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Modeling freshwater mussel habitat in a large river: How understanding processes can aid in restoration efforts

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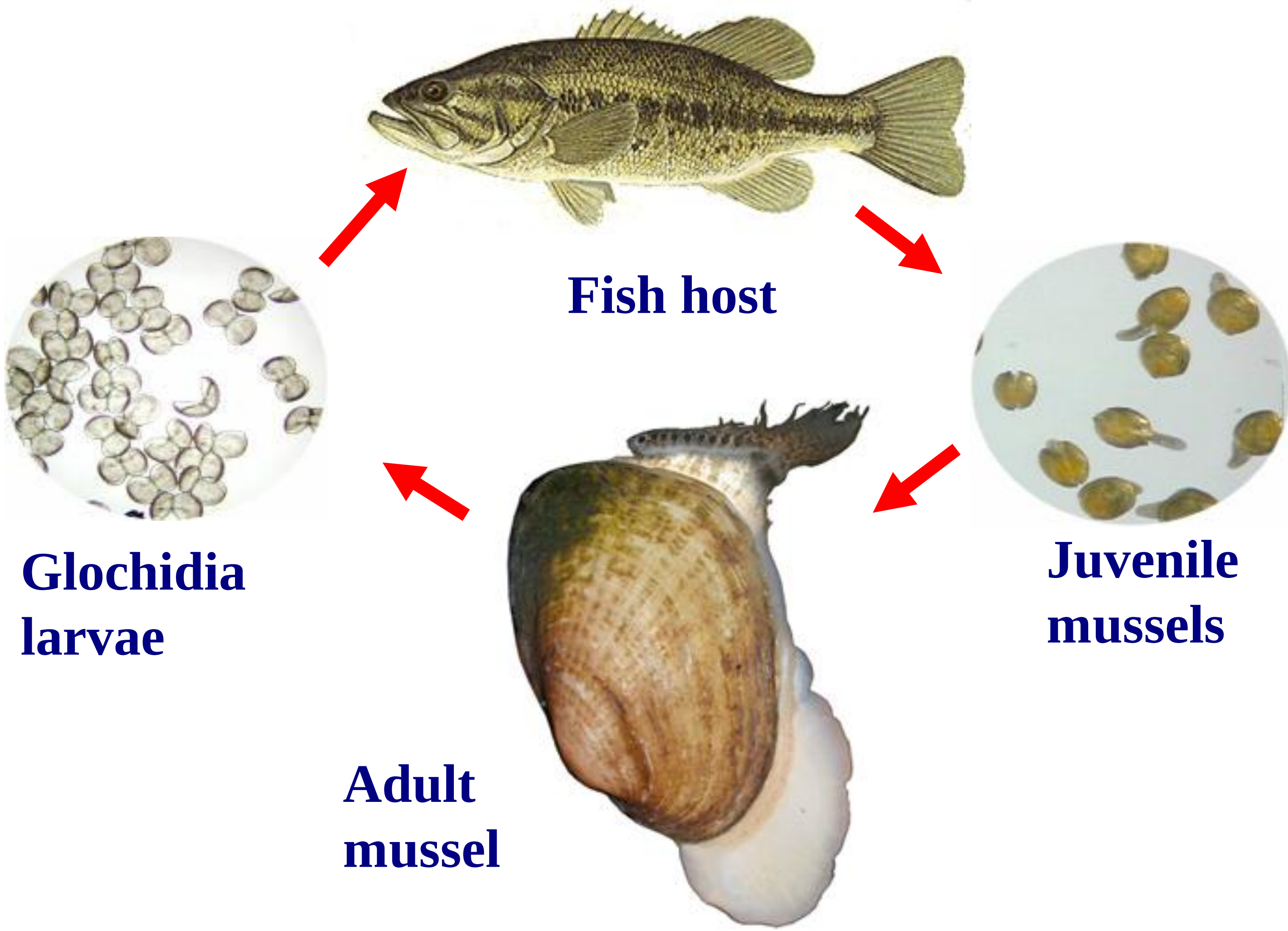
Native Mussel Life History

- Large (2-30 cm) bivalves that live in sediments of rivers, streams, and lakes
- 1000 species worldwide, 300 in NA
- One of the most imperiled groups of animals in world
- Long-lived (30-100 yrs)
- Delayed maturity (6-12 yrs)
- Reduced powers of dispersal
- Poor juvenile survival

- Most require a fish host to complete their life cycle

Life Cycle



Ecosystem Services by Mussels

- Biomass can exceed all other benthic animals by an order of magnitude
- Natural biological filters
- Food for fish and wildlife
- Economic significance
- Density & diversity of invertebrates are higher in mussel beds
- Important in nutrient cycling and stabilizing sediments

Functional Roles

Remove large amounts of particles from the water column

Excrete nutrients back to the water column

Stimulates primary and secondary production
(Vaughn et al. 2008)

alters algal community structure

Increased aquatic insect emergence rates
(Allen et al. 2012)

Increased terrestrial spider abundance
(Allen et al. 2012)

Biodeposit organic material to the sediment as feces and pseudofeces

Stimulate benthic productivity
(Howard & Cuffey 2006)

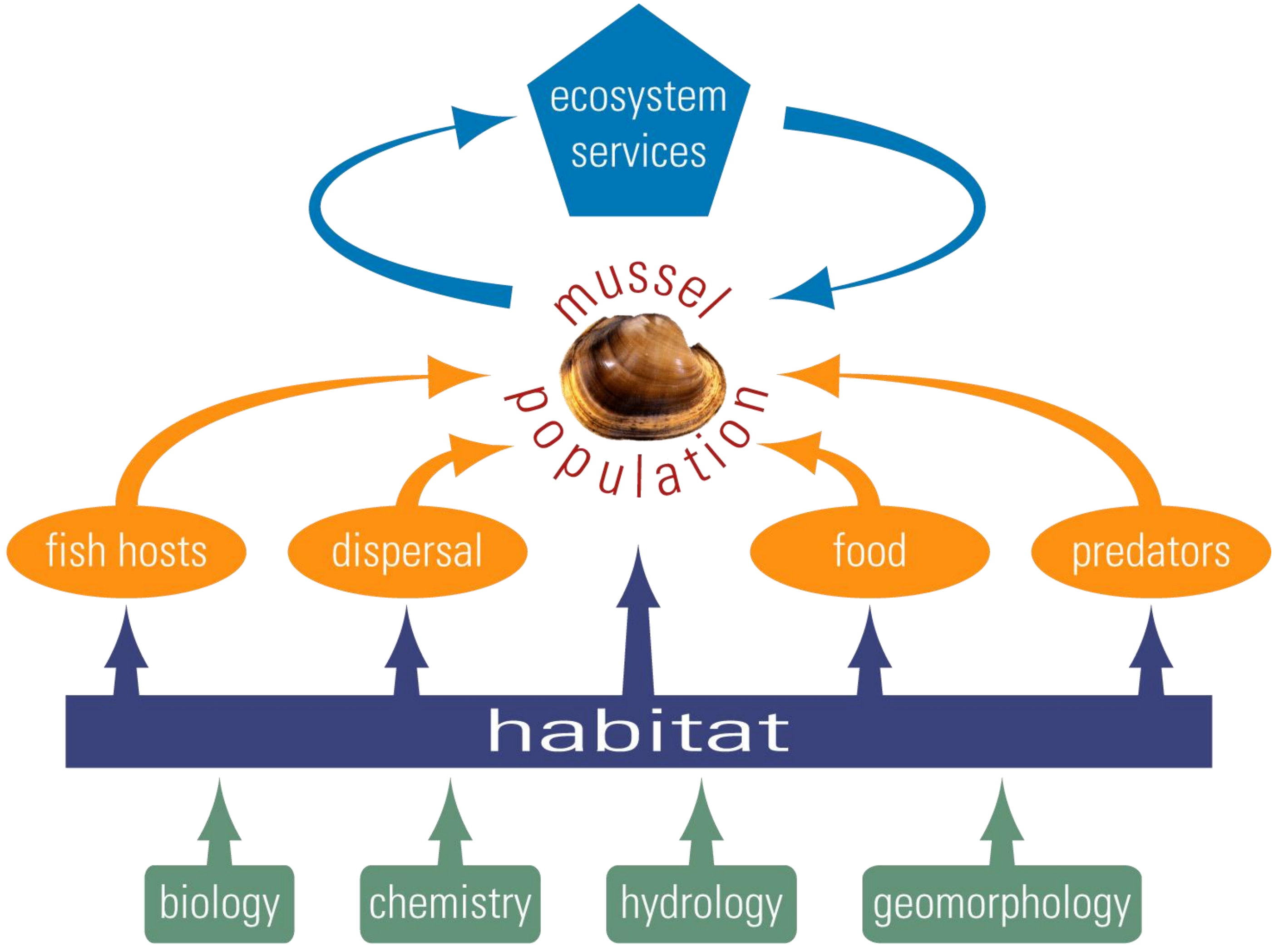
Increased benthic macroinvertebrate assemblages
(Vaughn & Spooner 2006)

Upper Mississippi River

- One of the world's major rivers in size and biological productivity
- 27 navigation pools, impoundment began the 1930's
- Mosaic of habitats types (backwaters, main channel, side channel)

- Large floodplain rivers are fundamentally different from smaller systems in their lateral complexity and hydrology

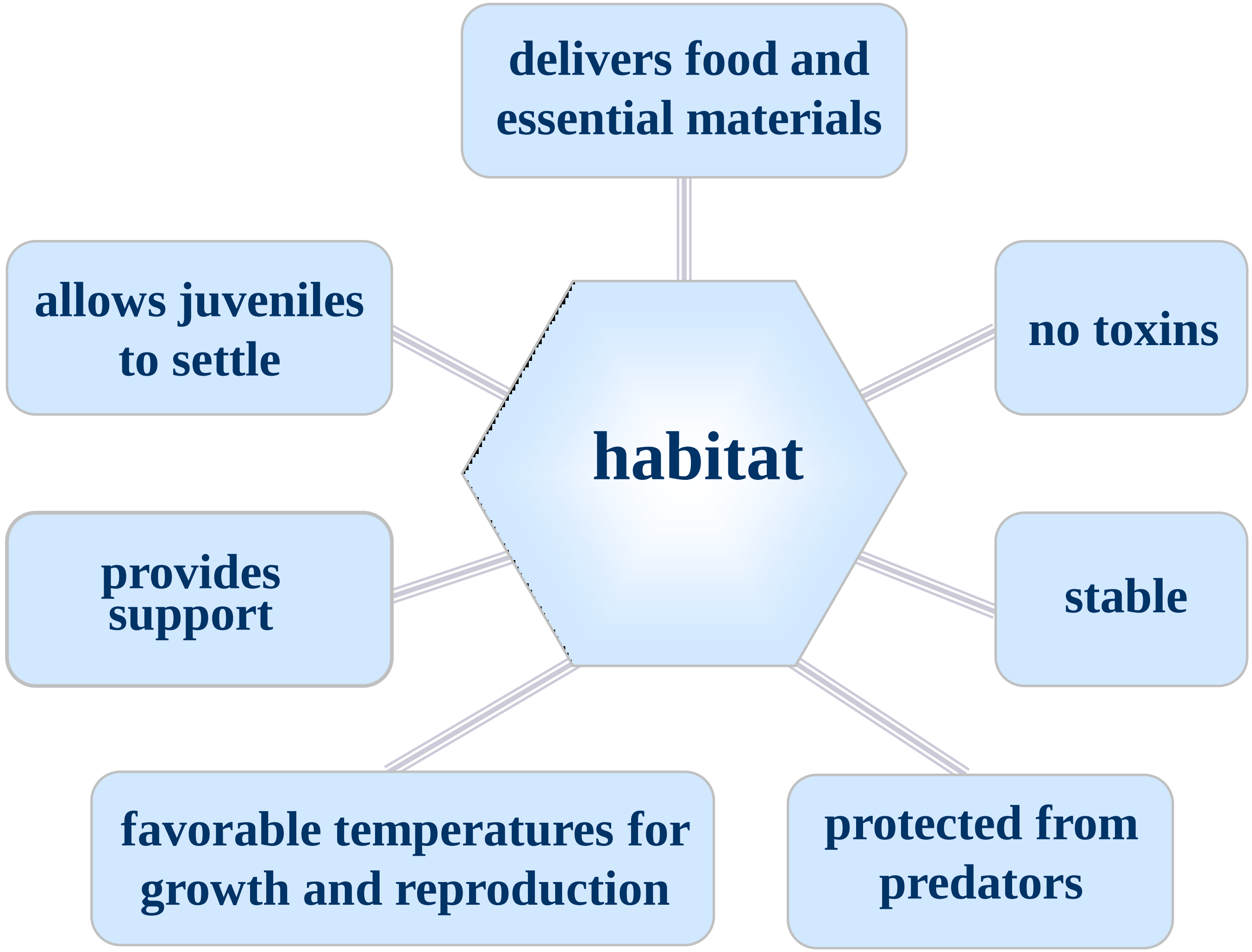
Generalized Population Model



Habitat Descriptions

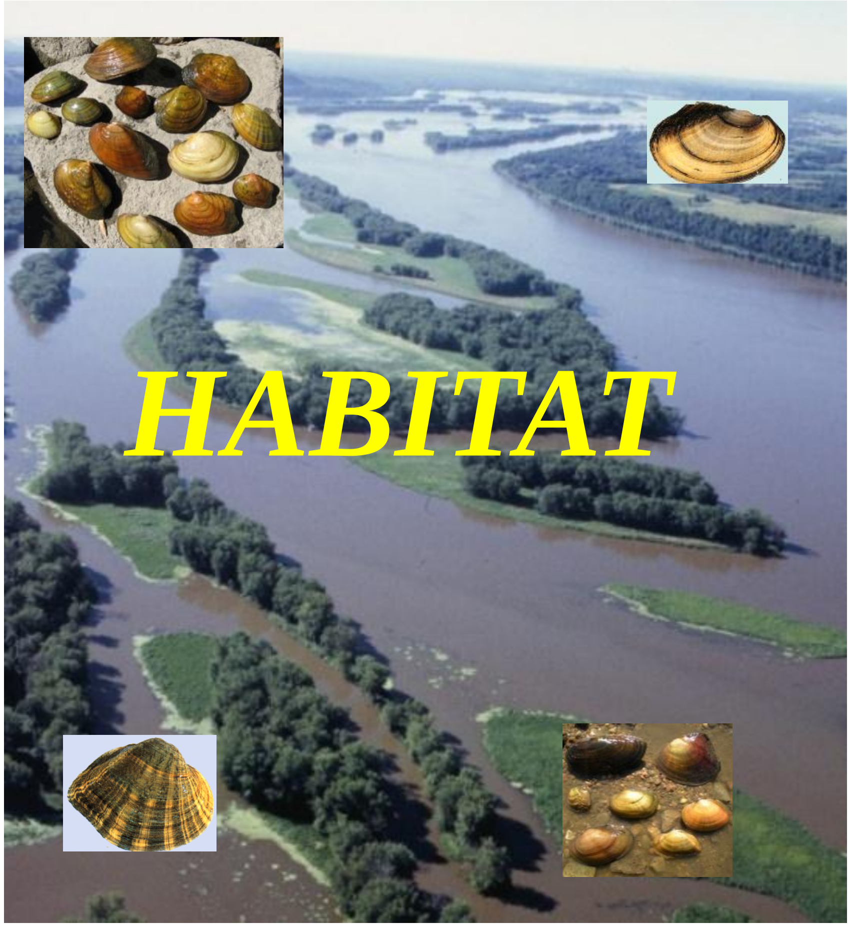
- Mussels are patchily distributed and often occur in multi-species aggregations called mussels beds
- Historic descriptions are vague ("*found on gravel or mud bottoms*" or "*found in stable areas of the river*")
- Traditional approaches have been largely unsuccessful at predicting mussel occurrence or abundance
- Prior research focused on a narrow suite of physical variables (e.g., depth, flow, substrate type)
- Results often not transferable

Functional Attributes Model



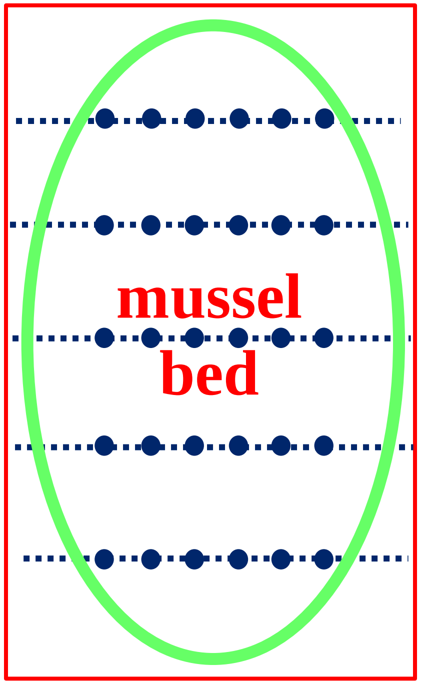
Research Question

What are the geomorphic and hydraulic mechanisms that limit native mussel populations in large rivers?

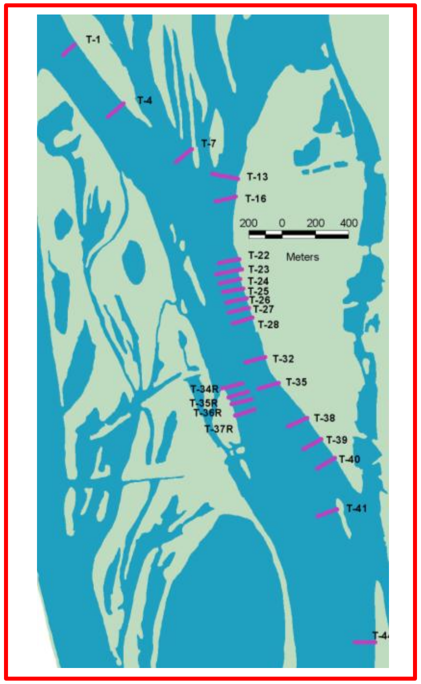


Our Approach

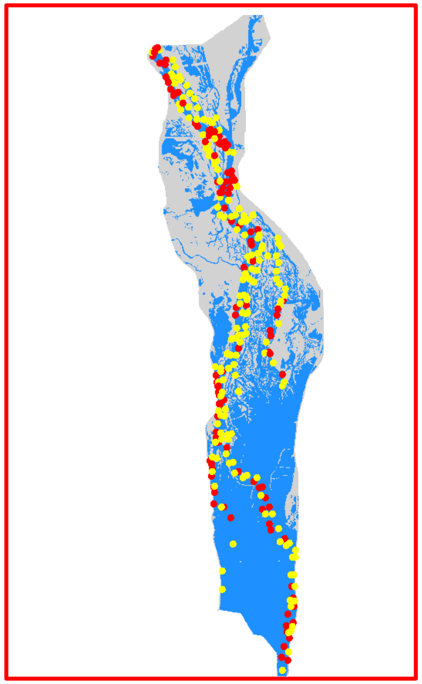
- Over the past 15 years, we have modeled the abundance and distribution of mussels in the Upper Mississippi River (UMR) using physical and hydraulic variables at multiple scales



0.4 km
mussel bed



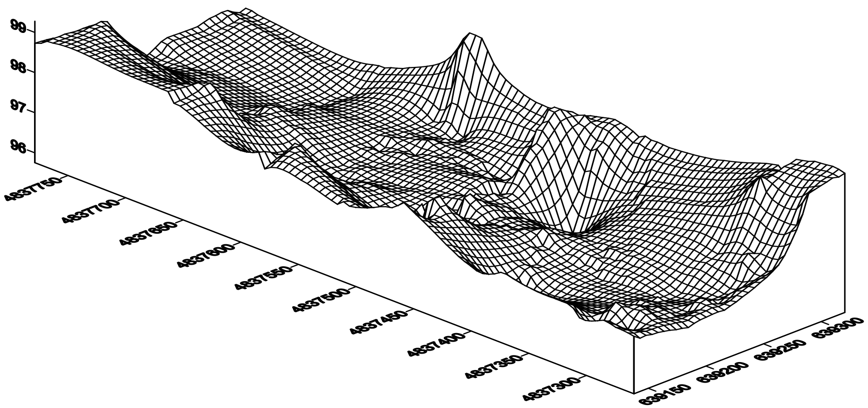
6 km river
reach



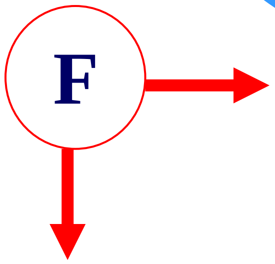
38 km
navigation pool

Needed Building Blocks

- Bathymetry
- Discharge-specific 2D or 3D current velocity (measured or modeled)
- Information on substrate (bed roughness or particle size)
- Hydrologic information relevant to life history and life span



Simple field-measured vs. complex hydraulic variables (flow-conditional)

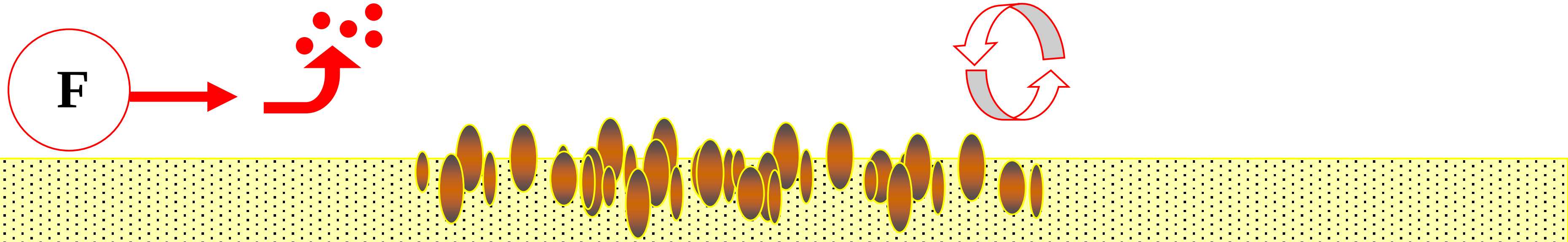


Froude number - ratio of inertial to gravitational forces

Shear stress - tangential force at the riverbed

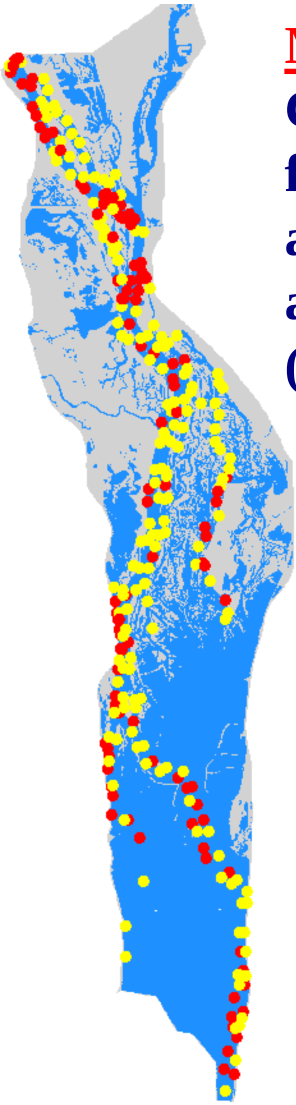
Relative substrate stability - ratio shear stress to shear stress needed to entrain substrate based on particle size

Boundary Reynolds – near bed turbulence



Hydraulic variables are discharge specific!

Data Gathering

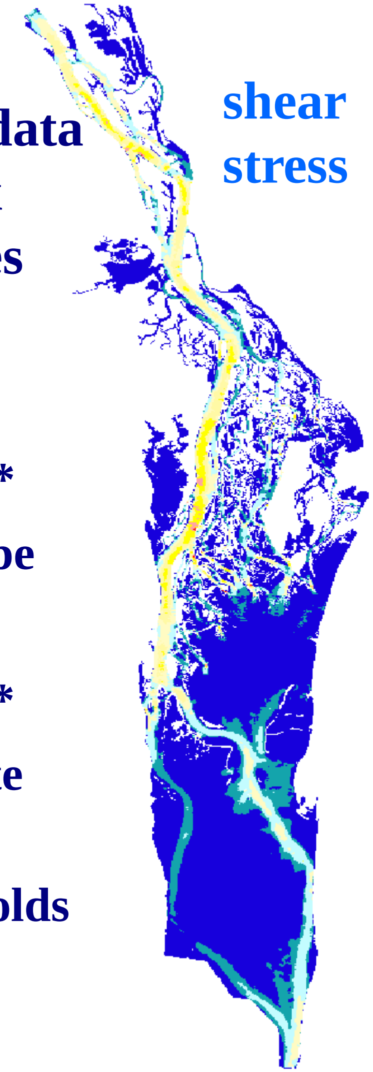


Mussel Data

Compiled from federal, state and private agencies (7 studies)

Hydrophysical Data

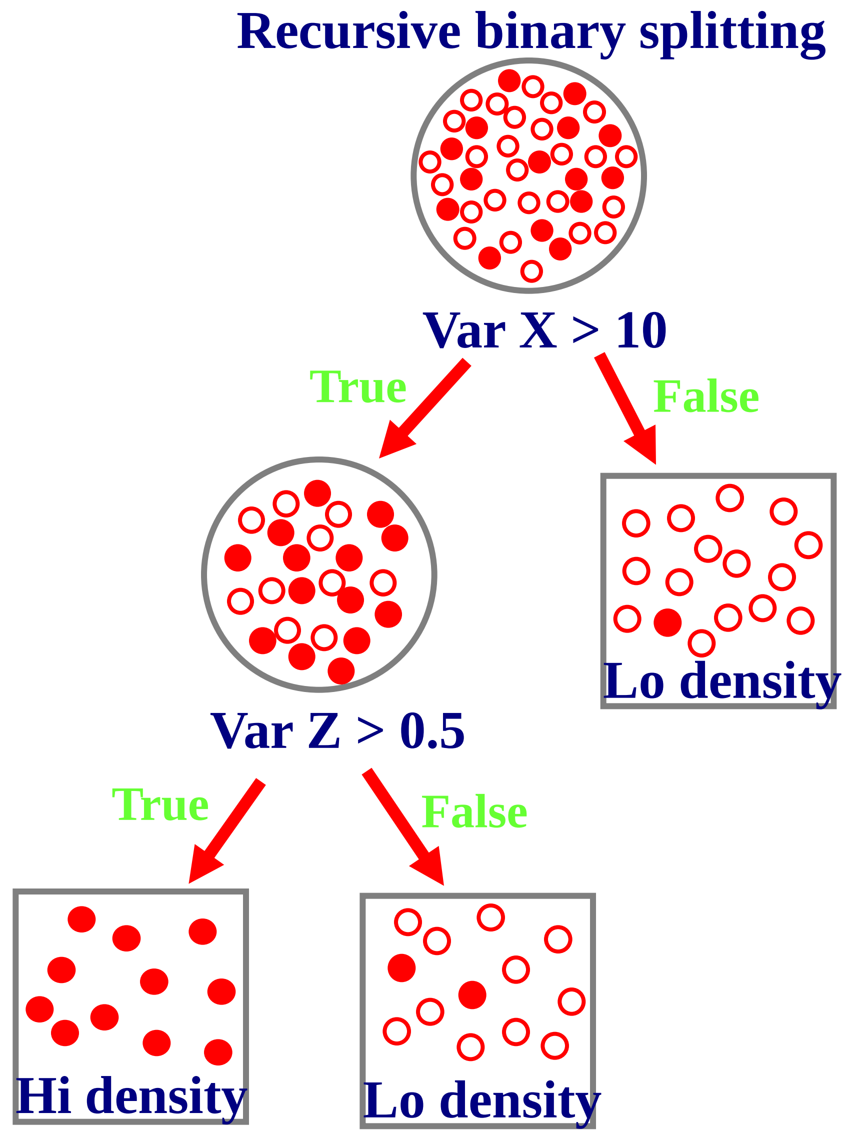
- Constructed GIS data layers for complex hydraulic variables
  - substrate class
  - depth
  - current velocity*
  - bathymetric slope
  - shear stress*
  - Froude number*
  - relative substrate stability*
  - boundary Reynolds number*



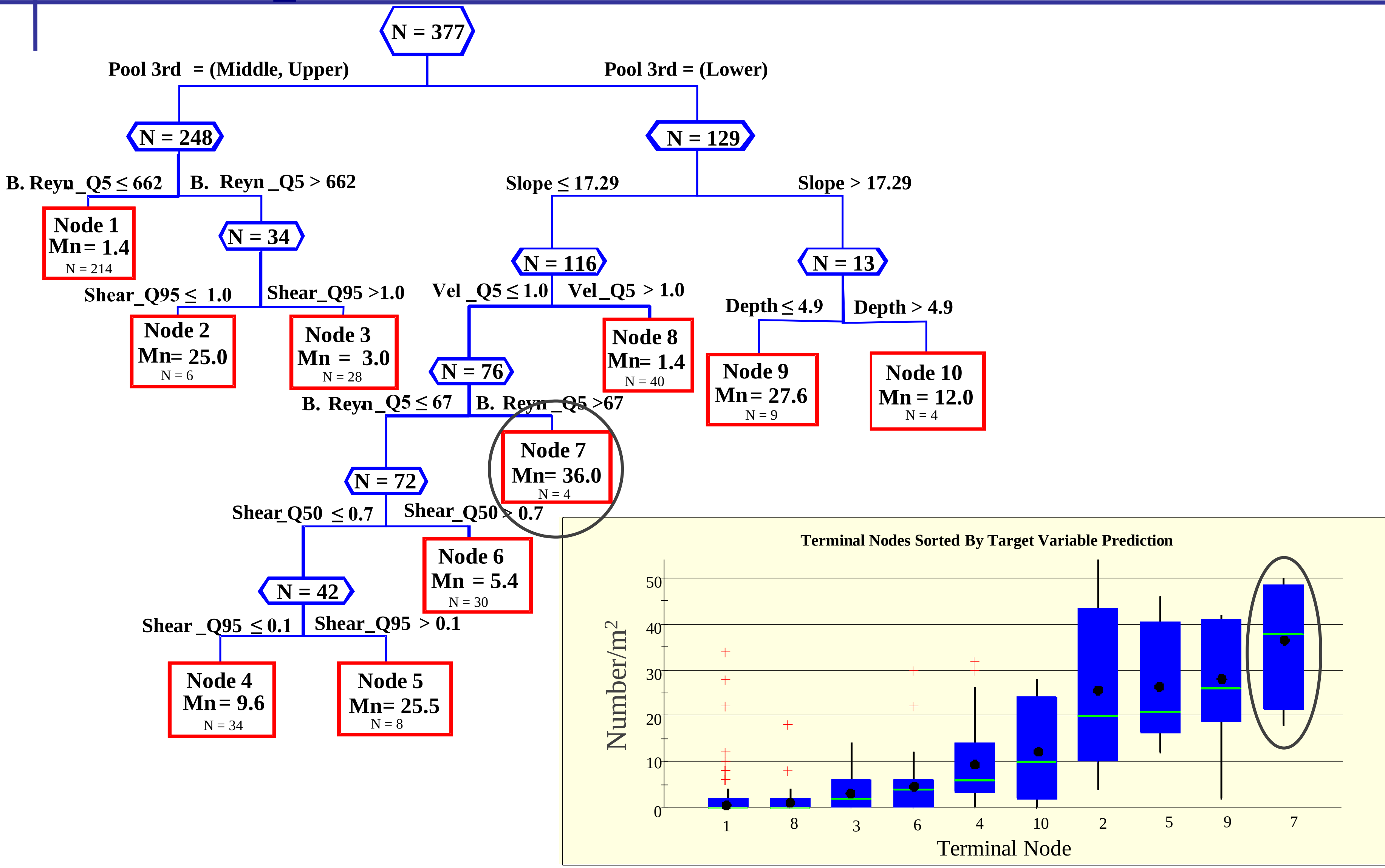
*low (95%), median (50%) and high (5%) discharge

Classification and Regression Tree Models

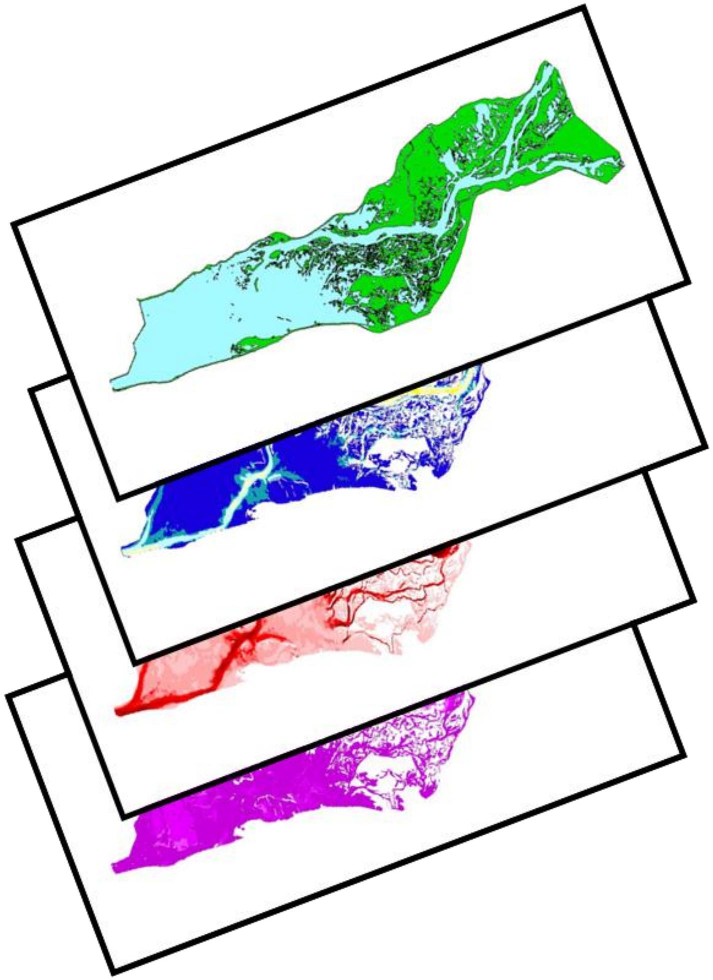
- Distribution-free
- Robust to outliers and missing data
- Context dependent interactions
- *A posteriori* variable selection



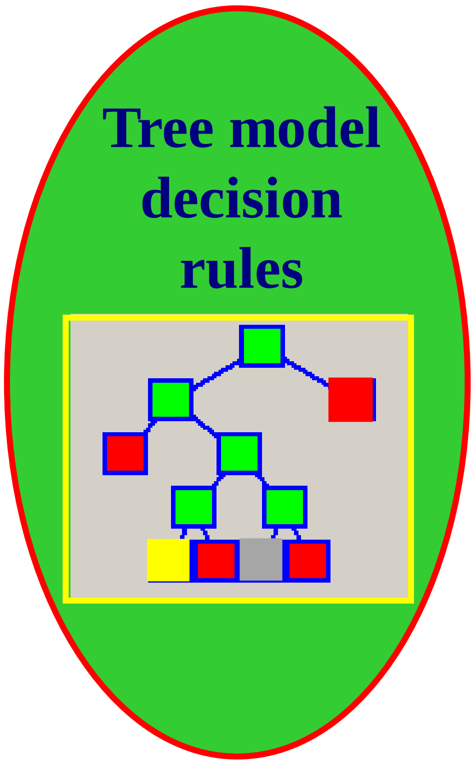
Example CART Model

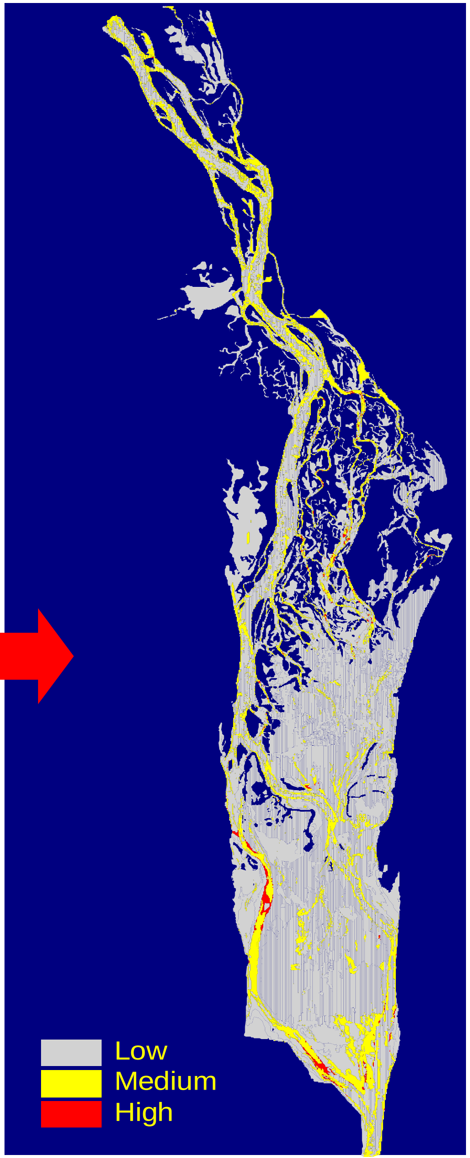


Translating CART Models to Geospatial Models



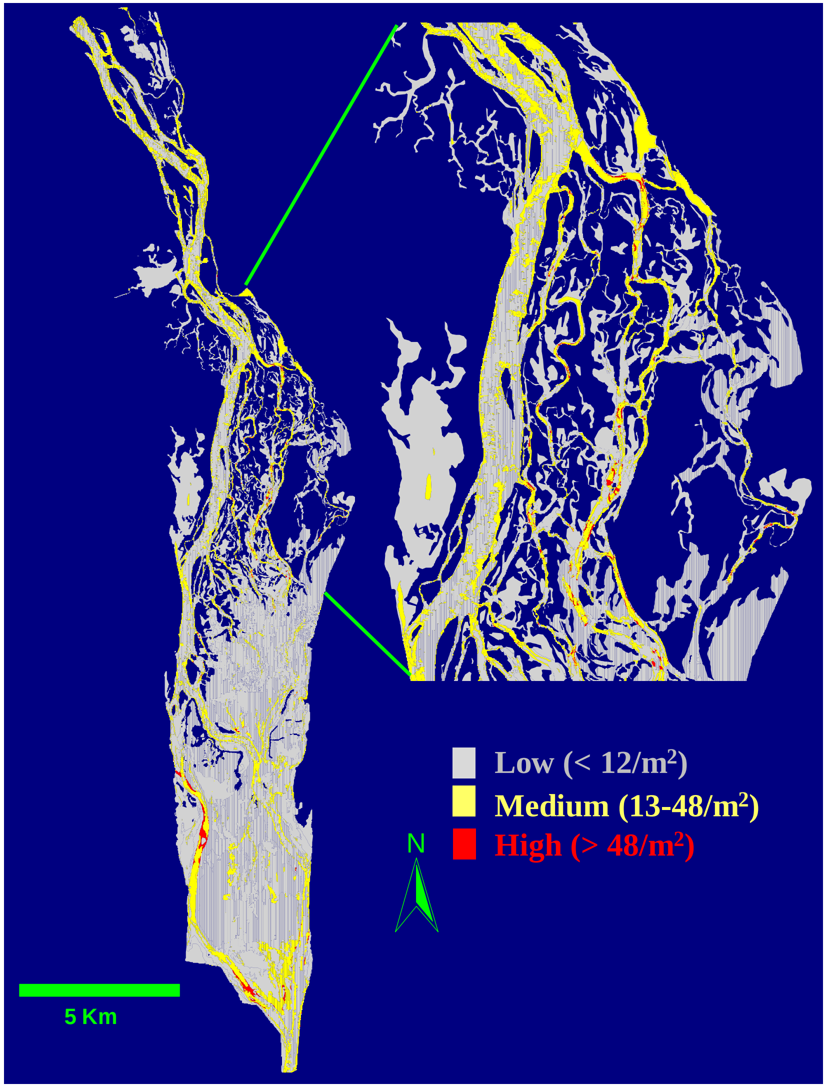
CART analyses of point data





Geospatial Predictions (pool scale)

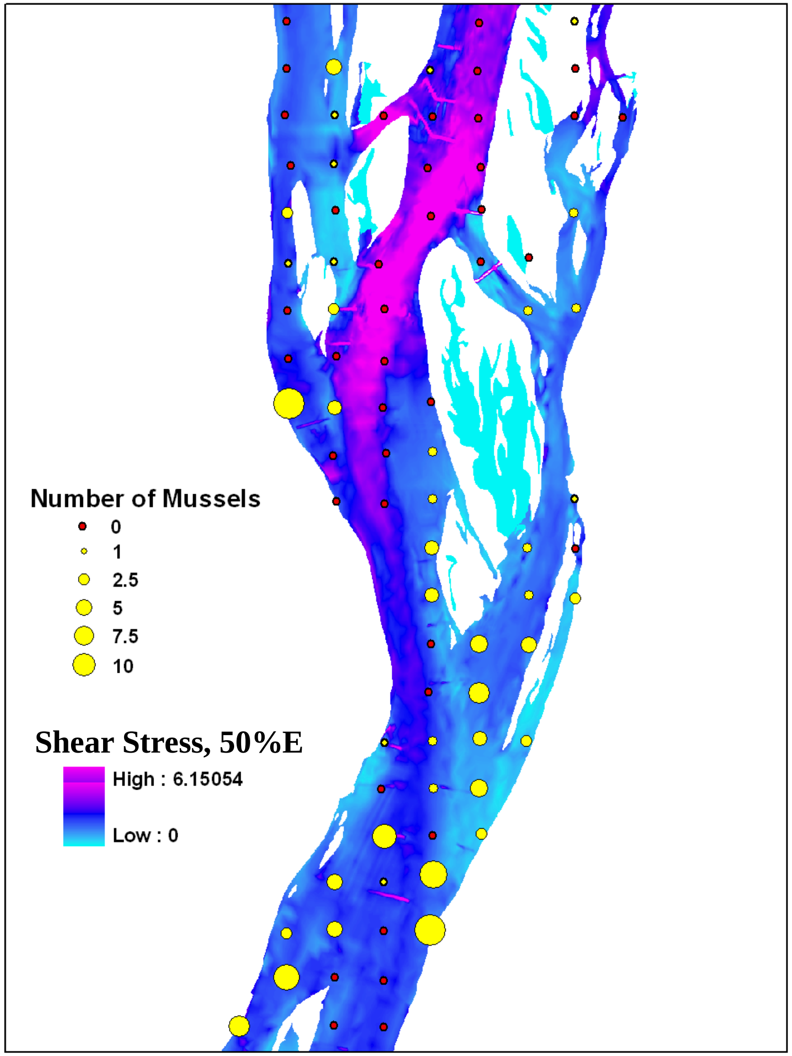
- Few mussels in poorly connected backwater areas and the navigation channel
- Higher densities occur in channel border areas with high geomorphic complexity



Synthesis of Hydrophysical Models

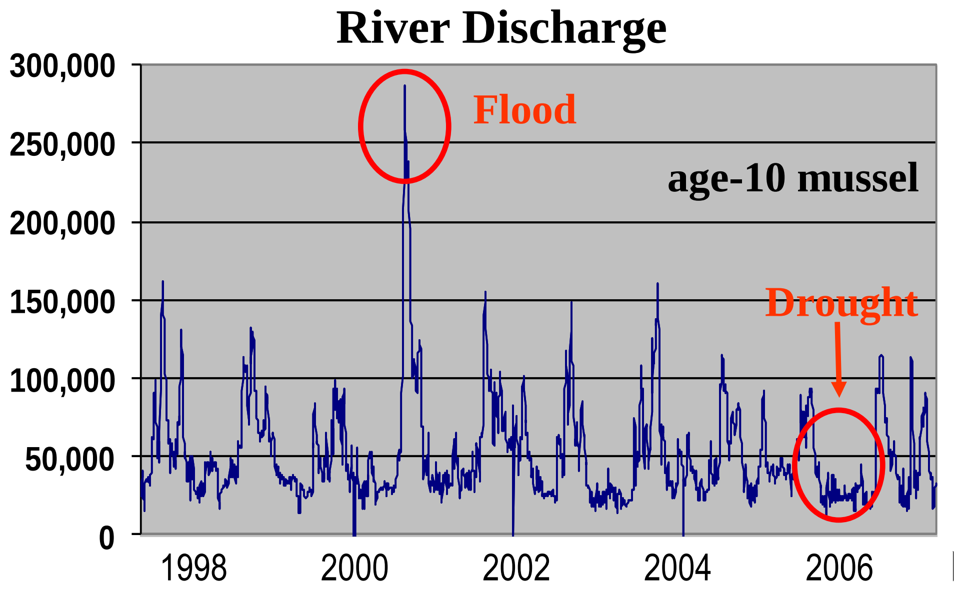
Thresholds for both low and high values of hydraulic variables constrain mussel distributions:

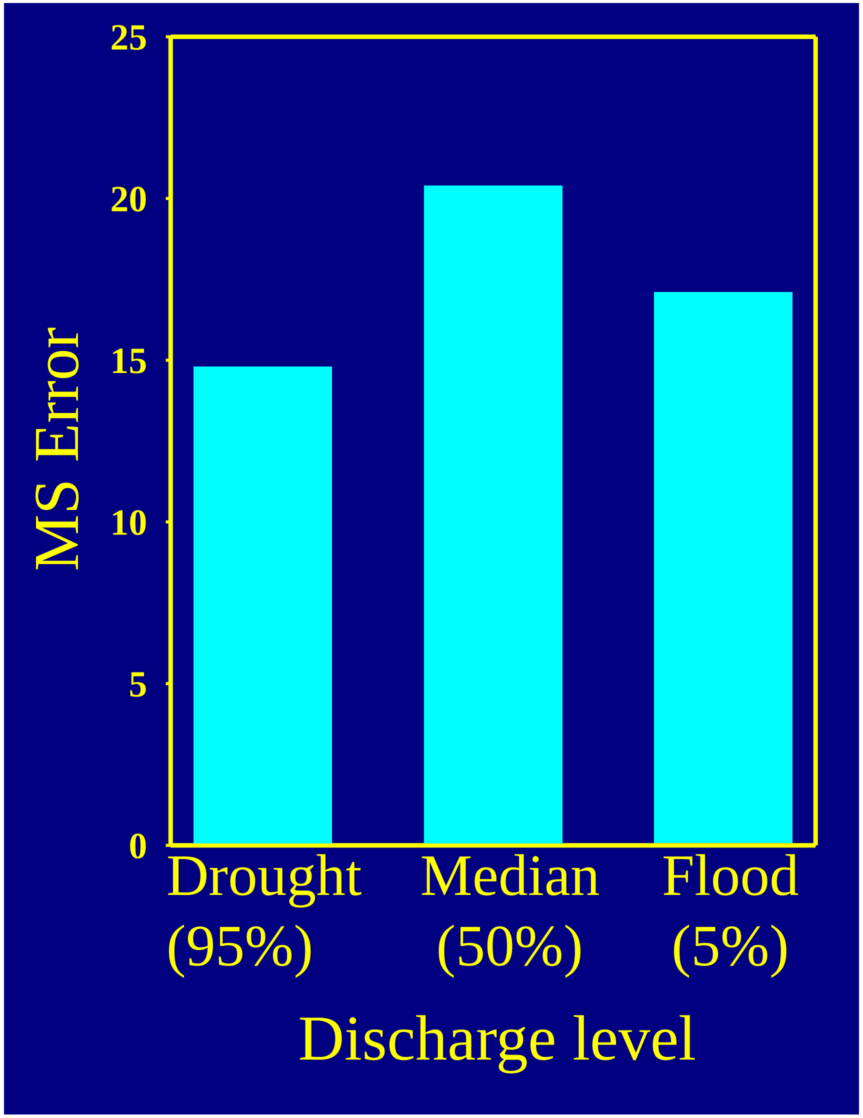
- Receive adequate flow during low water conditions *(bring in food and O_2 and remove wastes)*
- Exhibit high substratum stability and low shear stress under high flow conditions



Does Hydrology Make a Difference?

Models based on median discharge were less predictive than models based on low or high discharges; this suggests that episodic events such as droughts and floods are important in structuring mussel distributions



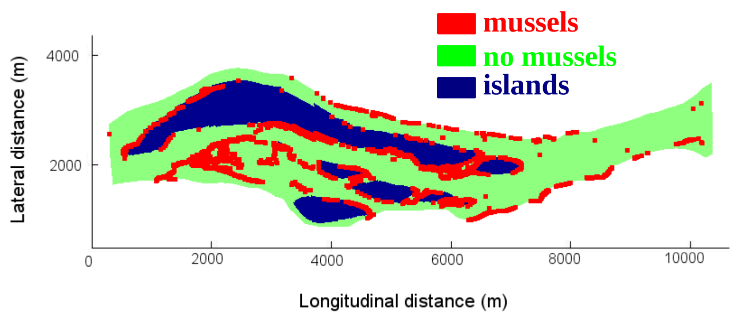


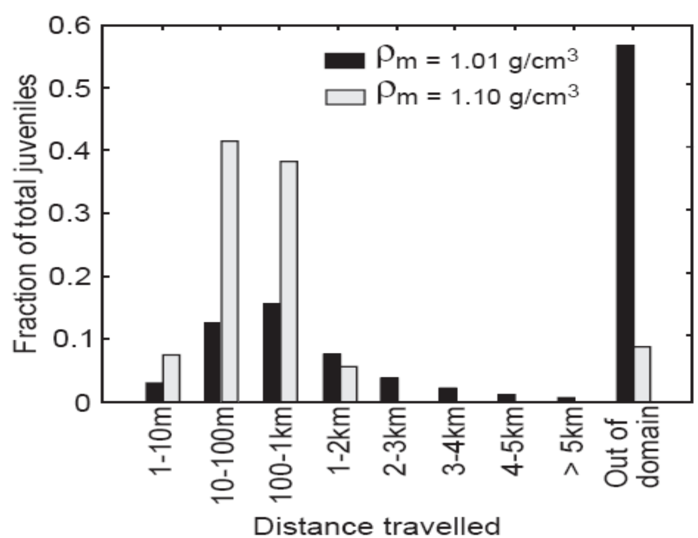
Management Implications

Description	Scale	Important variables	Value	Reference
mussel bed	0.4 km	Froude number	>0.05	Irmscher 2005
river reach	6 km	Boundary Reynolds (Q50)	>2.1	Steuer et al. 2008
		Grain size (Q50)	>2.8 mm	
large river reach	38 km	Shear stress (Q95)	$\leq$ 0.1 dynes/cm^2	Zigler et al. 2008
		Froude number (Q5)	$\geq$ 0.1	
		Slope	$\geq$ 4.4°	
		Depth	$\geq$ 2.6 m	
large river reach	43 km	Pool third	lower	Zigler et al. 2010
		Slope	$\leq$ 17.3°	
		Velocity (Q5)	$\leq$ 1.0 cm/sec	
		Boundary Reynolds (Q5)	> 67	

Hydrology → Hydraulics → Mussels

Juvenile Dispersal

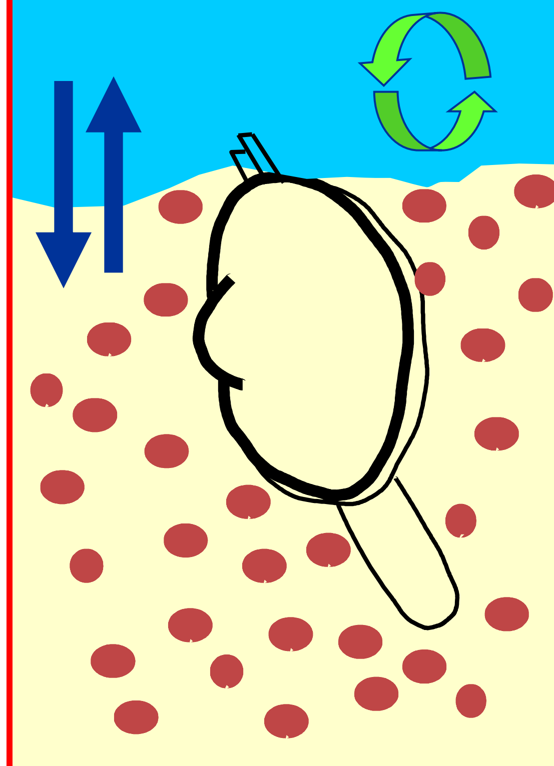




(Morales et al. 2006)

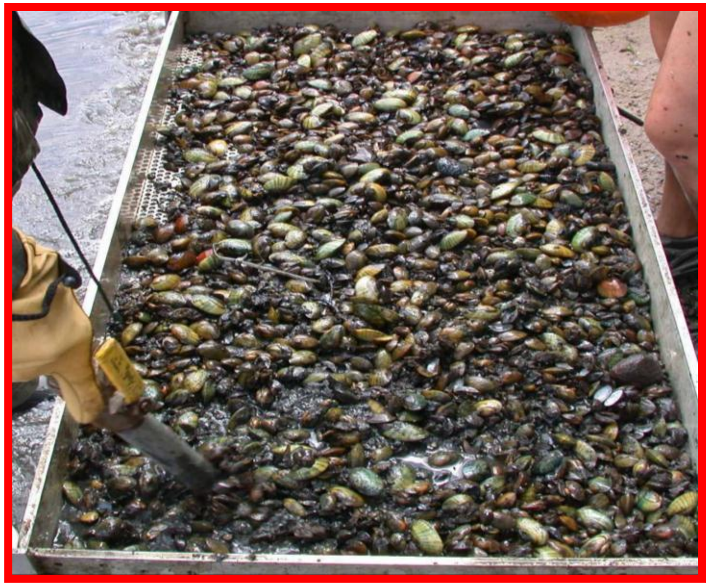
Delivery of food

Exchange of DO, ammonia across sediment-water interface



Inform Restoration Activities ?

- Help discern priority areas for conservation and restoration
- Tool for evaluating restoration designs to help create mussel habitat in the UMR
- Help managers determine where to place cultured juveniles



Opportunities for Habitat Restoration

Conclusions

- Habitat requirements of mussels are complex and not completely understood, but a suite of simple and complex hydraulic variables appear to be important predictors of mussel distribution and abundance in this large floodplain river
- Interaction of geomorphology and discharge produces a template of hydrophysical conditions that can be manipulated by managers to create quality mussel habitat to benefit restoration activities

Vision for Native Mussel Populations

- Is abundant and diverse
- Is self-sustaining
- Provides important ecological services to riverine biota
- Helps maintain good water and sediment quality that benefits all users


Thanks for your attention!!

Threats to Mussels

- Impoundment of streams
- Stream dredging and channelization
- Sedimentation
- Water quality degradation
- Mining
- Modified Hydrology
- Invasive species

Placement of Cultured Juveniles

- If you don't know where mussels are → narrow down area
- If you know where some beds are → identify more areas
- If know where beds are → limited utility ?

Model Predictions

- Few mussels in poorly connected backwater areas and the navigation channel
- Higher densities occur in channel border areas with high geomorphic complexity
- Receive adequate flow during low water conditions *(bring in food and O_2 and remove wastes)*
- Exhibit high substratum stability and low shear stress under high flow conditions