Holding their ground: impacts of high and low flows on freshwater mussel assemblages and distribution

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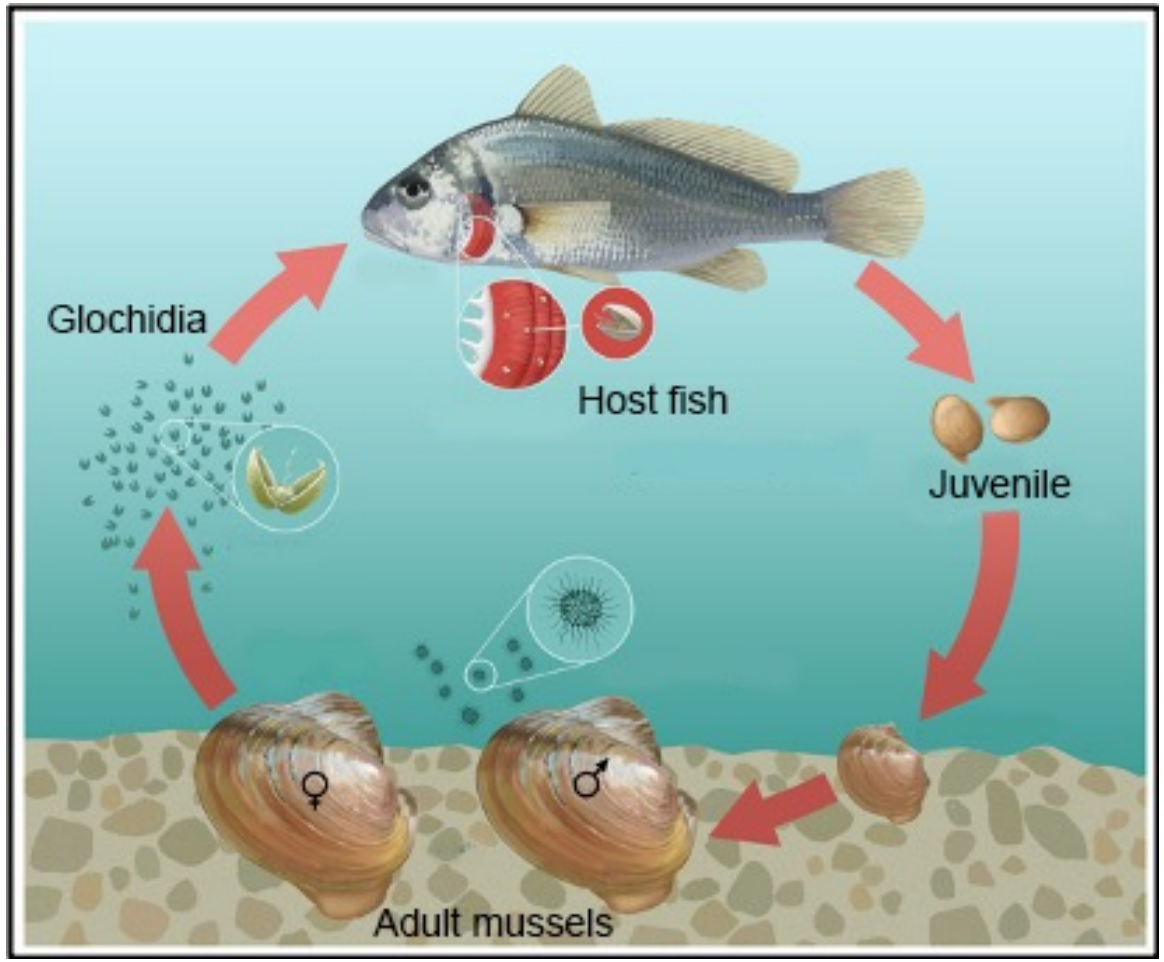
Study organism: Freshwater mussels-living rocks?

Diverse and imperiled organisms

Occupy rivers, lakes, and streams

Patchy distribution

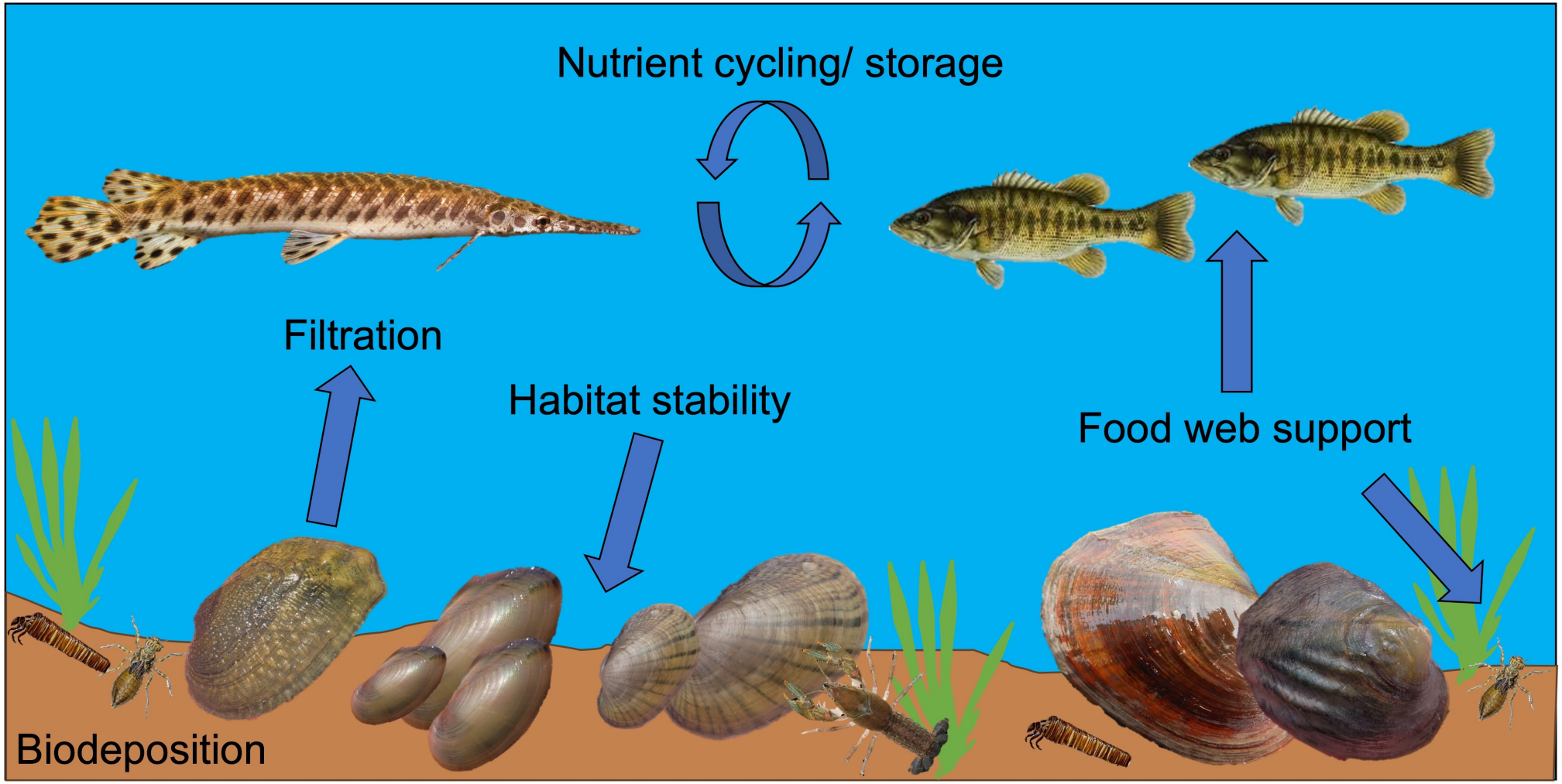
Unique life cycle



Credit: adapted from Hewitt et al. (2021)

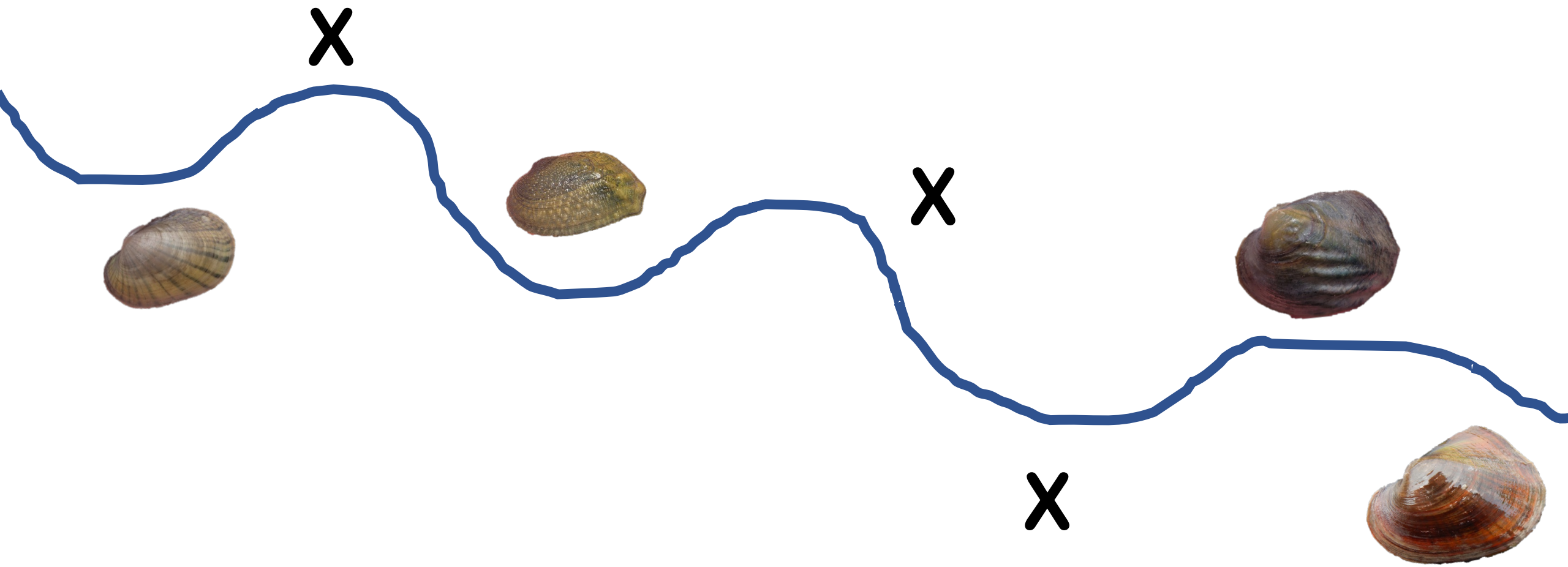
Haag 2012; Lopes-Lima 2018

Importance of mussels in ecosystems



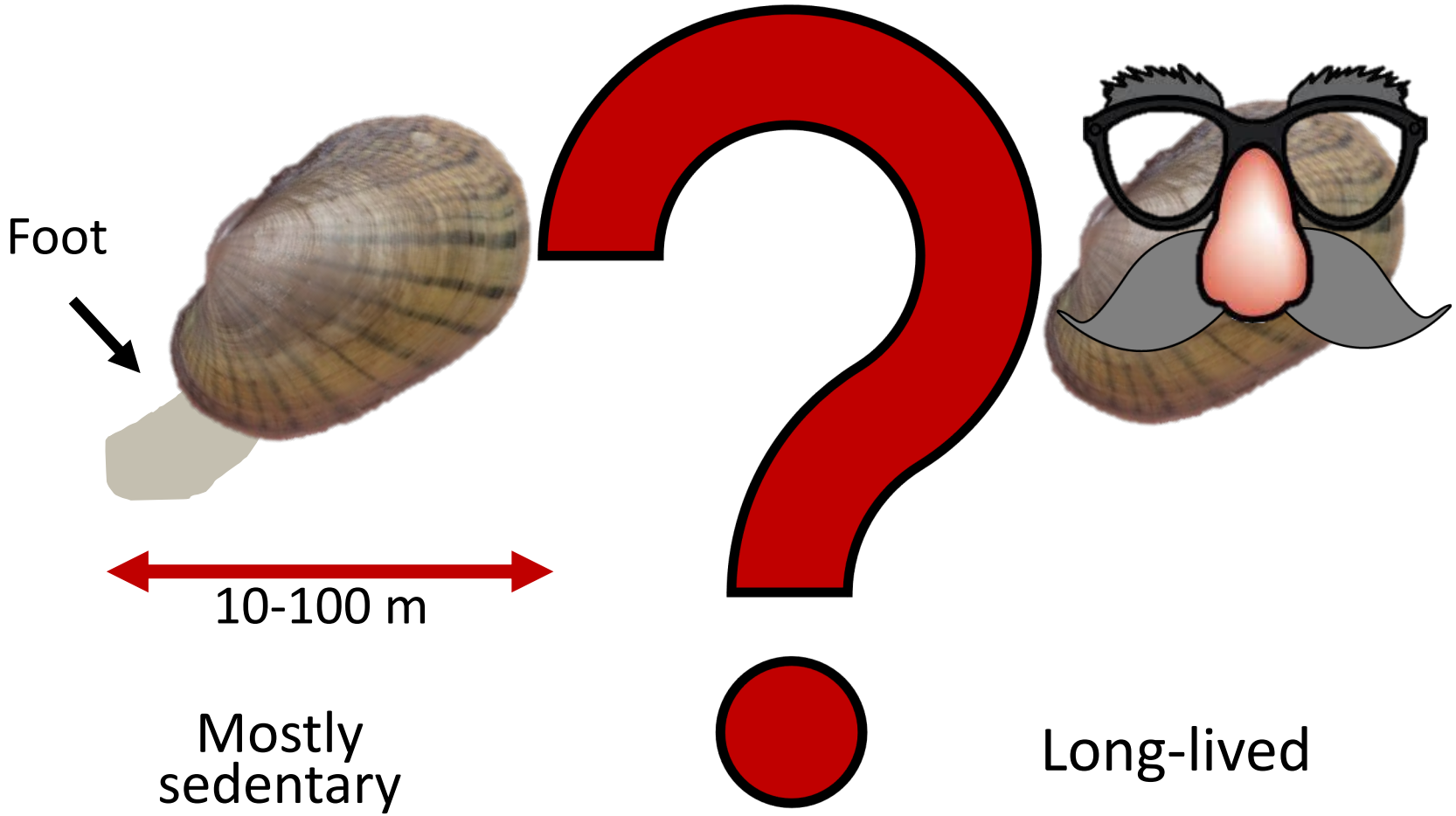
Adapted from Kreeger et al. (2018)

Mussels have a patchy distribution



Strayer 1999, Allen and Vaughn 2010

Why are mussels susceptible to flow events?



Defining low and high flows

Low flow: discharge below the median daily flow conditions

High flow: discharge greater than 10x median daily flow conditions

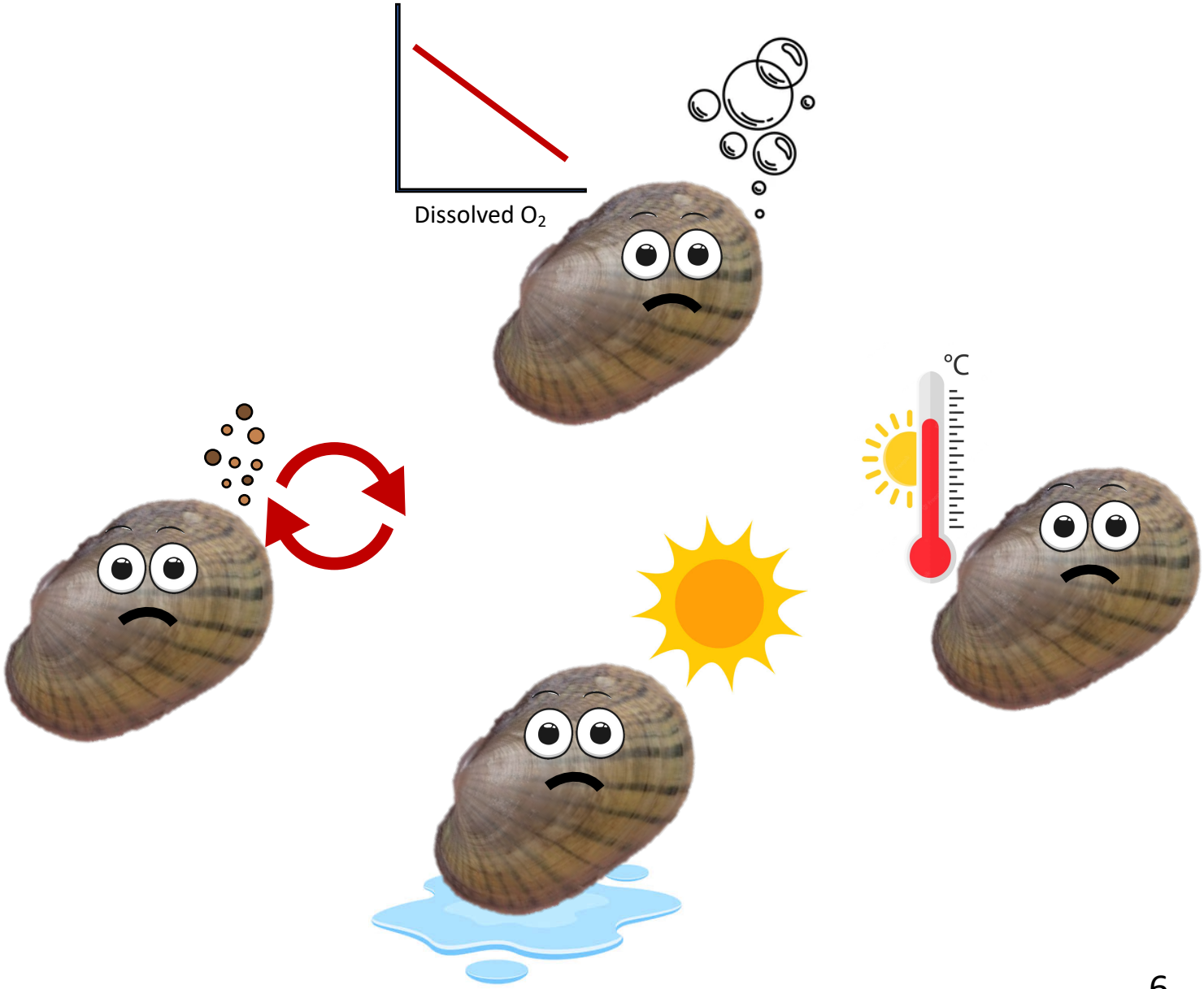
Potential effects of low flows on mussels

Decreased oxygen availability

Thermal stress

Emersion

Decreased food delivery



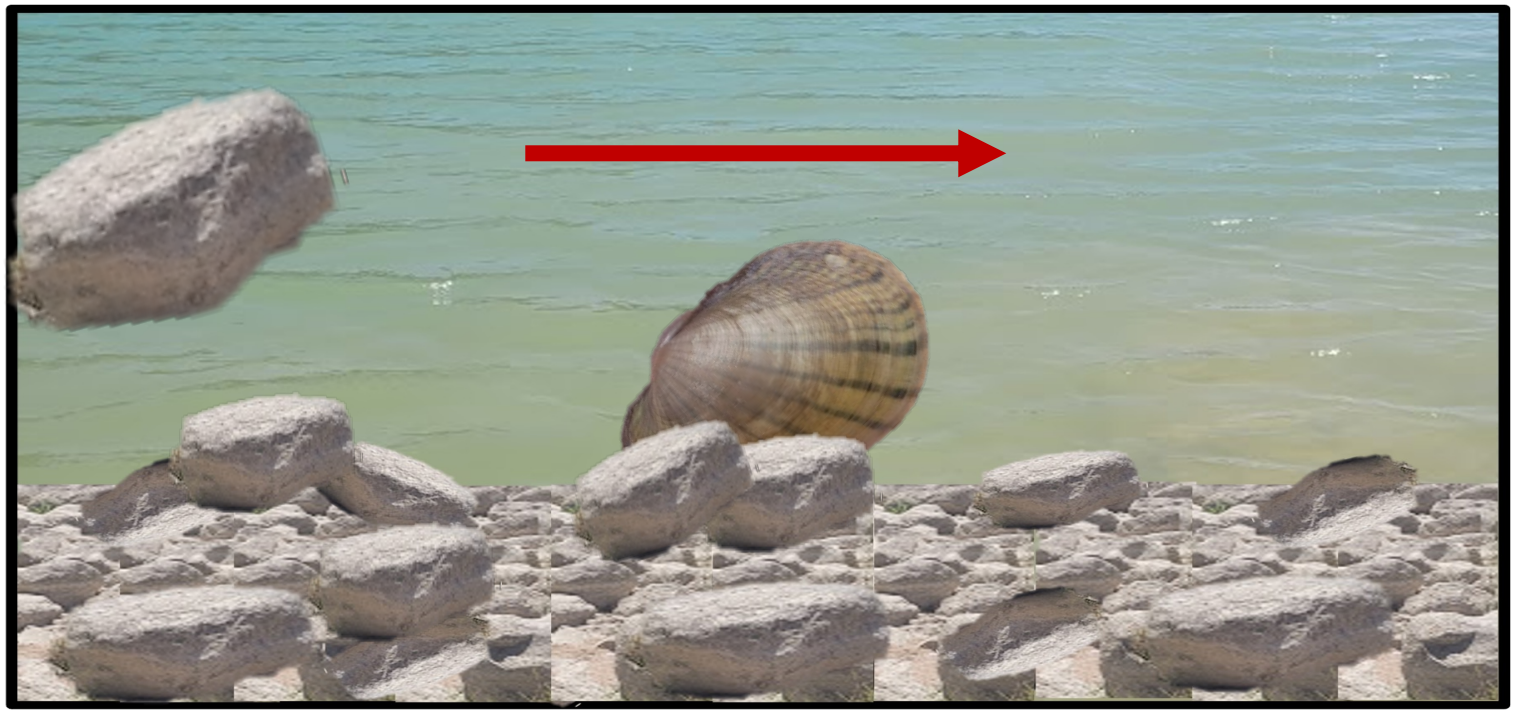
Gagnon et al. 2004, Mistry and Ackerman 2018

Potential effects of high flows on mussels

Substrate and bed mobility

Transport downstream

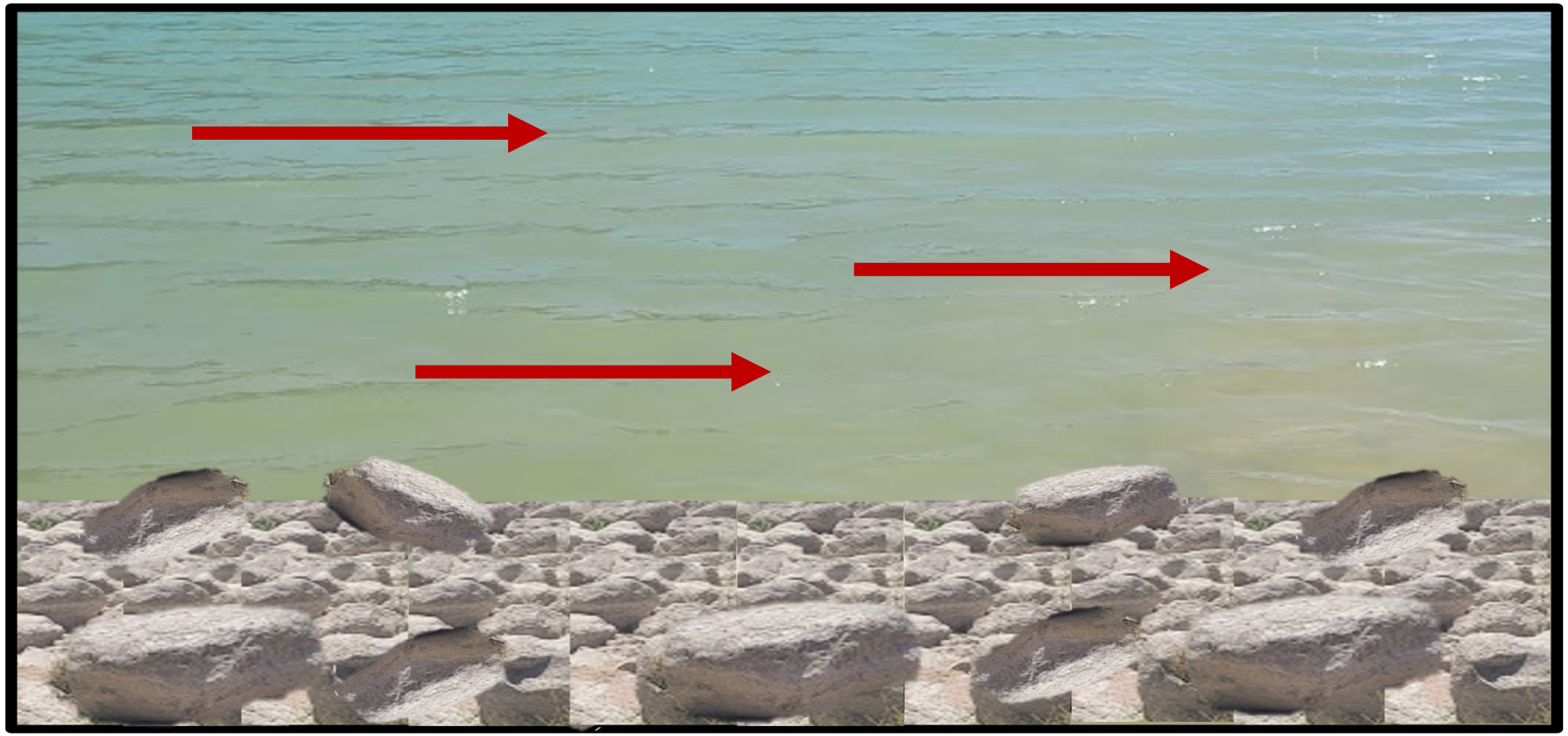
Post-flood stranding



Hastie 2001, Allen and Vaughn 2010

Crash course in (some) river hydraulics

Shear stress (τ) = force applied parallel to the stream bed

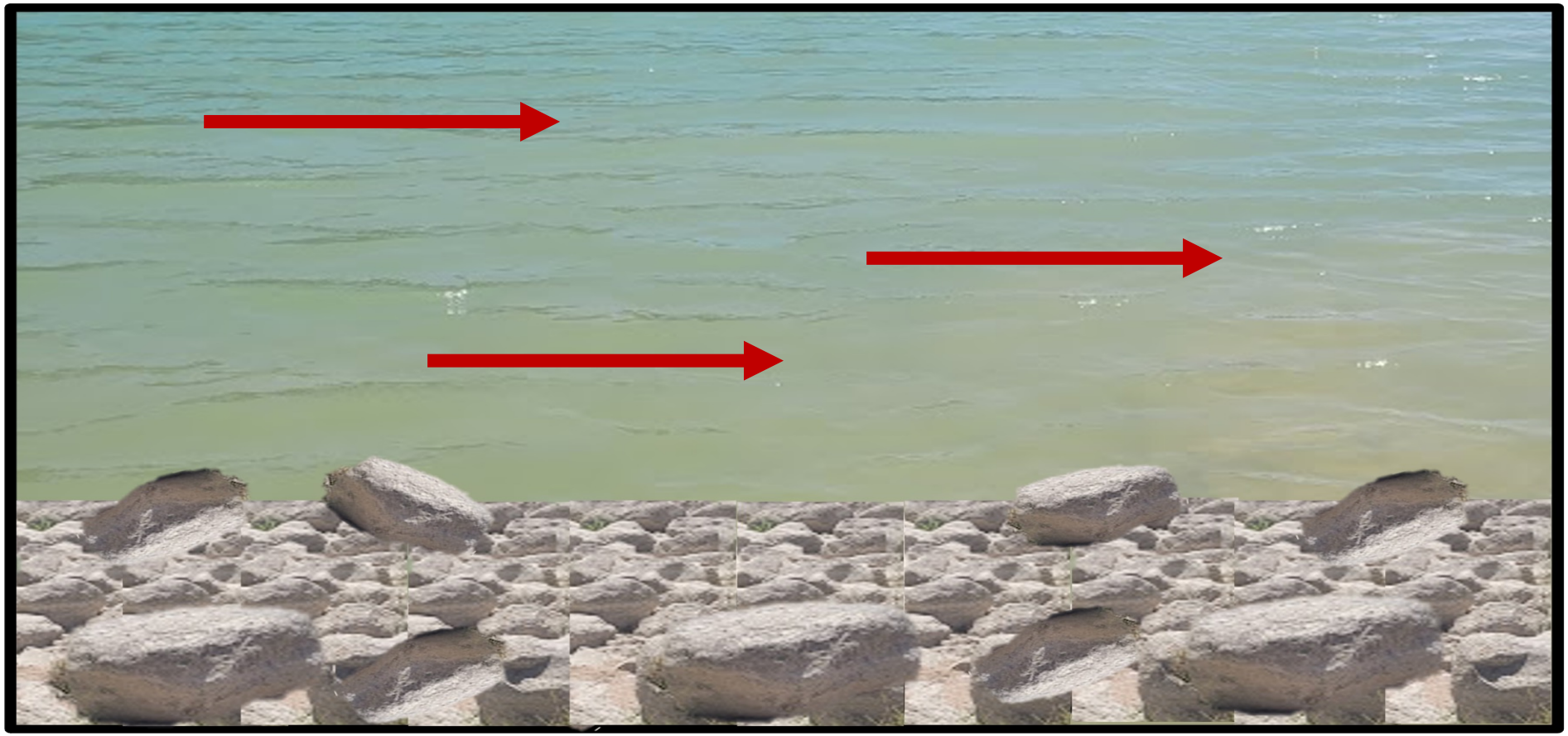


$$\tau = \gamma R_T S_f$$

Gordon et al. 2004,
U.S. Army Corps of Engineers 2020

Crash course in (some) river hydraulics

Stream power (Ω) = total energy from flow (ability of flow to do work)



$$\Omega = \nu\tau$$

Gordon et al. 2004,
U.S. Army Corps of Engineers 2020

Crash course in (some) river hydraulics

Froude number (Fr) = ratio of inertial to gravitational forces

$$Fr = \frac{v}{\sqrt{gD}}$$

Gordon et al. 2004,
U.S. Army Corps of Engineers 2020

Current knowledge: hydraulic variables and mussels

Complex hydraulic variables influence mussel distribution

Focus on rivers with fine sediments

Spatially extensive surveys are uncommon

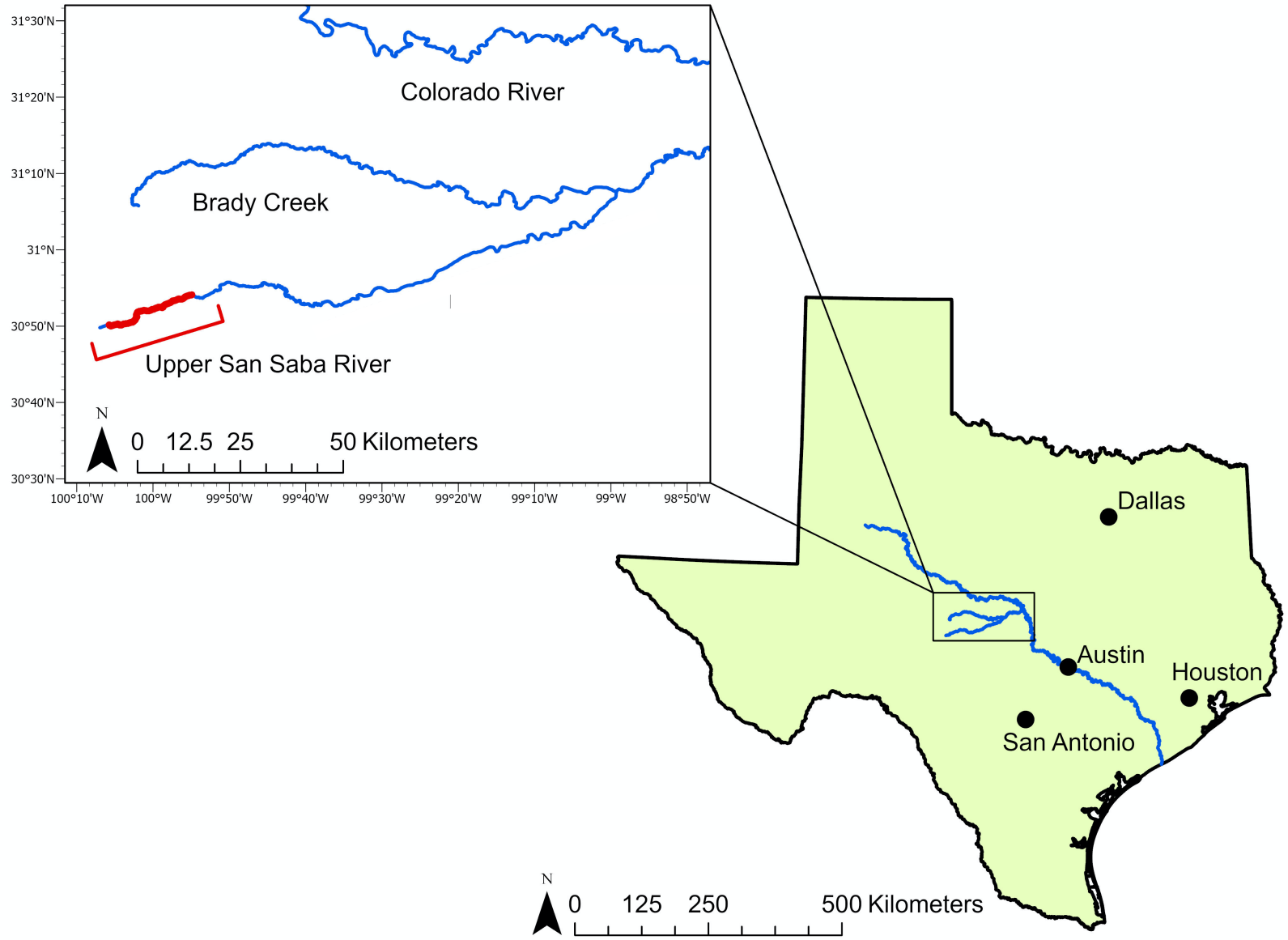
Howard and Cuffey 2003, Allen and Vaughn 2010, Lopez and Vaughn 2022

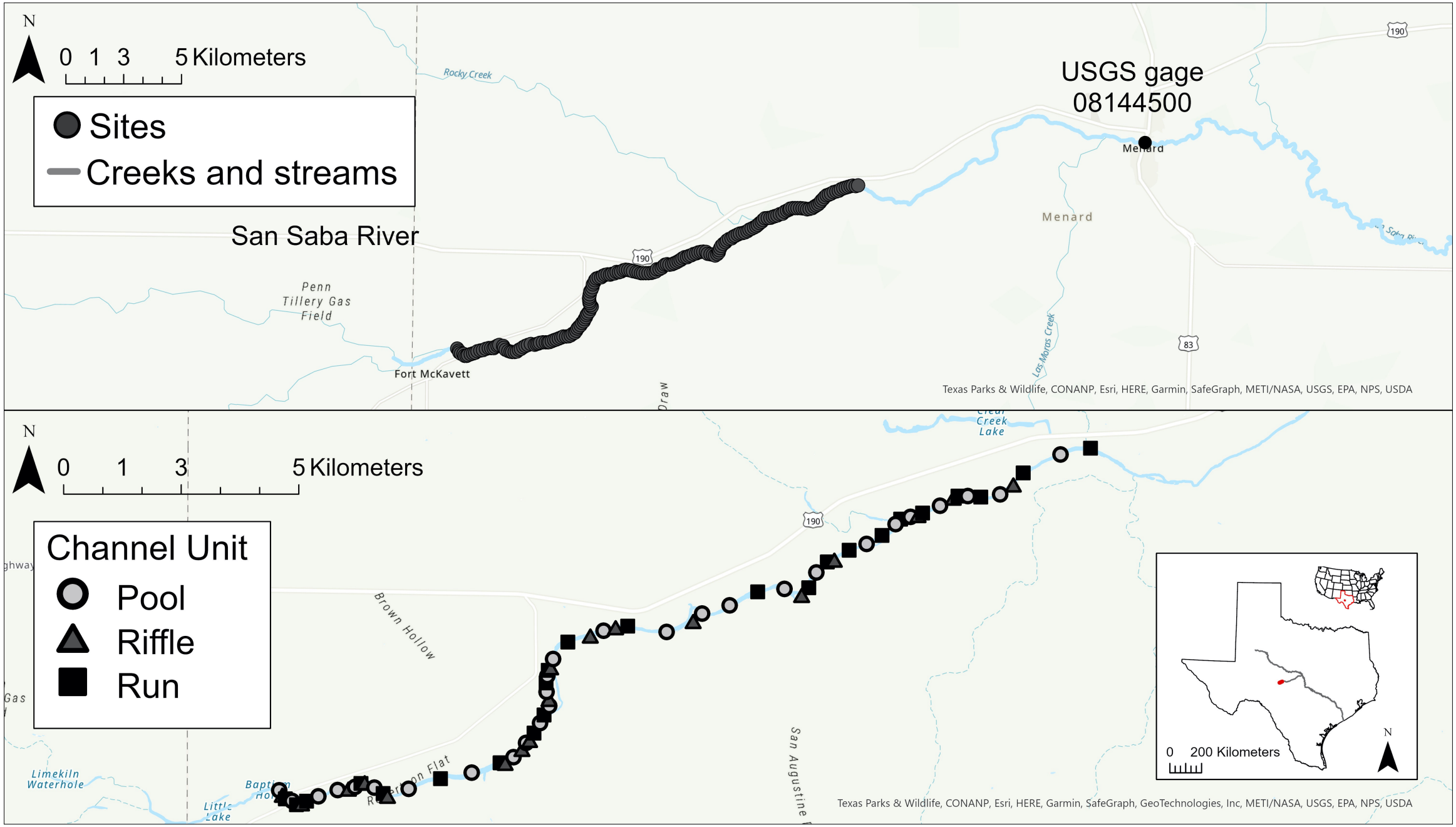
Questions and objectives

1) Do hydraulic conditions differ between hotspots of mussel richness and diversity during:
   - Low flows (0.7x median daily flow)
   - High flows (10-600x median daily flows)

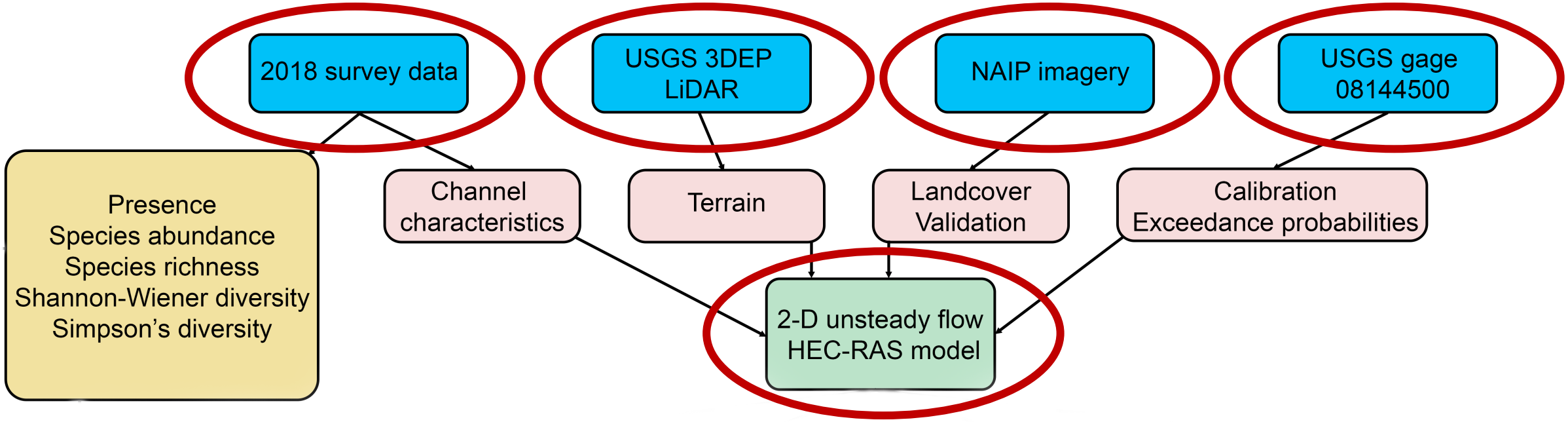
2) Can hydraulic conditions in bedrock-dominated systems accurately predict:
   - Site occupancy (mussel presence/absence)
   - Species abundance

Study area: San Saba River, TX

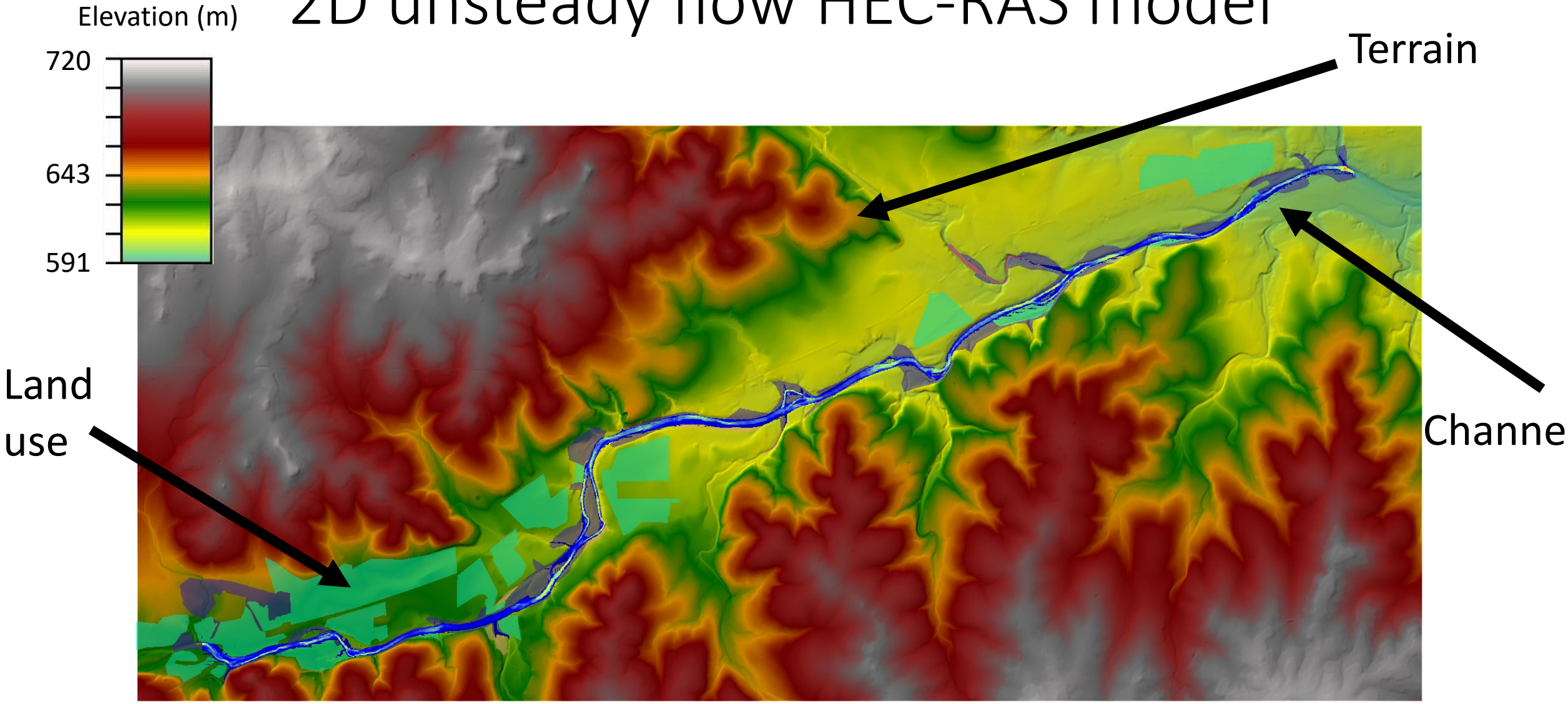




Mitchell et al. 2019, Mitchell 2020


2018 survey data
USGS 3DEP LiDAR
NAIP imagery
USGS gage 08144500
Presence
Species abundance
Species richness
Shannon-Wiener diversity
Simpson's diversity
Channel characteristics
Terrain
Landcover Validation
Calibration Exceedance probabilities
2-D unsteady flow HEC-RAS model

2D unsteady flow HEC-RAS model



Hydraulic variables: shear stress, stream power, Froude number, depth

Simulated flows

Low flow (0.4 m^3s^{-1}):

Calibrated flow; 0.7x median daily flow

Small flood (5.3 m^3s^{-1}):

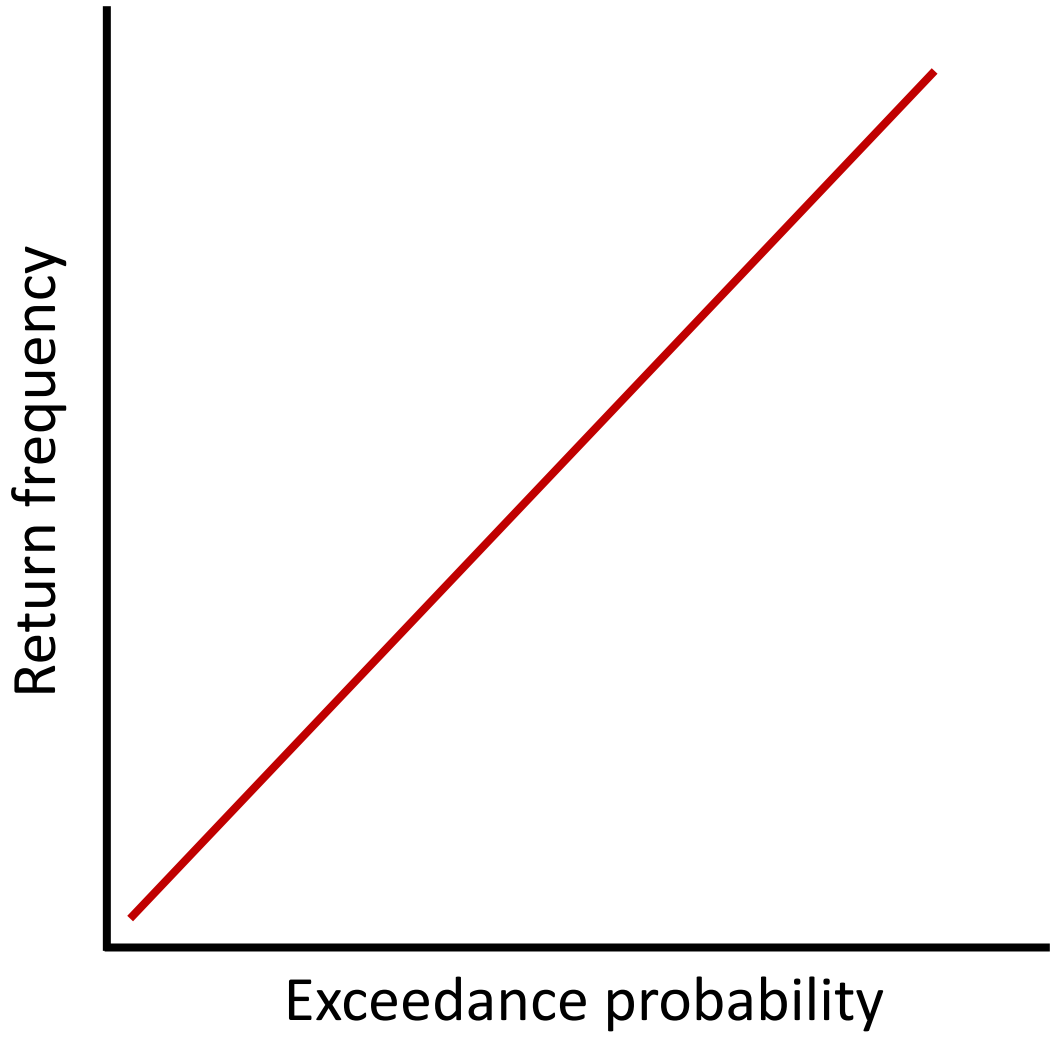
50 % exceedance probability (1998-2018)

Moderate flood (32.3 m^3s^{-1}):

50 % exceedance probability (1916-2022)

Large flood (361.9 m^3s^{-1}):

10 % exceedance probability (1916-2022)



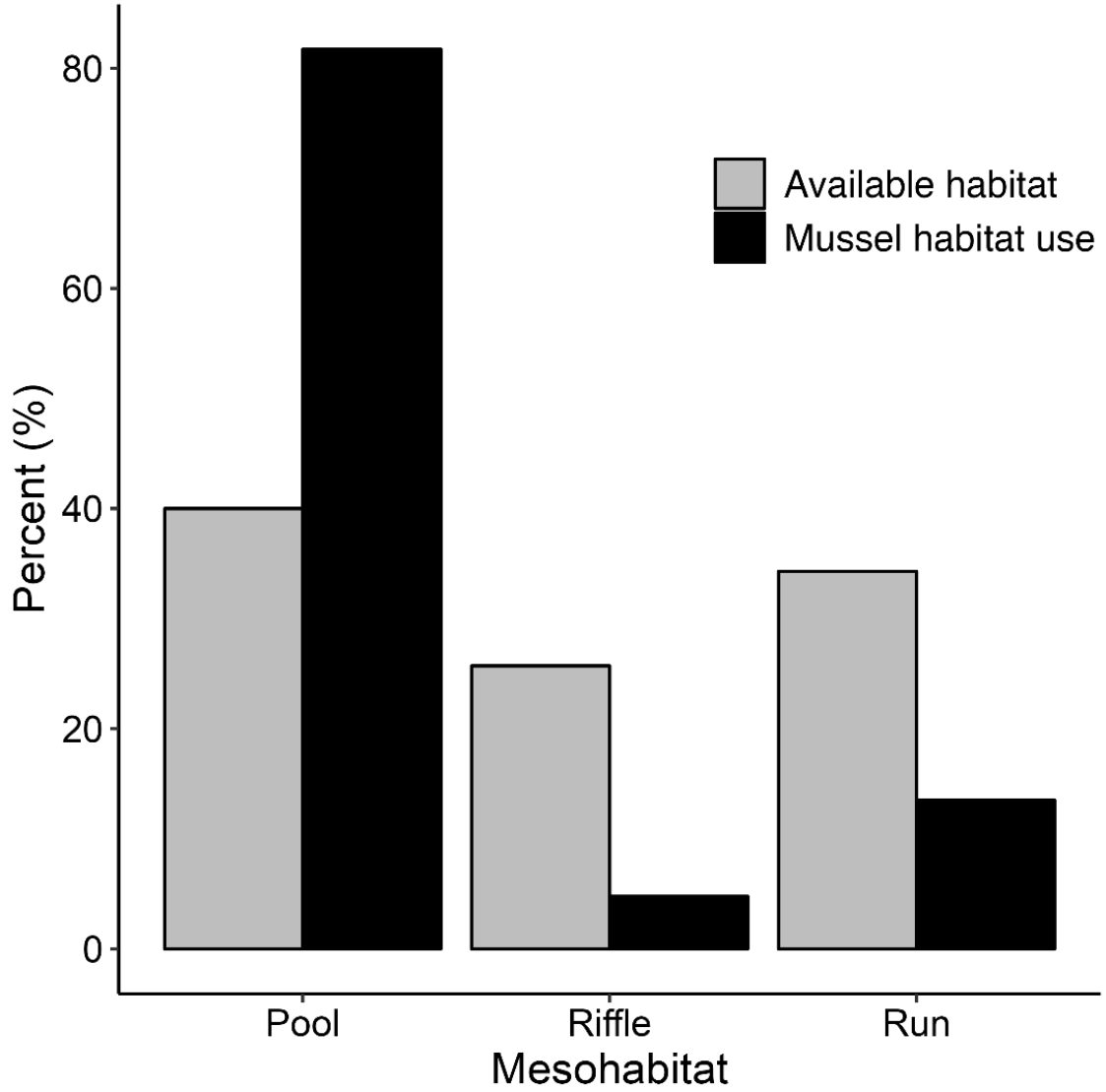
Survey results

Mussel surveys

859 mussels of 9 species

Presence at 52 % of sites and in 50 % of mesohabitat units

Preferentially occupied pool habitats



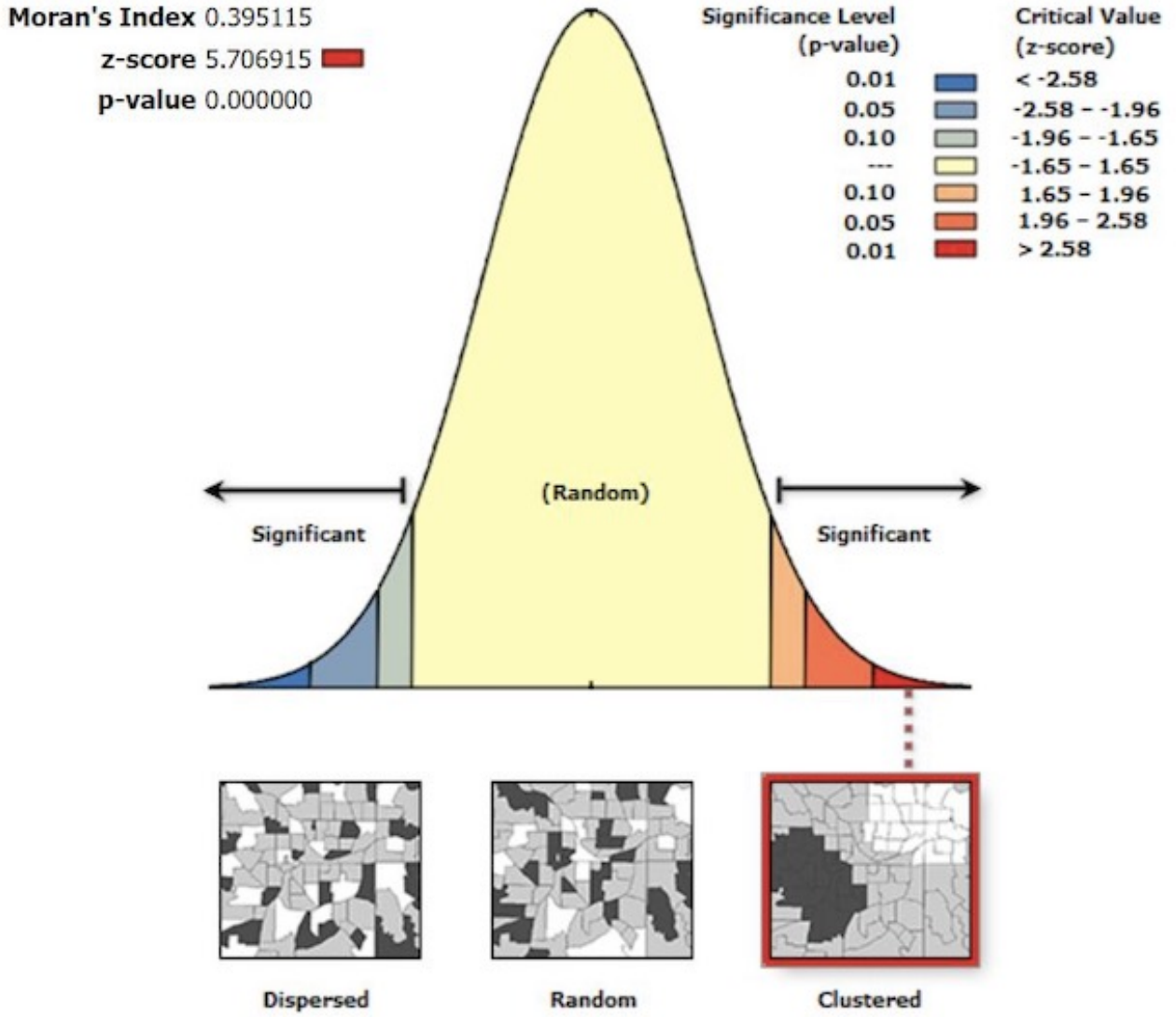
Mitchell et al. 2020

Objective 1

Do hydraulic conditions differ at hotspots of mussel richness and diversity and other sites during:

- Low flows (0.7x median daily flow)
- High flows (10-600x median daily flows)

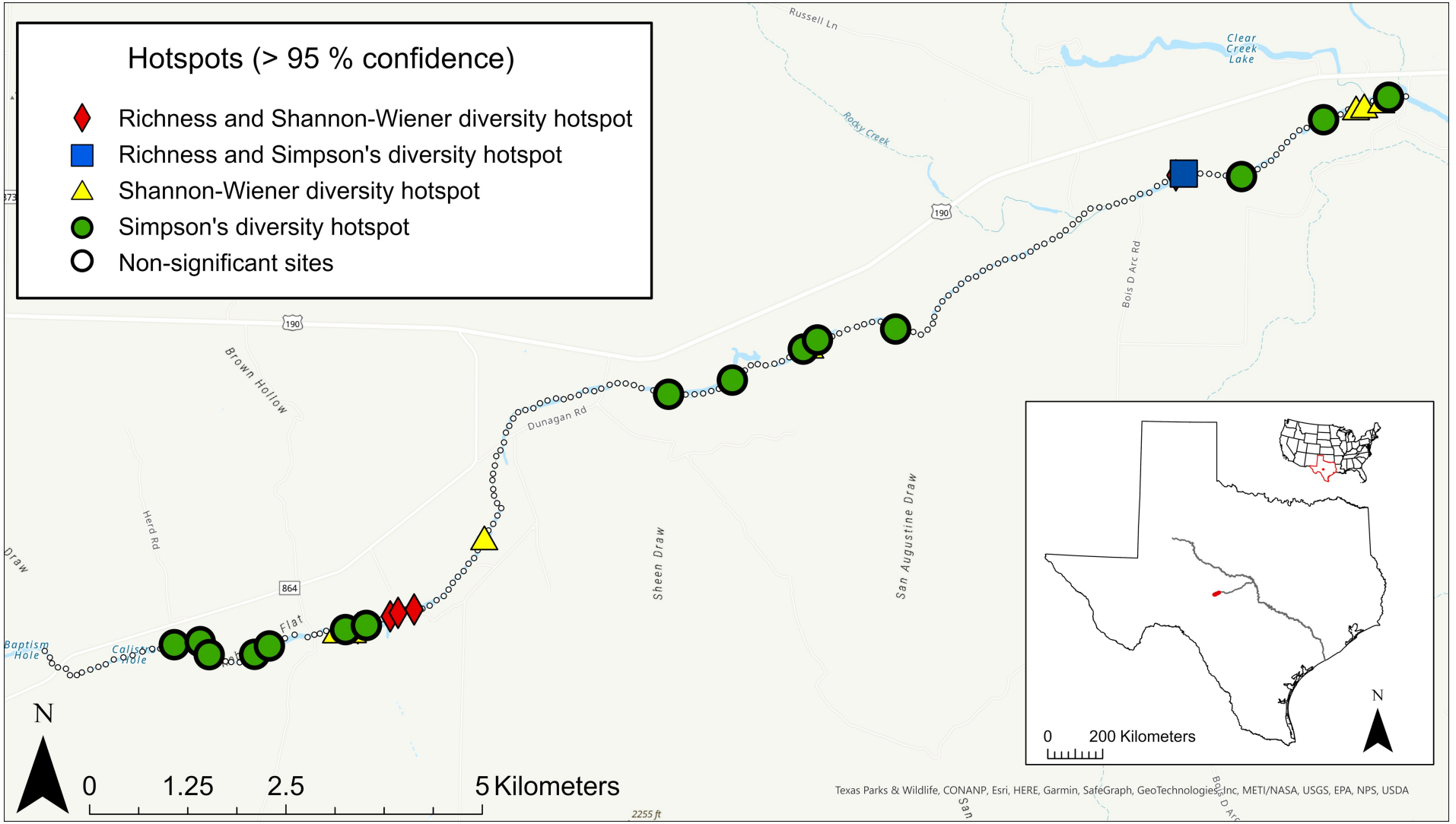
Getis Ord Gi* hotspot analysis



Credit: ESRI

Hotspots of richness and diversity

28 hotspots of richness and diversity across sites

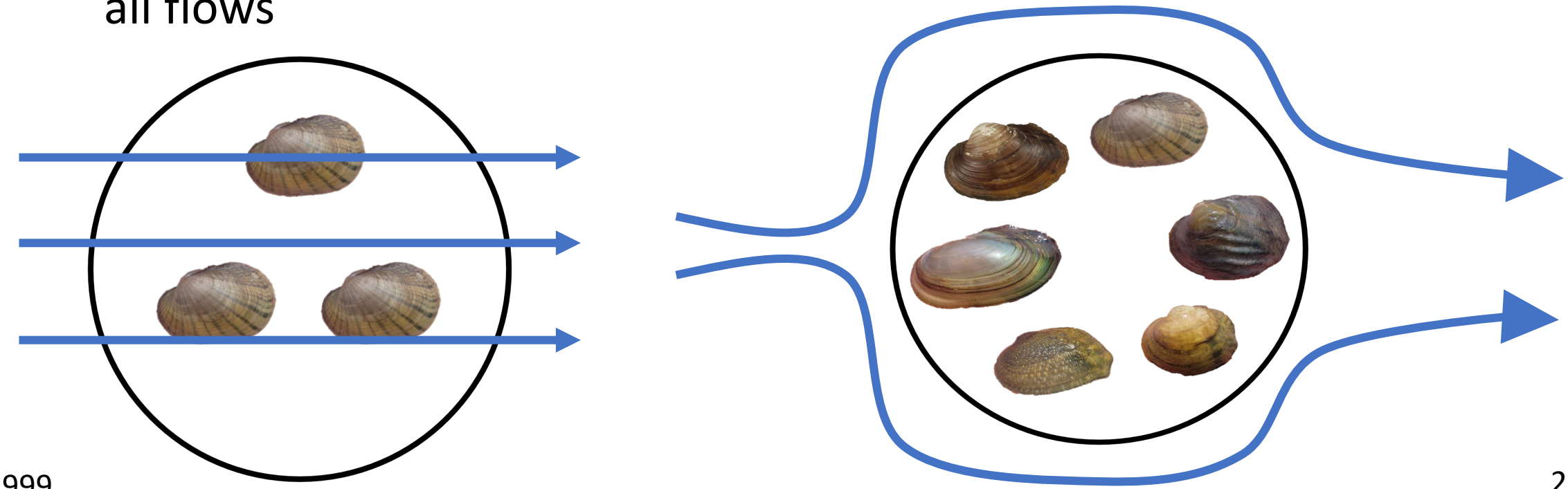


Hotspots of richness and diversity occur in flow refuges

Hotspots had:

- Significantly higher depths for all but the large flood

- Significantly lower shear stress, stream power, and Froude number at all flows



Strayer 1999

Objective 2

Understand whether hydraulic conditions in bedrock-dominated systems can accurately predict:

1. Site occupancy (mussel presence/absence)
2. Species abundances

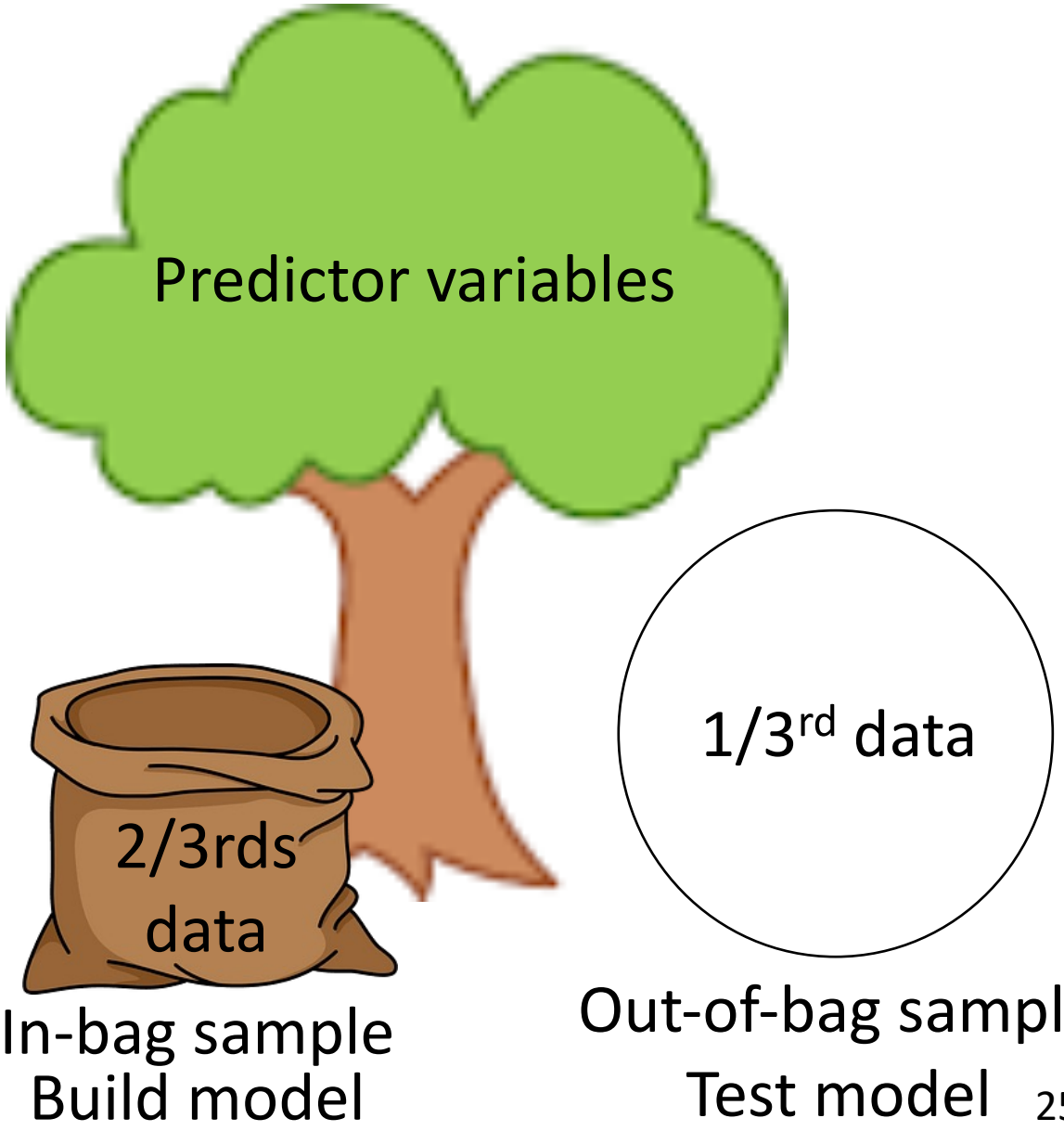
Random forest (RF) classification and regression

Random forest allows you to estimate how well a given set of predictors can:

1. Distinguish sites where mussels were present versus absent (classification; error rate)
2. Explain differences in species abundances across sites (regression; pseudo-R^2)

Random forest allows you to:

Understand the relative importance of selected variables



Breiman 2001

Hydraulic conditions at different flows influence mussel presence

Small flood
79 % accuracy

Low flow
77 % accuracy

Moderate flood
73 % accuracy

Large flood
68 % accuracy

Most important variables:
Depth and Froude number

Zigler et al. 2008, Allen and Vaughn 2010, Parasiewicz et al. 2012

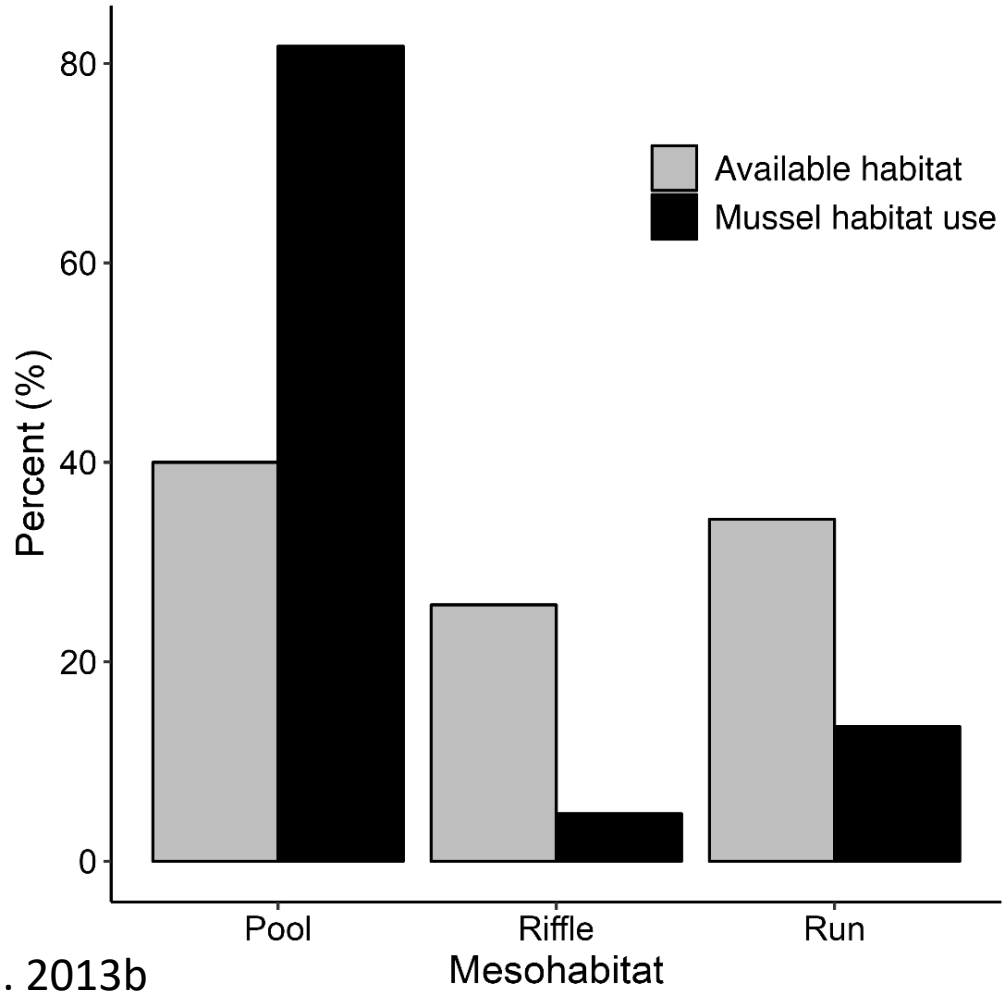
Flow refuges help mussels persist during unfavorable flows

Vegetation patches

Bedrock cracks and crevices

Howard and Cuffey 2003

Pools in bedrock systems can provide refuge from unfavorable hydraulic conditions



Howard and Cuffey 2003, Davis et al. 2013b

Hydraulic conditions influence species differently

Cyrtonaias tampicoensis

Variation explained:
45-55 %

Most important:
Shear stress/Stream power

Utterbackia imbecillis

Variation explained:
12-27 %

Most important:
Froude number

Lampsilis bracteata

Variation explained:
<1-14 %

Most important:
Flow-dependent

Limitations

1) Uncertainty at higher flows
2) Coarse lateral measurements
3) Groundwater and spring inputs and diversions not accounted for
4) Temporal gap in large flood timing allows for recolonization

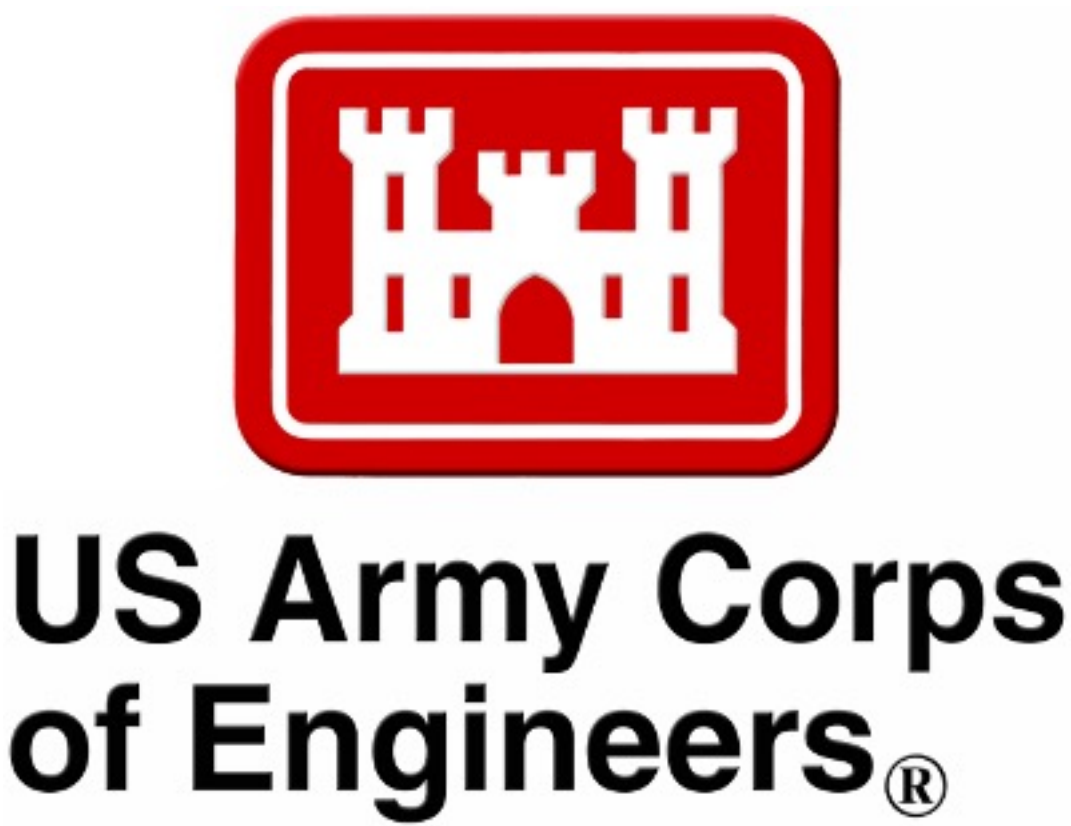
Management implications

Habitat suitability may be species- and flow-dependent

Flow refuges are essential habitats for maintaining biodiversity

Climate change is increasing the frequency and magnitude of high and low flow events

Multidisciplinary collaboration: opportunities for innovation



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Literature cited

Allen, D. C., and C. C. Vaughn. 2010. Complex hydraulic and substrate variables limit freshwater mussel species richness and abundance. *Journal of the North American Benthological Society* 29(2):383-394. https://doi.org/10.1899/09-024.1.

Breiman, L. 2001. Random Forests. *Machine Learning* 45:5-32. https://doi.org/10.1023/A:1010933404324.

Gagnon, P. M., S. W. Golladay, W. K. Michener, and M. C. Freeman. 2004. Drought responses of freshwater mussels (Unionidae) in Coastal Plain tributaries of the Flint River Basin, Georgia. *Journal of Freshwater Ecology* 19(4):667-679. https://doi.org/10.1080/02705060.2004.9664749.

Gordon, N. D., T. A. McMahon, B. L. Finlayson, C. J. Gippel, and R. J. Nathan. 2004. Stream hydrology: an introduction for ecologists. 2nd edition. John Wiley and Sons, West Sussex, UK.

Haag, W. R. 2012. North American freshwater mussels: ecology, natural history, and conservation. Cambridge Univ. Press, Cambridge.

Hastie, L. C., P. J. Boon, M. R. Young, and S. Way. 2001. The effects of a major flood on an endangered freshwater mussel population. *Biological Conservation* 98(1):107-115. https://doi.org/10.1016/S0006-3207(00)00152-X.

Howard, J. K., and K. M. Cuffey. 2003. Freshwater mussels in a California North Coast Range river: occurrence, distribution, and controls. *Journal of the North American Benthological Society* 22(1):63-77.

Lopes-Lima, M., L. E. Burlakova, A. Y. Karatayev, K. Mehler, M. Seddon, and R. Sousa. 2018. Conservation of freshwater bivalves at the global scale: diversity, threats and research needs. *Hydrobiologia* 810:1-14. https://doi.org/10.1007/s10750-017-3486-7.

Lopez, J. W., and C. C. Vaughn. 2021. A review and evaluation of the effects of hydrodynamic variables on freshwater mussel communities. *Freshwater Biology* 66(9):1665-1679. https://doi.org/10.1111/fwb.13784.

Mistry, R., and J. D. Ackerman. 2018. Flow, flux, and feeding in freshwater mussels. *Water Resources Research* 54(10):7619-7630. https://doi.org/10.1029/2018WR023112.

Mitchell, Z. A., L. E. Burlakova, A. Y. Karatayev, and A. N. Schwalb. 2019. Changes in community composition of riverine mussels after a severe drought depend on local conditions: a comparative study in four tributaries of a subtropical river. Hydrobiologia 848:3015-3029. https://doi.org/10.1007/s10750-019-04058-3(0123456789().,-volV() 0123458697().,-volV).

Mitchell, Z. A. 2020. The role of life history strategies and drying events in shaping mussel communities: a multiscale approach. Thesis. Texas State University. 163 pp.

Parasiewicz, P., E. Castelli, J. N. Rogers, and E. Plunkett. 2012. Multiplex modeling of physical habitat for endangered freshwater mussels. *Ecological Modeling* 228:66-75. https://doi.org/10.1016/j.ecolmodel.2011.12.023.

Strayer, D. L. 1999. Use of flow refuges by unionid mussels in rivers. *Journal of the North American Benthological Society* 18(4):468-476.

United States Army Corps of Engineers. 2020. HEC-RAS Mapper User's Manual version 6.0. 149 pp.

Zigler, S. J., T. J. Newton, J. J. Steuer, M. R. Bartsch, and J. S. Sauer. 2008. Importance of physical and hydraulic characteristics to unionid mussels: a retrospective analysis in a reach of a large river. *Hydrobiologia* 598:343-360. https://doi.org/10.1007/s10750-007-9167-1.