Gaining insights on responses of freshwater mussels to environmental heterogeneity and on their distribution

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Recent or ongoing projects in Schwalb Stream Ecology Lab

<u>Unionid mussels:</u>
Substrate choice experiments

Impacts of high and low flow on mussel distribution

Ammonia toxicity of several Central and East Texas mussels

<u>Zebra mussels:</u>
Thermal limitations of zebra mussels

Interaction between zebra mussels and Hydrilla

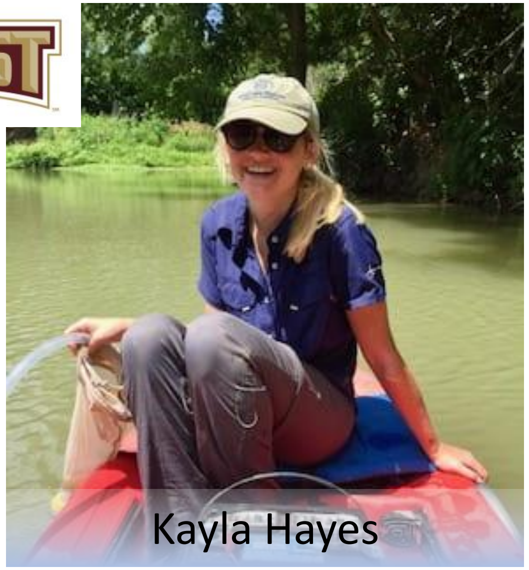
<u>Macroinvertebrates:</u>
Responses to drying and re-wetting

Seven Samurai tackling factors driving the distribution of mussels since 2017


Meghan Martinski


Kiara Cushway

TXST


Kayla Hayes


Zachary Mitchell

Seven Samurai by Akira Kurosawa

Josh Perkin

ATM


Karl Cottenie

UNIVERSITY of GUELPH


Mariana Perez Rocha

Texas Research Institute for Aquatic and Groundwater Ecology

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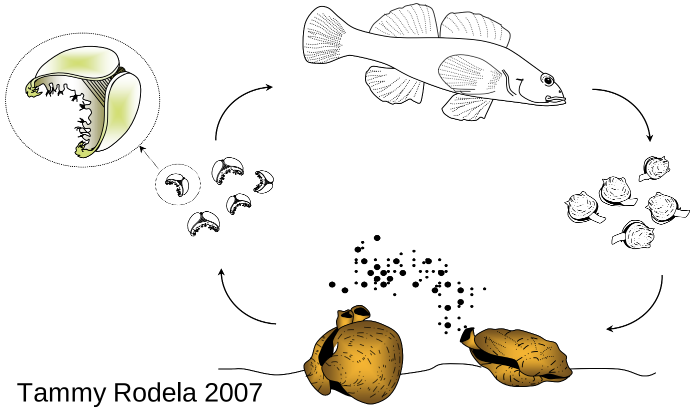
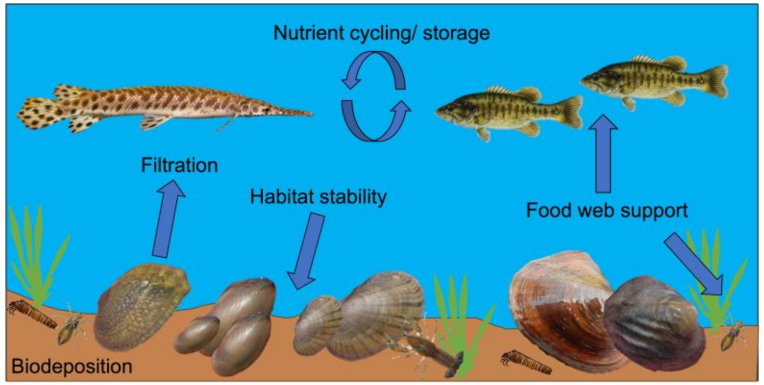


Tammy Rodela 2007

Freshwater Mussels



Adapted from Kreeger et al. 2018

<u>Unionid mussels 101:</u>

Unique life history, rely on host fish for reproduction and dispersal

Provide important ecosystem services

Highly imperiled, many species have experienced declines

<u>Goldilocks in respect to flow,</u>

Impacts of droughts: community wide-declines

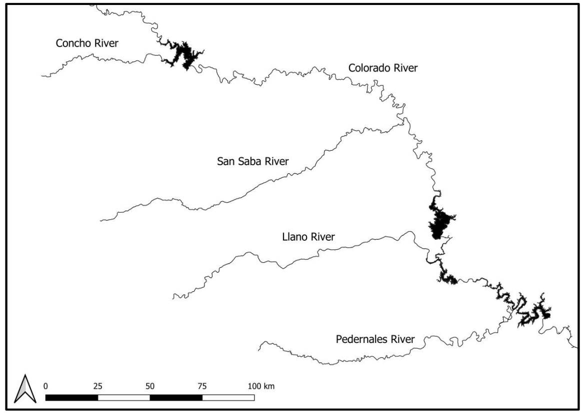
Impact of flooding: Dislodgement,

detrimental especially in combination with habitat degradation

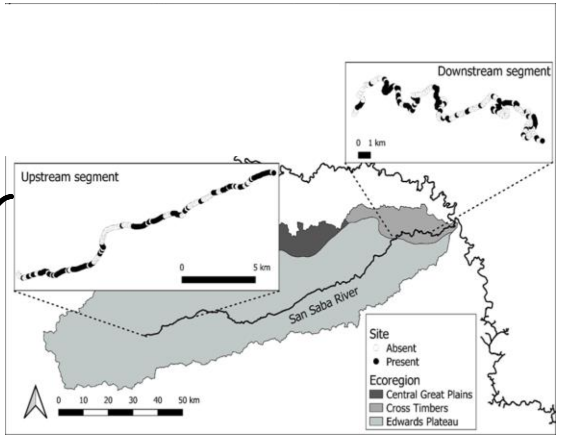
→ Higher risk of being transported into unsuitable habitat.

Testing responses to environmental heterogeneity at multiple spatial scales

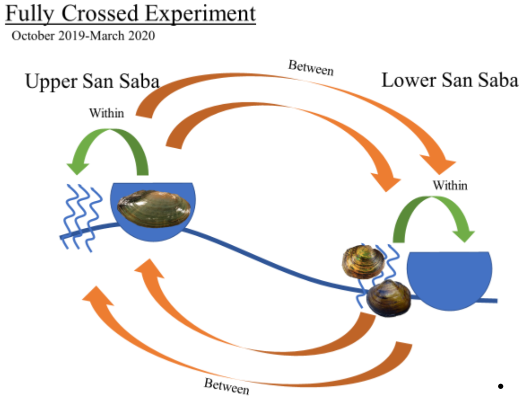
Observational data
Experiments
Modeling

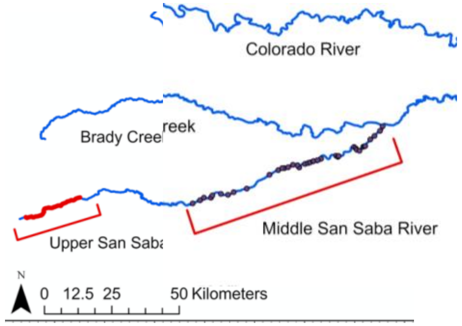


Sub-basin scale:
Nested sampling design
Impact of exceptional drought



River (tributary) scale:
Fine-scale distribution data
Trait and species responses



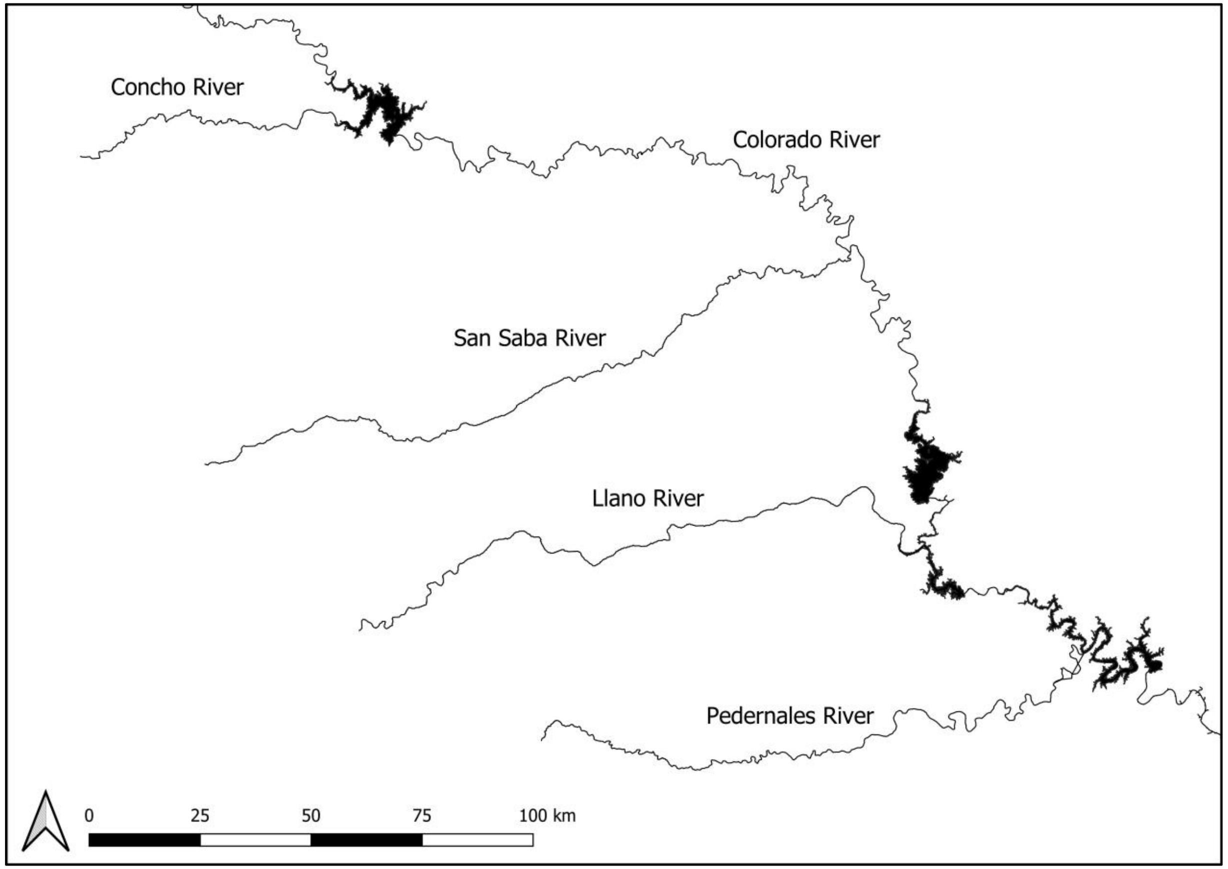


Segment-scale:
HEC-RAS model
Drought refuge

Tributary to mesohabitat:
Translocation experiments

Meso- and microhabitat scale
Substrate choice experiments

Study area: Upper Colorado River, Texas



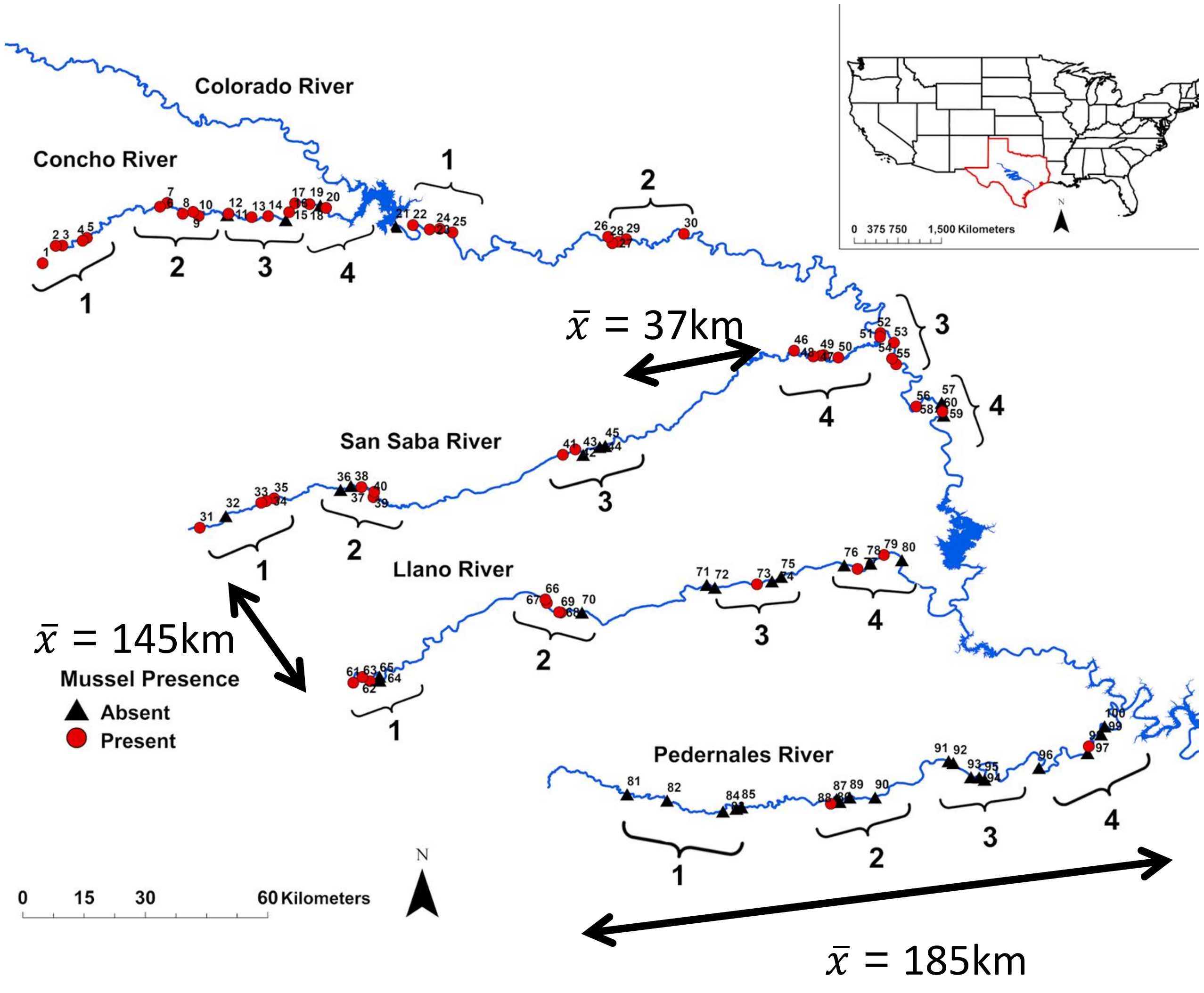
Texas Hill country
Limestone and karst

Mostly semi-arid ranchland.

Flow regime characterized by extended periods of extreme low flow and flash floods,

Major threats: Extreme droughts and groundwater extraction

Nested design at sub-basin scale



Sampling of mussels and fish at 100 pool/riffle sites:

4 tributaries + 1 mainstem

4 sections per river

5 sites per section, $\bar{x}$ = 4.4km apart

Riffle + pool per site

Across 6 ecoregions

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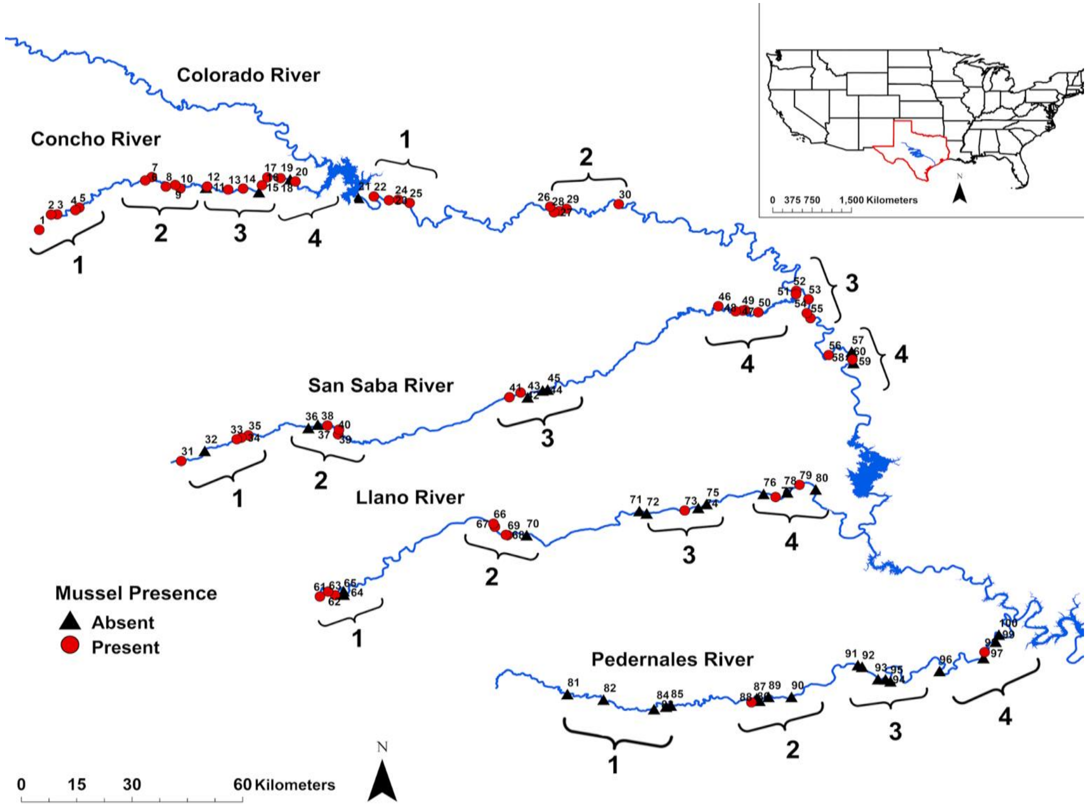
Richness and abundance

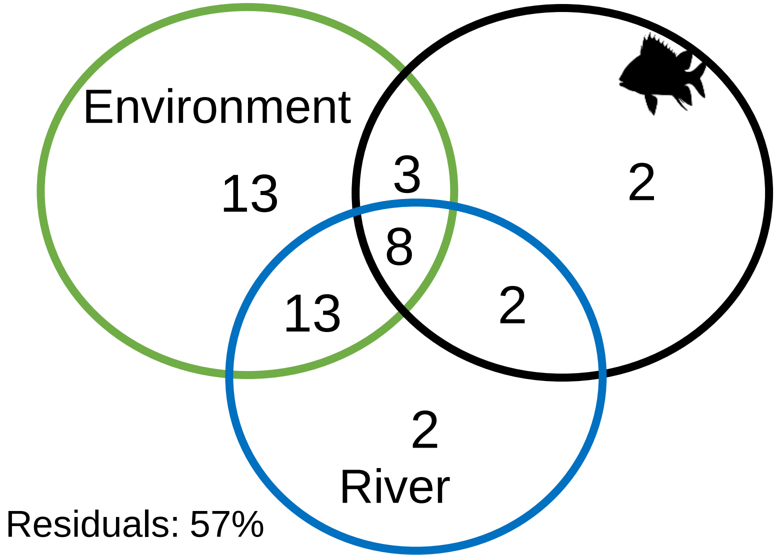


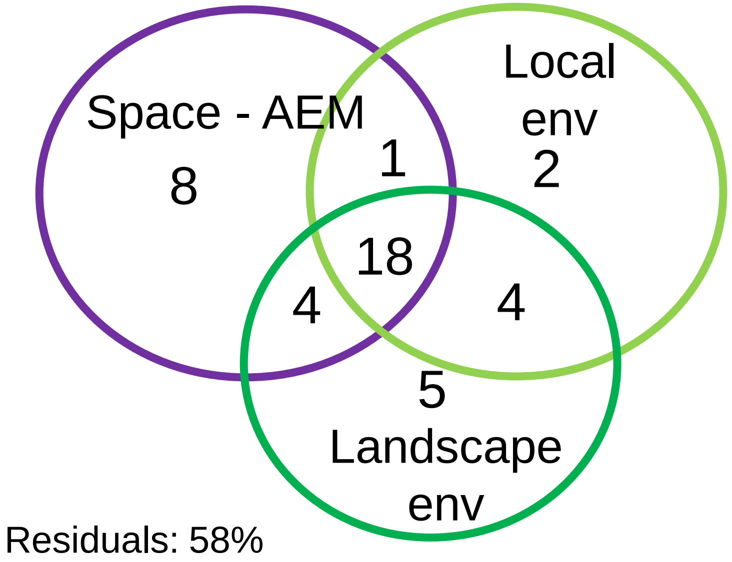
River	Richness	No of sites occupied	Average CPUE (p-h)
San Saba	12	14/20	4.3
Colorado	11	17/20	6.8
Llano	7	11/20	3.7
Concho	5	17/20	0.7
Pedernales	3	2/18	0.1

Concho: low richness and abundance, although historically highest richness

→ Depauperate mussel communities

Sub-basin scale

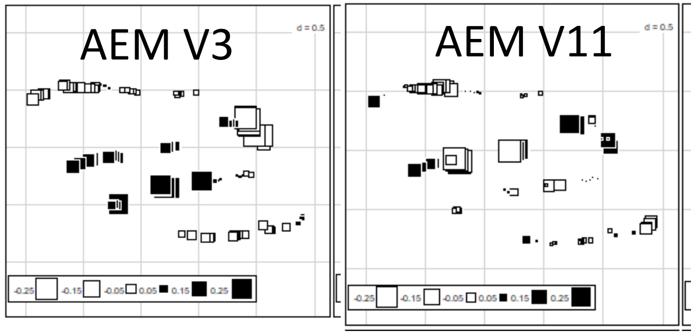




Environmental heterogeneity (landscape + local) best explanatory factors for community composition

Spatially structured, largely between rivers,
Also within rivers

11 significant AEM vectors (V3,V5,V1,V2,V6,V7,V11, V12,V34,V59,V89)



Differences between rivers also associated with variation in fish

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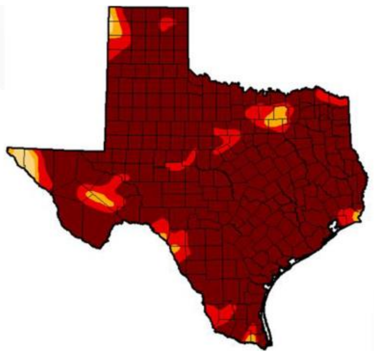
Significant environmental factors

Local:
Temperature,
Flow
DO, conductivity,
Chla, nutrients,
Aquatic vegetation coverage (%)

Landscape:
Mean precipitation (2001-2020),
Flow accumulation, elevation 10m,
network area (km), fragmentation,
Riparian buffer plant community
Watershed plant community

Texas 2011
Exceptional drought



Further exploration of:
Climate: impact of drought + drought refuges
Flow and elevation with HEC-RAS model

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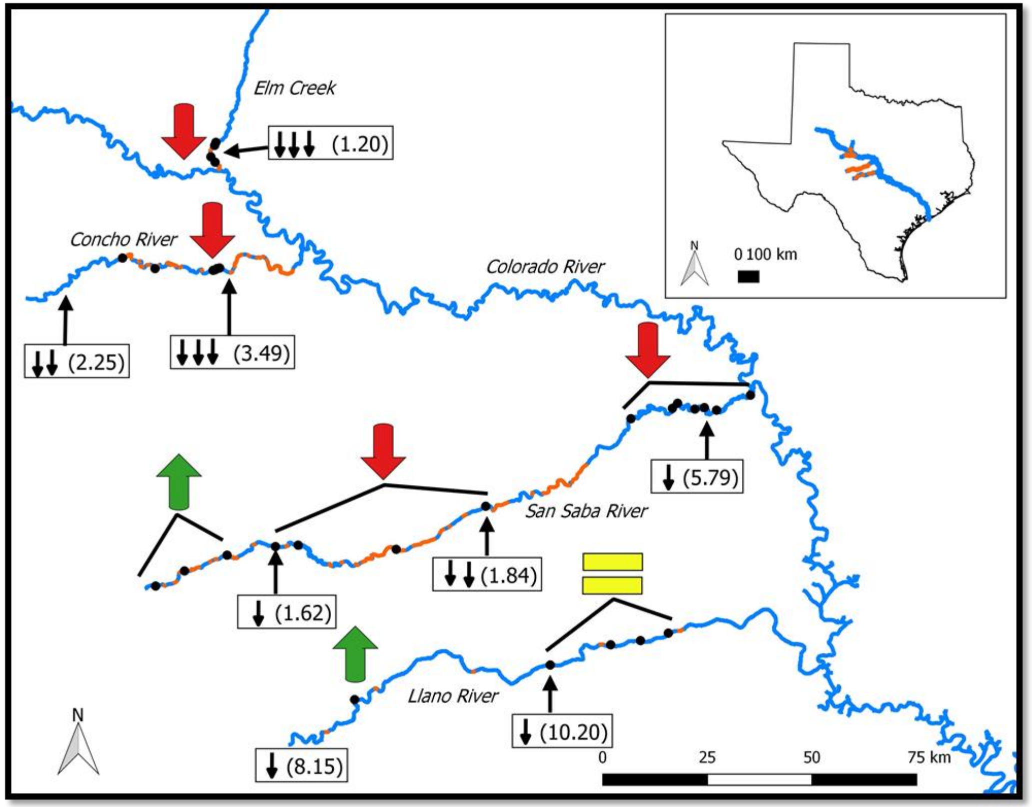
Community-wide declines after drought



Mussels absent at 9 out of 30 sites post-drought (2017)

Species richness and CPUE significantly lower (50-64%) post-drought.

Most severe declines in tributaries with the lowest discharge and highest estimated temperature (Concho +Elm)

Decrease in discharge:

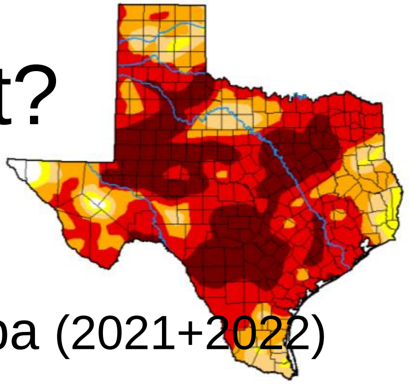
> 87%

82-86%

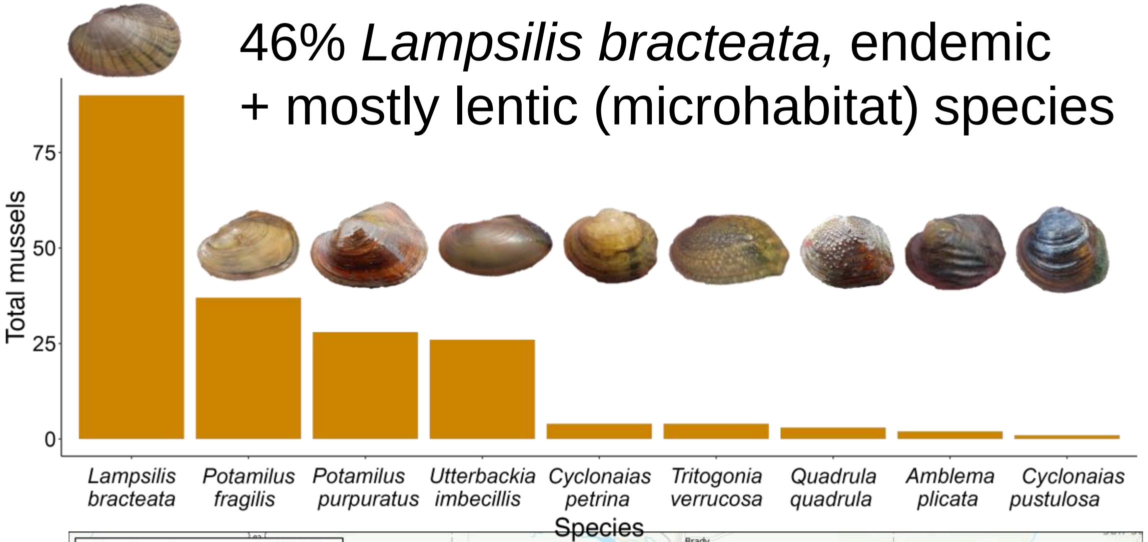
77-81%

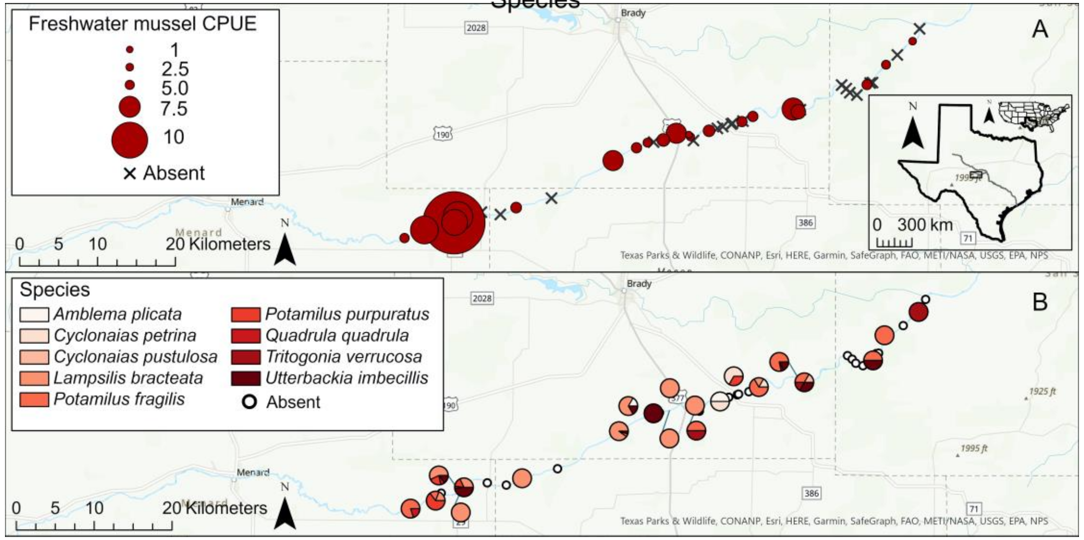
Mitchell et al. 2019

Pools as ecological refuges during drought?



46% *Lampsilis bracteata,* endemic
+ mostly lentic (microhabitat) species





41 pools sampled in middle San Saba (2021+2022)
Mussels in 21 perennial pools
→ may serve as important refuge in intermittent segment.

Relevant factors for abundance and richness: Pool size, temperature, aquatic and riparian vegetation, and underlying geology.

Very low abundances (195 mussels total)

Ecological refuges will not prevent a large decline of mussel populations during droughts

Cushway 2022

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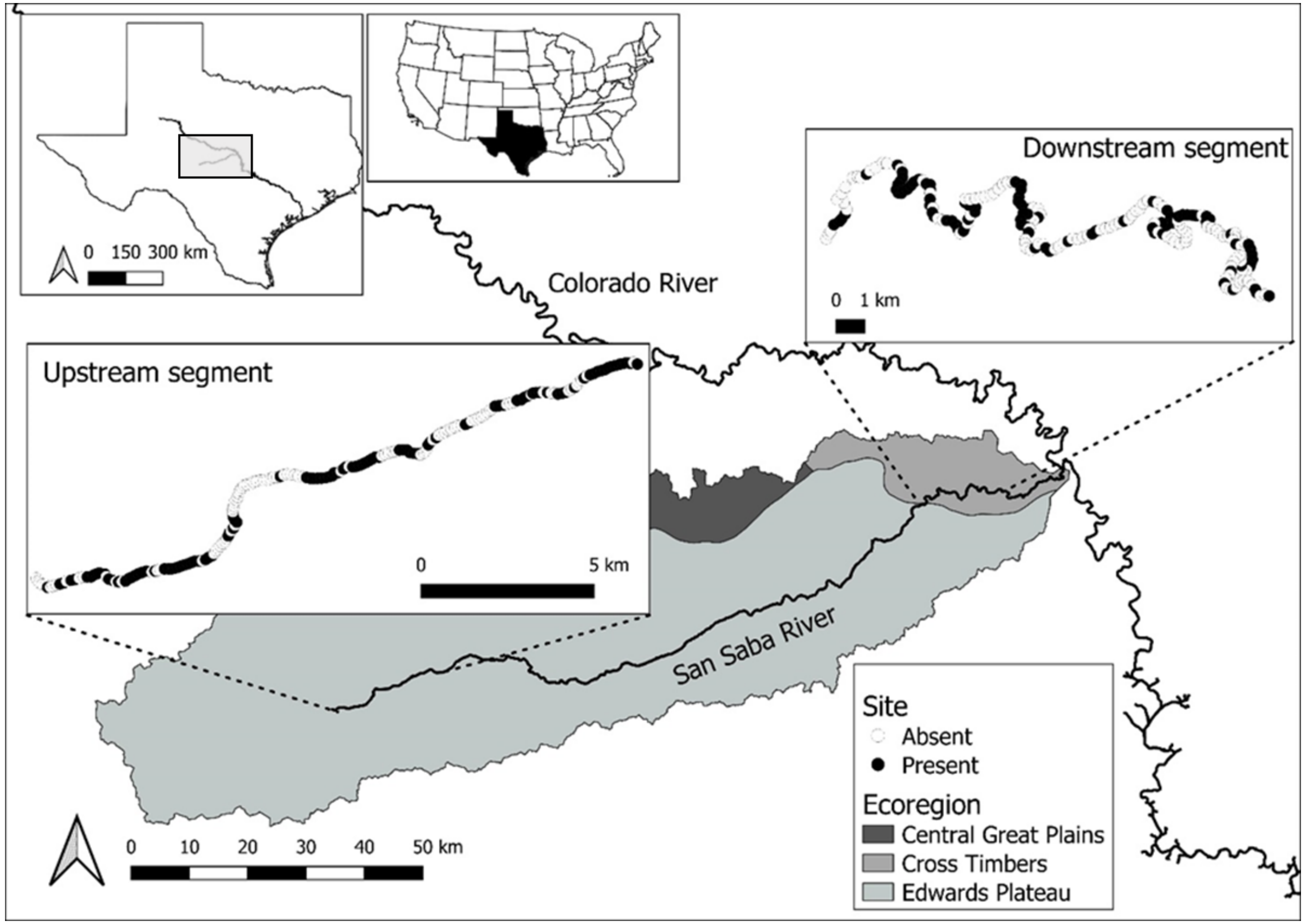
River-scale

Spatially extensive and fine-scale surveys in upper and lower San Saba:

Tactile timed searches (0.5 p-H)
every 100 m
within each 20 km segment
(summer 2018)

→ 200 sites per segment

→ 400 sites total

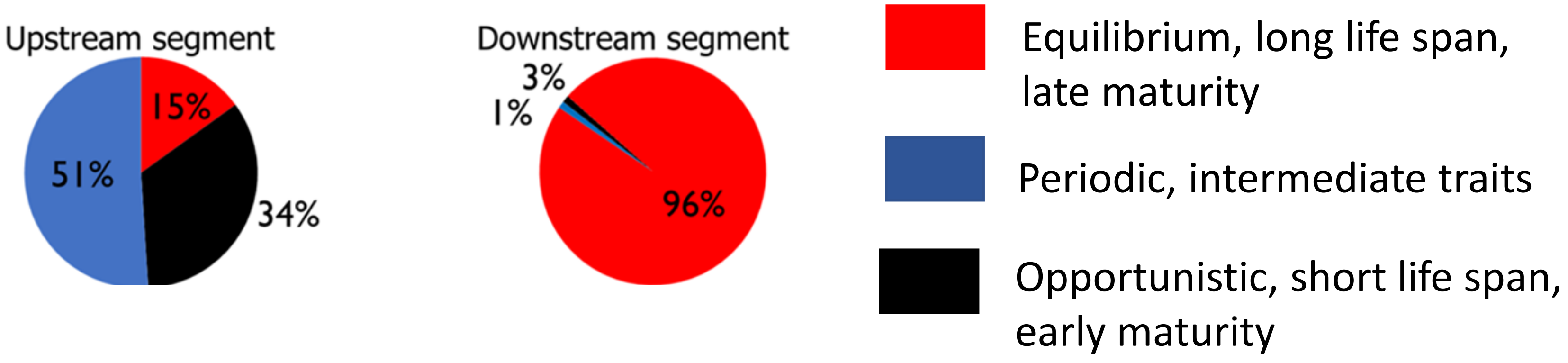


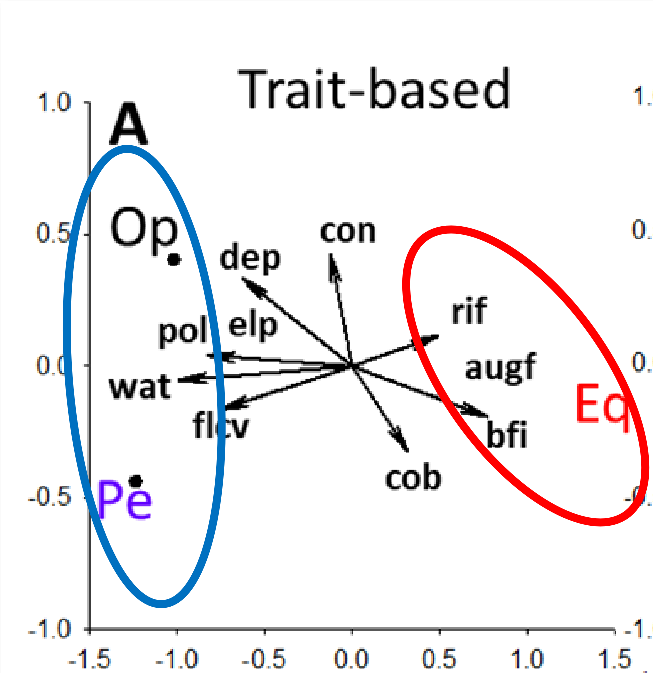
Mitchell et al. (accepted) Ecosphere

River-scale: Community structure

River scale: Distinct communities in upper vs. lower segment.

→ Different ecoregion, flow regime, substrate





Segment scale:
Equilibrium species mostly in riffles
Periodic and opportunistic primarily in pools

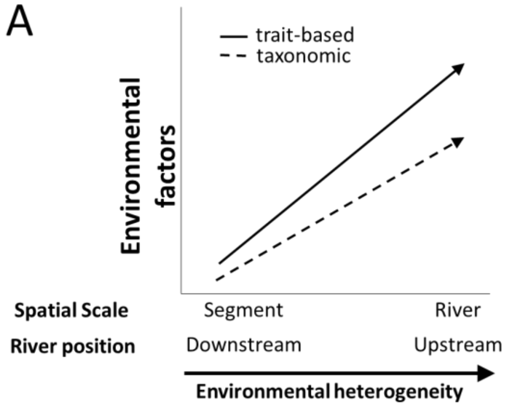
Mitchell et al. (accepted) Ecosphere

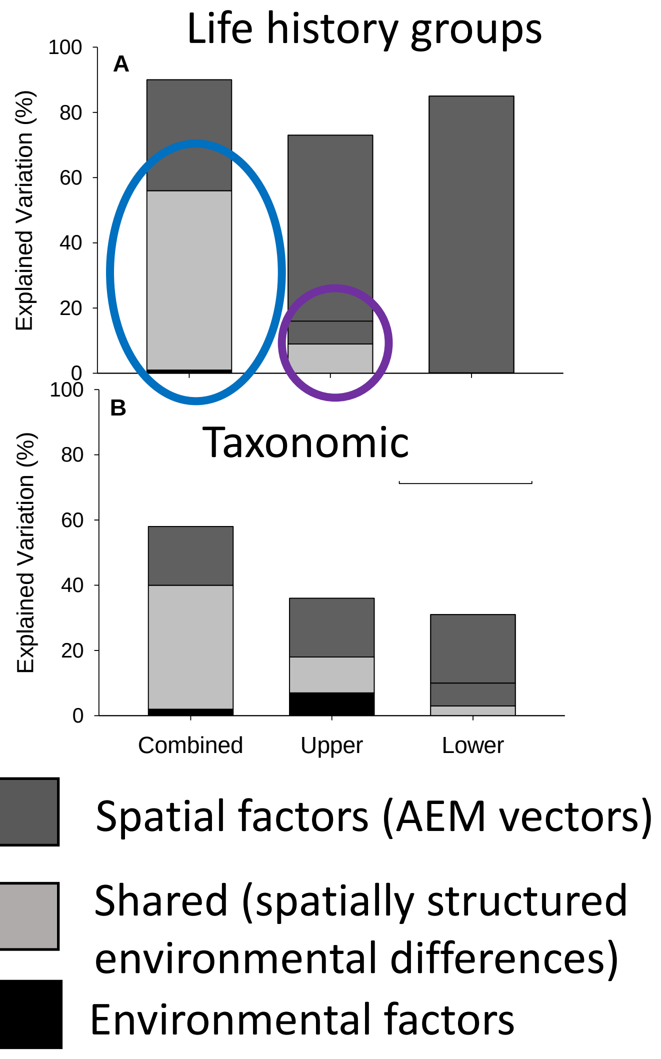
River-scale: environmental heterogeneity, life history and taxonomic level

Variation explained by environmental factors + Environmental heterogeneity

→ Between segments > within segment

→ Upper segment > Lower segment





Environmental heterogeneity = main driver for distribution for life history + taxonomic levels.

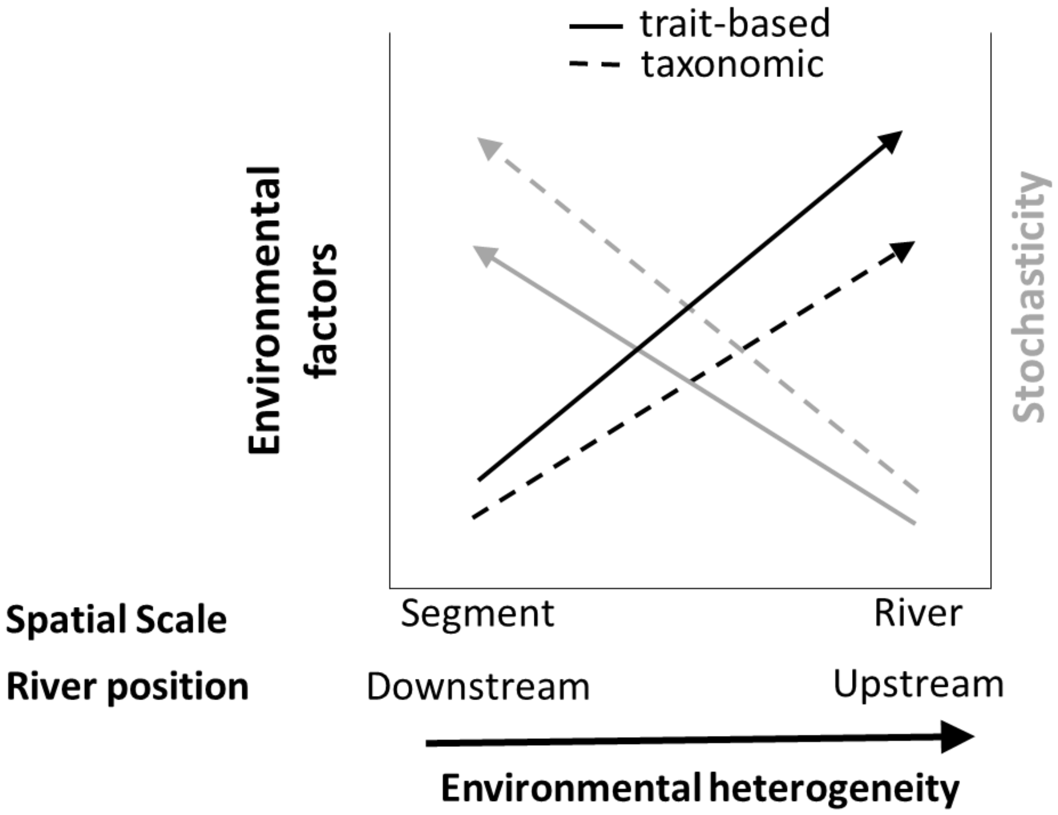
most noticeable for life history groups.

Mitchell et al. (accepted) Ecosphere

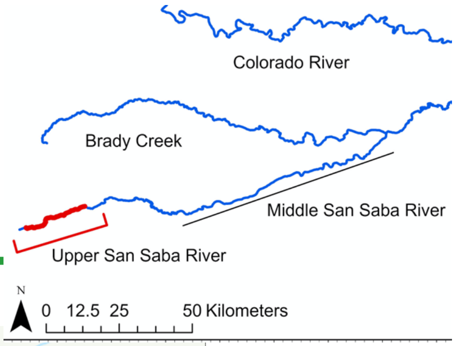
River-scale: Stochasticity

Usual assumption: Strong spatial effects caused by dispersal limitation or mass effects.

Pure spatial factors may also detect patterns created by stochastic processes
(e.g., stochasticity of recruitment and demographic events).



Mitchell et al. (accepted) Ecosphere



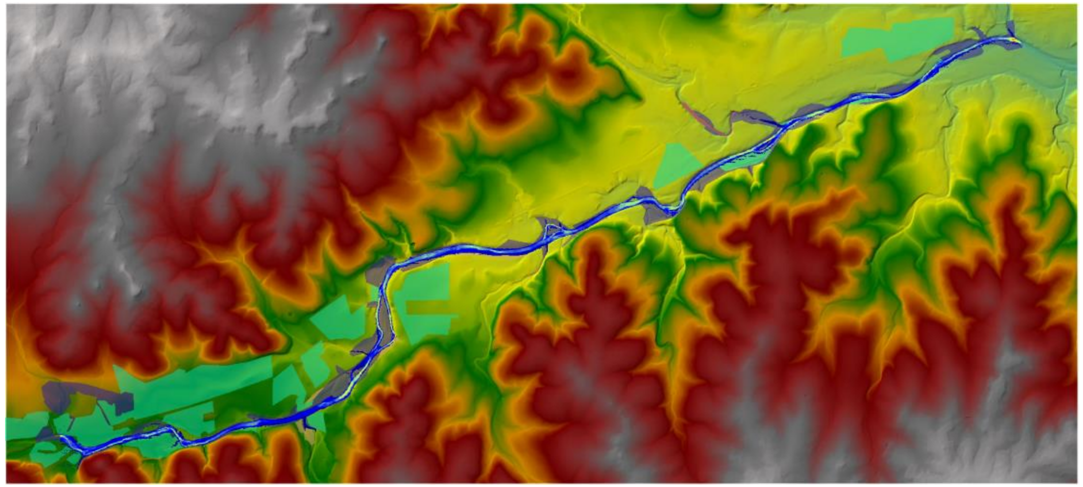
Segment scale – importance of high and low flows

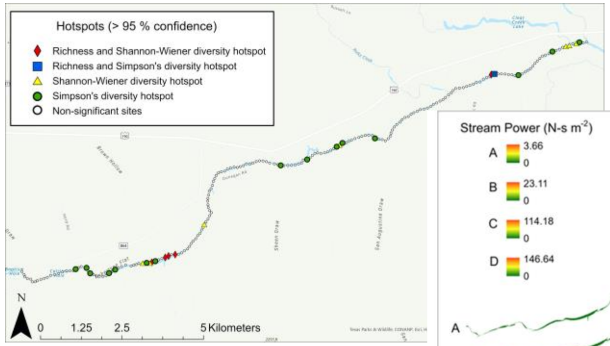
HEC-RAS model for upper segment,

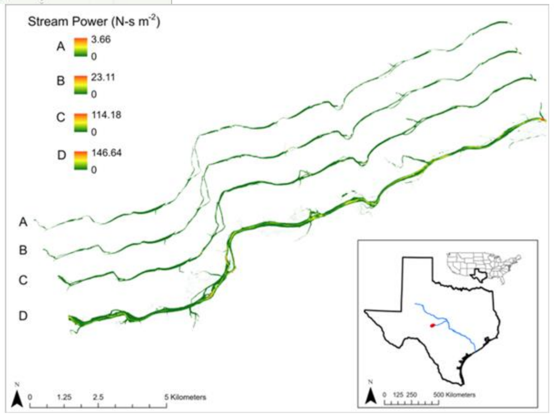
High and low flows

Complex hydraulic variables

→ Kiara’s talk







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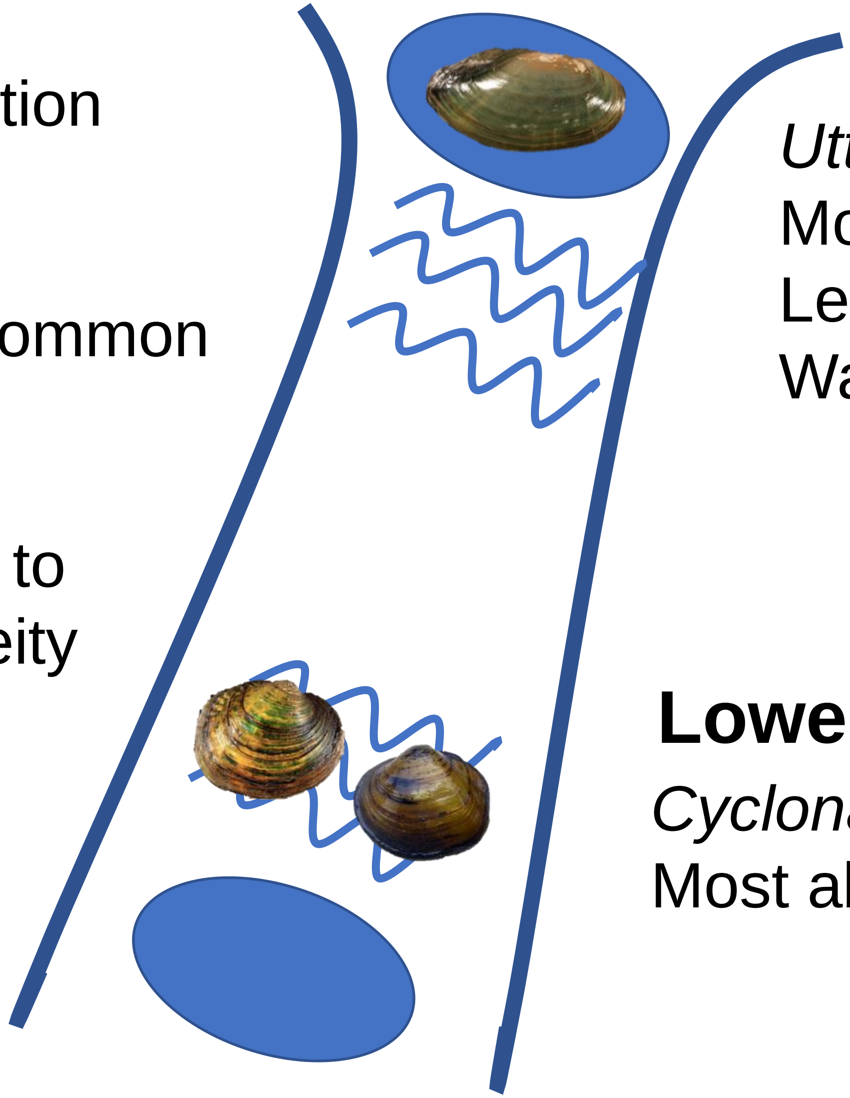
Experimentally testing responses to environmental heterogeneity

Species used in translocation experiment (2018-2020):

The most abundant and common species

Are differential responses to environmental heterogeneity driving these pattens?



Upper San Saba River

Utterbackia imbecillis

Most abundant in upper pools

Lentic species (Haag and Warren 2010)

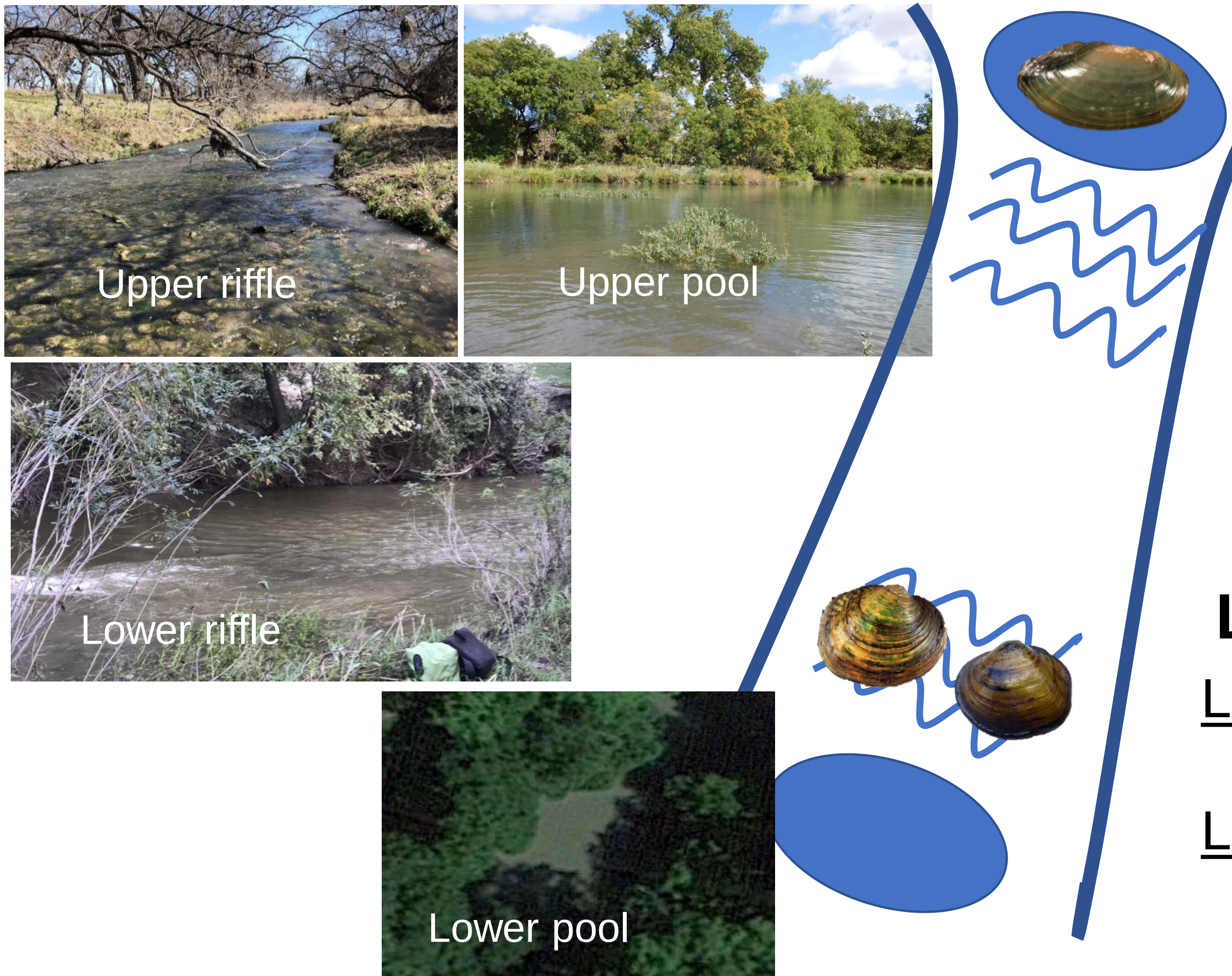
Lower San Saba River

Cyclonaias petrina and C. pustoloa

Most abundant in lower riffles

Hayes 2020

Environmental heterogeneity



Upper San Saba River

<u>Upper pool:</u> bedrock, rock shelves + emergent vegetation

<u>Upper riffle:</u> cobble, pebble, gravel

Lower San Saba River

<u>Lower pool:</u> sand, silt

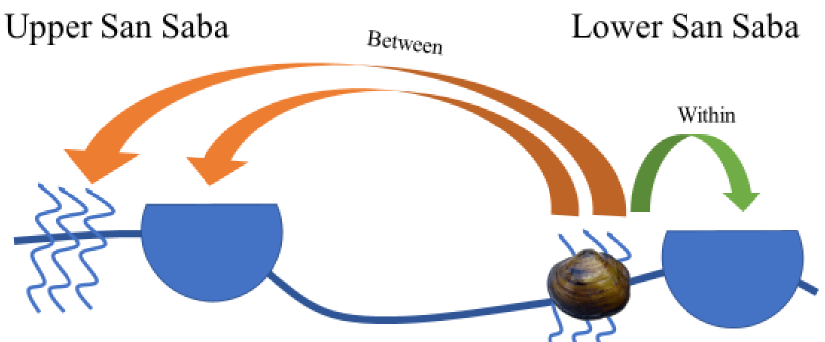
<u>Lower riffle</u>: gravel, pebble

Hayes 2020

Experimental design

First Experiment: *C. pustulosa* only

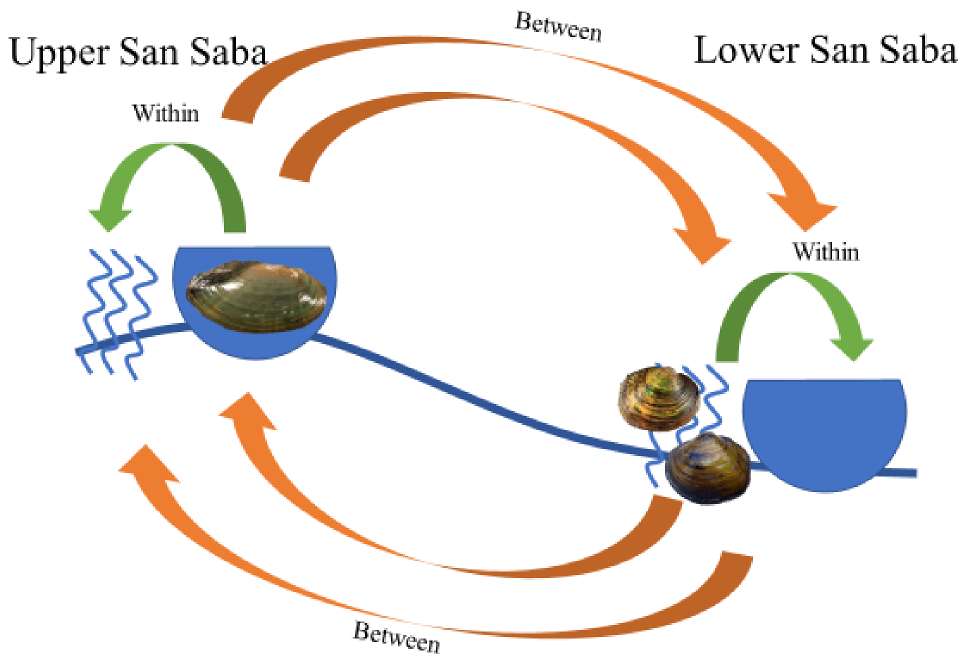
October 2018- October 2019/March 2020



28- 30 individuals in treatments and control

Fully Crossed Experiment

October 2019-March 2020



Duration: 1- 2 years

Performance variables:

Growth rates

Glyogen concentration in foot

Detection

Mortality (% of detected mussels that were found dead)

Number of individuals in treatments and control

Cyclonais: 20- 30

Utterbackia: 10 – 16

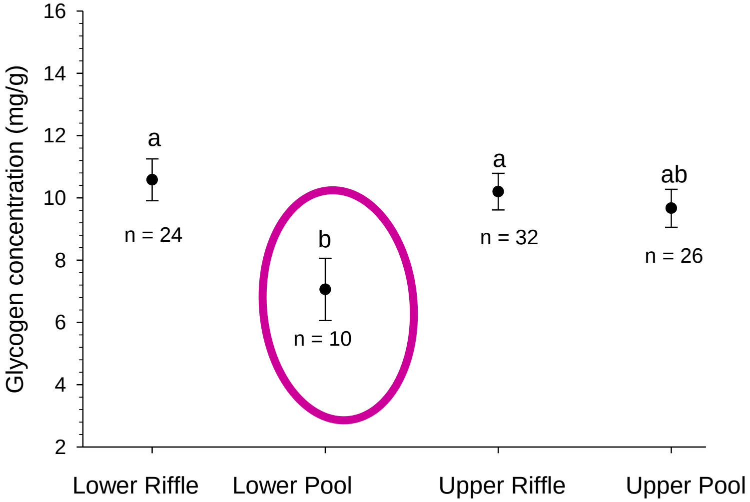
Hayes 2020

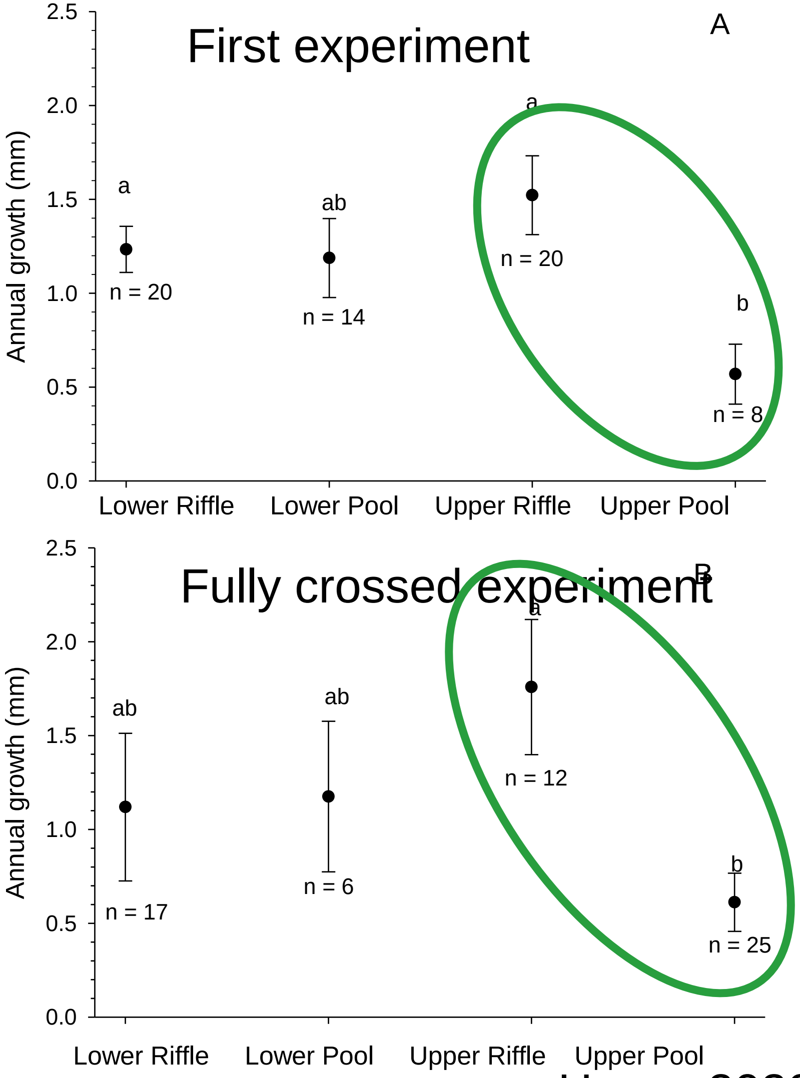
Cyclonaias: better performance in riffles?

<u>Within segment</u>

Lower **glycogen** in pool than control riffle.

but no significant differences in **growth** rates.





<u>Between segments</u>:

Growth rates:

highest in upper riffle, lowest in upper pool.

Glycogen lower in upper pool, but no significant difference to control.

Detection of Cyclonaias declined after flooding in the upper pool, but not the upper riffle.

Other factors, which may affect earlier life stages not tested here, may limit the distribution of *Cyclonaias.*

Hayes 2020

Utterbackia: only happy at home

Detection measured after 3 weeks and 5 months
Experiment discontinued after 5 months as only a few mussels were at the treatment sites.

100% detection in control habitat, 2 dead.
Lower glycogen than *Cyclonaias* in control habitat
→ *Utterbackia* likely sensitive to handling

5 of 10 mussels translocated to lower pool were found live
→ Vegetation in upper pool may act as flow refuge

Utterbackia: Distribution seems to be driven by environmental heterogeneity
→ requires lentic microhabitat

Substrate preferred by lentic-dwelling individuals differed significantly from non-lentic in substrate choice experiments

Hayes 2020

Microhabitat-scale: Testing behavioral responses to environmental heterogeneity

Substrate choice experiments

Tested substrate preference and mobility of 10 species.

407 individuals tested

Species specific differences in substrate preference and mobility

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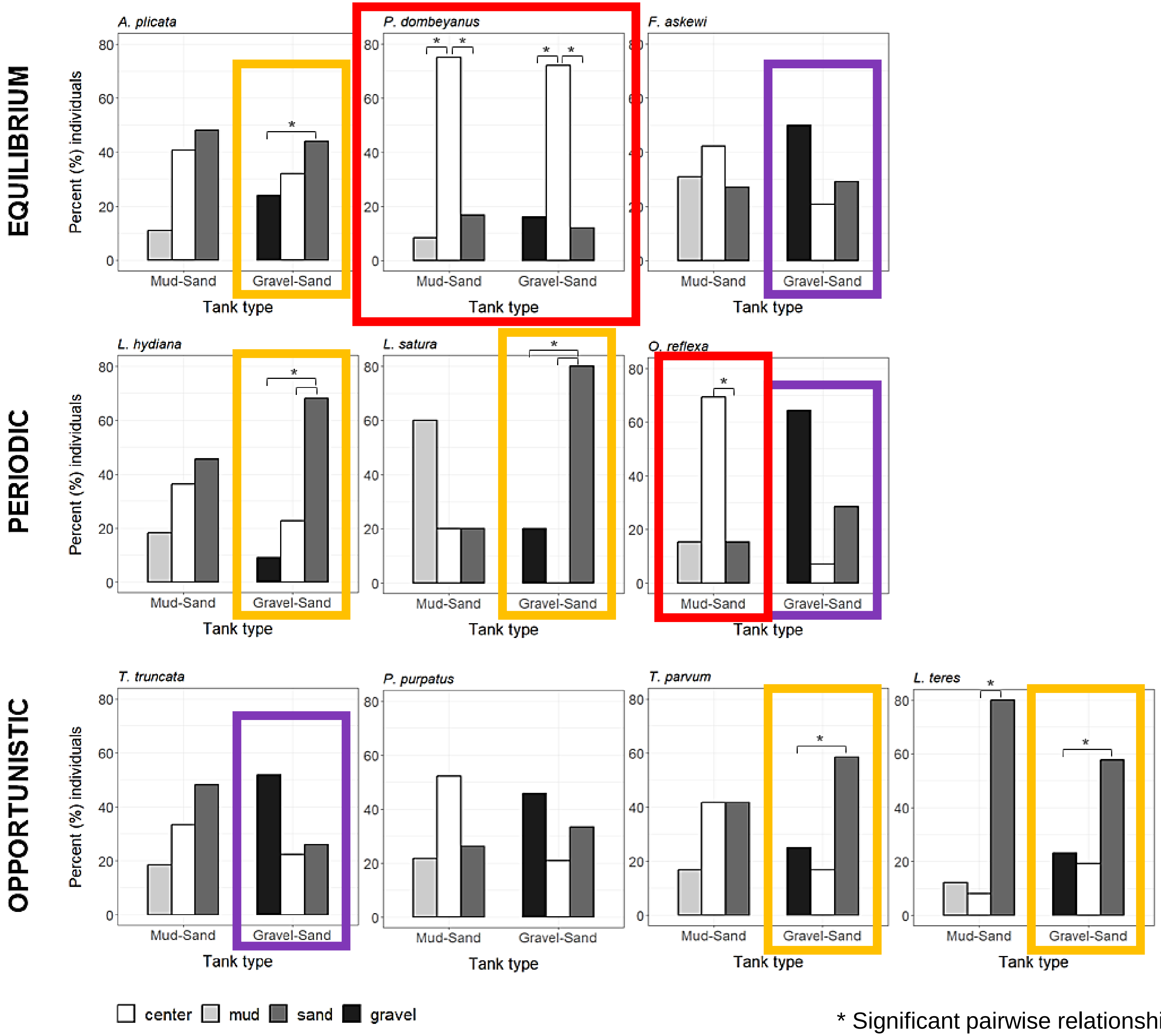

5 species showing significant preference for sand vs. gravel

3 species tended to prefer gravel over sand

Majority of individuals did not move

* Significant pairwise relationship ($p < 0.05$)

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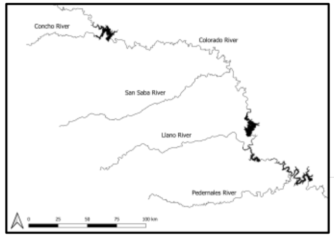
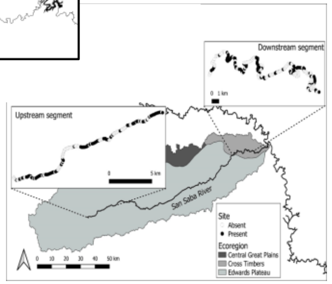
What have we learned about responses to environmental heterogeneity?

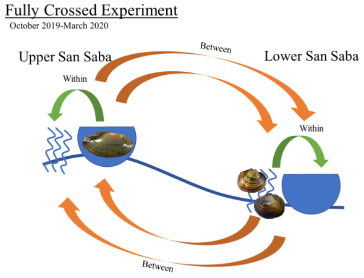




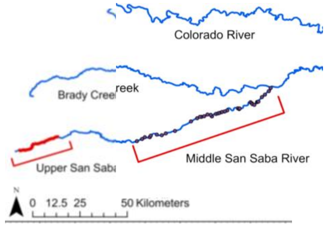
Multiple scales relevant:
Landscape + local environmental factors (e.g., Atkinson et al. 2012)
+ association with **fish** --> importance of their location/movement?

Distinct communities in upper vs. lower segment
further structured by pools and riffles.

Distribution of **life history groups** highly **predictable** (Haag 2012)
→ **stochasticity** more important for **species** (Leibold & Chase 2018)



Depauperate communities due to intense **droughts**.
Few lentic species able to persist in perennial pools in intermittent segments.



HEC-RAS model: Hydraulic conditions during **flooding** and **low flow**= important predictors

Microhabitat (+flow refuge) requirements matter

What's next?

Revisiting some TRIAGE sites sampled in 2021 to examine impact of 2022 drought.

HEC-RAS model for lower San Saba River (Aubrey Harris, USACE):
Are juvenile mussels washed out of pools during flooding?

How far are mussels transported downstream during flooding?

Relative importance of presence and movement of fish compared to hydraulic conditions?

Examining the role of stochasticity and colonization effects for community structure and dynamics in mesocosm experiments with macroinvertebrates

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Thank you!

An army of helpers, summer students, field technicians.
My dedicated graduate students
Thesis and dissertation committee members, collaborators
Landowners who provided access
Funding: US Army Corps of Engineers