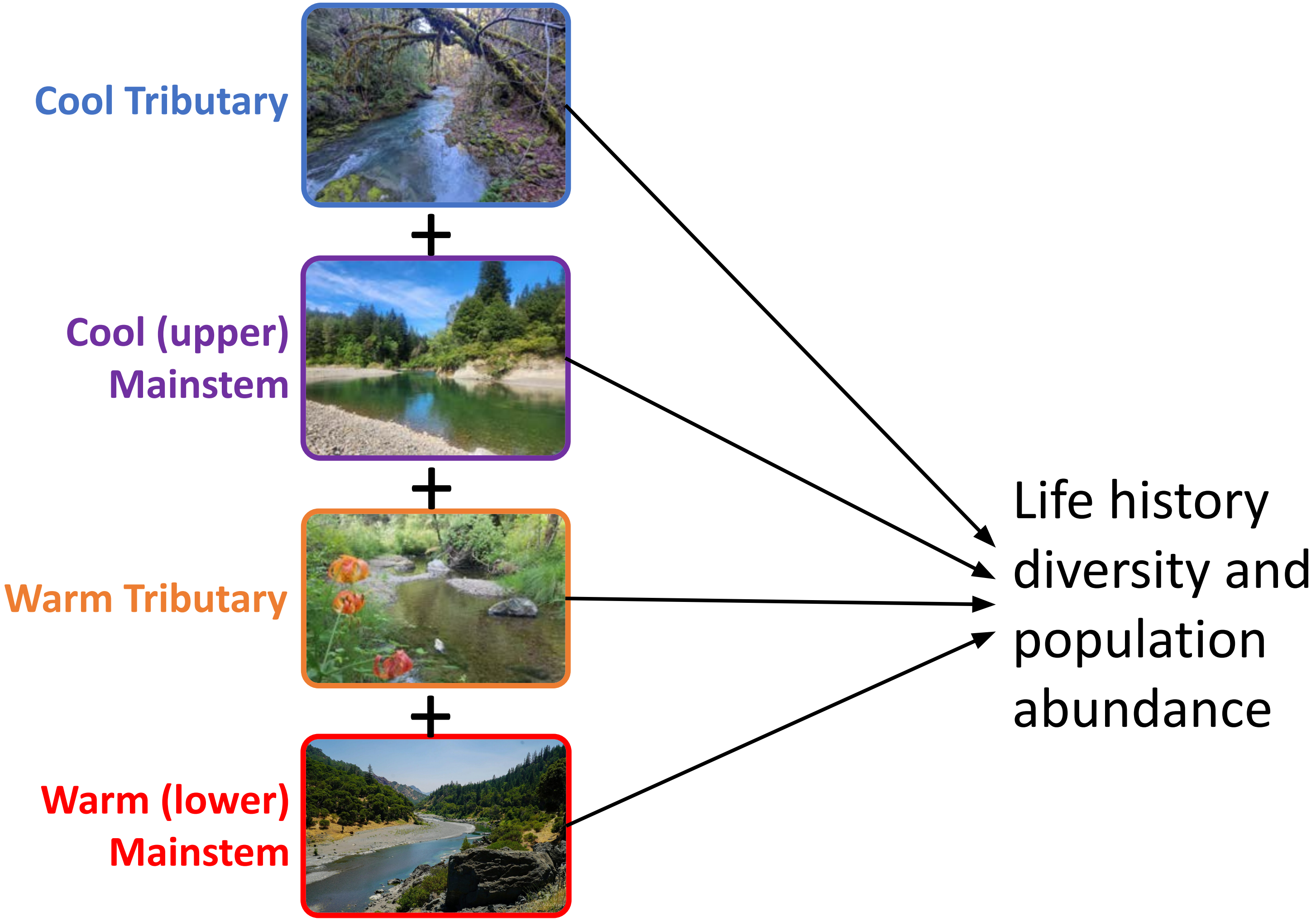
Habitat Aggregation Experiment



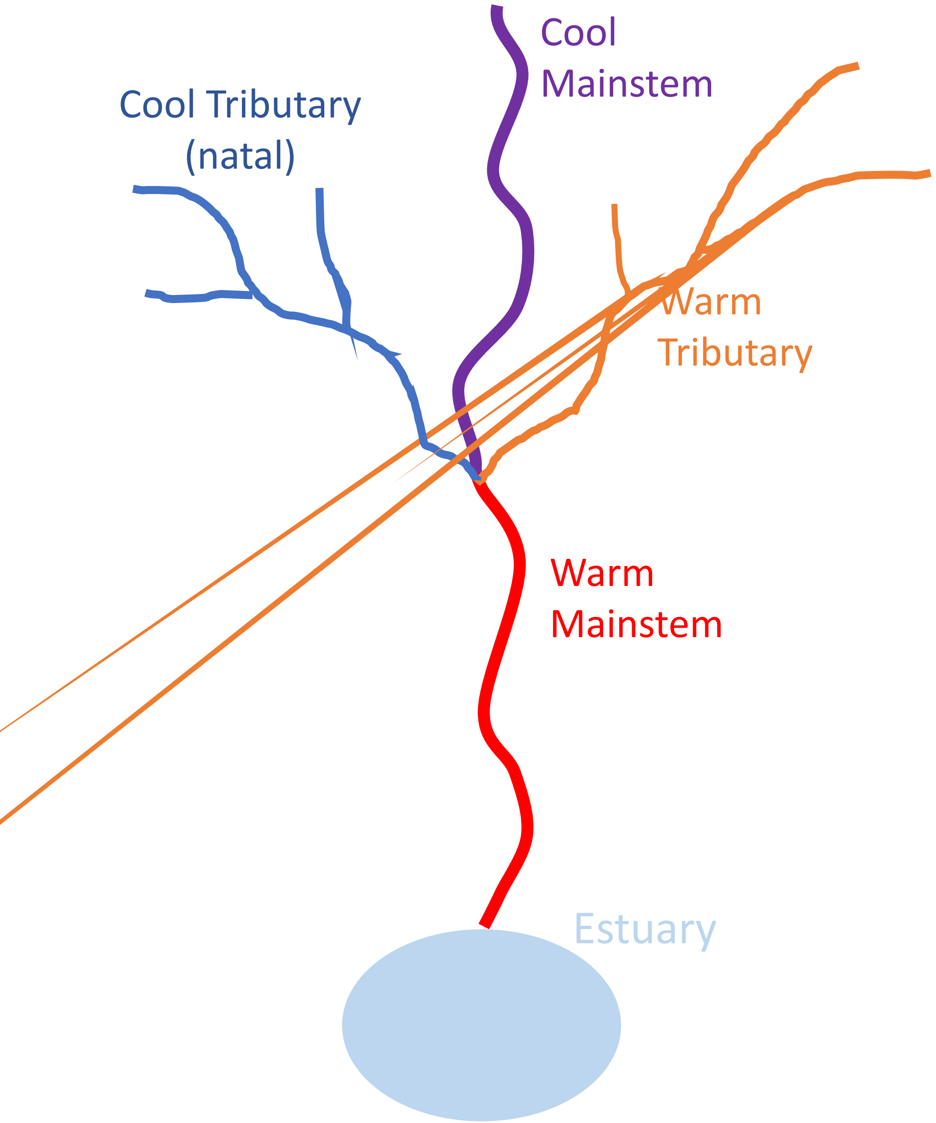


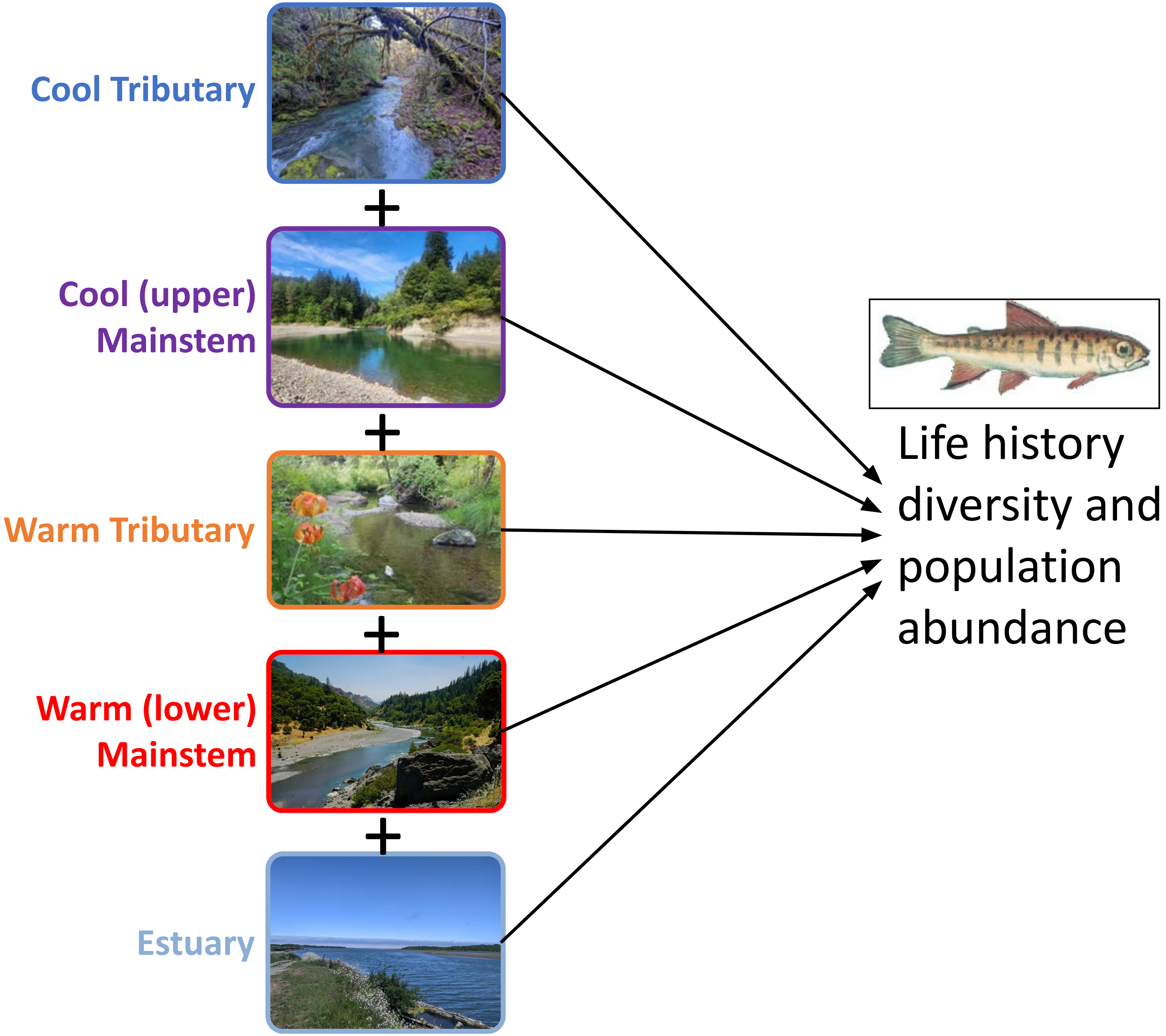
Habitat Aggregation Experiment





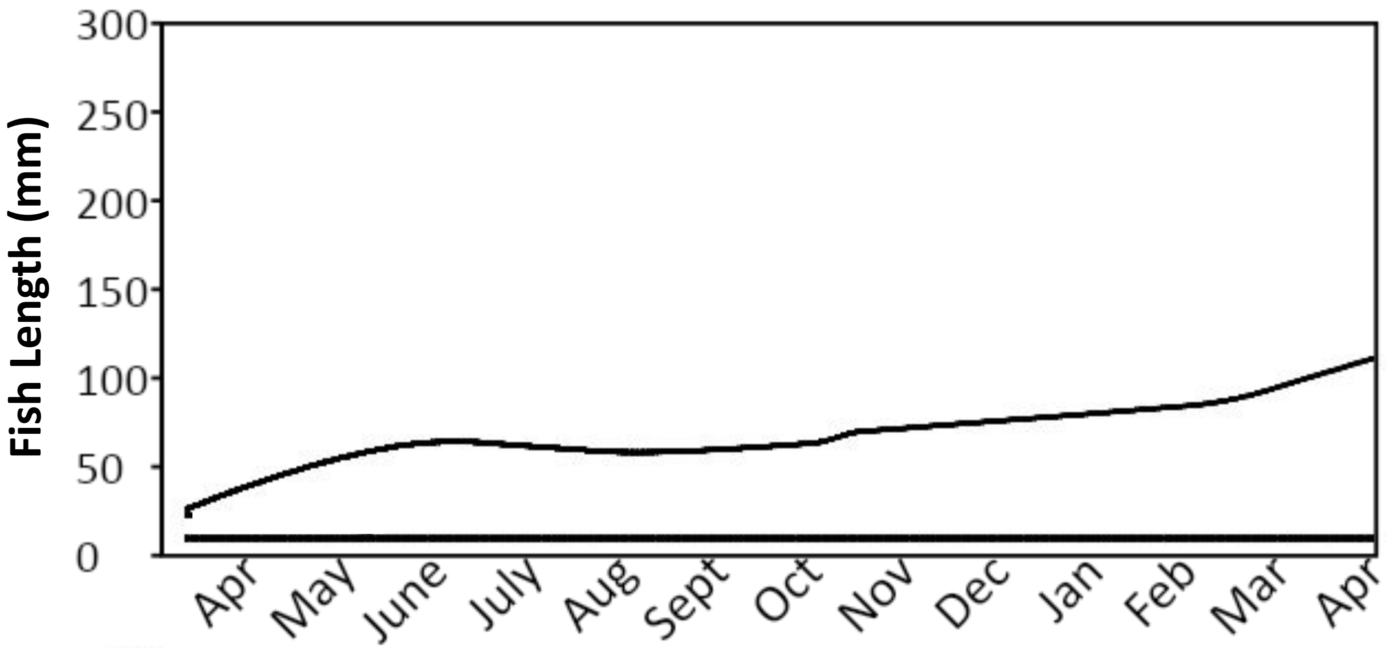
Habitat Aggregation Experiment

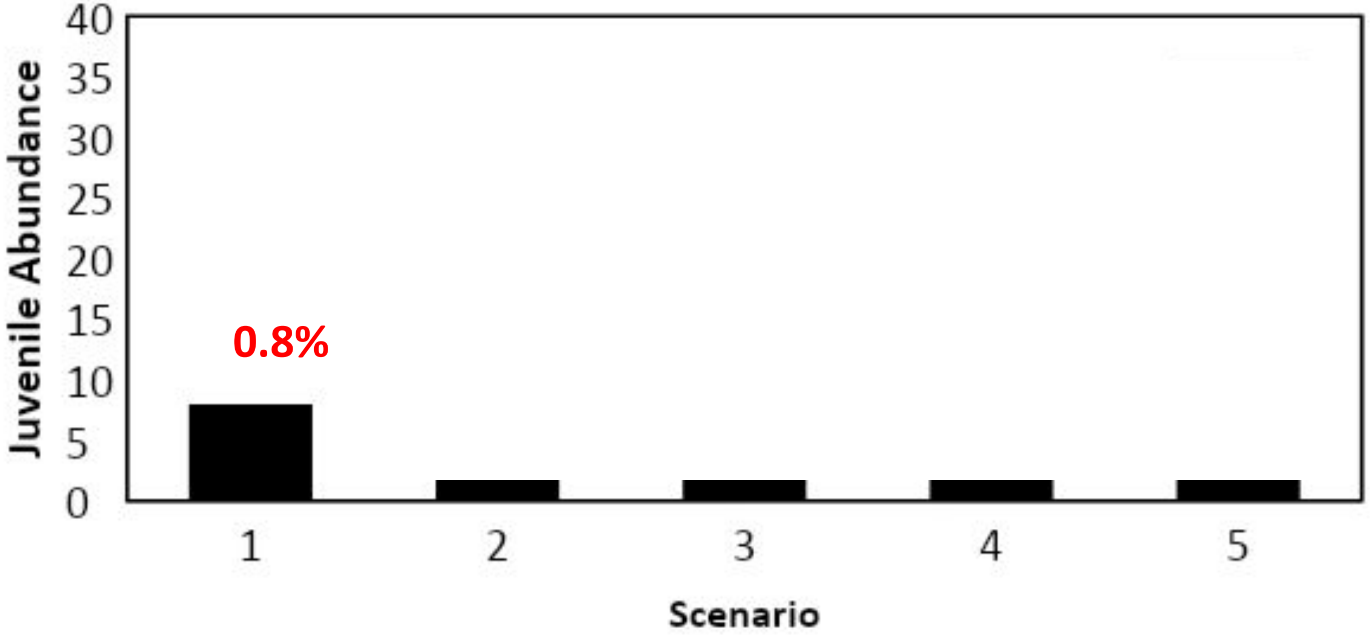




Scenario 1

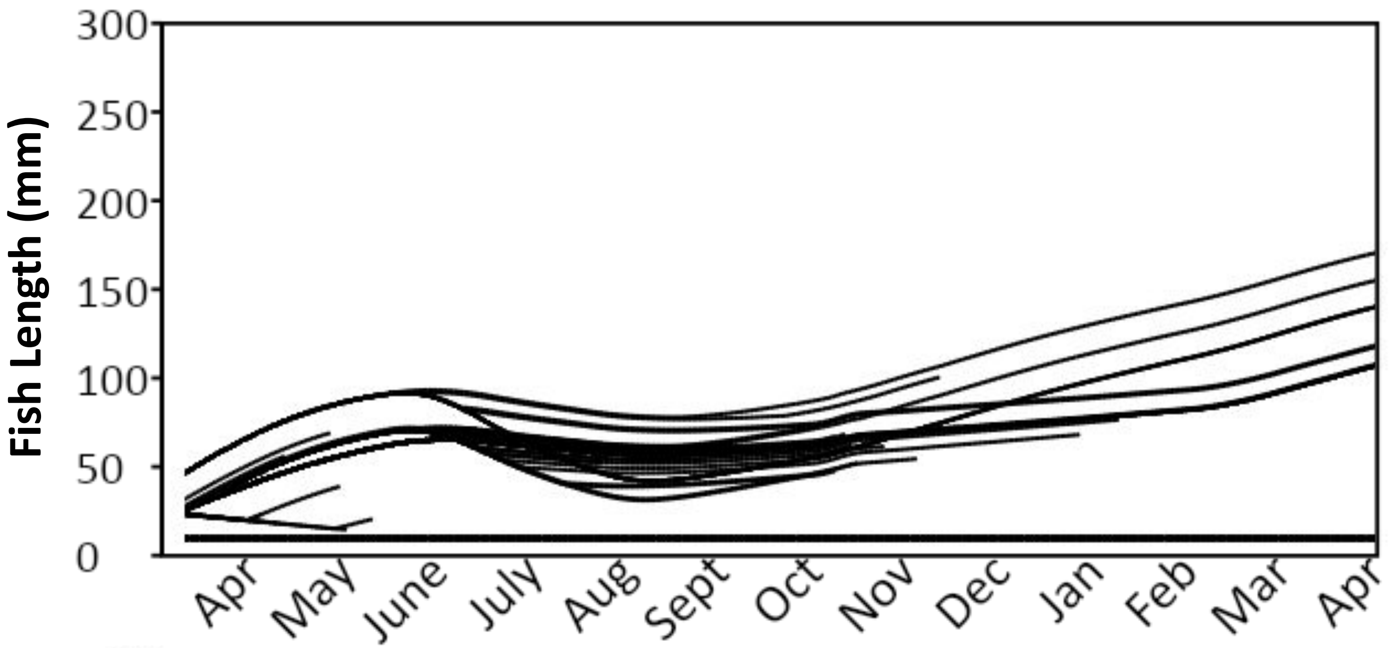
Cool Tributary



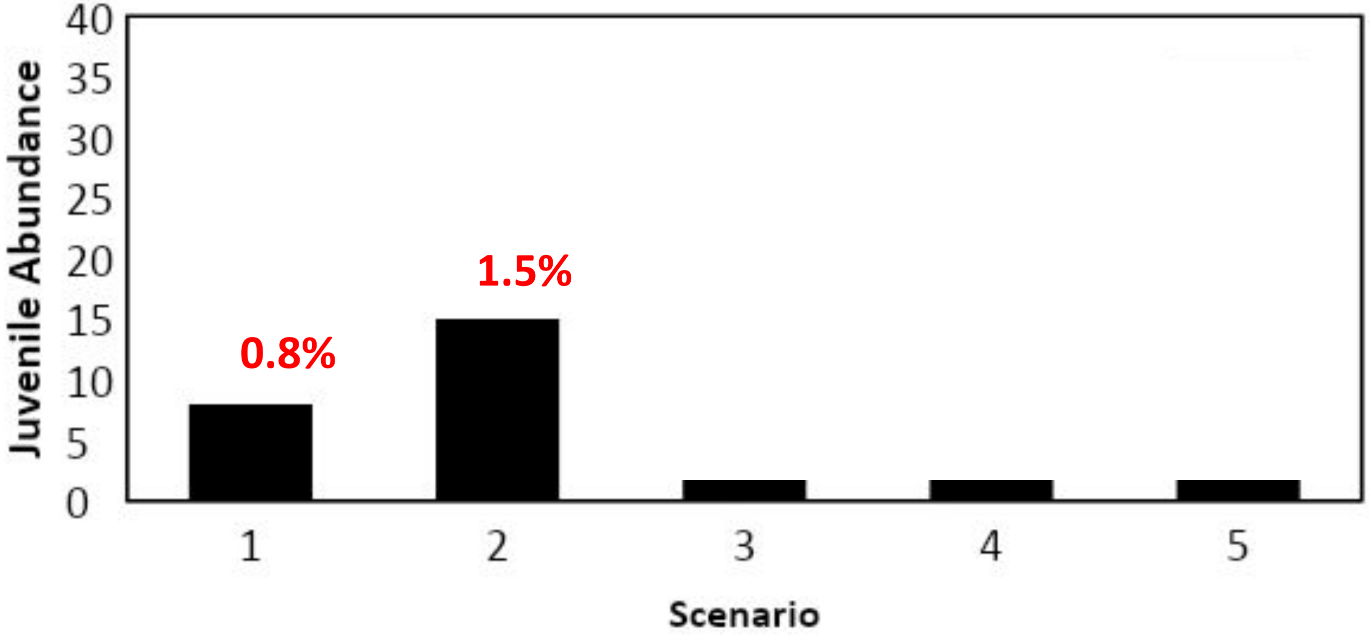


Scenario 2

Cool Tributary
+
Cool (upper) Mainstem



Fish Length (mm)
300
250
200
150
100
50
0
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr



Juvenile Abundance
40
35
30
25
20
15
10
5
0
0.8%
1.5%
1
2
3
4
5
Scenario

Scenario 3

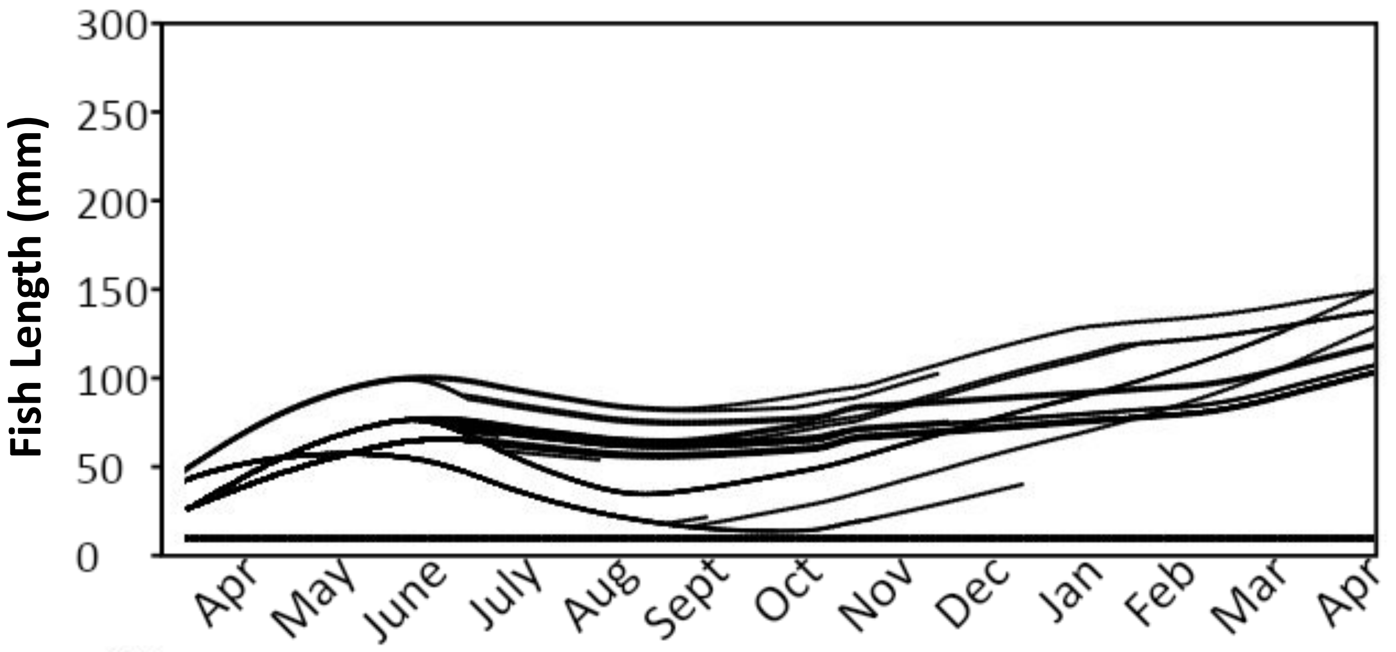
Cool Tributary

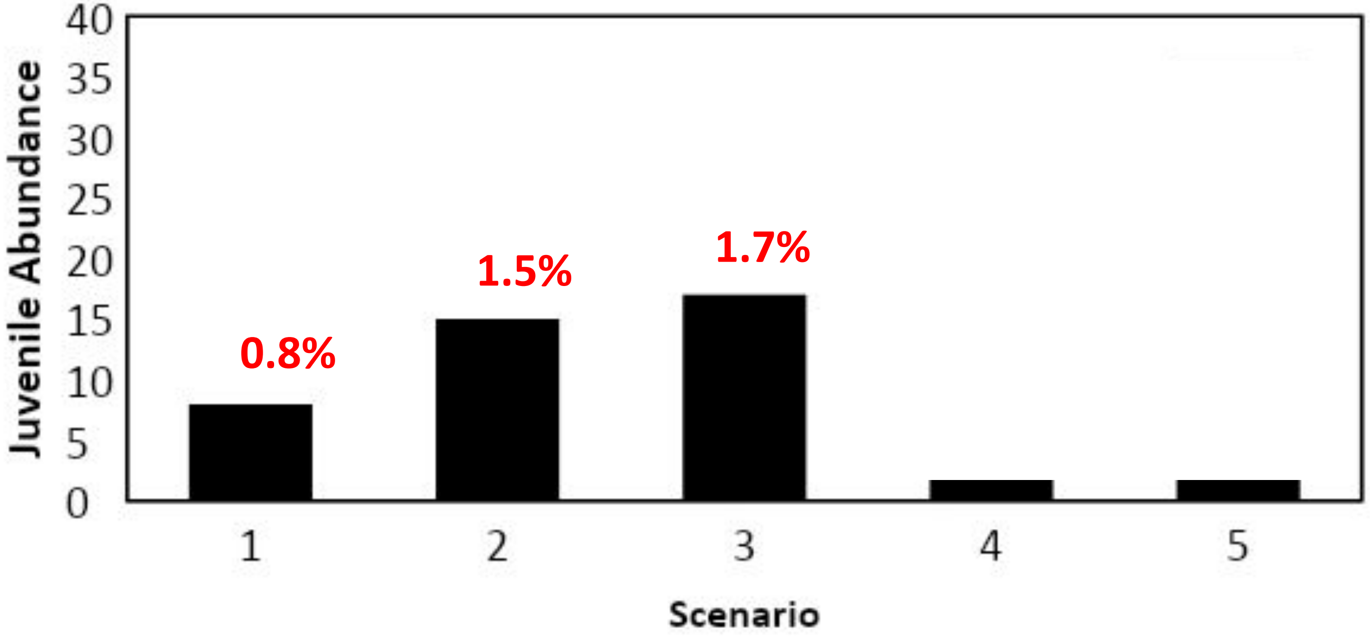
+

Cool (upper) Mainstem

+

Warm Tributary





Scenario 4

Cool Tributary

+

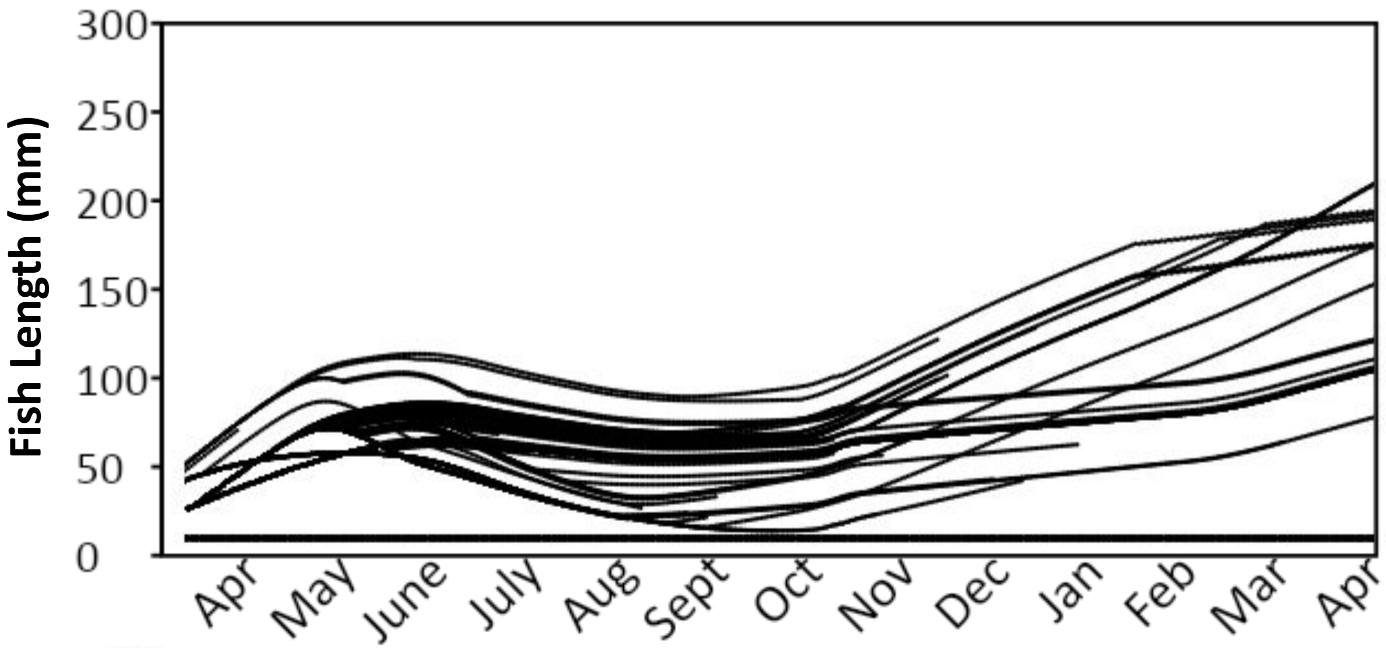
Cool (upper) Mainstem

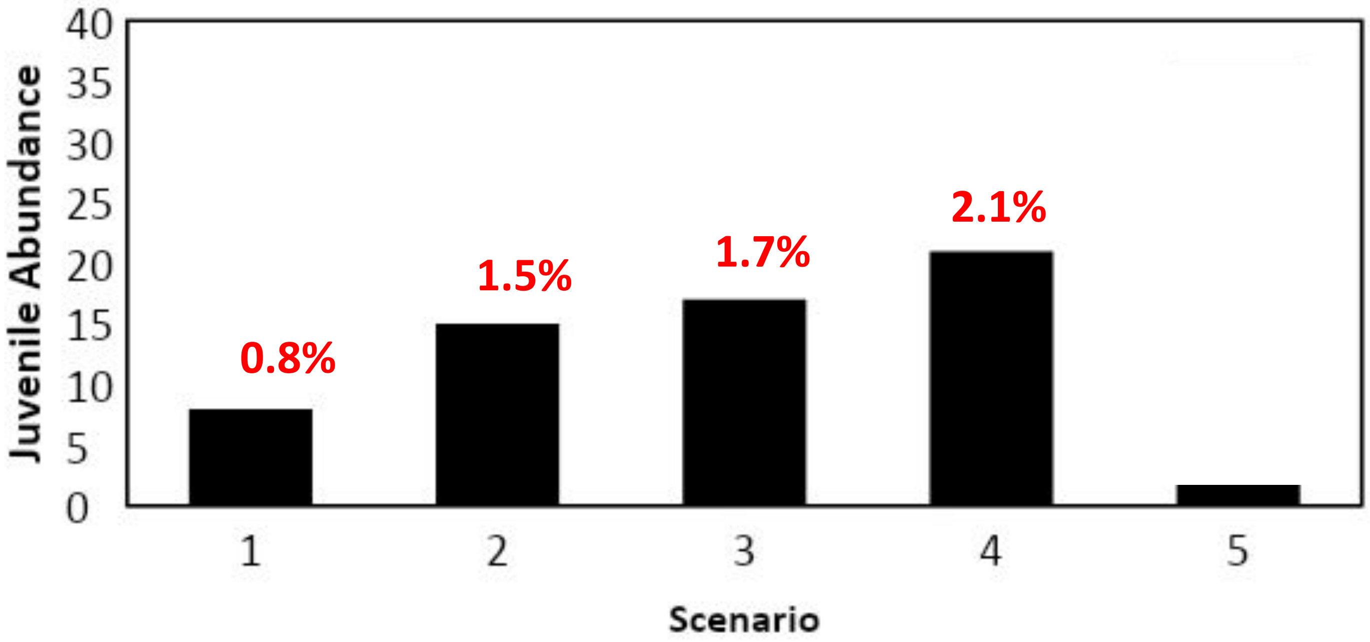
+

Warm Tributary

+

Warm (lower) Mainstem





Scenario 5

Cool Tributary

+

Cool (upper) Mainstem

+

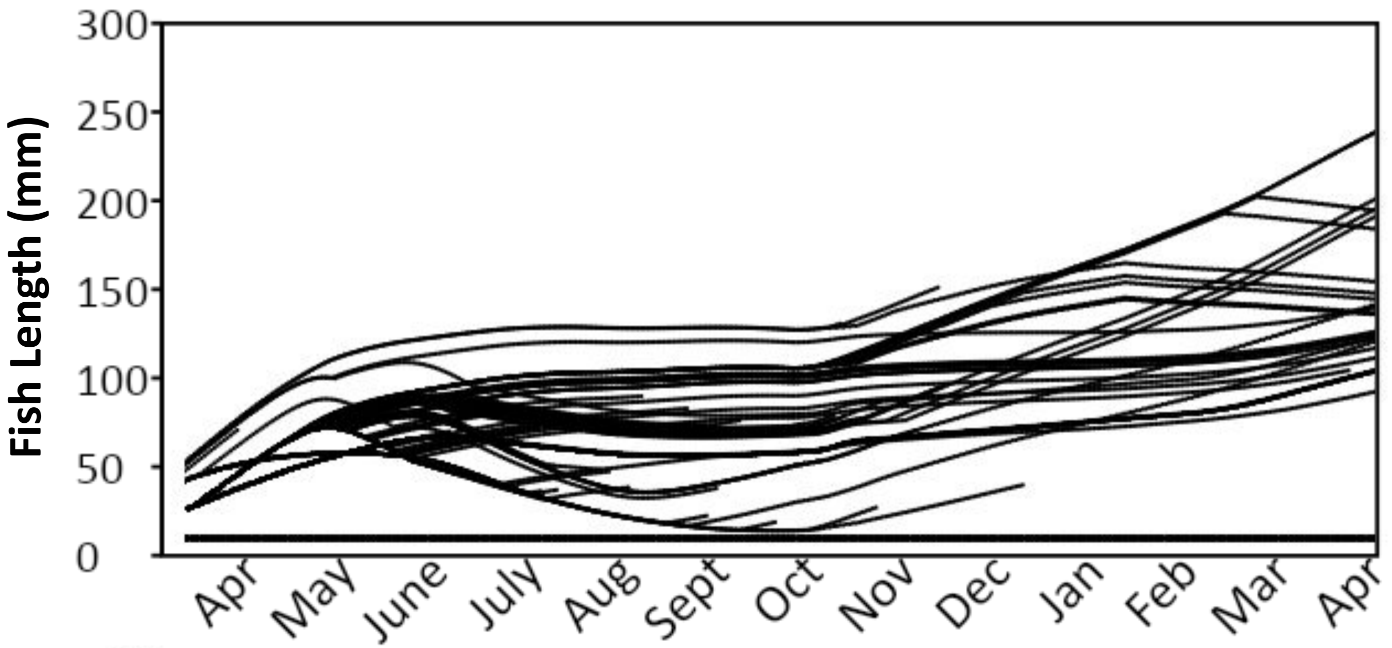
Warm Tributary

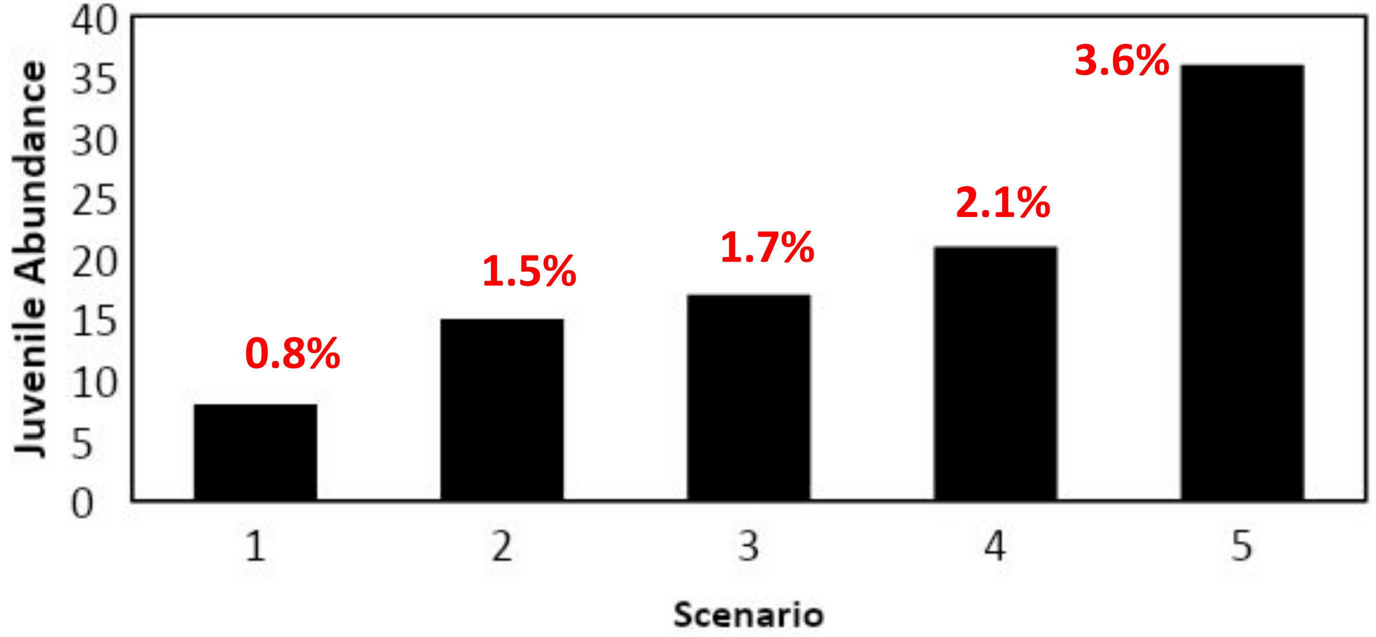
+

Warm (lower) Mainstem

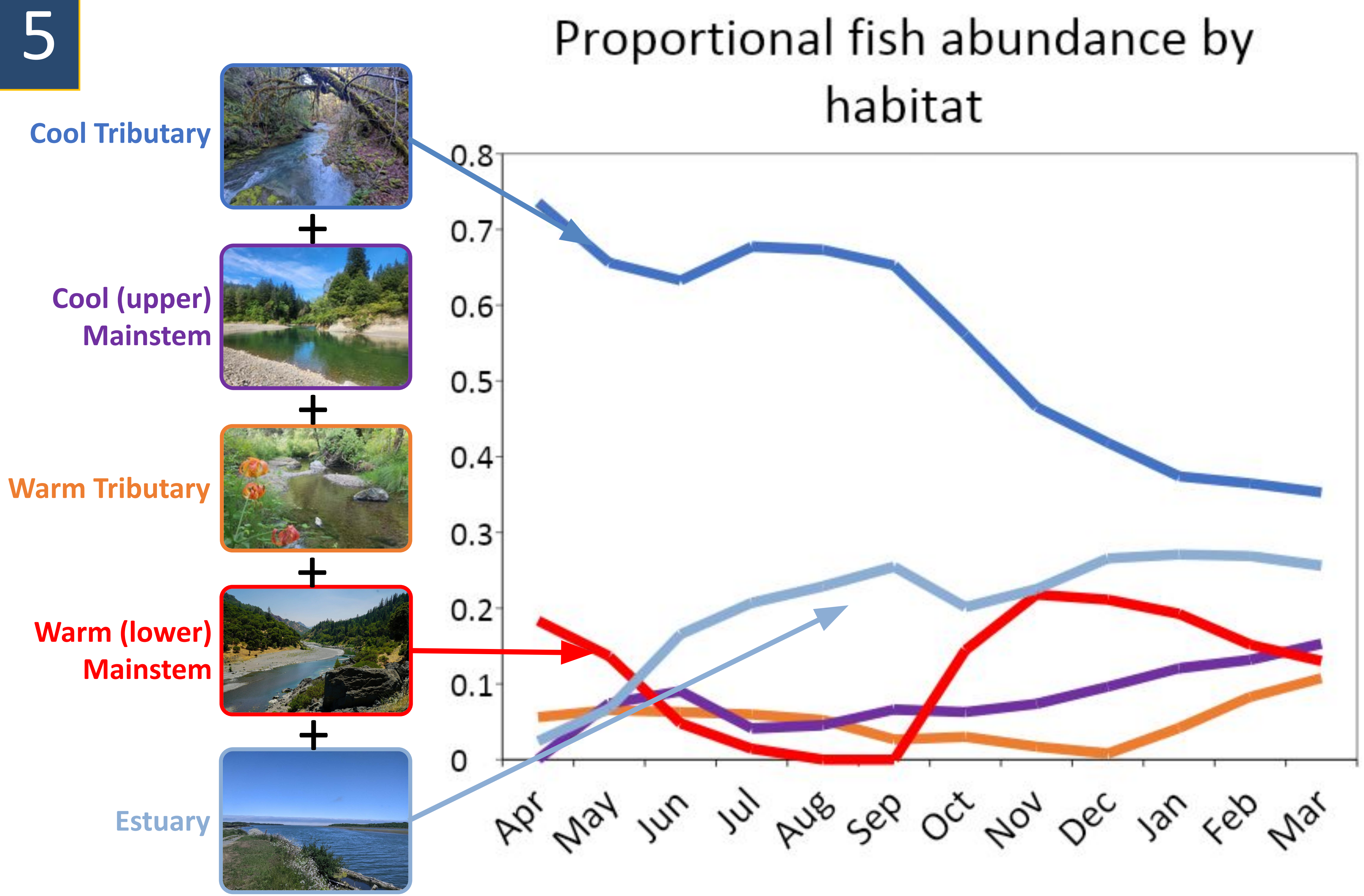
+

Estuary





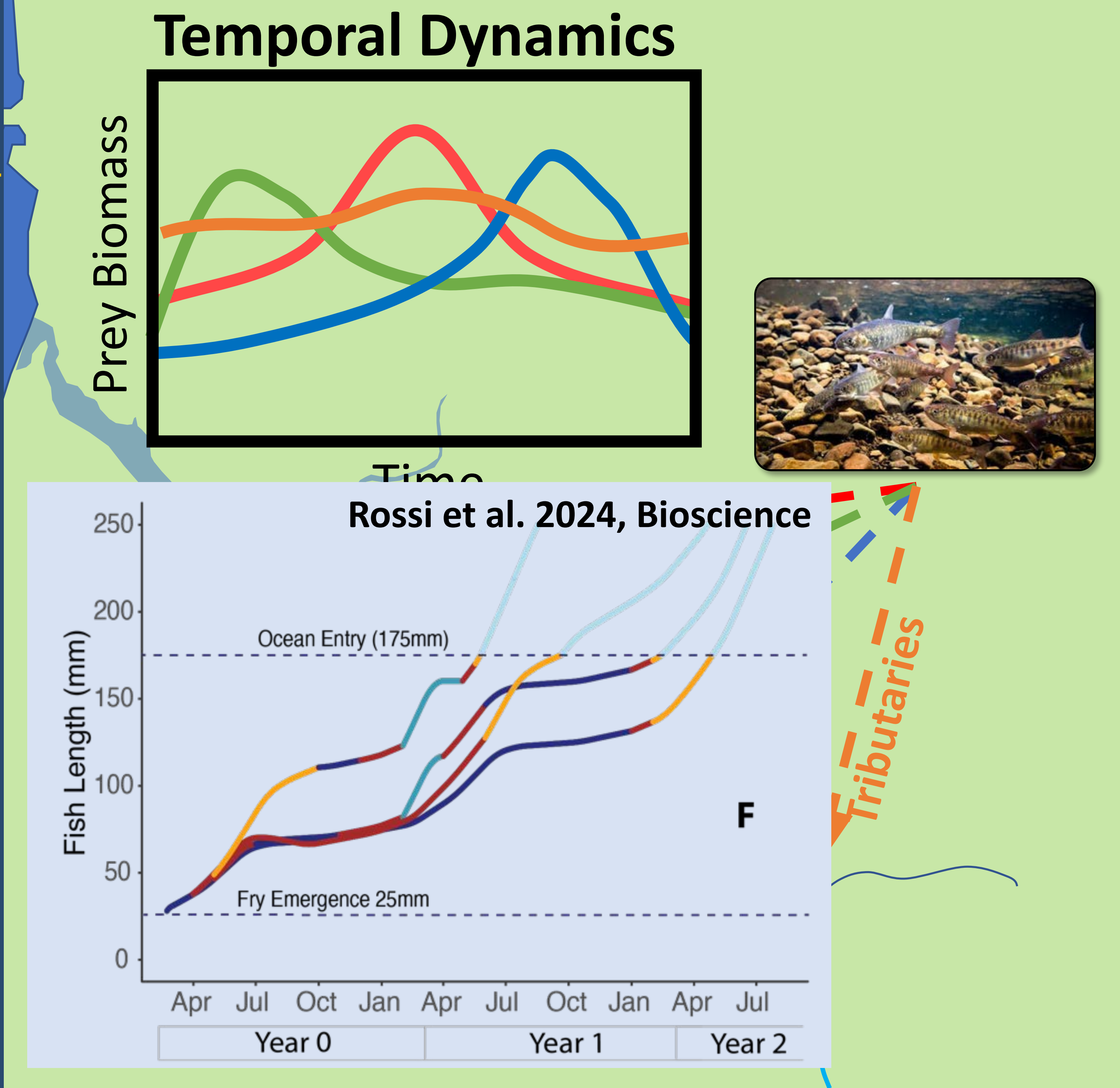
Scenario 5



Proportional fish abundance by habitat
Cool Tributary
Cool (upper) Mainstem
Warm Tributary
Warm (lower) Mainstem
Estuary
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar

Summary

- Accessible non-natal habitats can contribute substantially to population abundance
- Especially if those habitats host unique foraging and growth opportunities that promote life history diversity



Summary

We can integrate foodscape modeling into salmon life cycle models to envision how restoring healthy foodscapes promote healthy salmon populations.

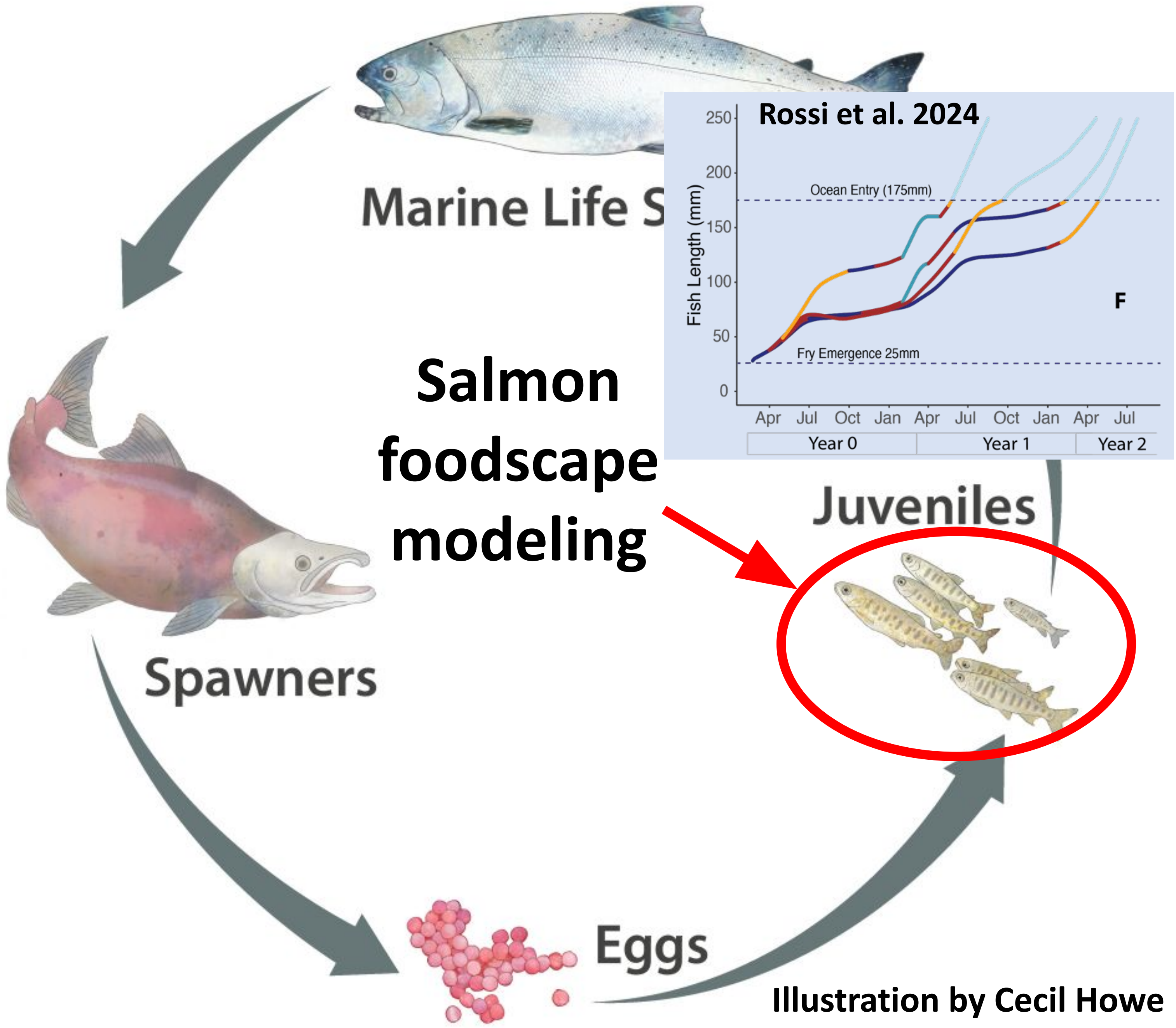
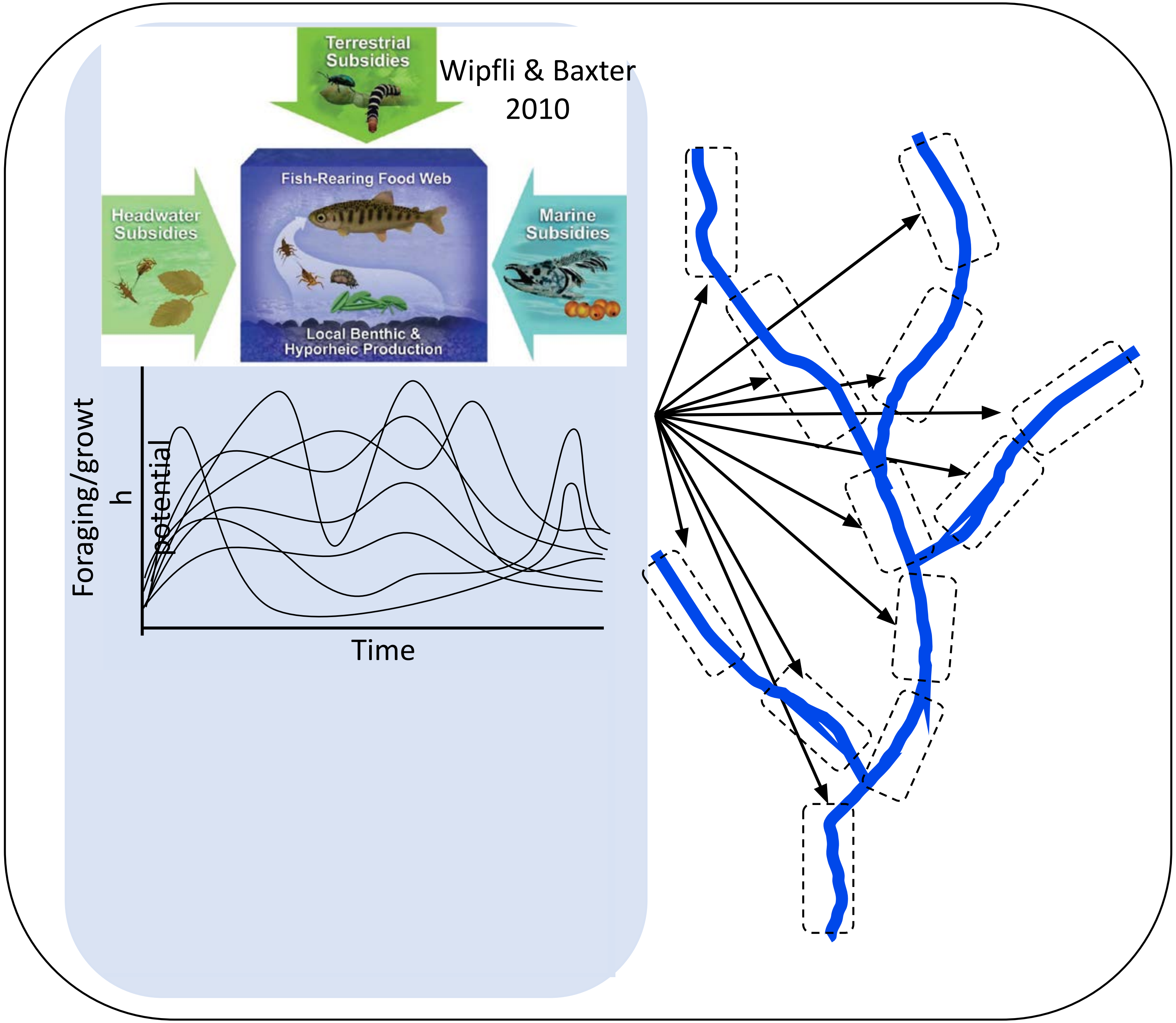


Illustration by Cecil Howe (Bellmore et al. 2023)

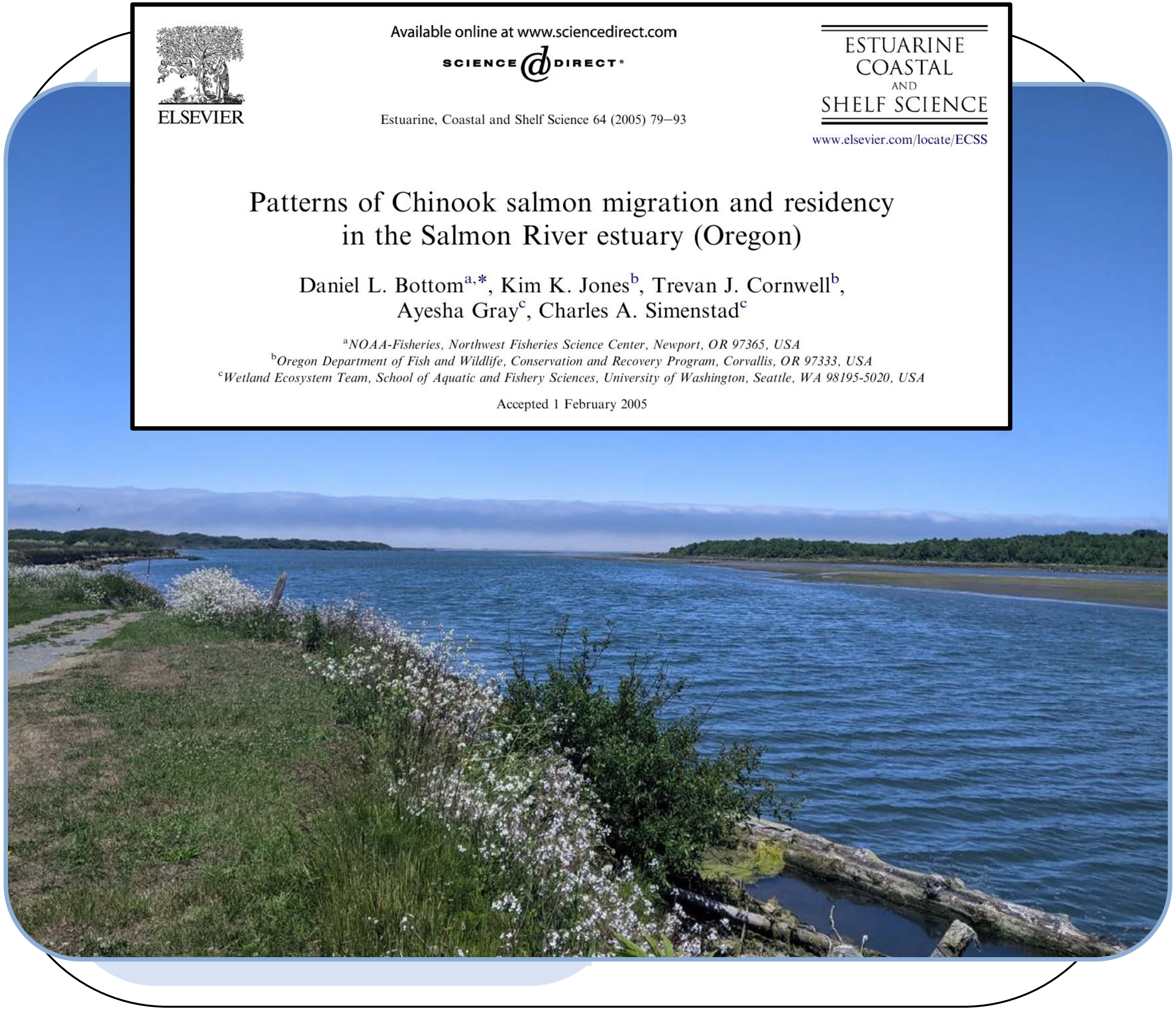
What did the foodscape used to look like?

- Develop a **“reference foodscape”** (Rossi et al. 2024)
- What are the potential trophic pathways, foraging/growth opportunities?
- What life histories a watershed could support?



What did the foodscape used to look like?

- How does the current foodscape compare to "reference foodscape"
- What has been lost?
- What are the opportunities for restoration?



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ESTUARINE COASTAL AND SHELF SCIENCE

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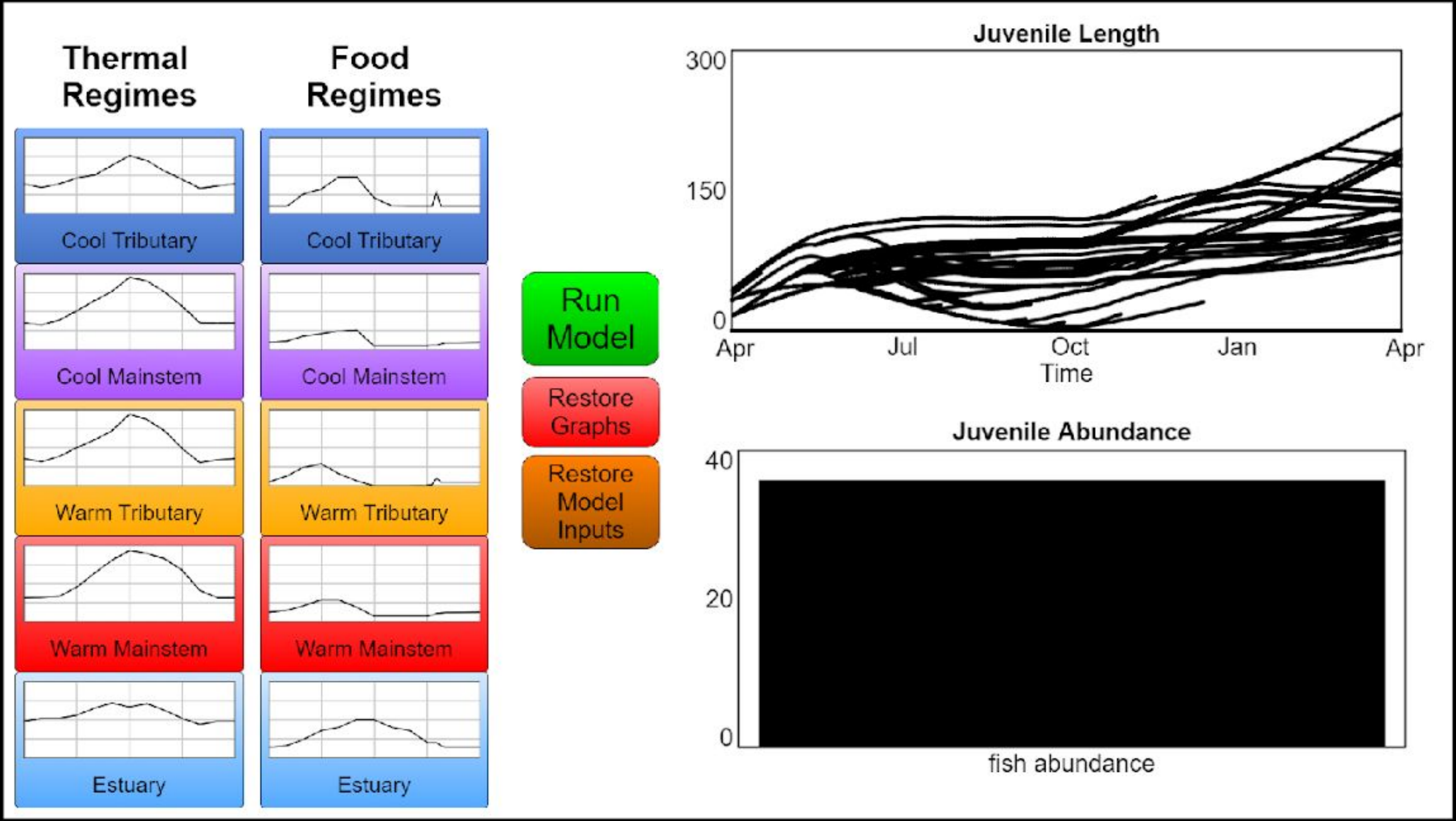
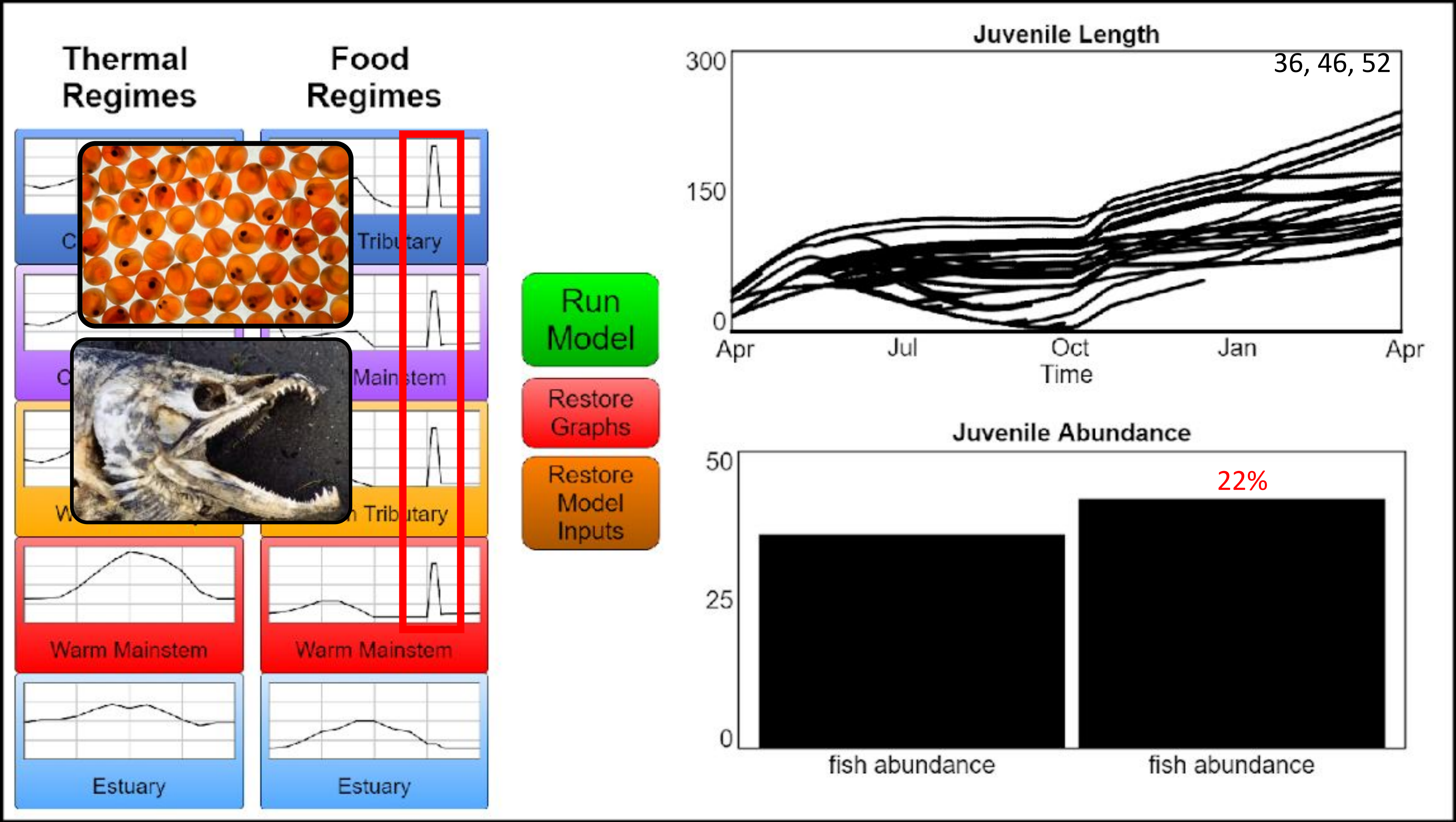
Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon)

Daniel L. Bottom[a,*], Kim K. Jones[b], Trevan J. Cornwell[b], Ayesha Gray[c], Charles A. Simenstad[c]

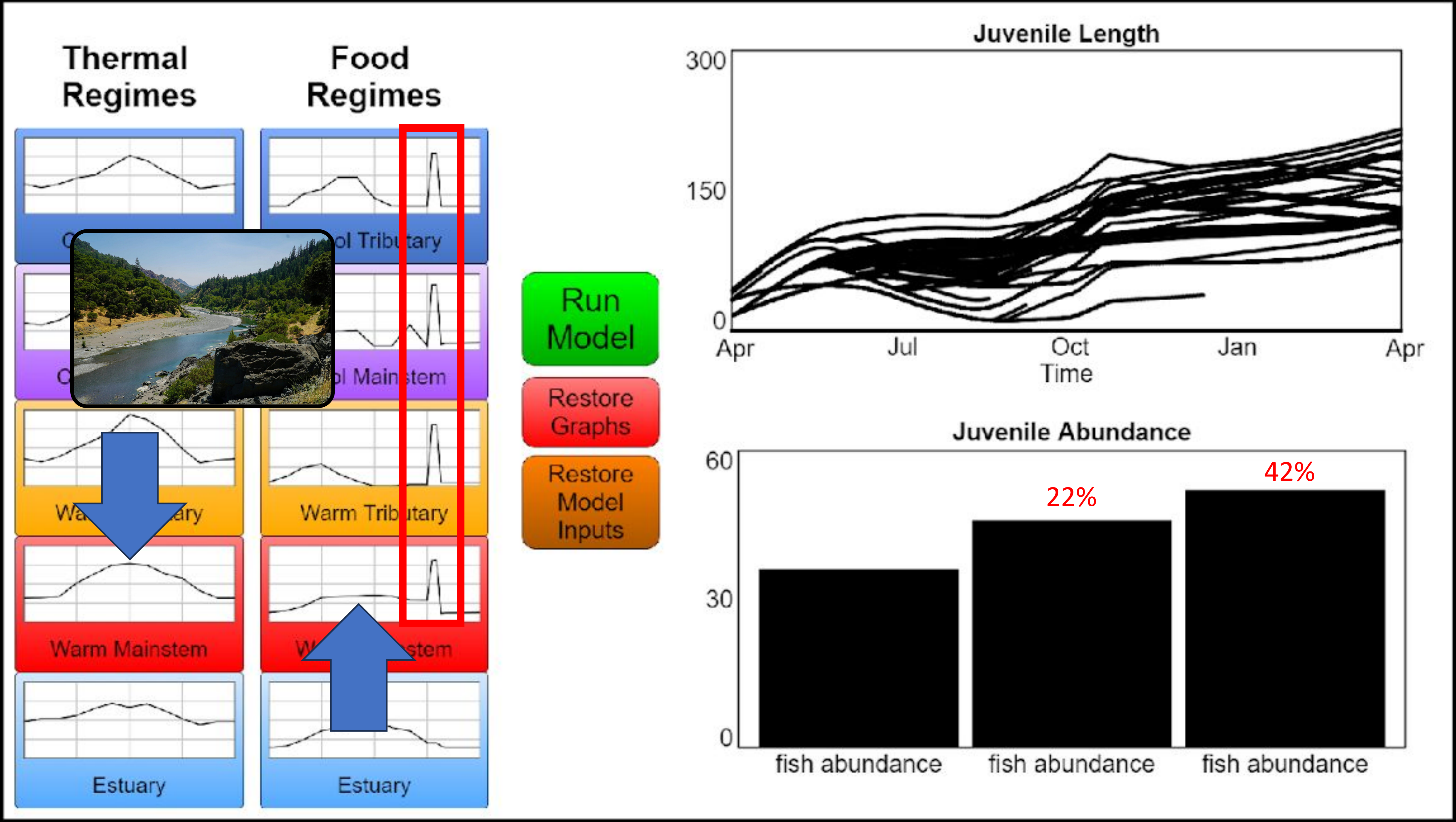
[a] NOAA-Fisheries, Northwest Fisheries Science Center, Newport, OR 97365, USA
[b] Oregon Department of Fish and Wildlife, Conservation and Recovery Program, Corvallis, OR 97333, USA
[c] Wetland Ecosystem Team, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195-5020, USA

Accepted 1 February 2005


Thermal Regimes
Food Regimes
Cool Tributary
Cool Tributary
Cool Mainstem
Cool Mainstem
Warm Tributary
Warm Tributary
Warm Mainstem
Warm Mainstem
Estuary
Estuary
Run Model
Restore Graphs
Restore Model Inputs
Juvenile Length
300
150
0
Apr
Jul
Oct
Jan
Apr
Time
Juvenile Abundance
40
20
0
fish abundance



Thermal Regimes
Food Regimes
Tributary
Mainstem
Tributary
Warm Mainstem
Warm Mainstem
Estuary
Estuary
Run Model
Restore Graphs
Restore Model Inputs
Juvenile Length
36, 46, 52
300
150
0
Apr
Jul
Oct
Jan
Apr
Time
Juvenile Abundance
50
25
0
22%
fish abundance
fish abundance

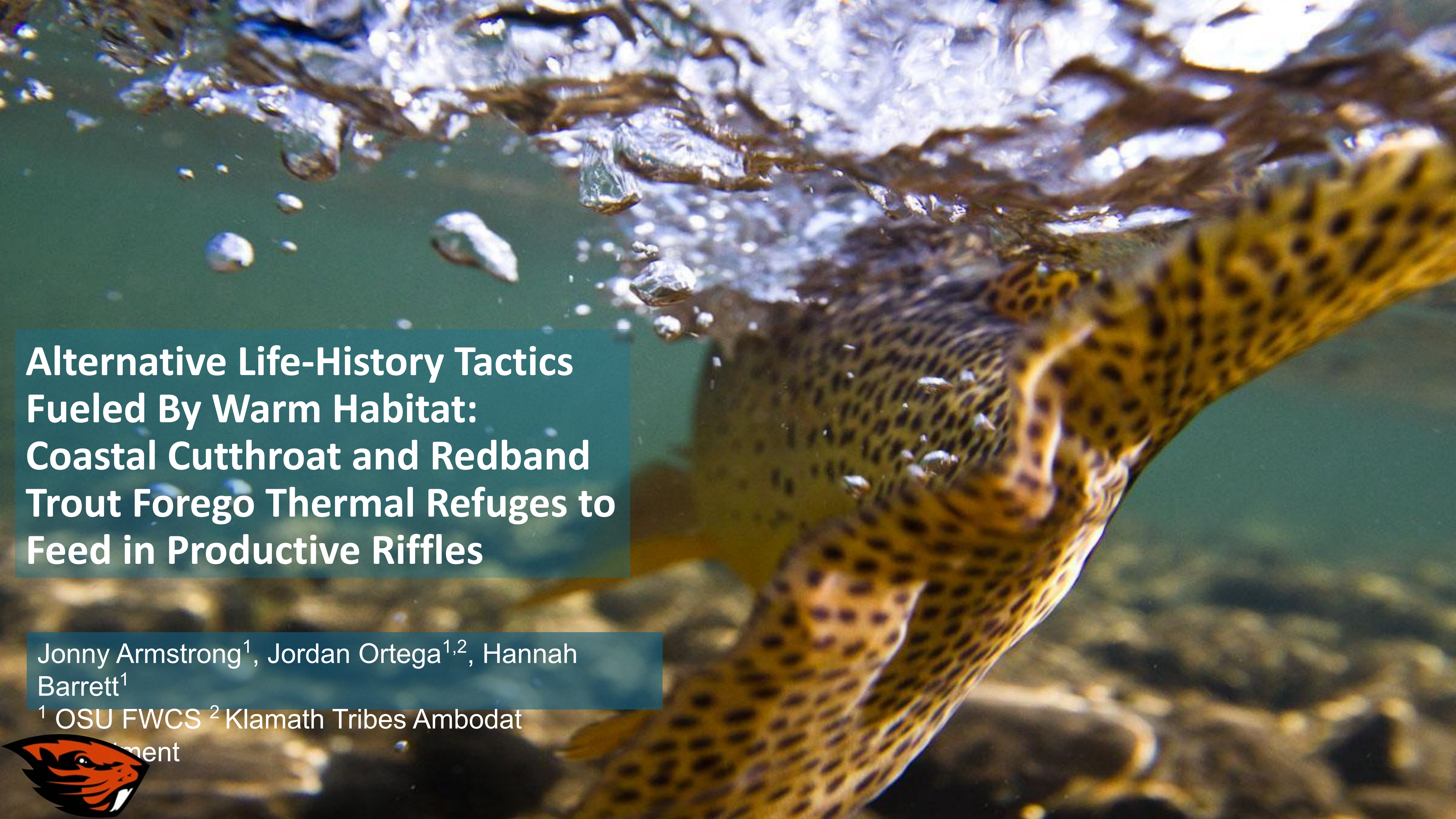


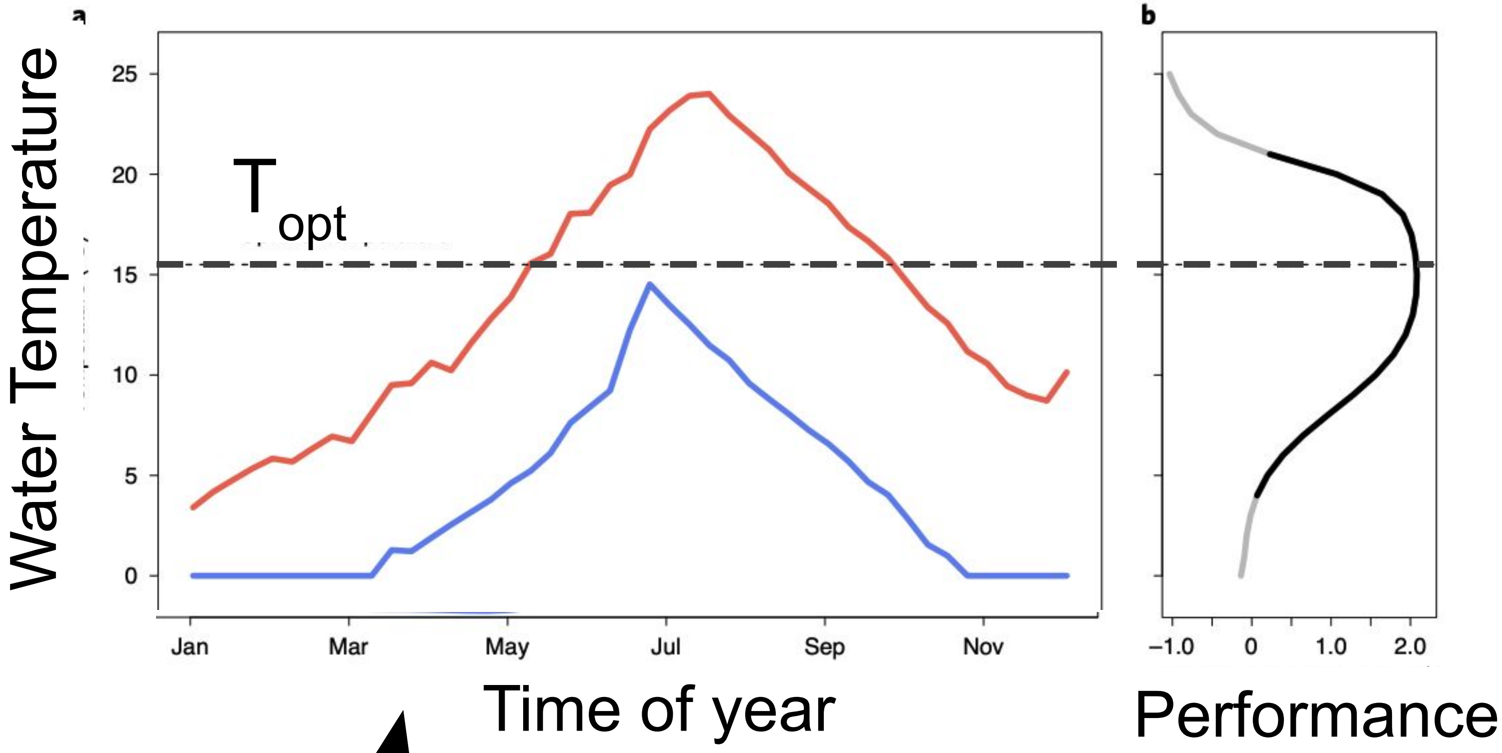
Thermal Regimes
Food Regimes
ol Tributary
ol Mainstem
Warm Tributary
Warm Mainstem
Estuary
Estuary
Run Model
Restore Graphs
Restore Model Inputs
Juvenile Length
300
150
0
Apr
Jul
Oct
Jan
Apr
Time
Juvenile Abundance
60
30
0
22%
42%
fish abundance
fish abundance
fish abundance

Thank you!

<u>Foodscape Team</u>

Jonathan Armstrong, David Beauchamp, Theodore Grantham, Carson Jeffres, Jacob Katz, Matthew Kaylor, Peter Kiffney, Martin Liermann, Sean Naman, Mary Power, Valerie Ouellet, Jordan Rosenfeld, Suzanne Rhoades, Beth Sanderson, Seth White


Alternative Life-History Tactics Fueled By Warm Habitat: Coastal Cutthroat and Redband Trout Forego Thermal Refuges to Feed in Productive Riffles
Jonny Armstrong[1], Jordan Ortega[1,2], Hannah Barrett[1]
[1] OSU FWCS [2] Klamath Tribes Ambodat
ment

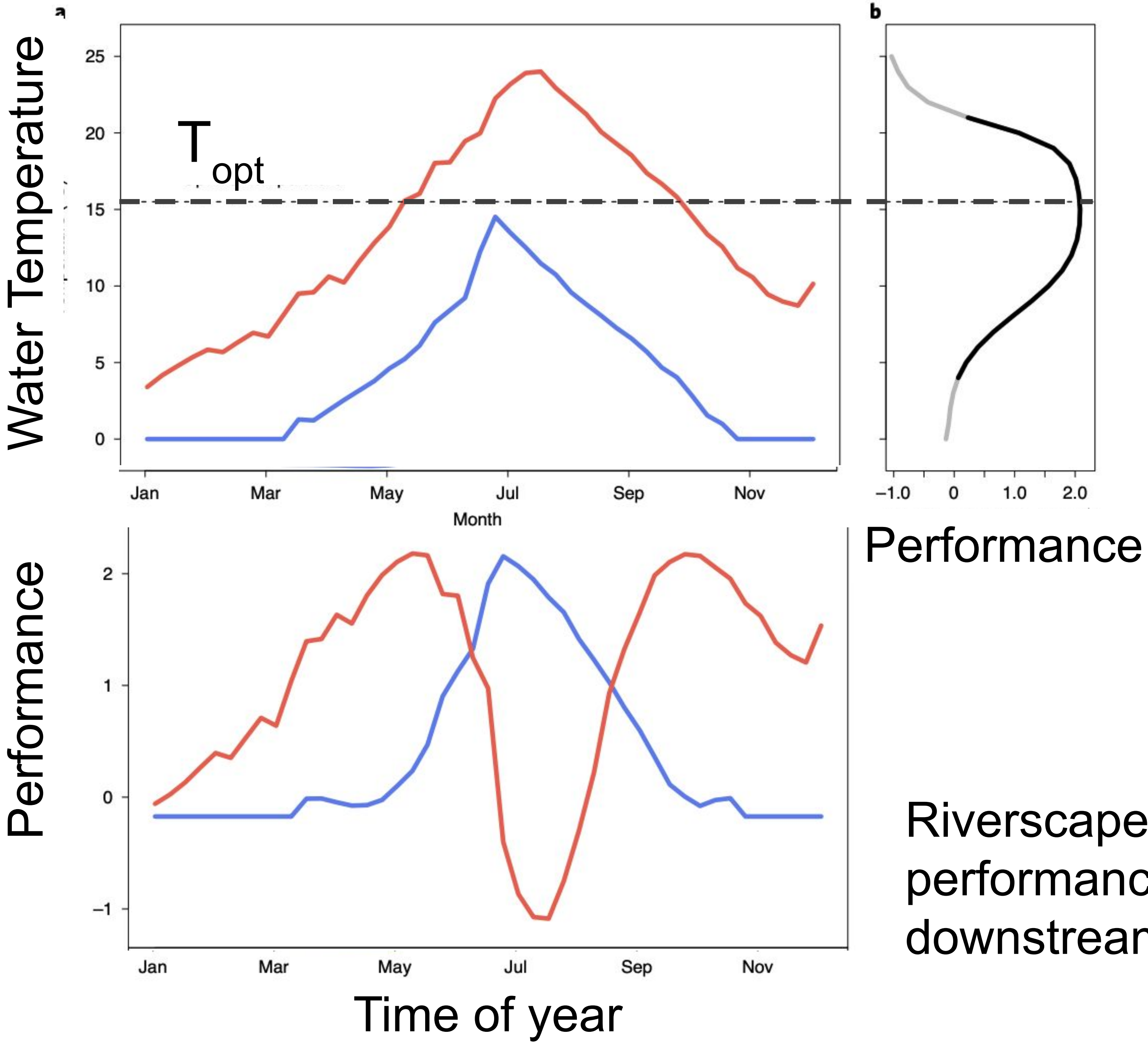


Thermal regime + Physiology = Growth regime

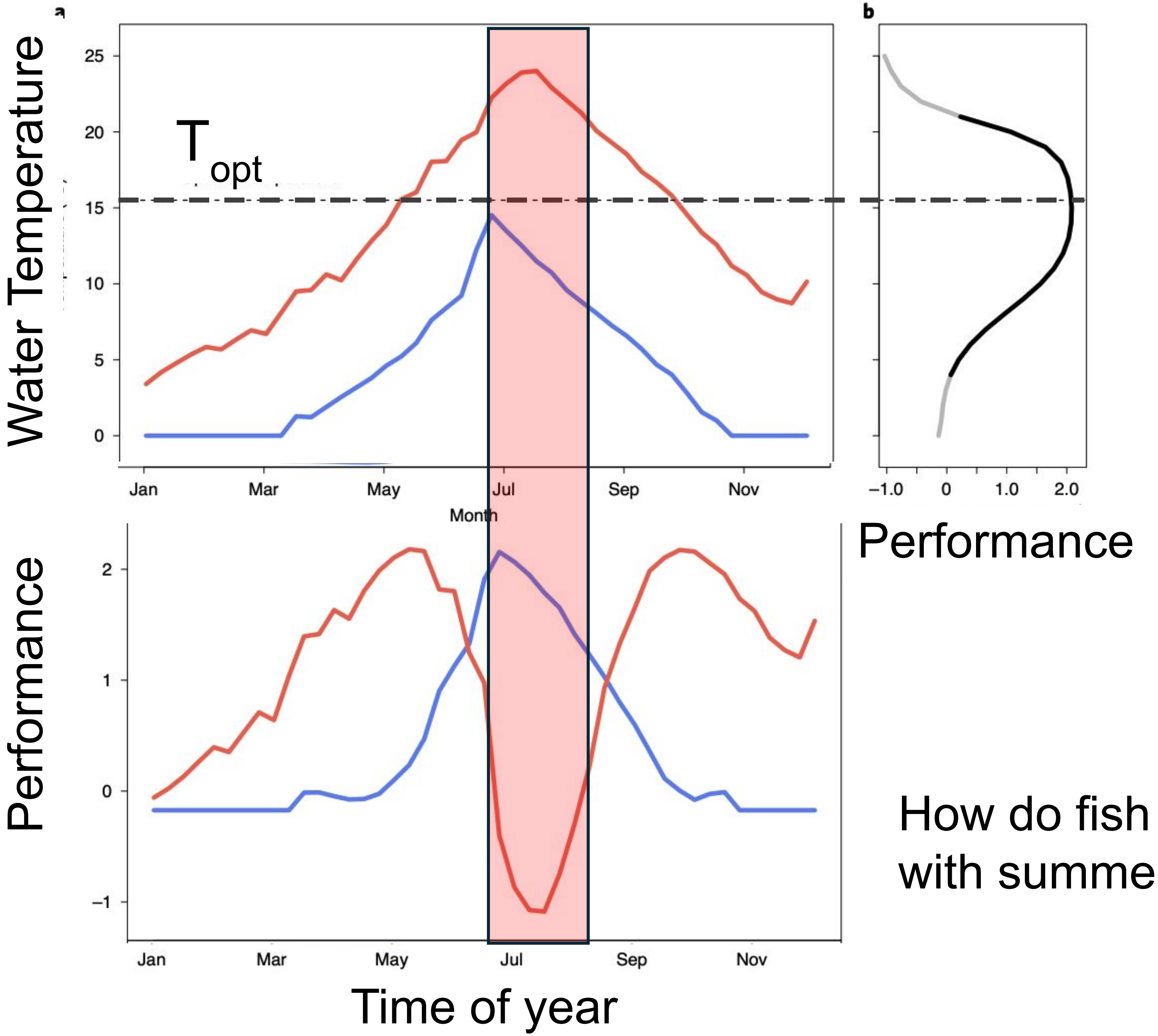

ARTICLES
https://doi.org/10.1038/s41558-021-00994-y
nature climate change

The importance of warm habitat to the growth regime of cold-water fishes

Jonathan B. Armstrong[1✉], Aimee H. Fullerton[2], Chris E. Jordan[2], Joseph L. Ebersole[3], J. Ryan Bellmore[4], Ivan Arismendi[1], Brooke E. Penaluna[5] and Gordon H. Reeves[5]



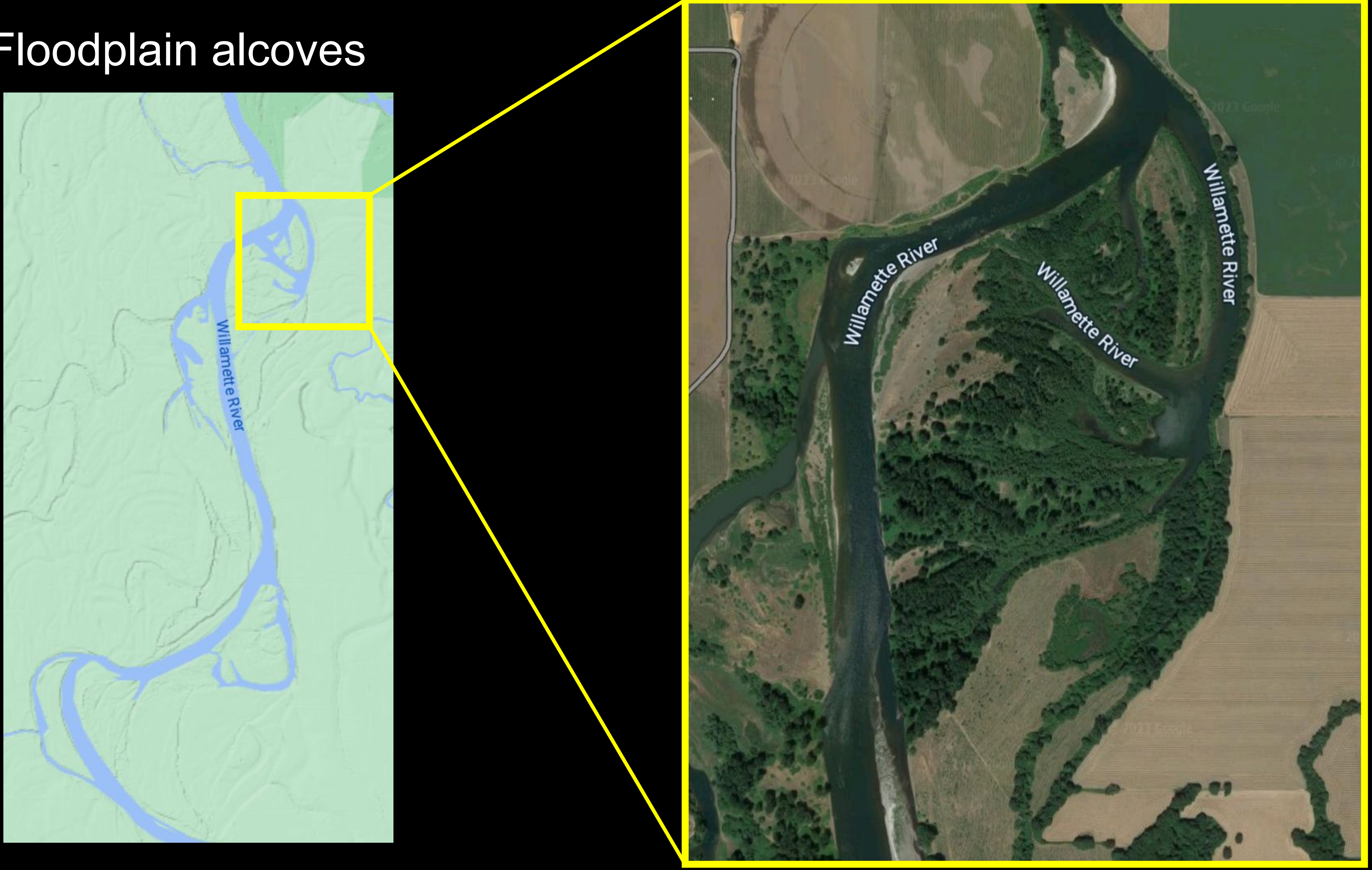
Riverscapes exhibit 3 peaks of physiological performance and two of them occur downstream



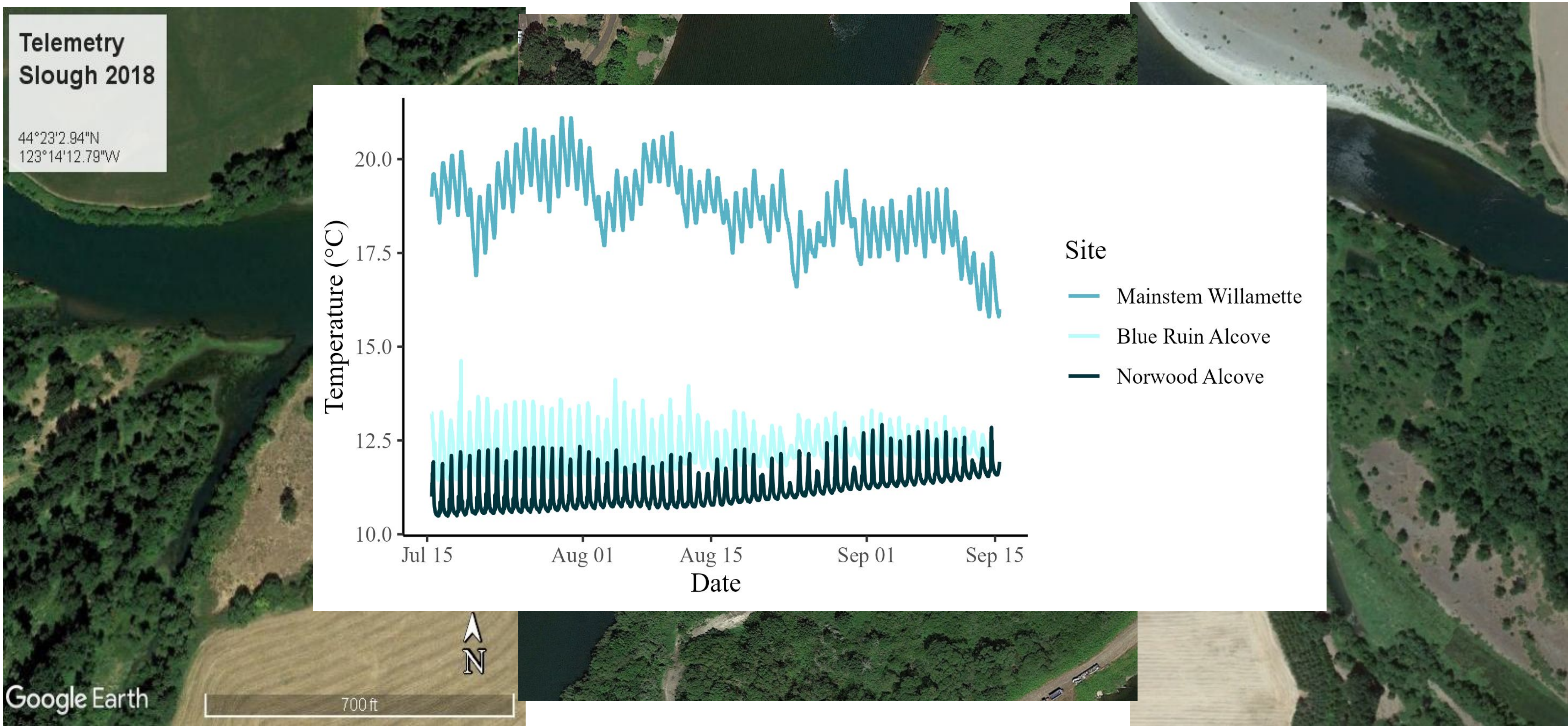
How do fish in downstream habitats cope with summer?

Coastal cutthroat trout, Willamette River

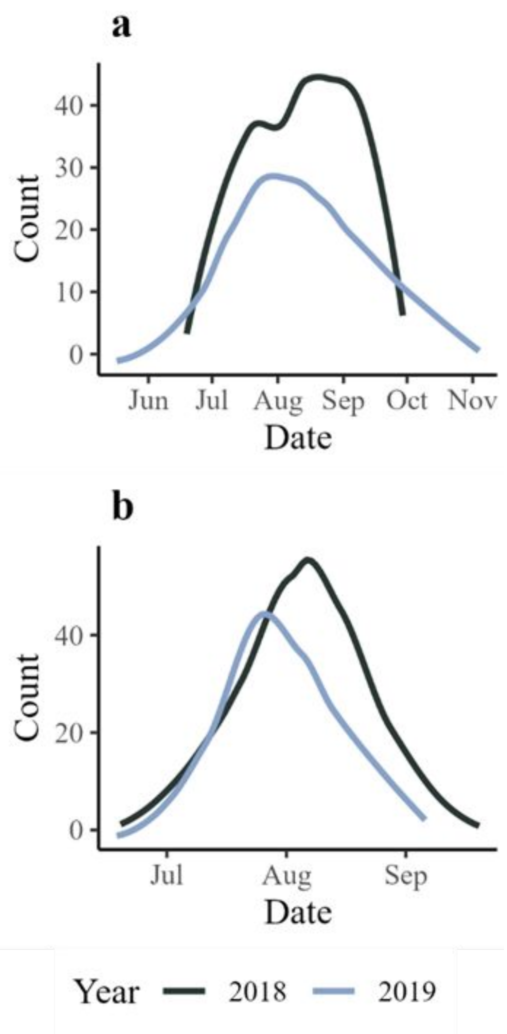
Floodplain alcoves



Alcoves with upwelling flows offer cool temperatures as mainstem reaches ~ 23C

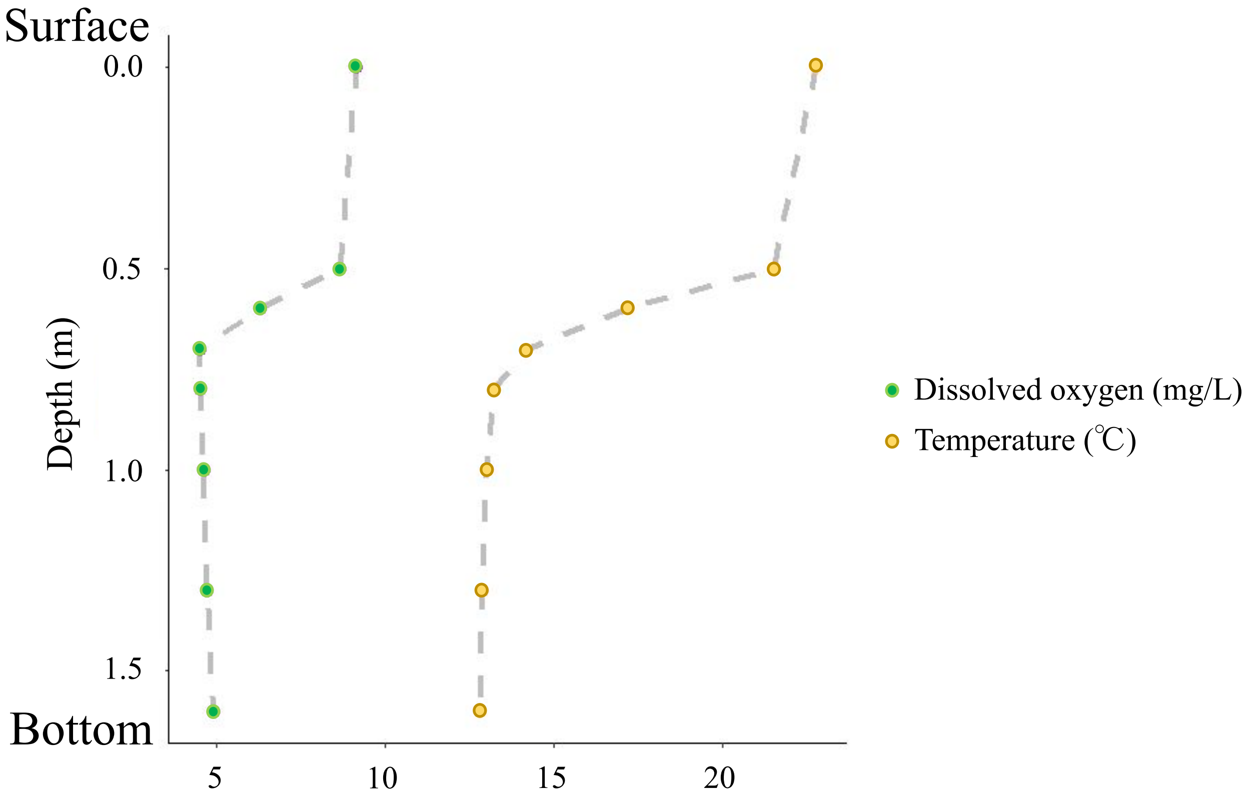


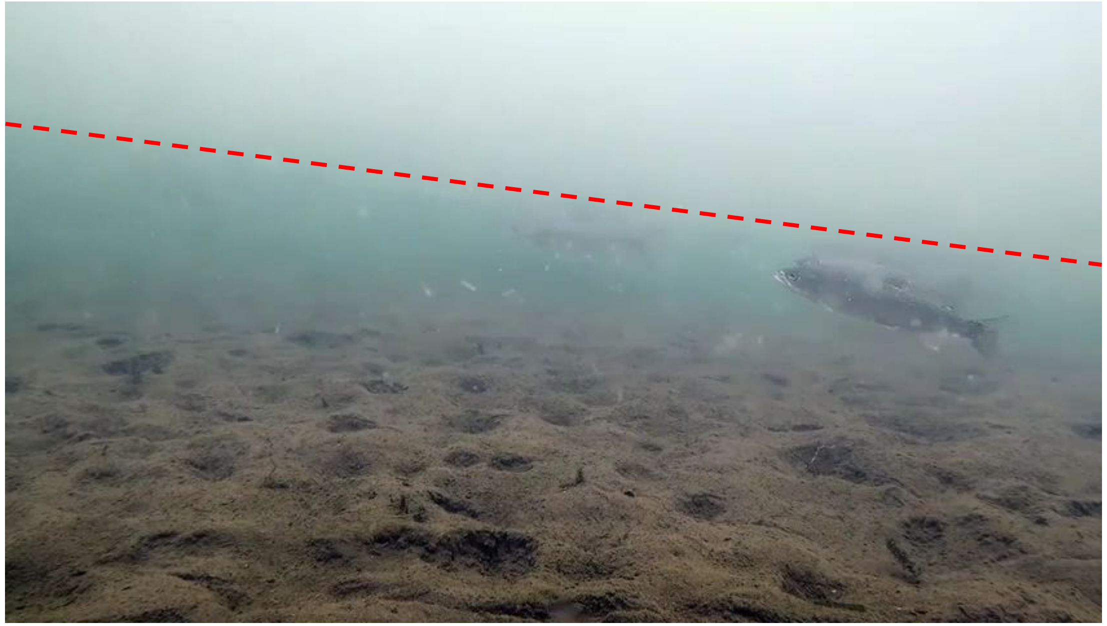
As the mainstem warms, cutthroat trout aggregate in floodplain alcoves



Blue Ruin

Norwood



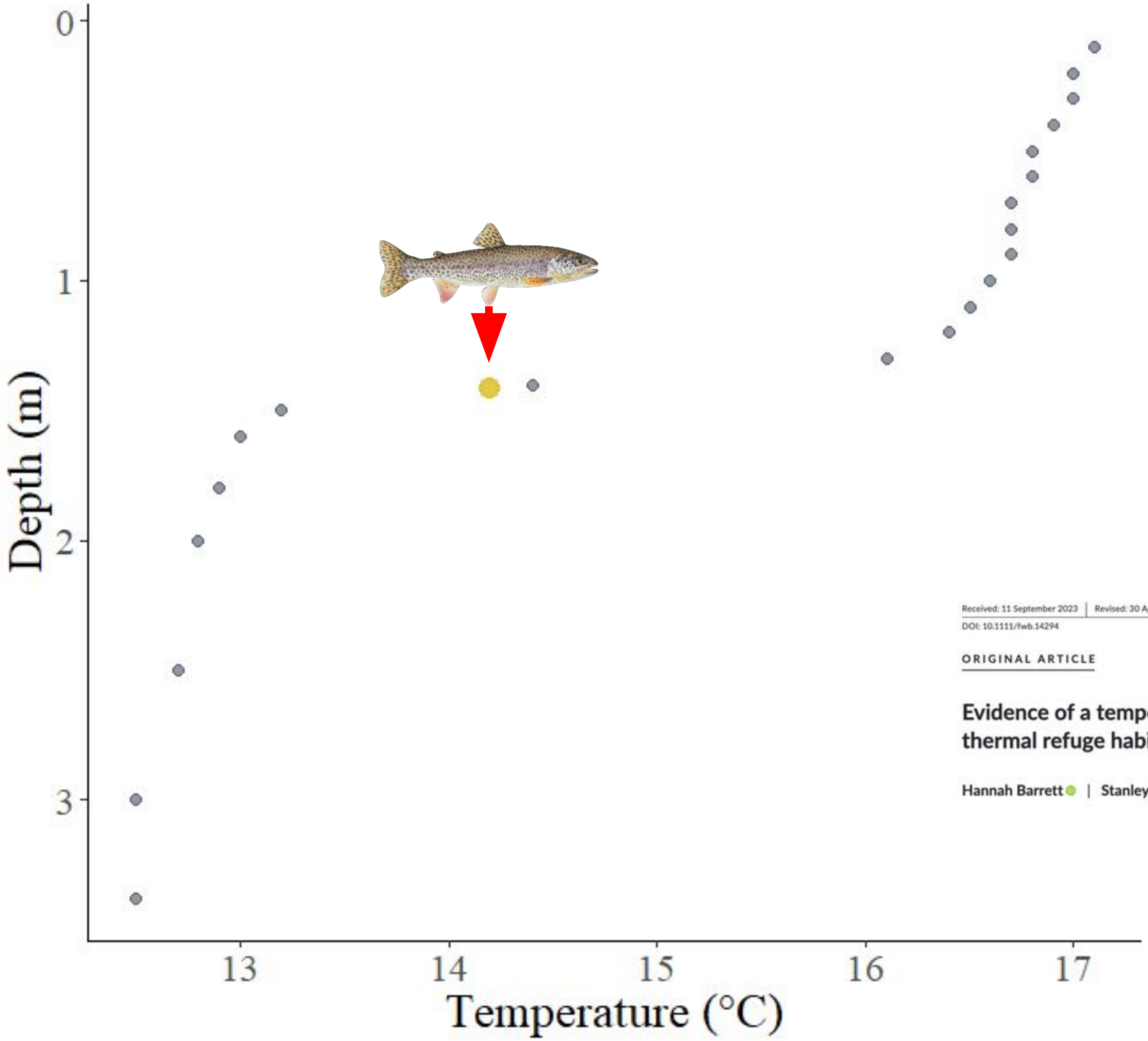



RESEARCH ARTICLE

AMERICAN WATER RESOURCES ASSOCIATION JAWRA

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]



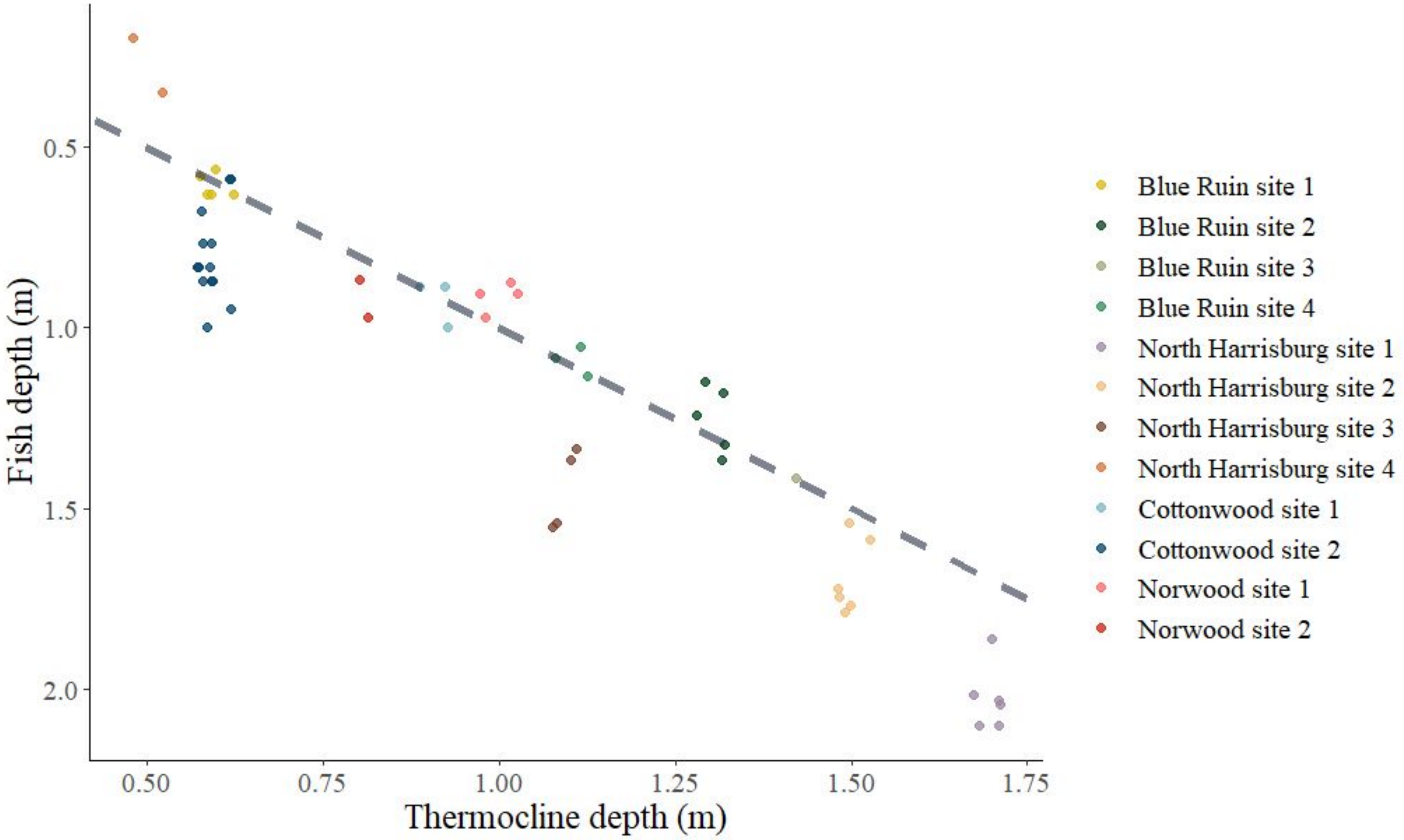
Received: 11 September 2023 | Revised: 30 April 2024 | Accepted: 8 May 2024
DOI: 10.1111/fwb.14294

ORIGINAL ARTICLE

Freshwater Biology WILEY

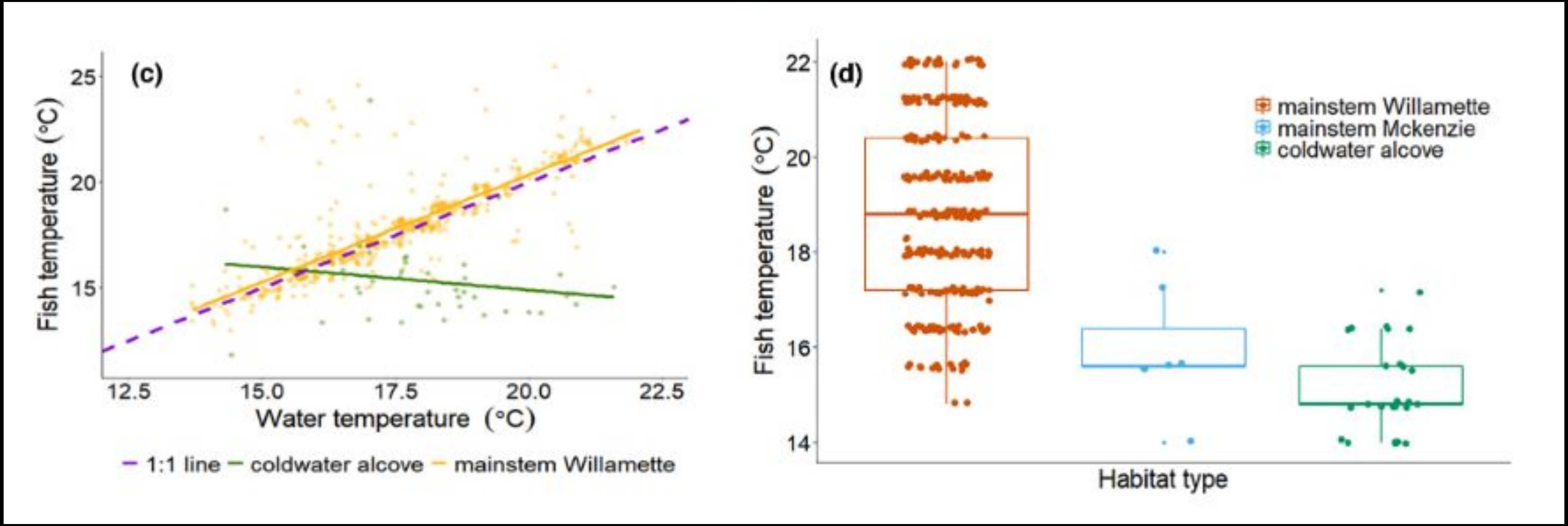
Evidence of a temperature–oxygen squeeze within floodplain thermal refuge habitats

Hannah Barrett | Stanley Gregory | Jonathan Armstrong



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

What fraction of the population moves to floodplain thermal refuges?



<10% in an approximately average summer (2020)

Barret and Armstrong 2022 *Ecosphere*

Mainstem Willamette (lotic)

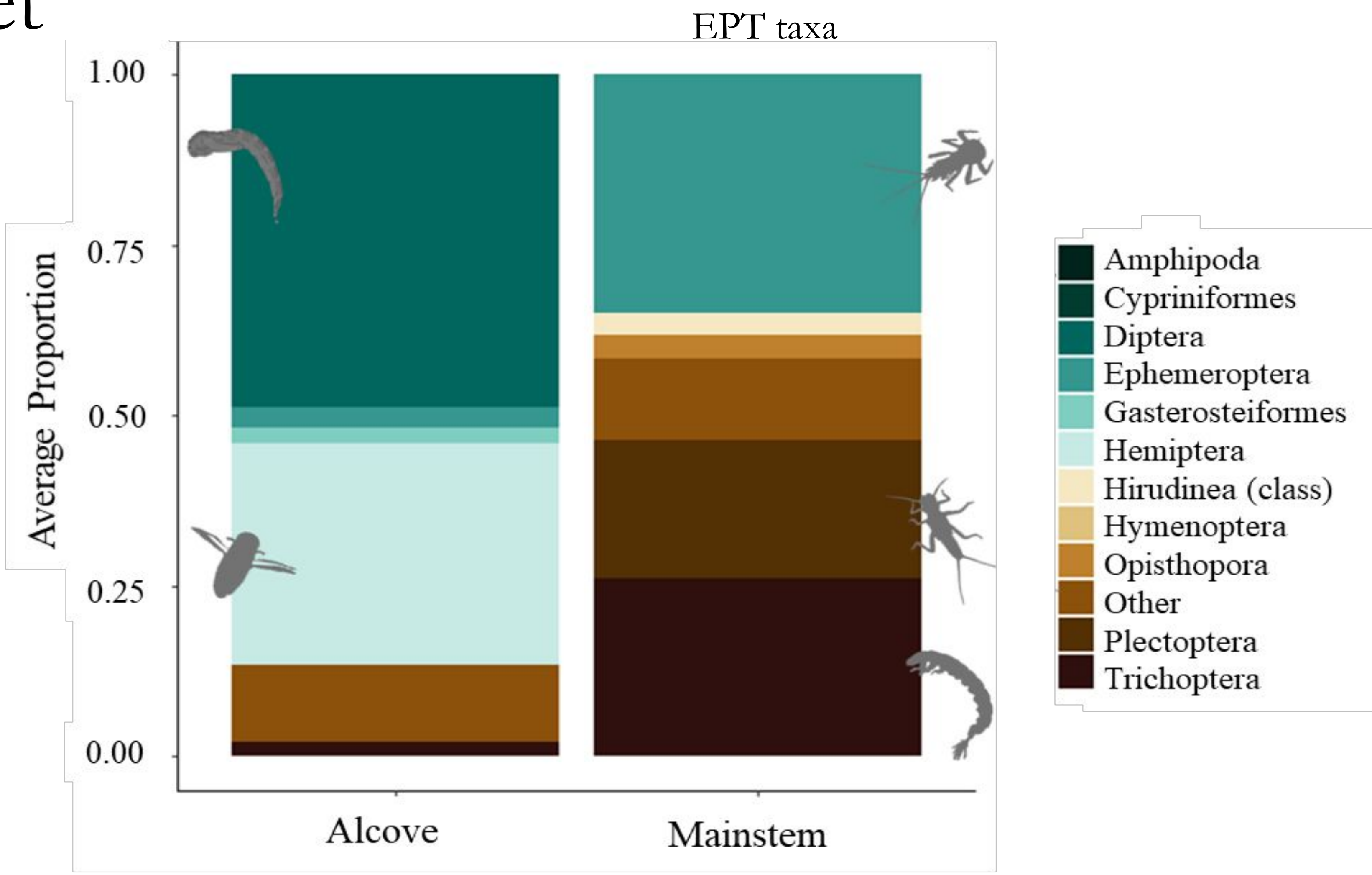
- Warm
- High velocity
- Presumably prey rich

Cold-water alcove (lentic)

- Up to 10℃ cooler
- Zero velocity
- Warm margins packed with invertebrates

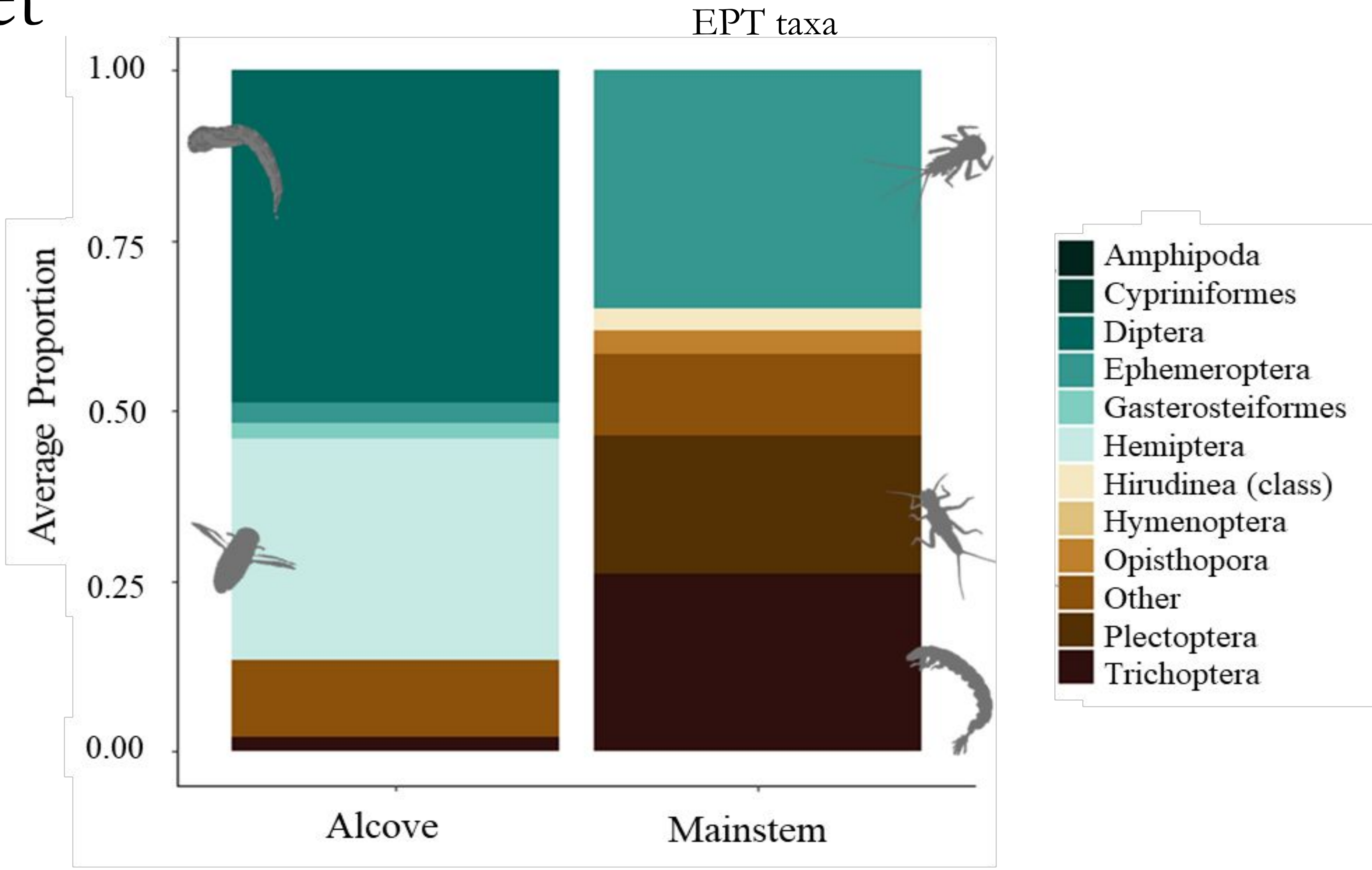
Characterizing diet

- Alcove fish eat chironomid pupae and diving water beetles



Characterizing diet

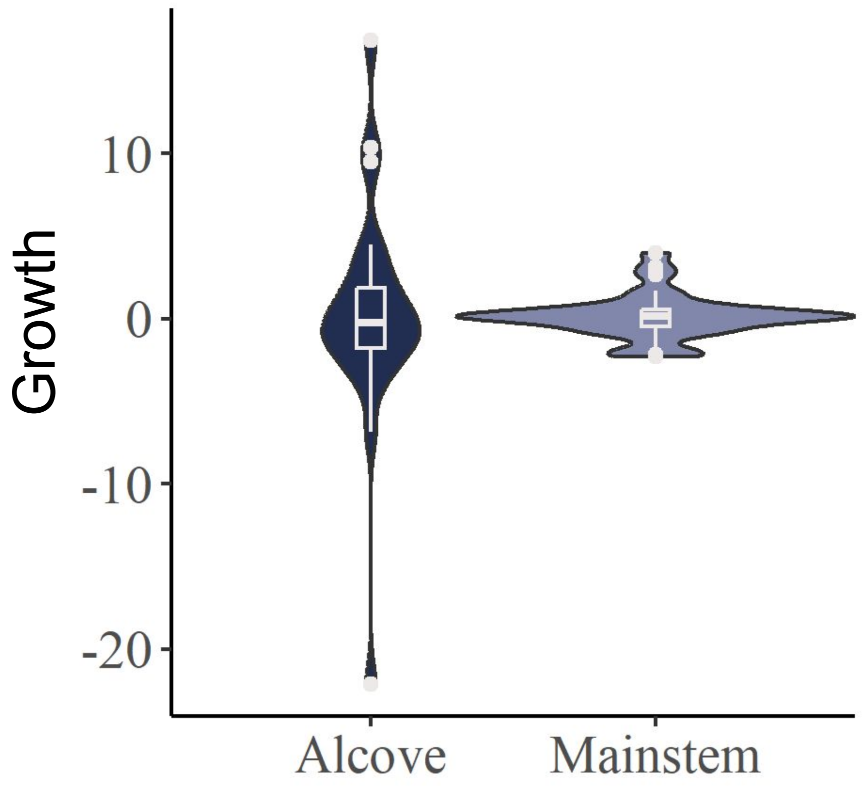
- Alcove fish eat chironomid pupae and diving water beetles
- Mainstem fish have >3x more energy in their diet

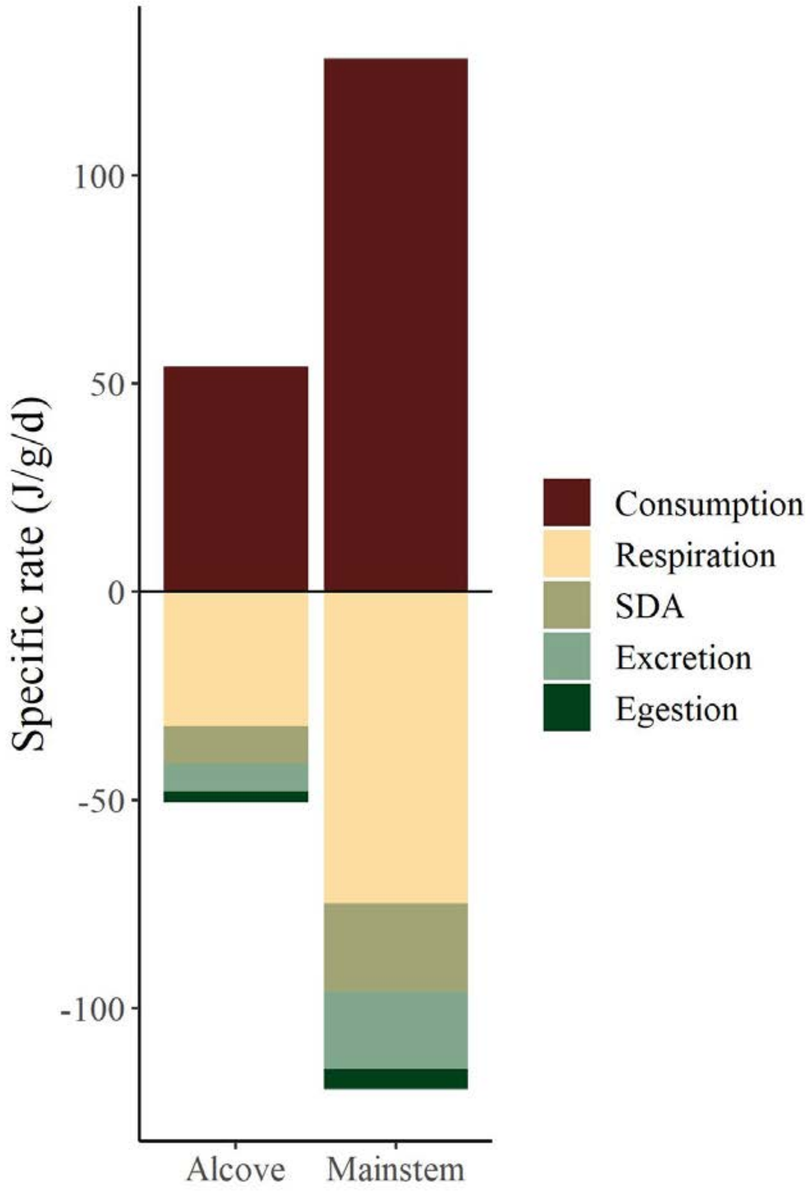


Growth and bioenergetics

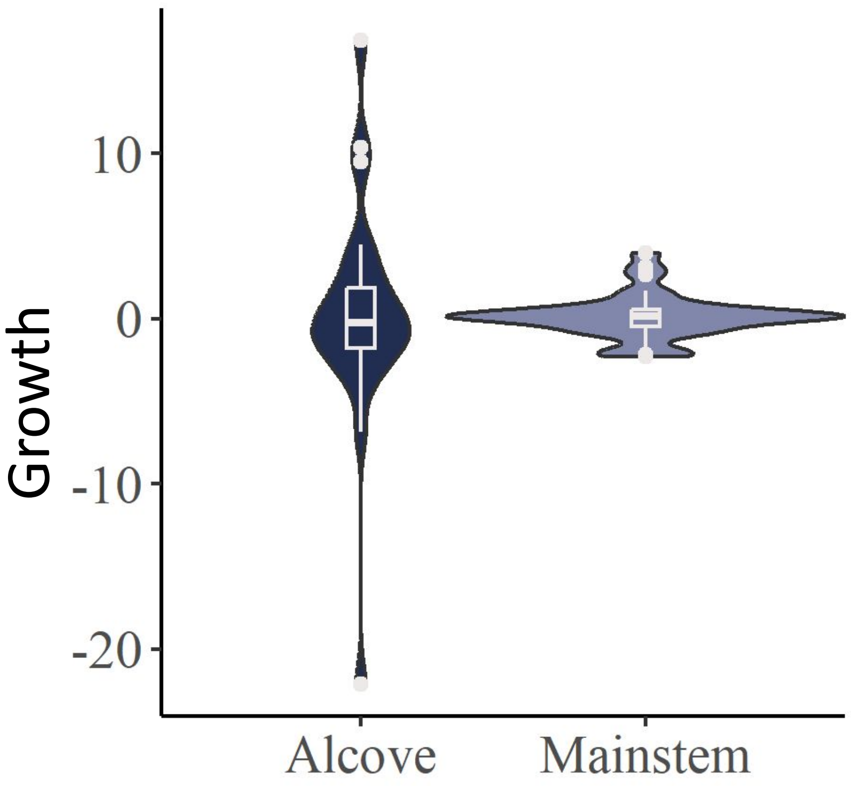
- Median growth is approximately equal

- Solve for energy budget that produces observed growth when C riffle = 3* C alcove





Specific rate (J/g/d)
100
50
0
-50
-100
Alcove
Mainstem
Consumption
Respiration
SDA
Excretion
Egestion



Growth
10
0
-10
-20
Alcove
Mainstem

Gain Maximizing

- Higher basal metabolism
- Higher activity costs
- Higher energy gain

Efficiency Maximizing

- Lower basal metabolism
- Lower activity
- Lower energy gain

Mainstem Willamette
Photo by Martyne Reesman

Received: 20 June 2022 | Revised: 1 August 2022 | Accepted: 18 August 2022
DOI: 10.1002/ece3.9280

RESEARCH ARTICLE

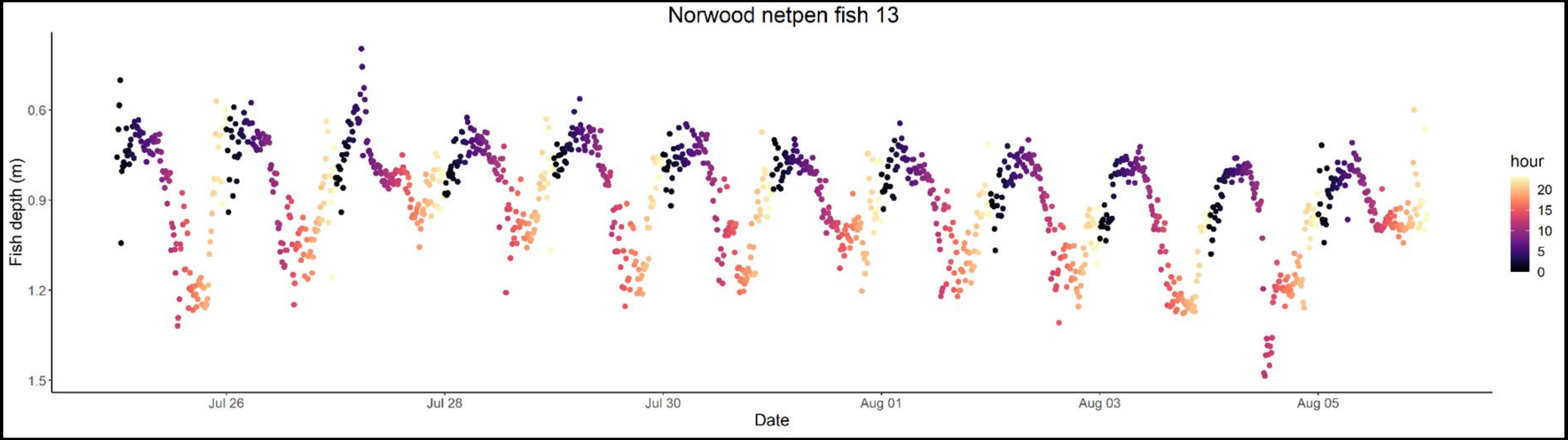
Ecology and Evolution Open Access WILEY

Divergence in digestive and metabolic strategies matches habitat differentiation in juvenile salmonids

Gauthier Monnet[1] | Jordan S. Rosenfeld[2,3] | Jeffrey G. Richards[1]

Alcove
Photo from USGS

Cutthroat trout exhibit DVM to balance Temperature and DO trade-off

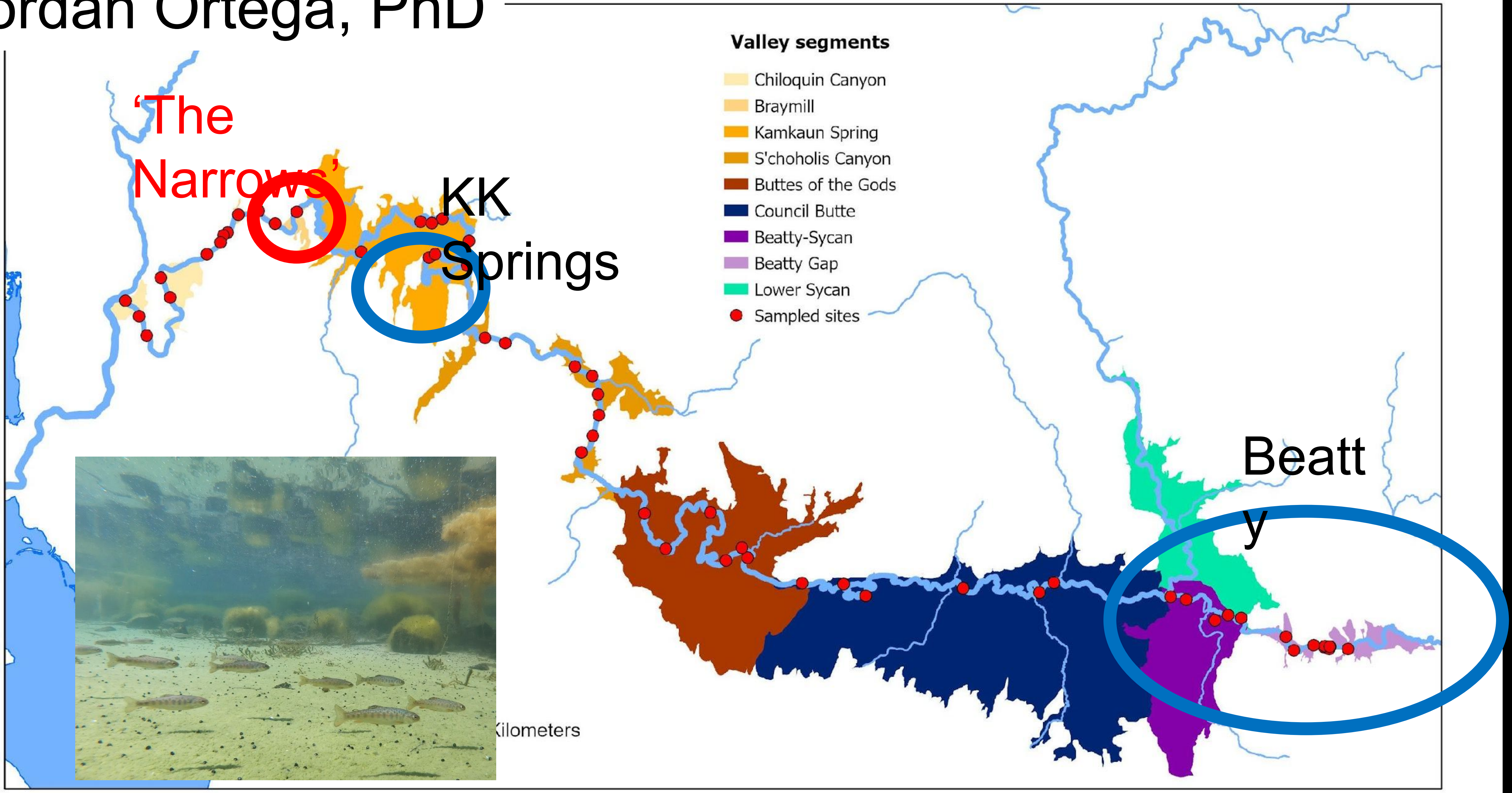


- Fish avoid DO minimums (< 2mg/L)
- BUT they endure hypoxia (2-4 mg/L) in exchange for cold temperatures

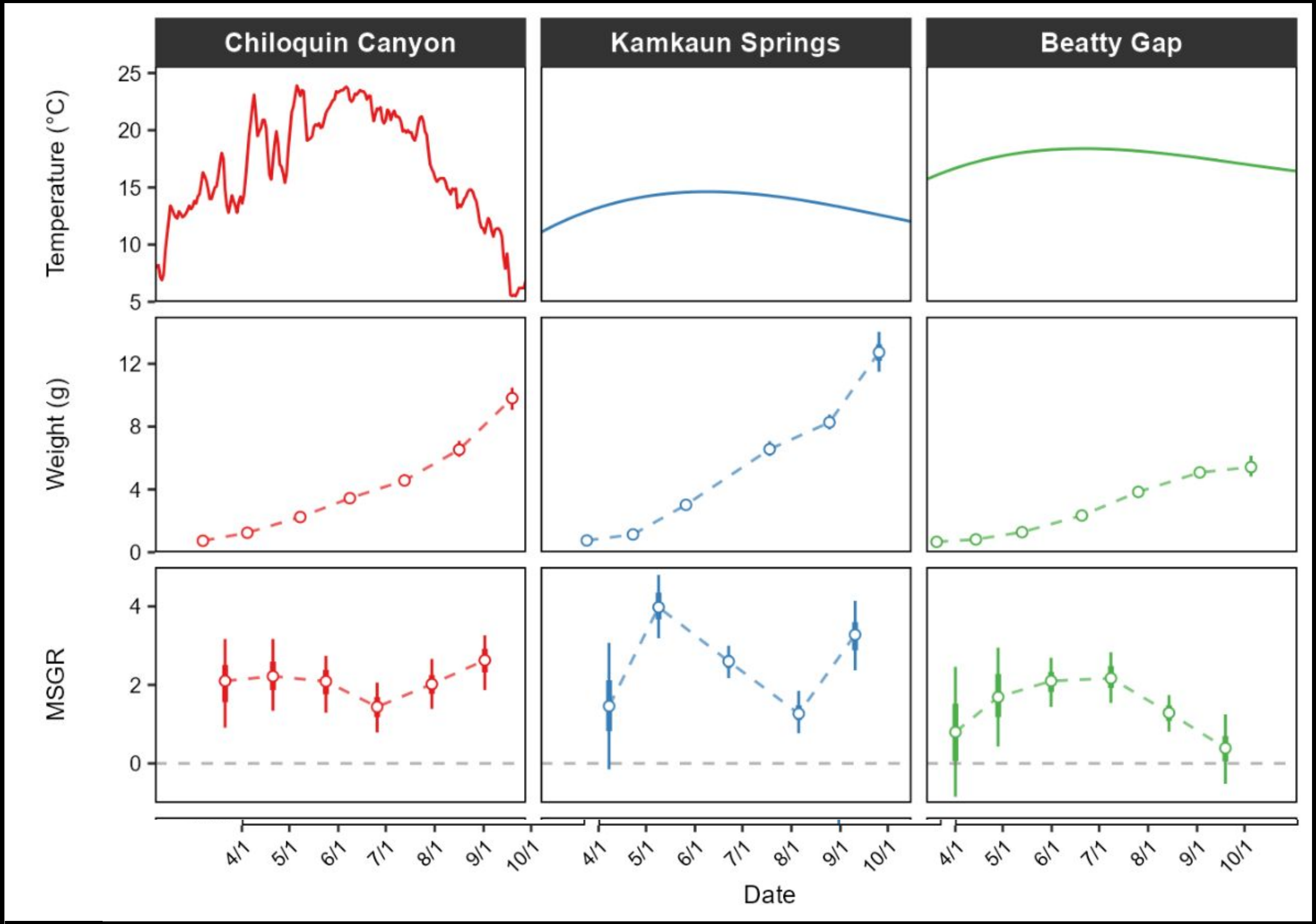
Barrett et al. in review *J Anim. Ecol.*

Part II: Klamath Redband trout

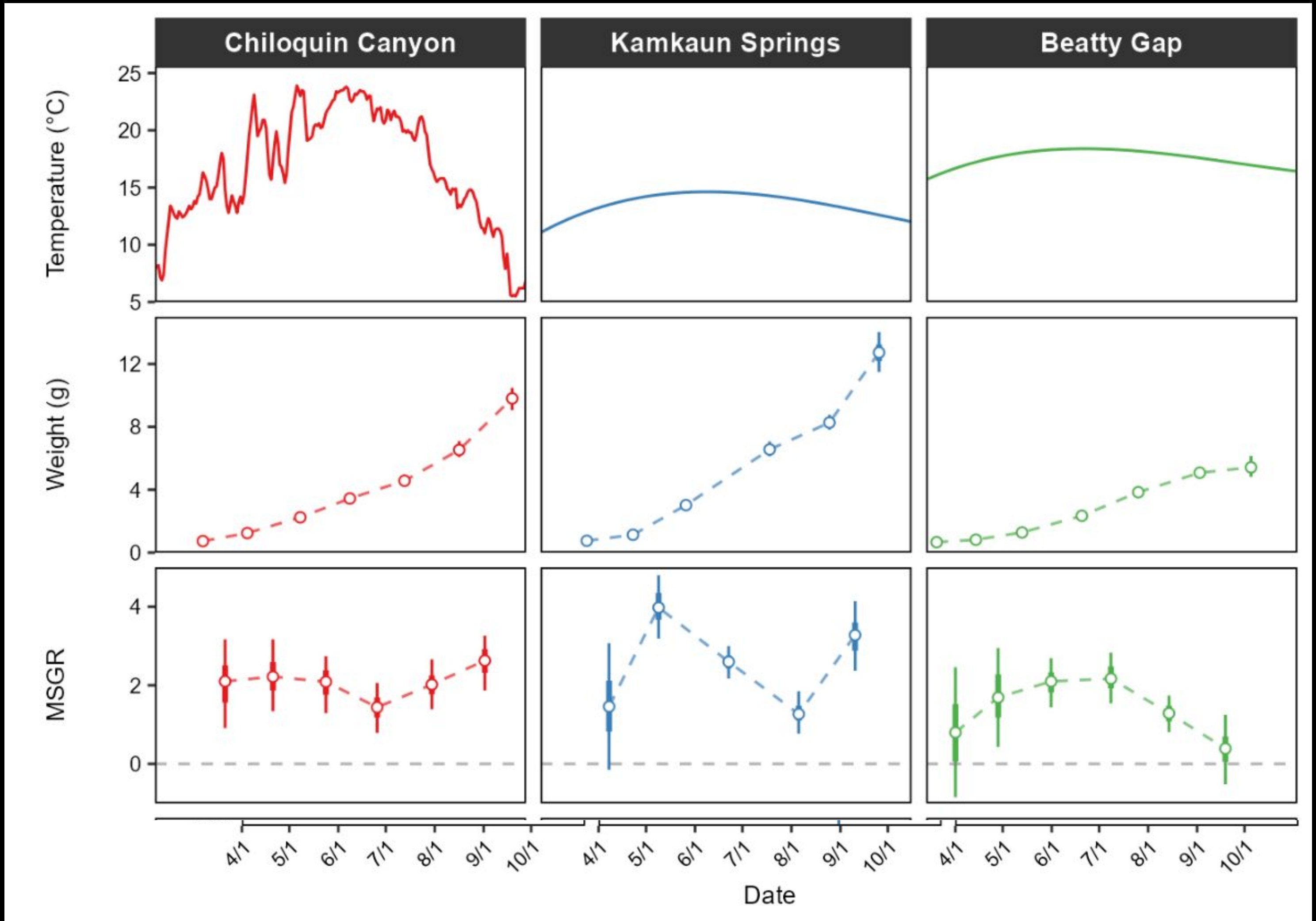
Jordan Ortega, PhD



How do these 3 locations support fish through time?



How do these 3 locations support fish through time?



How do food consumption rates compare among these sites?

Uncertainty over temperature vs. metabolic costs

BIOENERGETIC RATES OF YOUNG RAINBOW TROUT 319

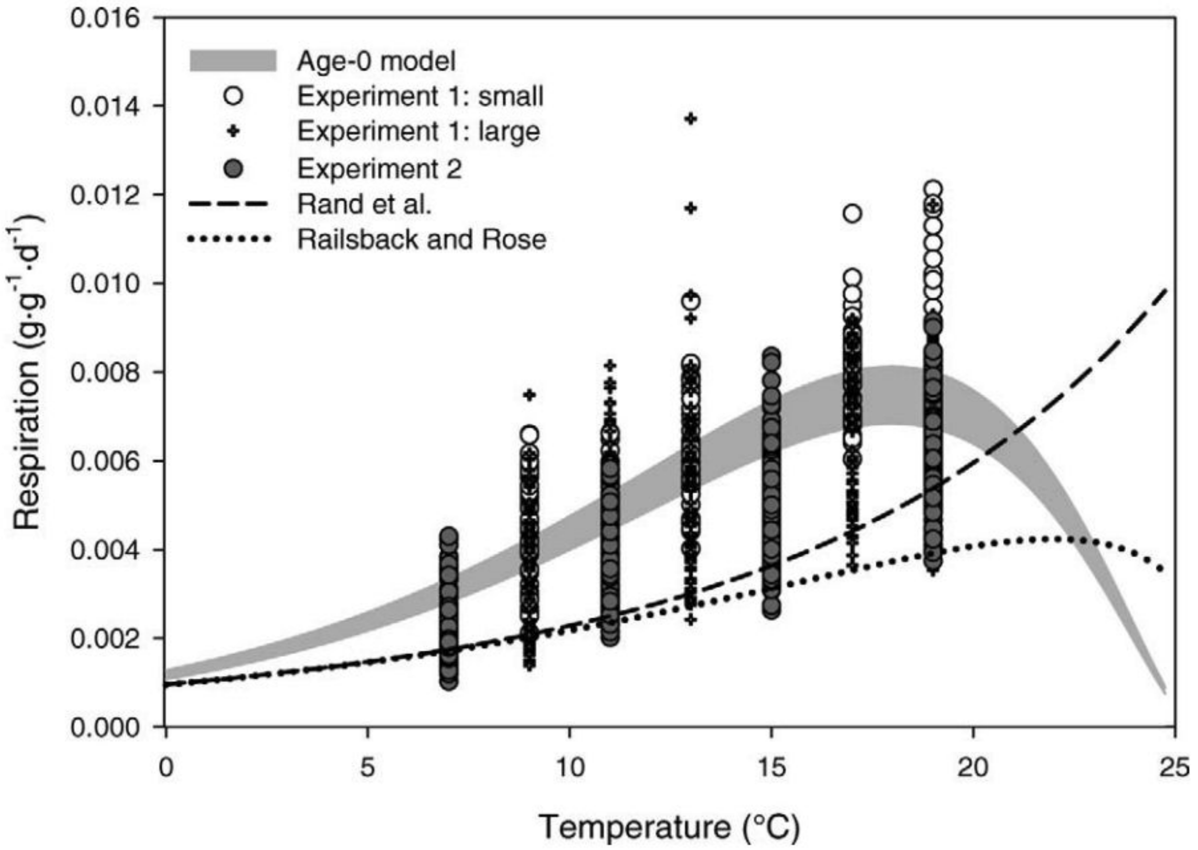
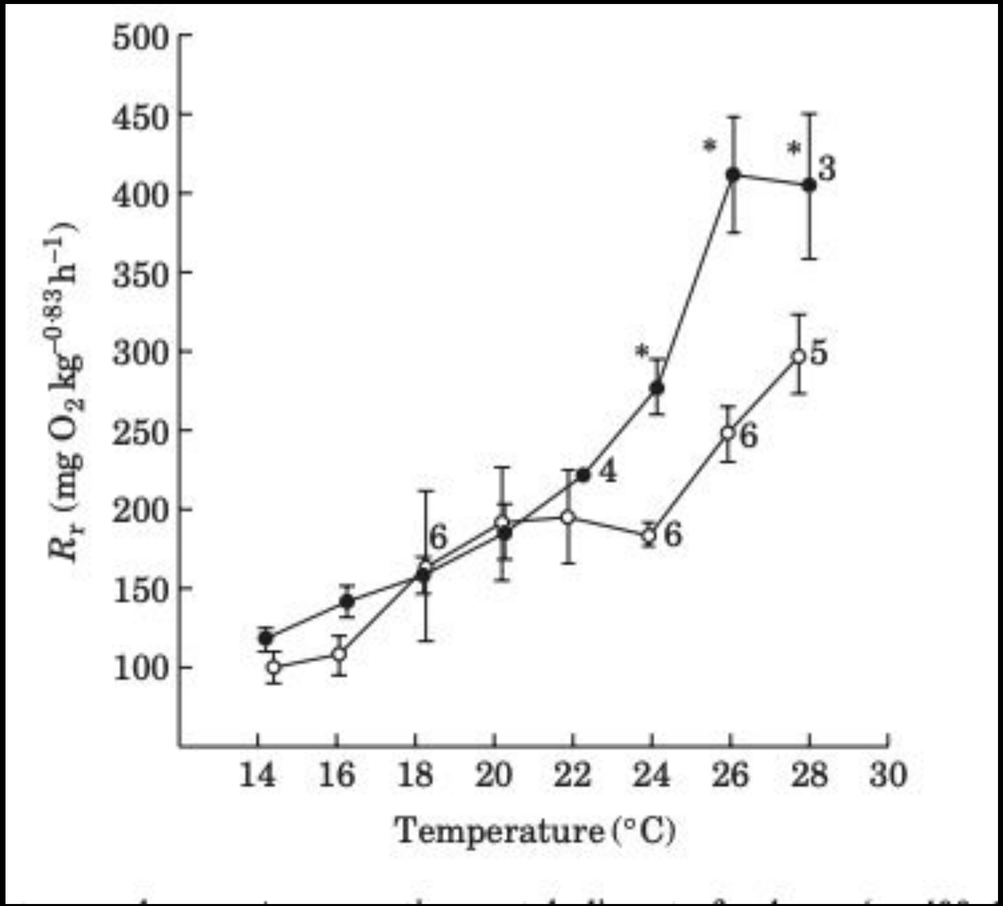


FIGURE 2.—Data and model predictions of the relationship between temperature and the respiration rate of age-0 rainbow trout. The data are shown as individual points. The shaded region shows the predictions from the new age-0 model over the range of weights determined by the mean weights of the small and large fish in experiment 1. The predictions from the models of Rand et al. (1993) and Railsback and Rose (1999) use the mean weight of all fish.

Tyler and Bolduc 2008 *TAFS*

What does T vs. R look like for Klamath redband trout?



Journal of Fish Biology (2004) **64,** 310–335
doi:10.1046/j.1095-8649.2004.00292.x, available online at http://www.blackwell-synergy.com

Thermal tolerance and metabolic physiology among redband trout populations in south-eastern Oregon

K. J. Rodnick*†, A. K. Gamperl‡§, K. R. Lizars‡, M. T. Bennett†, R. N. Rausch‡ and E. R. Keeley†

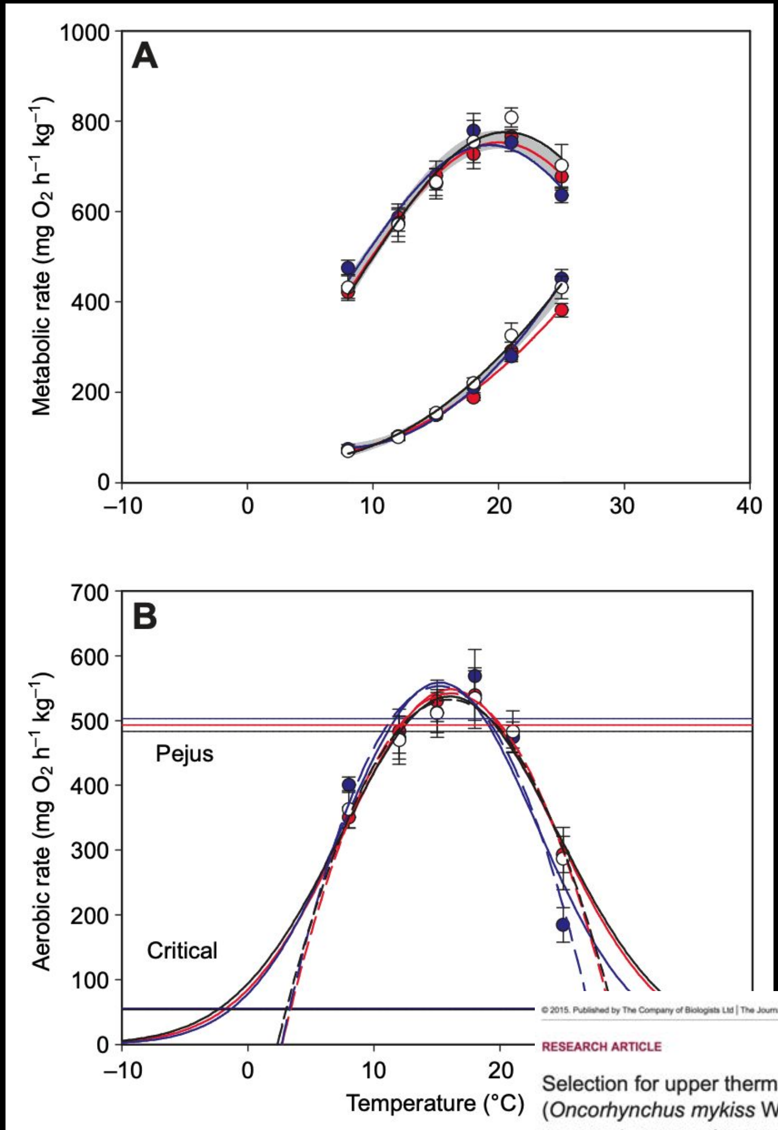


Fig. 3. Routine (RMR) and maximum (MMR) metal
scope for three family groups of rainbow trout. (A) RMR and MMR of three

© 2015. Published by The Company of Biologists Ltd | The Journal of Experimental Biology (2015) 218, 803-812 doi:10.1242/jeb.113993

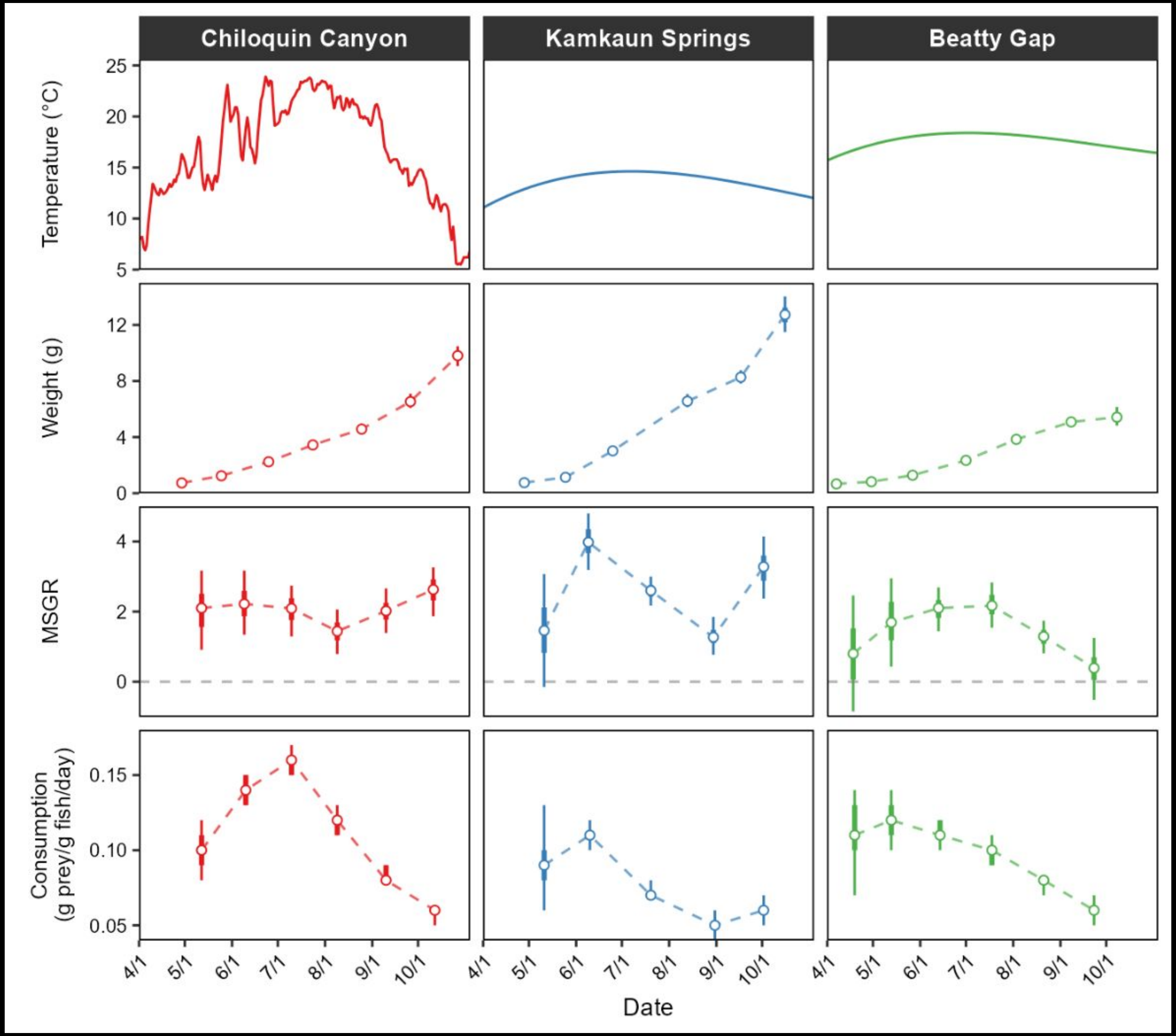
RESEARCH ARTICLE

Selection for upper thermal tolerance in rainbow trout (*Oncorhynchus mykiss* Walbaum)

Zhongqi Chen[1,*], Michael Snow[2], Craig S. Lawrence[2,3], Anthony R. Church[4], Shawn R. Narum[5], Robert H. Devlin[6] and Anthony P. Farrell[1,7]

- In the seasonally warm canyon fish consume ~50% more food during summer

- Phenology of consumption varies among sites

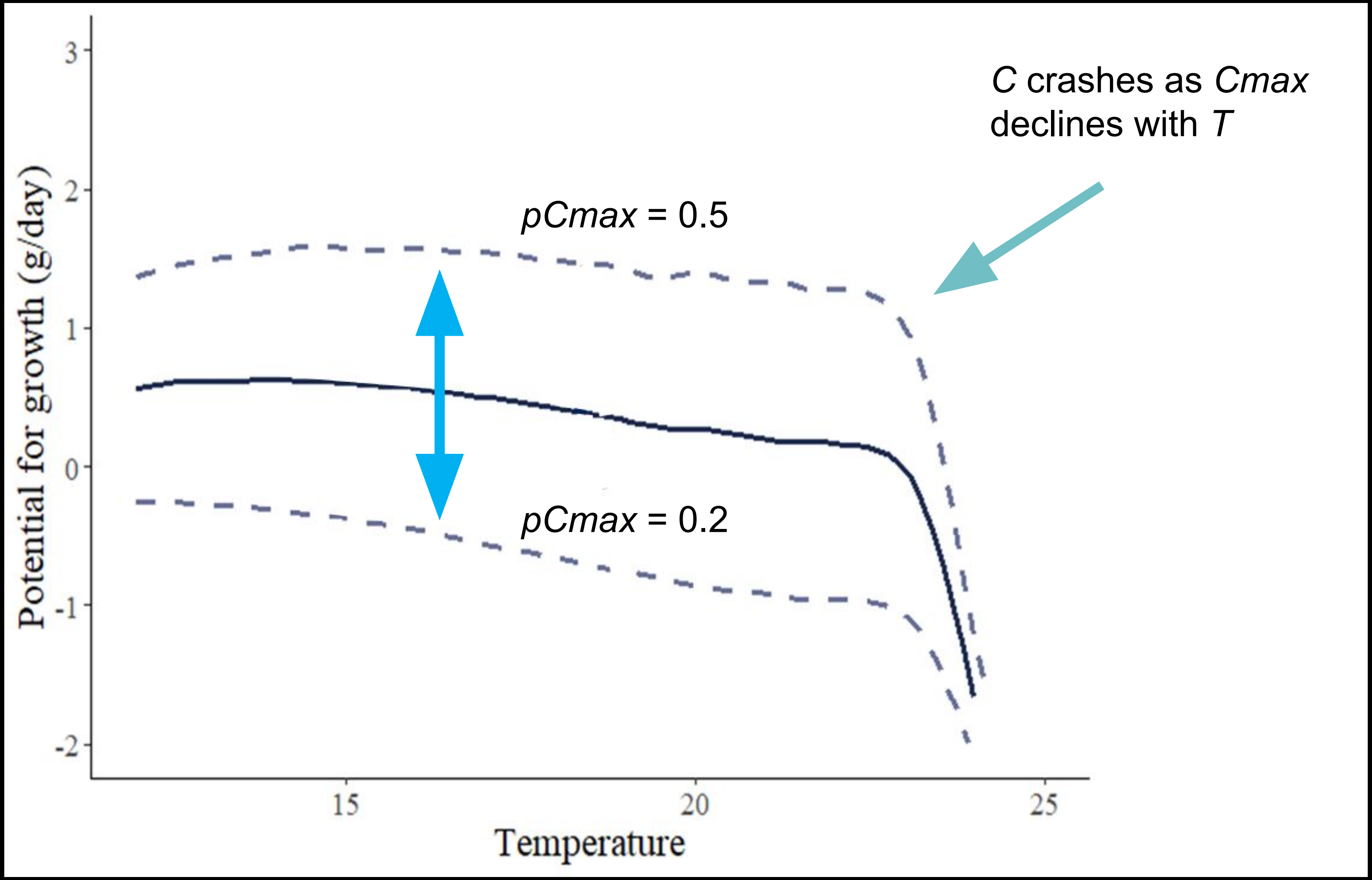


How to cope with hot summers

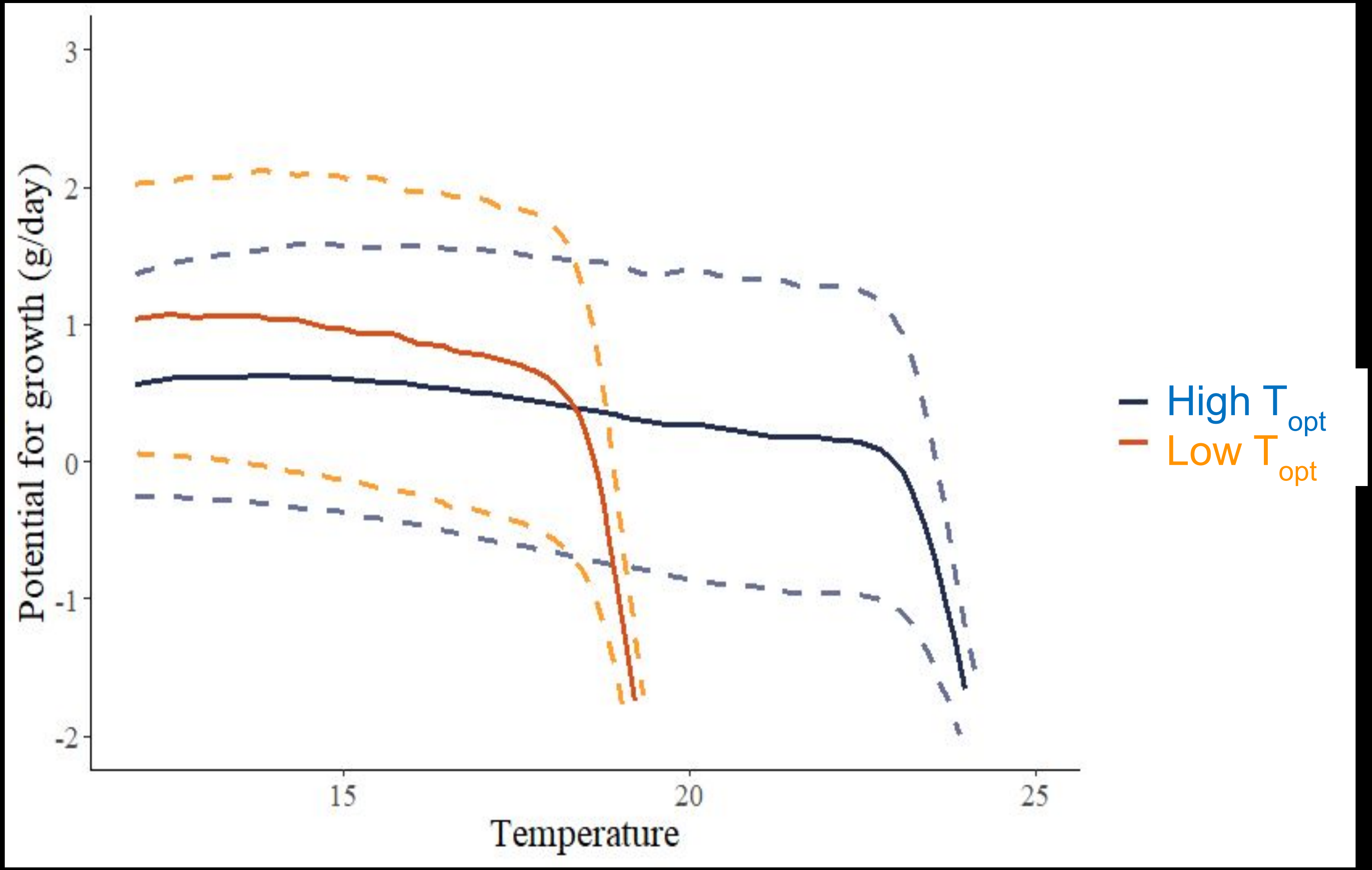
- Warm riffles support rate-maximizing strategies: big gains and big losses

- Thermal refuges support cost-minimizing strategies for adults, potentially different strategies for juveniles

Can salmonids eat their way out of trouble?



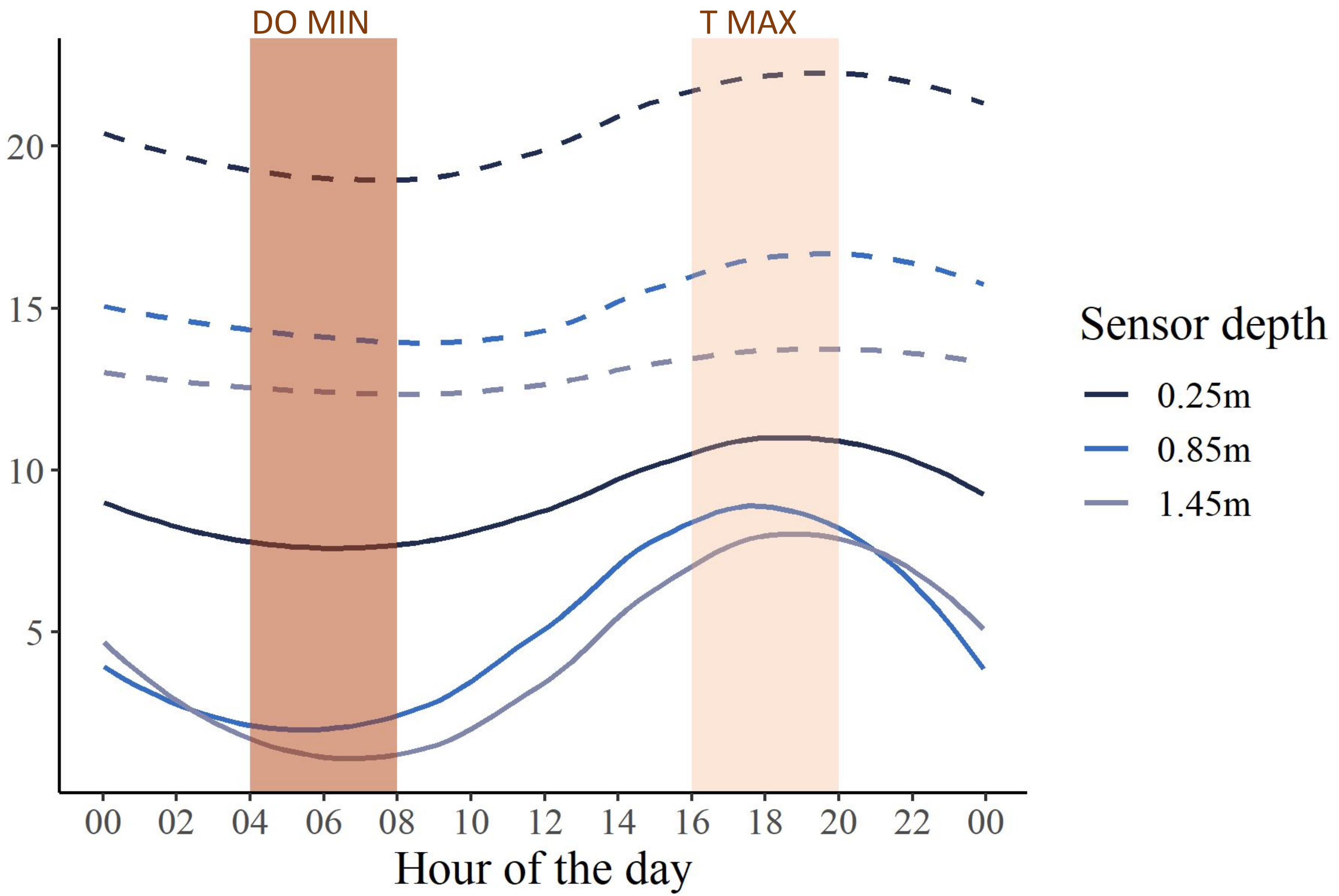
Where growth crashes depends on thermal physiology, which may vary a lot



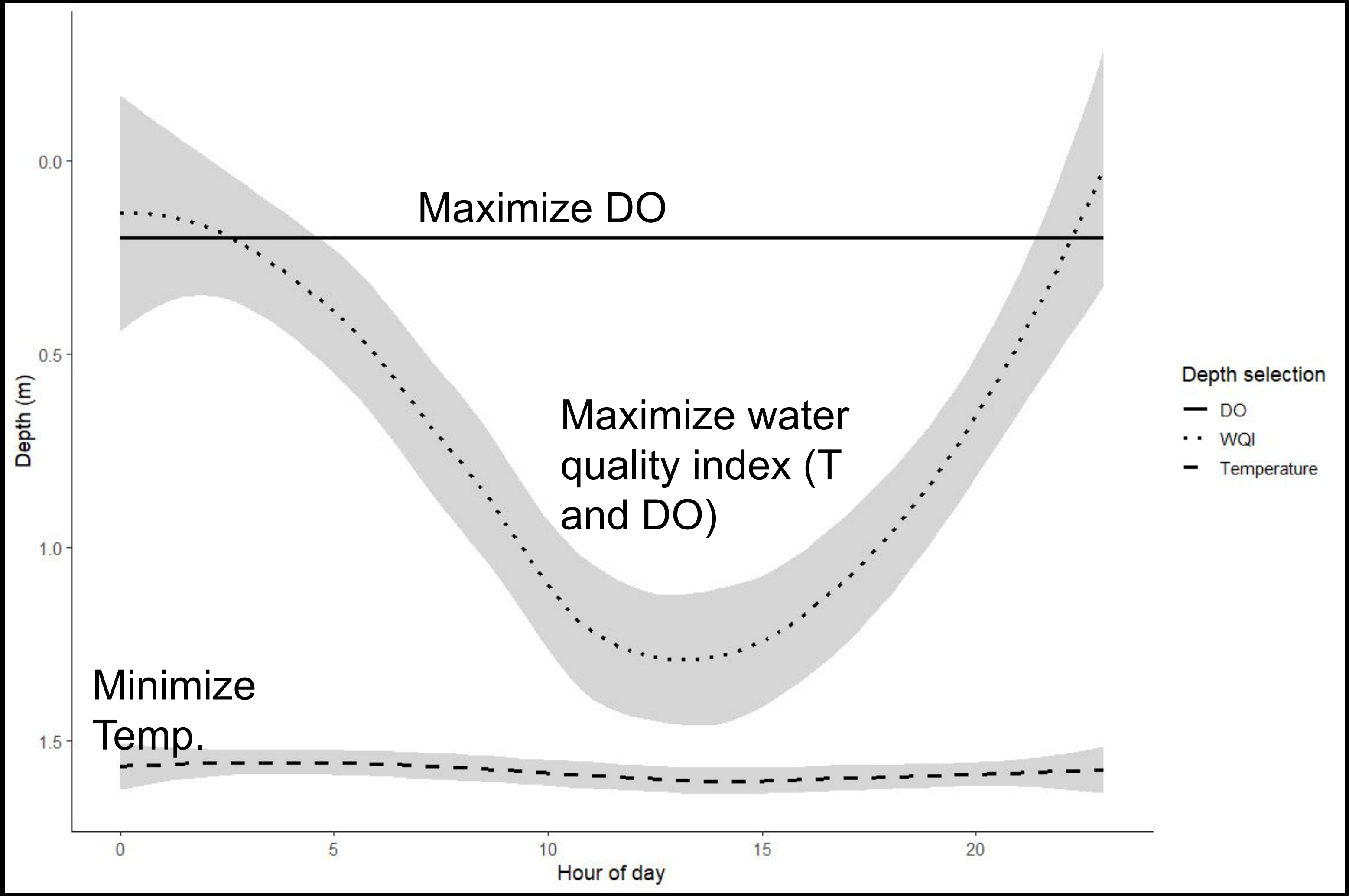
Thanks!

- PhD students: Hannah Barrett and Jordan Ortega
- Many collaborators
- Funding: NW CASC, NSF GRF, ODFW, USFWS/NFWF
- Gabe Rossi and Foodscapes group

Diel variation: stressors occur asynchronously

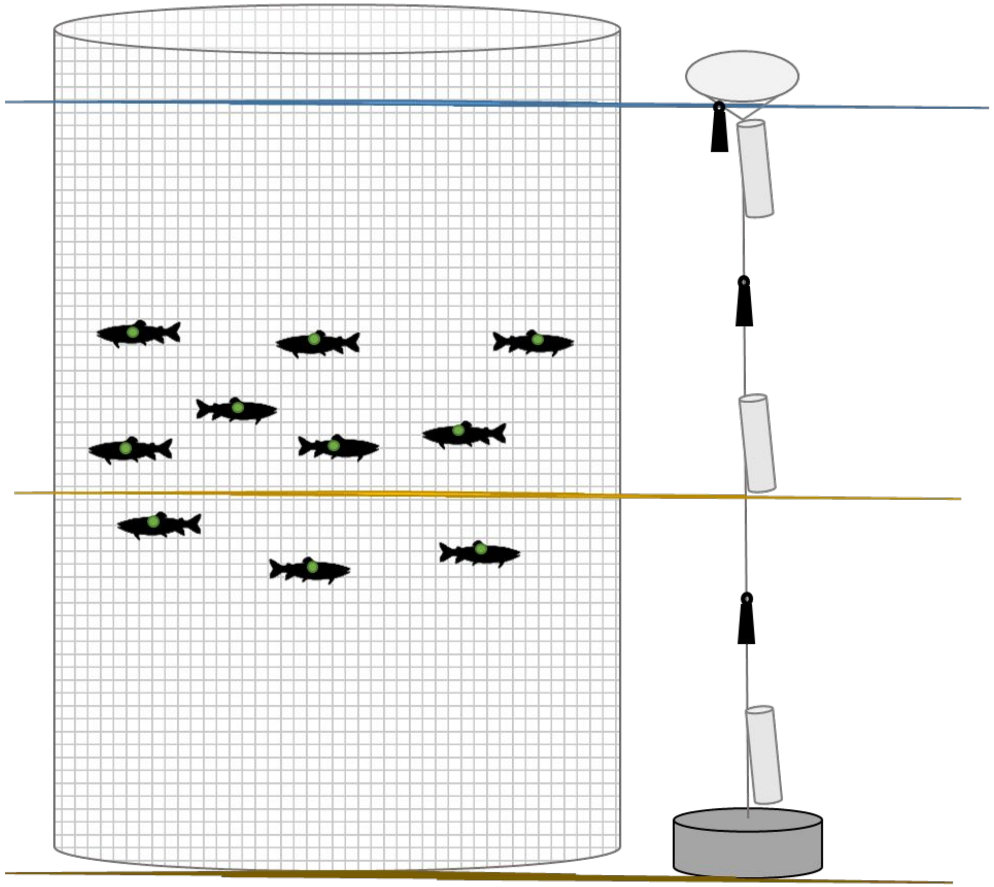


Emergent property: Diel vertical movement

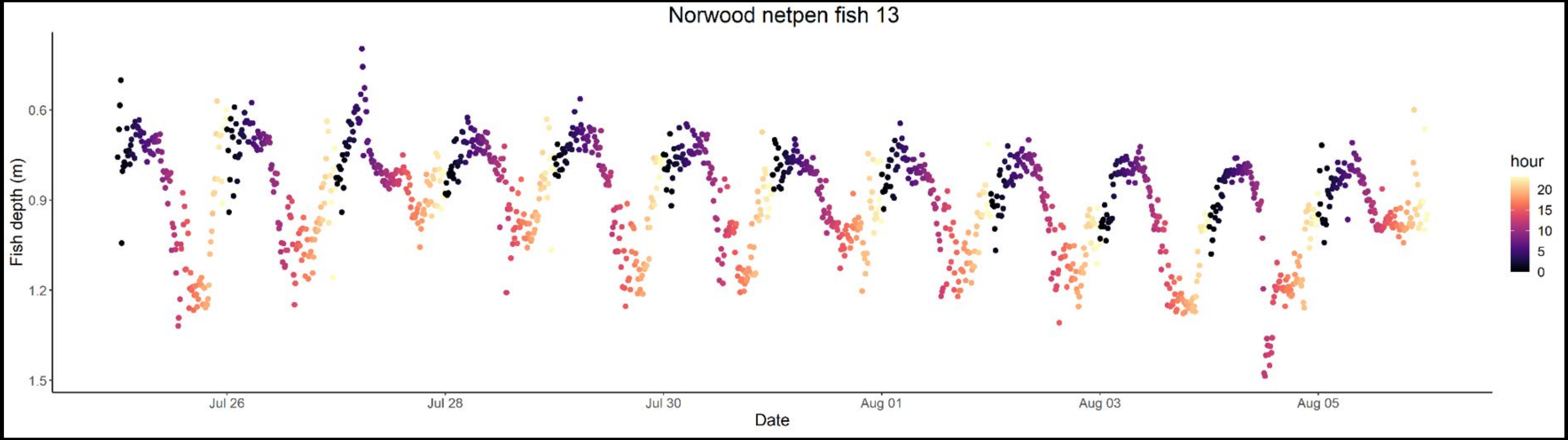


Simulated depth selection by fish experiencing observed conditions under different behavioral rules

Enclosure study in alcoves

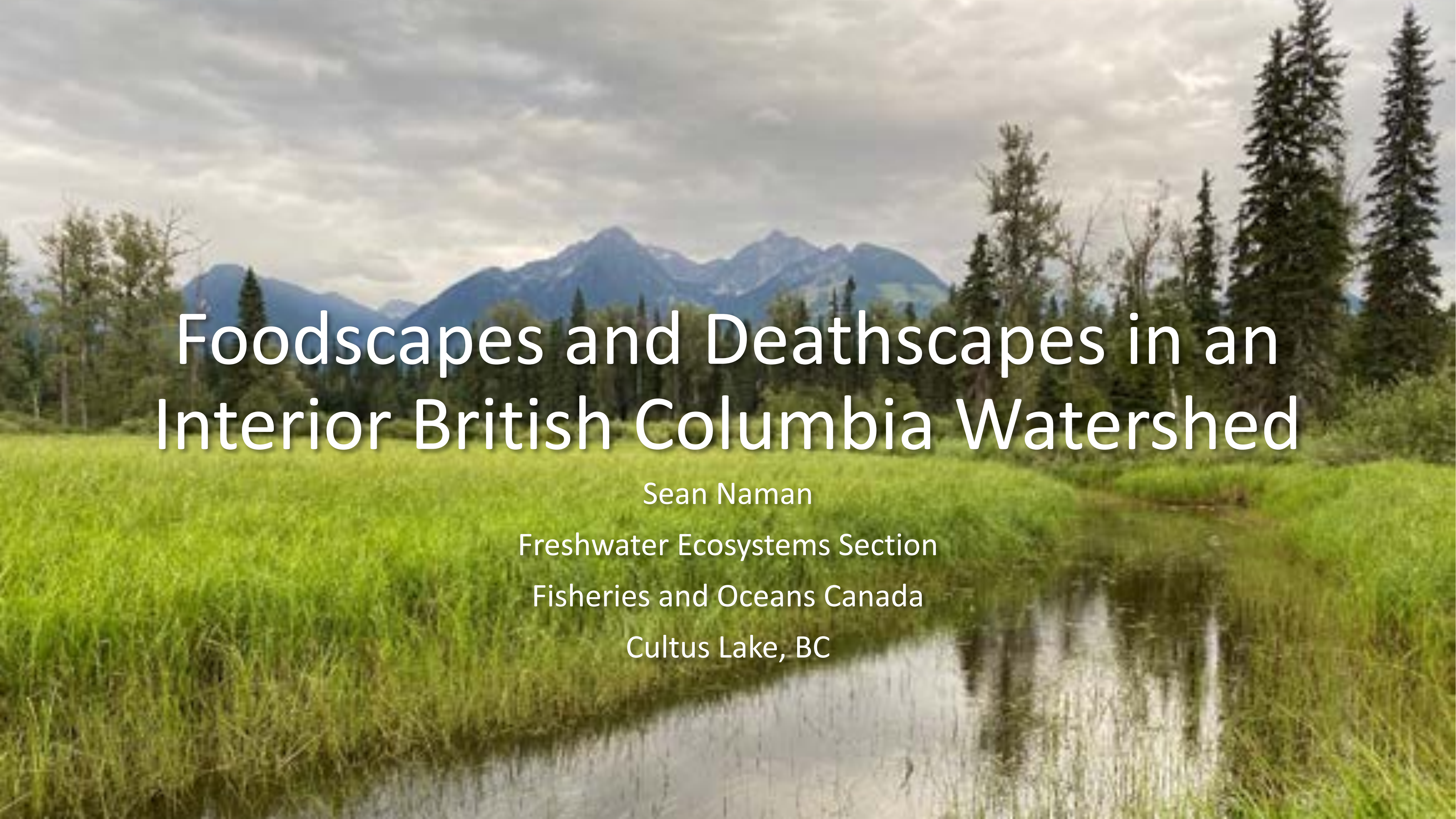


Cutthroat trout exhibit DVM to balance Temperature and DO trade-off



- Fish avoid DO minimums (< 2mg/L)
- BUT they endure hypoxia (2-4 mg/L) in exchange for cold temperatures

Barrett et al. in review *J Anim. Ecol.*



Foodscapes and Deathscapes in an Interior British Columbia Watershed

Sean Naman

Freshwater Ecosystems Section

Fisheries and Oceans Canada

Cultus Lake, BC

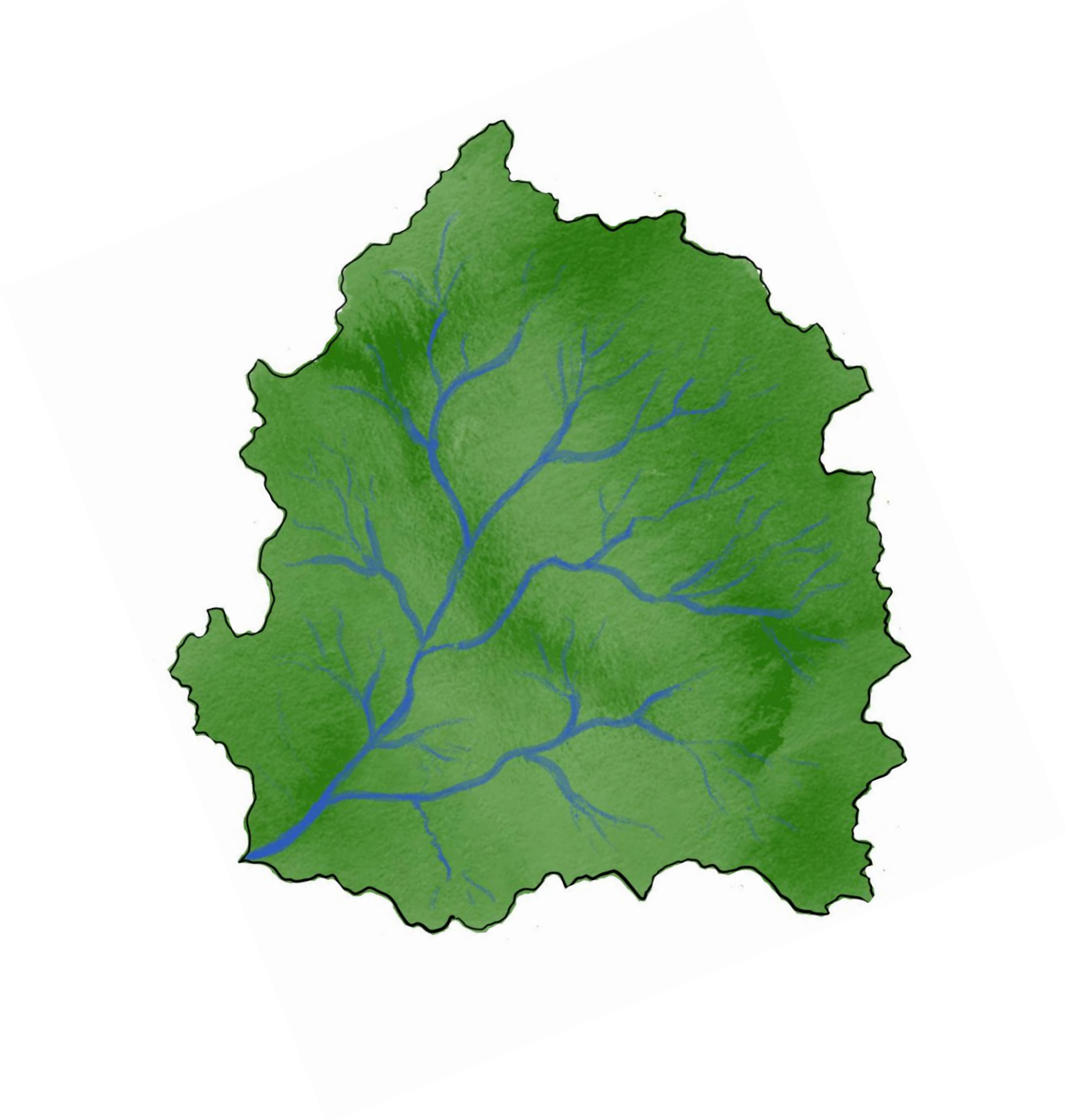

SalmonNet

Productivity

Risk

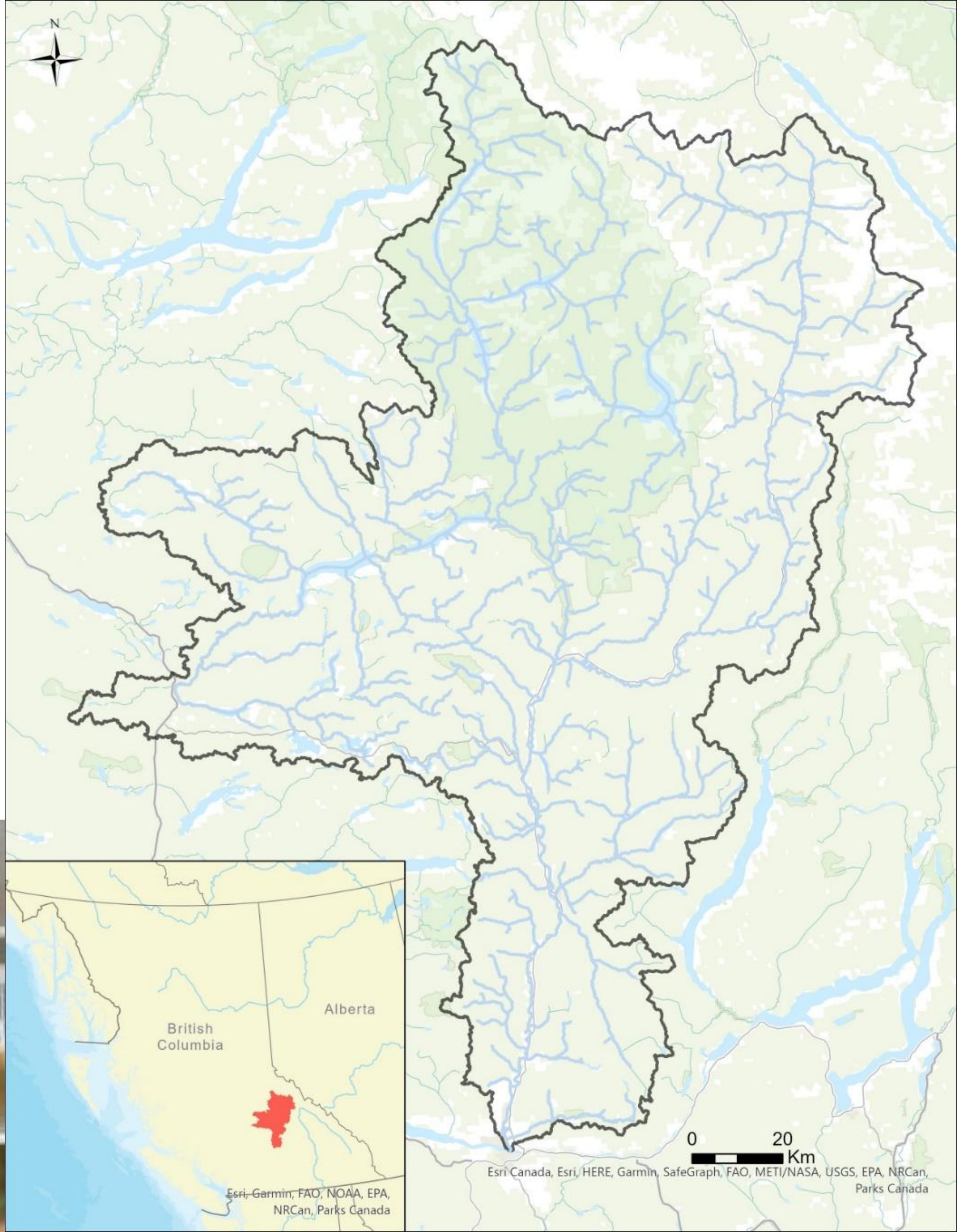
Critical Questions

- Where (and when) to protect?
- What to restore?
- How is this changing?



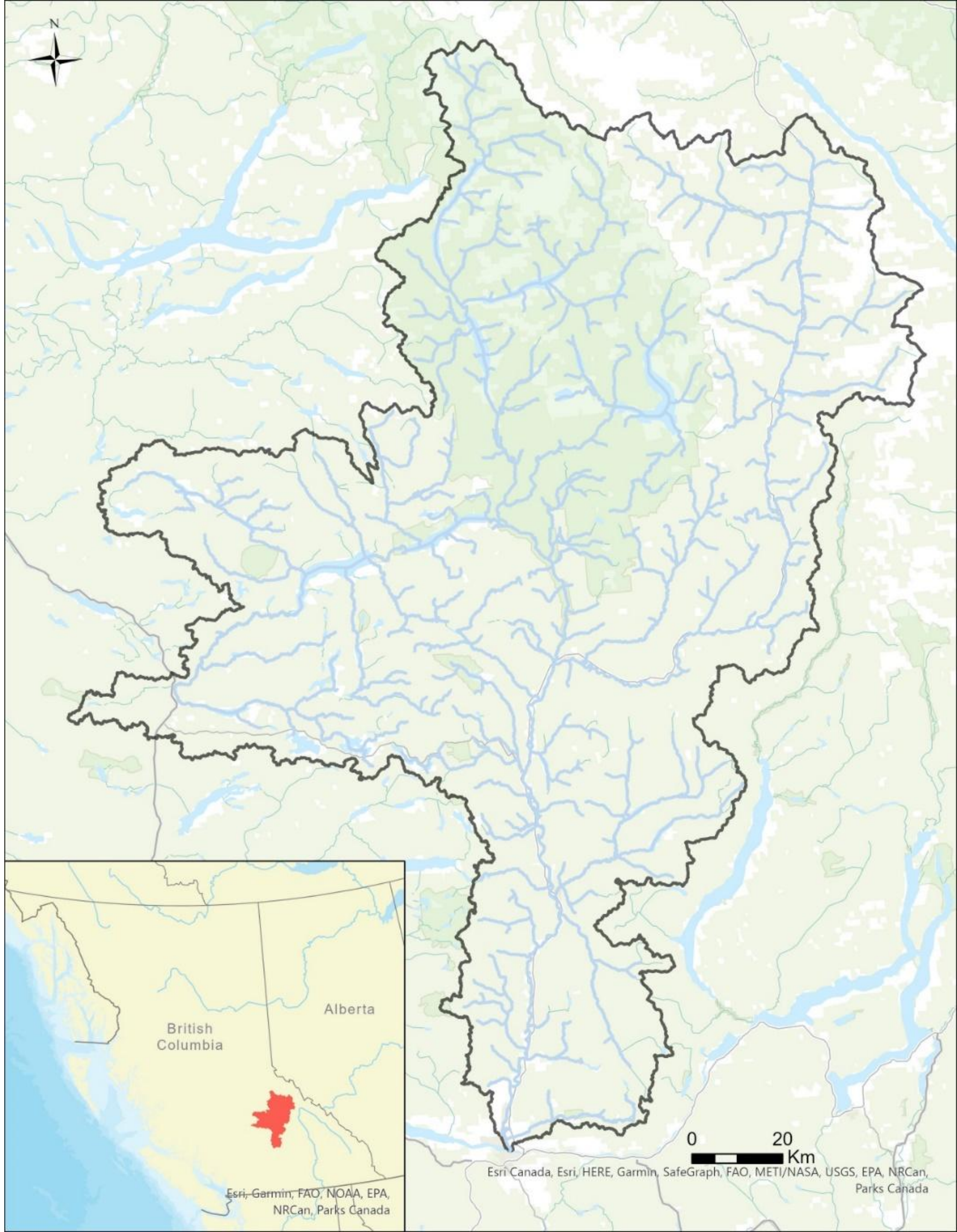
North Thompson Salmon Ecosystem Research Program

- Identify important coho salmon habitats and their contribution to productivity
- Understand habitat vulnerability and responses to human impact



North Thompson Salmon Ecosystem Research Program

Team:
Doug Braun
Emma Hodgson
Amanda Martens
Julian Gan
Sarah Hnytka
Daniella Loscerbo
Violaine Pemberton-Renaud
Sheena Parsons
Brittany Milner
Dylan Cunningham
Lindsey Boyd
Wendy Fleming
Mike Bradford



Watershed Approach to Habitat Science

Extensive → Intensive

Environmental Conditions

Temperature

Flow

Dissolved Oxygen

Water level

Light

Physical Habitat

In-stream habitat

Landscape features

Flood-inundation model

Hydraulic model

Ecosystem

Water chemistry and nutrients

Metabolism (GPP, respiration)

Invertebrate abundance

Stable isotopes and fish diets

Fish

Mark-recapture

Movement (PIT telemetry)

Size and age composition

Physiology (IGF-1, Lipid density)

Otolith microchemistry

Contrasting rearing habitats for coho

Tributary streams

Off-channel wetlands

Fish Studies

Canadian Journal of
**Fisheries and
Aquatic Sciences**

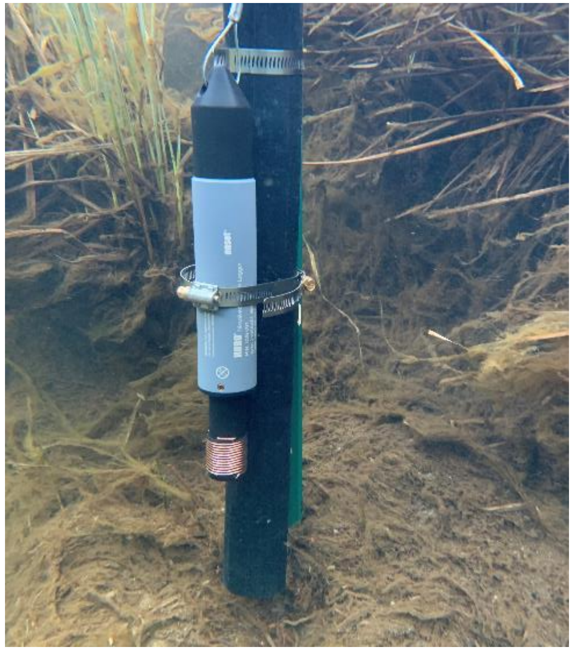
OPEN ACCESS | Research Article

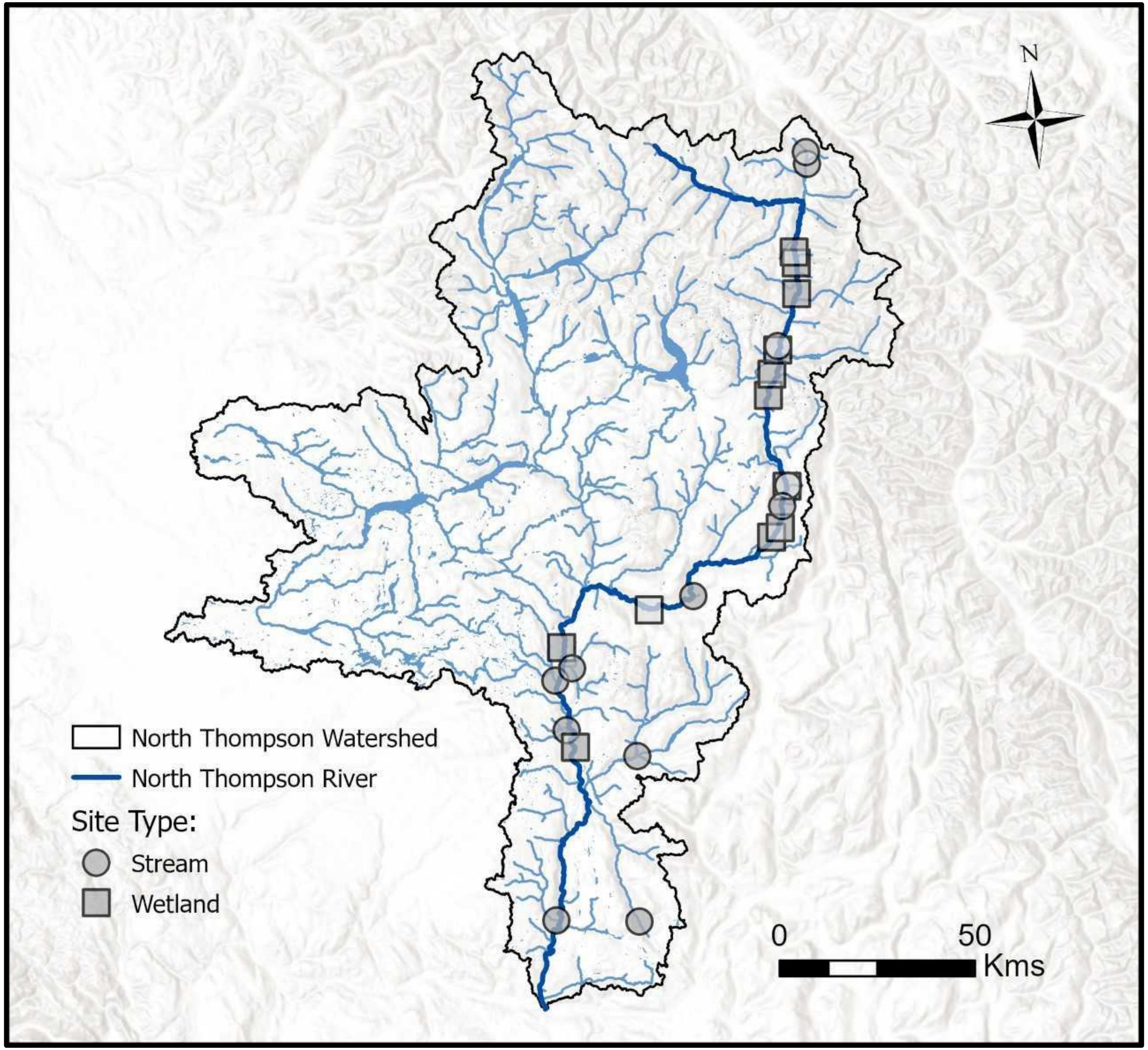
Seasonal dynamics of juvenile coho salmon (*Oncorhynchus kisutch*) in wetlands of the North Thompson River, British Columbia

Brittany L. Milner[a,b], Douglas Braun[a], Jonathan W. Moore[b], Amanda M. Martens[c], Daniella LoScerbo[a], and Sean Naman[a,c]

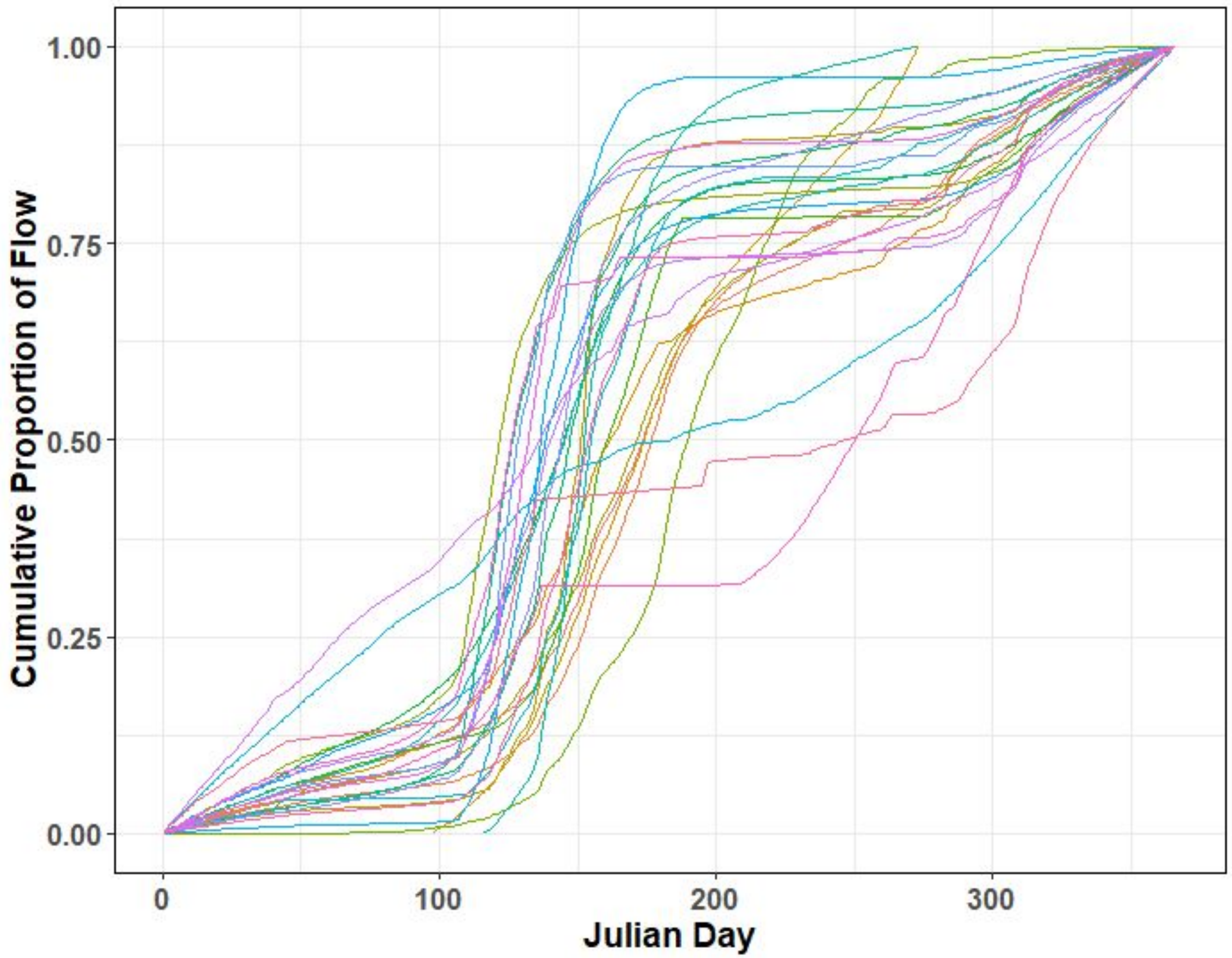
Environmental Monitoring

- Continuous monitoring of temperature, water level (flow), DO, and conductivity
- 25 streams and 15 wetlands





Diverse Hydrology

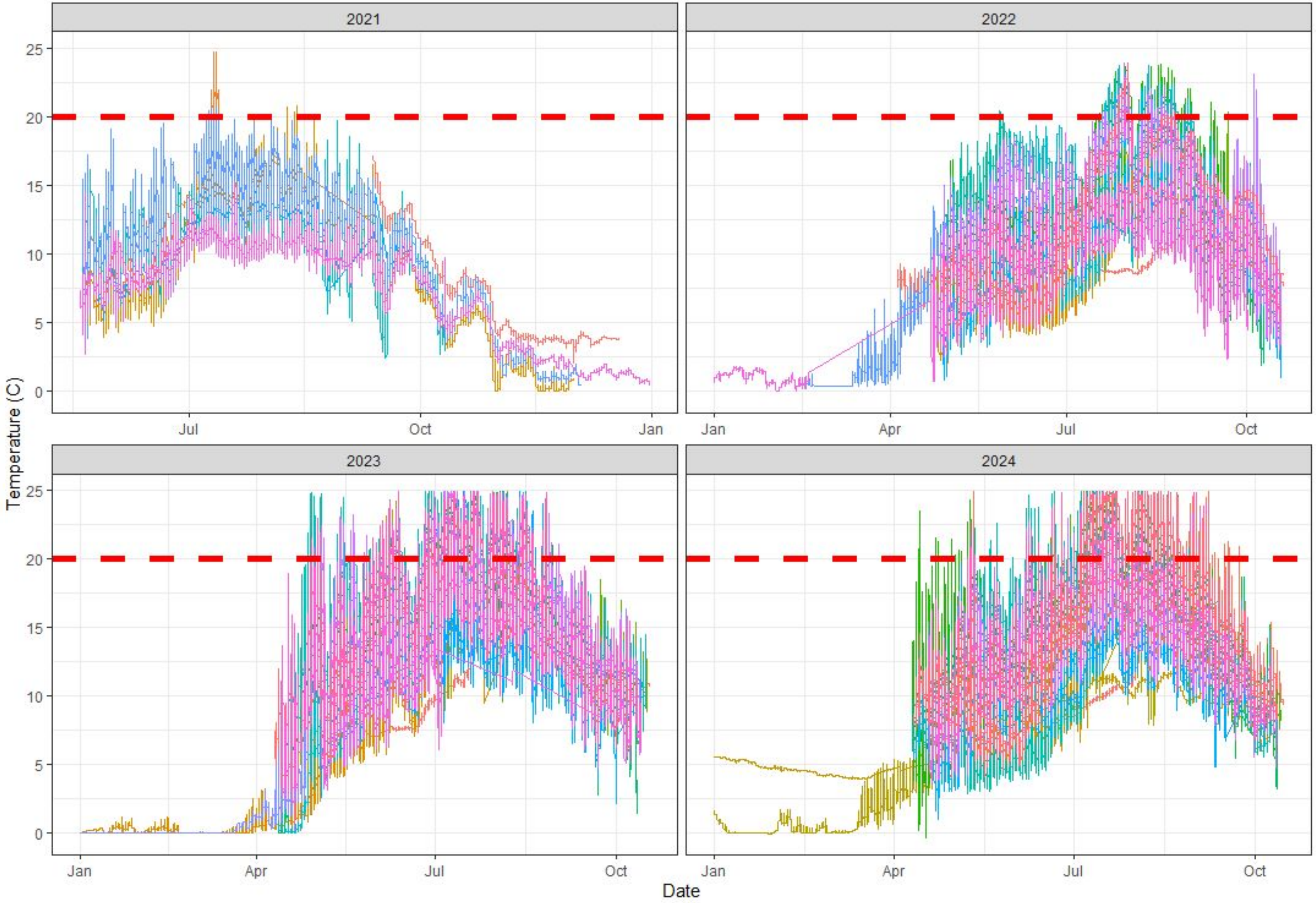


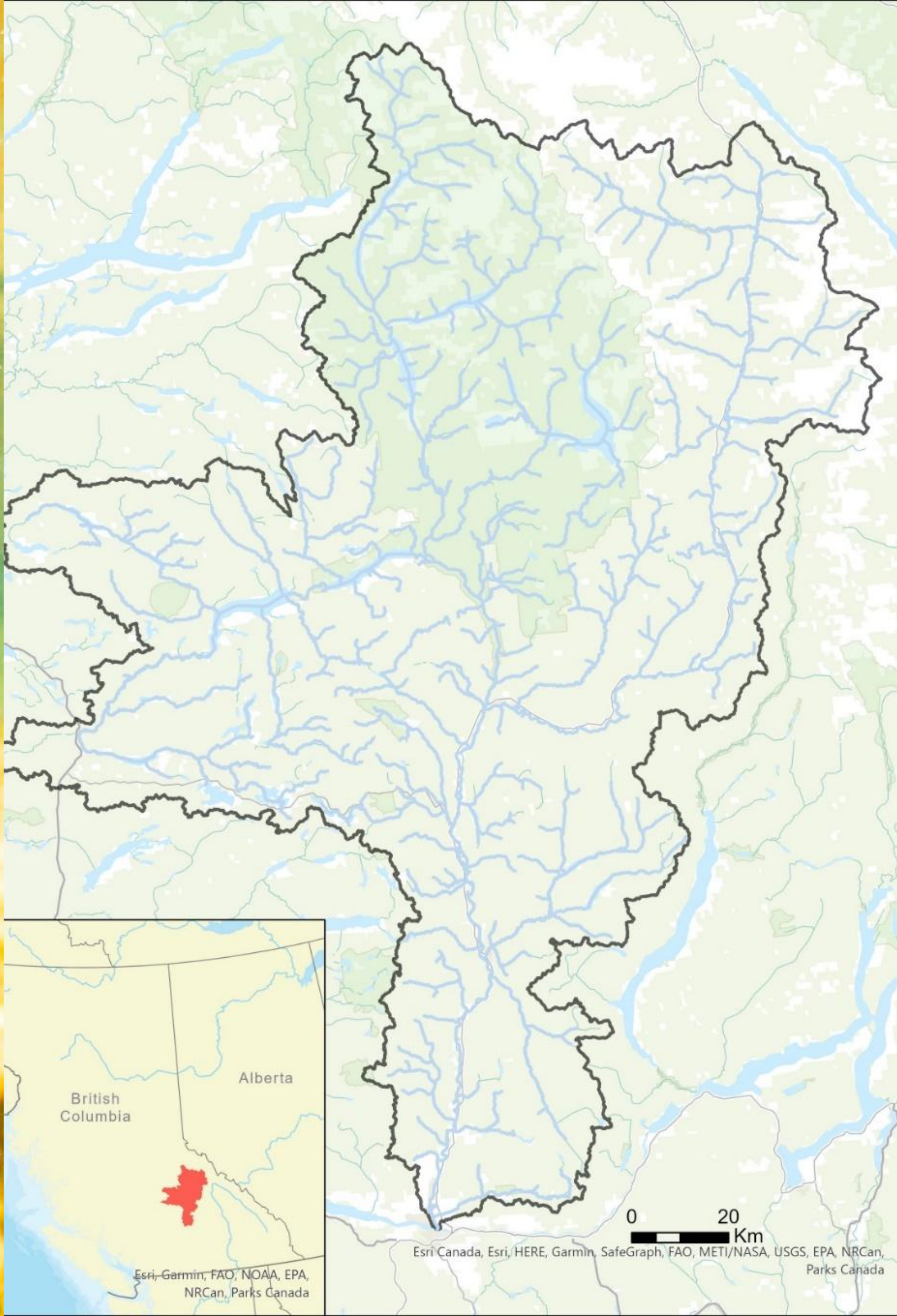

July


September

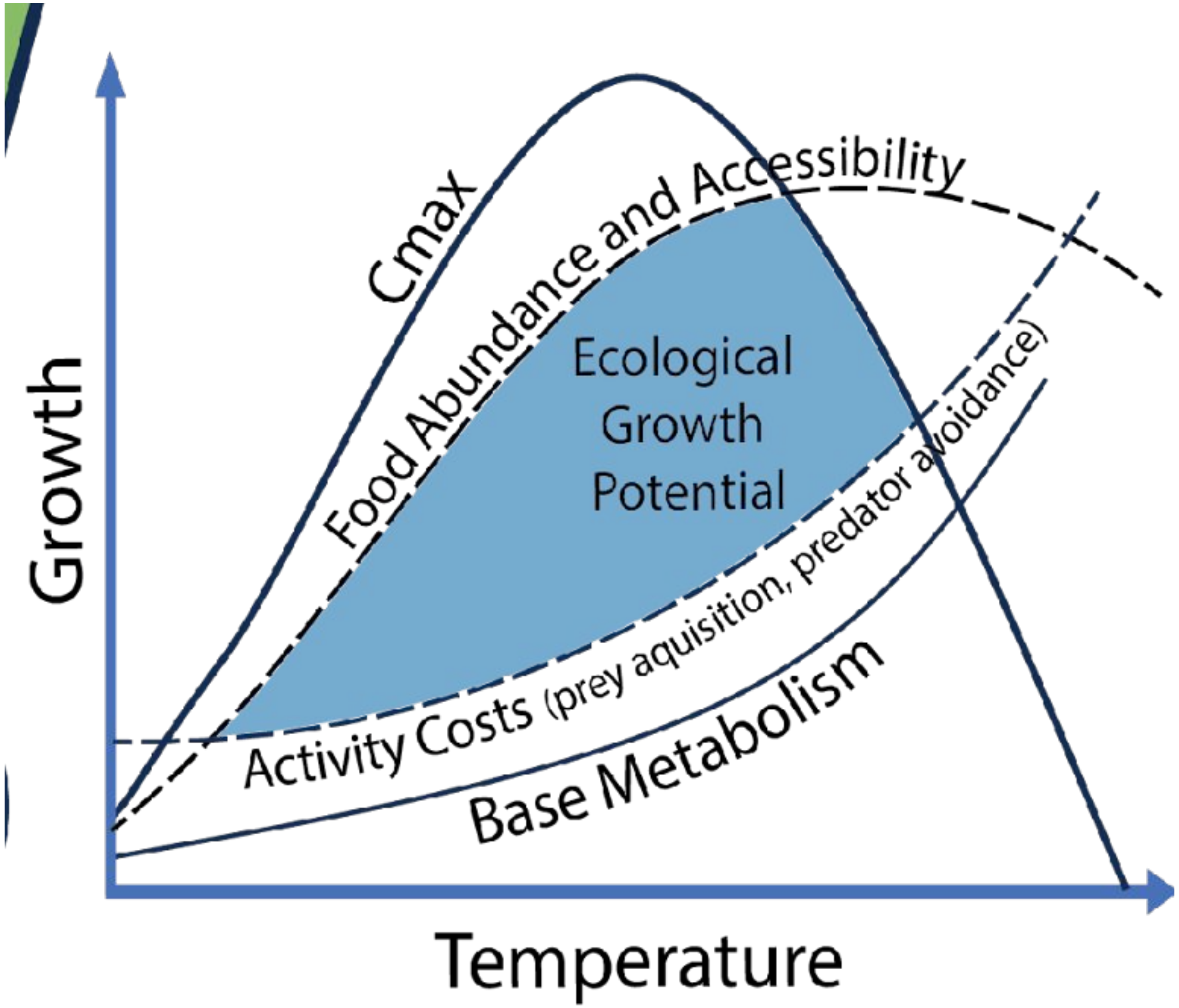
Wetland Dissolved Oxygen

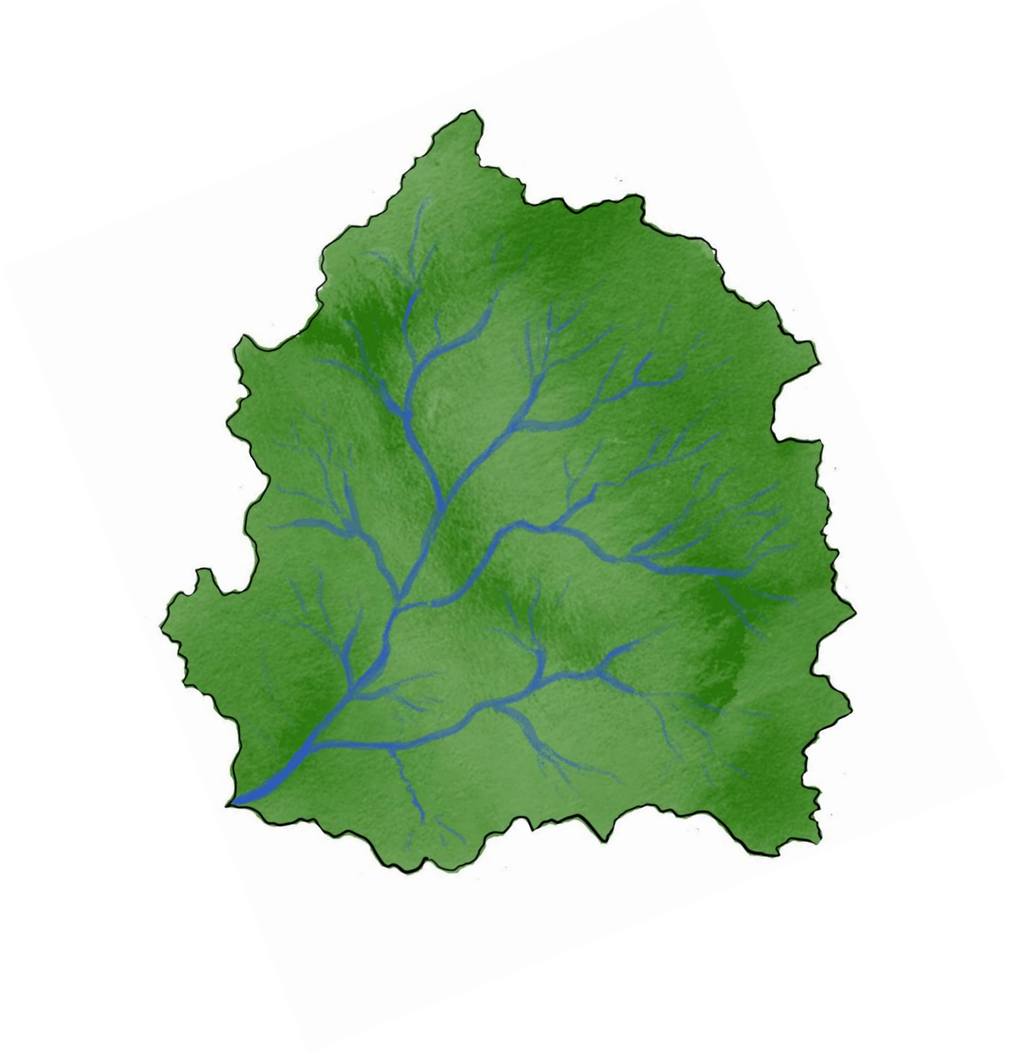
Wetland Temperature




British Columbia
Alberta
0
20
Km
Esri, Garmin, FAO, NOAA, EPA, NRCan, Parks Canada
Esri Canada, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NRCan, Parks Canada

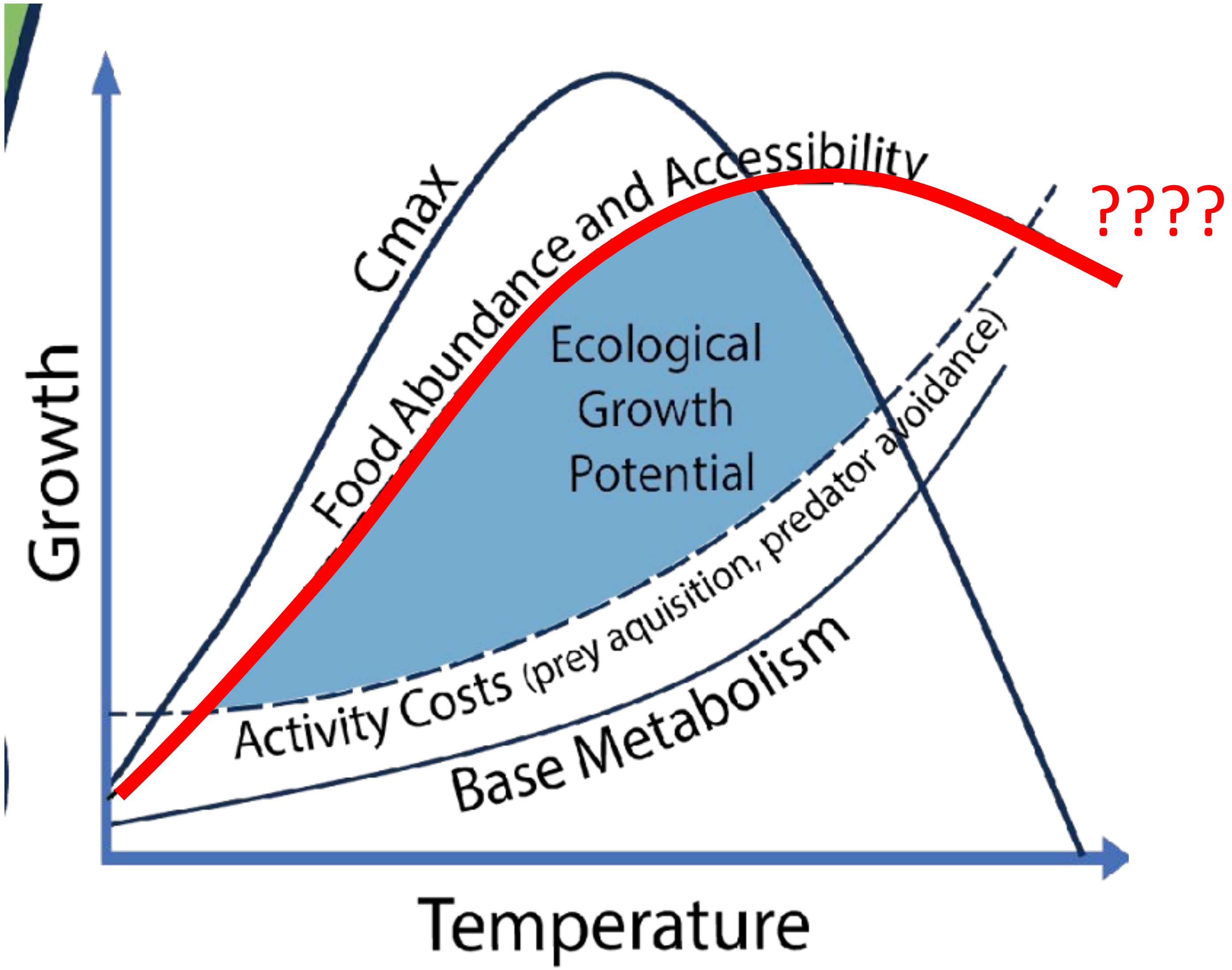
Foodscapes

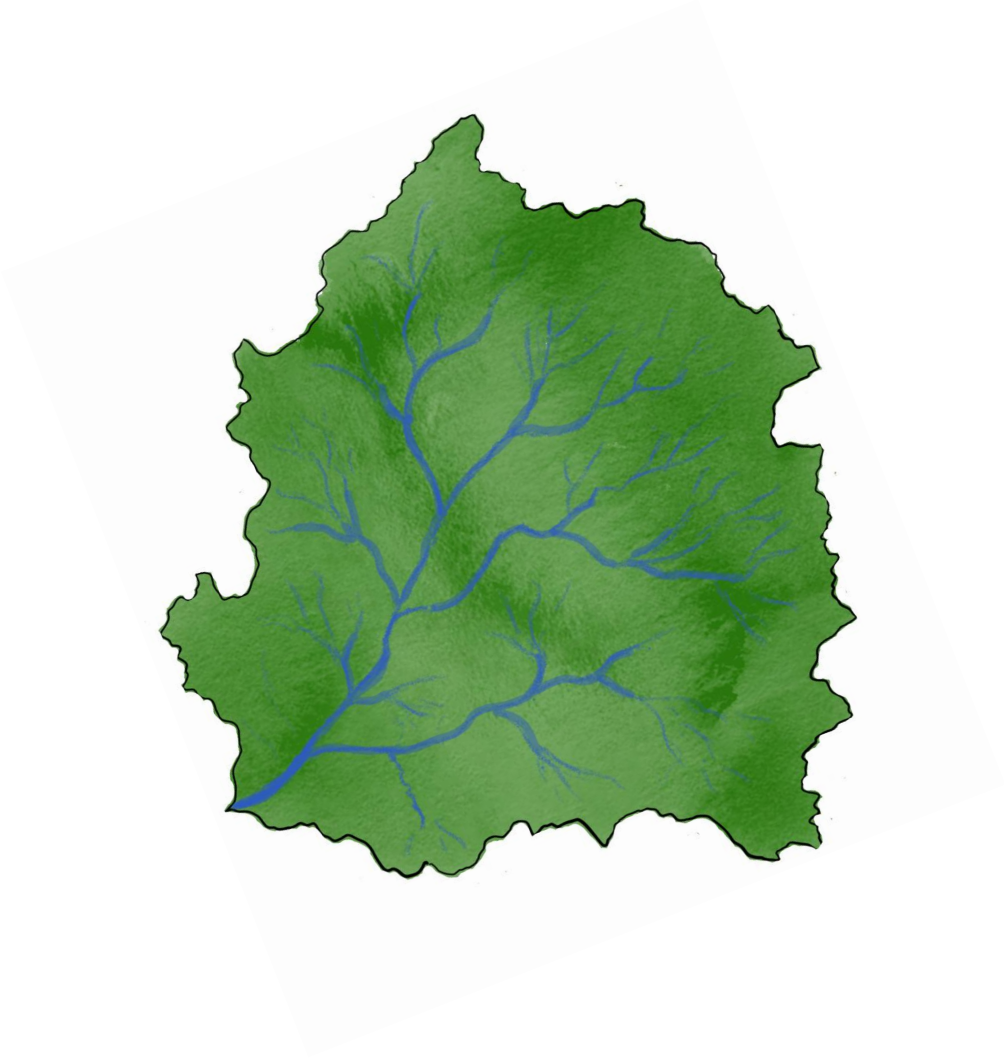




Rossi et al. (2024) *Bioscience*

Foodscapes





Rossi et al. (2024) *Bioscience*

Food Availability and Accessibility

- How does food availability vary spatially and temporally in streams and wetlands?

Sheena Parsons
M.Sc. Student, SFU Biology

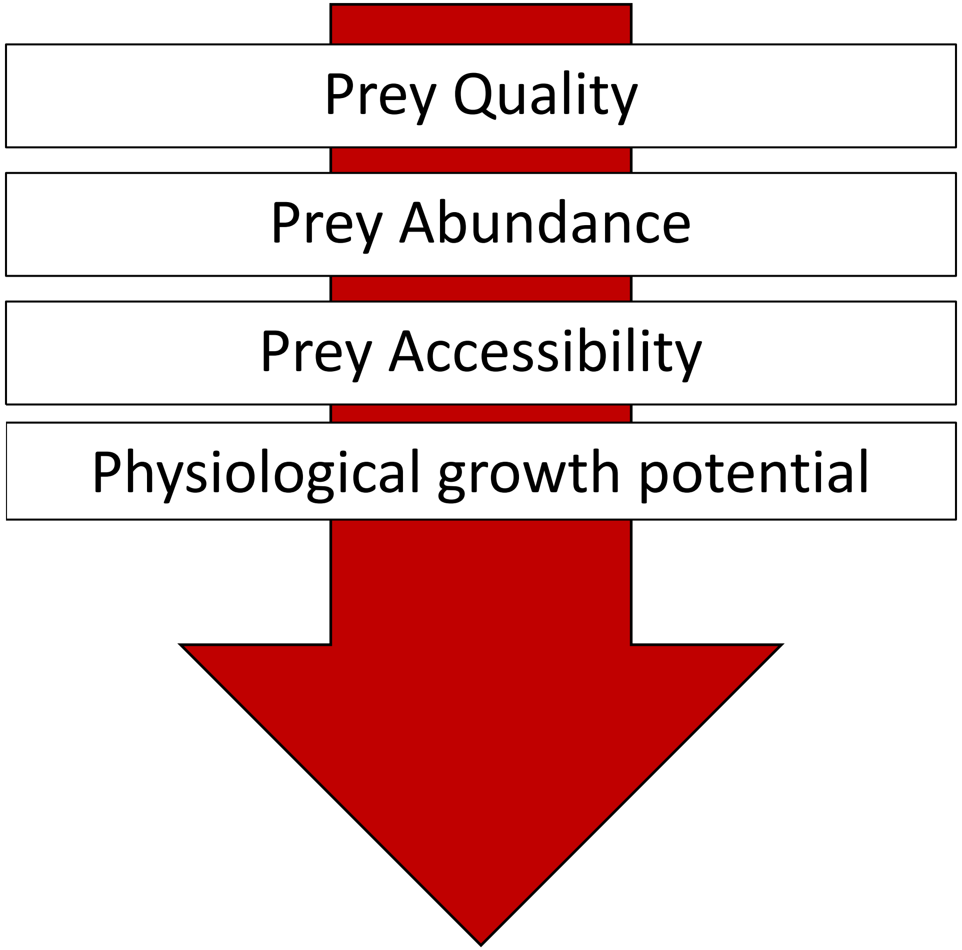
Food Availability

ADVANCED REVIEW

WIREs WATER WILEY

Food for fish: Challenges and opportunities for quantifying foodscapes in river networks

Valerie Ouellet[1,2] | Aimee H. Fullerton[3] | Matt Kaylor[4] | Sean Naman[5] | Ryan Bellmore[6] | Jordan Rosenfeld[7] | Gabriel Rossi[8] | Seth White[9] | Suzanne Rhoades[10] | David A. Beauchamp[11] | Martin Liermann[3] | Peter Kiffney[3] | Beth Sanderson[3]



Realized Growth

Ouellet et al. (2025) *WIREs Water*

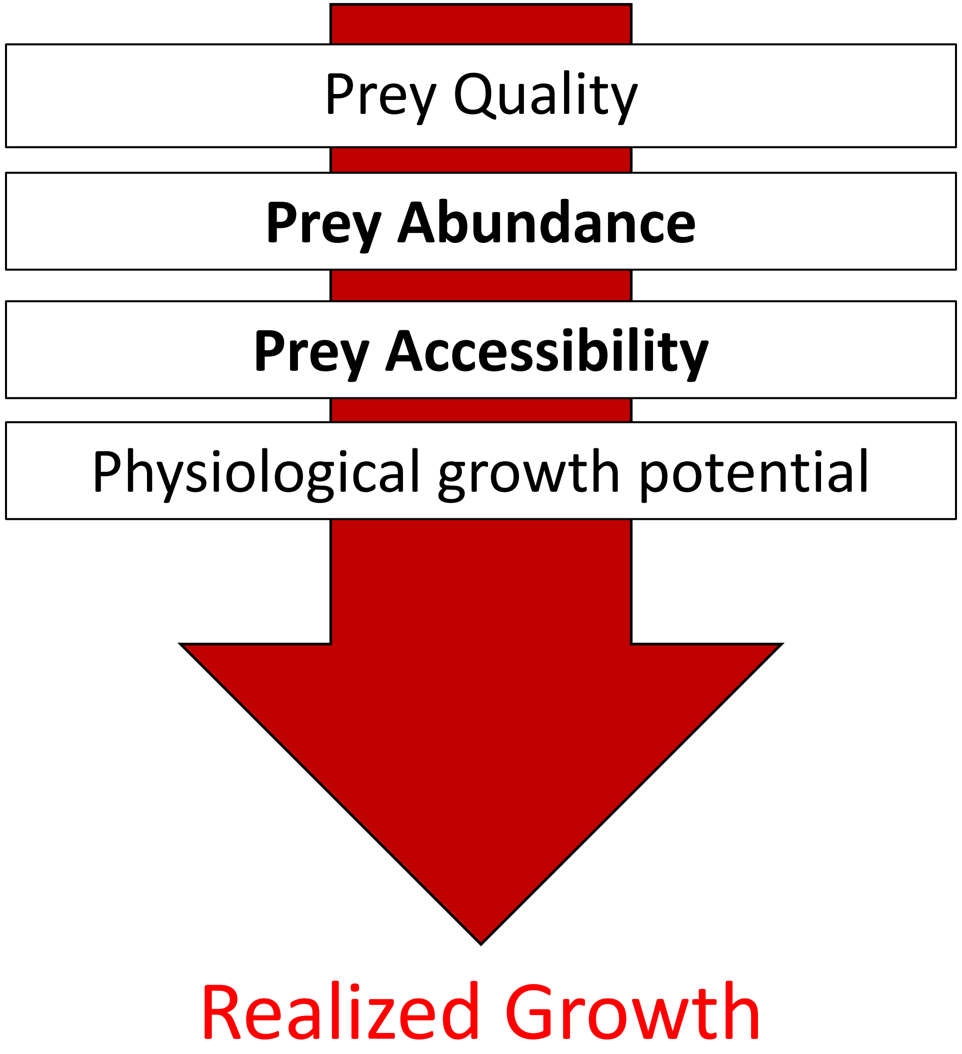
Food Availability

Prey Abundance

- Biomass concentration

Prey Accessibility

- Overlap with unsuitable abiotic conditions

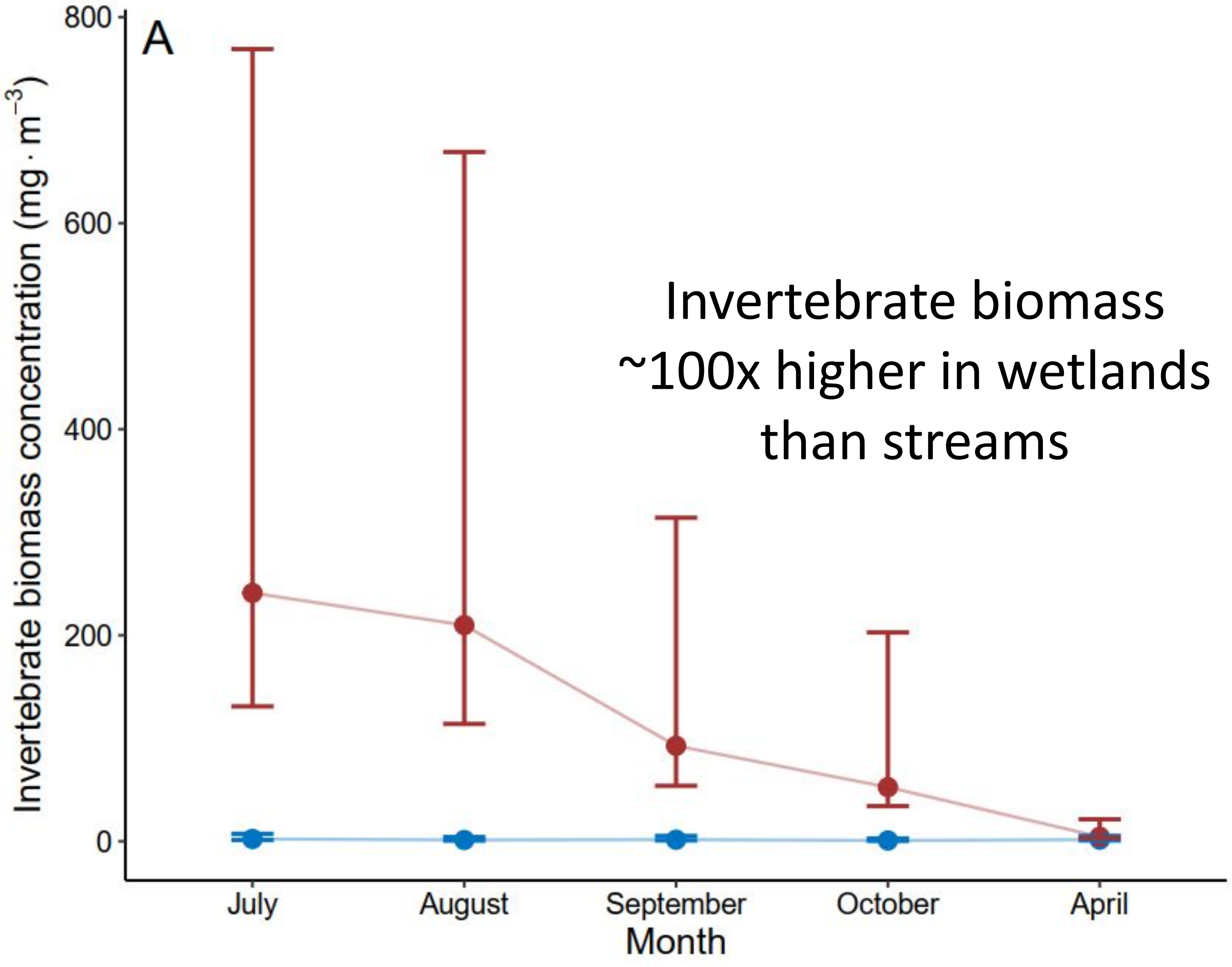


Ouellet et al. (2025) *WIREs Water*

Sampling

- 12 sites (6 streams 6 wetlands)
- Monthly sampling 2022-2023

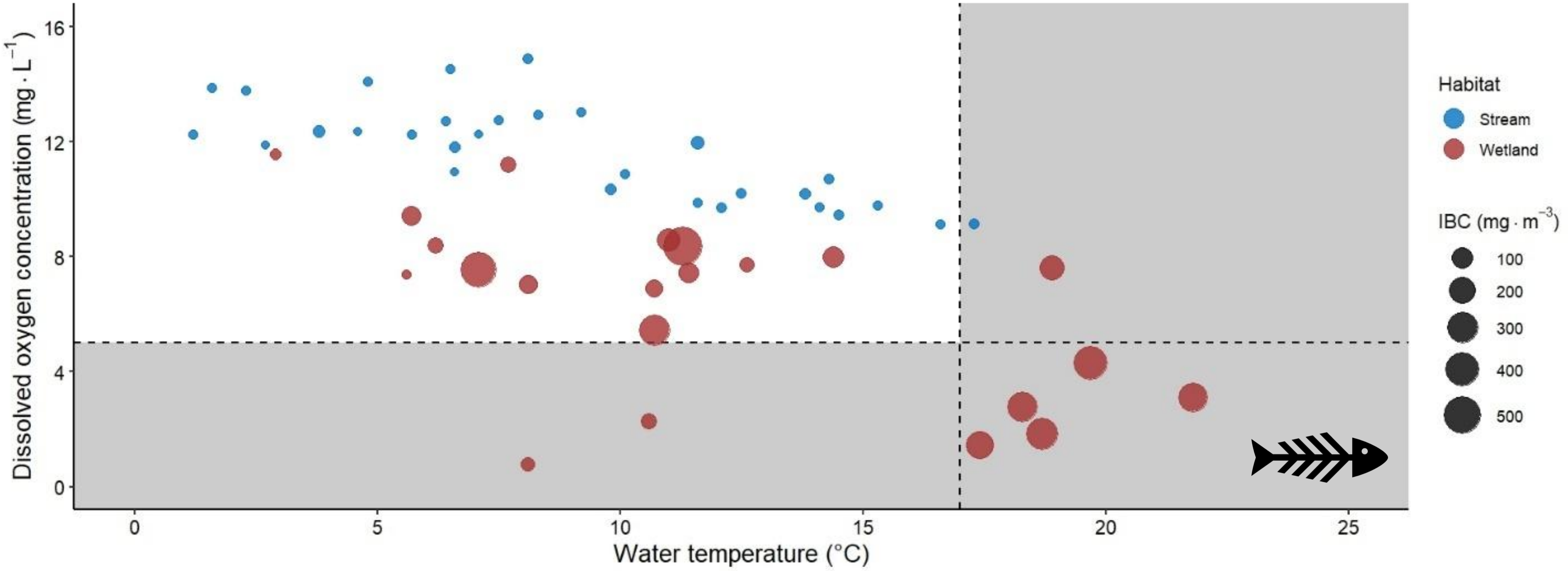
Prey Abundance



Invertebrate biomass
~100x higher in wetlands
than streams

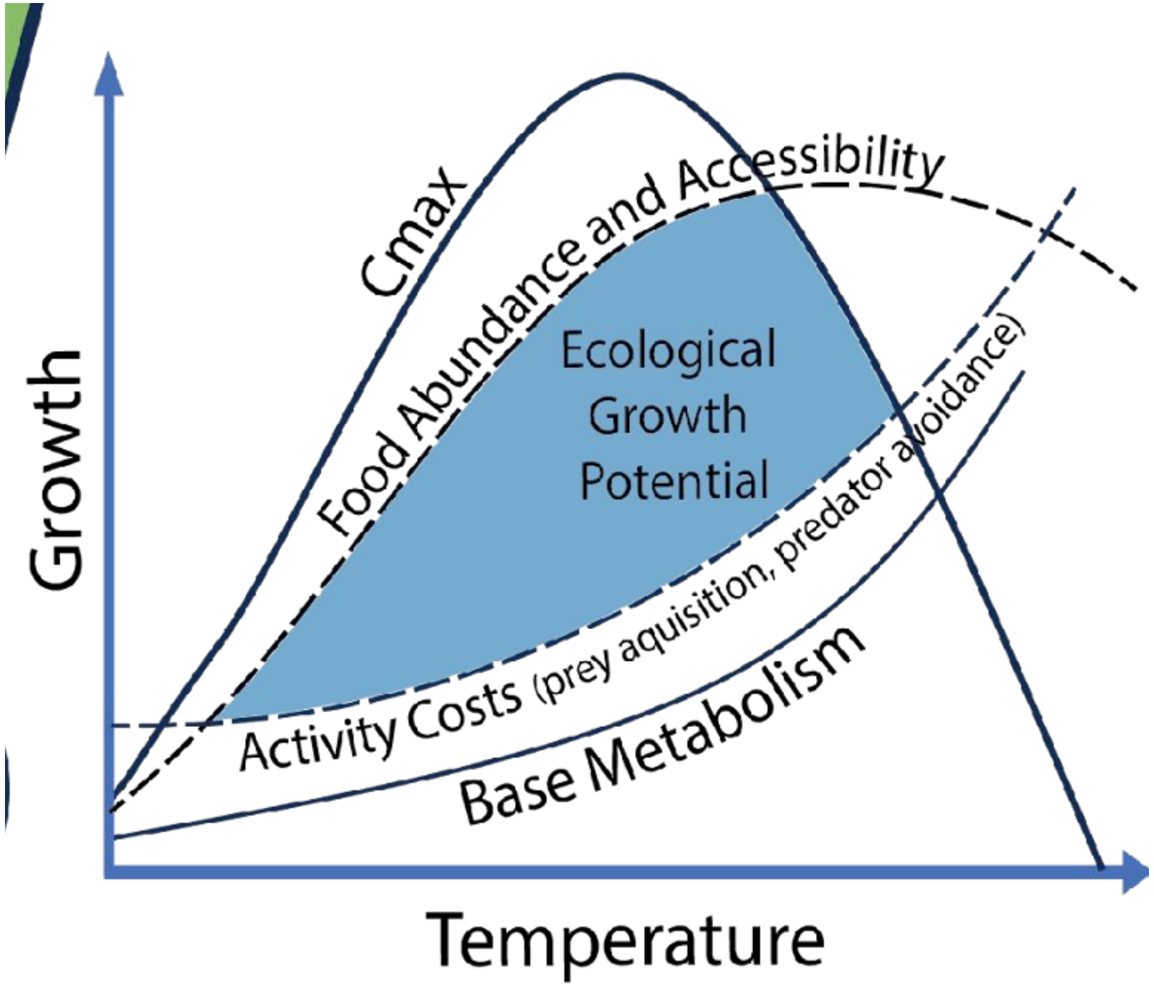
Parsons et al. (*In Review*)

Prey Accessibility



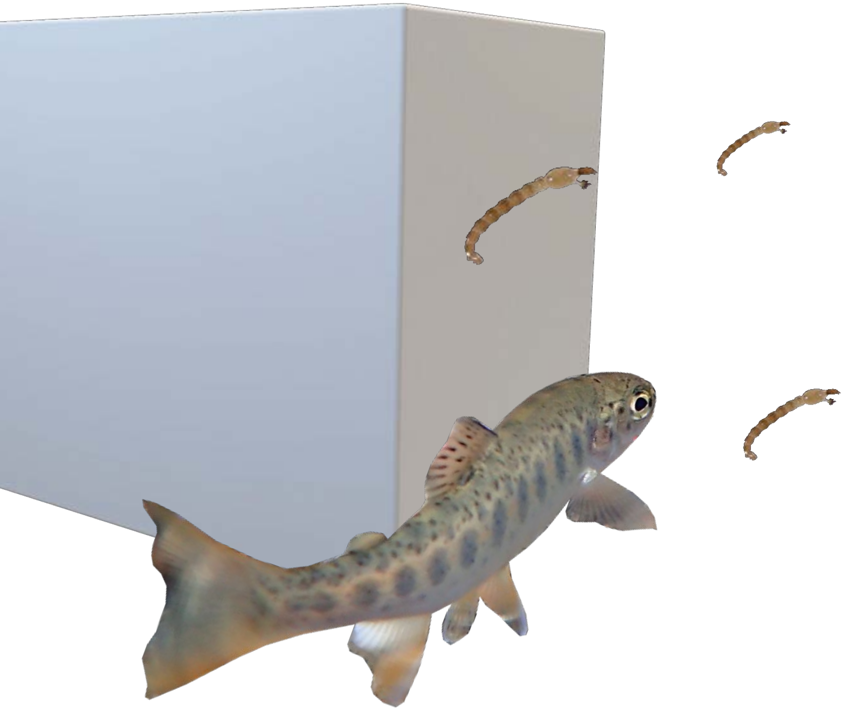
Parsons et al. (*In Review*)

Building the Foodscape



Rossi et al. (2024) *Bioscience*

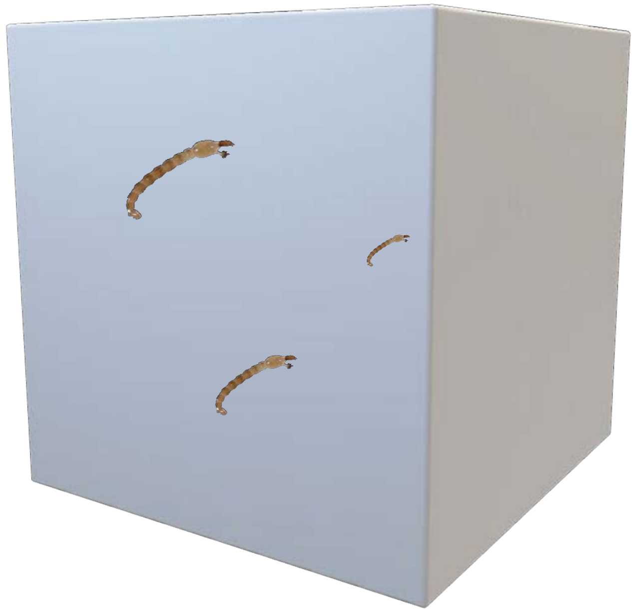
Prey Concentration



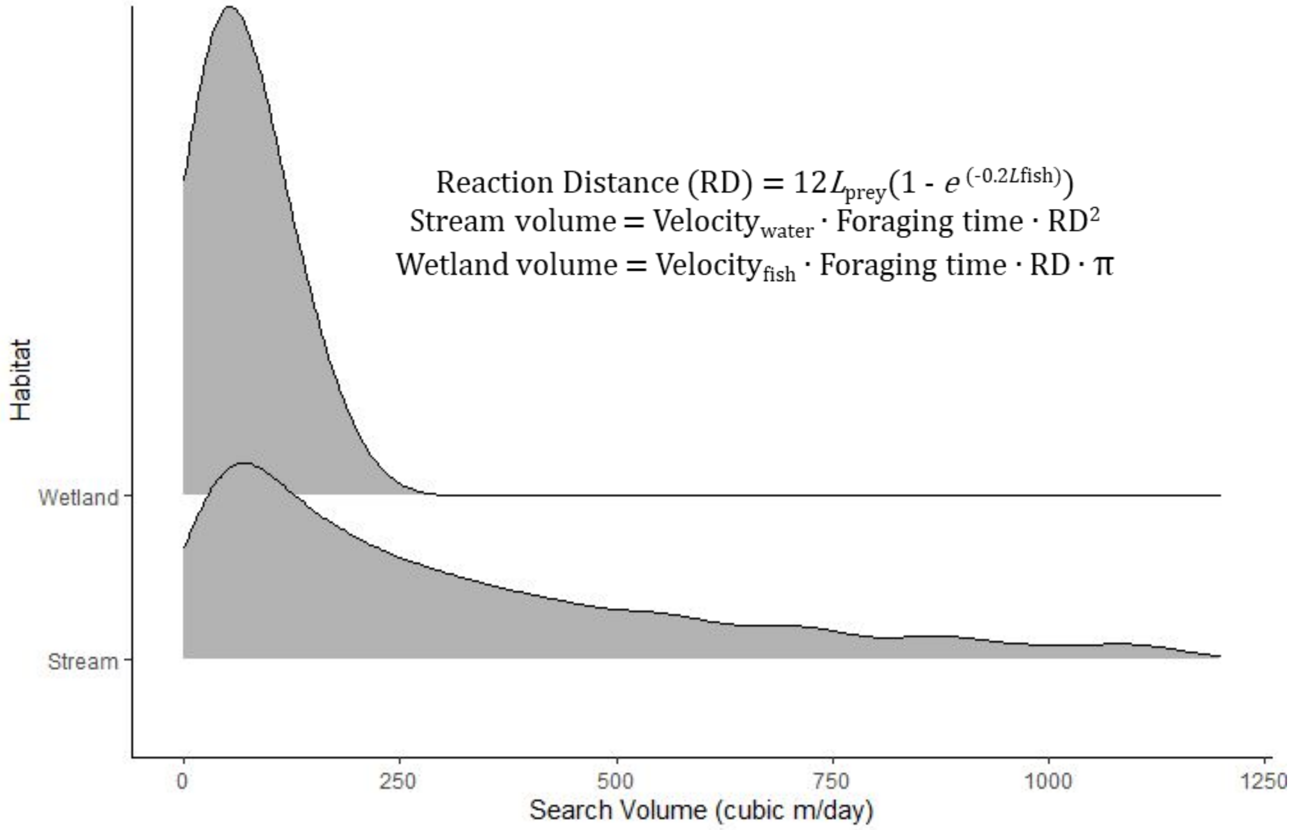
(mg m^{-3})

Prey Encounter Rates

Prey Concentration (mg m^{-3})



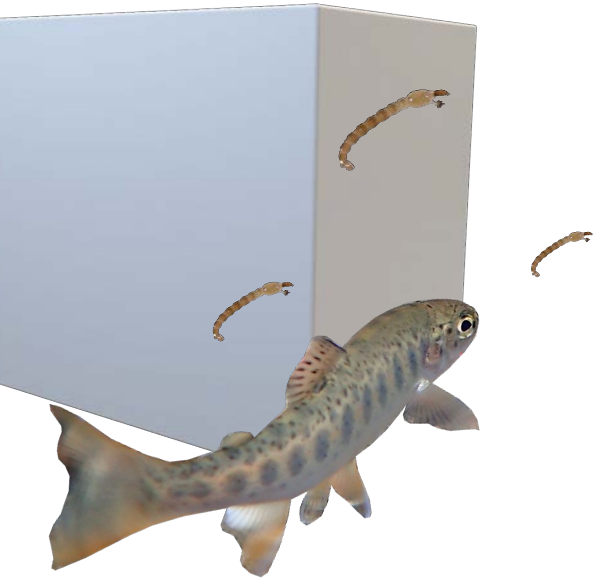
Potential Search Volume (m^3 / day)



Hughes and Dill (1990) CJFAS, Beauchamp et al. (1999) TAFS, Murphy et al. (2018) *CJFAS*

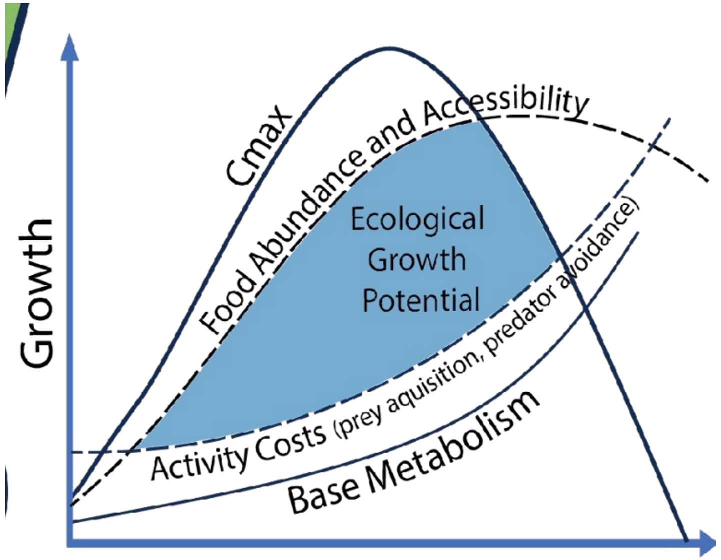
Growth Potential and Risk

Prey Encounter Rate (mg/day)



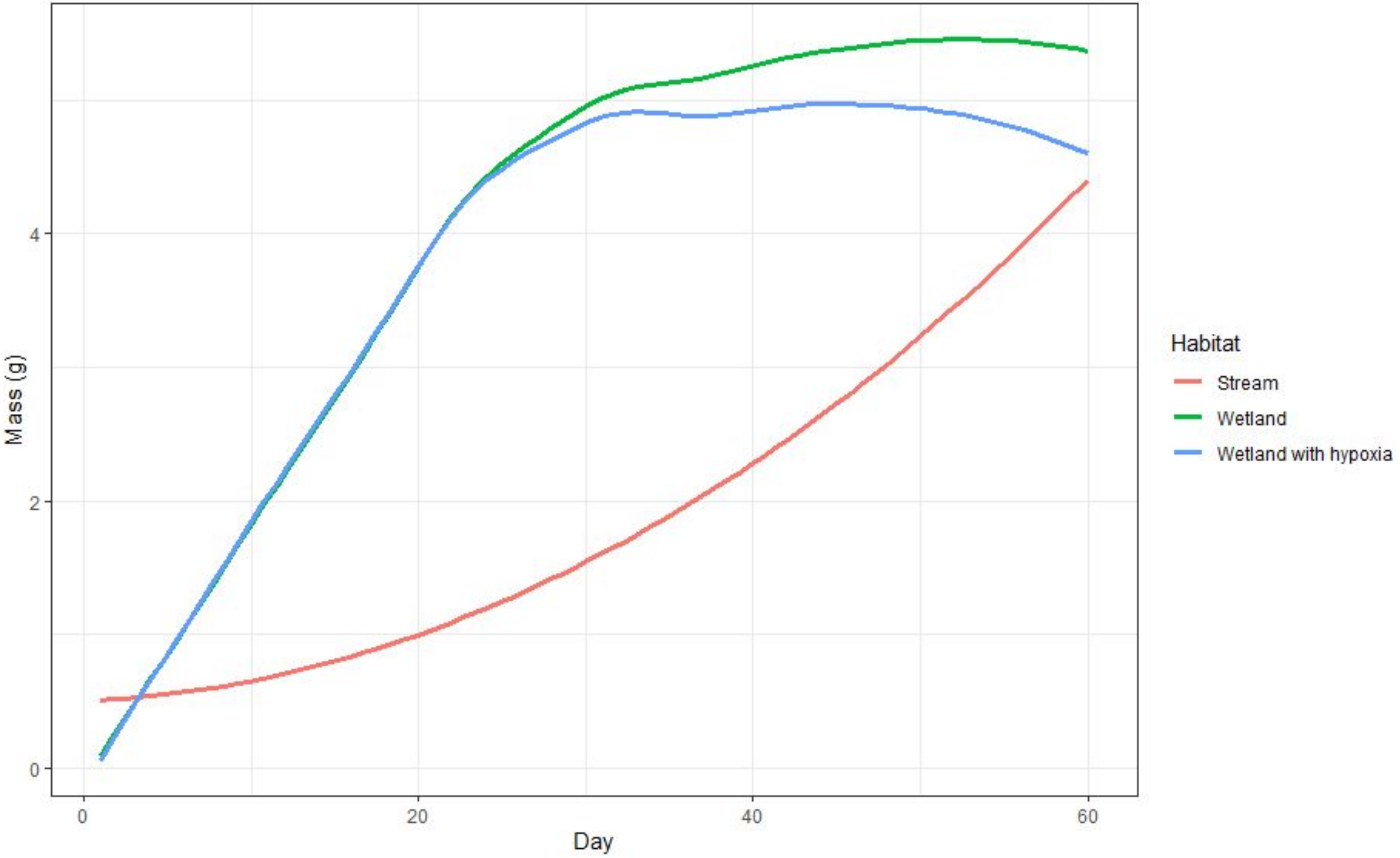
Prey capture success
Abiotic conditions
Physiological tolerance

Bioenergetics and growth



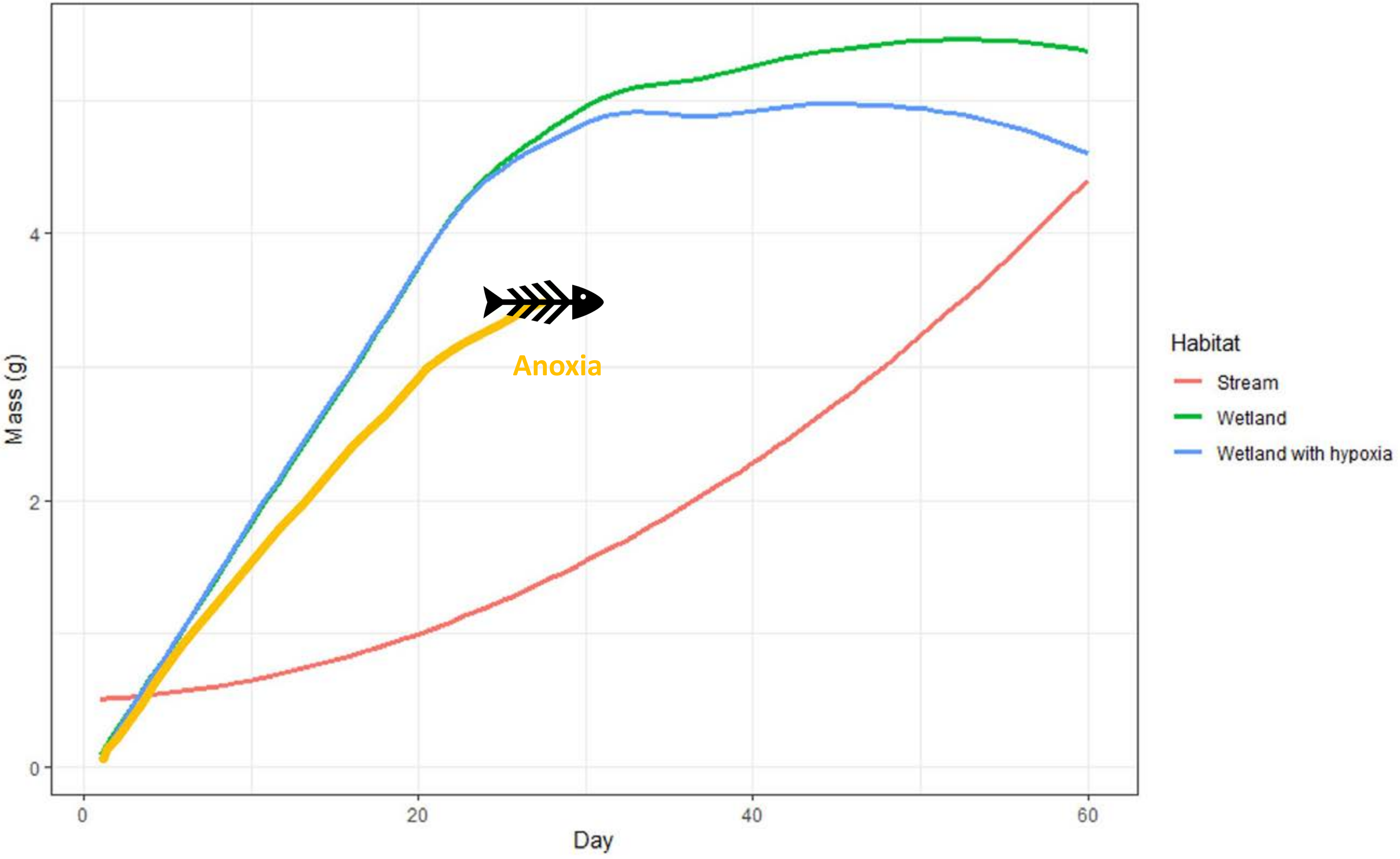
Simulating Growth Regimes

WARNING: PRELIMINARY



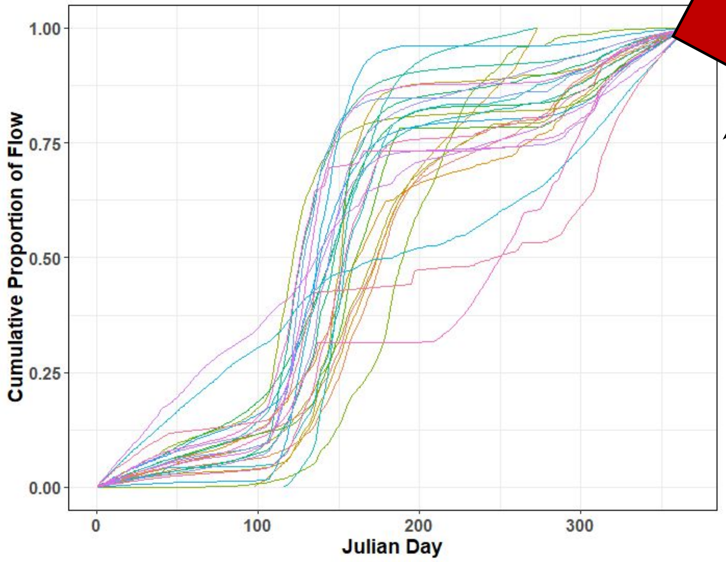
Simulating Growth Regimes

WARNING: PRELIMINARY



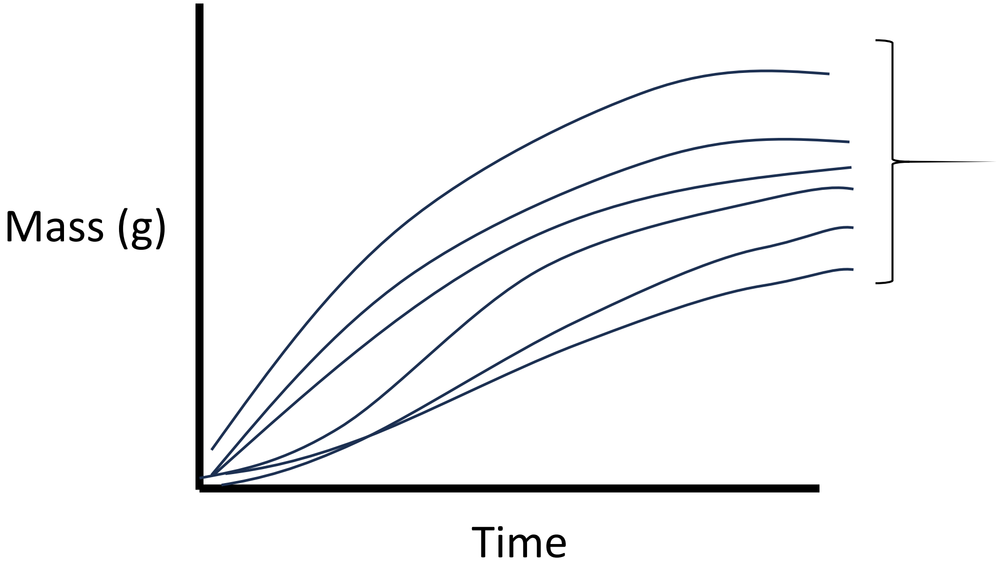
Future Work

Climate and hydrologic variability



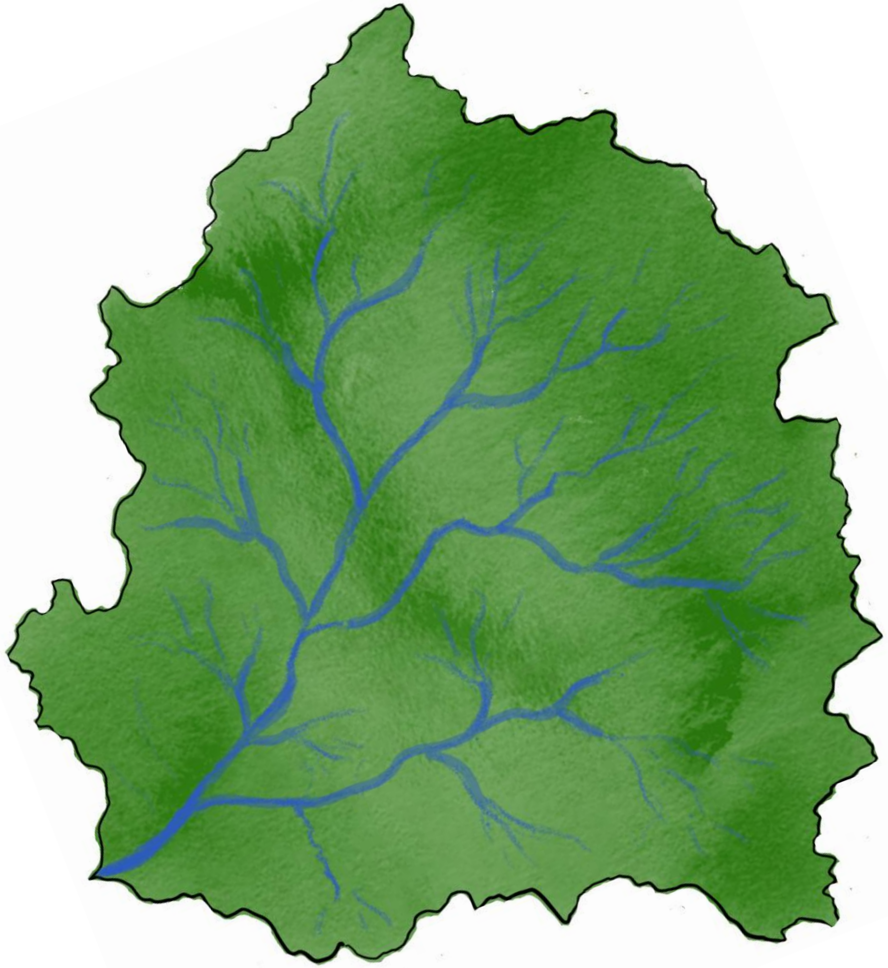
Abiotic conditions
Food Availability

Growth regimes across the foodscape



Critical Questions

- Where (and when) to protect?
- What to restore?
- How is this changing?



Thank You!

sean.naman@dfo-mpo.gc.ca

Location, location, location: stream type promotes variation in *Oncorhynchus mykiss* life-histories with implications for future climate scenarios

Nicholas J. Corline[1], Tyanna Blaschak[3], Damon Goodman[3], Ate Visser[4], Jean Moran[5], Emilio Grande[5], Sarah Howe[1], Amber Lukk[1], and Robert A. Lusardi[1,2]

UC Davis Center for Watershed Sciences[1], UC Davis Department of Wildlife, Fish and Conservation Biology[2], California Trout[3], Lawrence Livermore National Laboratory[4], Cal State East Bay, Department of Earth and Environmental Sciences[5]

UC DAVIS
DEPARTMENT OF WILDLIFE, FISH AND CONSERVATION BIOLOGY

CALIFORNIA STATE UNIVERSITY EAST BAY 1957 PER ASPERA AD ASTRA

Lawrence Livermore National Laboratory

CALIFORNIA TROUT
FISH · WATER · PEOPLE

Location determines size

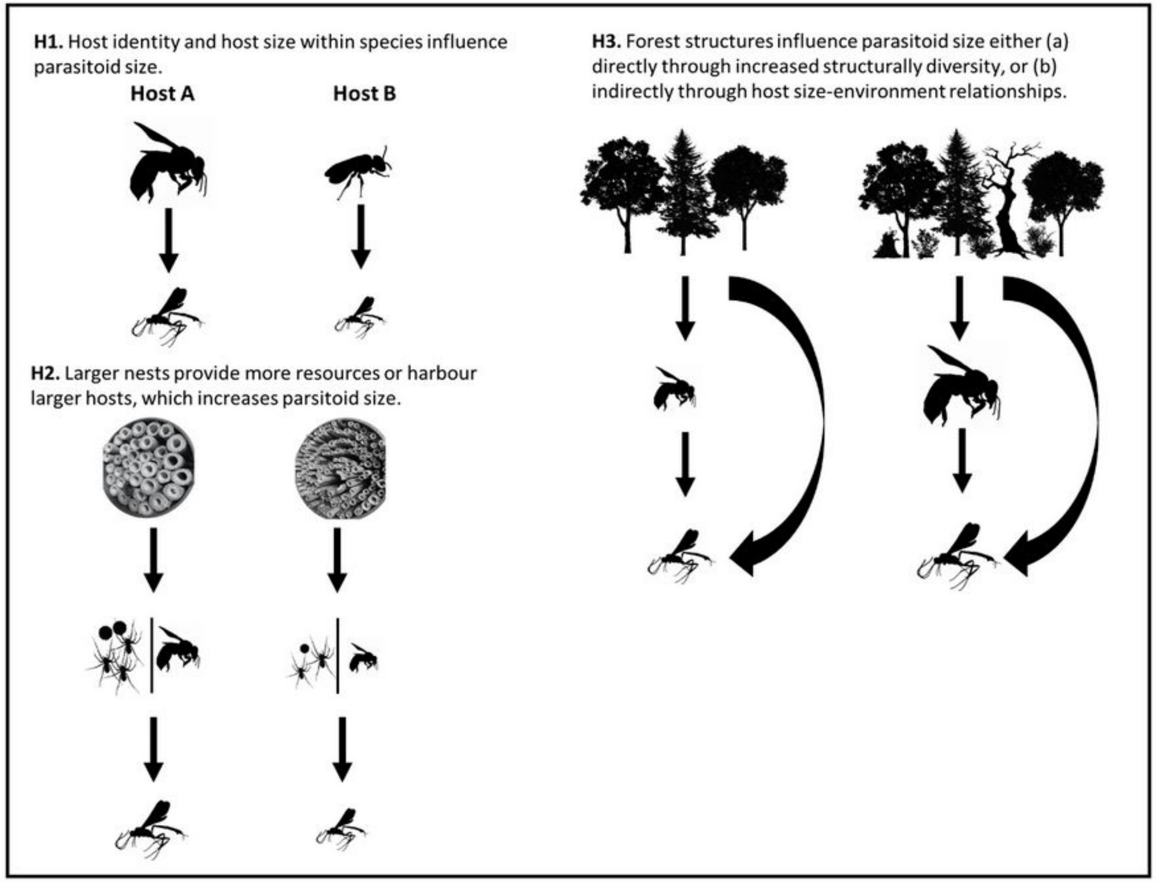
Lodge pole pine- Mendocino Pygmy Forest

Lodge pole pine- Sierra Nevada

Location determines size

Host identity, nest quality, and parasitism strategy: influences on body size variation in parasitoid bees and wasps.

Riko Fardiansah[1], Finn Rehling[1], Nolan Rappa[2], Carsten Dormann[1], and Alexandra-Maria Klein[3]



Lu *et al. BMC Ecol* (2018) 18:37
https://doi.org/10.1186/s12898-018-0194-8
BMC Ecology
RESEARCH ARTICLE Open Access

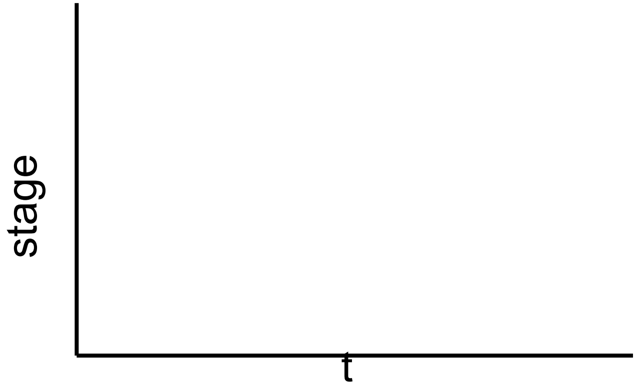
Environmental causes of between-population difference in growth rate of a high-altitude lizard

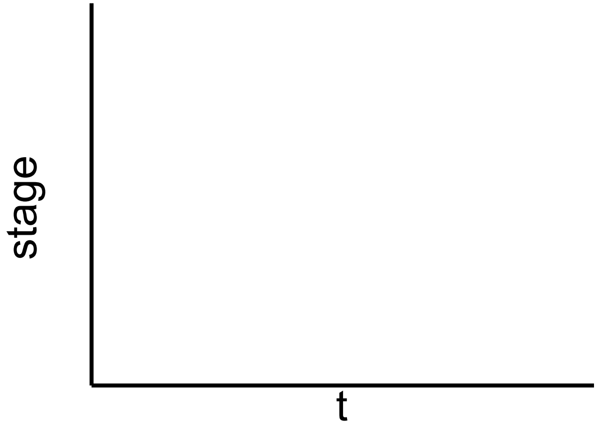
Hong-Liang Lu[1], Chun-Xia Xu[2], Zhi-Gao Zeng[2] and Wei-Guo Du[2*]

Location determines size

Precipitation Driven Stream

Volcanic Spring-fed



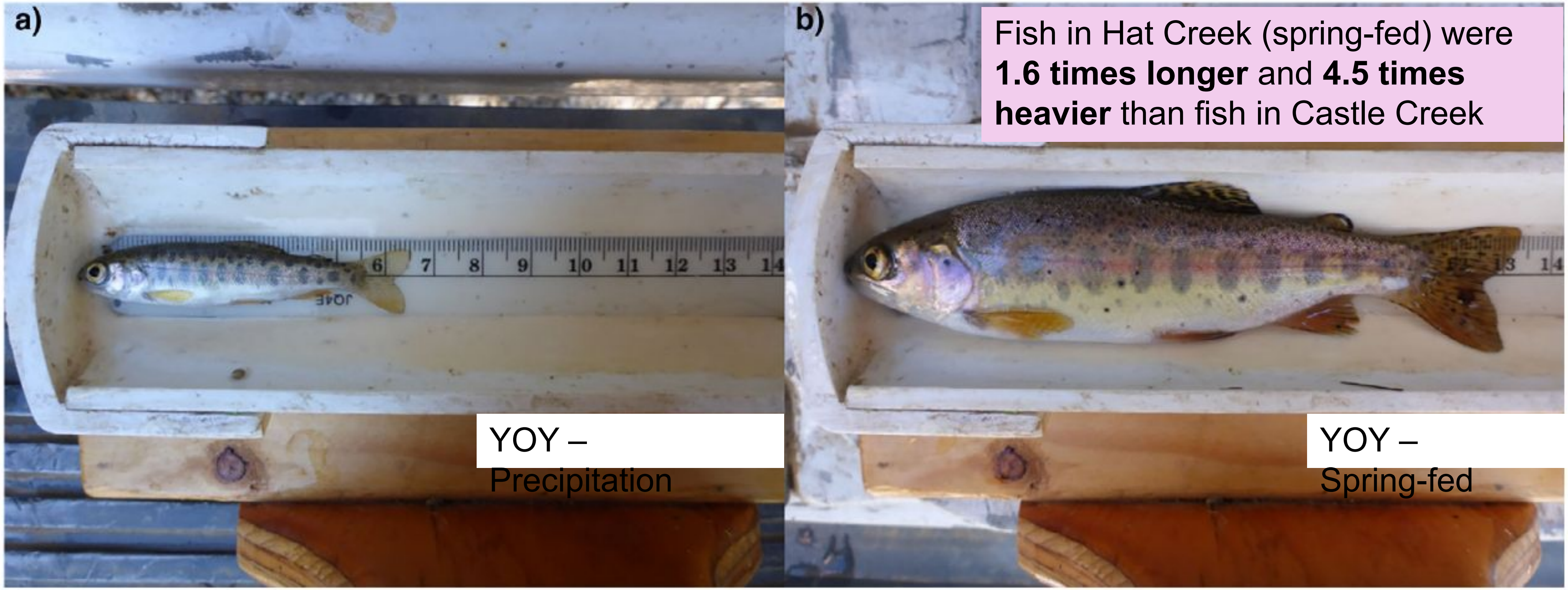


YOY rainbow trout in a volcanic springs were much larger than those in a precipitation driven stream

Received: 30 August 2022 | Revised: 28 April 2023 | Accepted: 9 May 2023
DOI: 10.1002/ecy.4107
THE SCIENTIFIC NATURALIST
ECOLOGY

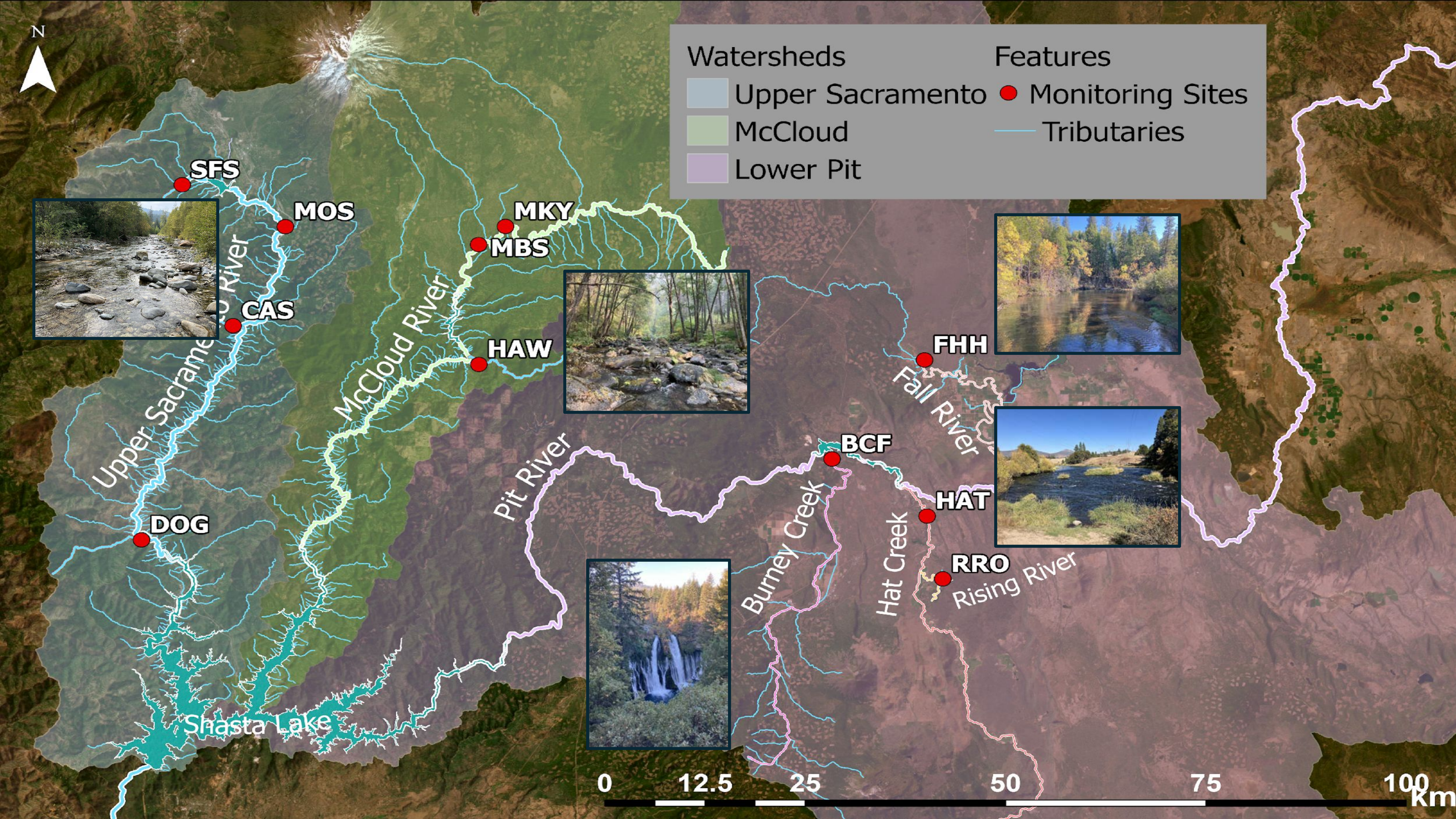
Does fine-scale habitat diversity promote meaningful phenotypic diversity within a watershed network?

Robert A. Lusardi[1,2] | Randy Dahlgren[2] | Erwin Van Nieuwenhuyse[3] | George Whitman[2] | Carson Jeffres[2] | Rachel Johnson[2,4]

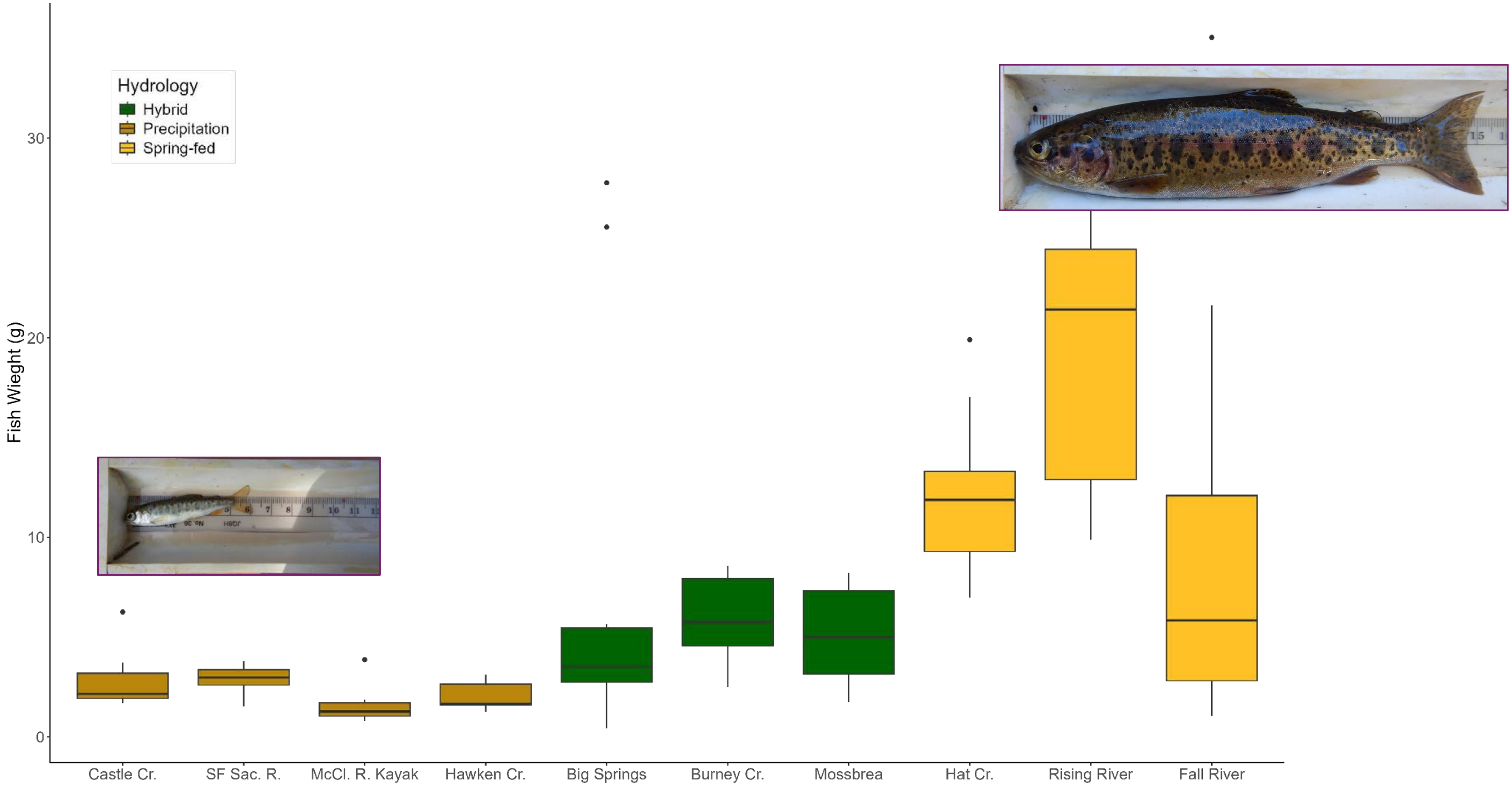


Fish in Hat Creek (spring-fed) were **1.6 times longer** and **4.5 times heavier** than fish in Castle Creek

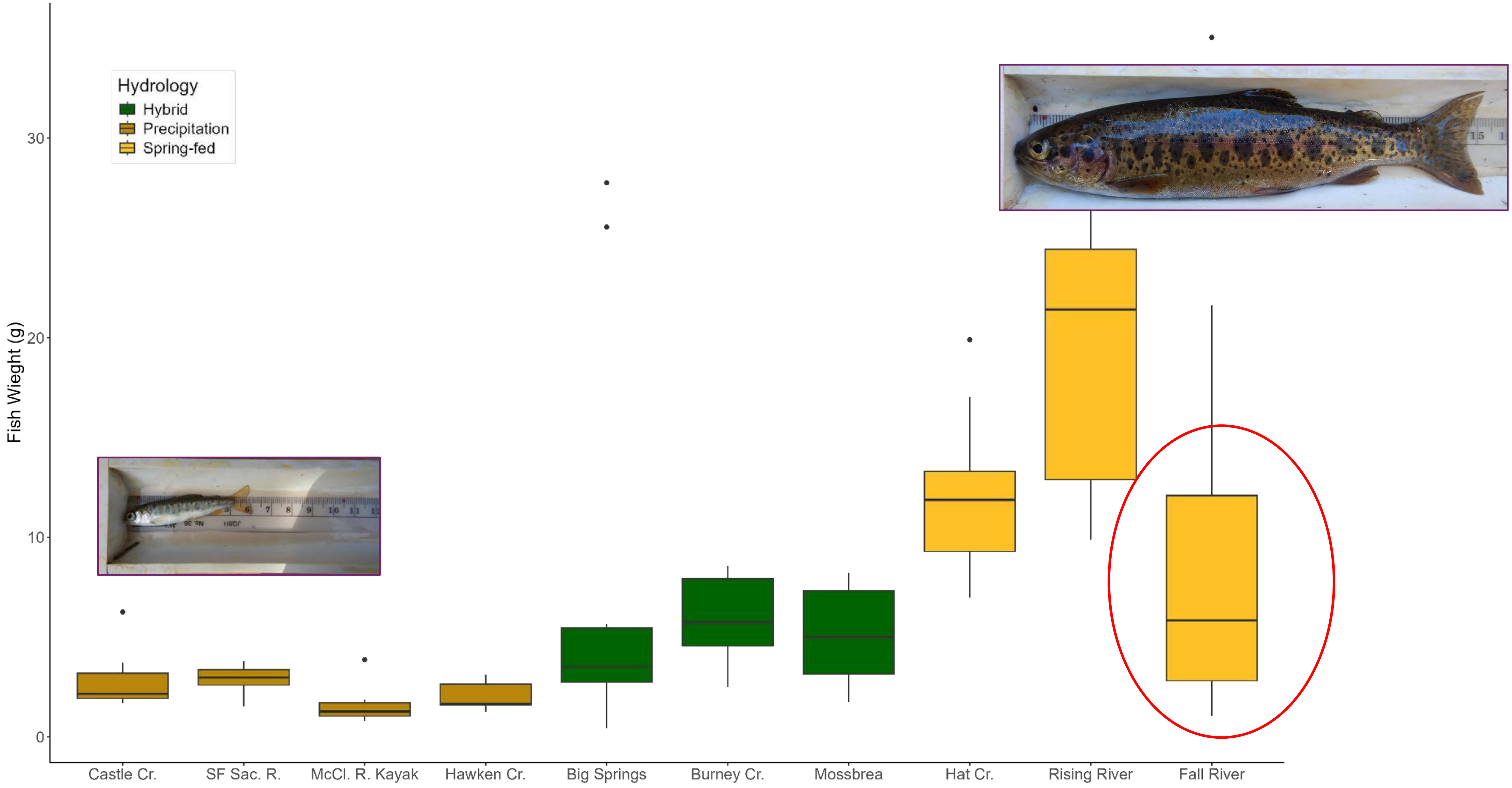
Are all spring-fed streams locations large young of the year rainbow trout? If so, why?


N
Watersheds
Upper Sacramento
McCloud
Lower Pit
Features
Monitoring Sites
Tributaries
SFS
MOS
CAS
DOG
MKY
MBS
HAW
FHH
BCF
HAT
RRO
Upper Sacramento River
McCloud River
Pit River
Fall River
Burney Creek
Hat Creek
Rising River
Shasta Lake
0
12.5
25
50
75
100
km

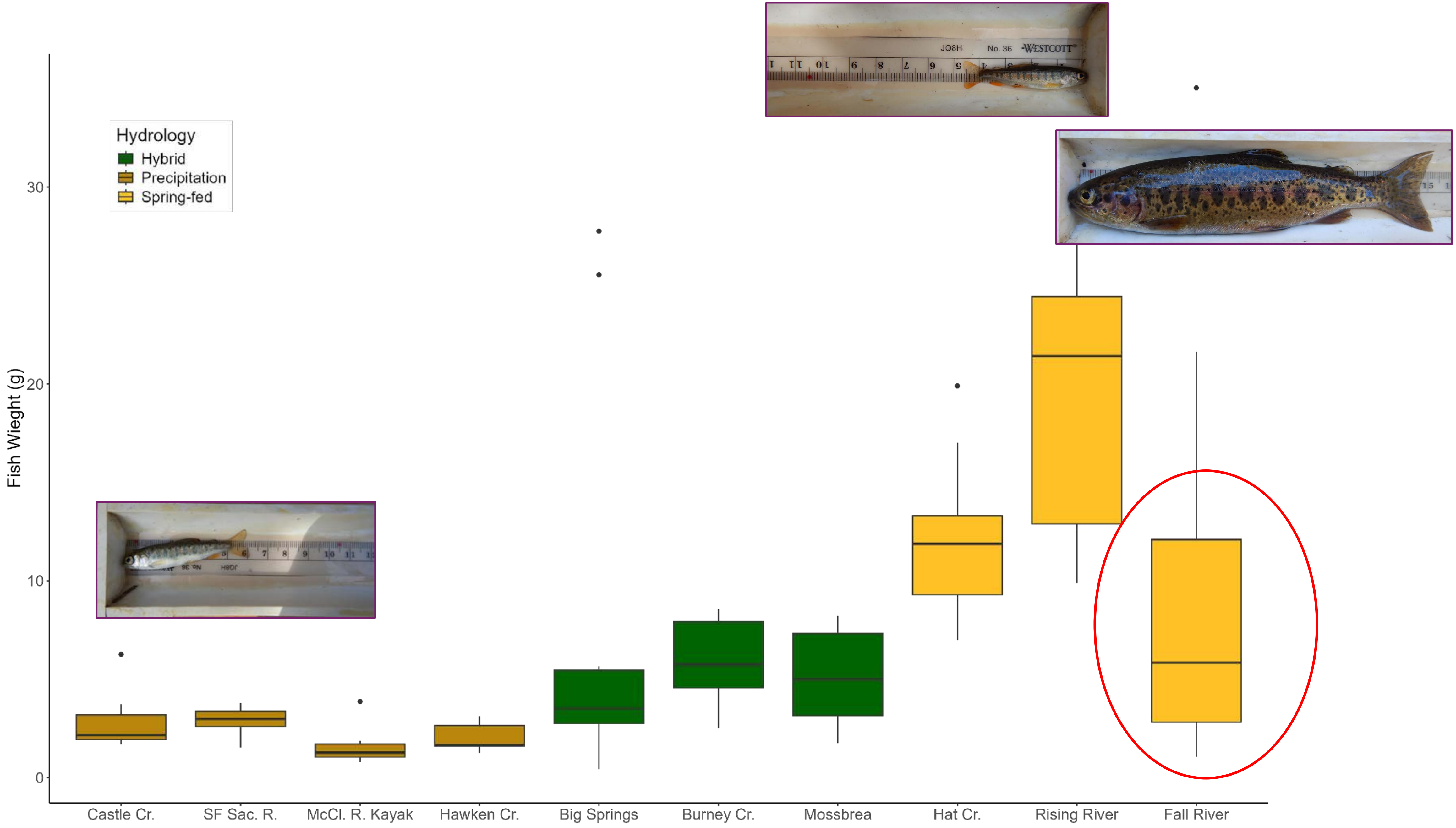
YOY rainbow trout were larger in springs



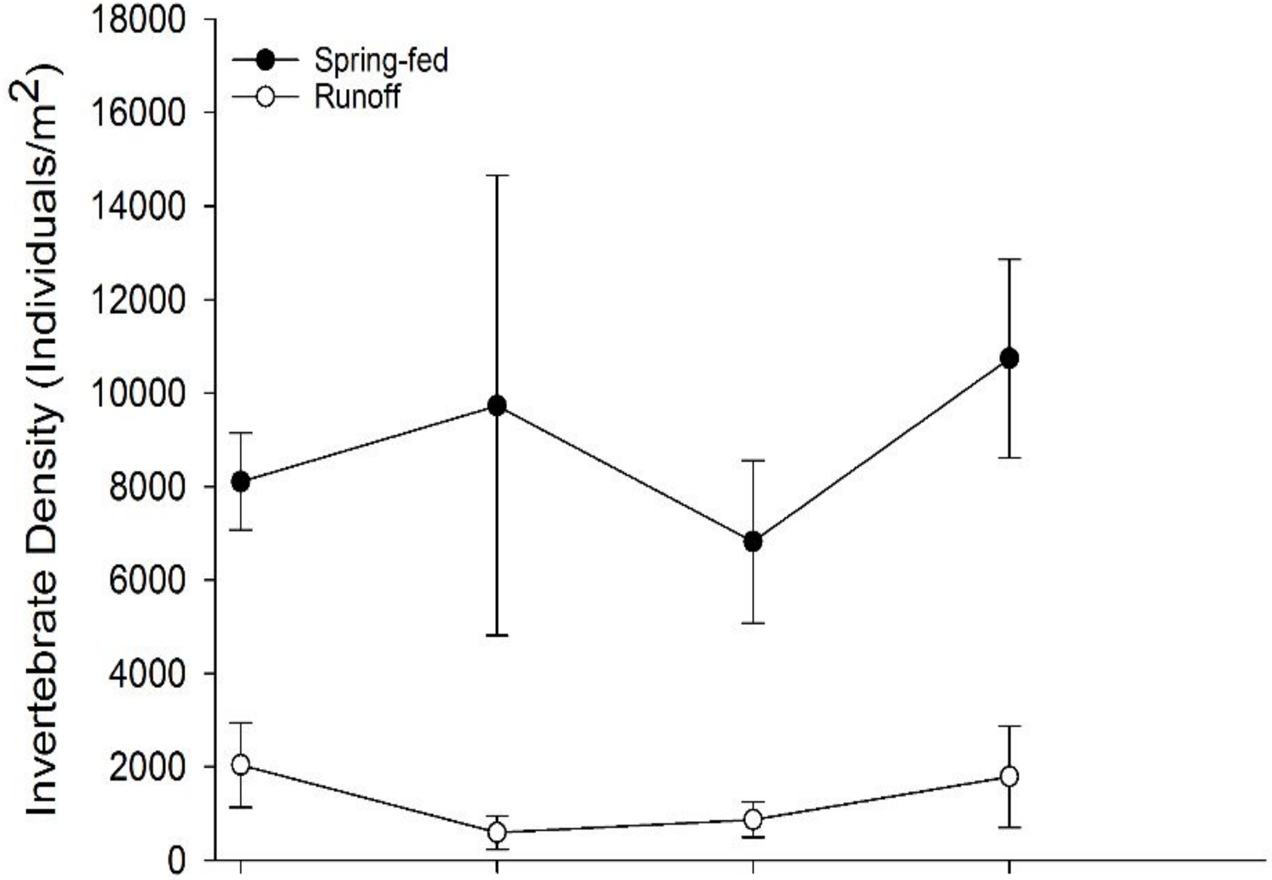
YOY rainbow trout were larger in springs



YOY rainbow trout were larger in springs

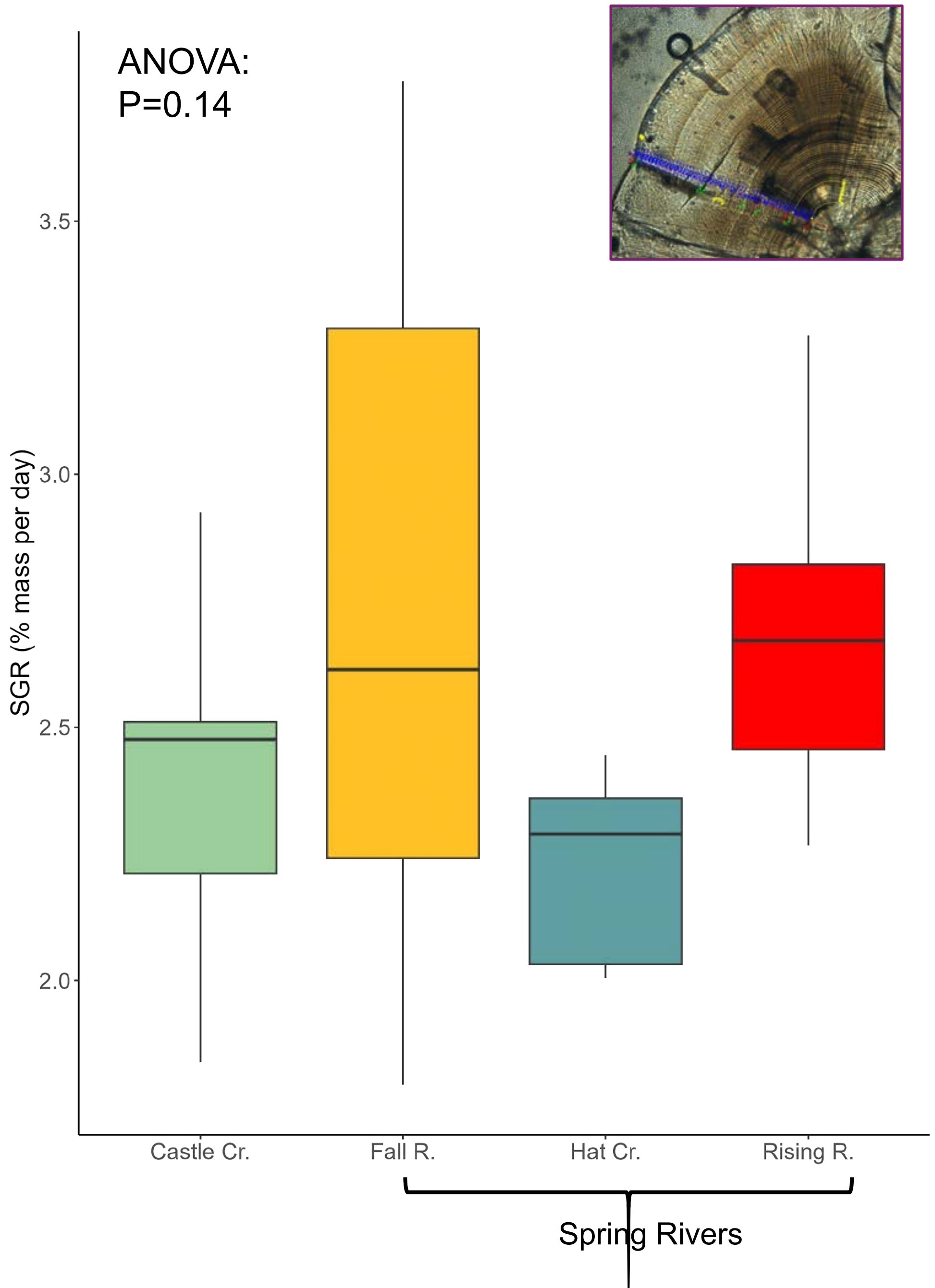


Springs are locations high productivity

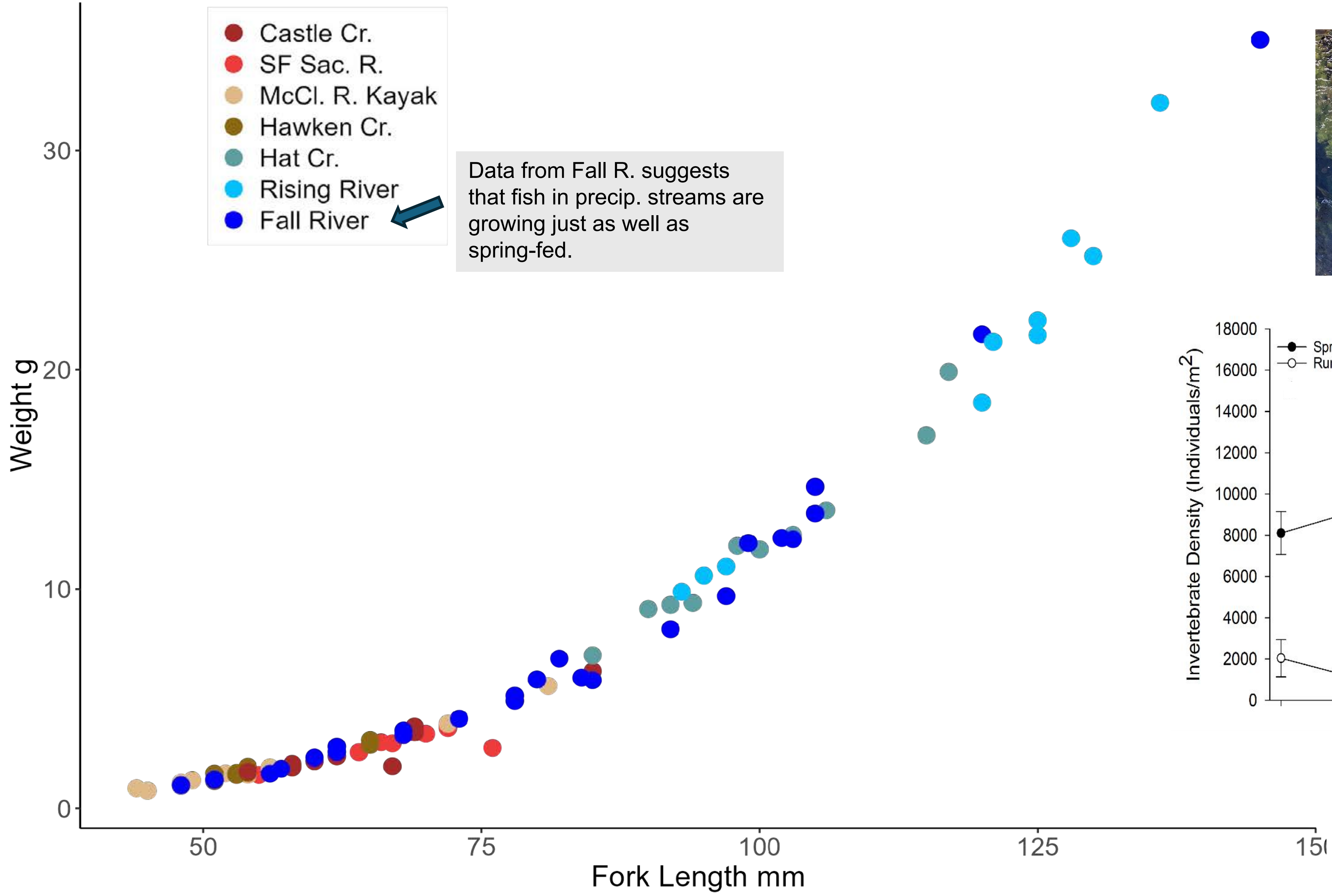


Lusardi et. al
2016

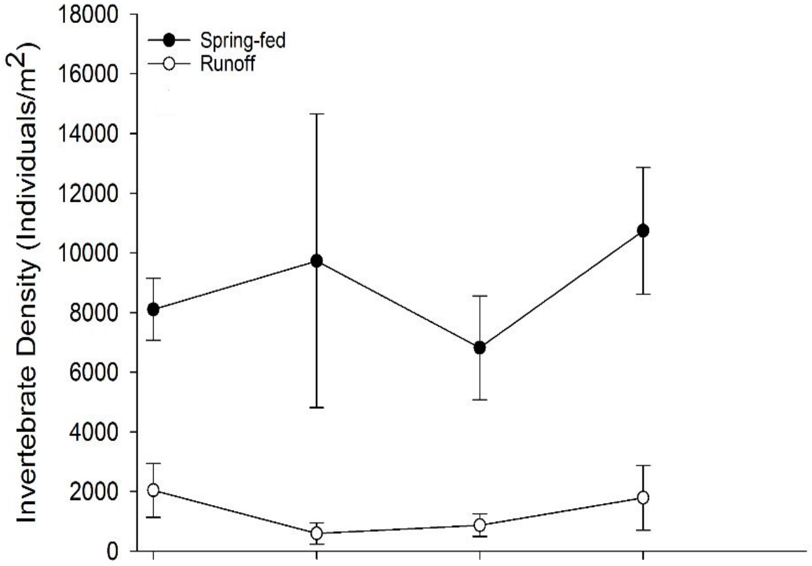
Specific growth rates suggest that although fish were larger in spring-fed rivers their growth rates were variable



Fish in precipitation rivers do not appear smaller for their size



Data from Fall R. suggests that fish in precip. streams are growing just as well as spring-fed.



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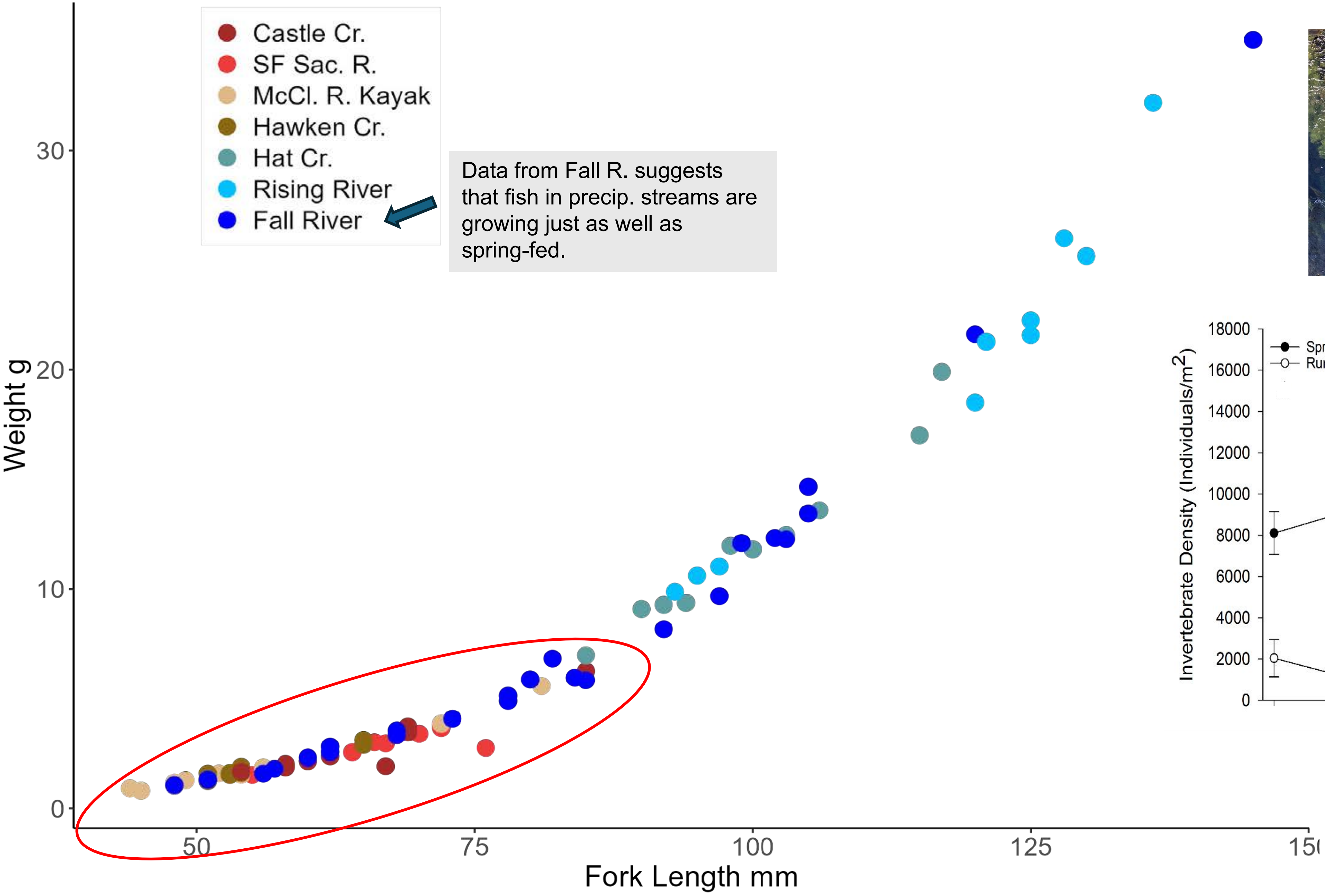

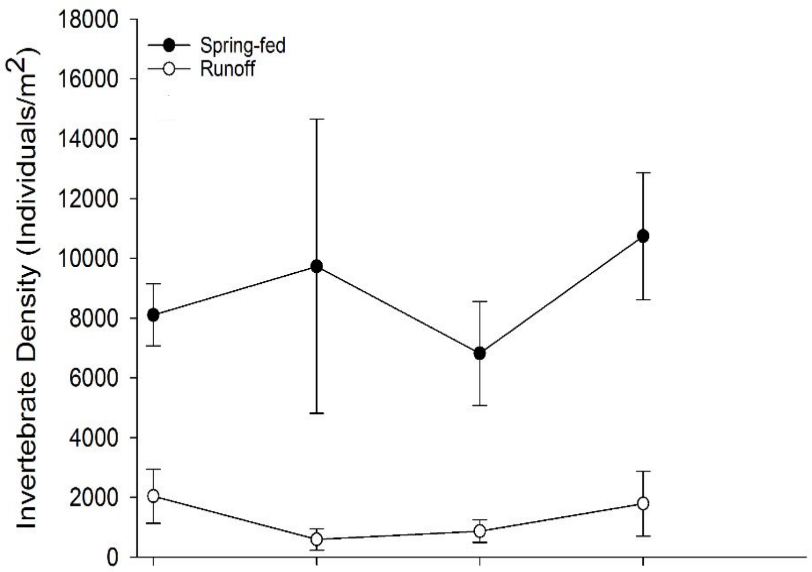

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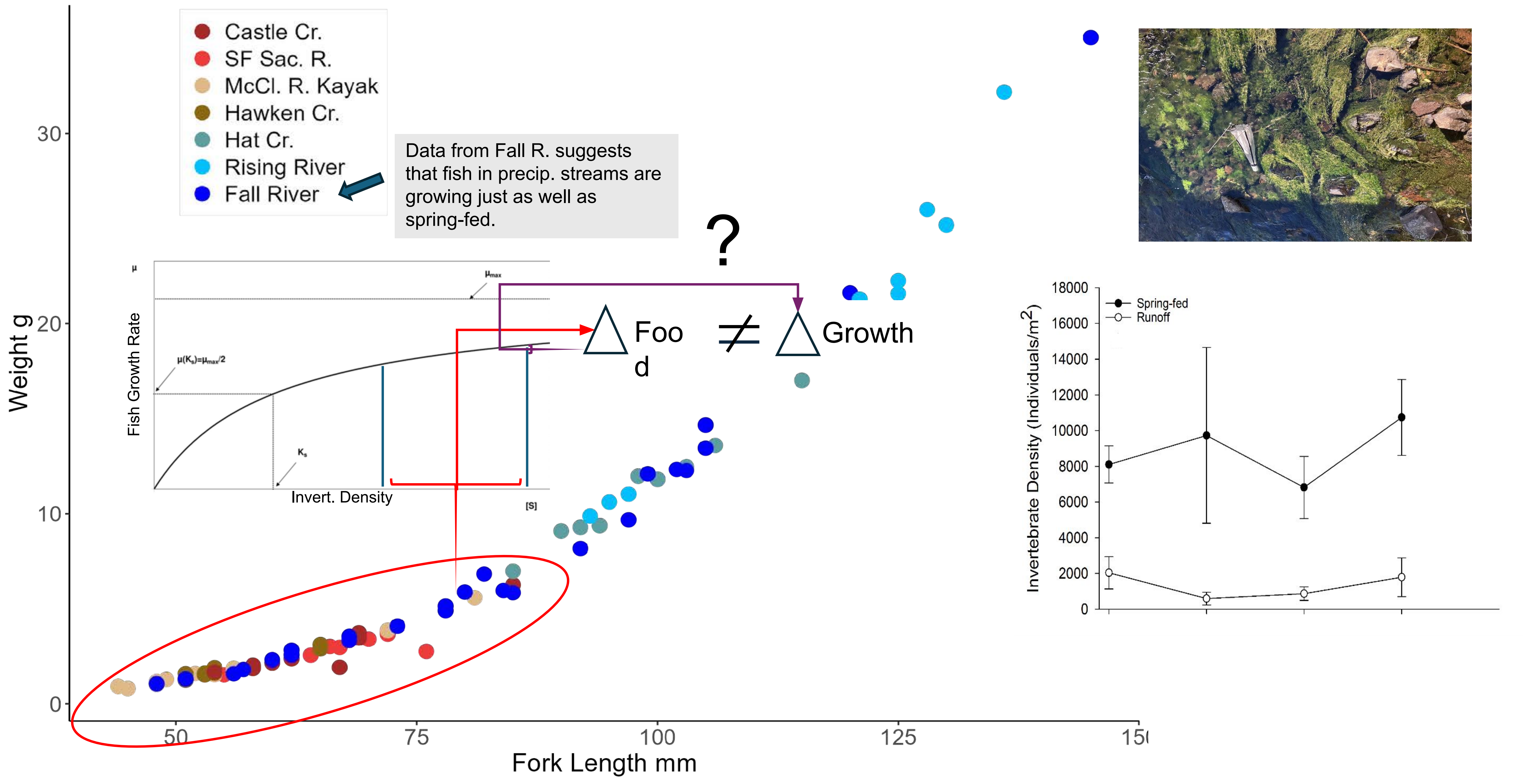
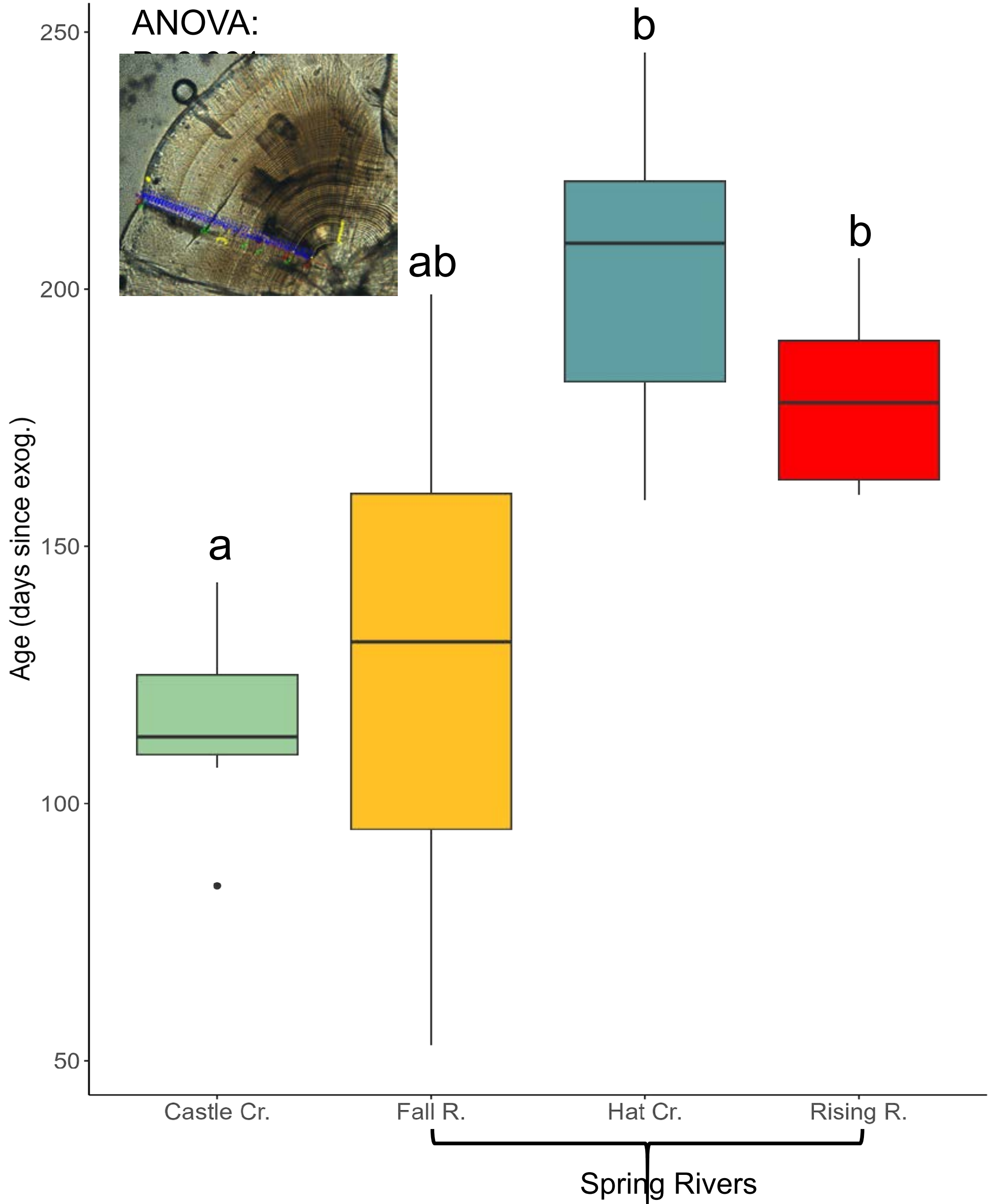


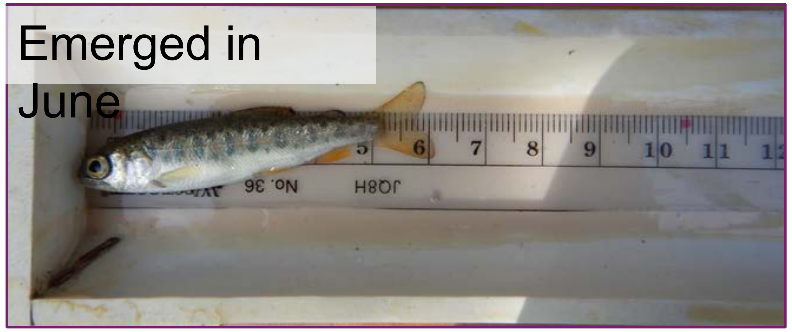
Specific growth rates suggest that although fish were larger in spring-fed rivers their growth rates were variable

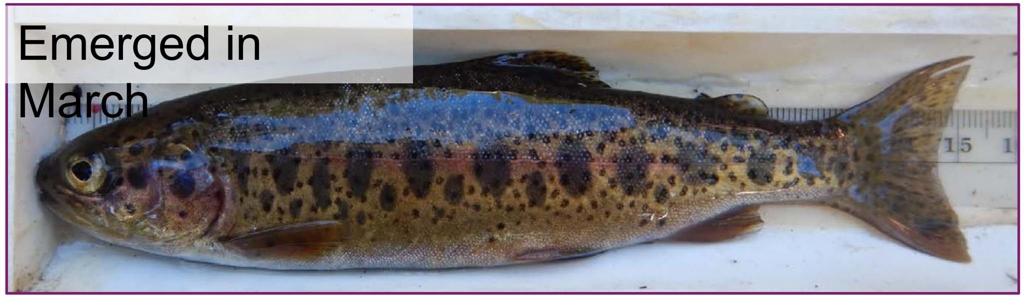
How can these fish be growing at similar rates, yet have such a large difference in size?

Specific growth rates suggest that although fish were larger in spring-fed rivers their growth rates were variable

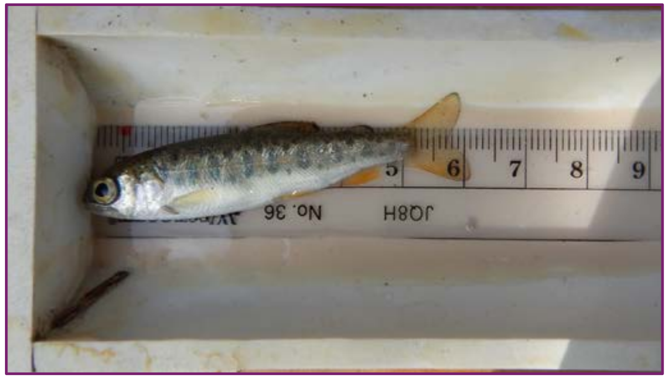


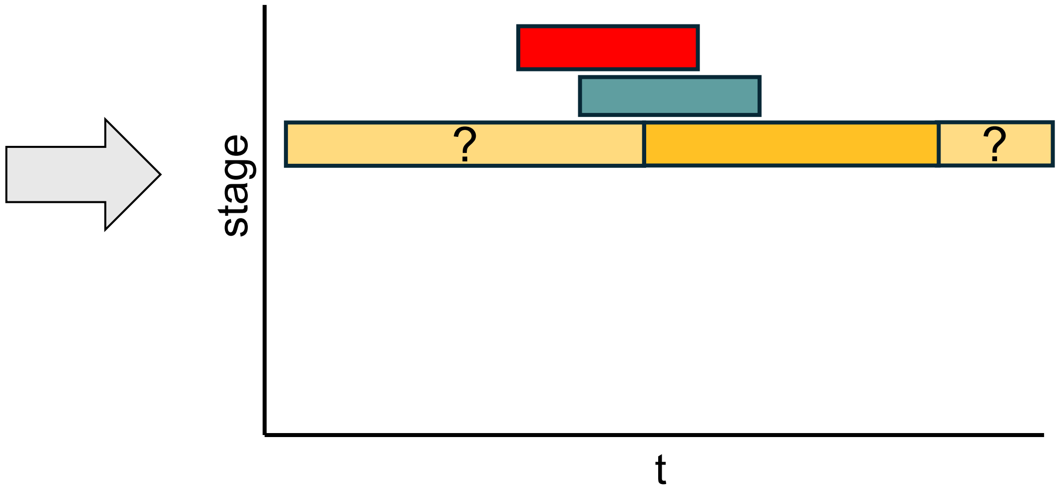
How can these fish be growing at similar rates, yet have such a large difference in size? **TIME**





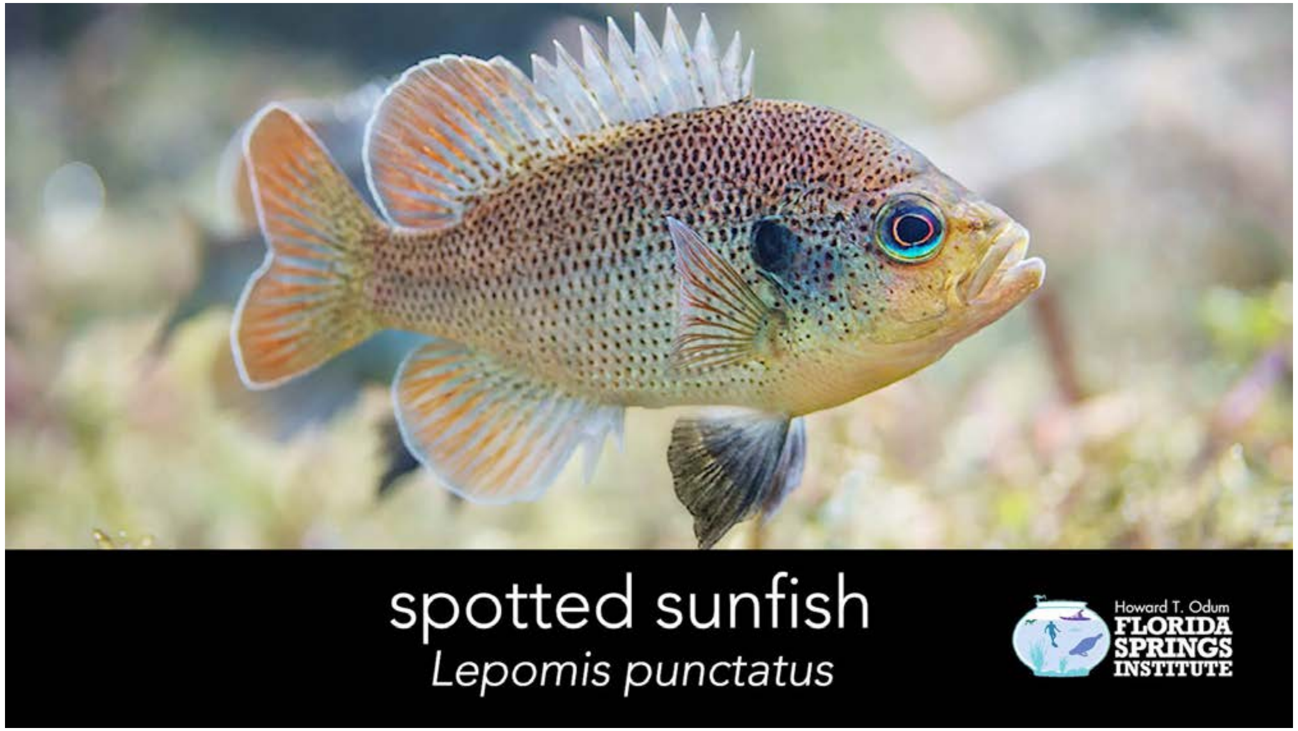
We often think about growth variation in terms of resources, here difference in size is likely due to ecosystem stability





Hydrological stability in springs-fed rivers alters life-history, specifically reproductive timing

Species in springs will often display continuous breeding or spawning, with lack of distinct age class structure



How does this relate to foodscapes?

"…springs…are collectively a giant laboratory for the study of natural communities" - H.T Odum, 1957

Here, the natural laboratory, illustrates the importance of time for fish growth.

Fish growth = *f(*Temperature, Food)

Fish growth in first year of life = *f*(Temperature, Food, TIME)

Main take aways

- Contrasting hydrology leads to variation in size of YOY fish
- This difference in size does not appear to be governed by productivity but time
- Fish in spring demonstrate an altered life history– due to ecosystem stability – that leads to a longer growing window for YOY rainbow trout.

Next Steps

-Use otolith increment widths to further understand growth rates through time

-Relate growth to temperature condition

-Relate growth to hydrology and future climate conditions

-Expand this research to other spring-fed rivers


JQ8H
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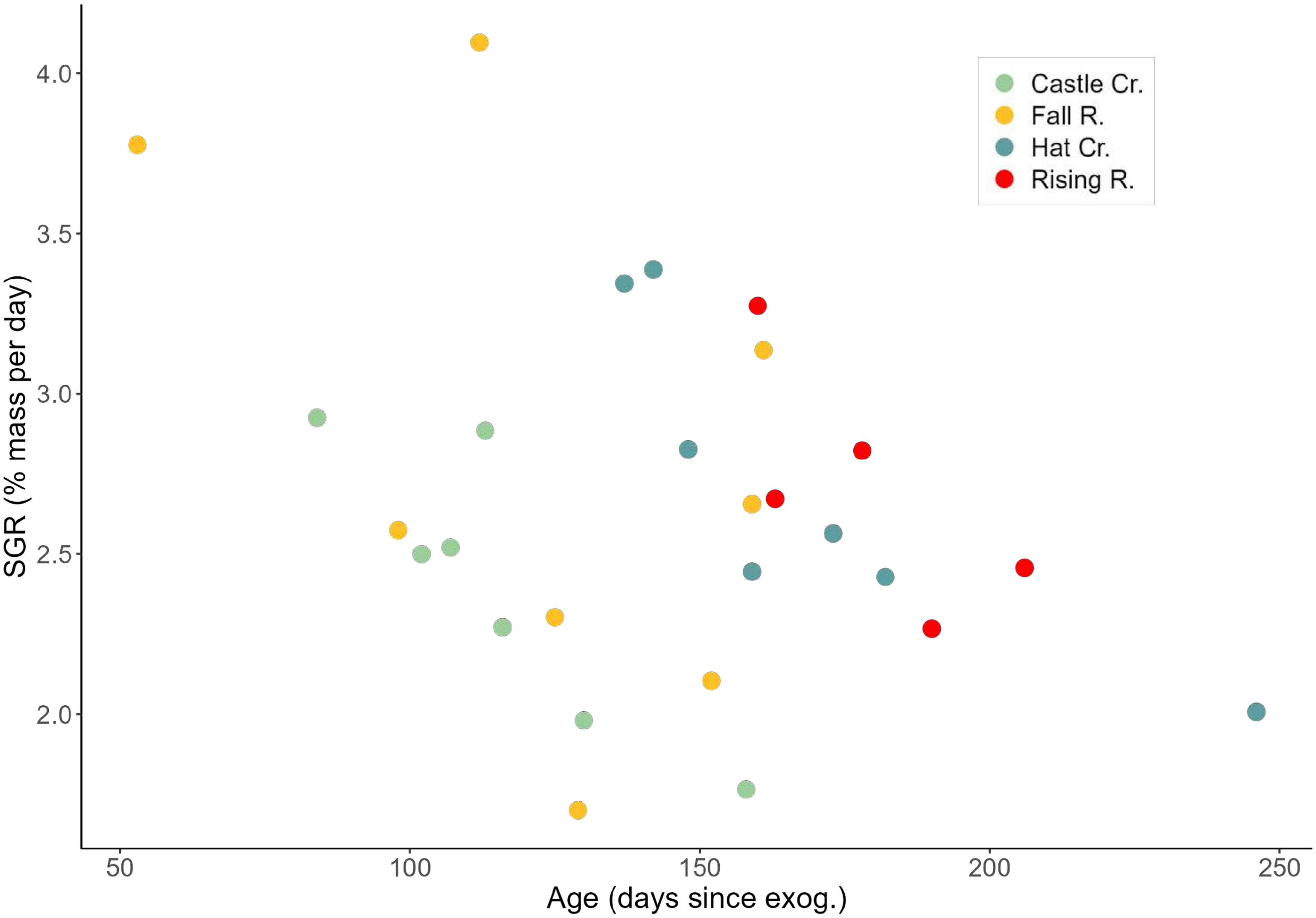
Hydrological stability in springs-fed rivers alters life-history, specifically reproductive timing



WILDFIRE IMPACTS TROPHIC SUPPLY AND DEMAND IN A COASTAL SALMONID FOOD WEB

Salmonid Restoration Federation | May 2, 2025

Katie M. Kobayashi, PhD

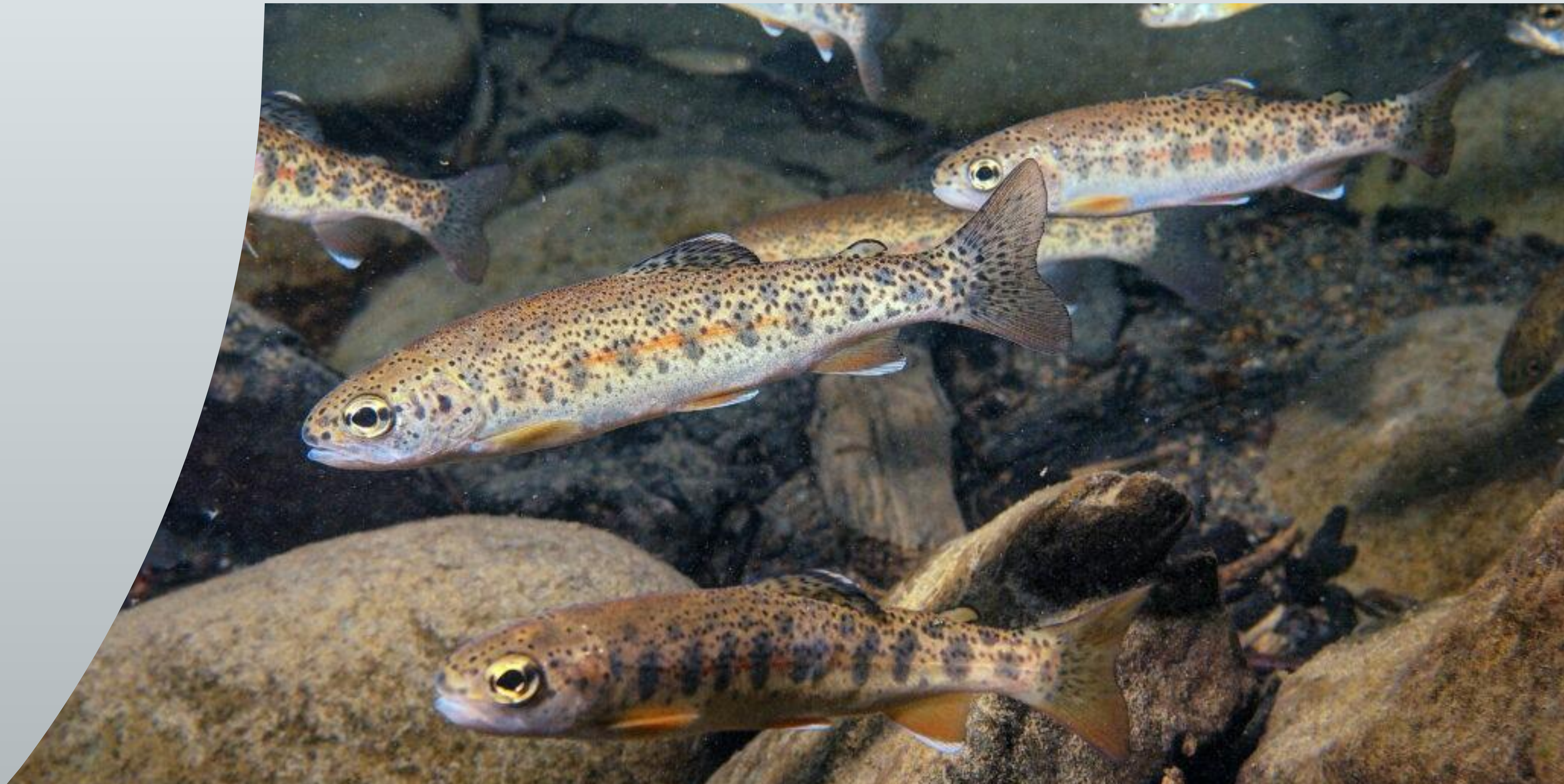
University of California, Santa Cruz | Stillwater Sciences

Co-authors: Raymond Hunter, David B. Herbst, Rosealea M. Bond, Joseph D. Kiernan, Eric P. Palkovacs

ESCALATING VULNERABILITY

OF COASTAL SALMOIDS TO A RAPIDLY CHANGING ENVIRONMENT

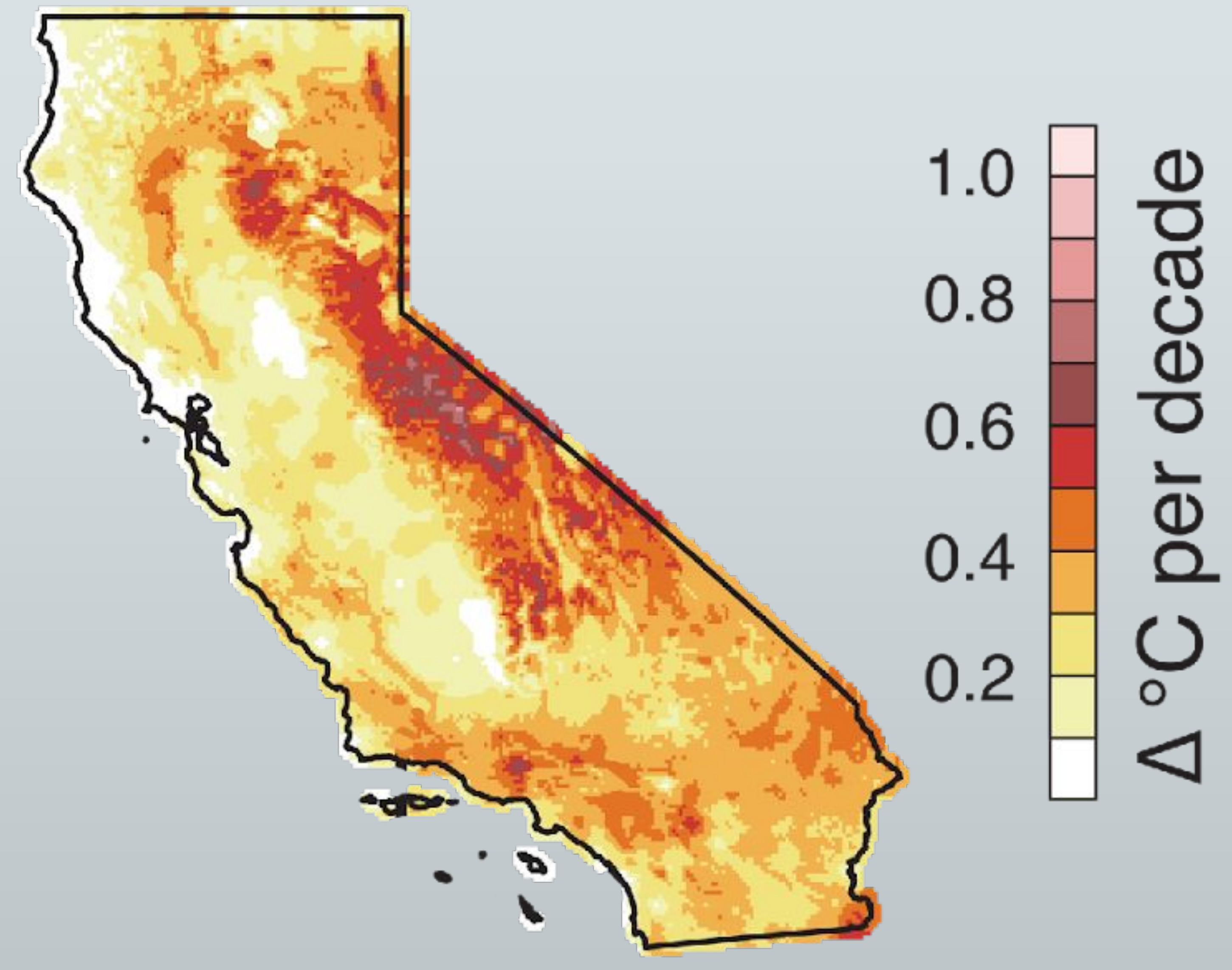
- Steelhead are ESA-listed as endangered and threatened throughout much of California
- Coastal watersheds provide critical habitat to anadromous salmonids
- Rearing juvenile salmonids are vulnerable to the effects of climate change (e.g. drought, temperature).



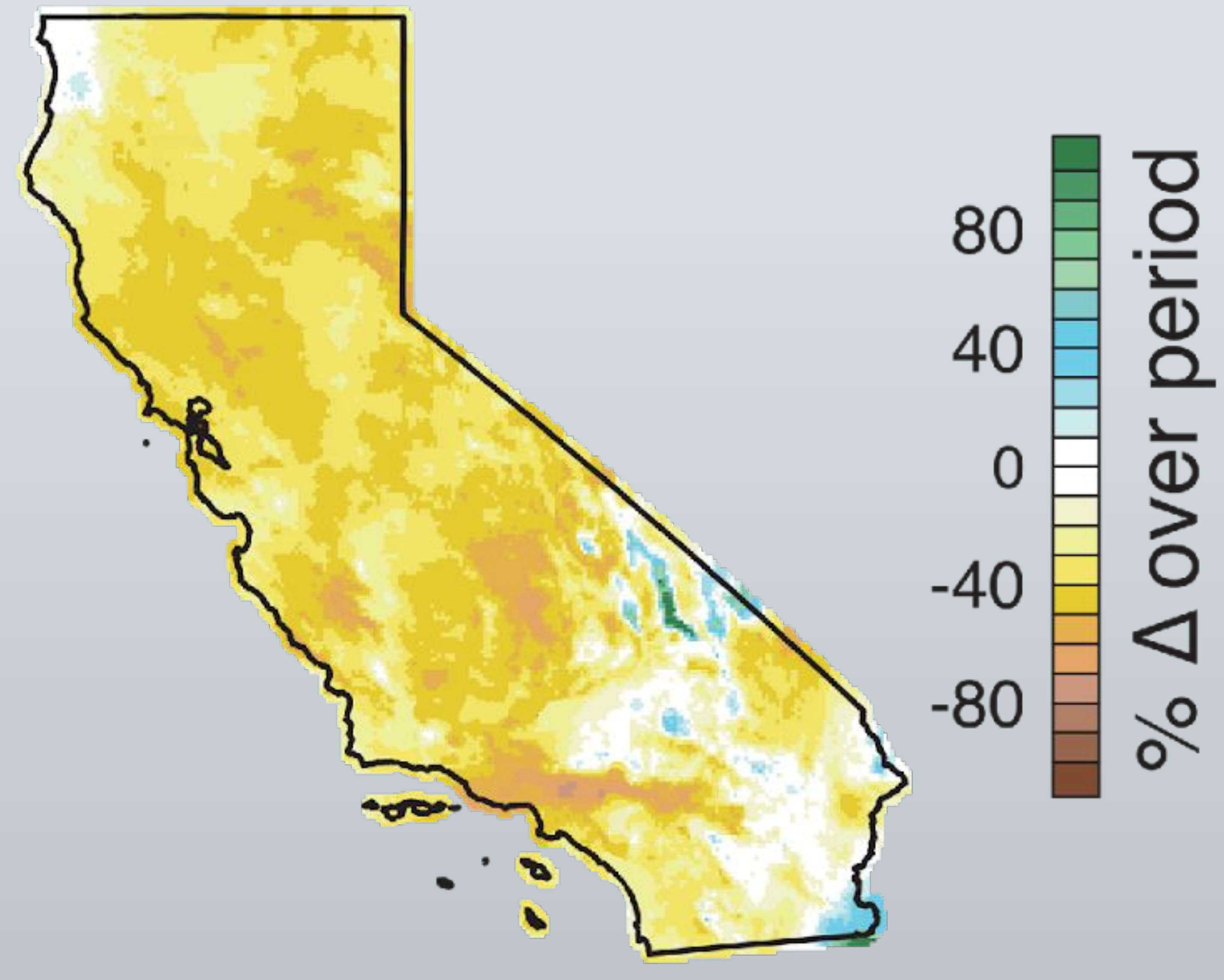
INTENSIFYING WILDFIRE REGIMES

POSE AN IMMEDIATE RISK TO VULNERABLE SALMONID POPULATIONS

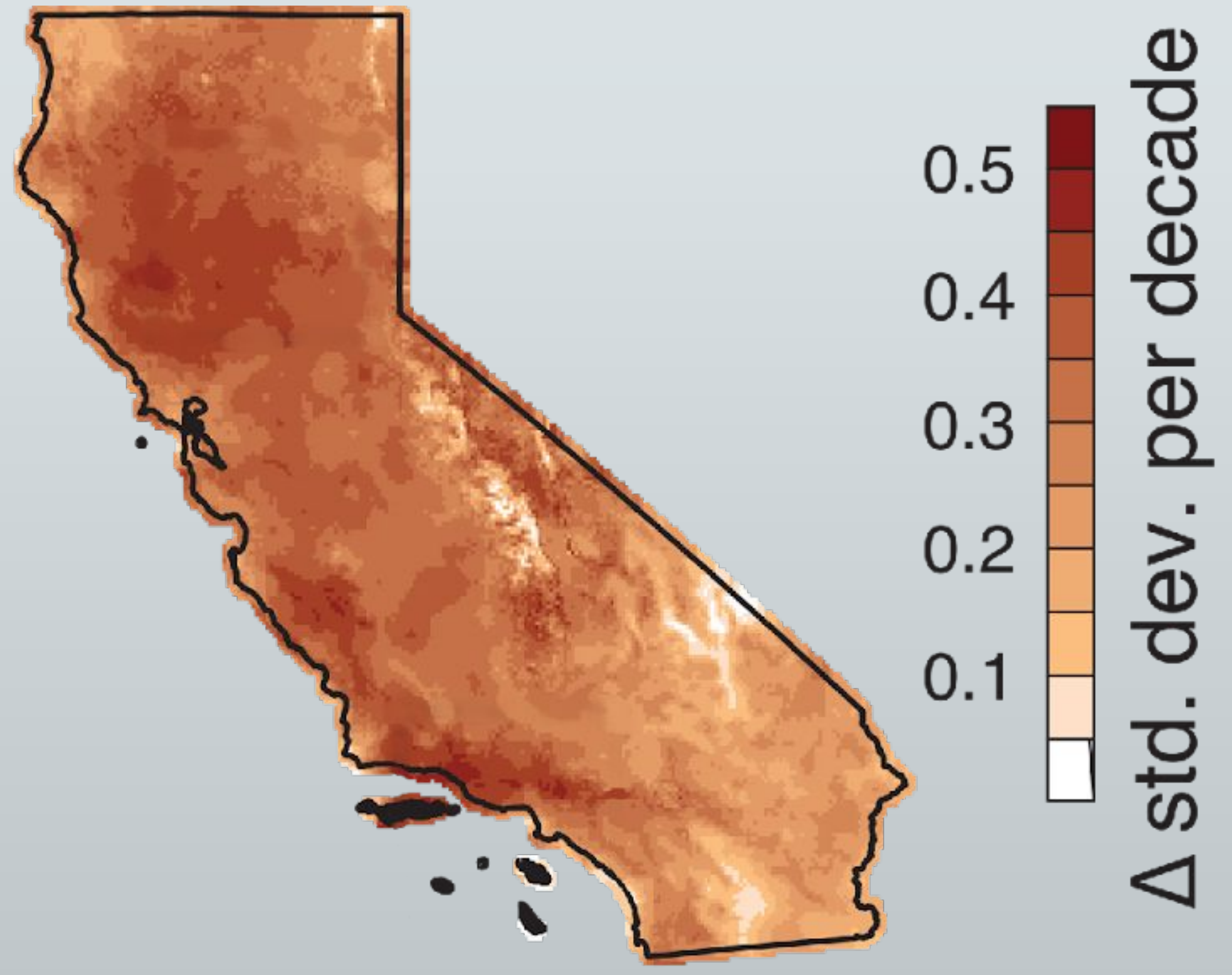
TEMPERATURE TRENDS



PRECIPITATION CHANGE



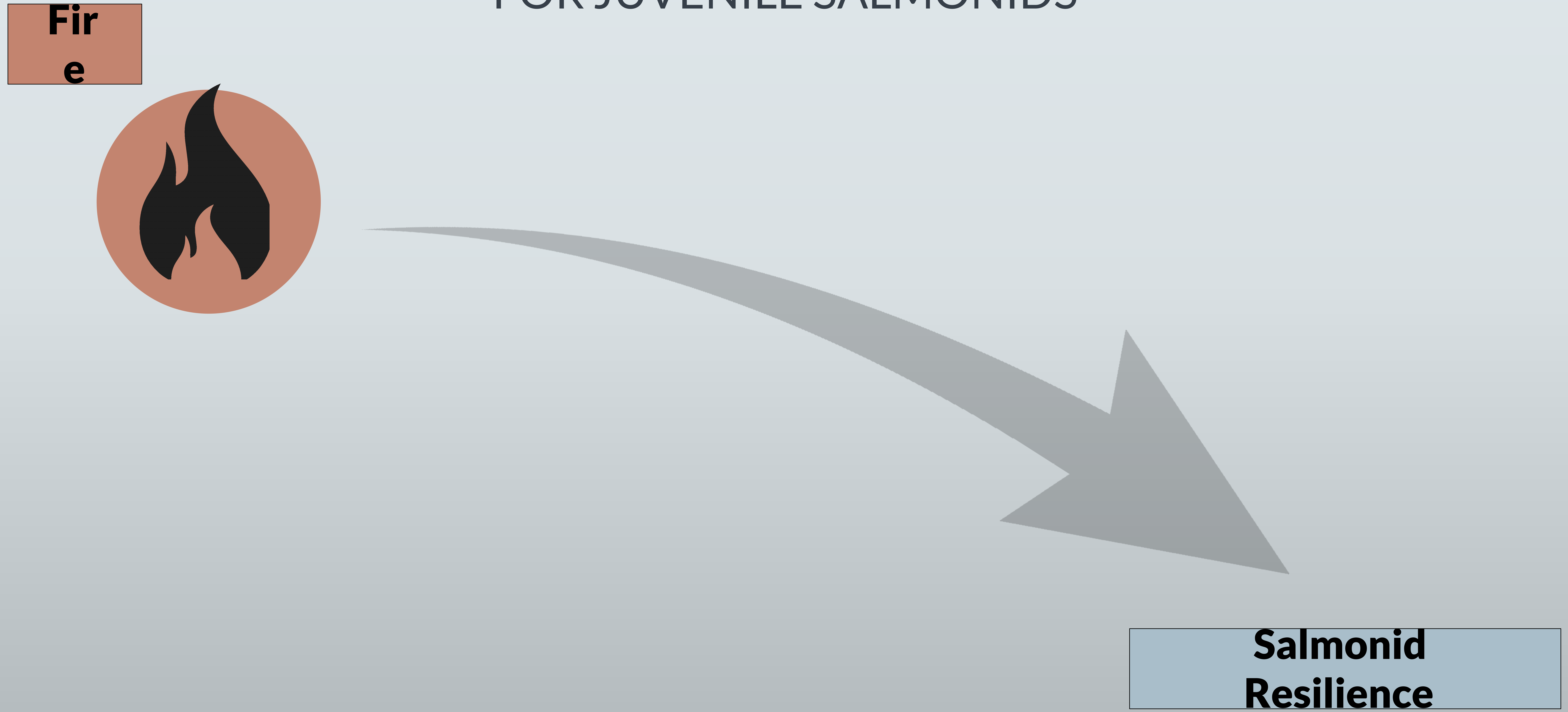
FIRE WEATHER INDEX TREND



(Goss et al. 2020)

POTENTIAL THREATS OF WILDFIRE

FOR JUVENILE SALMONIDS



POTENTIAL THREATS OF WILDFIRE

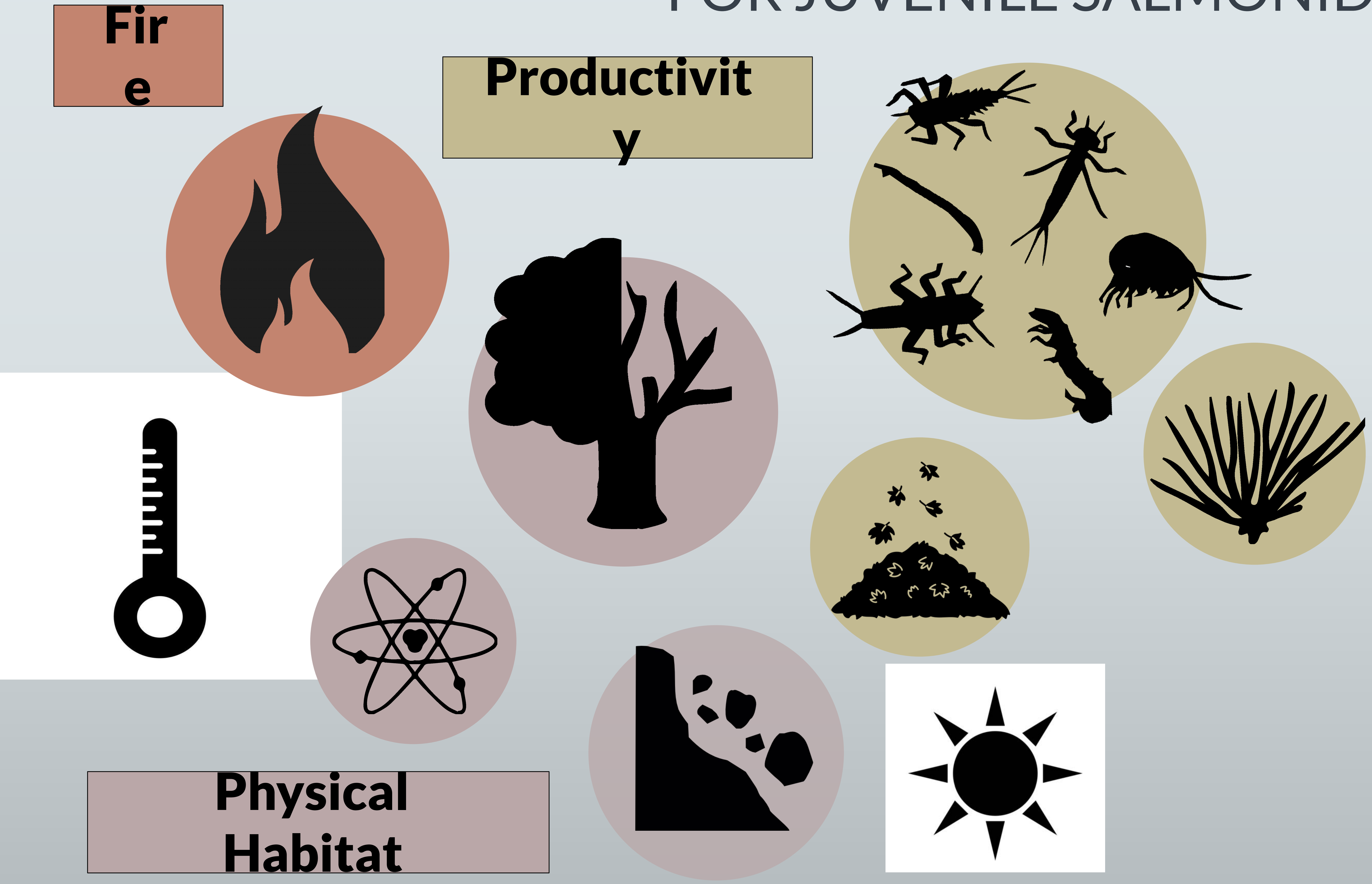
FOR JUVENILE SALMONIDS

Fir
e

Physical
Habitat

POTENTIAL THREATS OF WILDFIRE

FOR JUVENILE SALMONIDS



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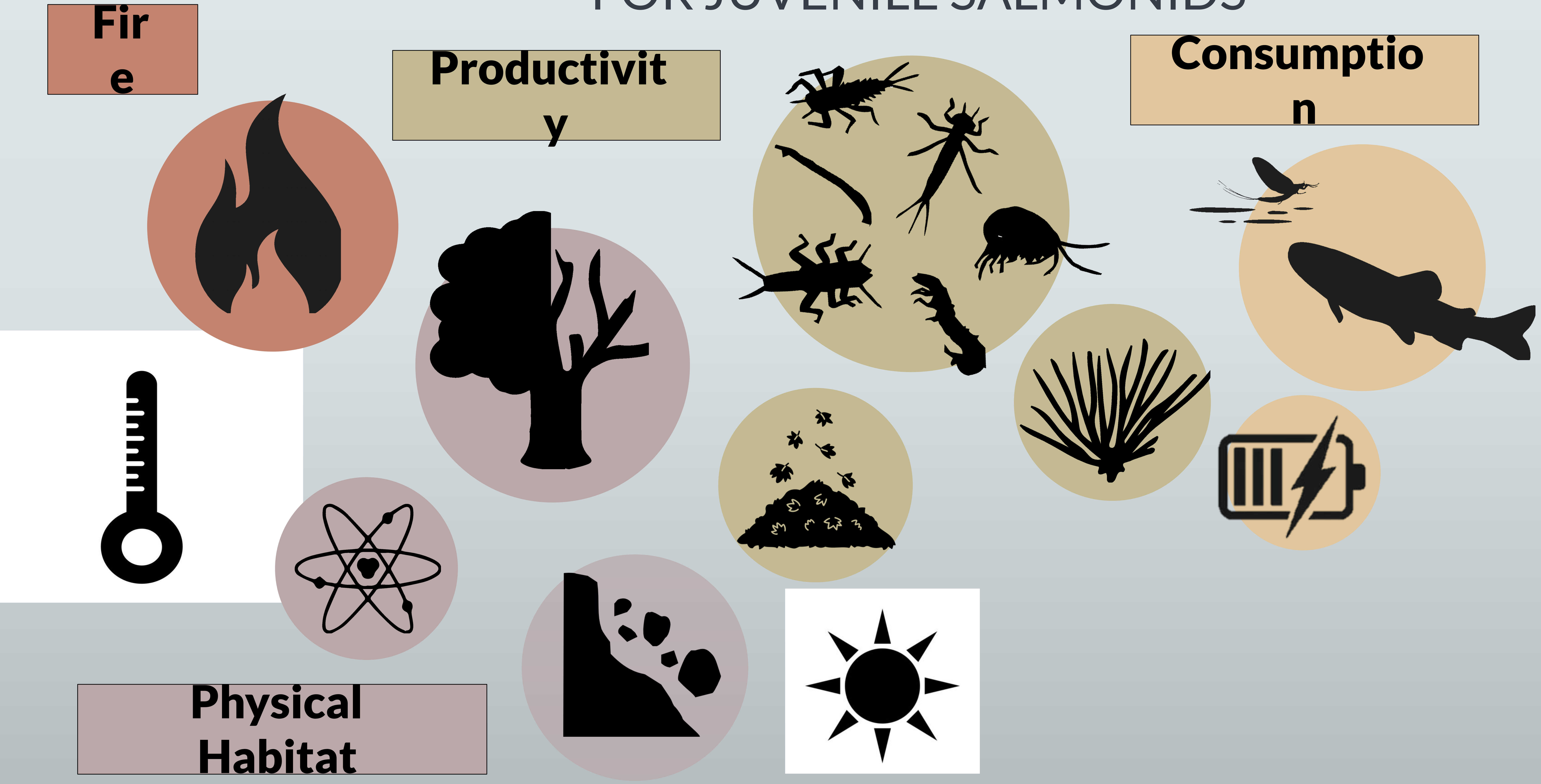
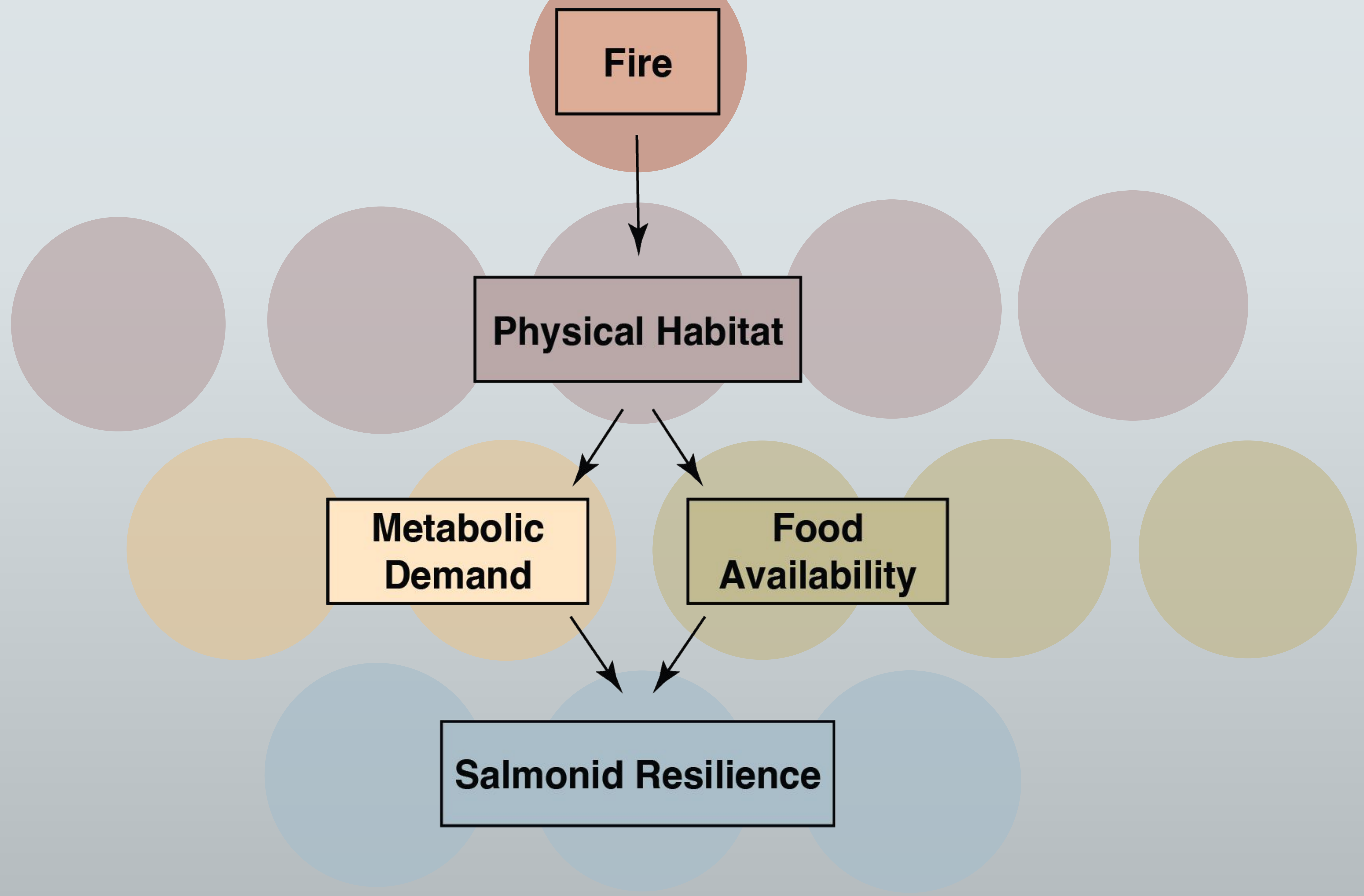


POTENTIAL THREATS OF WILDFIRE

FOR JUVENILE SALMONIDS

TROPHIC SUPPLY AND DEMAND

AS A FRAMEWORK FOR WILDFIRE ASSESSMENT



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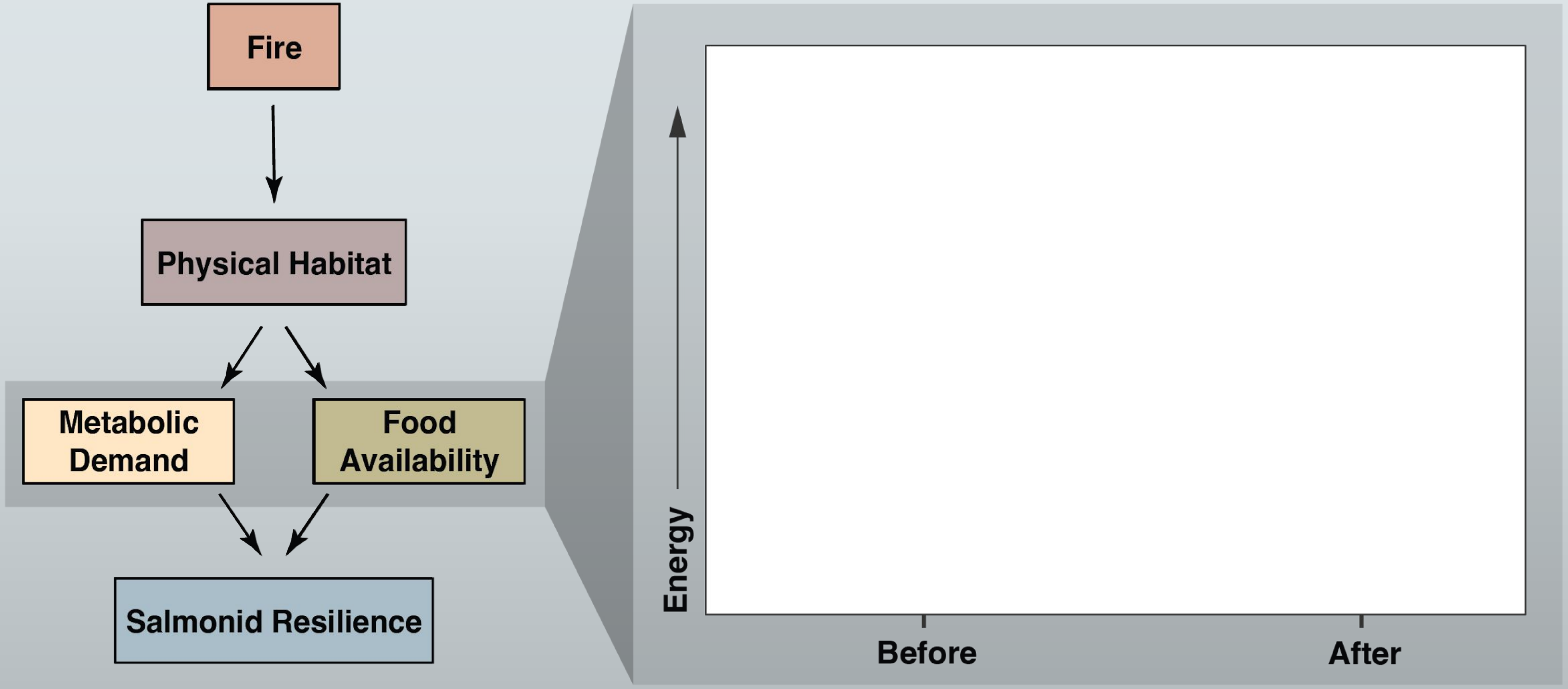

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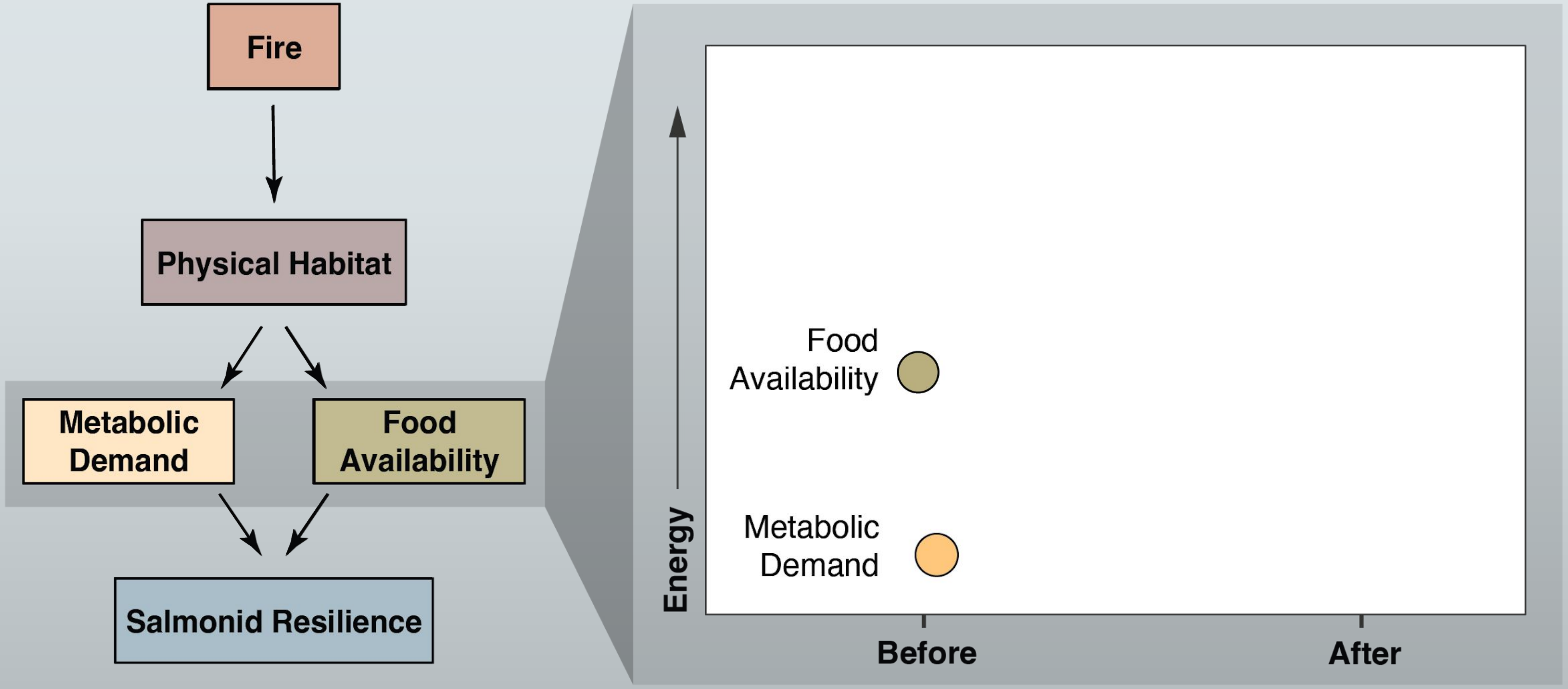

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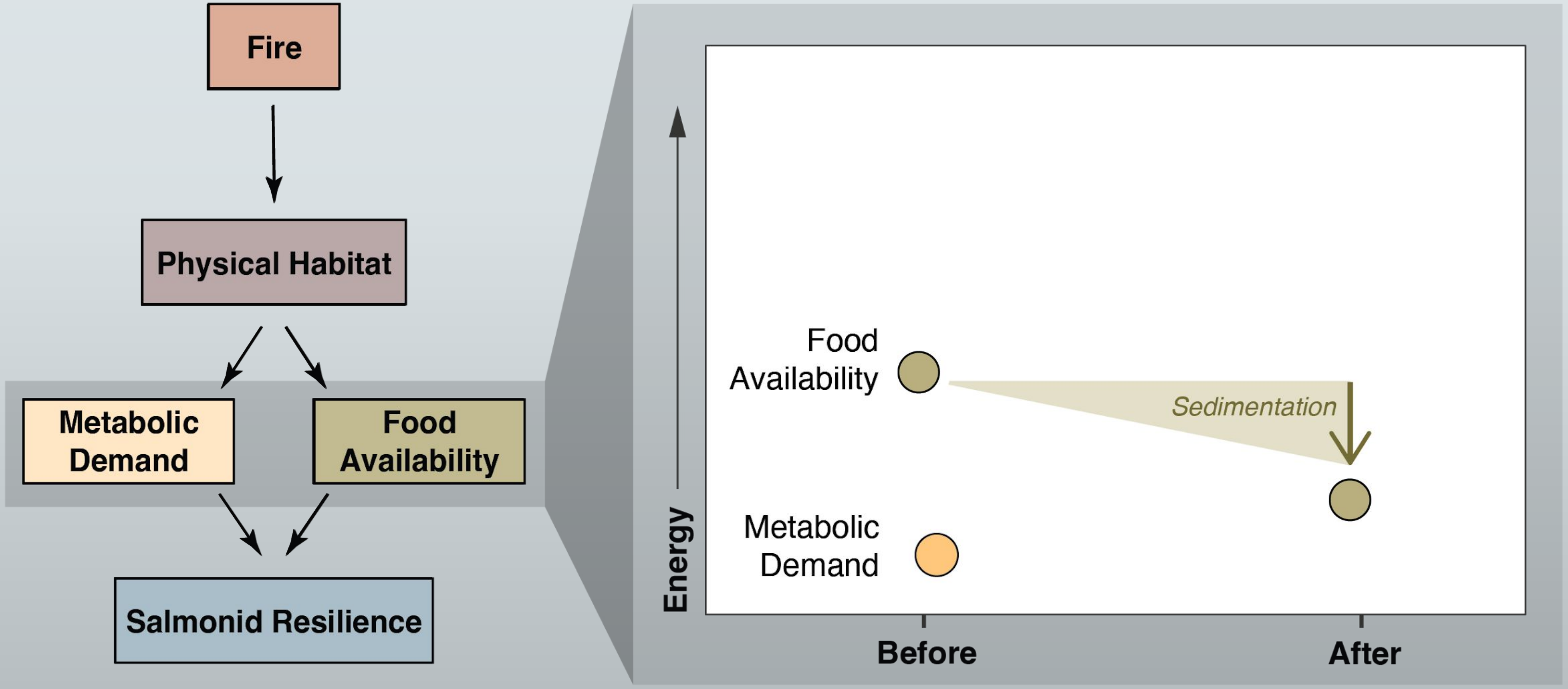

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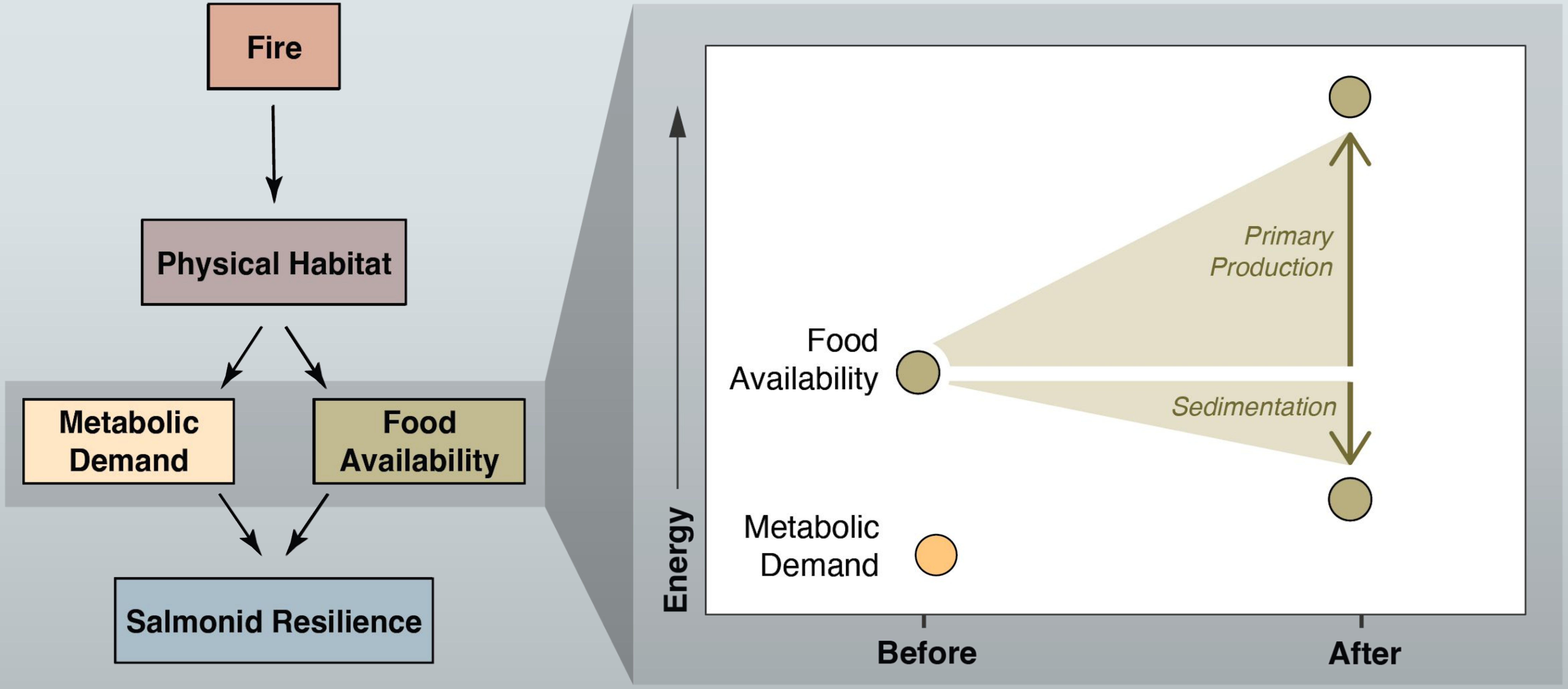

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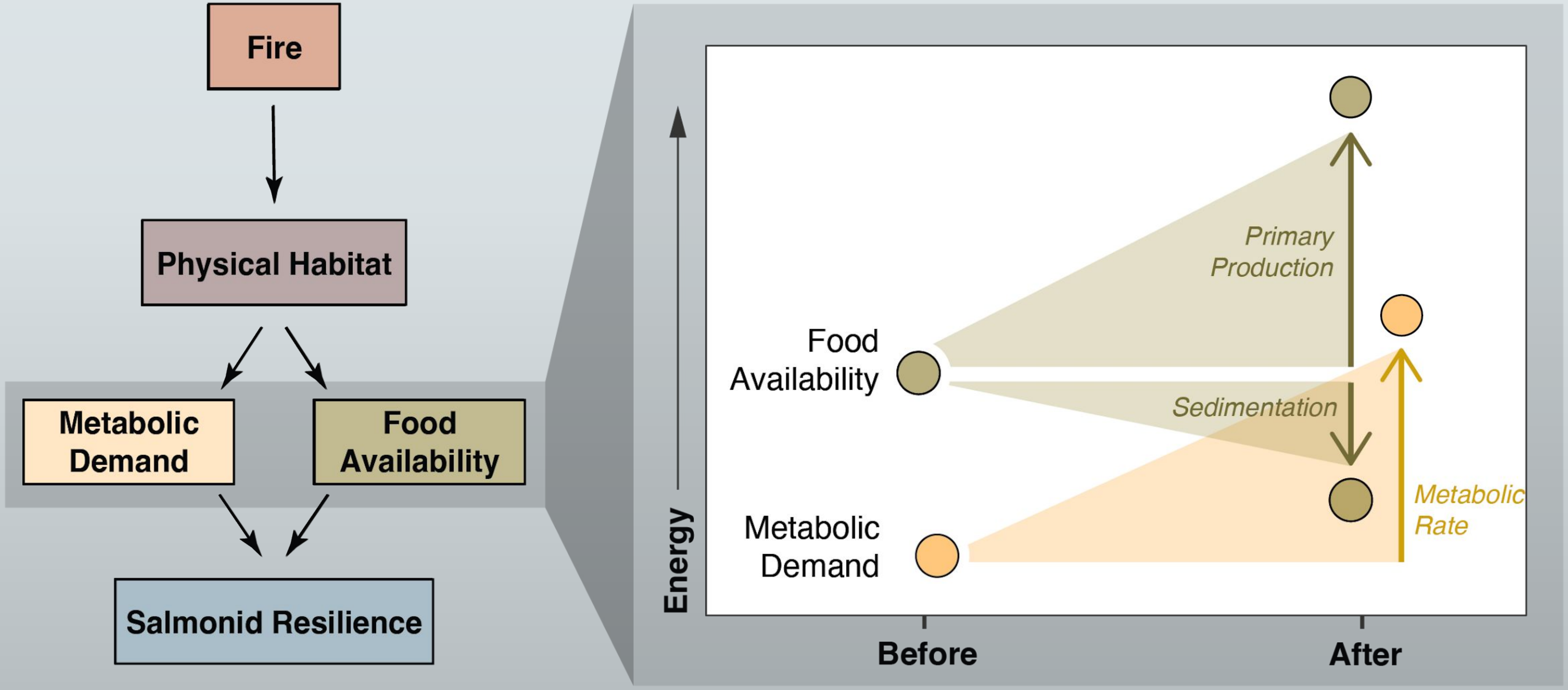

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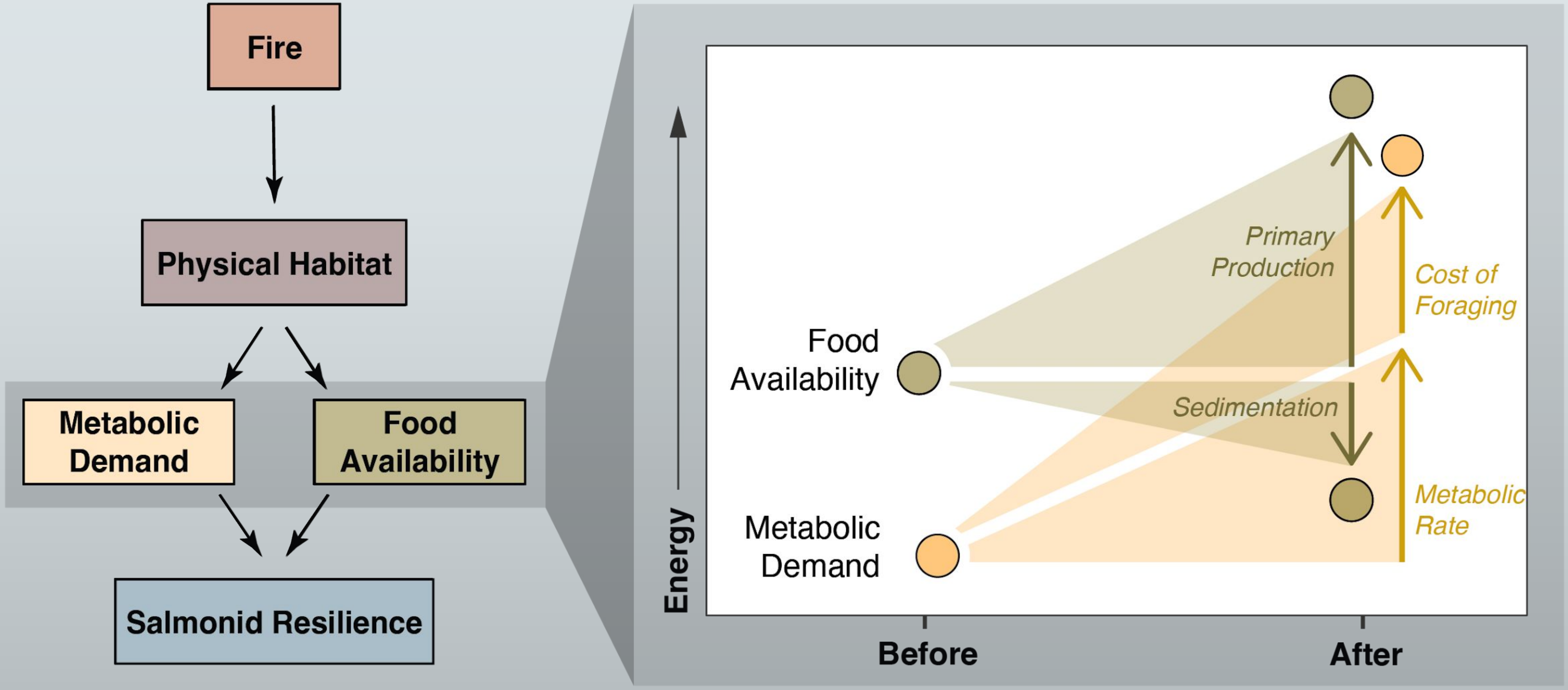
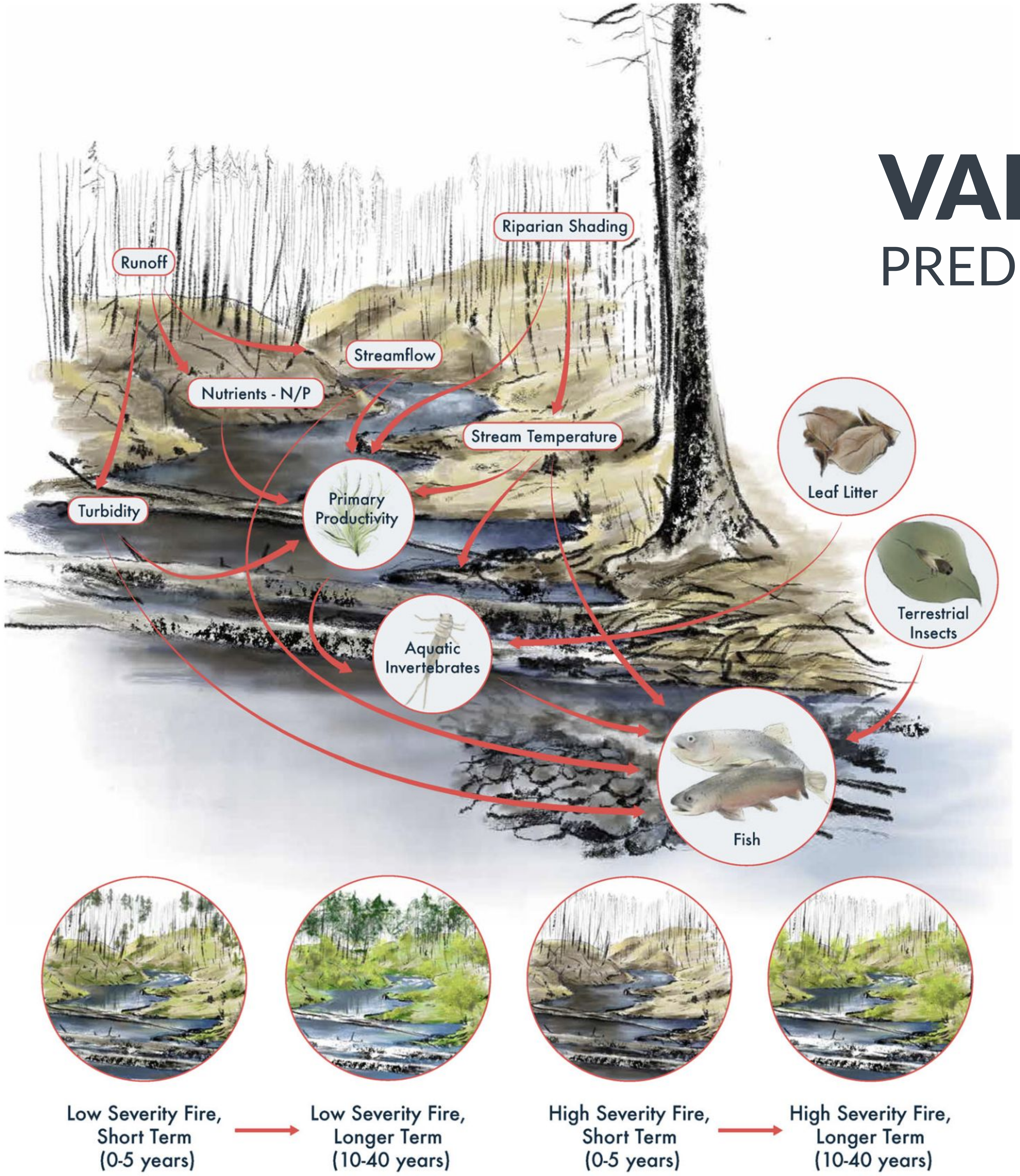




VARIABLE RESPONSES

PREDICTED BY FOOD WEB MODELING

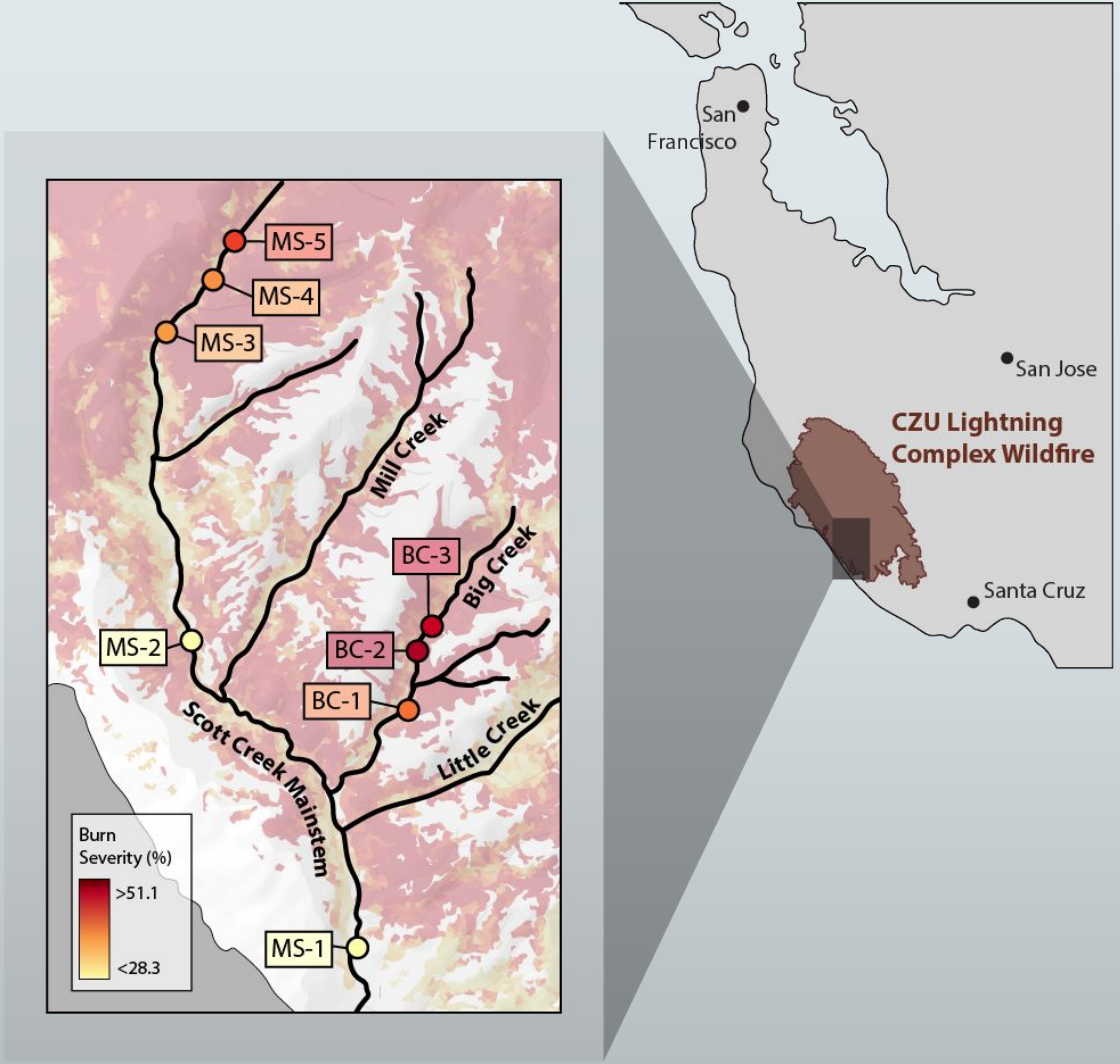
- Aquatic ecosystem response varies in direction, magnitude, and duration
- Dependent on fire severity, time since fire, trophic level
- Key drivers: water temperature, canopy cover, riparian shading, instream turbidity

(Roon et al. 2025)

SCOTT CREEK

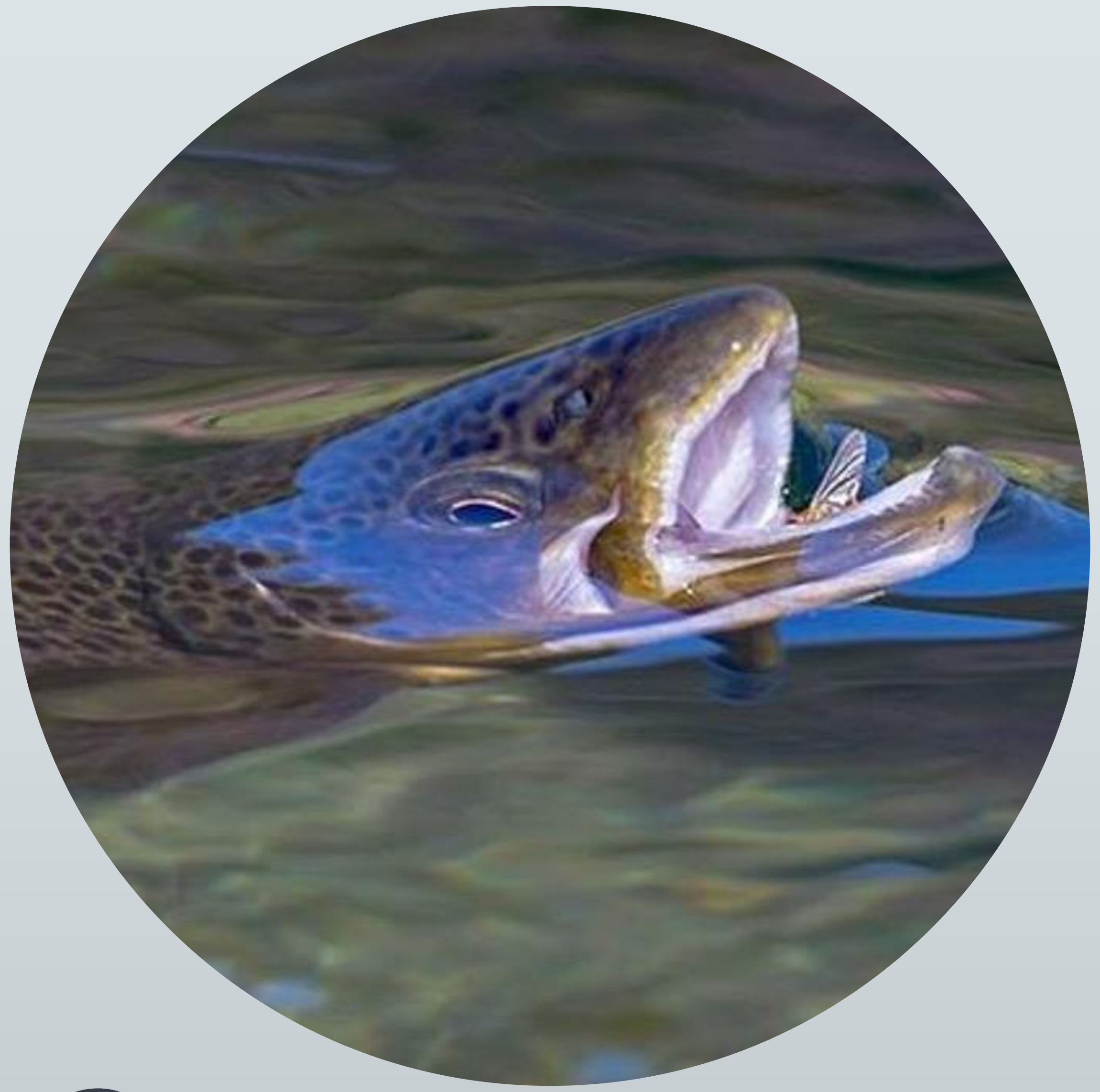
A CASE STUDY FOR APPLYING A FOODSCAPES FRAMEWORK

- CZU Lightning Complex Wildfire (August 2020) burned 86,509 acres across Santa Cruz Mountains
- Substantial heterogeneity in burn severity across landscape
- Provides a natural experiment to quantify the impacts of wildfire on salmonid foodscape



STUDY OBJECTIVES

How does wildfire affect key response variables in a salmonid food web?



1. PHYSICAL HABITAT
2. FOOD AVAILABILITY
3. METABOLIC DEMAND
4. SIZE & ABUNDANCE


2019
2021


2019
2021

STUDY OBJECTIVES

How does wildfire affect key response variables in a salmonid food web?

1. PHYSICAL HABITAT
2. FOOD AVAILABILITY
3. METABOLIC DEMAND
4. SIZE & ABUNDANCE

PHYSICAL HABITAT

RELATIVELY CONSISTENT CHANGES IN PHYSICAL HABITAT VARIABLES AFTER THE FIRE, REGARDLESS OF ESTIMATED BURN SEVERITY

PHYSICAL HABITAT

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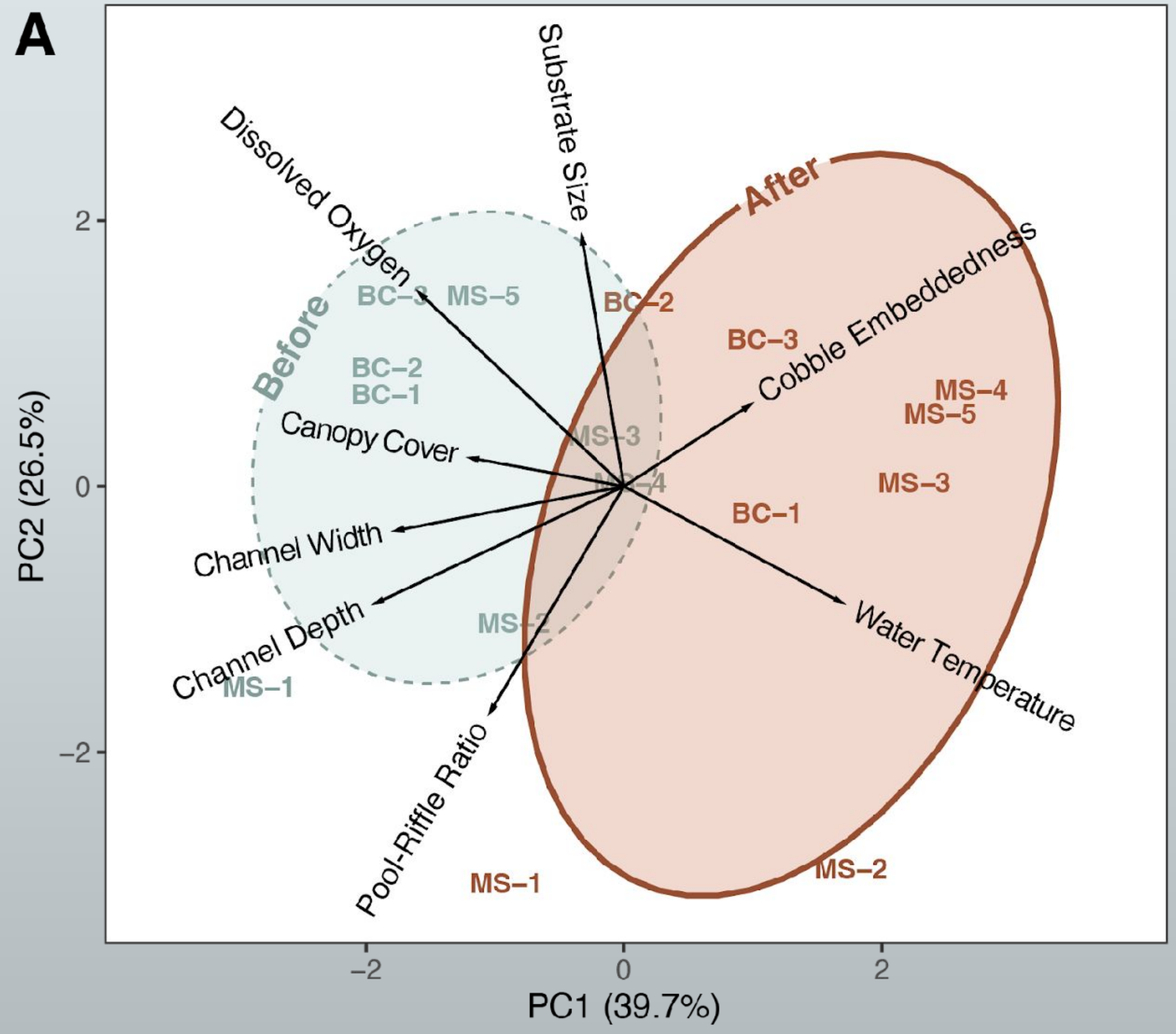

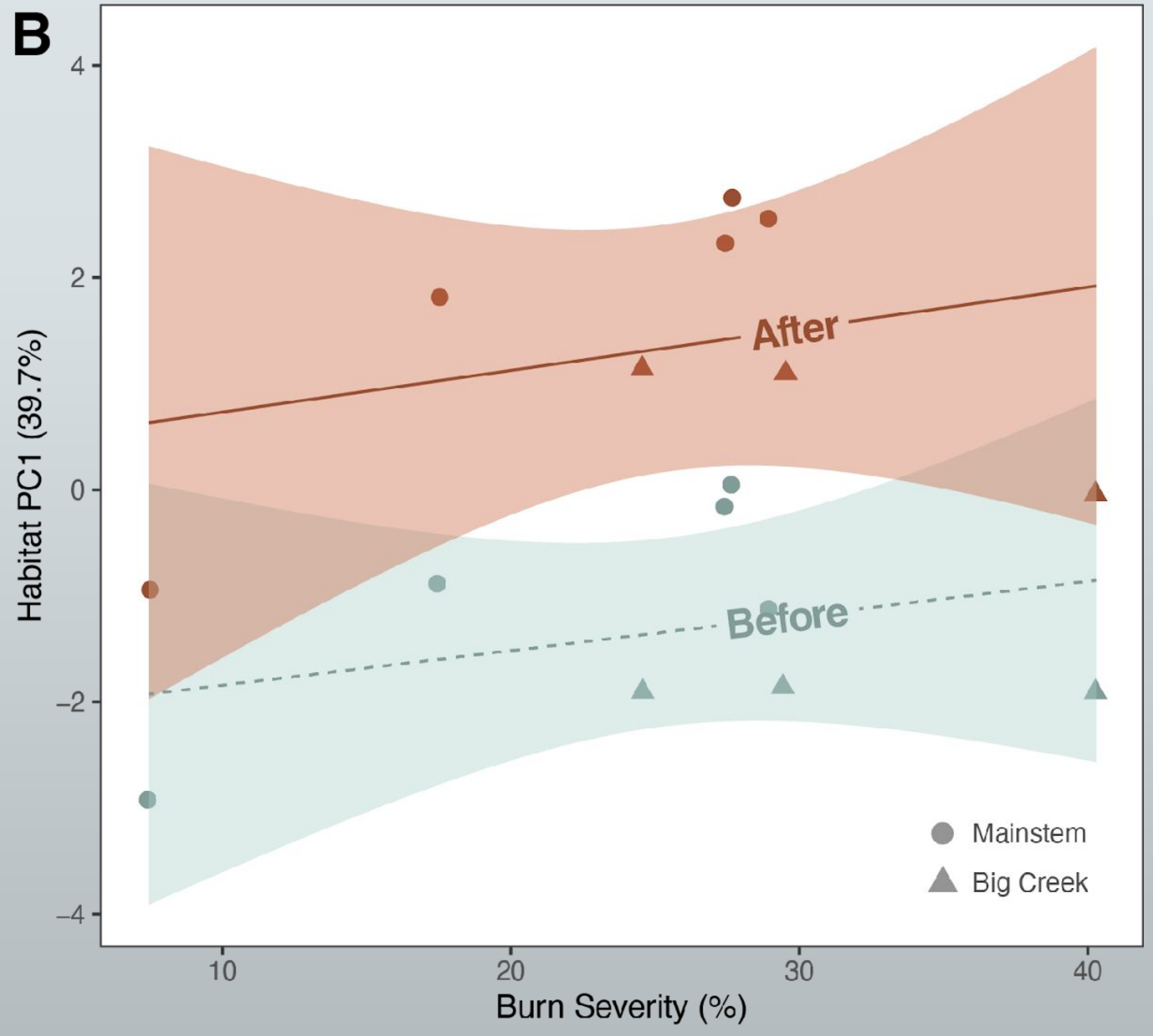

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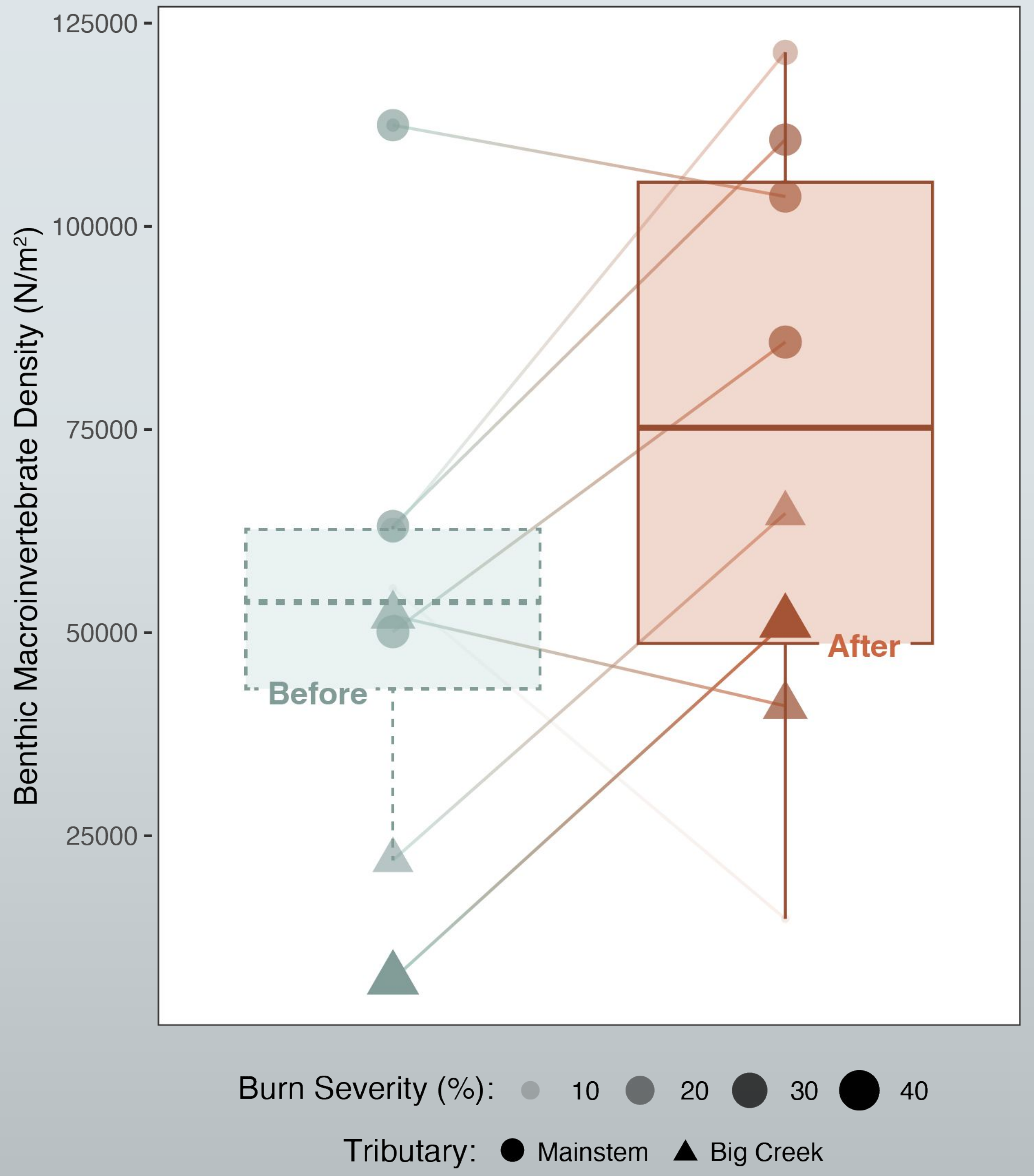
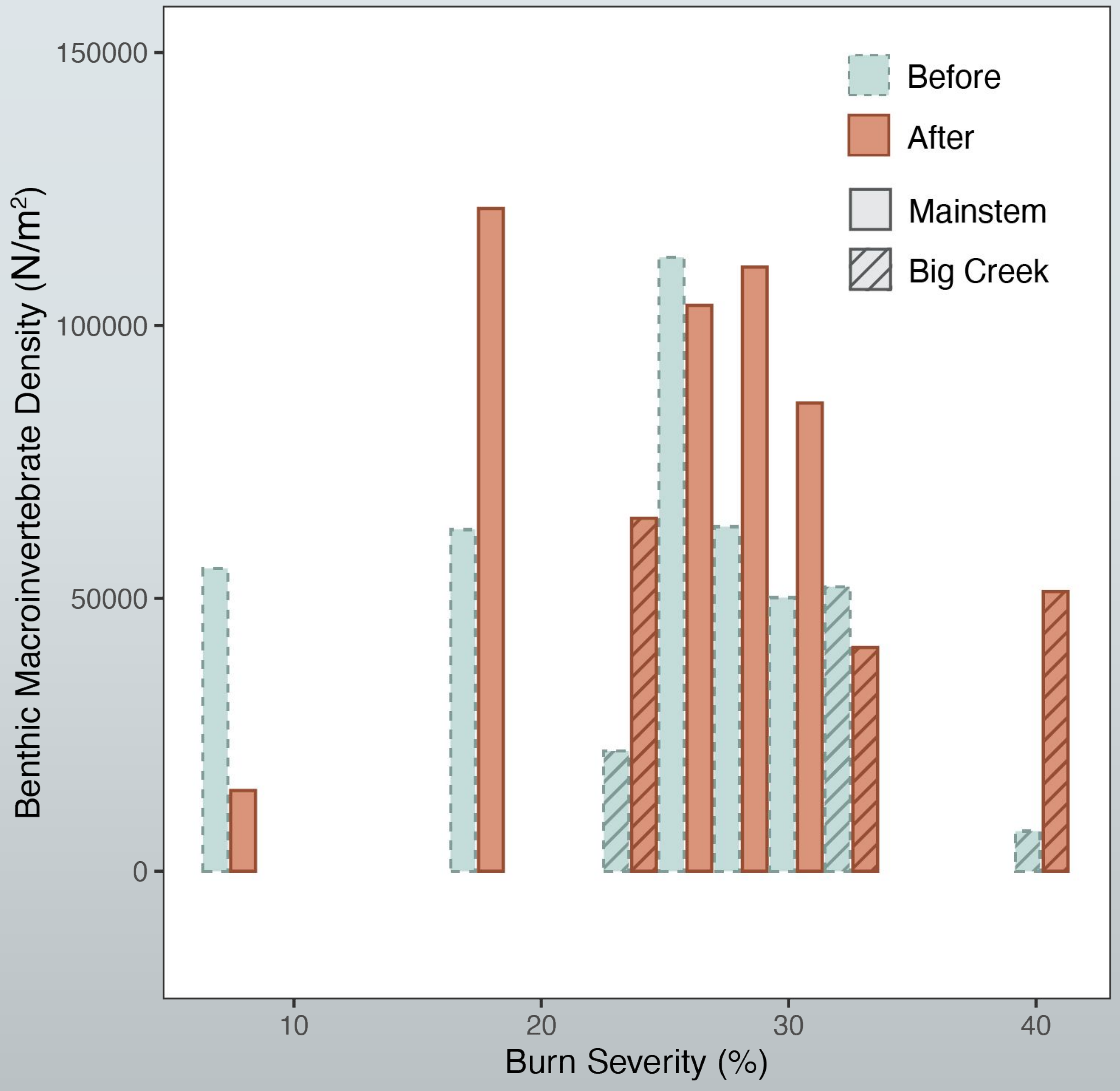
FOOD AVAILABILITY

FOOD AVAILABILITY





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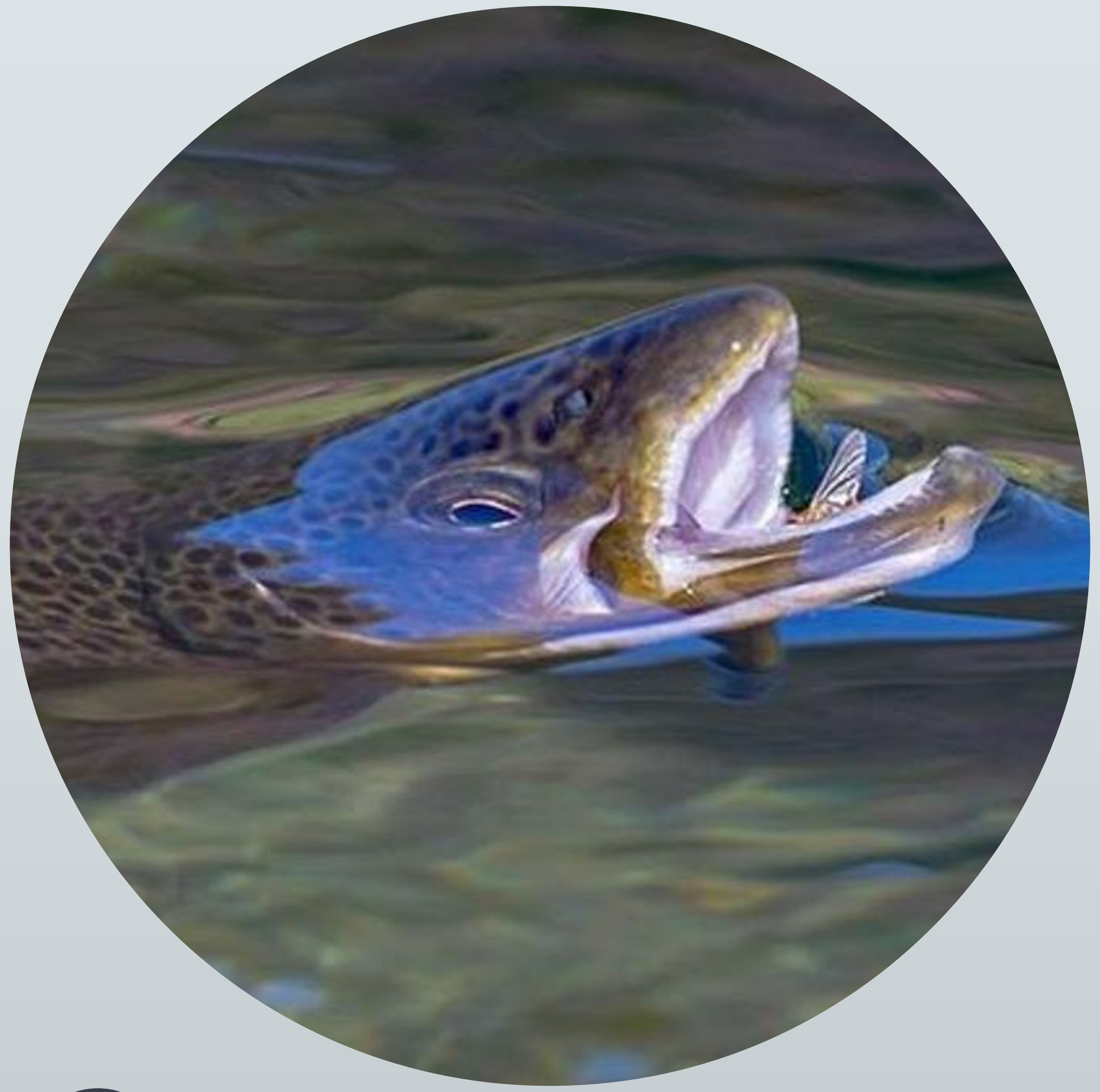
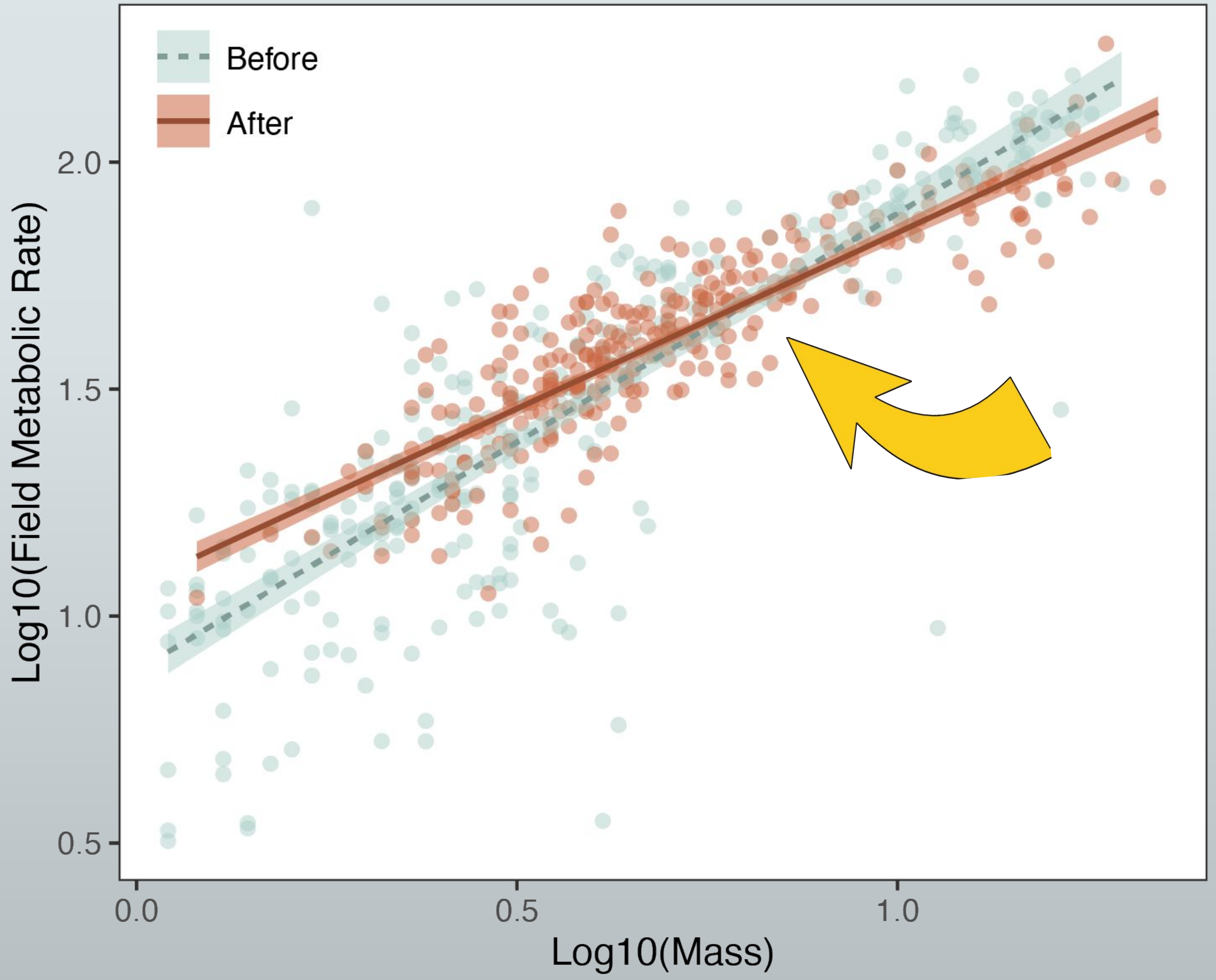


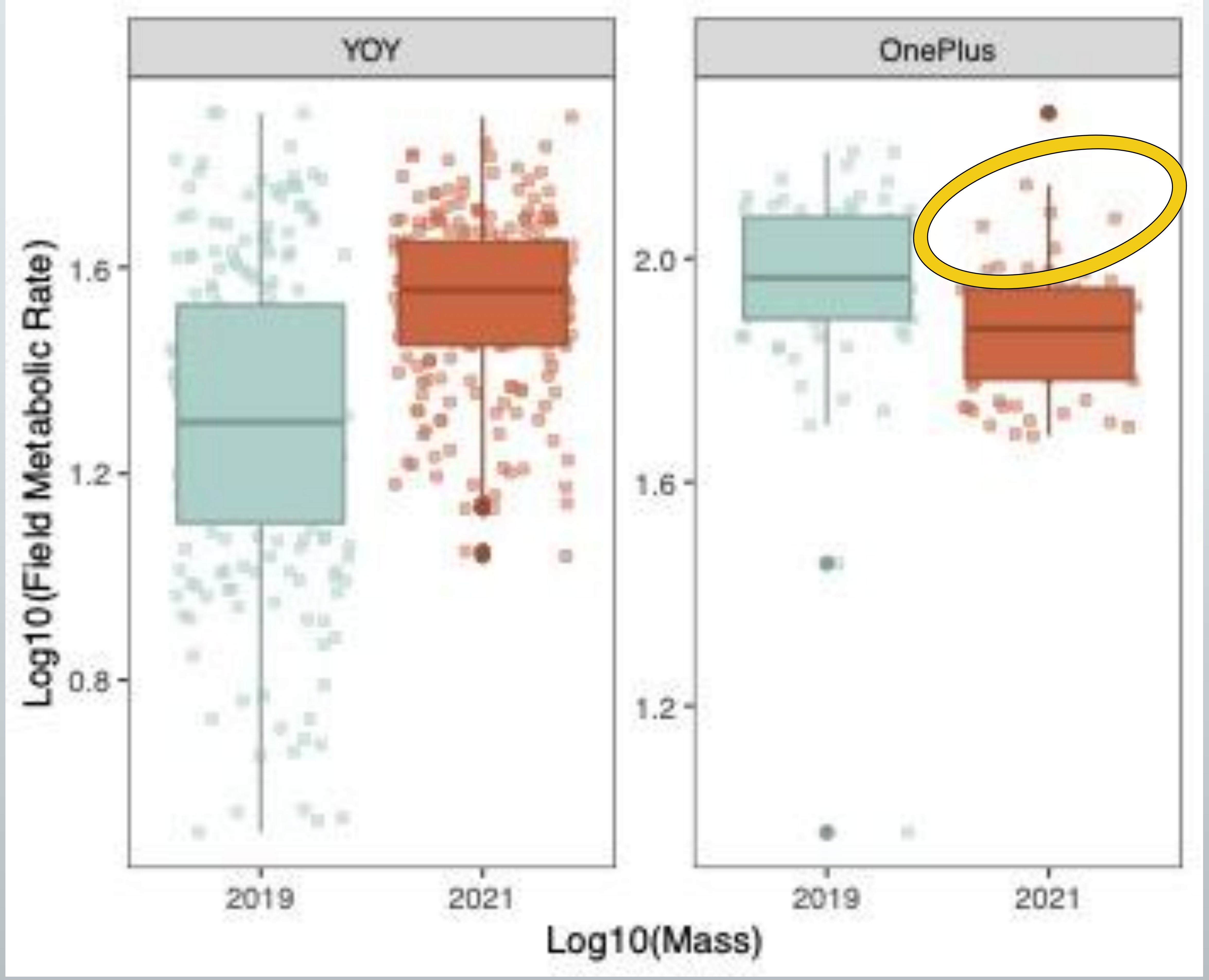
1. PHYSICAL HABITAT
2. FOOD AVAILABILITY
3. METABOLIC DEMAND
4. SIZE & ABUNDANCE


FIELD METABOLIC RATE

SHIFTS IN FIELD METABOLIC RATE

DIFFER AMONG SIZE CLASSES





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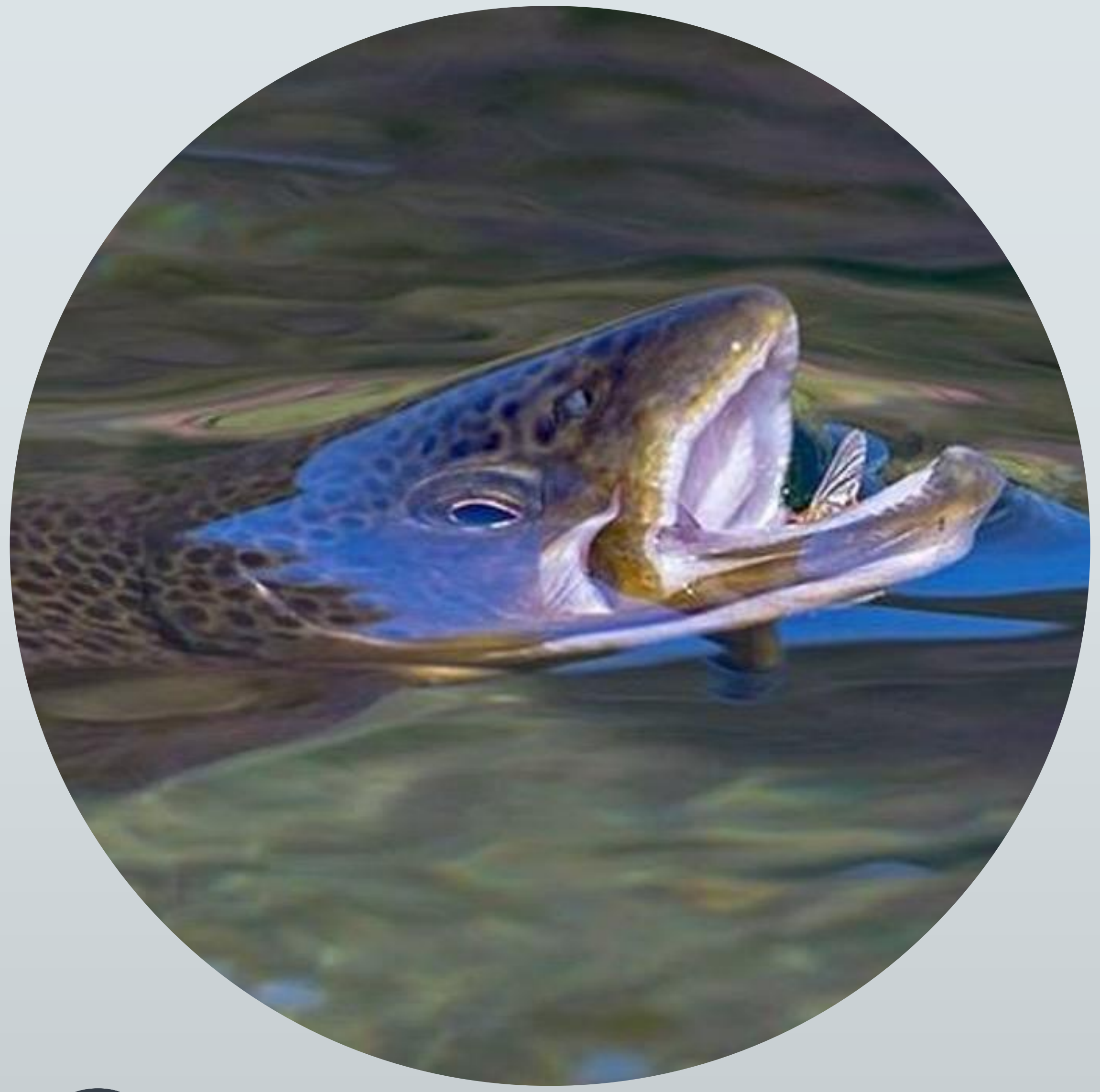
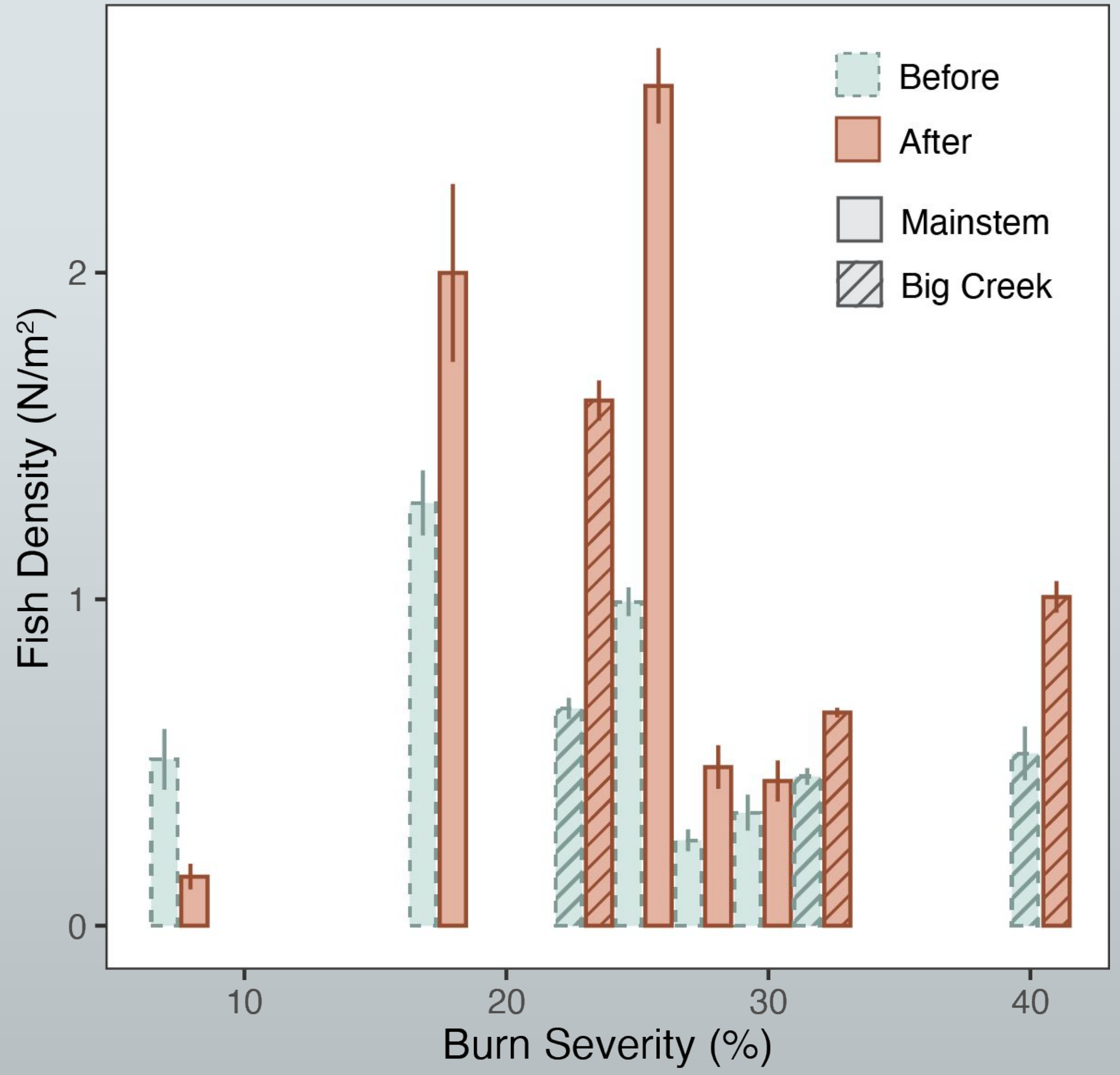


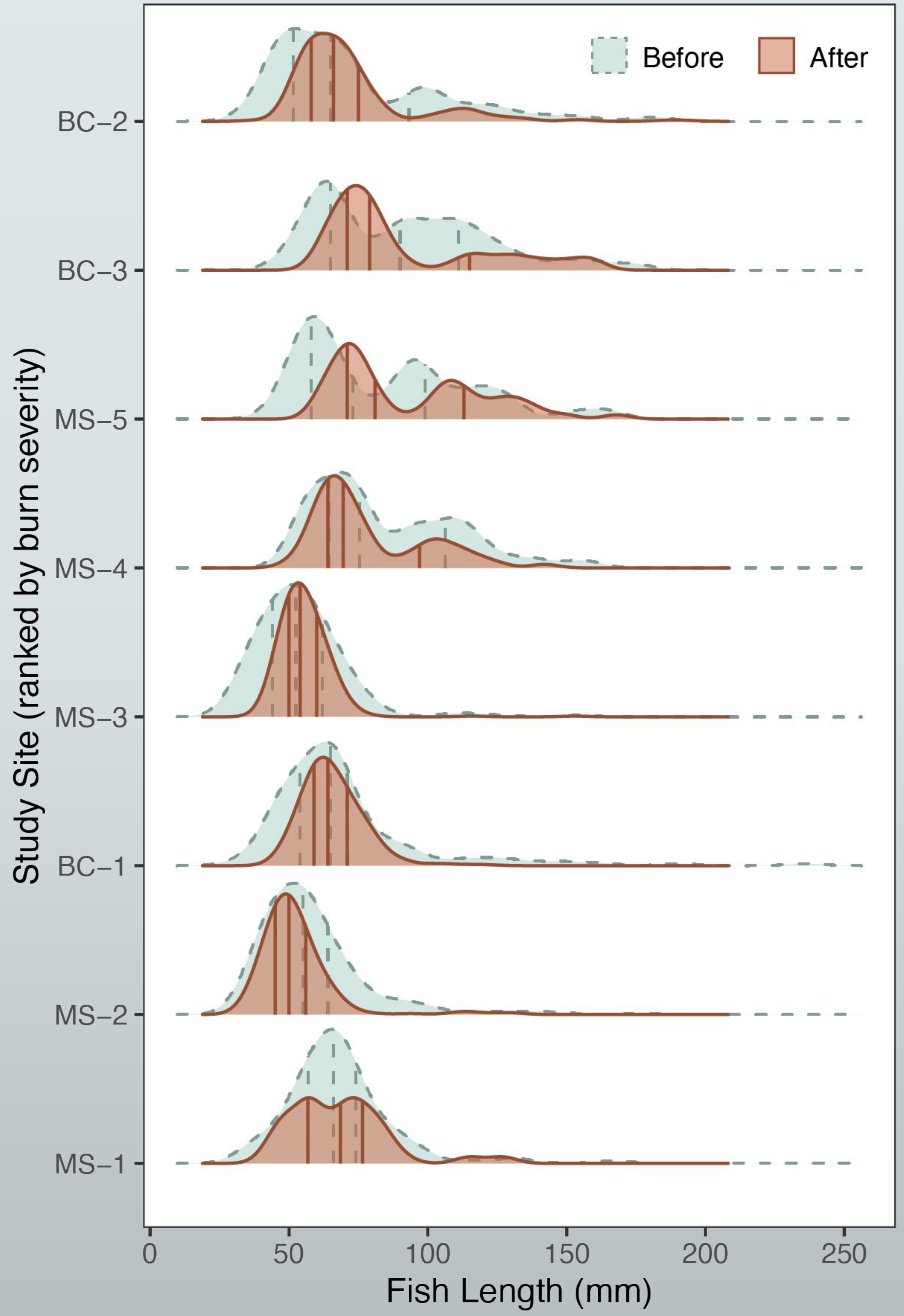
1. PHYSICAL HABITAT
2. FOOD AVAILABILITY
3. METABOLIC DEMAND
4. SIZE & ABUNDANCE

SIZE & ABUNDANCE

SIGNS OF RESILIENCE

SIZE AND DENSITY OF SMALL/YOUNG FISH INCREASED AT NEARLY ALL SITES





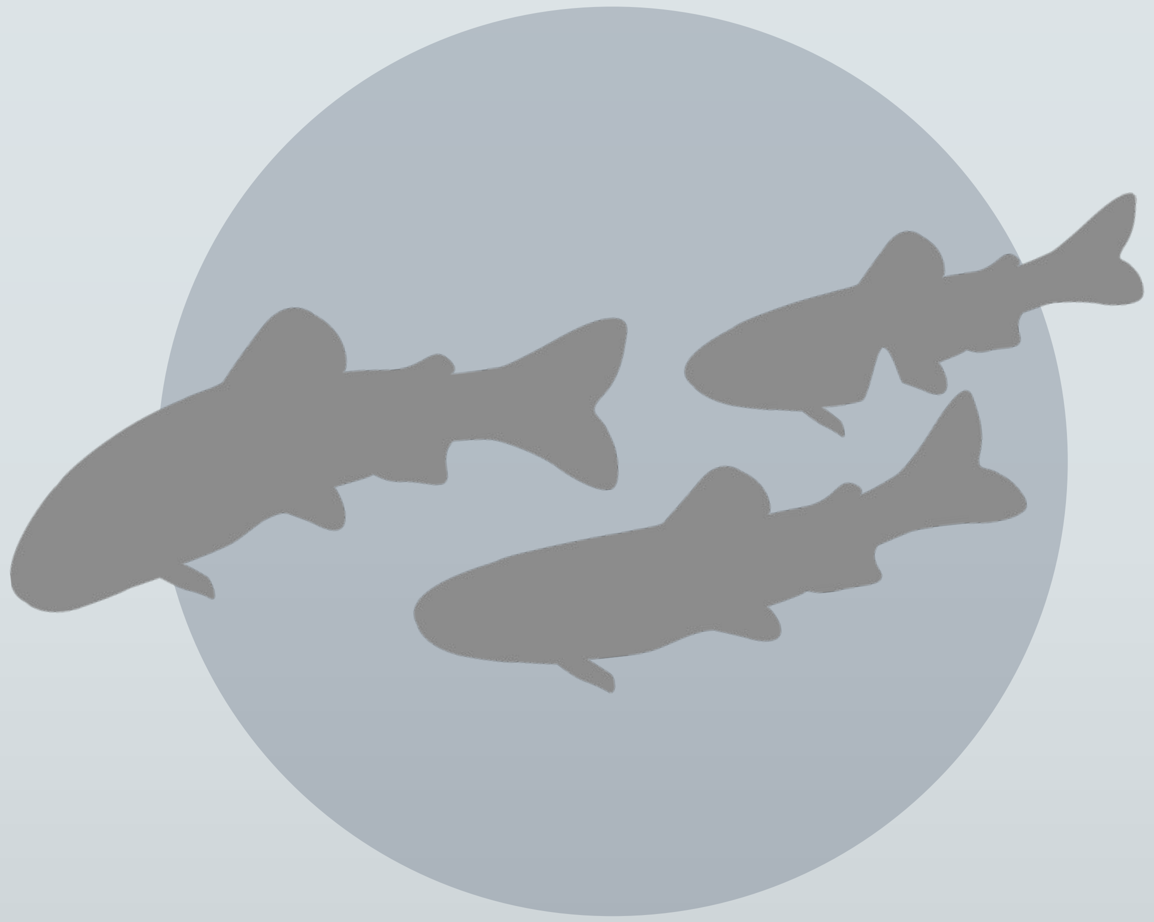
KEY TAKEAWAYS

ASSESSING WILDFIRE IMPACTS FOR COASTAL CALIFORNIA SALMONIDS THROUGH A FOODSCAPES LENS

1. **TROPHIC SUPPLY AND DEMAND**
   AS A FRAMEWORK FOR ASSESSMENT
2. **KEY PHYSICAL VARIABLES:**
   CANOPY COVER, STREAM TEMPERATURE, CHANNEL DEPTH/WIDTH
3. **SIZE-SPECIFIC DIFFERENCES**
   IN FISH RESPONSE VARIABLES
4. **LANDSCAPE-SCALE HETEROGENEITY**
   SUPPORTS POPULATION RESLIENCE

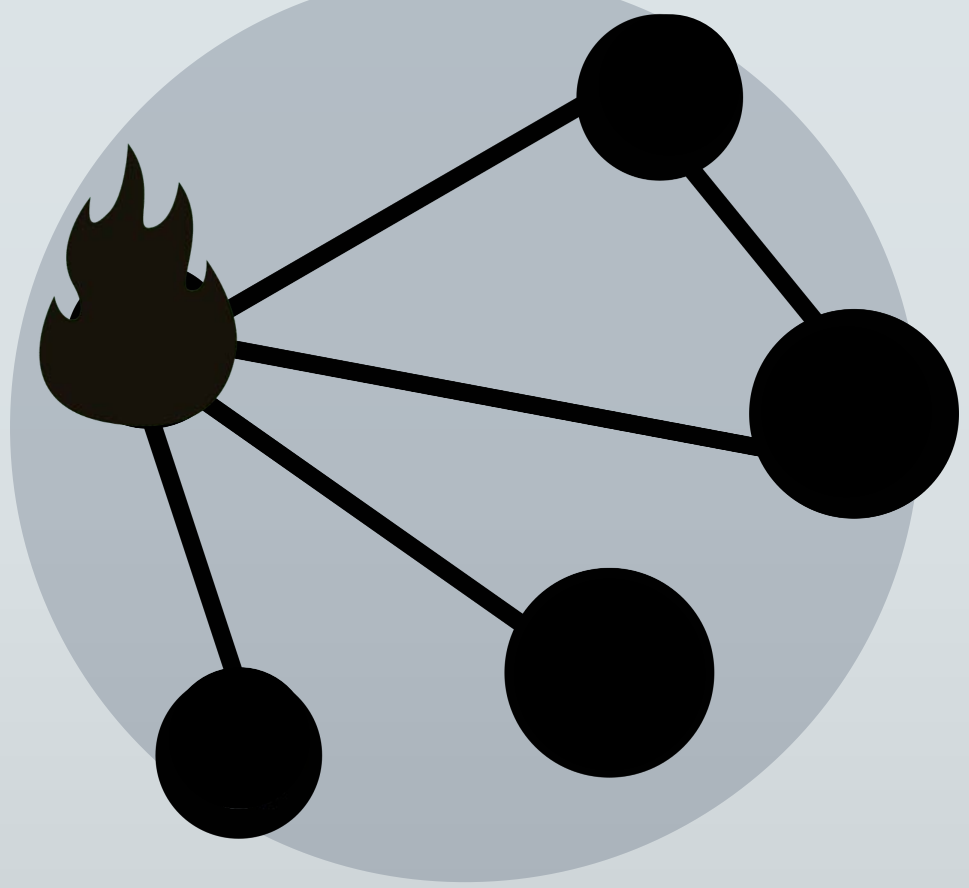
NEXT STEPS

IDENTIFYING AND ASSESSING WILDFIRE IMPACTS FOR COASTAL CALIFORNIA SALMONIDS



LONG-TERM MONITORING: EXPLORE IMMEDIATE RESPONSES AND LONG-TERM RECOVERY

COMMUNITY ANALYSIS: SHIFTS IN SIZE-STRUCTURE AND FUNCTIONAL FEEDING GROUPS



FOOD WEB MODELING: FURTHER EXPLORE LINKAGES AND TESTING PREDICTIONS

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