A CONSERVATION FRAMEWORK FOR BETTER UNDERSTANDING RISKS AND THREATS TO FRESHWATER MUSSELS: A CASE STUDY OF THE MERAMEC RIVER BASIN, MISSOURI

Kayla Key

West TN River Basin Authority, TN Department of Environment and Conservation

Amanda Rosenberger

TN Cooperative Fishery Research Unit, TN Tech University

Kristen Bouska

U.S. Geological Survey, Upper Midwest Environmental Sciences Center

Garth Lindner

Indiana Department of Natural Resources

How are mussels doing?
Where should we focus efforts?

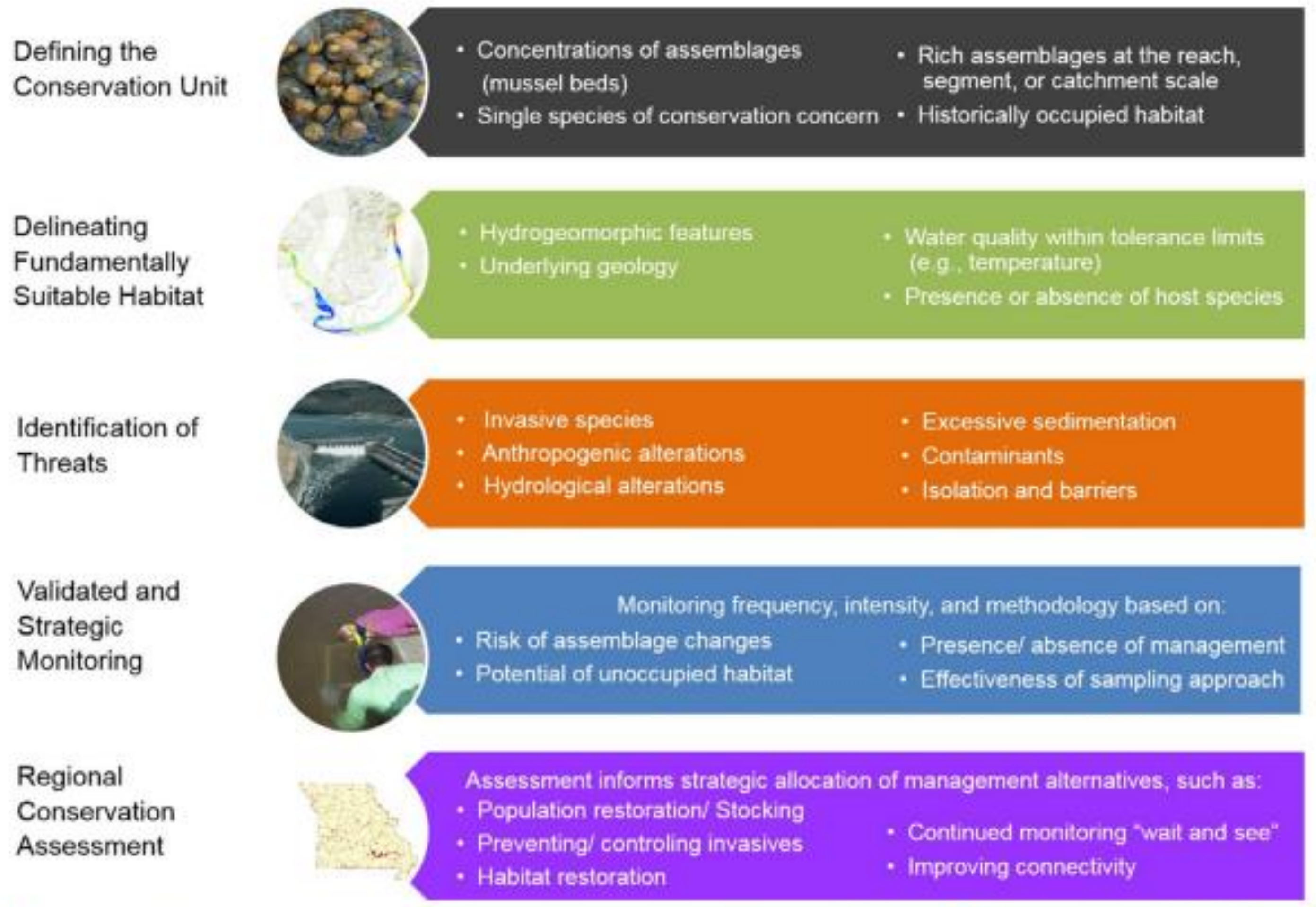


Figure 5. The steps of the mussel conservation assessment are intended to be adaptable to the needs and resources of natural resource agencies. Therefore, we provide examples of different areas of emphasis that align with each of our research steps.

Bouska et al., 2018. Fisheries

Develop a spatial assessment of the status and risks to mussel assemblages in the Meramec River Basin.

1. ID conservation unit
2. ID suitable habitat at scale relevant to managers & mussels
3. Spatially ID threats to mussels & ID areas at risk
4. Develop datasets and guidance for managers

Statewide MDC Long-term large dataset

Meramec River Basin:
Heavily sampled
Diverse (~40 sp) watershed

Conservation Unit = Mussel Beds

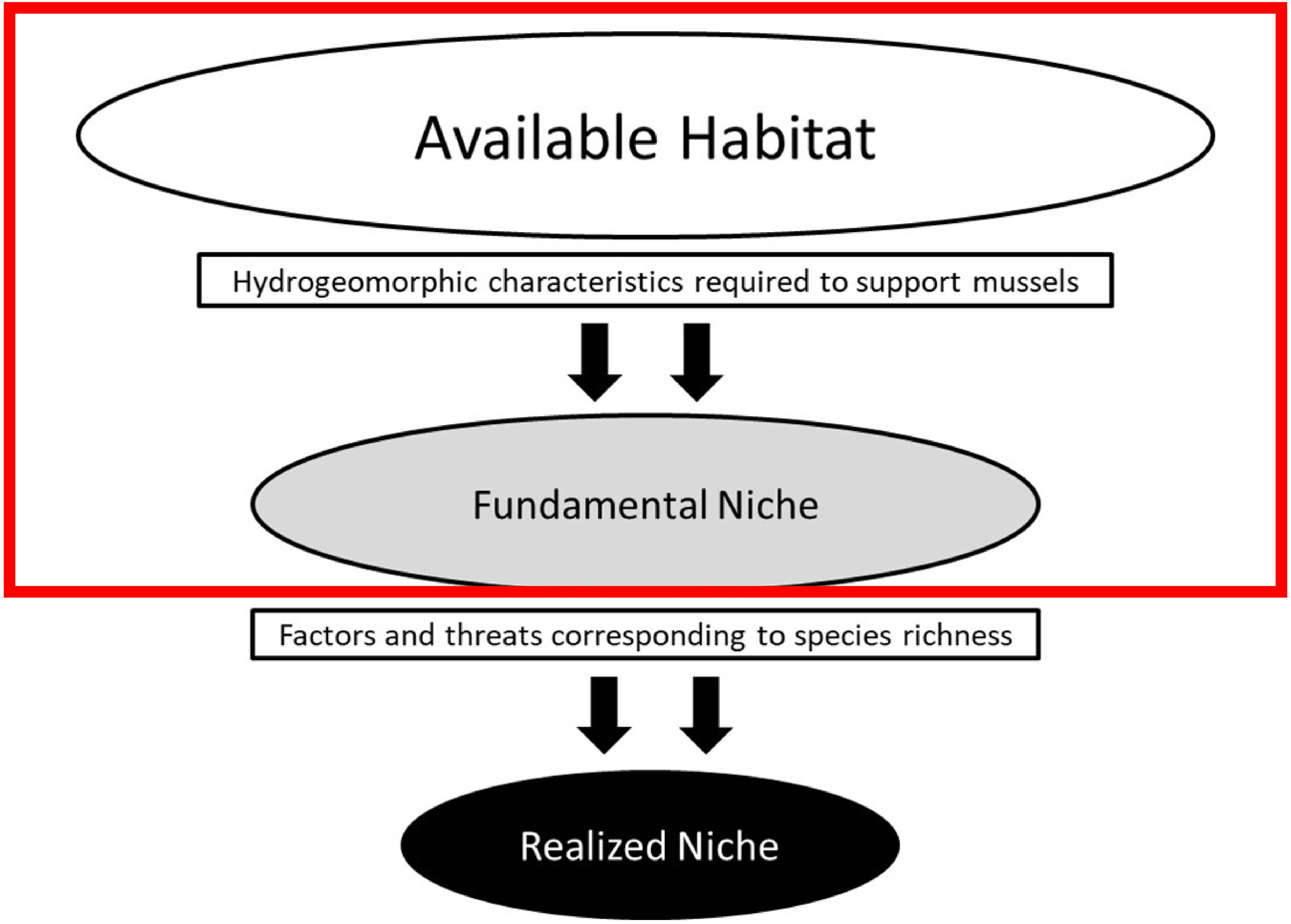
Modeling Mussel Communities as a unit

- Multi-species beds
- Hydrogeomorphic Variables

- Response variables
  - Presence/Absence of beds
  - Species Richness
    - Informative, cost effective
    - Measurable
    - ID & Quantify threat impacts

Defining the Conservation Unit

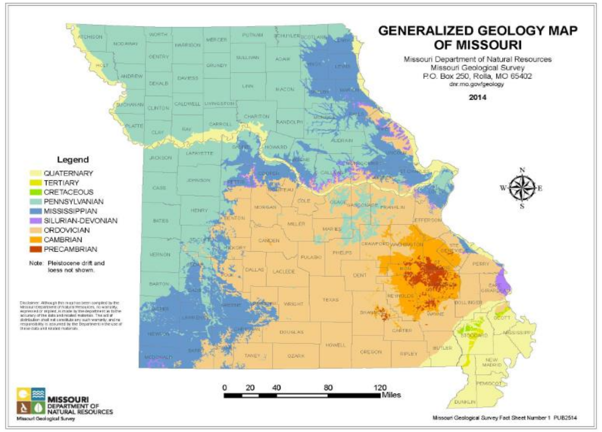
- Concentrations of assemblages (mussel beds)
- Single species of conservation concern
- Rich assemblages at the reach, segment, or catchment scale
- Historically occupied habitat



Bouska et al., 2018. Fisheries

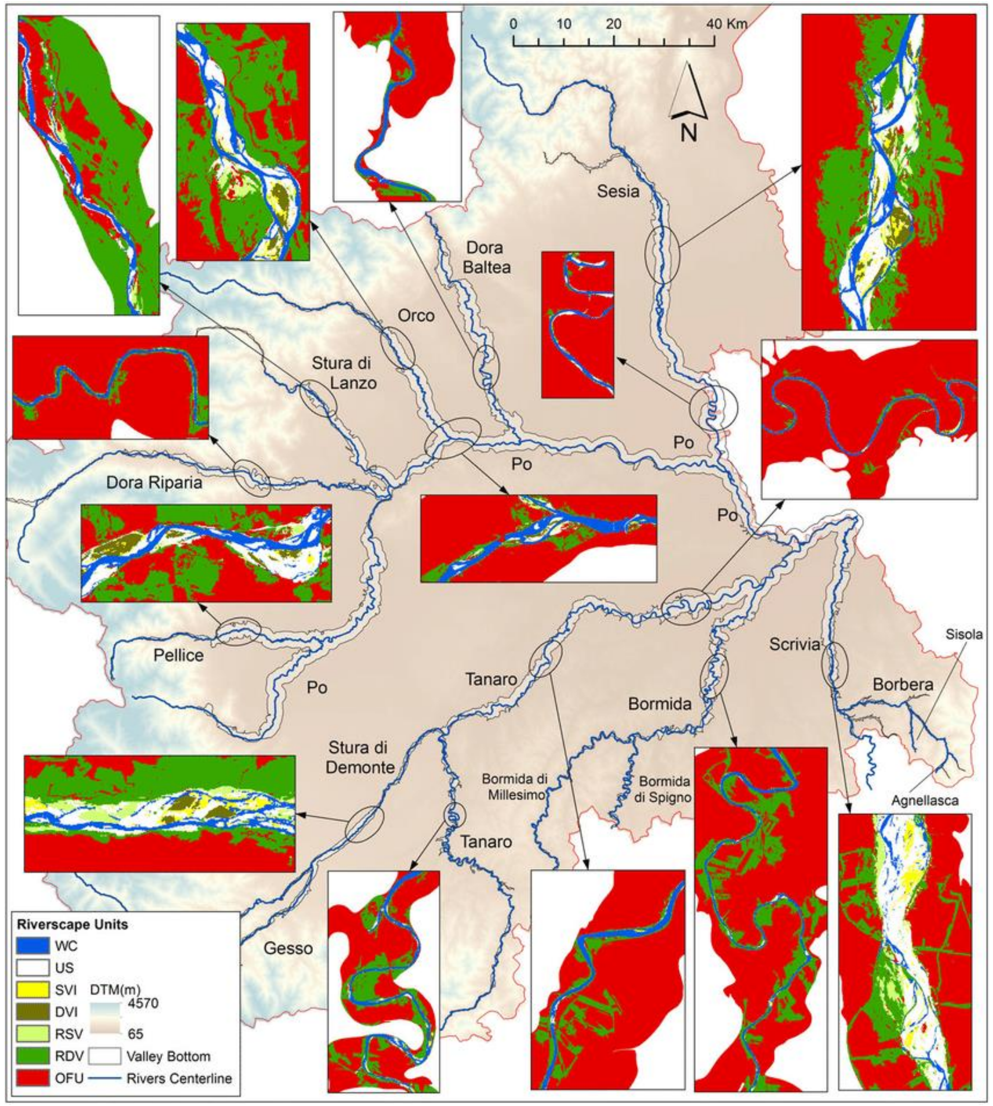
Past Modeling Efforts

- Microhabitat scale
  - Quadrat – substrate type and size
  - Difficult to scale up to watershed or even reach scale
- Reach scale
  - 100m reach
  - water chemistry & habitat type
  - Difficult to scale up to entire watershed
- Watershed scale
  - Information limits
  - Geology
  - Regional comparisons



Riverscape Scale

- Continuous
- Longitudinal
- Scalable
- Benefits
  - Predictive potential
  - Relevant to managers
  - Relevant to mussels?

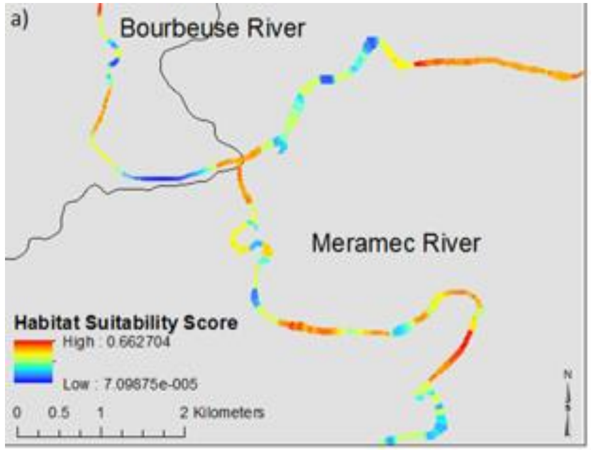


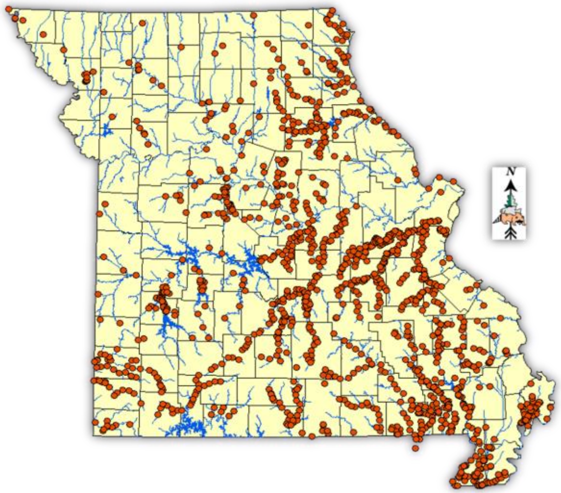
Demarchi et al 2016

Goal 1: ID Suitable Habitat

Objectives

1. **ID** high richness bed locations
2. **Derive** "Riverscape" hydro-geomorphic variables
3. **Develop** a fundamental niche model



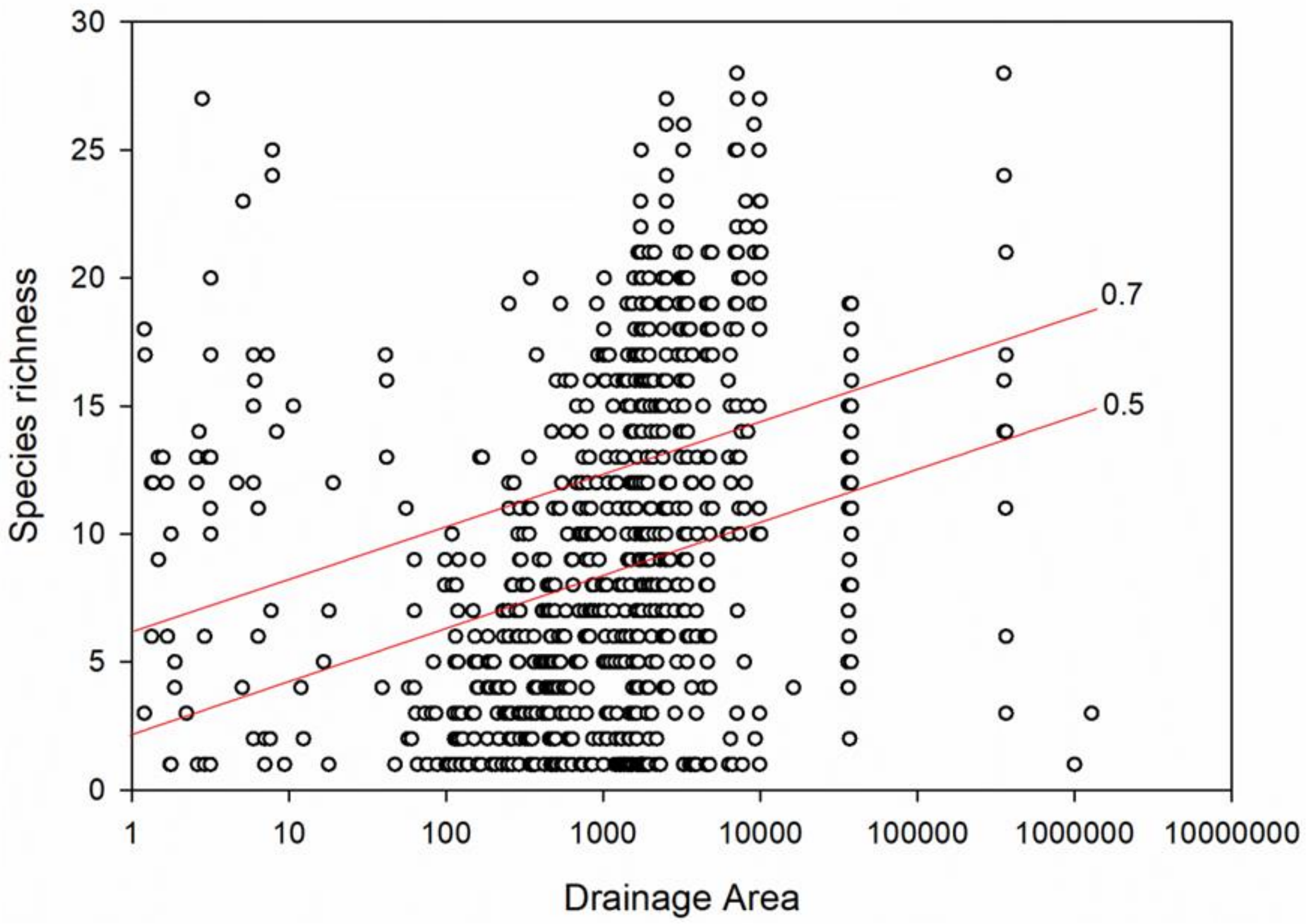


ID High Richness Locations

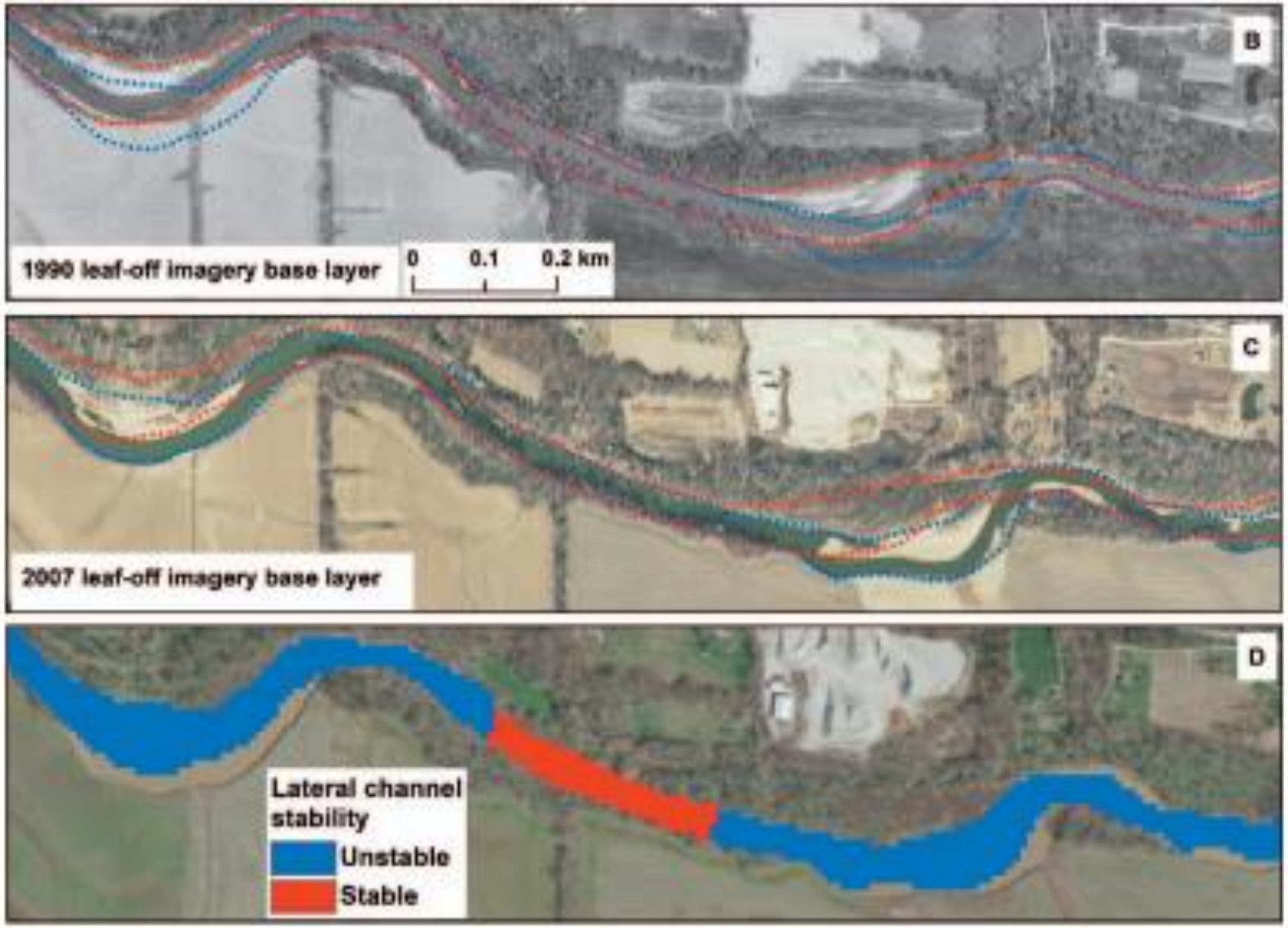
High SR (>70th) = Used in Model Training

Mid SR (50th – 70th) = Used in Validation

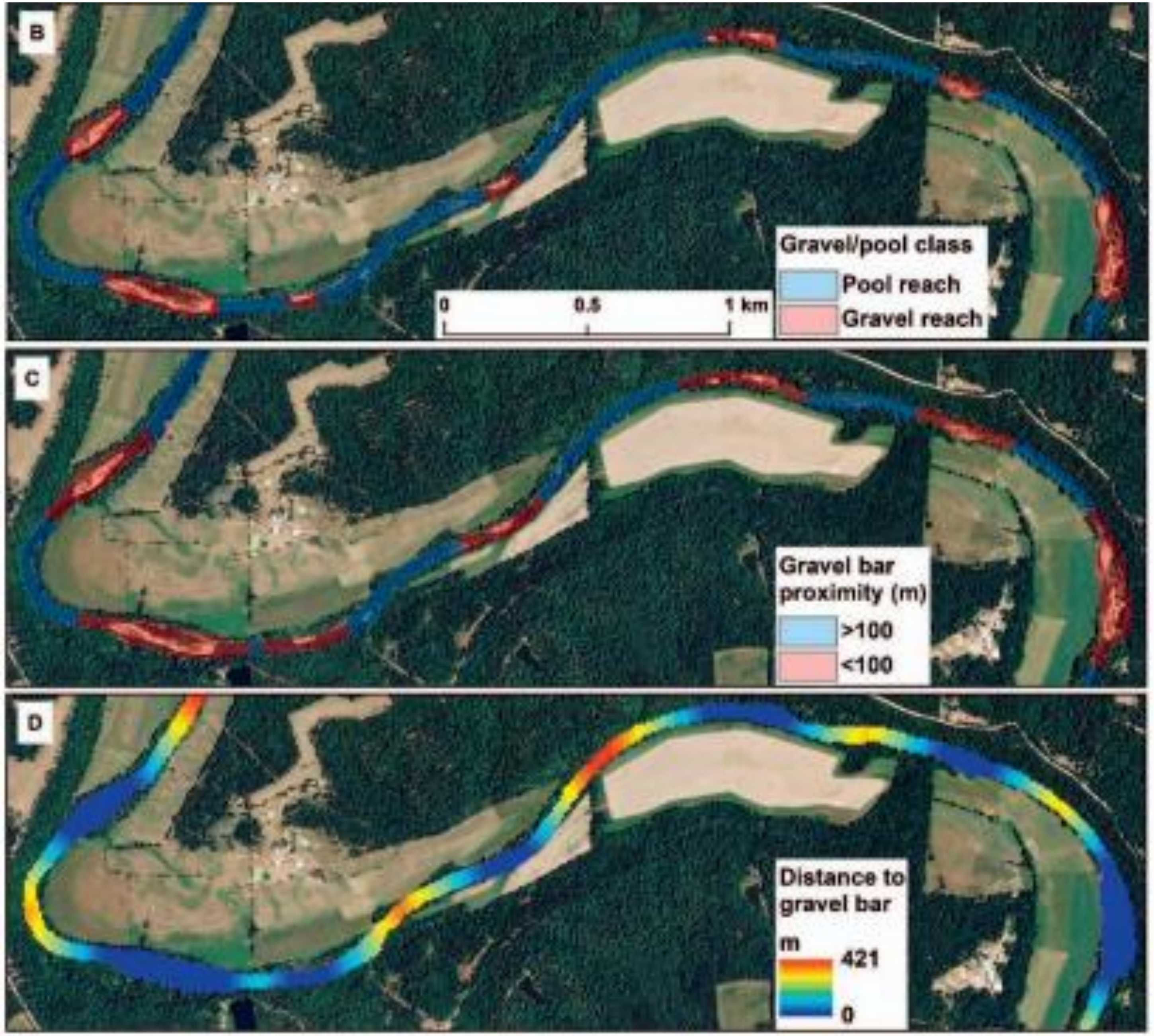
Low SR (< 50th) = Used in Validation



Lateral Channel Stability

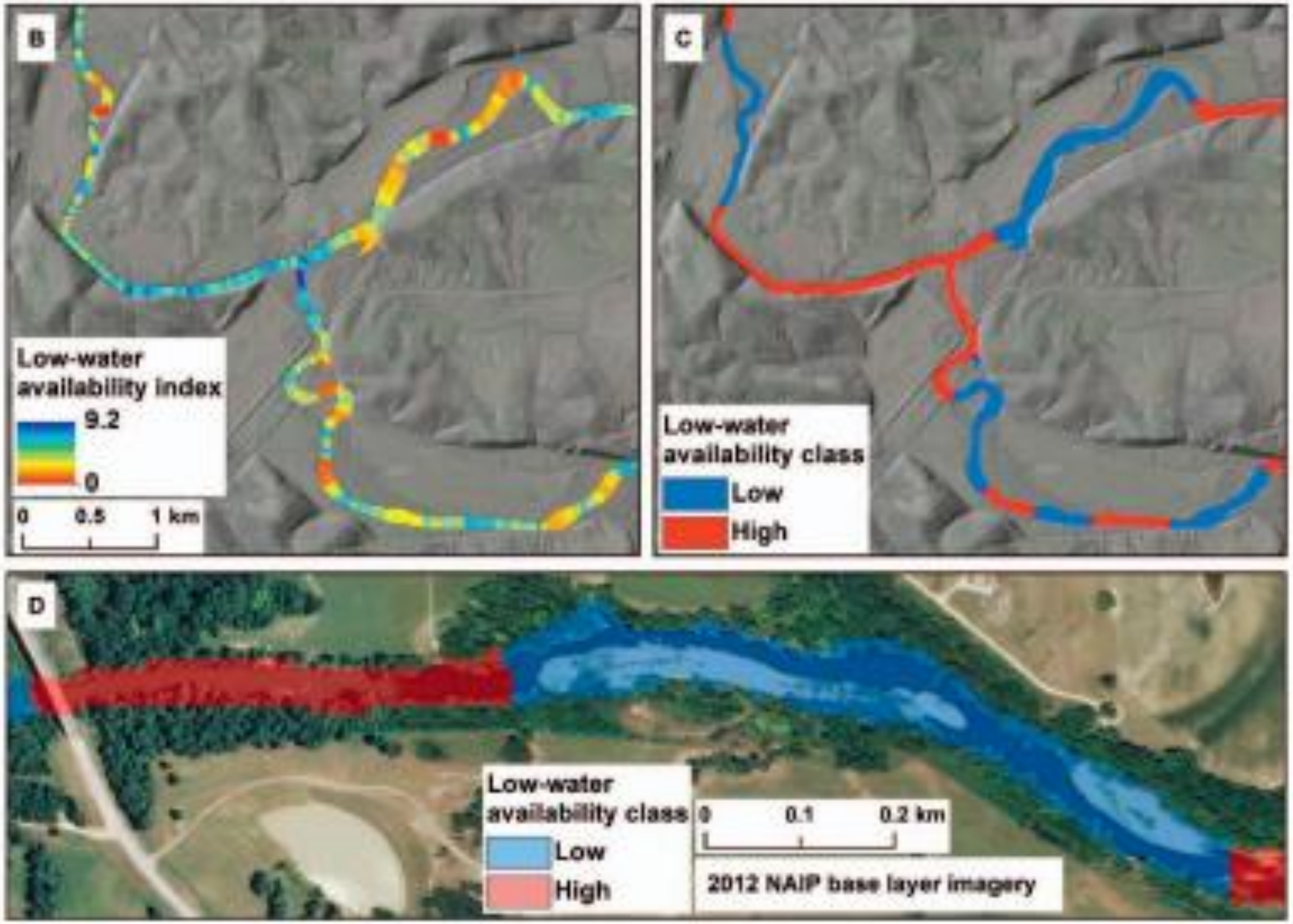


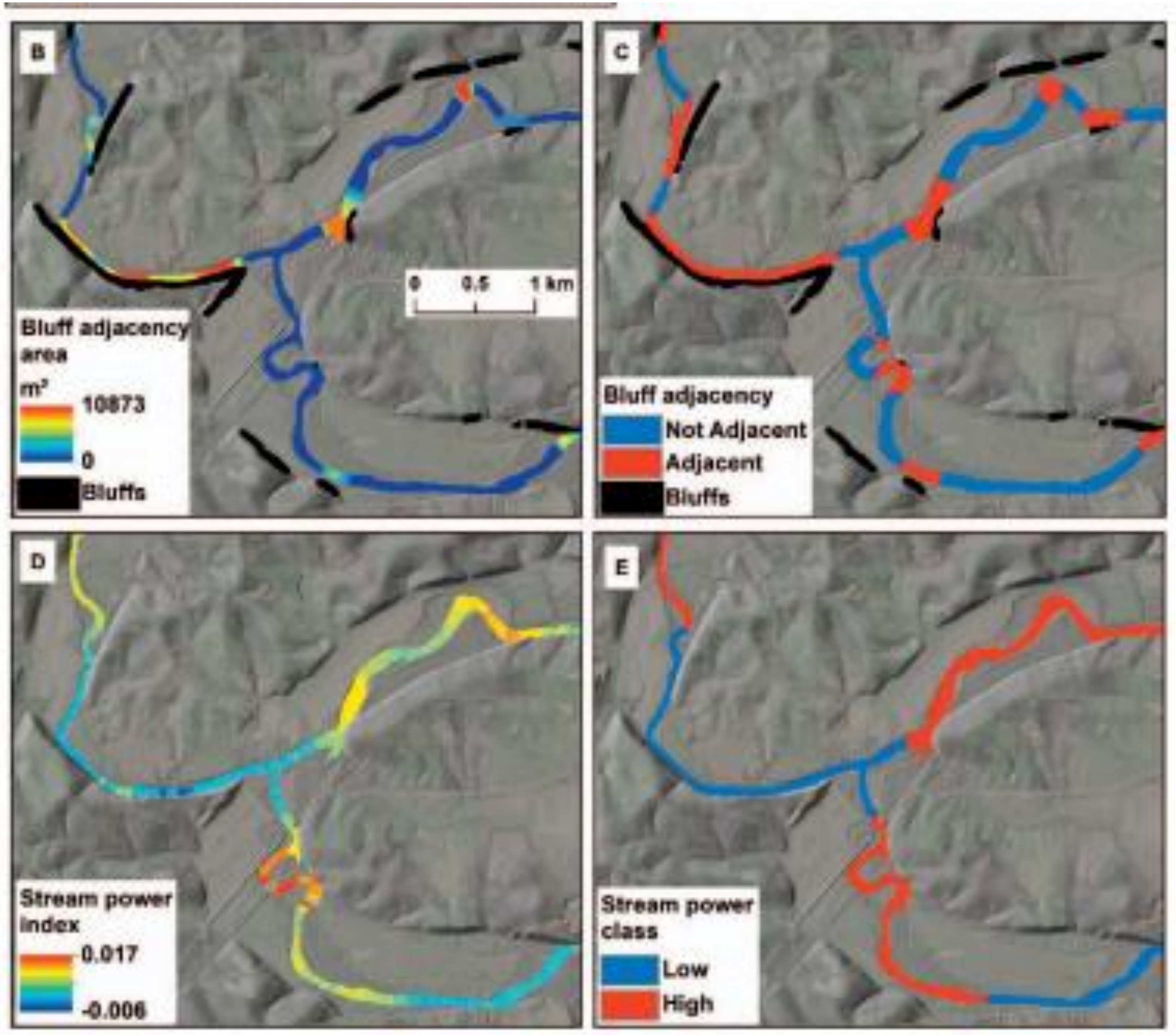
. Example maps of lateral channel stability layer: A) map of the Meramec River watershed with locations of the subsequent detailed maps, B) dig


B
Gravel/pool class
Pool reach
Gravel reach
0
0.5
1 km
C
Gravel bar proximity (m)
>100
<100
D
Distance to gravel bar
m
421
0

Gravel Bars

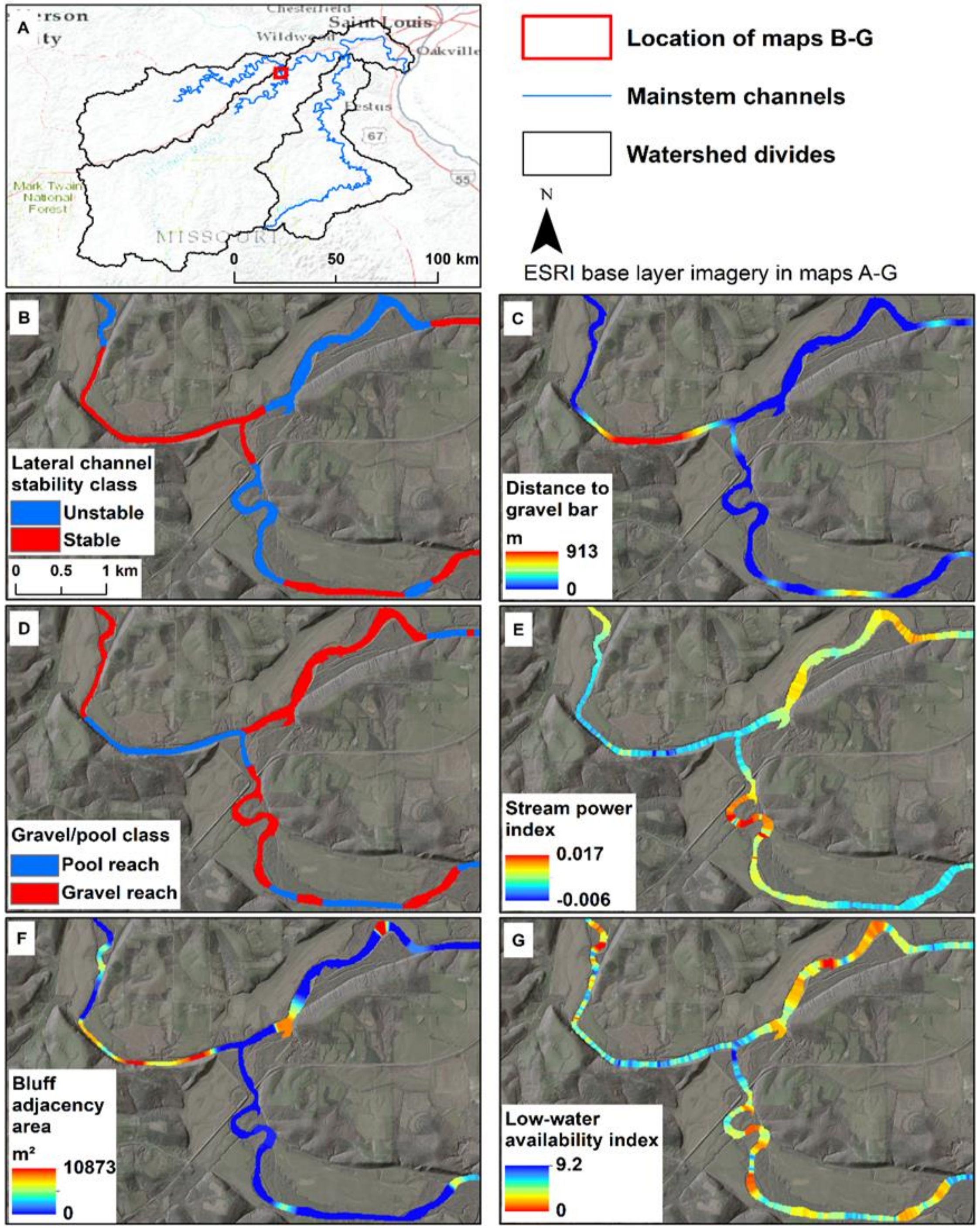
Drought Refugia?





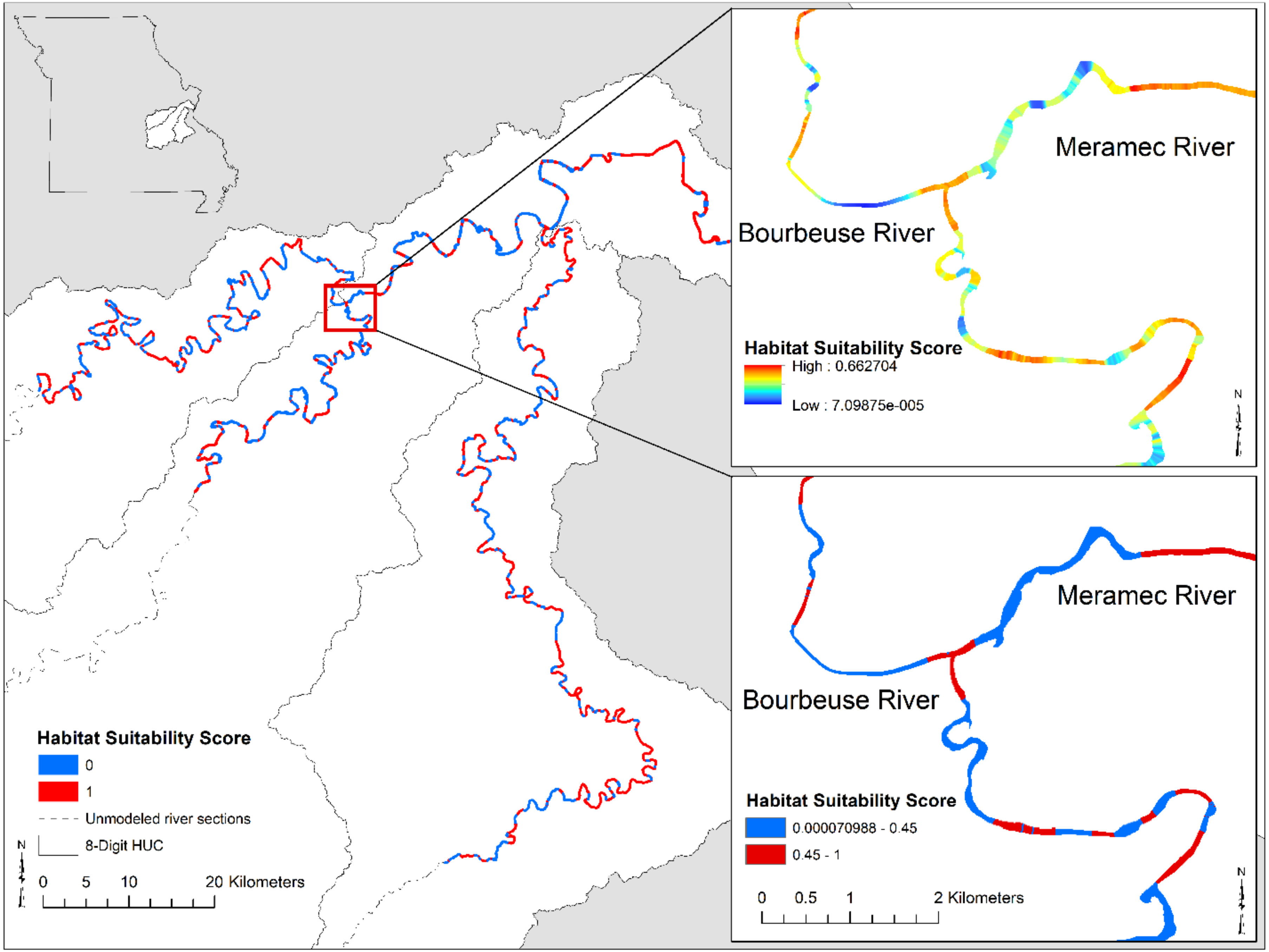
Bluffs?

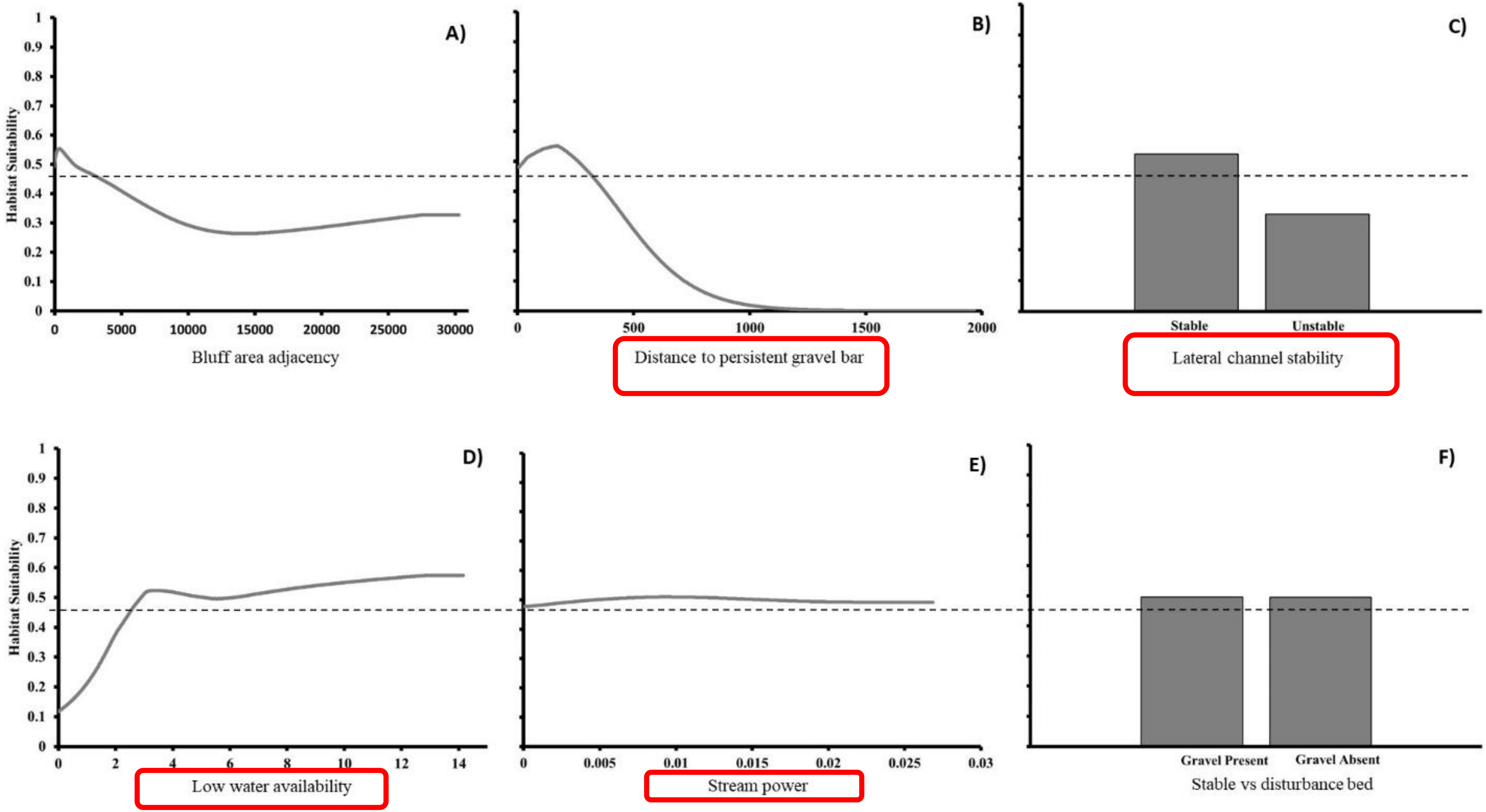
Stream Power



Final Model Hydrogeomorphic Riverscape scale variables

- Lateral stability
- Distance to stable gravel bar
- Presence of gravel
- Stream power
- Bluff area adjacency
- Low water


Meramec River
Bourbeuse River
Habitat Suitability Score
High : 0.662704
Low : 7.09875e-005
Meramec River
Bourbeuse River
Habitat Suitability Score
0.000070988 - 0.45
0.45 - 1
0 0.5 1 2 Kilometers
Habitat Suitability Score
0
1
Unmodeled river sections
8-Digit HUC
0 5 10 20 Kilometers
N



A)
B)
C)
D)
E)
F)
Habitat Suitability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5000
10000
15000
20000
25000
30000
Bluff area adjacency
0
500
1000
1500
2000
Distance to persistent gravel bar
Stable
Unstable
Lateral channel stability
Habitat Suitability
0
2
4
6
8
10
12
14
Low water availability
0
0.005
0.01
0.015
0.02
0.025
0.03
Stream power
Gravel Present
Gravel Absent
Stable vs disturbance bed

179 of 289 reaches = Suitable

83% (53/64) of Validation Beds within Suitable

7 seemed associated with similar portions of the channel

Goal 1 Outcomes

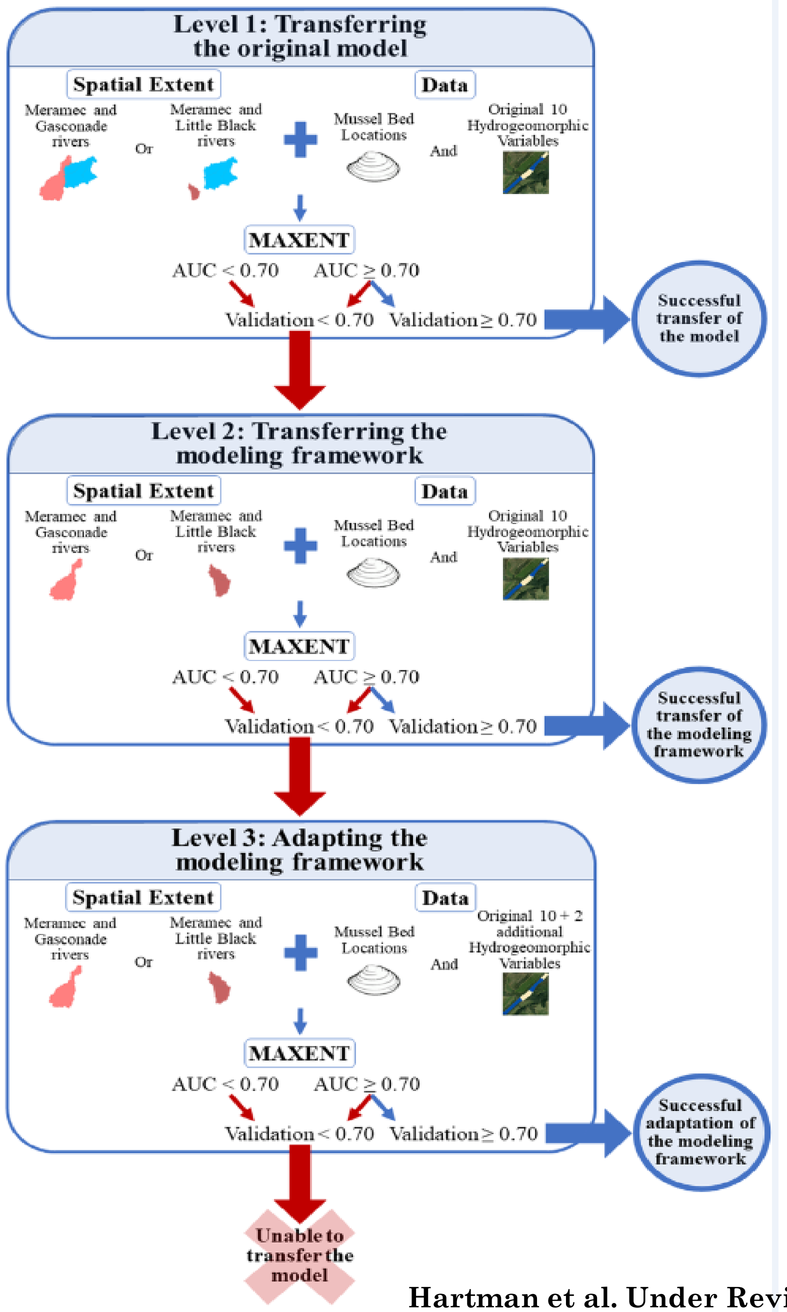
1. Mussel beds can be modeled as a unit
2. SR can be a useful metric
3. Riverscape hydrogeomorphic variables were successful in predicting suitable habitat

Successfully tested in 2 other Ozark watersheds

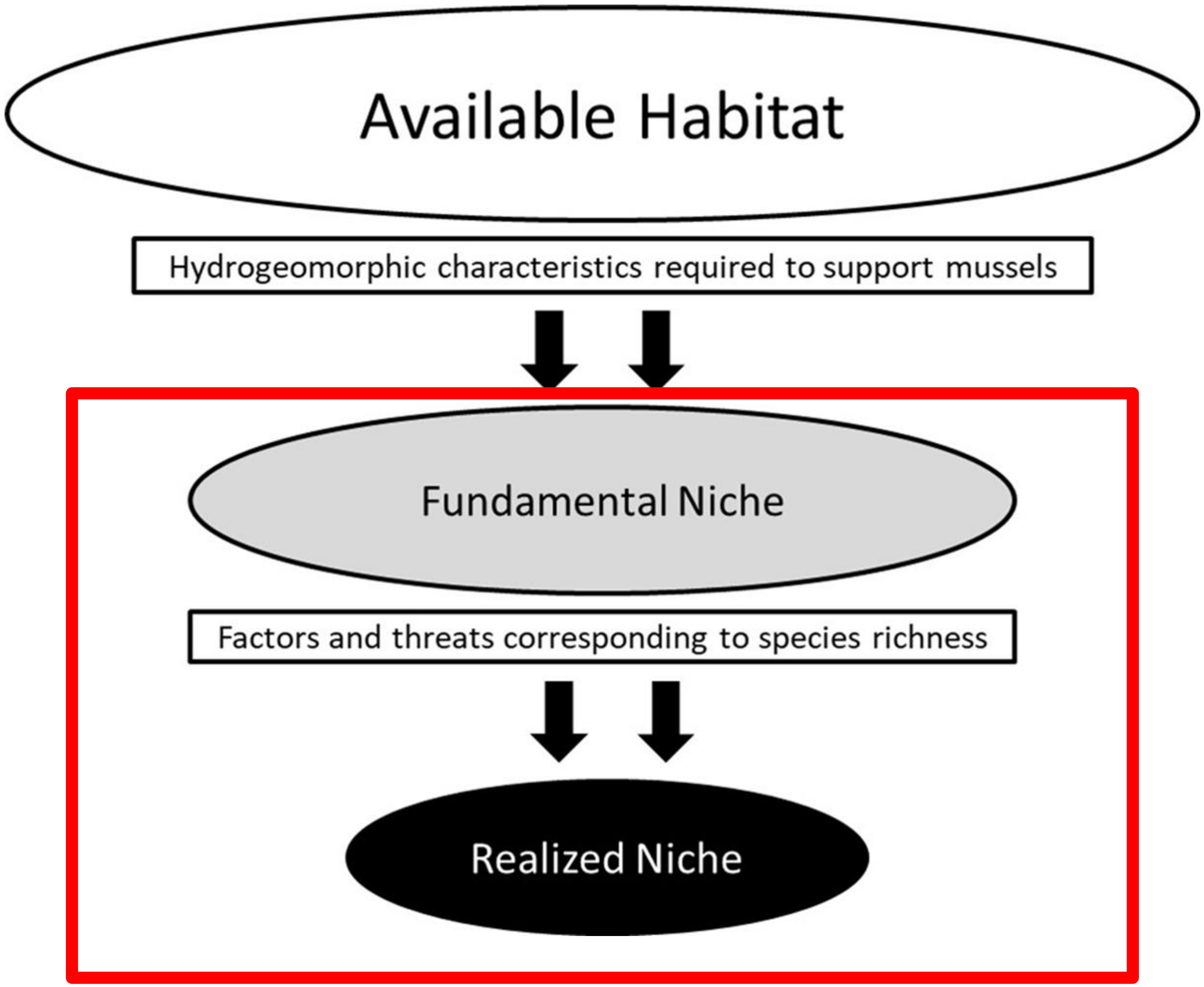
Under review in FMBC:

Hartman et al.

ASSESSING POTENTIAL HABITAT FOR FRESHWATER MUSSELS BY TRANSFERRING A HABITAT SUITABILITY MODEL WITHIN THE OZARK ECOREGION, MISSOURI



Hartman et al. Under Review


Available Habitat
Hydrogeomorphic characteristics required to support mussels
Fundamental Niche
Factors and threats corresponding to species richness
Realized Niche

Goal 2: Spatially ID threats & suitable reaches at risk

Objectives:

1. Stratified random sampling field design
   SR data for suitable reaches
2. ID & quantifying potential threats
3. ID realized threats via modeling
4. Categorize & prioritize reaches

Step 1 — 289

Bank survey

Absent | Step 2 — 179

Step 2 — Stratified Random Sampling

Bank Surveys for SR — 60

Reconnaissance survey

Representative bed ID

Step 3 — 53

Habitat assessment

Timed visual survey — 41 Beds

Potential Threat Covariates

Threat covariates

1. River
2. Length of reach
3. Distance to closest suitable reach
4. Distance to closest dam
5. Within 1km of a float zone
6. Within lead impact zone
7. Within 1km of a golf course
8. Within 1km of a landfill

24 variables tested in model development

Watershed & Reach level threat covariates

1. # of Road Crossings
2. P/A of Road Crossing
3. # of CAFOS
4. # of dams
5. # of hazardous waste generators
6. # of water treatment facilities
7. # of public access
8. % urban
9. % barren
10. % forest
11. % agriculture
12. % grasslands
13. % wetlands
14. # of Road Crossings
15. # of CAFOS
16. # of dams
17. # of registered hazardous waste generators
18. # of water treatment facilities
19. # of outfall locations of stormwater
20. # of NPDES permitted discharge features

Two-Method Threat Modeling Approach

1. MaxEnt Modeling
   - ID threats that influence P/A of mussel beds
2. Occupancy Modeling
   - Account for imperfect detection (species specific effects)
   - Estimate SR for each suitable reach
   - ID threats that influence SR/specific species

Method 1

Maxent Threat Modeling

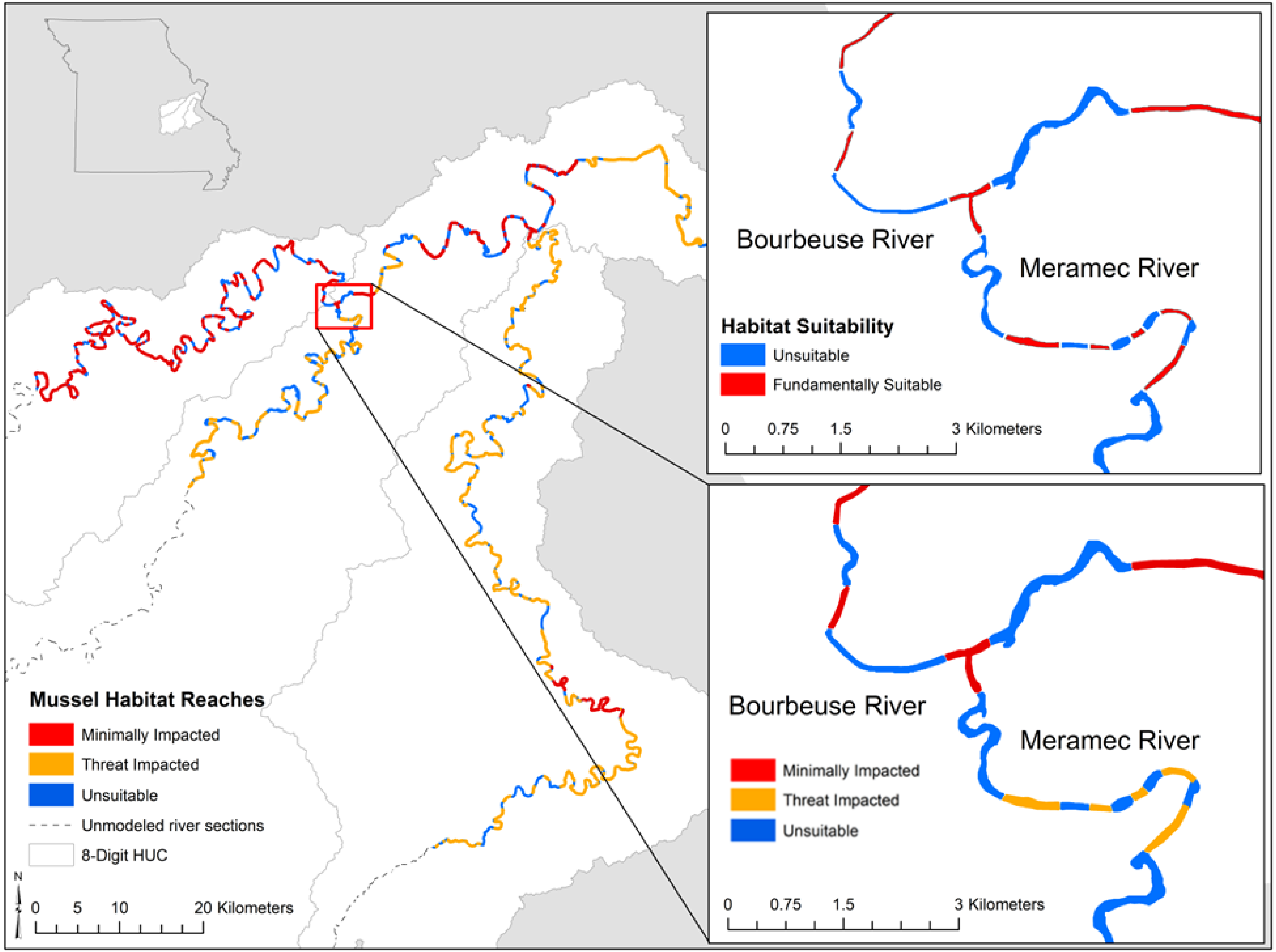
P/A Mussel Bed

Inputs

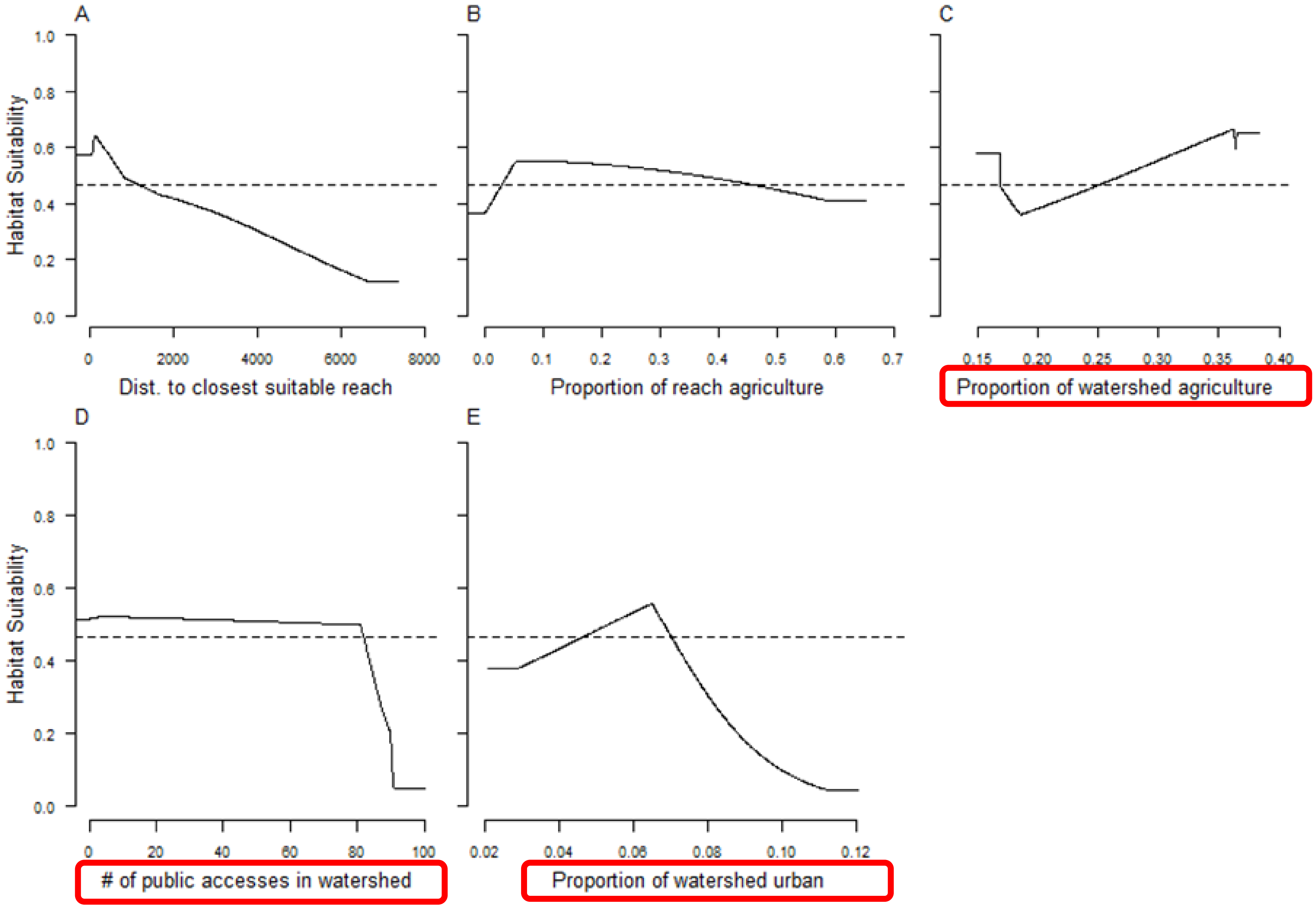
- Mussel bed locations (n=41)
- Spatial threat variables

Outputs

- Binary Map
  - Equal specificity and sensitivity logistic threshold
- Threat Impacted reaches (Low Scores)
- Minimally Impacted reaches (High Scores)
- Response curves for each threat



133 Minimally Impacted reaches and 156 Threat Impacted reaches


A
B
C
D
E
Habitat Suitability
1.0
0.8
0.6
0.4
0.2
0.0
0
2000
4000
6000
8000
Dist. to closest suitable reach
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Proportion of reach agriculture
0.15
0.20
0.25
0.30
0.35
0.40
Proportion of watershed agriculture
0
20
40
60
80
100
# of public accesses in watershed
0.02
0.04
0.06
0.08
0.10
0.12
Proportion of watershed urban

Method 2
Occupancy Modeling

Species Richness
Species Specific Effects

Bayesian Framework with Markov chain Monte Carlo (MCMC)

Inputs

- Raw species richness (Field Data)
- Detection data
- Threat site covariates

JAGS 'R2jags' in R

Output

- Species richness estimate based on imperfect detection
- Variable significance to the model
- Occupancy probability for each species at each sampled site

Predict SR and species occupancy for **unsampled** sites using output species-specific presence probabilities associated with threats

Occupancy Modeling Results

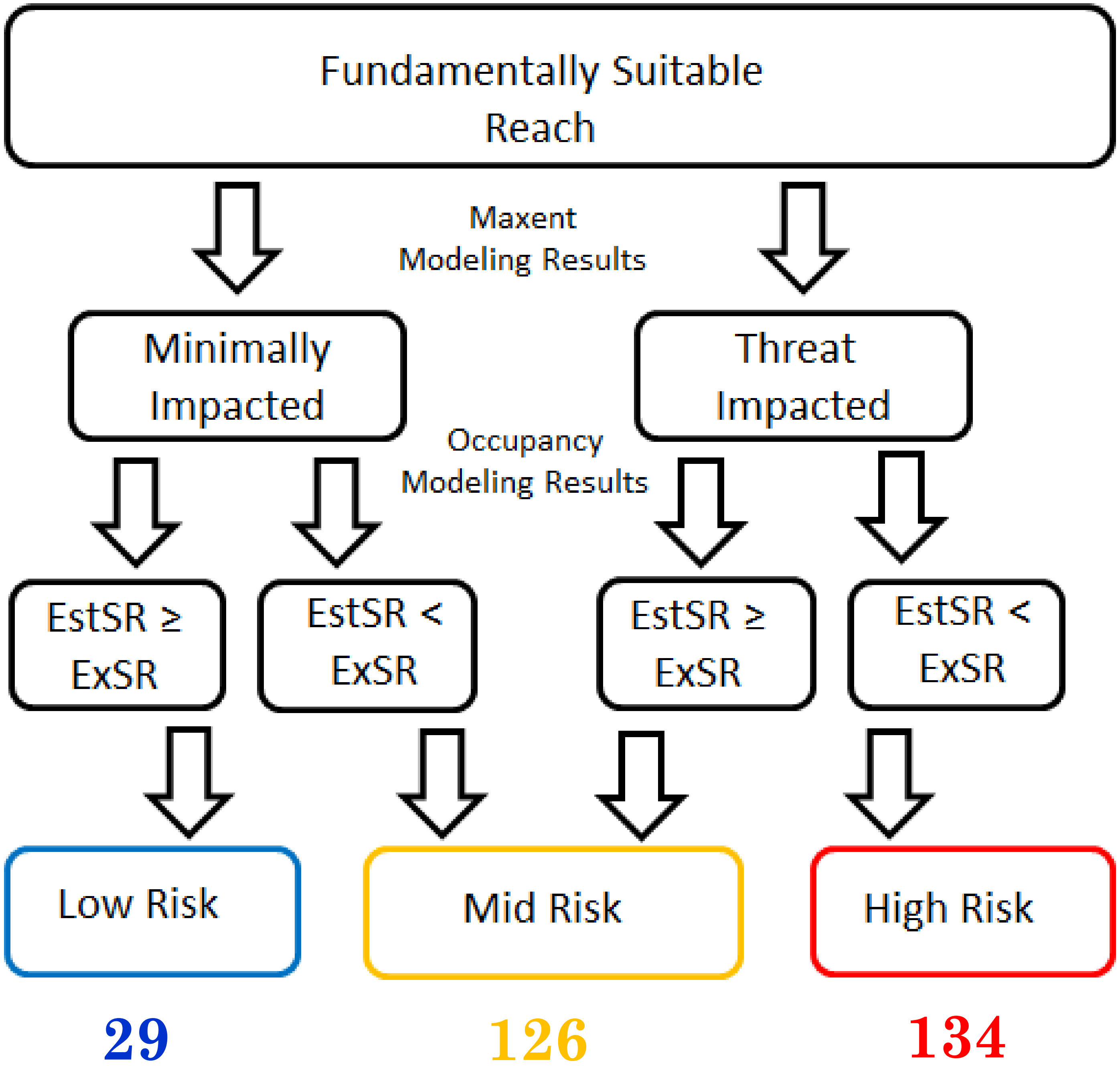
Table 5. Hypotheses driven occupancy models for freshwater mussels in the Meramec Basin, Missouri with occupancy covariate and Bayesian p-values. Extreme values (<0.05 or > 0.95) indicated consistent bias in model estimates.

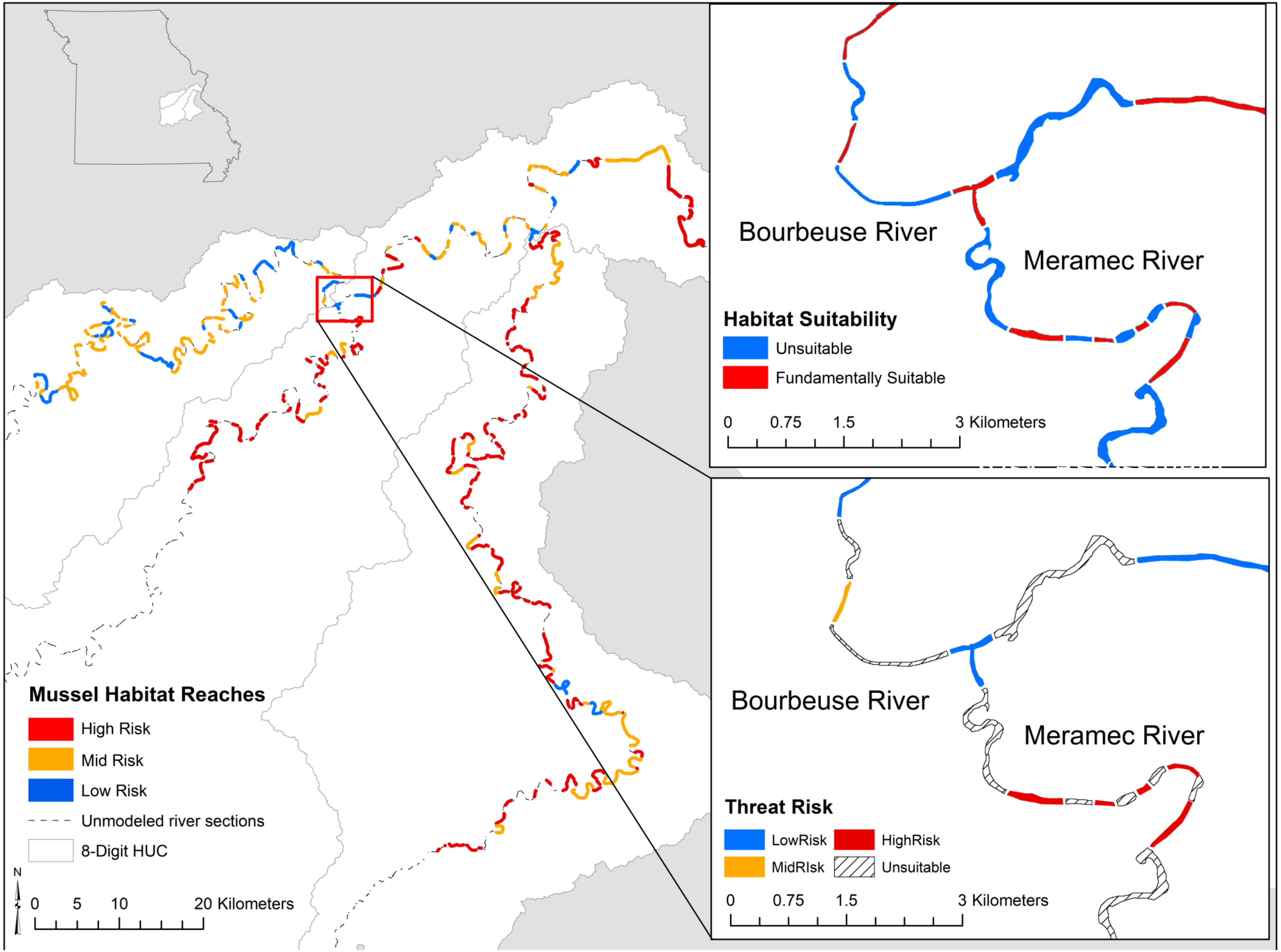
Model	Occupancy Variables	Bayesian p-value
Demographic	R.Length, River, DCSR	0.956
Fragmentation	W. BridgePA, R.BridgePA*, DCSR	0.96
Rural	FloatZone , R. BridgePA*, R. Agri, W.Agri, W.CAFOS, W.BridgePA	0.962
Urban	R.Urban, FloatZone, W.Urban, R.StormWater, R. BridgePA	0.9608
Water Quality	W.CAFOS, R.Agri, W.Urban	0.96
Physical Disturbance	R. BridgePA*, FloatZone, W. BridgePA, R.Agri, R.Urban	0.963
Maxent	R.Agri, W. Agri, W.BridgePA, W.Urban, DCSR	0.955

* Indicates variable has significant influence on dependent variable

- Predict Species Richness Estimates
- Occupancy Probabilities
- ID risk level

Categorize & Prioritize





Bourbeuse River
Meramec River
Habitat Suitability
Unsuitable
Fundamentally Suitable
0 0.75 1.5 3 Kilometers
Bourbeuse River
Meramec River
Threat Risk
LowRisk
HighRisk
MidRIsk
Unsuitable
0 0.75 1.5 3 Kilometers
Mussel Habitat Reaches
High Risk
Mid Risk
Low Risk
Unmodeled river sections
8-Digit HUC
N
0 5 10 20 Kilometers

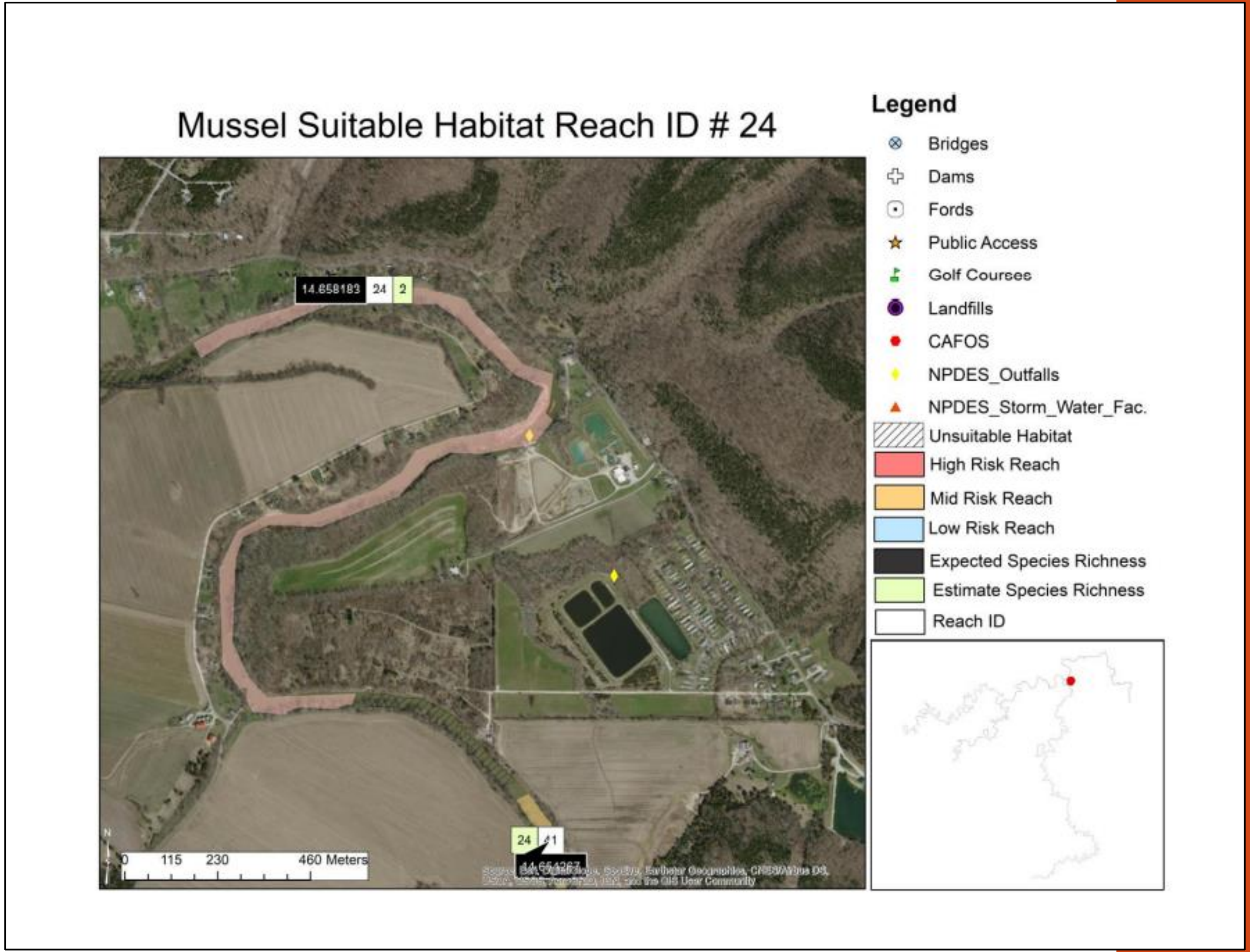
Monitoring by Risk Level

Table 7. Guidance on monitoring objectives, frequency, and intensity for each risk level.

Risk Level	Objective	Frequency	Intensity
Low-risk	Determine if there are major changes to threat presence on landscape and if the mussel bed is still showing signs of healthy recruitment of juvenile mussels to the population.	Regular and infrequent for the mussel bed (e.g., every 5 years), yearly to determine presence of new threats on the landscape.	Low intensity monitoring focused on species richness and presence/absence of recruitment.
Mid-risk (mitigated or few threats)	Mussel recruitment and the addition of rare species to the population.	Targeted (e.g., where mitigation efforts are taking place or for certain species) and frequent (e.g., yearly).	High intensity monitoring to investigate recruitment potential of multiple species.
Mid-risk (Many threats)	Species richness, loss or addition of rare species.	Targeted (e.g., where threats are mitigable or for certain species) and frequent.	High intensity monitoring to investigate recruitment potential of multiple species.
High-risk	Species richness only.	Infrequent	Low intensity to focus on loss/gain of new species

Deliverables to MDC

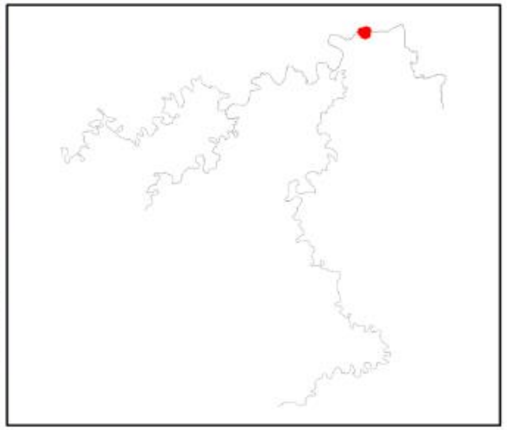
- Guidance document
  - Framework
  - Reach-specific information
    - all 289 suitable reaches
    - SR Predictions
    - Species occupancy probability
    - Threat information
- GIS Data
  - Spatial variables
  - Model results
- Modeling codes
- Adaptive framework



Mussel Suitable Habitat Reach ID # 2

Legend

- Bridges
- Dams
- Fords
- Public Access
- Golf Courses
- Landfills
- CAFOS
- NPDES_Outfalls
- NPDES_Storm_Water_Fac.
- Unsuitable Habitat
- High Risk Reach
- Mid Risk Reach
- Low Risk Reach
- Expected Species Richness
- Estimate Species Richness
- Reach ID



Mussel Suitable Habitat Reach ID # 6

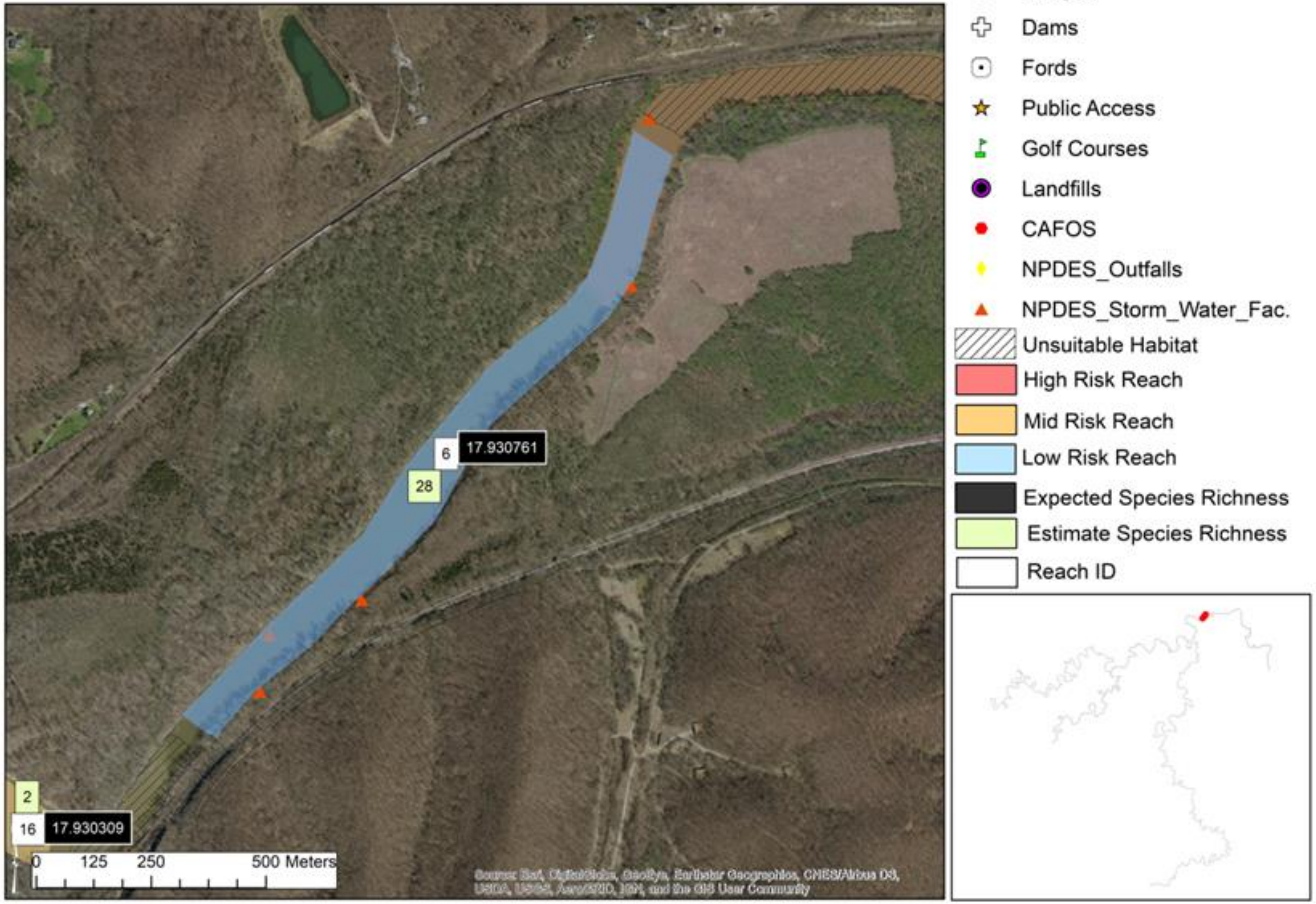


Table 9. Example of attribute table of the vector shapefiles give to state agency partners showing reach information and threat assessment results for each fundamentally suitable mussel habitat reach. Not all threats and RIDs are shown in this example due to space limitations. DAREA = Drainage area, CI = Credible interval.

RID	River	Length	DAREA	ExSR	EstSR	2.5% CI	97.5%CI	MaxEnt Threat Results	Risk_Level
1	LowMera	9109.837	10043.66	17.96838	29	6	38	0	Mid
2	LowMera	2609.068	9915.822	17.93786	2	0	7	0	High
3	LowMera	364.432	10192.94	18.00353	2	0	7	0	High
4	LowMera	4300.67	10087.12	17.97867	2	0	7	0	High
5	LowMera	314.31	9841.018	17.91982	2	0	0	1	Mid
6	LowMera	1662.628	9886.329	17.93076	28	0	38	1	Low
7	LowMera	1571.845	10092.93	17.98004	2	0	7	0	High
8	LowMera	729.667	9875.03	17.92804	2	0	7	1	Mid
9	LowMera	348.094	9813.484	17.91314	2	0	7	0	High
10	LowMera	563.954	9840.99	17.91981	2	0	7	1	Mid
11	LowMera	198.381	9876.531	17.9284	2	0	7	1	Mid
12	MidMera	651.463	7131.322	17.15246	2	0	6	1	Mid
13	MidMera	299.529	7252.193	17.19251	2	0	6	1	Mid
14	LowBourb	3990.331	2100.408	14.24002	26	7	38	1	Low
15	LowMera	325.837	9881.921	17.9297	2	0	7	1	Mid
16	LowMera	866.434	9884.452	17.93031	2	0	7	1	Mid
17	LowMera	993.374	9783.344	17.90581	35	20	38	1	Low
18	LowMera	6856.863	10173.85	17.99907	2	0	7	0	High
19	LowMera	534.225	9811.575	17.91268	2	0	7	1	Mid
20	MidMera	171.568	7254.133	17.19314	2	0	6	1	Mid

Table 10. A portion of the attribute table of the vector shapefiles give to state agency partners showing threat values for each fundamentally suitable mussel habitat reach. Not all threats and RIDs are shown in this example due to space limitations. Descriptions of threats can be found in Table 3.

RID	LeadImpact	Landfill	GolfCourse	Floattrip	DCSR	R.WaterFac	W.urban	W.forest
1	0	1	0	0	4872.926	29	0.069207	0.688389
2	0	1	0	0	3763.041	6	0.061304	0.693672
3	0	0	0	0	574.2383	1	0.075604	0.684335
4	0	1	1	0	2353.467	9	0.071892	0.686554
5	0	0	1	0	696.9908	0	0.060494	0.693297
6	0	0	0	0	2074.951	6	0.060824	0.693654
7	0	0	0	0	1600.411	4	0.072083	0.686436
8	0	0	0	0	561.0863	4	0.060674	0.693776
9	0	0	1	0	884.0518	0	0.059502	0.693903
10	0	0	1	0	696.9908	0	0.060494	0.693297
11	0	0	0	0	561.0863	0	0.060675	0.693803
12	0	0	0	0	805.84	0	0.055996	0.682432
13	0	0	0	1	525.6638	0	0.056349	0.683536
14	0	0	0	0	2403.453	0	0.0692	0.56351
15	0	0	0	0	653.4504	0	0.060836	0.693597
16	0	0	0	0	1579.478	1	0.06082	0.693645
17	0	1	0	0	1853.947	2	0.059314	0.693697
18	0	1	0	0	1703.533	9	0.074185	0.685407
19	0	1	0	0	487.5577	2	0.059469	0.693962
20	0	0	0	1	826.7977	0	0.056359	0.683369

Table 8. Example of occupancy probability estimates generated from occupancy model for all species for each site.

Site	Species	Occupancy Probability
6	*Actinonaias ligamentina*	0.86
6	*Alasmidonta marginata*	0.77
6	*Amblema plicata*	0.81
6	*Anodontoides ferussacianus*	0.71
6	*Cumberlandia monodonta*	0.76
6	*Cyclonaias tuberculata*	0.68
6	*Ellipsaria lineolata*	0.87
6	*Elliptio crassidens*	0.68
6	*Eurynia dilatata*	0.72
6	*Epioblasma triquetra*	0.69
6	*Fusconaia flava*	0.81
6	*Lampsilis abrupta*	0.75
6	*Lampsilis brittsi*	0.97
6	*Lampsilis cardium*	0.96
6	*Lampsilis siliquoidea*	0.83
6	*Lampsilis teres*	0.66
6	*Lasmigona complanata*	0.67
6	*Lasmigona costata*	0.65
6	*Leptodea fragilis*	0.92
6	*Leptodea leptodon*	0.77
6	*Ligumia recta*	0.74
6	*Megalonaias nervosa*	0.67
6	*Obliquaria reflexa*	0.85
6	*Plethobasus cyphyus*	0.76
6	*Pleurobema sintoxia*	0.74
6	*Potamilus alatus*	0.91
6	*Potamilus ohiensis*	0.74
6	*Pyganodon grandis*	0.66
6	*Quadrula fragosa*	0.72
6	*Quadrula metanevra*	0.76
6	*Cyclonaias pustulosa*	0.74
6	*Quadrula quadrula*	0.65
6	*Tritogonia verrucosa*	0.72
6	*Strophitus undulatus*	0.68
6	*Toxolasma parvus*	0.75
6	*Truncilla donaciformis*	0.70
6	*Truncilla truncata*	0.74
6	*Venustaconcha ellipsiformis*	0.72

Outcomes

FEATURE

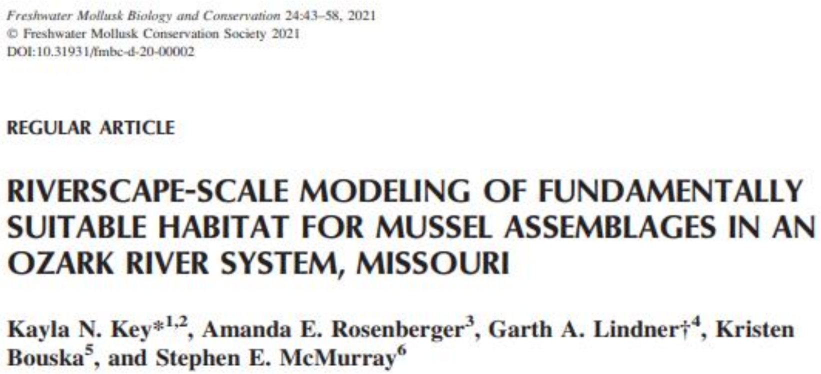
State-Level Freshwater Mussel Programs: Current Status and a Research Framework to Aid in Mussel Management and Conservation

Kristen L. Bouska | Missouri Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife Sciences, University of Missouri, Columbia, MO 65211; and U.S. Geological Survey, Upper Midwest Environmental Sciences Center, 2630 Fanta Reed Rd., La Crosse, WI 54603. E-mail: kbouska@usgs.gov

Amanda Rosenberger | U.S. Geological Survey, Missouri Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife Sciences, University of Missouri, Columbia, MO

Stephen E. McMurray | Missouri Department of Conservation, Resource Science Division, Columbia, MO

Garth A. Lindner and Kayla N. Key | Missouri Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife Sciences, University of Missouri, Columbia, MO



Freshwater Mollusk Biology and Conservation 24:43–58, 2021
© Freshwater Mollusk Conservation Society 2021
DOI:10.31931/fmbc-d-20-00002

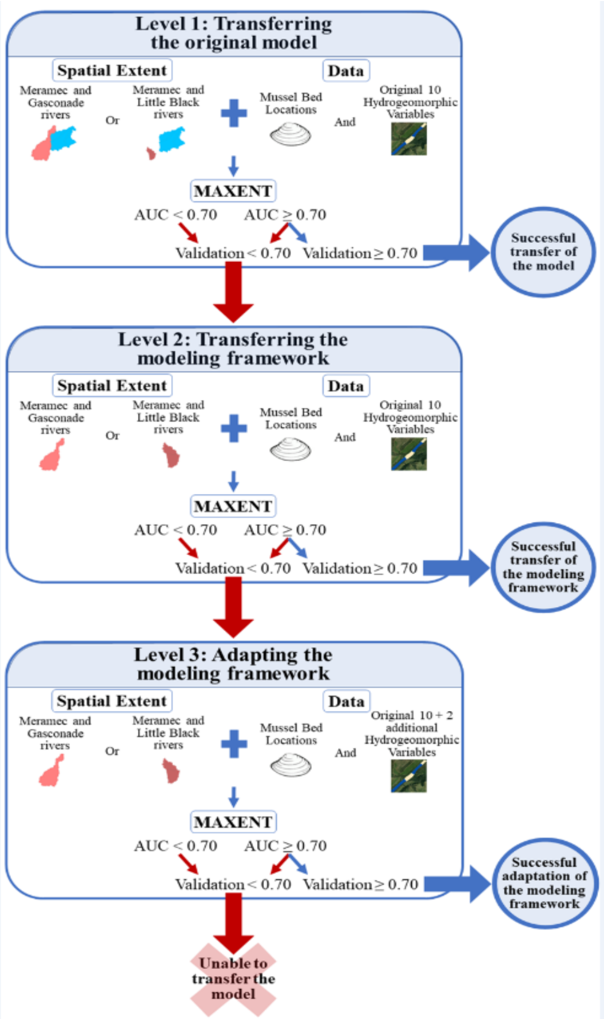
REGULAR ARTICLE

RIVERSCAPE-SCALE MODELING OF FUNDAMENTALLY SUITABLE HABITAT FOR MUSSEL ASSEMBLAGES IN AN OZARK RIVER SYSTEM, MISSOURI

Kayla N. Key*[1,2], Amanda E. Rosenberger[3], Garth A. Lindner†[4], Kristen Bouska[5], and Stephen E. McMurray[6]

Successfully tested in other MO watersheds

Hartman et al. ASSESSING POTENTIAL HABITAT FOR FRESHWATER MUSSELS BY TRANSFERRING A HABITAT SUITABILITY MODEL WITHIN THE OZARK ECOREGION, MISSOURI



Framework being Implemented in TN

- 2 regions
- Duck River, TN <- Brittany Bajo-Walker
- Hatchie River, TN <-Looking for MS student!

Acknowledgements

Committee Members

- Amanda Rosenberger
- Kit Wheeler
- Justin Murdock
- Alfred Kalyanapu
- Tammy Boles
- Craig Paukert (MU)
- Jodi Whittier (MU)
- Susannah Ewrin (MU)

Guidance

- Garth Lindner
- Kristen Bouska
- Steve McMurray
- Scott Faiman
- Andy Roberts
- Leslie Lueckenhoff
- Matt Schrum
- Tom Blanchard
- Lance Williams

Field Assistance

- Nick Ciaramitaro
- Joel Yeager
- Lauren Toivenen
- Matt Schrum
- Jake Adams
- Jordan Holtswarth
- Joe Chilton
- Trent Pearson
- Lauren Kelley

West Tennessee
WTRBA
River Basin Authority

kayla.key@tn.gov

Table 2. Summary of values for each of the two classes of the six binary hydrogeomorphic variables and the values of the sample mussel beds for the same six layers. Included for both the six layers and the sample points are the percentages for each class, the minimum and maximum lengths (m) of each reach class, and the mean and standard deviation of each reach class.

Habitat characteristic	Class	Percent of layers	Percent of samples	Reach length minimum	Reach length maximum	Mean reach length	Reach length standard deviation
Bluff adjacency ("ba")	Adjacent	40.6	40.6	30	3,885	615	523
	Not adjacent	59.4	59.4	10	9,977	886	1,159
Gravel/pool class ("gpc")	Gravel	51.3	59.4	37	9,943	603	874
	Pool	48.7	40.6	50	4,392	571	498
Gravel bar proximity ("gbp")	<100 m	67.3	71.0	61	1,1761	845	1,028
	>100 m	32.7	29.0	10	4,187	412	502
Lateral channel stability ("lcs")	Stable	85.4	88.4	148	47,643	4,464	6,395
	Unstable	14.6	11.6	73	4,545	784	869
Low-flow surface water availability class ("lwac")	High	58.1	55.1	95	7,216	1,392	1,304
	Low	41.9	44.9	113	11,819	989	1,352
Stream power class ("spc")	High	43.1	50.7	47	6,661	1,014	900
	Low	56.9	49.3	142	7,427	1,365	1,334

Table 3. Minimum, maximum, mean, and standard deviation for the four continuous habitat layers that we generated and the values of the layers at mussel-bed locations.

Habitat characteristic	Layer/Location	Minimum	Maximum	Mean	Standard deviation
Bluff adjacency area ("baa)	Layer	0	28,173	1,393	2,769
	Mussel location	0	17,678	1,129	2,672
Distance to gravel bar ("dgb")	Layer	0	1,820	121	222
	Mussel location	0	371	67	105
Low-flow surface water availability index ("lwai")	Layer	0	13.30	4.53	1.98
	Mussel location	0.78	8.55	4.34	1.73
Stream power index ("spi")	Layer	−0.0146	0.0243	0.0035	0.0031
	Mussel location	−0.0073	0.0120	0.0037	0.0029

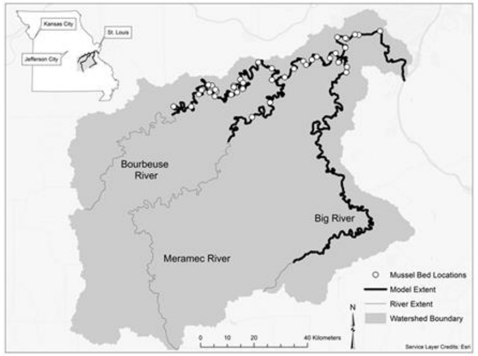
Table 1. List of hydrogeomorphic variables generated, including the abbreviated names, the type of layer (continuous/binary), ecological justification, methodological description, and hypotheses of where mussels are expected. * denotes layers used in our model.

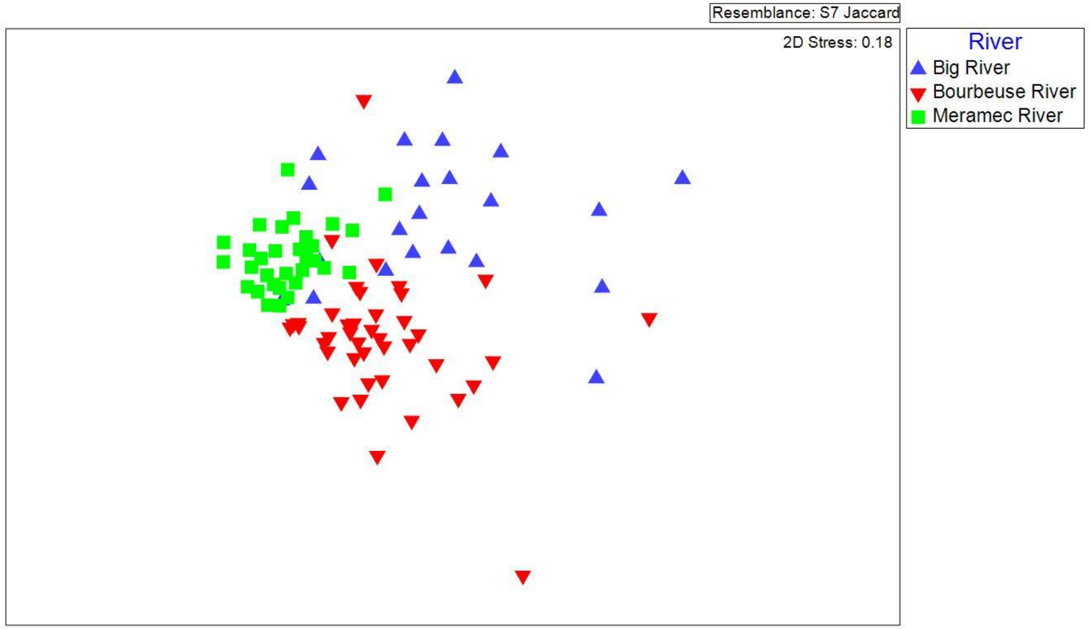
Habitat Characteristic ("layer name"): type	Justification	Description	Hypothesis
*Bluff adjacency area ("baa"): continuous	Conversations with malacologists indicate that mussel beds are usually found in the vicinity of bluffs adjacent to the stream channel	Total bluff area (m^2) within one channel width of each bank	The probability of mussel presence increases with increasing bluff area adjacent to the channel
Bluff adjacency ("ba"): binary		Whether there is a bluff within one channel width of each bank	The probability of mussel presence increases in channels adjacent to bluffs
*Stream power index ("spi"): continuous	Stream power is a major control of slope toe erosion (Nefeslioglu et al. 2008), which can have negative effects on mussels (Hartfield 1993)	Index of potential energy of water in the channel, using $spi = \ln(A_d) \times S_{500}$	The probability of mussel presence increases in areas with moderate stream power
Stream power class ("spc"): binary		Potential energy of water in the stream channel, classed as either high or low, based on spi	The probability of mussel presence increases in areas with low stream power
*Lateral channel stability ("lcs"): binary	Lateral channel movement and bank erosion could disrupt substrate stability and mussel occurrence (Strayer 1999; Strayer et al. 2004)	Lateral channel movement of > 10 m in 17 years classed as unstable, all else classed as stable	The probability of mussel presence increases in stable channels
*Gravel/pool class ("gpc"): binary	(1) Conversations with malacologists indicate that mussels are frequently found near gravel bars, and (2) areas with persistent gravel bars indicate areas that have stable beds, a necessary condition for mussel persistence (Bates 1962; Peck 2005; Zigler et al. 2008)	Reaches dominated by gravel are classed at gravel, all else classed as pool reaches	The probability of mussel presence increases within gravel class reaches
Gravel bar proximity ("gbp"): binary		All areas within 100 m of a gravel bar are classed as adjacent to a gravel bar, all else classed as not adjacent to a gravel bar	The probability of mussel presence increases within 100 m of gravel reaches
*Distance to gravel bar ("dgb"): continuous		Euclidean distance (m) to nearest gravel bar	The probability of mussel presence increases in areas with close proximity to gravel reaches
*Low-flow surface availability index ("lwai"): continuous	Refuge during drought periods is necessary for mussel survival (Golladay et al. 2004)	Cross-sectional average of the area of water pixels surrounding each cell, normalized by stream width	The probability of mussel presence increases in areas with higher low-water availability index values
Low-flow surface water availability class ("lwac"): binary		Cross-sectional average of the area of water pixels surrounding each cell, normalized by stream width, classed as high or low	The probability of mussel presence increases in areas with high low-water availability classification

A_d is the total drainage area upstream of the site, and S500 is the slope over 500 m.

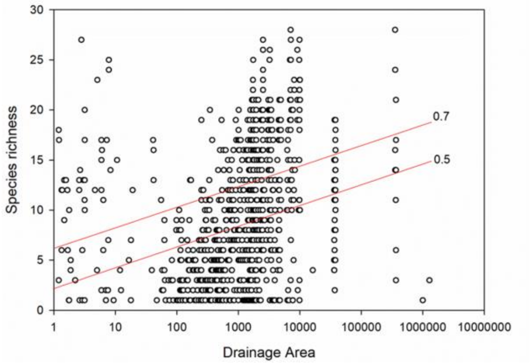
Non-metric multidimensional scaling (NMDS)

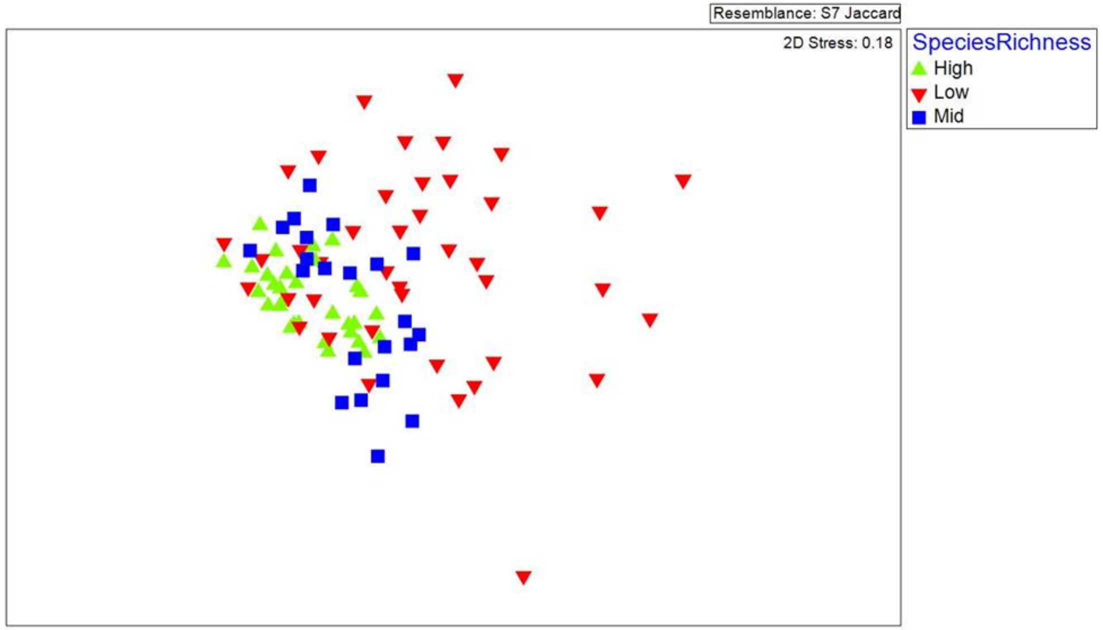
River

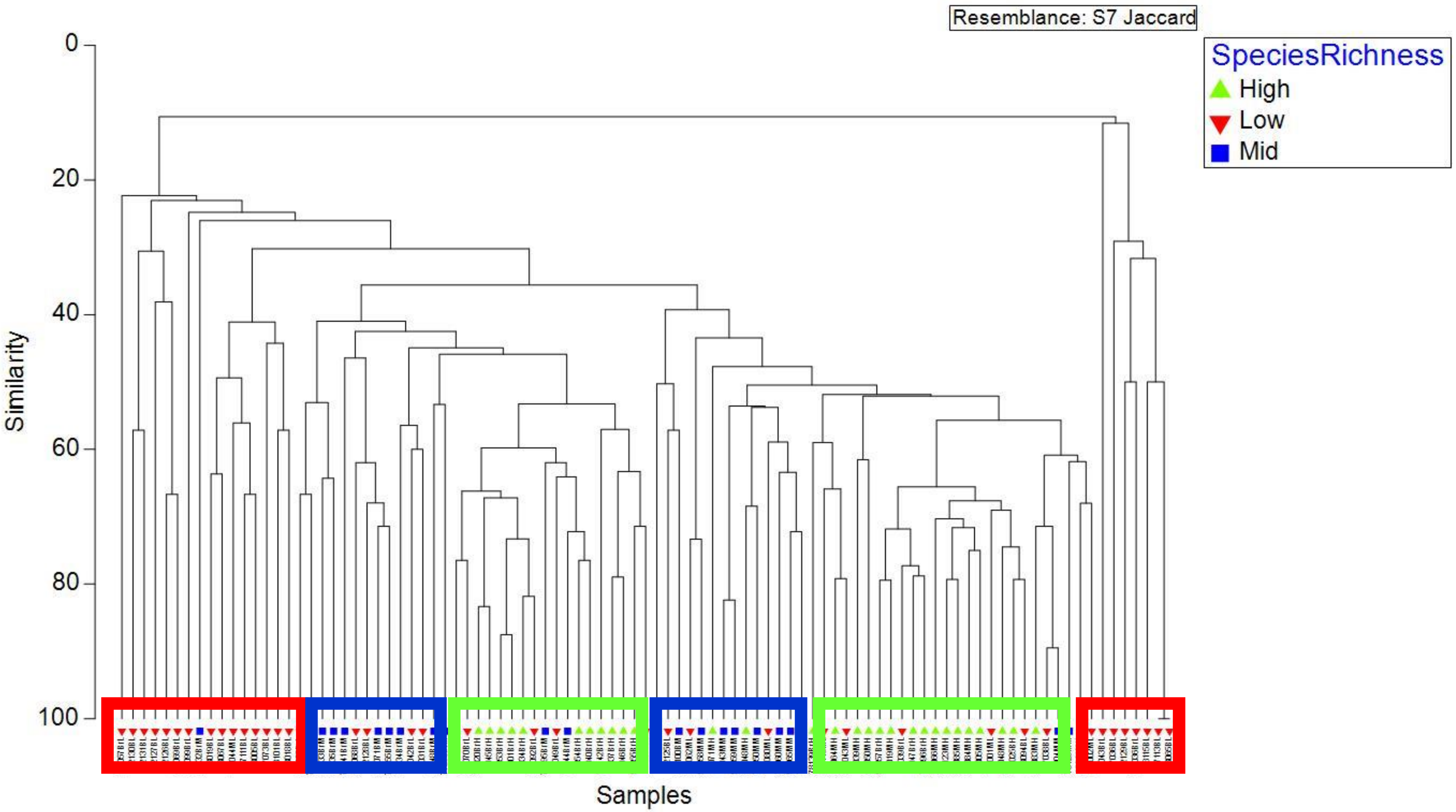




Species Richness







Resemblance: S7 Jaccard
SpeciesRichness
High
Low
Mid
Similarity
0
20
40
60
80
100
Samples

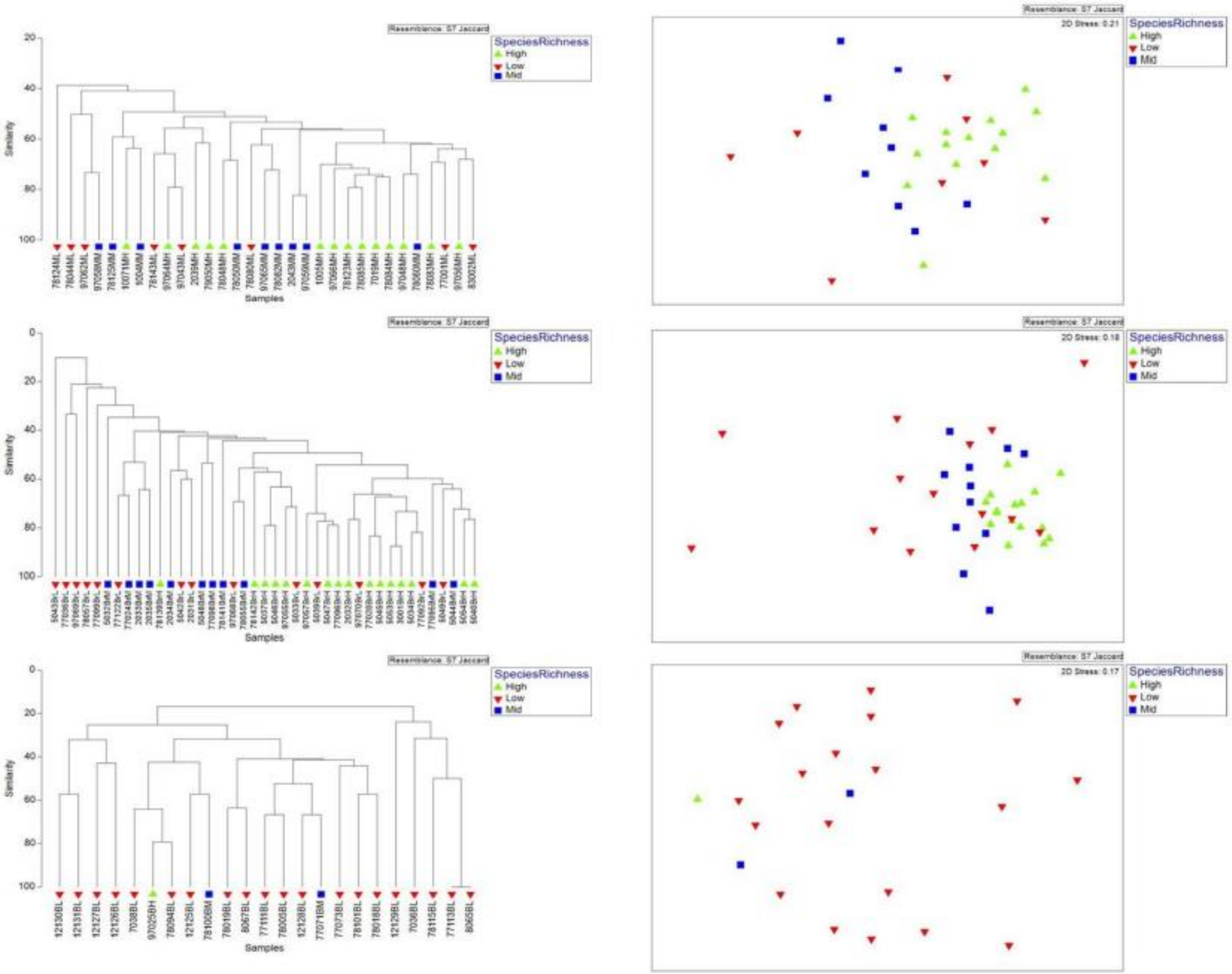


Figure 14. Non-metric multidimensional scaling (NMDS) and dendrogram of mussel assemblages for the Meramec (top), Bourbeuse (middle), and Big (bottom) rivers in relation to river and species richness.