Freshwater Mussels and the New Ammonia Standard

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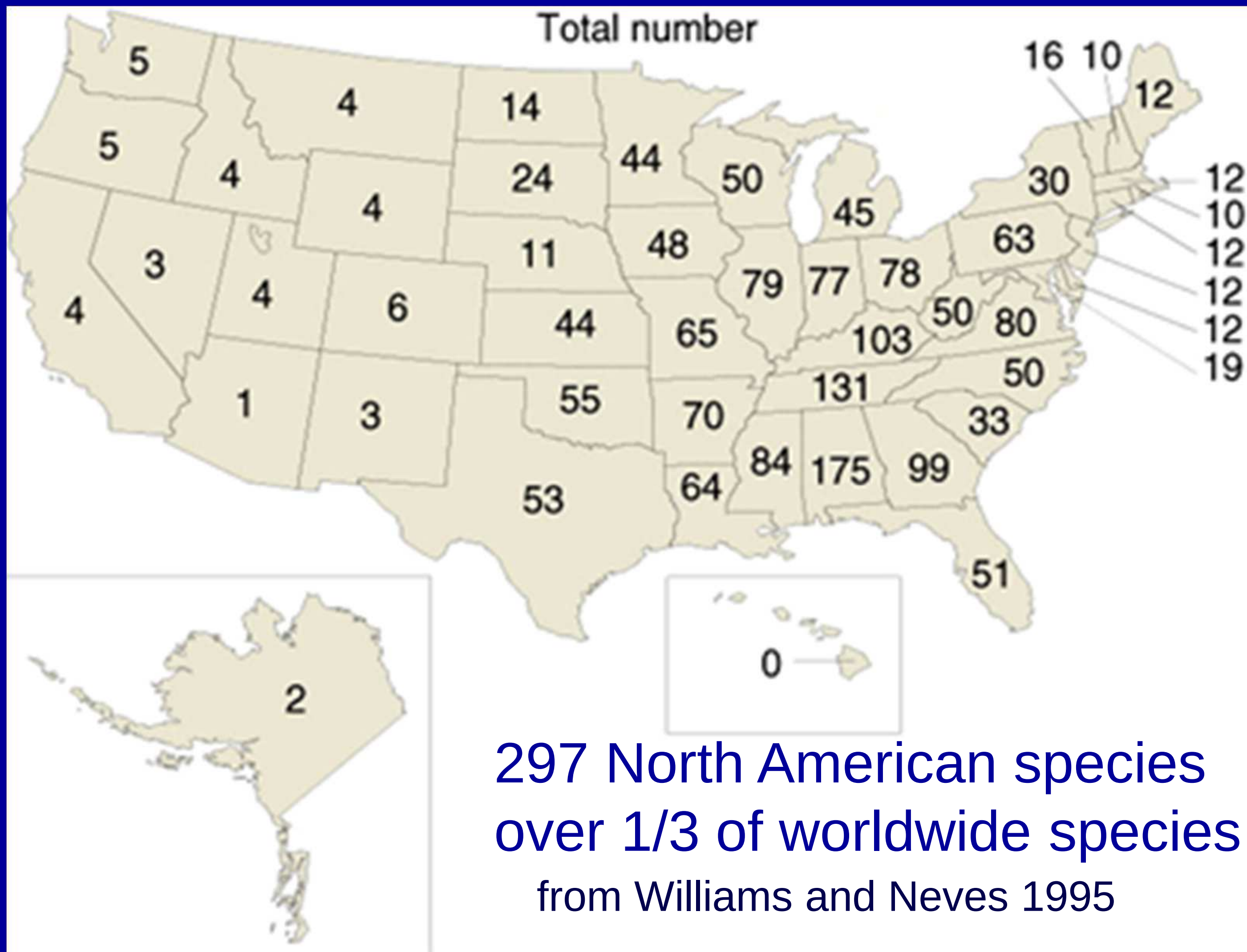
What are Freshwater Mussels?

Class Bivalvia (Bivalves)

- Subclass Paleoheterodonta
  - **Order Unionoida/Unionida-native**
    - **Family Unionidae**
    - **Family Margaritiferidae**
- Subclass Heterodonta
  - Order Veneroida
    - **Family Sphaeriidae (fingernail clams)-native**
    - Family Corbiculidae (asian clams)-introduced
    - Family Dreissenidae (zebra/quagga mussels)-intro.

Unionoida Distribution in USA



297 North American species
over 1/3 of worldwide species
from Williams and Neves 1995

Unionids are Unique

Unio=Pearl in Latin

Evolved in freshwater riverine ecosystems-

Depend on hydrological cycle

- Floods/droughts

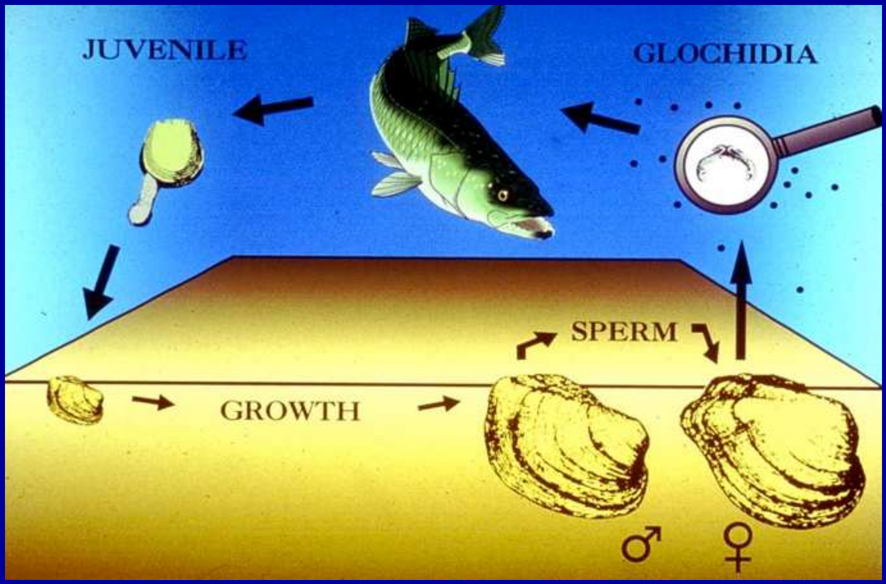
Depend on local hydraulic conditions

- Flow refugia
- Bed stability

Presence of mussels indicative functioning river system –

"Canary in the coal mine"

Unique Life Cycle



Male releases sperm balls

Female takes up sperm balls

Fertilized eggs develop in gills

Eggs develop into glochidia

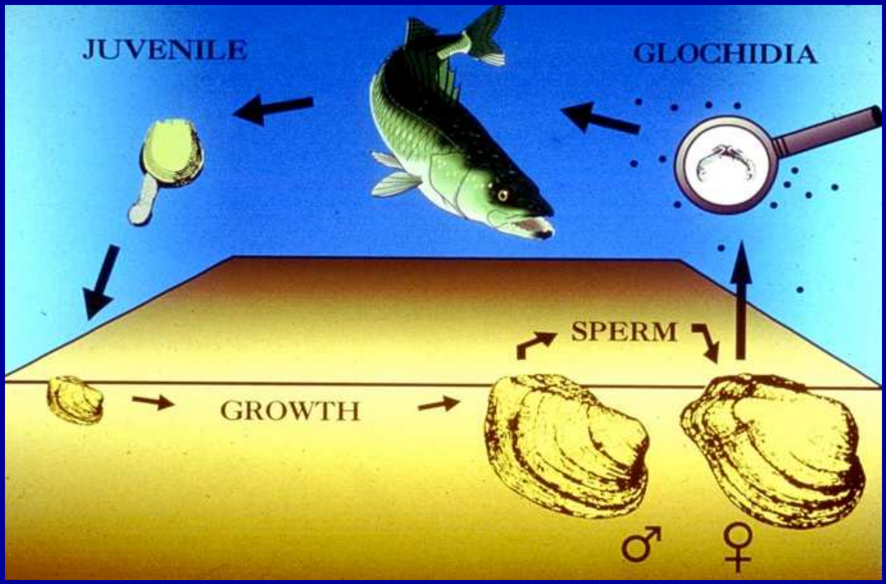
(larval unionid mussels)

Glochidia attach to fish host

Metamorphosis on fish host

Juvenile drops off

Why the fish host?



Downstream migration w bedload

Upstream migration on fish

Very Alluring

Snuffbox snaring a log perch

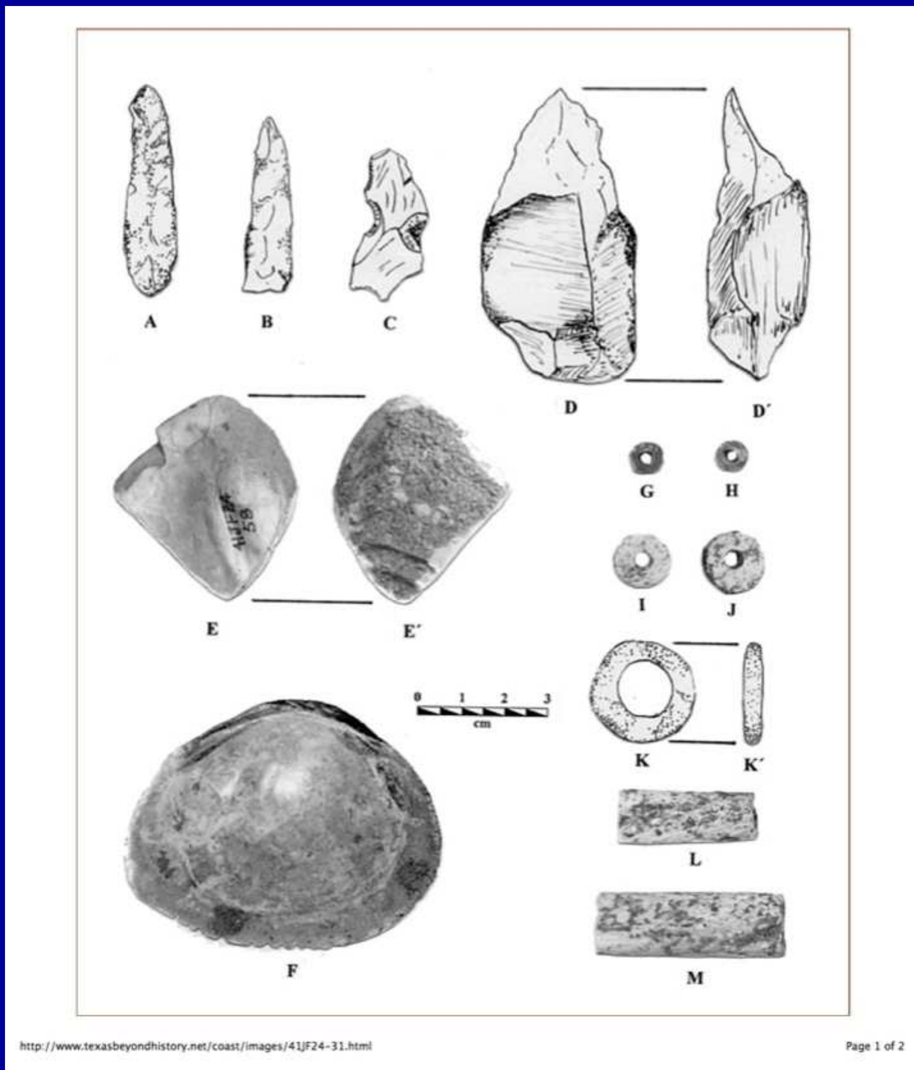
Ouachita Kidneyshell conglutinates

Orange nacre mucket super-conglutinate

Broken-rays mussel mantle flap

Barnhart, M. C. 2008. Unio Gallery: http://unionid.missouristate.edu.

What are they good for?



Cultural Heritage

Food
Shell tools
Beads
Pearls
Pottery

Commercial Value

Pearl Button Industry
Late 1800's to early 1950's
Raw shell >$1mil/yr
Buttons >$6mil/yr

Cultured Pearl Industry
Mid 1950's to present
- Declined due to declining number of mussels,
- Zebra mussel infestation
- Development of alternate nuclei

Ecosystem Services

Supporting Services

- Structural habitat
  - -cover for fish
  - -substrate for algae, insects, snails
    - Attract fish
- Substrate modification –aeration, stability
- Food for other organisms
  - - fish, muskrats, otters, raccoons

Water Purification Services

Adult mussel filters 0.1-3L gram dry tissue/hr

or

5-144 L/mussel/day

Photo and Data provided by Caryn Vaughn and Chris Barnhart

Nutrient Cycling

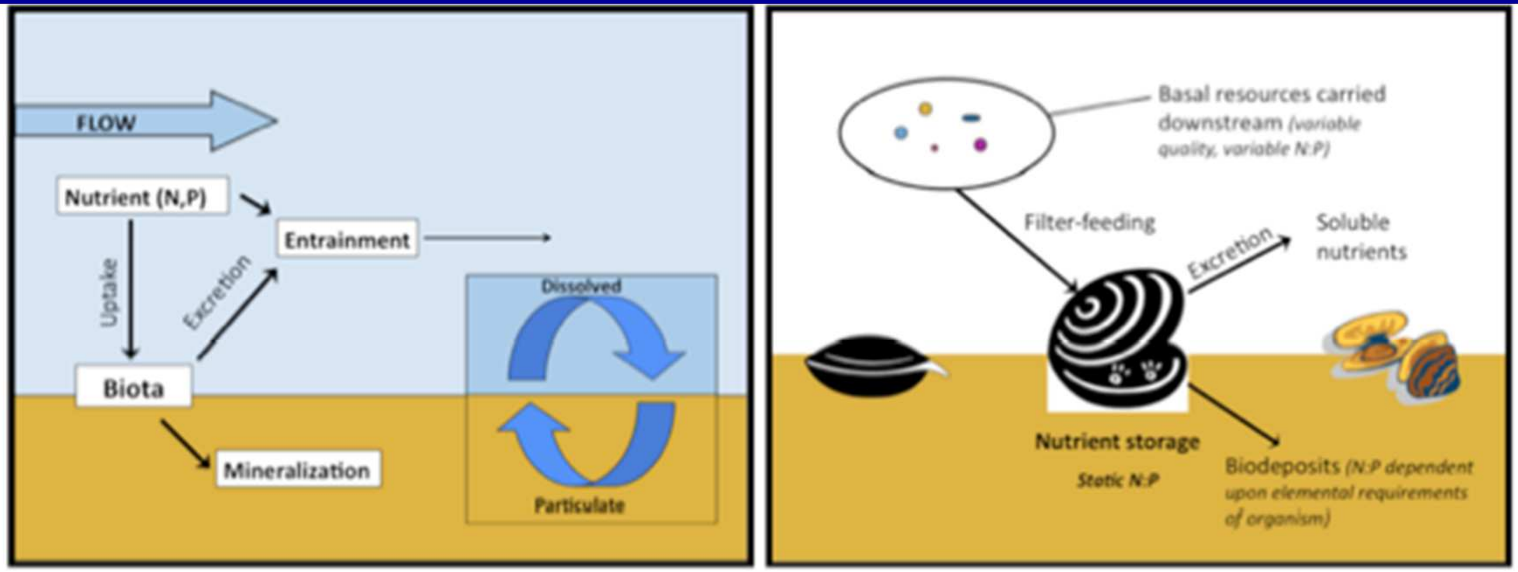


Figure 4. Left panel: nutrient recycling in a stream reach. Right panel: proposed mussel role in nutrient recycling.

Nitrogen storage in soft tissue

26kg N/km

42 kg N/mile

Diagram from Carla Atkinson; data provided by Caryn Vaughn

Very Endangered

United States

- about 297 species
- 21 Extinct since 1900
- 88 Federally threatened or endangered
- 70% of fauna imperiled

Male and Female Scaleshell

Male Higgins Eye Pearly mussel

Most states also have Unionoida listed as threatened and endangered

Why so endangered?

Habitat loss – Modification of rivers/streams

Poor water quality

Sedimentation – Siltation

Commercial harvest

Invasive species –
Zebra mussels, Asian clams

What are we loosing?

Unique animals

What other animals can fish?

Produce pearls

Biodiversity

River's natural filtering system – increased stream clarity

Habitat for plants and animals – increased fish and fishing

Stream/river stability

Tourism and Recreational opportunities

How can we help these animals and our rivers?

National Strategy for Conservation of Native Freshwater Mussels
(1998 currently under revision)

- Preserve/Enhance Existing Communities
- Protect/Enhance/Create Habitat
- **Improve Water Quality**
- Propagation/Population Augmentations

Preserving/Improving Water Quality

“Current water quality standards are insufficient to protect mussels”

National Strategy Section 5.2-
Determine if water quality criteria protect all life stages of freshwater mussels

- Standard Protocols for mussel toxicity testing-2006

ASTM E2455 - 06 Standard Guide for Conducting Laboratory Toxicity Tests with Freshwater Mussels

Propagation/Population Augmentation

- Missouri State
- Virginia Polytechnic Institute
- Ohio State University

- U. S. Fish and Wildlife Service Hatcheries
- State Hatcheries
- Zoos

Data and photos from Chris Barnhart (MO State) and Steve McMurray (MDC)

Mussels are very sensitive

14 Acute WQC comparisons…

Criteria	GMAVs in WQC	GMAVs w/Mussels	Lowest Mussel Rank (1 = Most Sensitive)
Ammonia (1999)	34	42	1 (1, 2, 3, 4)
Ammonia (2009 draft)	67	67	1 (1, 2, 4)
Atrazine (2003 draft)	17	21	15
Cadmium (2001)	55	60	7
Chlorine (1985)	28	35	2 (2, 5, 9, 14)
Chlorpyrifos (1986)	15	16	13
Copper (1996)	43	57	1 (1, 2, 3)
Copper-BLM (2007)	27	35	1 (1, 2, 4)
Diazinon (2005)	20	21	21
Lead (1984)	10	11	2
Mercury (1995)	29	30	10
Nonylphenol (2005)	15	21	13
PCP (1995)	33	38	17
Zinc (1995)	36	43	3

Mussels are very sensitive

Mussels among most sensitive to Ammonia and Copper

Mussels in lower 15% for Chlorine and Zinc

Acutely tolerant to some other toxicants

Ammonia Sensitivity

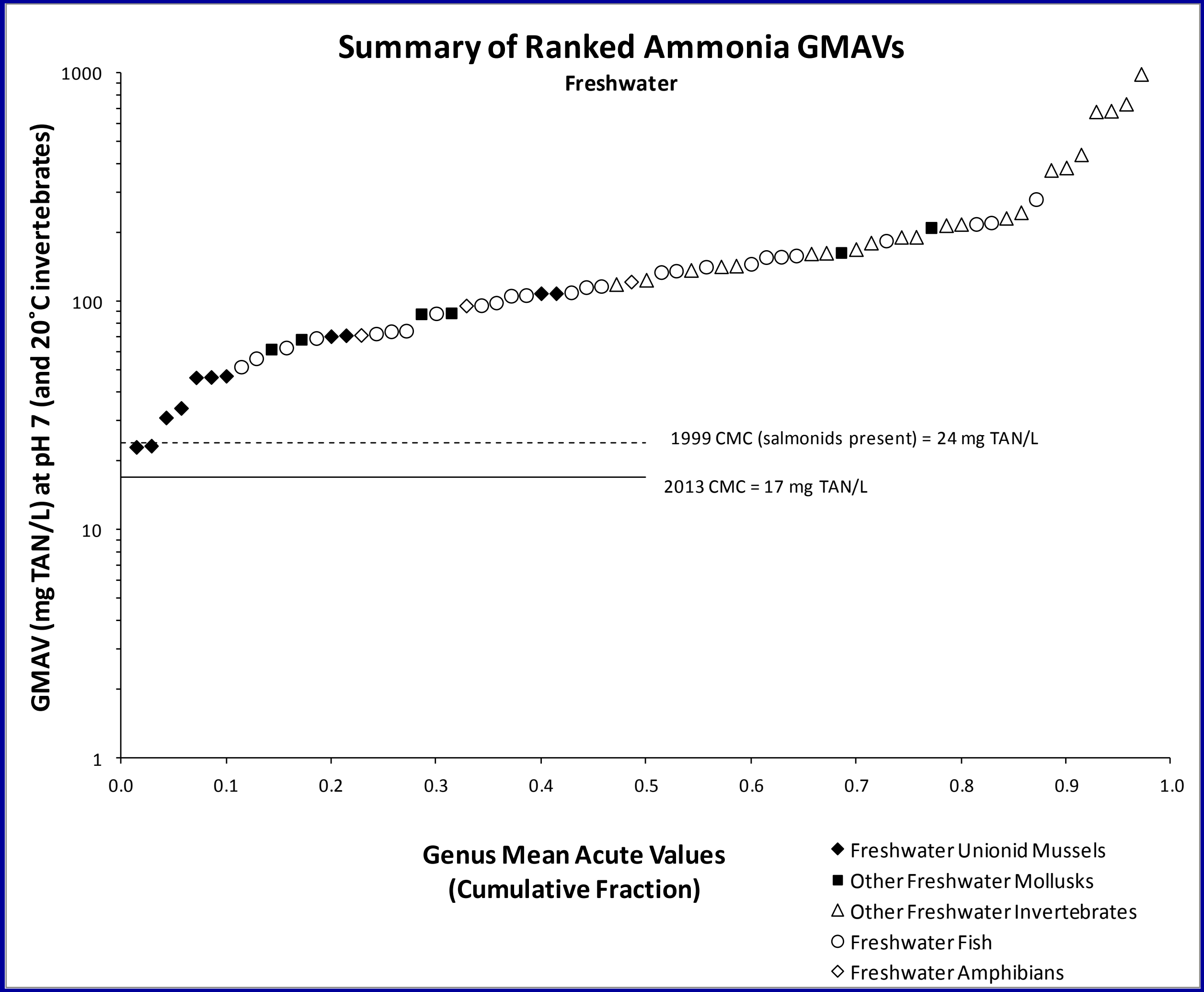


Figure 3. Ranked Freshwater Genus Mean Acute Values (GMAVs) with Criterion Maximum Concentrations (CMCs).

Ammonia Sensitivity

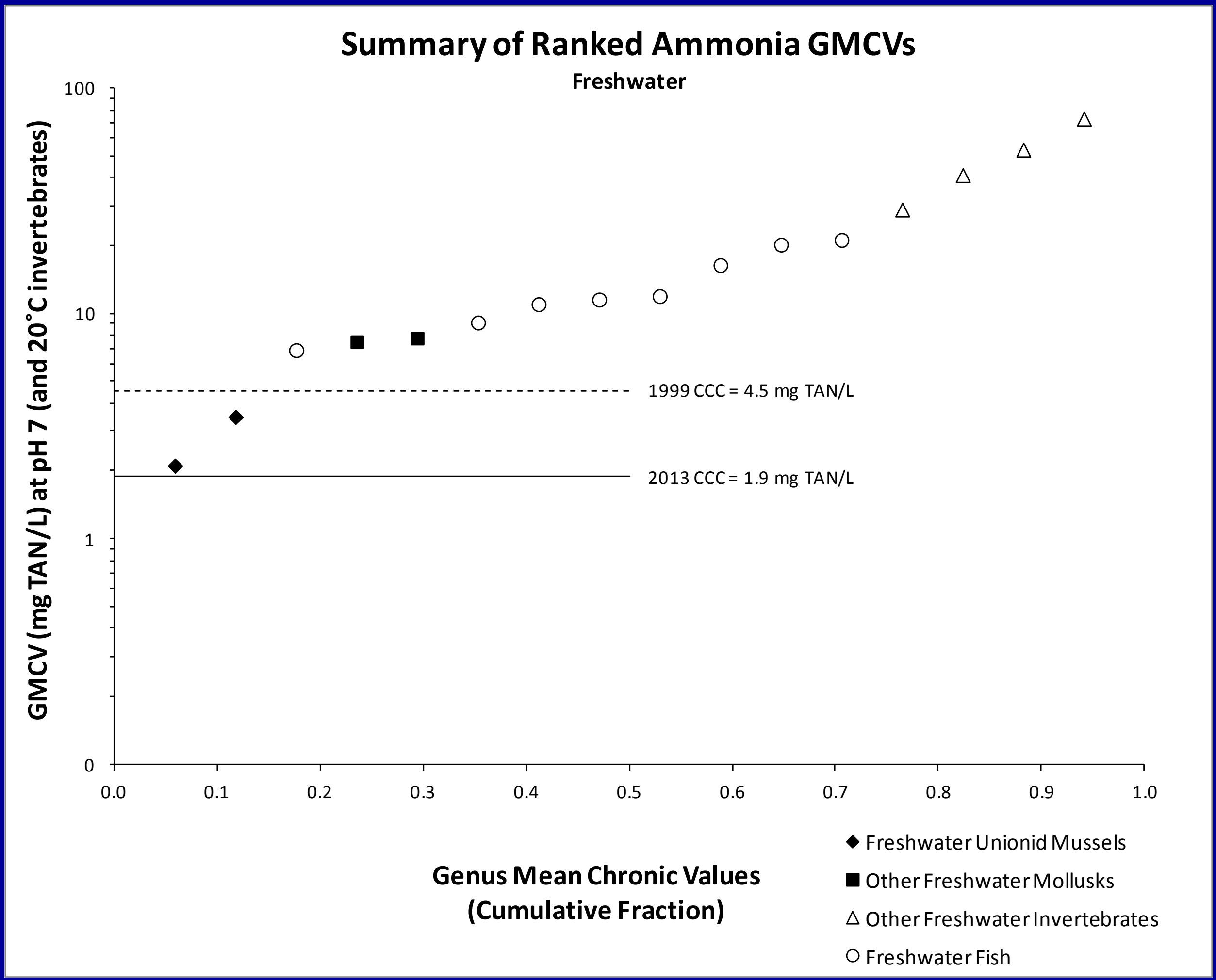


Figure 4. Ranked Freshwater Genus Mean Chronic Values (GMCVs) with Criterion Continuous Concentrations (CCCs).

Tested Species-are they representative?

- 15 species
- Rank 1 to 15 in sensitivity
- Interior basin to the Atlantic slope
- Small stream to large river
- Low gradient to high gradient
- Restricted to widespread distribution
- Rare to common
- 4 Federally endangered

2013 USEPA Standard

- States will adopt 2013 Standard

- Summer
  - 1.7 mg/L maximum daily
  - 0.6 mg/L monthly average
- Winter
  - 5.6 mg/L maximum daily
  - 2.1 mg/L monthly average

Flexibility

- Recalculation procedure for site specific criteria
- Variances
- Revisions to designated uses
- Dilution allowances
- Compliance schedule

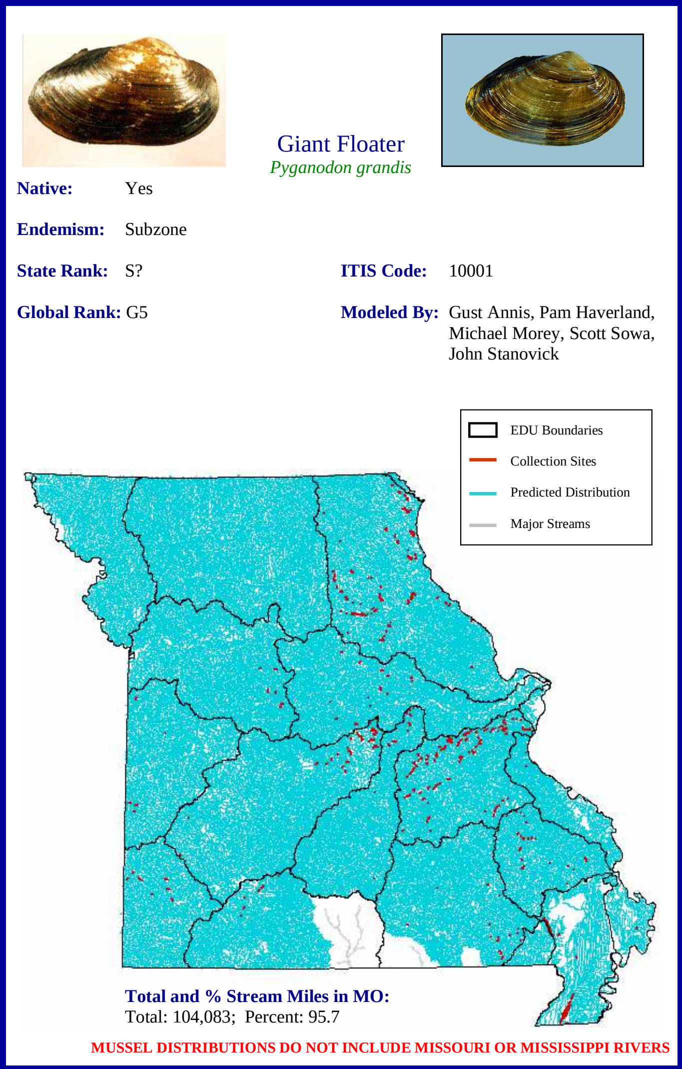
How do we implement it?

- Where do Unionid mussels live?
- Are they places they don't/can't live?
- Are all species the same?
- How do we sample mussels?
    - Presence/Absence
    - Species composition
- How do we define a site?
    - How far downstream?
    - Can mussels move back in?

Live in 98% permanent aquatic habitats

- Large to small rivers/streams
- Ponds/lakes
- Don't forget snails- live in many areas without mussels

- Species preferences
  - Stream size
  - Temperature
  - Substrate preference
  - Flow preferences



Missouri GAP analysis (USGS, 2005)

Ubiquitous to Restricted

Fatmucket
Lampsilis siliquoidea

Native: Yes

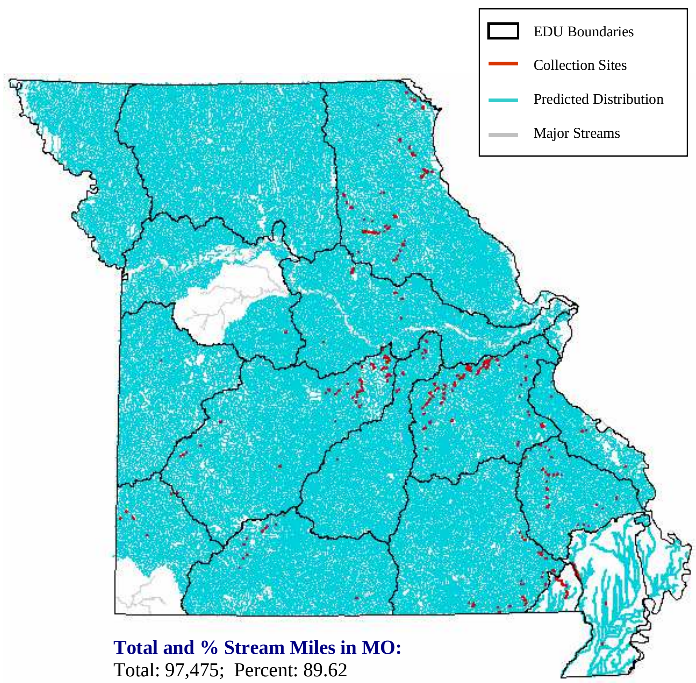
Endemism: Subzone

State Rank: S?

ITIS Code: 80028

Global Rank: G5

Modeled By: Gust Annis, Pam Haverland, Michael Morey, Scott Sowa, John Stanovick



Total and % Stream Miles in MO:
Total: 97,475; Percent: 89.62

MUSSEL DISTRIBUTIONS DO NOT INCLUDE MISSOURI OR MISSISSIPPI RIVERS

Curtis Pearlymussel
Epioblasma florentina curtisii

Native: Yes

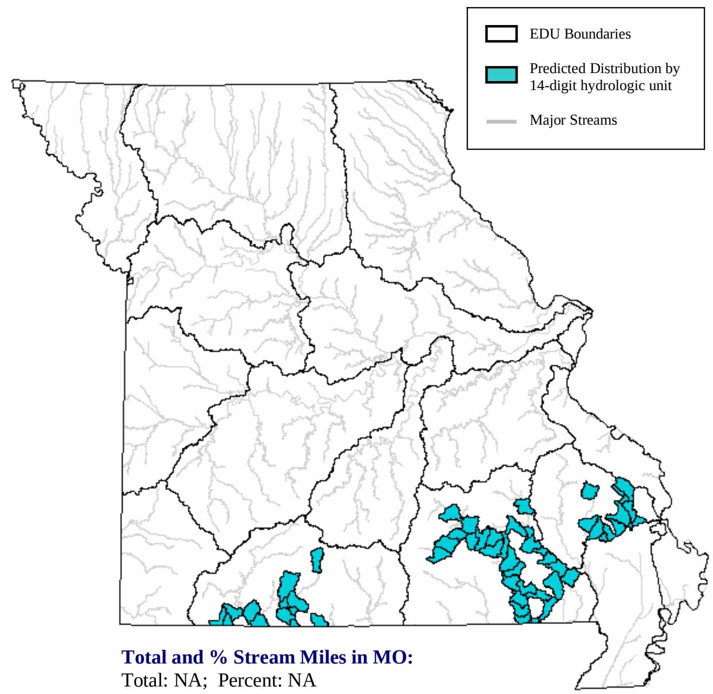
Endemism: Ecological Drainage Unit

State Rank: S1

ITIS Code: 80310

Global Rank: G1T1

Modeled By: Gust Annis, Pam Haverland, Michael Morey, Scott Sowa, John Stanovick



Total and % Stream Miles in MO:
Total: NA; Percent: NA

MUSSEL DISTRIBUTIONS DO NOT INCLUDE MISSOURI OR MISSISSIPPI RIVERS

Where do they live?

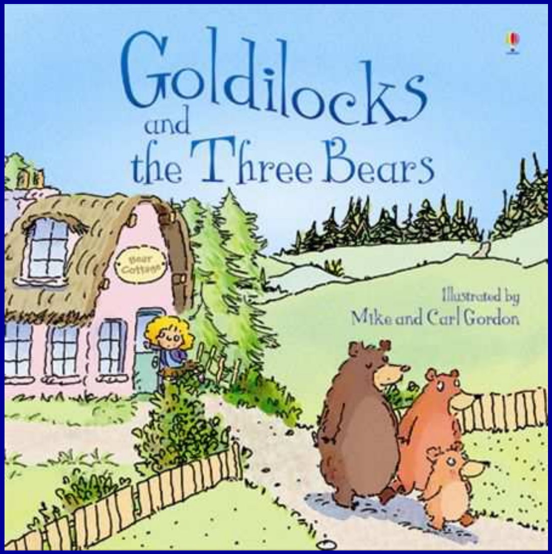
- **Most** Species in Mussel Beds in Permanent Streams/Rivers
  - Mussel Community
  - Multiple species
  - Multiple size classes
  - Density greater than surrounding area
  - Physical boundaries

Habitat Attributes

- Allows juveniles to settle
  - Shears not excessive
- Provides support
  - Soft enough for burrowing
  - Firm enough to support
- Stable
  - Stays in place during floods
  - No sudden scour or fill
- Delivers food
  - Sediment organic matter (juvs)
  - Suspended food (adults)
- Delivers essential materials
  - Oxygen
  - Calcium
- Provides favorable temperatures
  - Growth
  - Reproduction
- Protection from predators
- No toxic materials
- Habitat for fish hosts

Physical Habitat

Moderate Flow and Stable Substrate



- Moderate velocity
- Refuge from high velocity
- Limited siltation
- Low hydrological variability
- Heterogeneous substrate
- Stable substrate for flow conditions
- Loose enough for interstitial flow

What defines the physical boundaries?

- Changes in substrate, depth, and current velocity
- Substrate, depth, and current velocity result of entire hydrological cycle
- Complex hydraulic variables correlate with mussel present, species
  - Shear stress – Tangential force acting on a streambed (force/area; dynes/cm^2)
    - Depth and velocity are forces acting on the substrate
  - Relative substrate stability (RSS) – Shear stress/critical shear stress – shear stress needed to move substrate
  - Substrate complexity and roughness affect force needed for movement
  - Near bed turbulence- boundary Reynolds number, substrate roughness

Morales- Pool 16

- 566 m^3/s= 99% exceedance
  - Low flow
- 2039 m^3/s= 35% exceedance
  - Average flow
- 3965 m^3/s=5% exceedance
  - Mean peak annual flow

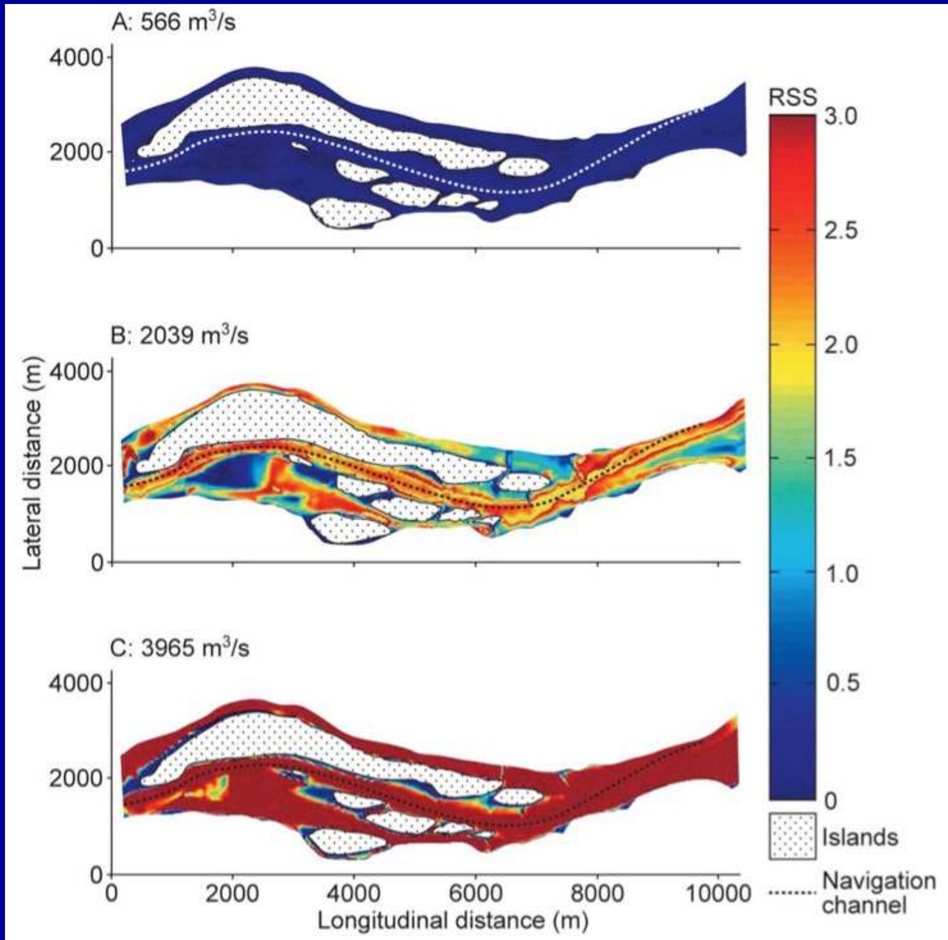


Fig. 3. Variation in shear stress ratio (RSS) in the study area across 3 flow regimes: 566 m^3/s (A), 2039 m^3/s (B), and 3965 m^3/s (C). An RSS > 1 indicates areas where the shear stress required to initiate sediment motion has been exceeded. Flow direction is from right to left.

RSS<1=Stable Substrate

- 566 m^3/s= 99% exceedance
  - Low flow
- 2039 m^3/s= 35% exceedance
  - Average flow
- 3965 m^3/s=5% exceedance
  - Mean peak annual flow

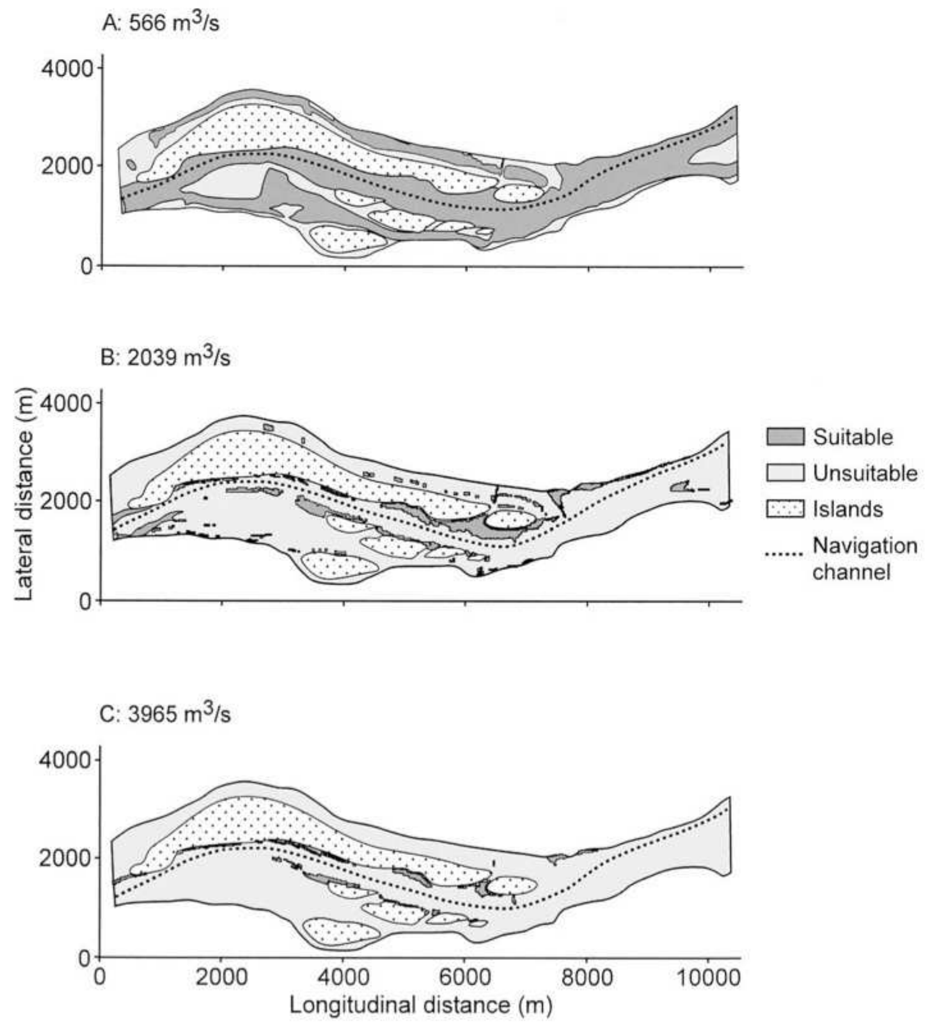
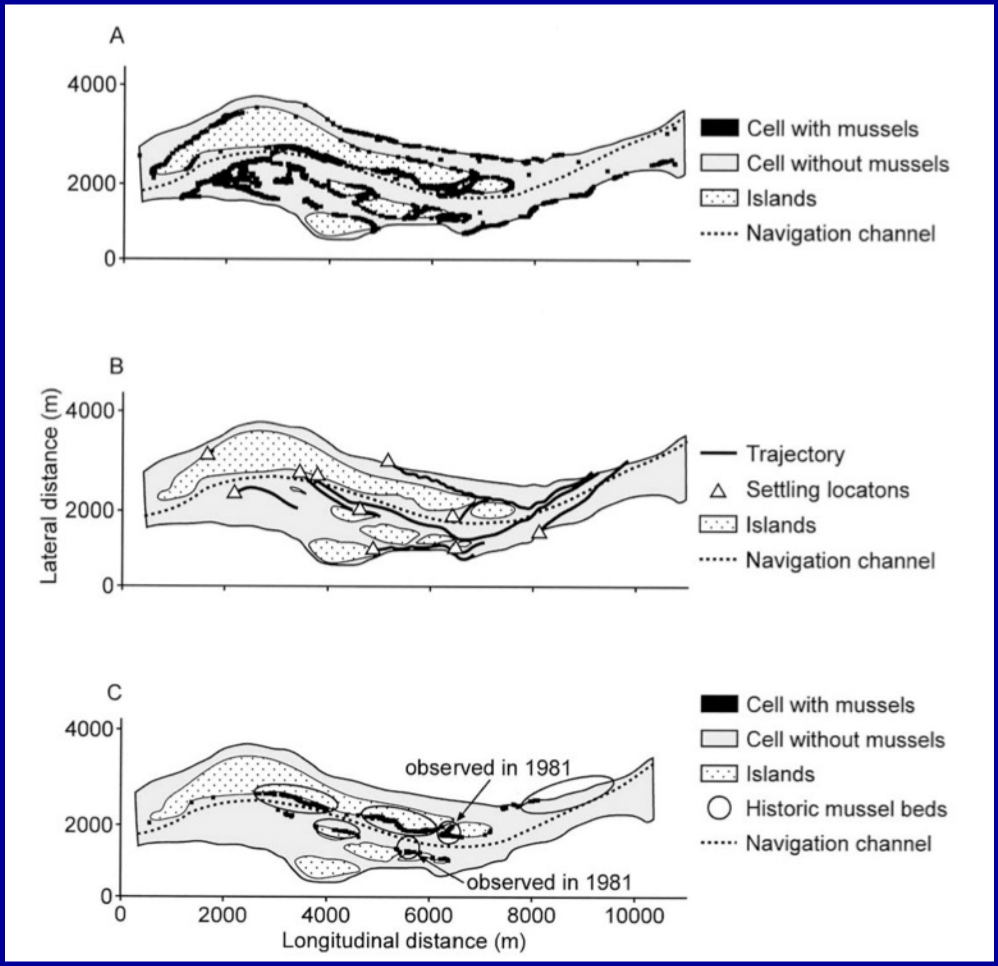


FIG. 4. Variation in habitat suitability in the study area across 3 flow regimes: 566 m^3/s (A), 2039 m^3/s (B), and 3965 m^3/s (C). Unsuitable areas are those with a habitat suitability score of 0, and suitable areas those with a habitat suitability score >0. Flow direction is from right to left.

RSS<1 and Juvenile Dispersal = Mussel beds



NO Habitat Suitability Index

…inconsistencies

- among models, rivers, and species
- among which variables correlate with habitat
- among magnitude of variables
- exceedance flow levels, and
- Multiple variables and combinations needed for model

Experimental- long way from modeling suitable habitat

- Use general hydraulic principles
- Evaluate habitat by experience
  - Nearby similar streams
  - Upstream areas

Determine Presence/Absence

- Do mussels occur in all rivers/streams
  - At least some species occur or can occur in most perennial streams
  - Snail species are also part of criteria – live in ephemeral streams

- Some river reaches might not have suitable habitat
  - Habitat modification
  - Water quality problems
- Species composition varies
  - stream size
  - gradient
  - physiographic region

Sampling Approach

Technical Support Document for Conducting and Reviewing Freshwater Mussel Occurrence Surveys for the Development of Site-Specific Water Quality Criteria for Ammonia- USEPA 2013

- How do we define a site?
- How do we define absence?
- Is species composition important?

Sampling Approach

- Tiered approach
  - Delineate the site and define presence/absence
  - Check databases, literature, and reports
  - Conduct a survey
  - If no mussels- develop site-species criteria
  - Re-evaluate criteria as needed

Delineate the Site

Site could be a region, watershed, waterbody, or segment of a water body

- Criteria must protect the entire site-
  - how far up and downstream until criteria can be met
  - Model transport/fate from point source
- Connectivity/Proximity to other mussel communities
  - Is there a source for recolonization?
  - Do host fish occur in the area?
  - Could host fish recolonize?
- Is habitat available?
  - Look at upstream/nearby streams with similar habitat
  - What is “normal” habitat/density/species composition for that area

Habitat suitability

- In general – Homogeneous substrate not good habitat but…
- Silt thickness
  - Persistent thick silt – Smothering
  - Variable with time
  - Unionids can withstand some silt cover for a period of time
  - Exceptions- many Anodontini (Pyganodon, Utterbackia), some Lampsilini (*Potamilus capax*)
- Sand
  - Coarse sand in faster areas – smothering, unstable
  - Fine packed sand in slow flow – may be ok
- Gravel
  - Loose gravel – not good
  - Look under the gravel –
    - Clean gravel – interstitial flow
    - Unionids could get a foot hold in heterogeneous substrate under the loose gravel
- Bedrock
  - Look for silt/sand in the cracks
  - *Cumberlandia monodonta* often found in bedrock cracks near high current velocity

Define Presence/Absence

- Presence- find live mussels
- Absence- no live mussels?-not so fast!
  - Define in terms of Probability and Density
    - Example- Effort sufficient to detect density of x/m^2 with x% probability (Smith 2006)
    - Base decisions on
      - Similar streams
      - Acceptable risk

  - Sources of recolonization-
    - could glochidia be dropped in the area
    - could mussels wash in from upstream

DEFINITION SHOULD BE CLEAR, REASONABLE, TRANSPARENT, DEFENSIBLE, AND PUBLIC

Check for existing info

- Check databases, literature, reports
  - EPA 2013 has databases listed
  - Site specific information from State Resource Agencies, Museum databases
  - Reports from consultants sometimes available from resource agencies
  - No one source, check with local experts

- May be able to determine presence/species composition
- Most sources do not list absence
- Consider age of the data
  - Present if after Nov 28, 1975
- Evaluate data on a case by case basis (when, who, how often)

Most important aspect of determining how to sample: clear idea of *sample objectives*

- **Mussel presence/absence**
- **What species are present?**
- How are mussels distributed?
- Has or will a community change over time?
- How will or did a particular activity affect a mussel community?
- What are the baseline characteristics of a mussel community?
- Population estimate of a mussel community or species in a given area

Sampling

- Most techniques designed to determine presence not absence
- Methods and techniques depend on objectives and field conditions
- No one size fits all
- Basic techniques methods in USEPA 2013
- Need experienced malacologist to design and implement study

Basic Types of Sampling

Informal Sampling

– Limited statistical comparability

- Reconnaissance
  - Exploratory survey
  - Determine presence or absence
- Semi-quantitative sampling
  - Search an area, minimal or no excavation
  - Map unionid/habitat distribution
- Qualitative sampling
  - Free search
  - Collect as many individuals/species as possible

- Formal Sampling
- –statistically comparable
- Quantitative sampling
  - Collect all animals in a small area
  - Determine density, age structure, other community characteristics

- Complete Removal
  - Salvage
  - Relocation
  - Special research projects

How to look

- <6 inches
  - View bucket
  - Hands and knees
- 6 inches to 0.75 m
  - Snorkel
- > 0.75 m
  - Dive

* Clear Water
  * Broad to Narrow view
  * Feel with hands, knees
  * Flip rocks and logs
  * Fan substrate
  * Probe substrate
* Turbid water or loose substrate
  * Sweep hands across substrate
  * Get hands under loose substrate
  * Squish through silt/clay

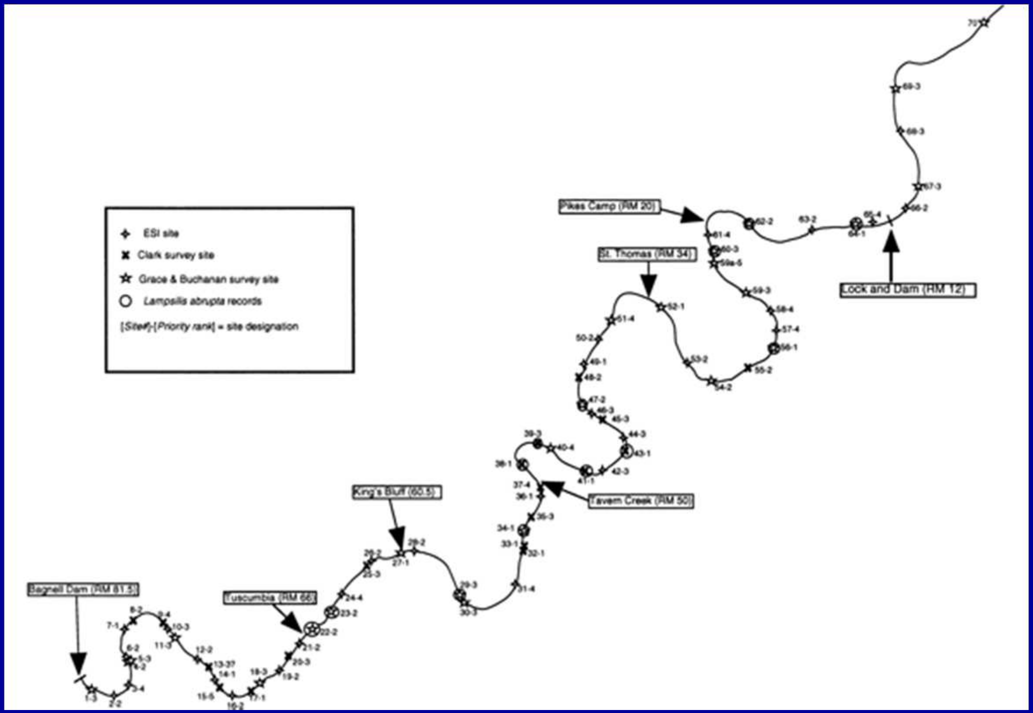
Informal Methods

- Techniques
  - Reconnaissance
  - Semi-quantitative sampling
  - Qualitative sampling
- Pros
  - Collect information quickly
- Cons
  - Not Quantitative
  - Limited statistical comparability over time/space
  - Results dependent of experience of collector/field conditions

Reconnaissance

- Objective
  - Quickly obtain an idea of mussel distribution over a large area
  - Presence/absence over a large area
  - Select sample sites for more intensive sampling/monitoring
  - Determine logistics and field conditions for sample design

* Pre-field preparation
  * Review maps- Google earth
    * select areas of likely habitat
  * Literature review
    * What species occur there?
    * Where were mussels found?
  * GPS landmarks
    * Know where you are



Reconnaissance

- Small Wadable River
  - Float/Canoe
  - Walk banks
  - Look for habitat
  - Shells
  - Muskrat middens

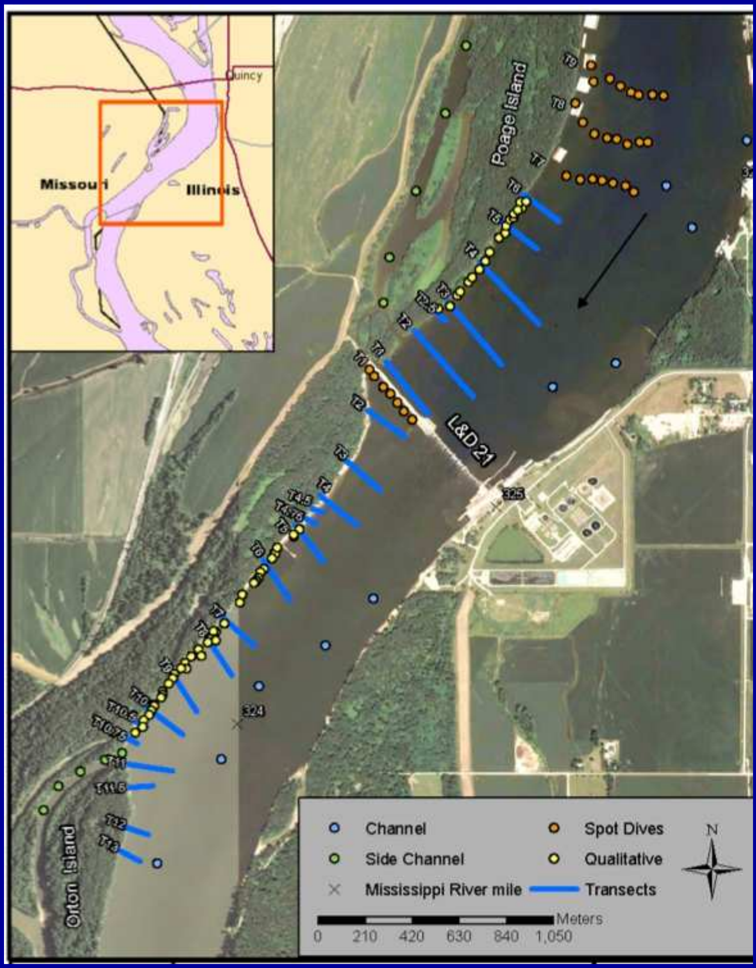
- Field Tools
  - Snorkel/Viewing bucket
  - Collecting bag
  - GPS
  - Field notebook (RIR paper)
  - Safety gear

Reconnaissance

- Non Wadable River
  - Look for likely habitat
    - Shells, middens
    - Sand/gravel banks
  - Brailing (very inefficient, but cheap)
    - Cover large area
    - Results inconclusive
  - Diving (more efficient, more labor intensive and dangerous)
    - Surface Supplied Air w communications – Safest, most efficient
    - SCUBA- rivers not accessible with SSA

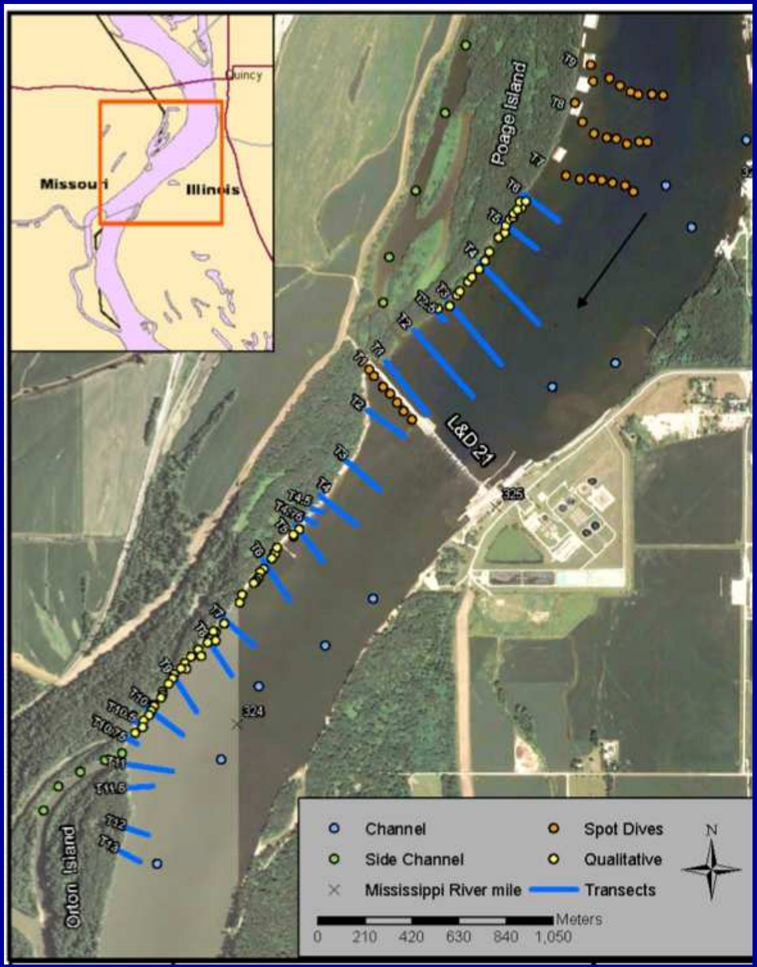
Semi-Quantitative

- Systematic search of an area visually and/or tactually
- Minimal or no substrate excavation
  - move rocks, logs, probe substrate
- Not quantitative, as not all animals are collected within the area
- Not collecting any buried animals
- Typically insufficient time to collect all animals present
- Provides a map of relative distribution and habitat
- Can apply probability of detection to determine effort



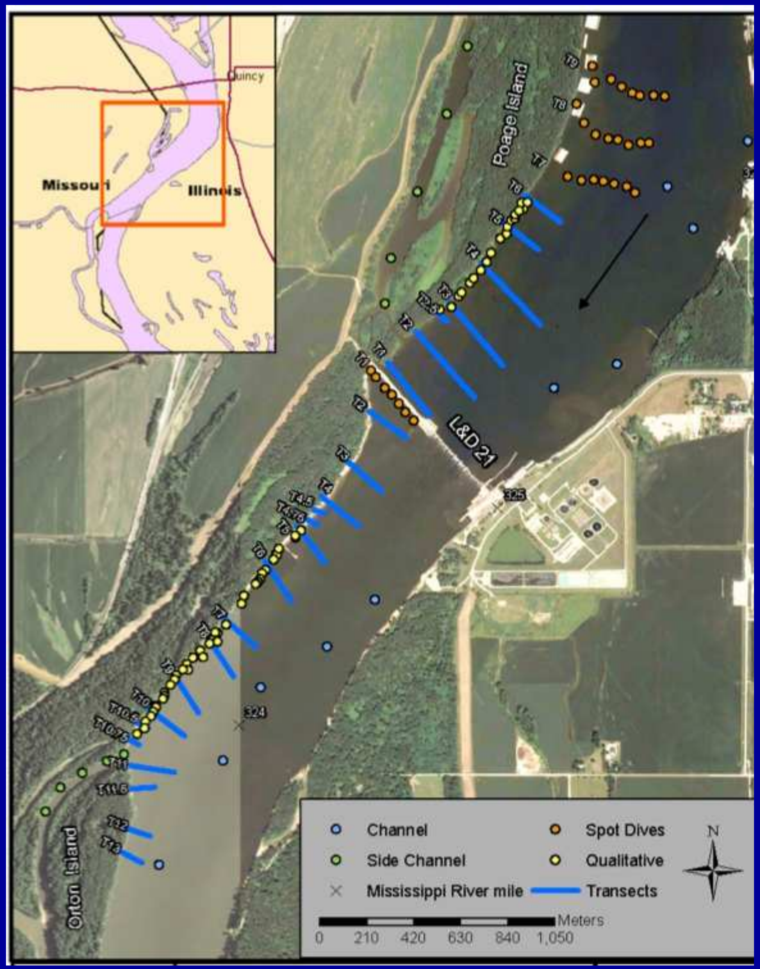
Semi-Quantitative

- Objective
  - Determine unionid/habitat distribution over a smaller area than reconnaissance
    - Within a proposed impact area
    - Best used for a few miles of river or smaller area
    - Best used for a few hundred meters of a smaller system
  - Searches for rare species (Smith, 2006)
  - Establish area (polygon) for probability based sampling



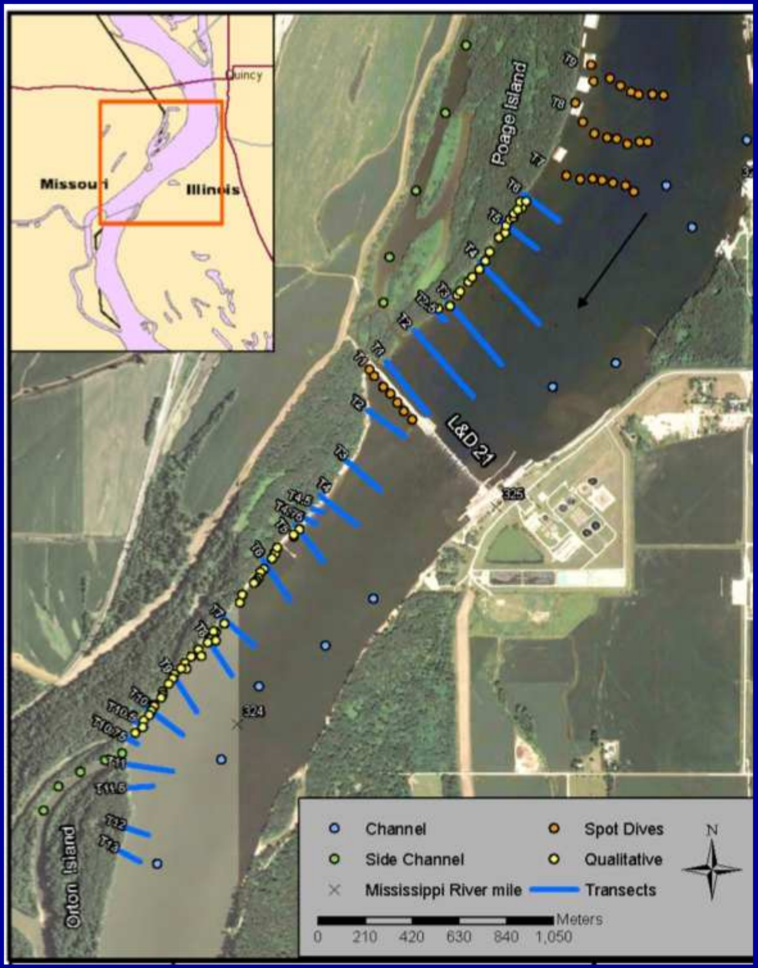
Semi-Quantitative

- Transects - Methods
  - Lines established perpendicular to flow
    - Unionids generally in parallel strips
  - At equal intervals or random starts
  - Mark intervals on lines (10m)
  - Visual/tactual search within 1m of line
  - Record at 10m intervals
    - Species, number of animals (Juv or adult)
    - Shells
    - Substrate type (Wentworth Scale)
    - Depth
    - Velocity (Hydropower)
    - Temperature/DO (316a)



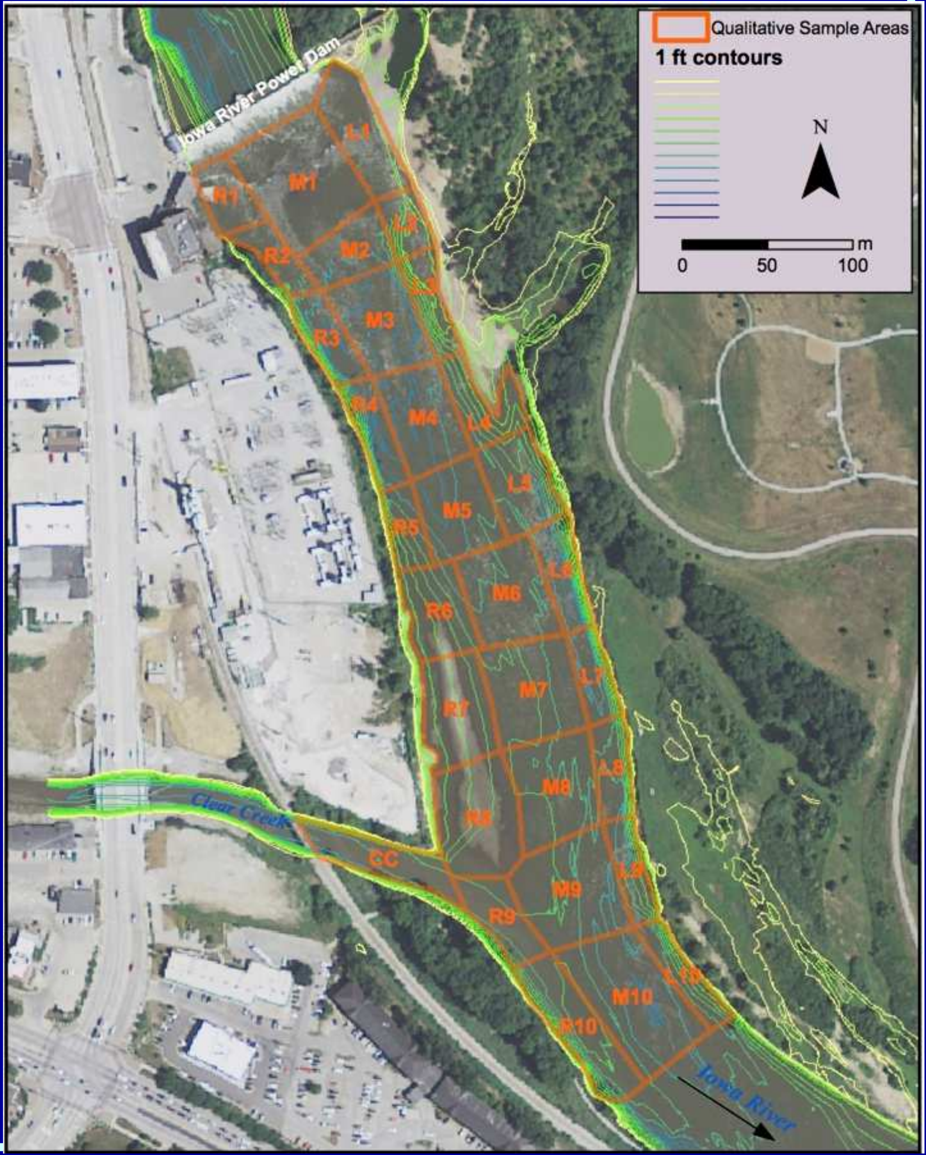
Semi-Quantitative

- Transects – Field Considerations
  - Distance between transects
  - Transect length
  - Intervals along transects
  - Sample time per interval
  - Locating start points
  - Keeping transect on bottom
  - Locating transect in deep turbid water
  - Locating interval in deep turbid water



Semi-Quantitative

- Grids - Methods
  - Establish grid over area
  - Equal grid cells or based on habitat
  - Visual/tactual search of each cell for selected time
  - Record for each cell
    - Species, number of animals (Juv or adult)
    - Shells
    - Substrate type (Wentworth Scale)
    - Depth



Qualitative

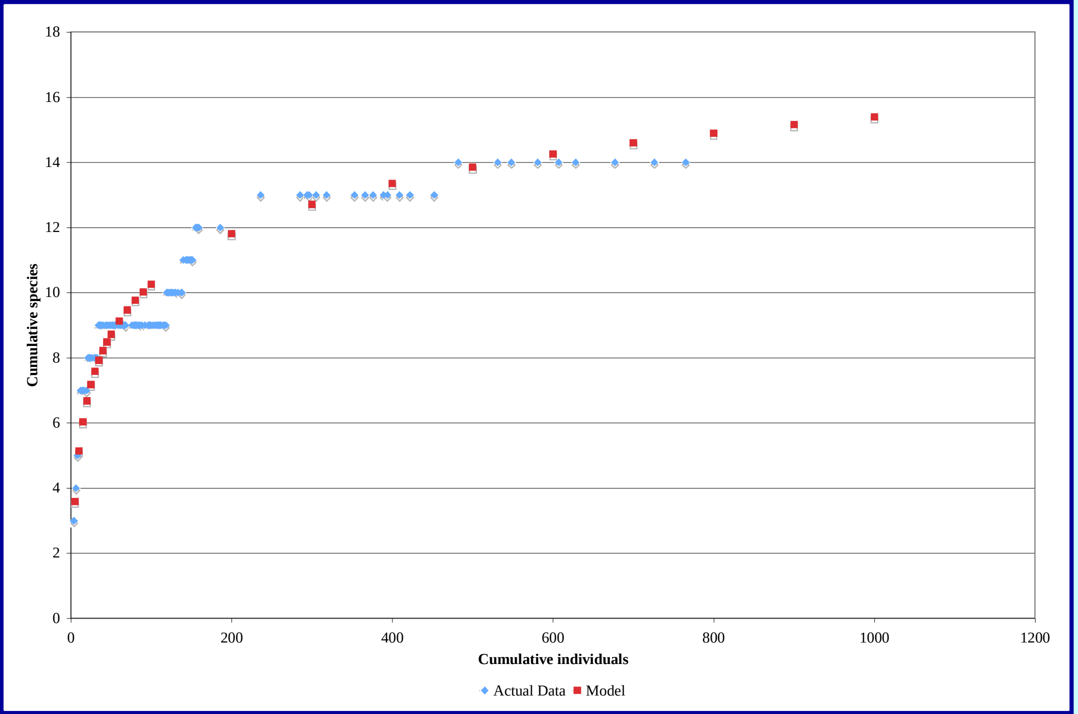
- Free search (usually timed) of a loosely defined area
- Objective – Collect sufficient number of individuals to detect the majority of species and/or size classes within a sample site
- Inexpensive
- Collect a large number of individuals quickly

Qualitative

- Techniques
  - Usually conducted in area with known mussel concentration to determine species composition
  - Cover a variety of habitats
  - Get hands/eyes as close to the substrate as possible

Qualitative

- Techniques
  - Collect in timed increments or lots (number/bag)
  - Generate species accumulation curve
- Record
  - Depth, substrate
  - Species, no. of individuals
  - Adults/juveniles
  - Location of search points



Quantitative

- **Probability based sampling**
- **Determine unbiased estimate**
  - Density
  - Species relative abundance
  - Age structure
  - Distribution
- **Statistical Temporal and Spatial Comparison**
- **EXPENSIVE – LABOR INTENSIVE**
  - *(but….you get what you pay for)*

- **Simple Random Design**
- **Systematic Design**
- **Stratified Random Design**
- **Adaptive Design**
- **Two Stage Sequential Design**
- **Double Design**

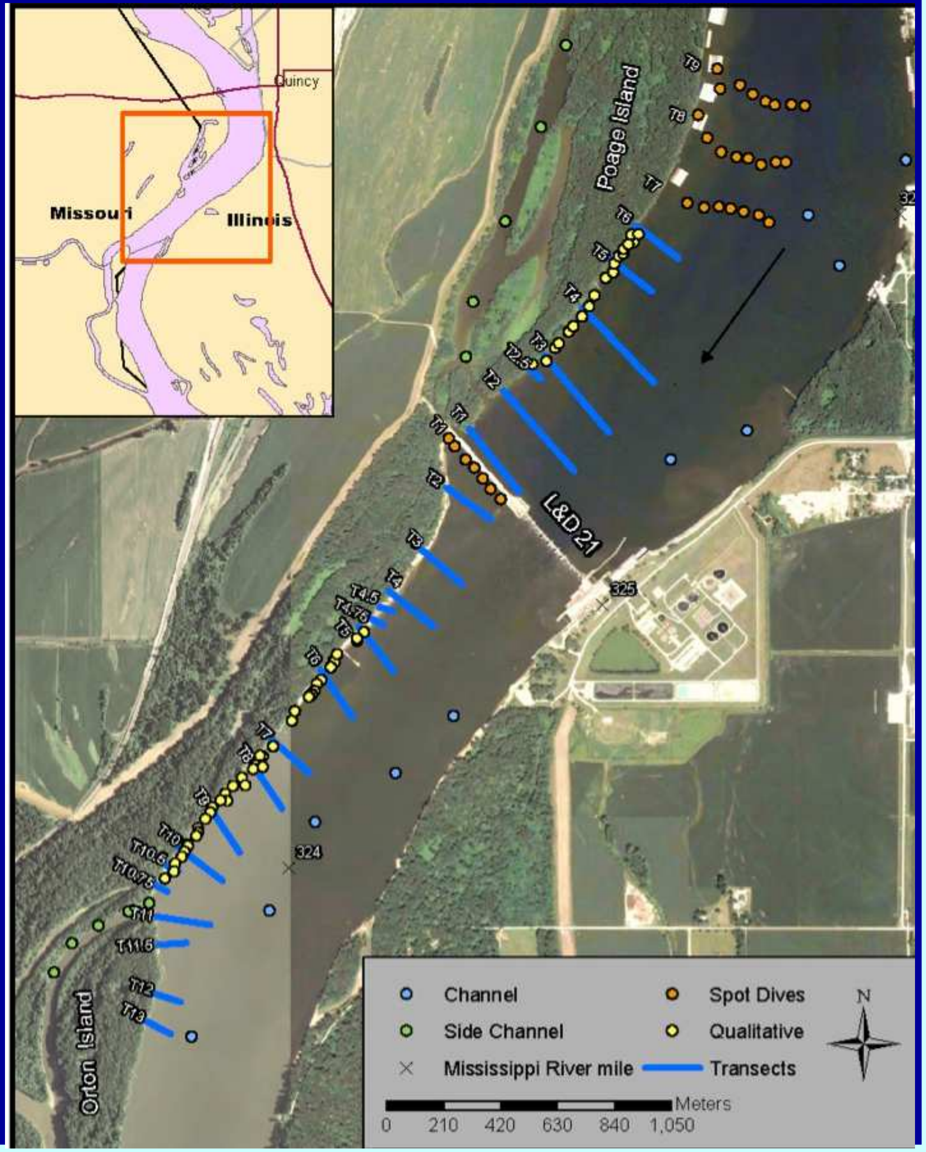
see Strayer, D. L. and D. R. Smith. 2003. A guide to sampling freshwater mussel populations. Also, D. R. Smith has several papers with examples and analysis of methods.

Quantitative

- Techniques
  - Keep quadrat in place
  - 0.25m^2 typical for mussels
  - Dig all substrate to 15 cm into bucket/bag/sieve
  - Sieve substrate (12 and 6mm)
  - Separate animals from debris

Combination of Techniques

- Reconnaissance
  - Determine sample area
- Semi-quantitative
  - Determine distribution of mussels/habitat
- Qualitative
  - Refine estimate of mussel bed edges- polygon
- Quantitative
  - Random 0.25m^2 samples in mussel bed to determine community metrics
- Qualitative
  - 5 minute qualitative samples to estimate species richness



Presence/Absence Design

Reconnaissance- Cover the study area

- Mussels found- Yes
  - What species? – Qualitative sampling
    - Areas with high concentrations
    - Unique habitats

- No mussels?
  - More intensive semi-quantitative or qualitative
  - Effort based on probability of detection determined in Step 1

How much effort?

Probability of detection = how likely am I to find a mussel with a given density, search efficiency, and search area if it is present in the study area

Density

- Consider density in reference streams or nearby
- Consider acceptable risk of not finding an animal

Search efficiency- (detectability)

- What proportion are likely buried?
- How much time spent searching?
- Local conditions (turbidity, substrate type)
- Searchers experience

Proportion of area sampled (search area/site area)

Example- Calculate Sample Effort

Semi-quantitative sampling- 5 min/10 x 1 m

Density = 0.0001/m^2 (1 mussel per 100 x 100 m area)

Search efficiency= 0.4 (60% of animals buried-may need to decrease this based on sample time and experience)

Probability of detection = 0.95

Sample area = -LN (1-prob of detection)/(density*search efficiency) = 74,893 m^2 = 250 hours (plus set up and mussel work up time)

Tiered approach

Determine acceptable effort (time and money)

- Less sample time
- Smaller sample area
- Higher density
- Lower probability of detection

Find mussels- focus on species

No mussels

- Additional sampling
  - increase search efficiency (time, amount of excavation), acceptable density (search area), probability of detection

- evaluate cost of survey/calculation of alternative criteria vs. cost of meeting the standard

Summary

- Unionids unique – worth saving
- New ammonia criteria should facilitate recovery
- Alternatives
  - Mussels not present
  - Species composition differs
- Sampling can be expensive
  - Tiered approach
  - Base design on objectives and data goals
  - Need experienced malacologist
- Evaluate cost of sampling vs. meeting criteria