Determining Mitigation Needs for NiSource Natural Gas Transmission Facilities - Implementation of the Multi-Species Habitat Conservation Plan (MSHCP)

Mitigation Site Report

Freshwater Mussels

Section 6 Cooperative Endangered Species Conservation Fund Grant (IDFW Subtask 2.2)

Prepared by The Conservation Fund

DECEMBER 2010

FRESHWATER MUSSELS MITIGATION SITE REPORT

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Mitigation Site Report Summary

The key task of the NiSource Multi-Species Habitat Conservation Plan (MSHCP) Section 6 grant is to identify potential mitigation opportunities for take species outlined in the MSHCP. The Conservation Fund (the Fund), in consultation with the US Fish and Wildlife Service (USFWS), NiSource, and state natural resource agencies, has prepared customized mitigation site reports, organized by species that provide selection criteria and an initial list of potential mitigation project opportunities that are likely to meet the requirements outlined in the MSHCP.

Additional information on individual projects will be required at the time of mitigation need as outlined in the Mitigation Proposal Requirements section of the MSHCP. Whether a mitigation proposal can be funded will depend on a number of factors, including but not limited to the species affected, the location of the mitigation activities compared to the location of the species impacts, the cost of the mitigation proposal, whether the proposal satisfies the mitigation proposal criteria, and the scientific justification for the mitigation proposal. This species report is a helpful resource in preparing the future applications for mitigation funding and should be used in conjunction with the Decision Support Framework for Evaluating and Ranking Mitigation Sites report.

Mitigation Project Criteria

Each take species has a set of project selection criteria that will be used to help evaluate and rank potential mitigation projects. The MSHCP currently includes nine take species where potential mitigation projects meeting specific requirements will need to be identified over the 50-year timeframe of the MSHCP (see table).

NiSource MSHCP Take Species Requiring Mitigation
Bog Turtle
Clubshell
Fanshell
Indiana Bat
James Spinymussel
Madison Cave Isopod
Nashville Crayfish
Northern Riffleshell
Sheepnose

The Fund generated an initial set of mitigation project selection criteria for each species based upon an analysis of the draft MSHCP. These criteria were reviewed and refined in detail during a series of webinars held by the Fund, NiSource, and USFWS in spring 2010. These criteria were then presented to the states during focus group meetings in summer 2010 where additional enhancements were made. The Fund synthesized the comments from the states in September 2010 and organized the criteria for each species into a hierarchical structure known as a 'decision tree'.

Each decision tree evaluates to what extent a potential mitigation project meets the particular take species mitigation needs and desires (including habitat quality, location, likely protection in perpetuity, and protection of other listed species) as well as how it supports the green infrastructure network design, advances state and regional planning goals, and leverages other financial and partnership resources. The Fund has included a copy of the decision tree as a reference in this report.

Each criterion spans a range of characteristics from most to least suitable in terms of meeting species mitigation requirements. Where each project falls within this range is represented numerically on a standard scale from 0-100 that describes how well it satisfies that particular criteria (100 being the highest). In addition to the score for each criterion, weights are assigned relative to other criteria within its 'branch of the tree' since some factors are more important than others in evaluating a potential project. In addition, criteria have a 'logic structure' that designates them as mandatory, sufficient, or desired based on their contribution to species protection. The Fund has included descriptions of the criteria and their values as reference in this report. The project selection criteria provide an applicant with insight into project characteristics that make them more attractive for mitigation funding and hopefully will lead to well prepared applications that are responsive to the articulated goals of the mitigation effort.

The design of the decision trees is based on a state-of-the-art method known as 'logic scoring of preference' (LSP) to ensure that all criteria and weightings are designed to reflect fundamental properties of human reasoning and ensure that the benefits calculated accurately reflect the desired intent of decision makers (Dujmović, 2007). Dr. Jozo Dujmović, one of the world's pioneers in the use of LSP for decision making, has designed a customized desktop software package (ISEE) and a web-based application (LSPWeb) to support the ongoing refinement of the species decision trees as the MSHCP begins to be implemented in 2011. Instructions on the use of LSP software are found within the ISEE Users Manual- Integrated System Evaluation Environment V1.1. For web applications, refer to the LSP Methods for Evaluation over the Internet V1.

Although the details of the application review process are not firm at this time, it is likely that the application reviewer(s) would enter the criteria values into the LSP software for each potential mitigation project. Next, the LSP software generates a numerical score on a 100-point scale that represents the percent satisfaction that the project meets the decision tree criteria. The *ISEE* desktop application is the tool that ensures the criterion scores, weights, and logic structure are structured properly and follow the scientifically rigorous techniques of the LSP method. A project's percent satisfaction, when combined with the costs of implementing the project, can be used to help evaluate and rank potential mitigation projects. When trying to select a single project to meet mitigation requirements, the *LSPWeb* application streamlines the selection process and helps clarify the tradeoffs involving benefits and costs for potential projects.

In situations where a large number of projects need to be selected concurrently within a relatively fixed budget constraint, tools using the concept of optimization are most suitable for helping to select multiple projects at a time. The Fund has collaborated with Dr. Kent Messer from the University of Delaware to develop the Optimization Decision Support Tool (*ODST*). The ODST is an Excel™ based application that allows users to evaluate mitigation opportunities based on a variety of evaluation techniques: (1) identifying an optimal set of mitigation projects within a fixed budget constraint, (2) exploring the relative cost effectiveness of mitigation projects and selecting the portfolio with the highest benefit: cost ratio, and/or (3) identifying the minimum cost required to achieve a defined benefit level. The details of the use of the software application are covered in the user manual "Optimization Decision Support Tool Reference Guide –Lite Version.

<u>All mitigation project selection will be governed by the decision making process outlined in the MSHCP. A final MSHCP will not be available before the end of the Section 6 grant project. The weights and logic structure outlined in the enclosed decision trees are likely to be adjusted in the future by USFWS and NiSource, in consultation with the states</u>.

With the above caveats in mind, this species mitigation site report summarizes each state's Wildlife Action Plan recommendations, Maxent models and mitigation opportunities; and provides a true landscape scale snap shot of the alternatives. This document hopefully will serve as a desk reference for mitigation needs and opportunities for these listed freshwater mussels.

Potential Mussel Mitigation Opportunity Summary Table

The following table summarizes potential mitigation site opportunities for the mussel take species. The bulk of sites were contributed by state agency staff at two outreach meetings held in 2008 and 2010. Each site represents a general location for a potential mitigation opportunity, but the features in the associated GIS layer are not accurate to the parcel scale.

ID	Species Need	Opportunity	Location	Notes
IN722	Clubshell / Fanshell / Northern Riffleshell / Sheepnose	Protect riparian zone + Northern Riffleshell reintroduction site	Lower Tippecanoe River below Oakdale dam	
IN726	Clubshell / Sheepnose	Protect riparian zone	Middle Tippecanoe River - Pulaski County	Clubshell may or may not be present
IN730	Clubshell / Sheepnose	Protect riparian zone	Upper Tippecanoe River - Fulton County	
IN734	Sheepnose	Protect riparian zone	Lower Eel River	Sheepnose may or may not be present
IN738	Fanshell	Protect riparian zone	East Fork White River downstream of Williams Dam	
KY842	Clubshell / Fanshell / Sheepnose	Protect riparian zone	Licking River	Add to existing public land
KY850	Clubshell / Fanshell / Sheepnose	Protect riparian zone	Licking River	Add to existing public land
KY854	Clubshell / Fanshell / Sheepnose	Dam removal	Green River near Mammoth Cave NP	Restore 18 miles of Green River on public land
KY872	Fanshell / Northern Riffleshell / Sheepnose	Protect riparian zone	Lower Licking River	Add to existing public land
KY876	Fanshell	Protect riparian zone	Salt River	

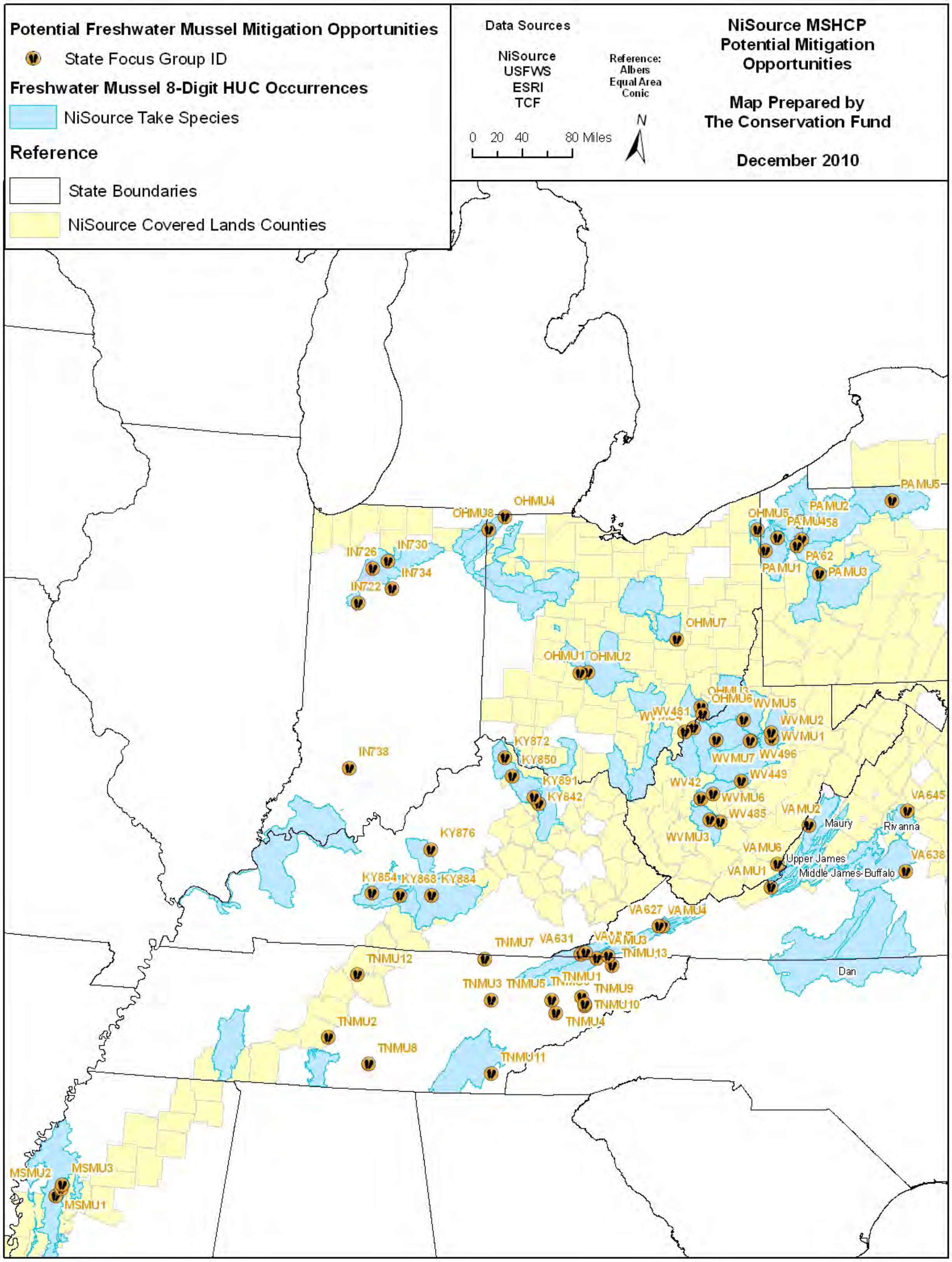
KY868	Sheepnose	Mussel propagation program	Middle Green River: Mammoth Cave Mussel Hatchery	Propagation of Sheepnose + 8 endemic mussels
KY884	Sheepnose	Mussel propagation program	Green River: Minor Clark Hatchery	
KY891	Fanshell / Sheepnose	Protect riparian zone + augmentation + reintroduction + propagation	Licking River (Blue Licks Area)	
MSMU1	Sheepnose	Restoration of riparian zone	Big Sunflower River - Landfield Road (Live)	
MSMU2	Sheepnose	Restoration of riparian zone	Big Sunflower River - Blaine Road (Live)	
MSMU3	Sheepnose	Restoration of riparian zone	Big Sunflower River - Doddsville (Fresh Dead)	
OHMU1	Northern Riffleshell	Protect riparian zone + augmentation	Big Darby Creek	
OHMU2	Clubshell	Protect riparian zone	Little Darby Creek	
OHMU3	Fanshell / Sheepnose	Protect riparian zone	Muskingum River	
OHMU4	Clubshell	Protect riparian zone	E. Fork W. Branch St. Joseph	
OHMU5	Clubshell	Protect riparian zone	Pymatuning Creek	
OHMU6	Fanshell / Sheepnose	Protect riparian zone	Ohio River	
OHMU7	Clubshell / Fanshell / Sheepnose	Protect riparian zone	Walhonding River	
OHMU8	Clubshell	Protect riparian zone	Fish Creek	
PA58	Sheepnose	Surveys	Allegheny River & French Creek	

PA62	Clubshell / Northern Riffleshell	Protect riparian zone	Allegheny River & French Creek	
PAMU1	Clubshell	Protect riparian zone	Shenango River btn reservoirs	
PAMU2	Clubshell / Northern Riffleshell	Protect riparian zone	French Creek tributaries	
PAMU3	Clubshell / Northern Riffleshell	Protect riparian zone	Allegheny River Pools	
PAMU4	Clubshell	Protect riparian zone	Shenango River tributaries	
PAMU5	Clubshell / Northern Riffleshell	Surveys	Upper Allegheny River	
TNMU1	Fanshell / Sheepnose	Protect riparian zone	Clinch River (TN section)	
TNMU10	Fanshell / Sheepnose	Reintroduction site	Pigeon River	
TNMU11	Fanshell / Sheepnose	Reintroduction site	Hiwassee River	
TNMU12	All T&E Mussel Species	Mussel propagation program	Mussel propagation and relocation facility	
TNMU13	Sheepnose	Reintroduction site	Upper Holston River	
TNMU2	Fanshell / Sheepnose	Protect riparian zone	Duck River	
TNMU3	Clubshell / Fanshell / Sheepnose	Protect riparian zone	Pickwick Tailwater (Pickwick Dam to Kentucky Dam)	
TNMU4	Fanshell	Reintroduction site	Lower French Broad River NEP	
TNMU5	Fanshell	Reintroduction site	Lower Holston River NEP	
TNMU6	Fanshell	Reintroduction site	Nolichucky River	
TNMU7	Fanshell	Reintroduction site	Big South Fork River	
TNMU8	Fanshell	Reintroduction site	Elk River	

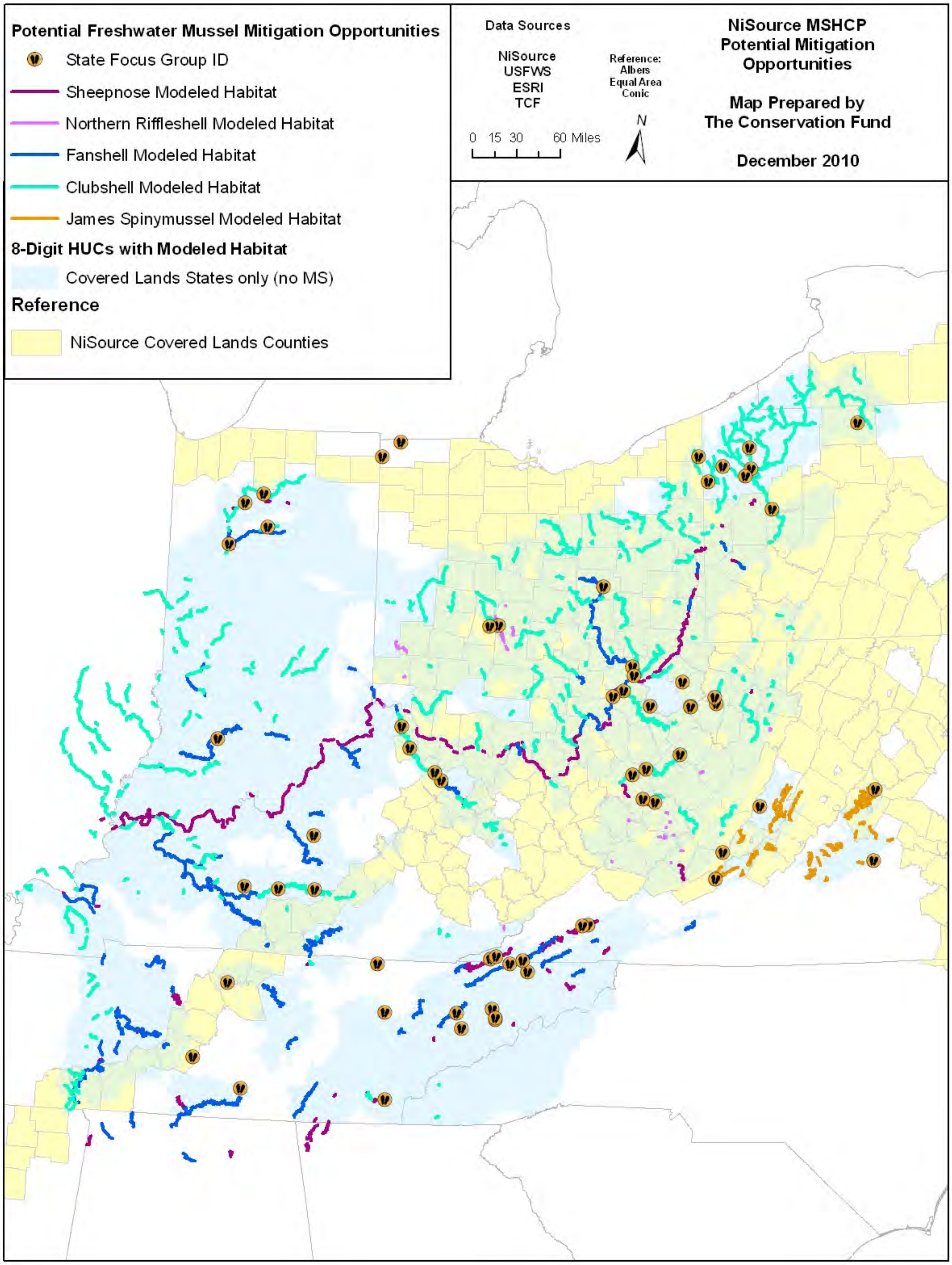
TNMU9	Fanshell / Sheepnose	Reintroduction site	Upper French Broad River	
VA627	Fanshell / Sheepnose	Protect riparian zone	Pinnacla NAP	
VA631	Fanshell / Sheepnose	Protect riparian zone	Powell River	
VA645	James Spinymussel	Protect riparian zone	Rivanna River watershed, Greene County	
VA638	James Spinymussel	Augmentation	Middle James River watershed	
VAMU1	James Spinymussel	Protect riparian zone	Little Oregon Creek/Dicks Creek: Craig City	
VAMU2	James Spinymussel	Protect riparian zone	Mill Creek, Bath City	
VAMU3	James Spinymussel	Protect riparian zone	Peddlar River, Ahherst City	
VAMU4	Clubshell	Protect riparian zone	Lower Clinch River, Cleveland Barrens NAP	
VAMU6	James Spinymussel	Protect riparian zone	Need to locate placename	
VAMU5	Sheepnose	Protect riparian zone	Powell River, Cedar NAP and near TNC's Fletcher Ford Preserve	
WV449	Clubshell	Protect riparian zone	Need to locate placename	
WV496	Clubshell	Restoration of riparian zone	Hacker's Creek restoration on private land	
WV481	Sheepnose	Restoration of riparian zone	Ohio River Island Backchannel Restoration, also embayments	
WV485	Fanshell / Sheepnose	Protect riparian zone	Upper Kanawha River land purchase easement	

WV42	Clubshell / Northern Riffleshell	Protect riparian zone + restoration	Elk River Watershed	
WV44	Clubshell	Restoration of riparian zone	Hacked Creek/ Middle Island Creek restoration	
WVMU1	Clubshell	Restoration of riparian zone	Hacker's Creek	
WVMU2	Clubshell	Restoration + Dam Removal	Westfork River - Harrison County	
WVMU3	Sheepnose	Protect riparian zone + augmentation	Upper Kanawha	
WVMU4	Clubshell	Augmentation	Ohio River	
WVMU5	Clubshell	Restoration of riparian zone	Middle Island Creek	
WVMU6	Northern Riffleshell	Protect riparian zone + augmentation + restoration	Elk River	
WVMU7	Clubshell	Restoration of riparian zone	South Fork of the Huges River	

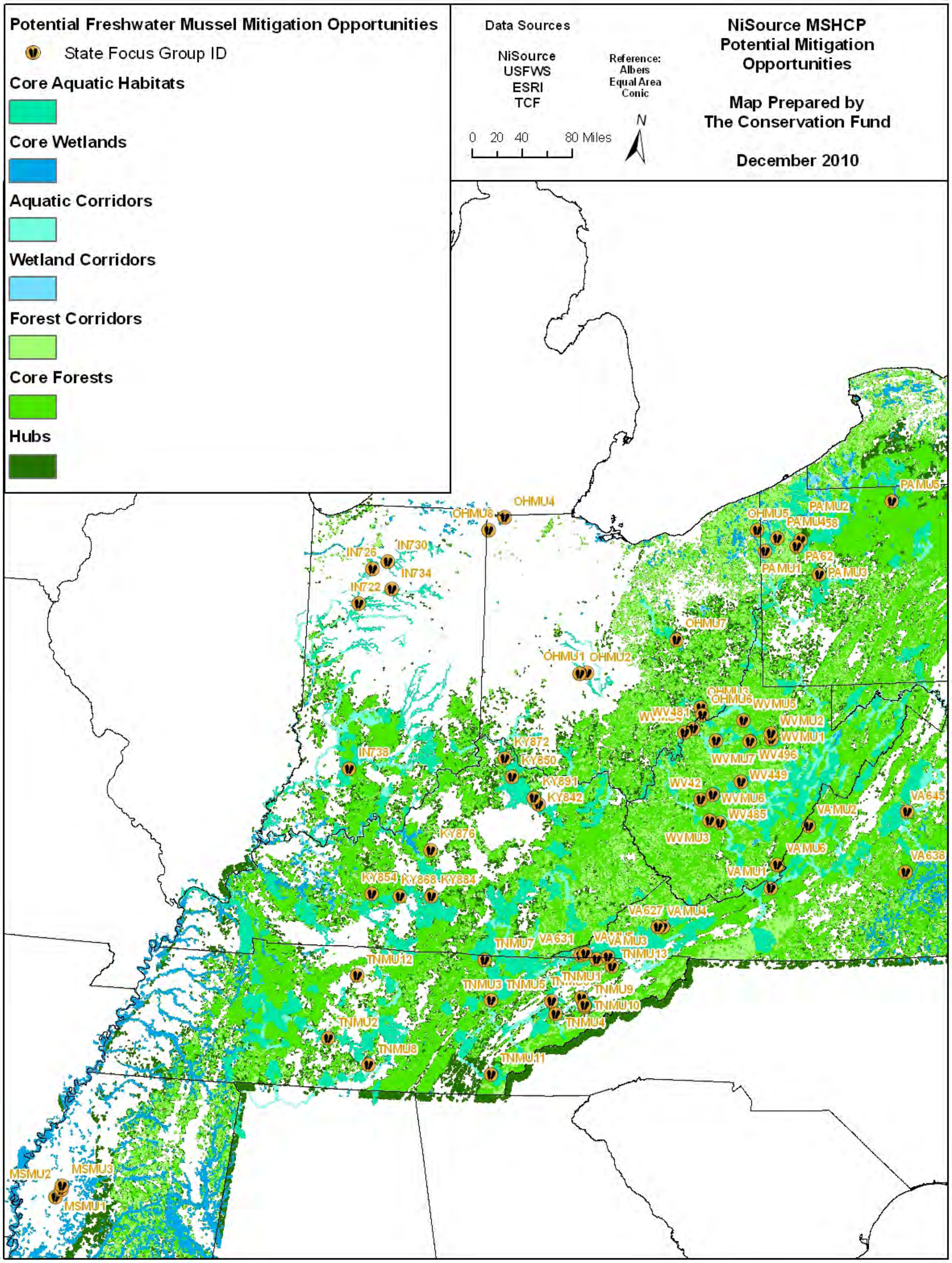
Map 1 – Freshwater Mussel Opportunities and Occurrences


Potential Freshwater Mussel Mitigation Opportunities
State Focus Group ID
Freshwater Mussel 8-Digit HUC Occurrences
NiSource Take Species
Reference
State Boundaries
NiSource Covered Lands Counties
Data Sources
NiSource
USFWS
ESRI
TCF
Reference: Albers Equal Area Conic
0 20 40 80 Miles
N
NiSource MSHCP
Potential Mitigation Opportunities
Map Prepared by The Conservation Fund
December 2010

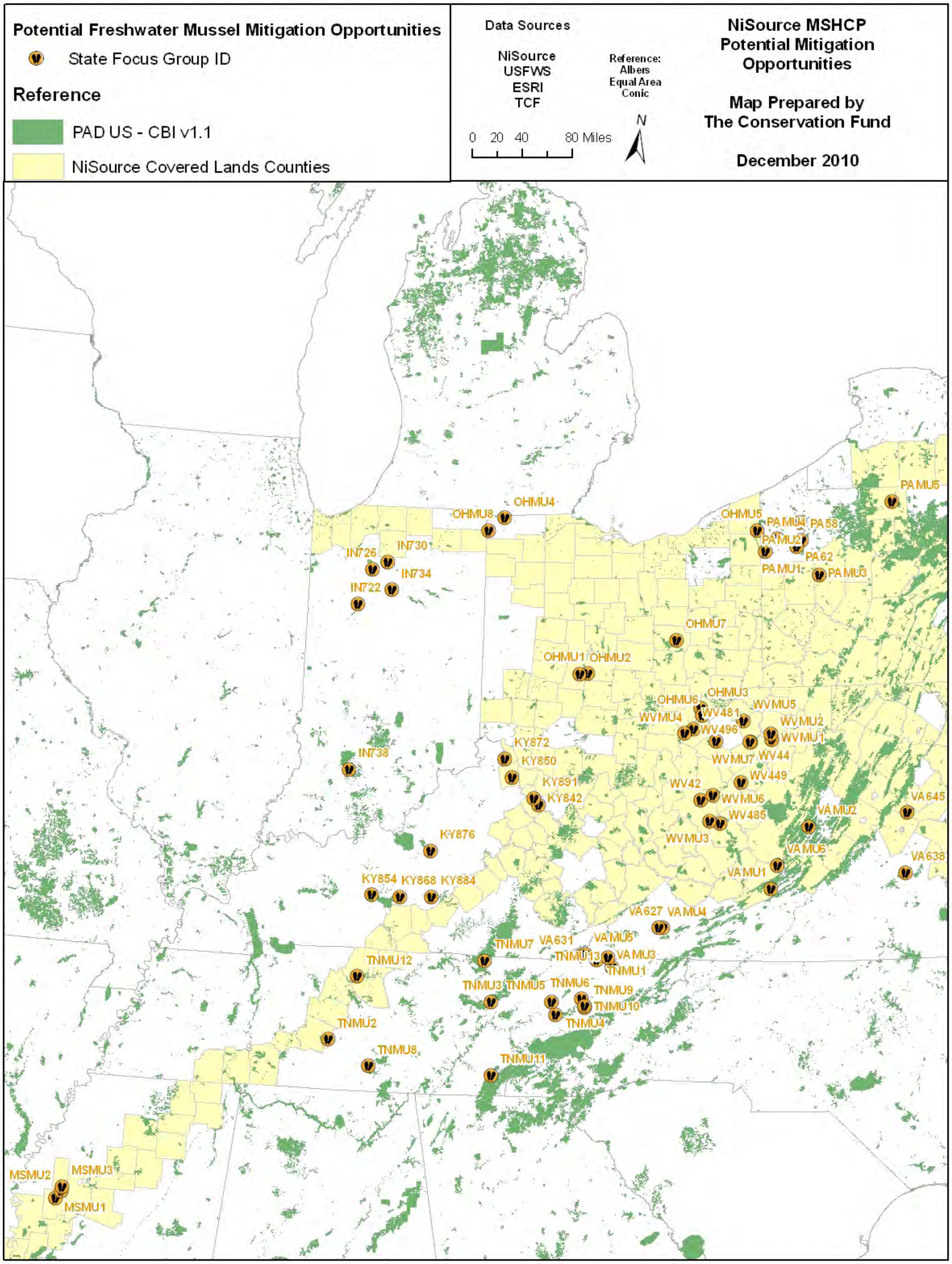
Map 2 - Freshwater Mussel Opportunities and Modeled Habitat


Potential Freshwater Mussel Mitigation Opportunities
State Focus Group ID
Sheepnose Modeled Habitat
Northern Riffleshell Modeled Habitat
Fanshell Modeled Habitat
Clubshell Modeled Habitat
James Spinymussel Modeled Habitat
8-Digit HUCs with Modeled Habitat
Covered Lands States only (no MS)
Reference
NiSource Covered Lands Counties
Data Sources
NiSource
USFWS
ESRI
TCF
Reference:
Albers
Equal Area
Conic
0 15 30 60 Miles
N
NiSource MSHCP
Potential Mitigation
Opportunities
Map Prepared by
The Conservation Fund
December 2010

Map 3 – Freshwater Mussel Opportunities and the Green Infrastructure Network


Potential Freshwater Mussel Mitigation Opportunities
State Focus Group ID
Core Aquatic Habitats
Core Wetlands
Aquatic Corridors
Wetland Corridors
Forest Corridors
Core Forests
Hubs
Data Sources
NiSource
USFWS
ESRI
TCF
Reference:
Albers
Equal Area
Conic
0 20 40 80 Miles
N
NiSource MSHCP
Potential Mitigation
Opportunities
Map Prepared by
The Conservation Fund
December 2010
OHMU4
OHMU8
IN730
IN726
IN734
IN722
PA MU5
PA MU2
OHMU5
PA MU458
PA 62
PA MU1
PA MU3
OHMU7
OHMU1
OHMU2
OHMU6
WV MU5
WV 481
WV MU2
WV MU1
WV MU7
WV 496
IN738
KY872
KY850
KY891
KY842
WV 42
WV 449
WV MU6
WV 485
WV MU3
VA 645
VA MU2
VA MU6
VA 638
VA MU1
KY876
KY854
KY868
KY884
VA 627
VA MU4
VA MU3
VA 631
TNMU7
TNMU12
TNMU13
TNMU1
TNMU3
TNMU5
TNMU9
TNMU10
TNMU4
TNMU2
TNMU8
TNMU11
MSMU2
MSMU3
MSMU1

Map 4 – Freshwater Mussel Opportunities and Protected Lands


Potential Freshwater Mussel Mitigation Opportunities
State Focus Group ID
Reference
PAD US - CBI v1.1
NiSource Covered Lands Counties
Data Sources
NiSource
USFWS
ESRI
TCF
Reference: Albers Equal Area Conic
0 20 40 80 Miles
N
NiSource MSHCP Potential Mitigation Opportunities
Map Prepared by The Conservation Fund
December 2010
OHMU8
OHMU4
IN726
IN730
IN734
IN722
OHMU5
PA MU4
PA58
PA MU2
PA62
PA MU1
PA MU3
PA MU5
OHMU7
OHMU1
OHMU2
OHMU6
OHMU3
WV481
WV MU5
WV MU4
WV496
WV MU2
WV MU1
WV MU7
WV44
WV449
WV42
WV MU6
WV485
WV MU3
IN738
KY872
KY850
KY891
KY842
KY876
KY854
KY868
KY884
VA MU2
VA645
VA MU6
VA638
VA MU1
VA627
VA MU4
VA MU5
VA631
TNMU7
TNMU13
VA MU3
TNMU1
TNMU12
TNMU3
TNMU5
TNMU6
TNMU9
TNMU10
TNMU4
TNMU2
TNMU8
TNMU11
MSMU2
MSMU3
MSMU1

Freshwater Mussels Decision Tree

1 Freshwater Mussels Mitigation Projects
- 11 *Habitat Mitigation Needs*
  - 111 *Mandatory Requirements*
    - **1111 Mitigation Units**
    - 1112 *Site Assessment*
      - **11121 Buffer Size & Shape**
      - **11122 Intact Buffer Sites**
      - **11123 Mussel Distribution**
    - 1113 *Physical Conditions*
      - **11131 Substratum**
      - **11132 Water Quality**
      - **11133 Bed Stability**
      - **11134 Barriers to Fish Passage**
    - 1114 *Species Occurrence*
      - **11141 Known & Potential Host Fish**
      - **11142 Mussel Population Viability**
      - **11143 Mussel Diversity**
      - **11144 Mussel Density**
      - **11145 Detrimental Invasive Species**
    - **1115 Project Location**
  - 112 *Desired Characteristics*
    - *1121 Protection in Perpetuity*
      - **11211 Point & Nonpoint Pollution Risk**
      - **11212 Sedimentation & Substrate Removal Risk**
      - **11213 Stream Impoundment Risk**
      - **11214 Stream Buffer Clearing Potential**
      - **11215 Project Monitoring**
    - *1122 Listed Species Protection*
      - **11221 NiSource MSHCP Take Species**
      - **11222 Federal & State Listed Species**
- 12 *Strategic Conservation Goals*
  - **121 Green Infrastructure Network**
  - 122 *Adopted Plans & Leverage*
    - **1221 State Wildlife Action Plans**
    - **1222 Conservation Planning**
    - **1223 Collaboration**

KEY

Bold - Criteria where values are directly input into Decision Tree Software

Italic - Categories with logic structure (i.e. mandatory/desired, simultaneity, replaceability)

Freshwater Mussel Tree Logic & Criteria Weights

1 **Freshwater Mussel Mitigation Projects** [CPA -20+15]
- 11 MANDATORY Take Species Habitat Mitigation Requirements
- 12 DESIRED Other Conservation Goals

The DESIRED input cannot compensate the absence of MANDATORY input, but the MANDATORY input can significantly compensate the absence or low value of the DESIRED input. There is a 20% penalty for a low DESIRED value and a 15% reward for a high DESIRED value. This is known as conjunctive partial absorption (CPA).

11 **Habitat Mitigation Needs** [CPA -25+20]
- 111 MANDATORY Requirements
- 112 DESIRED Characteristics

The DESIRED input cannot compensate the absence of MANDATORY input, but the MANDATORY input can significantly compensate the absence or low value of the DESIRED input. There is a 25% penalty for a low DESIRED value and a 20% reward for a high DESIRED value. This is known as conjunctive partial absorption (CPA).

111 **Mandatory Requirements** [C+- Medium-strong simultaneity]
- 1111 Mitigation Units – 25%
- 1112 Site Assessment – 20%
- 1113 Physical Conditions – 15%
- 1114 Species Occurrence – 25%
- 1115 Project Location – 15%

In medium-strong simultaneity, all inputs must be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1112 **Site Assessment** [C-+ Medium-weak simultaneity]
- 11121 Buffer Size & Shape – 40%
- 11122 Intact Buffer Sites – 30%
- 11123 Mussel Distribution – 30%

In medium-weak simultaneity, all inputs should be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1113 **Physical Conditions** [C-+ Medium-weak simultaneity]

11131 Substratum – 20%
11132 Water Quality – 40%
11133 Bed Stability – 20%
11134 Barriers to Fish Passage – 20%

In medium-weak simultaneity, all inputs should be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1114 **Species Occurrence** [C-+ Medium-weak simultaneity]

11141 Known & Potential Host Fish – 20%
11142 Mussel Population Viability – 25%
11143 Mussel Diversity – 20%
11144 Mussel Density – 20%
11145 Detrimental Invasive Species – 15%

In medium-weak simultaneity, all inputs should be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

112 **Desired Characteristics** [C-- Very-weak simultaneity]

1121 Protection in Perpetuity – 60%
1122 Listed Species Protection – 40%

In very weak simultaneity, all inputs should be to some extent simultaneously satisfied. A zero input does not necessarily yield a zero output. This is known as soft partial conjunction (SPC), which is used to model non-mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1121 **Likely Protection in Perpetuity** [C-+ Medium-weak simultaneity]

11211 Point & Nonpoint Pollution Risk – 25%
11212 Sedimentation & Substrate Removal Risk – 25%
11213 Stream Impoundment Risk – 20%
11214 Stream Buffer Clearing Potential – 15%
11215 Project Monitoring – 15%

In medium-weak simultaneity, all inputs should be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1122 **Protection of Other Listed Species** [DA Strong replaceability]
11221 NiSource MSHCP Take Species – 75%
11222 Other Federal and State Listed Species – 25%

In strong replaceability, each input can be used to completely compensate the lack of remaining inputs. This is known as hard partial disjunction (HPD), which is used to model sufficient conditions. Percentages correspond to the relative weights of each criterion within this branch of the tree.

12 **Other Conservation Goals** [C- Weak simultaneity 65/35]
121 Support for Green Infrastructure Goals – 65%
122 Planning Goals and Leverage Opportunities -35%

In weak simultaneity, all inputs should be to some extent simultaneously satisfied. A zero input does not necessarily yield a zero output. This is known as soft partial conjunction (SPC), which is used to model non-mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

122 **Planning Goals and Leverage Opportunities** [DA Strong replaceability 30/20/50]
1221 State Wildlife Action Plans – 30%
1222 Other State and Regional Plans – 20%
1223 In-Kind Support – 50%

In strong replaceability, each input can be used to completely compensate the lack of remaining inputs. This is known as hard partial disjunction (HPD), which is used to model sufficient conditions. Percentages correspond to the relative weights of each criterion within this branch of the tree.

Freshwater Mussel Criteria Descriptions & Values

1 Freshwater Mussel Mitigation Projects
11 Habitat Mitigation Needs
111 Mandatory Requirements
1111 **Mitigation Units** – (25%)

1111		**Mitigation Units [0,100]**
Value	*%*	Evaluated as the following normalized indicator:
0	0	U = 100 * M / Mmax [%]
100	100	where
		M = Mitigation area protected by proposed project
		Mmax = Mitigation required by MSHCP
		(M and Mmax are measured in same units)
		The value of Mmax can be either expressed as:
		(a) the total mitigation required in the MSHCP, or
		(b) an annual or project specific mitigation requirement
		Mitigation units and amount will vary by mussel species.
		This criterion represents a mandatory requirement.

1 Freshwater Mussel Mitigation Projects
11 Habitat Mitigation Needs
111 Mandatory Requirements
1112 Site Assessment (20%)
11121 **Buffer Size & Shape** – 40%
11122 **Intact Buffer Sites** – 30%
11123 **Mussel Distribution** – 30%

11121		**Buffer Size & Shape [0,150]**
Value	*%*	FWS, NiSource, and States have determined that the
49	0	average buffer size with an optimal ratio of length
50	25	to width is an important factor for evaluating potential
75	50	mitigation projects. This criterion represents a mandatory
125	75	requirement.
150	100	
		The buffer size is measured in feet.
		FWS and NiSource will determine how to define
		optimal for each mussel species. Values within

		this criteria are currently tied only to the width, but a revised table incorporating the length-width ratio may be developed in the future.

11122		**Intact Buffer Sites [0,3]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon four potential buffer configurations that may result from a mitigation project. 3 = Includes ONE site that is internally intact (i.e. there can be no unprotected or unrestored gaps > 100 feet on each bank at the conclusion of the project) This is the most suitable. 2 = 2 sites internally intact, but sites less than one mile upstream (as measured from the bottom of the first site to the bottom of the second) 1 = 3 sites internally intact, but sites more than one mile upstream 0 = > 3 sites. This is considered unsuitable. This criterion represents a mandatory requirement.
0	0	
1	20	
2	80	
3	100	

11123		**Mussel Distribution [0,3]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon four potential spatial distributions that may occur within a mitigation project location. 3 = Spatially distributed over wide area (> 3 locations in stream). This is considered highly suitable. 2 = Restricted to 3 areas in stream 1 = Restricted to 2 areas in stream 0 = Restricted to one small area. This is considered unsuitable. This criterion represents a mandatory requirement.
0	0	
1	20	
2	60	
3	100	

1 Freshwater Mussel Mitigation Projects
11 Habitat Mitigation Needs
111 Mandatory Requirements
1113 Physical Conditions (15%)
11131 **Substratum** – 20%
11132 **Water Quality** – 40%
11133 **Bed Stability** – 20%
11134 **Barriers to Fish Passage** – 20%

11131		**Substratum [0,6]**
Value	*%*	FWS, NiSource, and the states have determined suitability based upon six potential substratum conditions that may occur within a mitigation project location. Stream sites should have the following features: 1) vary in width from 10-75 feet, 2) have depth of 1/2 to 3 feet, 3) contain a slow to moderate water current, 4) include clean sand and cobble bottom sediments, 5) have an optimal degree of embeddedness, and 6) have no barriers to mussel bed expansion. One point is assigned to each of the above features. Evaluation is based on the sum of these points (min=0, max=6) This criterion represents a mandatory requirement.
0	0	
1	10	
2	40	
3	60	
4	80	
5	90	
6	100	

11132		**Water Quality [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon a characterization of water quality indicators that may occur within a mitigation project location. Project should be in a stream reach with favorable water quality indicators. Exact threshold values will be determined for each species and watershed. Indicators may include, but are not limited to: Ammonia, metals, dissolved oxygen, daily mean
0	0	
4	100	

		temperature, and conductivity. Where there is insufficient data for water quality, benthic IBI scores could be used. Evaluation based on the five-level scale: 4 = Excellent water quality indicators (ideal) 3 = Very Good 2 = Good 1 = Fair 0 = Poor (not suitable) This criterion represents a mandatory requirement.

11133		**Bed Stability [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon bed stability for a mitigation project location. Protocols for evaluating mussel bed stability will be adopted. Mussel Bed Stability Assessment: 4 = Very stable 3 = Stable 2 = Somewhat stable 1 = Somewhat unstable 0 = Very unstable This criterion represents a mandatory requirement.
0 4	0 100	

11134		**Barriers to Fish Passage [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon barriers to fish passage for a mitigation project location. Protocols for barriers to fish passage will be adopted. Assessment of barriers to fish passage: 4 = Absent of all fish blockages 3 = Few fish blockages 2 = Some fish blockage
0 4	0 100	

		1 = Many fish blockages 0 = Major fish blockages This criterion represents a mandatory requirement.

1 Freshwater Mussel Mitigation Projects
11 Habitat Mitigation Needs
111 Mandatory Requirements
1114 Species Occurrence (25%)
11141 **Known & Potential Host Fish** – 20%
11142 **Mussel Population Viability** – 25%
11143 **Mussel Diversity** – 20%
11144 **Mussel Density** – 15%
11145 **Detrimental Invasive Species** – 15%

11141		**Known & Potential Host Fish [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon four scenarios that describe the presence of known and potential host fish for a mitigation project location. Stream reach is evaluated as follows: 4 = Abundant population of multiple known host fish + High Fish IBI Score - Highest suitability 3 = Abundant population of at least two known host fish + High Fish IBI Score - High suitability 2 = No known host fish + high IBI score - Medium suitability 1 = No known host fish + medium IBI score - Low suitability 0 = No known host fish + low IBI score - Not suitable This criterion represents a mandatory requirement.
0 4	0 100	

11142		**Mussel Population Viability [0,1000]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon four scenarios that describe mussel population viability for a mitigation project location. Evaluated as the number of individuals, including sub-adults. The zero value denotes the case of few individuals (not preproducing) This criterion represents a mandatory requirement.
0	0	
250	20	
1000	100	

11143		**Mussel Diversity [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon mussel diversity for a mitigation project location based upon the number of other native mussel species. Evaluated as the number of species (0-4) This criterion represents a mandatory requirement.
0	0	
1	20	
2	60	
4	100	

11144		**Mussel Density [0,2]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon mussel density for a mitigation project location based upon an assessment of mussel density. Protocols to be developed or adopted to make assessment. 2 = High 1 = Medium 0 = Low This criterion represents a mandatory requirement.
0	0	
1	50	
2	100	

11145		Detrimental Invasive Species [0,2]
Value	*%*	FWS, NiSource, and the States have determined suitability based upon the presence of detrimental invasive species for a mitigation project location Assessment of presence of invasives: 2 = Absent 1 = Present, but not a major management concern 0 = Present, with a significant management concern This criterion represents a mandatory requirement.
0 1 2	0 75 100	

1 Freshwater Mussel Mitigation Projects
11 Habitat Mitigation Needs
111 Mandatory Requirements
1115 **Project Location** – 15%

1115		Project Location [0,4]
Value	*%*	Location of the project based on priority locations for species viability and geographic equity considerations for MSHCP take impact. The suitability of locations will be based on factors such as FWS Recovery Plans, recent evidence of species occurrence and viability, and NiSource covered lands impacts and operating states. Each species will have a matrix that characterizes the relative suitability of project locations where: 0 = Not suitable 1 = Low suitability 2 = Medium suitability 3 = High suitability 4 = Highest suitability This criterion represents a mandatory requirement.
0 4	0 100	

1 Freshwater Mussel Mitigation Projects
11 Habitat Mitigation Needs
112 Desired Characteristics
1121 Protection in Perpetuity (60%)
11211 **Point & Nonpoint Pollution Risk** – 25%
11212 **Sedimentation & Substrate Removal Risk** – 25%
11213 **Stream Impoundment Risk** – 20%
11214 **Stream Buffer Clearing Potential** – 15%
11215 **Project Monitoring** – 15%

11211		**Point & Nonpoint Pollution Risk [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon the risk of upstream point and nonpoint source runoff from activities near a mitigation project location. Potential magnitude of nearby, upstream point and nonpoint source runoff, which may include, but is not limited to residential/commercial development, gravel mining, quarries, sewage treatment, forestry and agricultural operations, acid mine drainage, energy development (e.g. coal), toxic chemical spills and contamination or other pollution sources: 4 = None 3 = Low 2 = Medium 1 = High 0 = Very High This criterion is not a mandatory requirement.
0 4	0 100	

11212		**Sedimentation & Substrate Removal Risk [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon the risk of sedimentation and substrate removal near a mitigation project location. Potential magnitude of activities that result in sedimentation, including dam removal, resource extraction (e.g. sand and gravel dredging or gravel bar removal), bridge/road/pipeline construction, agriculture, urban development in riparian zones, and energy development
0 4	0 100	

		(e.g. wind): 4 = None 3 = Low 2 = Medium 1 = High 0 = Very High This criterion is not a mandatory requirement.

11213		**Stream Impoundment Risk [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon the risk of future stream impoundments near a mitigation project location. Likelihood of future, nearby upstream impoundments. 4 = None 3 = Low 2 = Medium 1 = High 0 = Very High This criterion is not a mandatory requirement.
0 4	0 100	

11214		**Stream Buffer Clearing Potential [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon the risk of stream buffer clearing near a mitigation project location. Is the project located on or near a stream that has been designated a legal drain (OH, IN), wet weather conveyance (TN), or comparable designation that entitles clearing of vegetation without a permit? Evaluated using the likelihood of clearing: 4 = None 3 = Low 2 = Medium 1 = High
0 4	0 100	

		0 = Very High This criterion is not a mandatory requirement.

11215		**Project Monitoring [0,4]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon the quality and efficacy of the monitoring program for a mitigation project. An excellent monitoring program would be multi-year, require dual phase qualitative and quantitative sampling, and have an experienced monitoring team. 4 = Excellent 3 = Very Good 2 = Good 1 = Fair 0 = Poor This criterion is not a mandatory requirement.
0 4	0 100	

1 Freshwater Mussel Mitigation Projects
 11 Habitat Mitigation Needs
 112 Desired Characteristics
 1122 Listed Species Protection (40%)
 11221 **NiSource MSHCP Take Species** – 75%
 11222 **Federal & State Listed Species** – 25%

11221		**NiSource MSHCP Take Species [0,3]**
Value	*%*	FWS, NiSource, and the States have determined suitability based upon where the potential mitigation project supports protection of other NiSource MSHCP take species. Evaluated as the number of supported species. This criterion is not a mandatory requirement.
0 1 3	0 80 100	

11222		Federal & State Listed Species [0,3]
Value	*%*	FWS, NiSource, and the States have determined suitability based upon where the potential mitigation project supports protection of federally listed threatened or endangered species, G1-G3 species, GCN species, or state listed rare habitats or communities not included as take species within the MSHCP: Evaluated as the number of species (0-3). This criterion is not a mandatory requirement.
0	0	
1	80	
3	100	

1 Freshwater Mussel Mitigation Projects
12 Strategic Conservation Goals
121 **Green Infrastructure Network** (65%)

121		Green Infrastructure Network [0,5]
Value	*%*	Characterized green infrastructure network. The value is generated by combining the following GIS layers: GI hubs (2 points), GI core forest (1), GI aquatic areas (1), GI wetlands (1) and GI corridors (1). The maximum number of points is 6, and 5 points is sufficient for complete satisfaction of this criterion. The value is a proxy for the contribution of the mitigation project to the protection of an interconnected network of natural resource lands. This criterion is not a mandatory requirement.
0	0	
1	50	
2	70	
3	80	
4	90	
5	100	

1 Freshwater Mussel Mitigation Projects
12 Strategic Conservation Goals
122 Adopted Plans & Leverage (35%)
1221 **State Wildlife Action Plans** – 30%
1222 **Conservation Planning** – 20%
1223 **Collaboration** – 50%

1221		State Wildlife Action Plans [0,4]
Value	*%*	How well does the potential mitigation project support the adopted State Wildlife Action Plan. Evaluated as the number of supported actions/plans. This criterion is not a mandatory requirement.
0	0	
1	50	
3	90	
4	100	

1222		Conservation Planning [0,4]
Value	*%*	Does the potential mitigation project support other state and regional planning efforts? Plans may include, but are not limited to: Coastal and Estuarine Land Conservation Plan State Wetlands Plan State Greenways and Trails Plan State Forestry Plan Climate Action Plans Statewide Comprehensive Recreation Plan State GAP Analysis, Forest Legacy Needs Assessment, Natural Areas Statewide Plan Nature Conservancy Eco-regional Plans/Assessments Eastern Brook Trout Joint Venture Report Ohio River Valley Ecosystem Mollusk Conservation Plan Ohio River Islands National Wildlife Refuge CCR Partners in Flight North American Conservation Plan Chesapeake Bay Health and Restoration Assessment Evaluated as the number of supported actions/plans. This criterion is not a mandatory requirement.
0	0	
1	50	
3	90	
4	100	

1223		**Collaboration [0,100]**
Value	*%*	How well does the potential mitigation project leverage in-kind resources for restoration, monitoring, stewardship, management, and education/interpretation? Projects that bring additional resources will receive additional consideration when compared with projects that rely solely on funding from the project application. Value range is 0-100% based on the level of collaboration included in the mitigation project proposal. This criterion is not a mandatory requirement.
0 100	0 100	

Freshwater Mussel Criteria Lookup Tables

Freshwater Mussel Project Location Scores (#1115)

Clubshell

4 = Highest suitability

IN – Tippecanoe River
KY – Green River
OH – Little Darby Creek
PA – Allegheny River
PA – French Creek
TN – Clinch River
VA – Clinch River
WV – Elk River
WV – Hackers Creek

3 = High suitability

OH - Pymatuning Creek
OH - East Fork West Branch St Joseph River
WV – Middle Island Creek
WV – Westfork River

2 = Medium suitability

OH – Fish Creek
PA – Shenango River

1 = Low suitability

KY – Licking River
OH – Walhounding River
TN – Pickwick Tailwater
WV – Ohio River
WV – South Fork of Huges River
All other watersheds

Fanshell

4 = Highest suitability

IN – East Fork White River
IN – Tippecanoe River
KY – Licking River
OH – Ohio River
TN – Clinch River
WV – Kanawha River

3 = High suitability

KY – Green River
KY – Salt River
OH – Muskingum River

2 = Medium suitability

TN – All Rivers except Clinch
VA – Powell River

1 = Low suitability

OH – Walhonding River
All other watersheds

Northern Riffleshell

4 = Highest suitability

OH – Big Darby Creek
PA – Allegheny River
PA – French Creek
WV – Elk River

3 = High suitability

KY – Licking River

2 = Medium suitability

IN – Tippecanoe River

1 = Low suitability

All other watersheds

Sheepnose

4 = Highest suitability

IN – Tippecanoe River
IN – Eel River
KY – Green River
OH – Muskinghum River
OH – Ohio River
OH – Walhounding River
PA – Allegheny River
PA – French Creek
TN – Clinch River
WV – Kanawha River

3 = High suitability

KY - Licking River
VA – Powell River

2 = Medium suitability

MS – Big Sunflower River
All other TN Rivers
WV – Ohio River

1 = Low suitability

All other watersheds

James Spinymussel

4 = Highest suitability

VA - Little Oregon Creek (trib to Dicks Creek)

3 = High suitability

VA – Dicks Creek
VA – Johns Creek VA (trib to Craig Creek)
VA - Mill Creek (Maury River)

2 = Medium suitability

VA - South Fork Mayo River

1 = Low suitability
All other watersheds

Coarse-Scale Modeling

Pleurobema Clava (Clubshell) Habitat

(12/29/2010)

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Introduction

Overview
The Conservation Fund (TCF) is assisting the US Fish and Wildlife Service (USFWS), NiSource, and 13 affected states (DE, IN, KY, LA, MD, MS, NJ, NY, OH, PA, TN, VA, and WV) to create a multi-species, multi-state habitat conservation plan covering future construction, operation, and maintenance of NiSource natural gas pipelines and ancillary facilities. The clubshell (*Pleurobema clava*), a federally endangered mussel, is one of the covered species.

North America has the highest diversity of freshwater mussels in the world. Mussels historically occurred in dense multi-species assemblages, and provide important ecosystem functions like sediment stabilization and nutrient cycling. Unfortunately, this taxa is highly imperiled; some 68% of freshwater mussel species are vulnerable, and many have gone extinct.

Habitat requirements
Pleurobema clava was once widely distributed in the in the Wabash, Ohio, Kanawha, Kentucky, Green, Monongahela, and Allegheny Rivers and their tributaries, but has been extirpated from probably more than 80% of its historic range (NatureServe, 2009). For unknown reasons, many of the remaining populations do not appear to be reproducing in locations where many other species of freshwater mussels are (USFWS, 2010). *P. clava* is now limited to a few distinct populations, although population size can be high in localized areas (USFWS, 2010).

Similar to other freshwater mussels, *P. clava* is a filter feeder, siphoning phytoplankton, diatoms, and other microorganisms from the water column (USFWS, 2010). Mussels tend to grow relatively rapidly their first few years until sexual maturity, when energy is diverted to reproduction. Clubshells are relatively long-lived, living 20 years or more (USFWS, 2010).

Most mussels, including the clubshell, have separate sexes. Males expel clouds of sperm into the water column, which are drawn in by females through their incurrent siphons. Fertilization takes place internally, and the resulting zygotes develop within the gills into specialized larvae termed glochidia. Glochidia must come into contact with a specific host fish, usually within 24 hours, to survive (USFWS, 2010). Suitable host fish for *P. clava* include, but are probably not limited to striped shiner, blackside darter, central stoneroller, and logperch (NatureServe, 2009).

Glochidia parasitize the fishes' gill tissues for a few weeks; then detach to begin a free-living existence on the stream bottom. This unique method of dispersal allows freshwater mussels to colonize areas upstream as well as downstream. Unless released in suitable habitat, the released glochidia will die (USFWS, 2010). Like other mussels, the clubshell probably experiences very low annual juvenile survival. A single female's reproductive output is reduced from thousands of glochidia to less than one surviving juvenile per year (USFWS, 2010). Thus, small populations have a high risk of extirpation.

Pleurobema clava. (Photo USFWS)

Dispersal barriers include climate, drainage divides, dams and other fish barriers, pollution, habitat modification (e.g., channelization), and the lack of suitable host fish. Further, dispersal rates range widely across species. Although mobile or migratory host fish may move long distances, small benthic fish like darters and sculpins may move 30 m or less. The effects of reduced migration rates are especially severe for rare species. Some populations may be functionally extinct, with no possibilities of propagation, or populations too low to persist. The long lifespan of many mussels may mask this "extinction debt" (Strayer, 2008).

Many freshwater mussels are habitat-specific; e.g., some preferring riffles, and some preferring pools. Mussels are most abundant in oxygenated, shallow waters (<2 m) of medium to large rivers and occupy a variety of stable substrates including different combinations of silt, sand, gravel, cobble, and boulders (Pennak, 1989, in Arbuckle and Downing, 2000). Rivers and larger streams, if unimpaired, generally contain more habitat niches and host fish than smaller streams. They are also less likely to dry out than smaller streams. Suitable habitat allows juveniles to settle, has substrate firm enough for support but soft enough for burrowing, is stable during floods, is wet during droughts, delivers food and essential materials (oxygen, calcium, etc.), provides favorable temperatures for growth and reproduction, povides protection from predators, and contains no toxic materials (Strayer, 2008).

According to NatureServe (2009) and USFWS (2010), *P. clava* inhabits small to medium-sized rivers and streams. It is generally found in clean, coarse sand and gravel in shallow riffles and runs with moderate current, in less than 1.5 to 3 feet of water. It cannot tolerate mud or slackwater conditions, and because most individuals bury themselves, is presumed to be highly dependent on interstitial flow for oxygen and food.

<u>Threats</u>

Stressors to freshwater mussels include stream channelization; hydrologic modifications and stream instability associated with development (e.g., impervious surfaces); lack of riparian forest; sedimentation from construction, mining, and farming; water supply withdrawals; acid mine drainage; hog farm runoff; other source pollution; dams; and other fish blockages. Mussels are more sensitive to ammonia, copper, and other metals than other aquatic organisms, and current water quality standards may be insufficient for their survival. Mussel presence and diversity indicate clean water. Coal and oil extraction can decrease downstream mussel abundance by 90%. Inadequate water flow or high-volume floods are other key stressors, with drying being the worst. Dam failure or removal can transport trapped sediment downstream and smother mussels.

USFWS (2010) identified the main threats to *P. clava* as siltation, impoundments, in-stream sand and gravel mining, and pollutants:

> "These include water quality degradation from point and non-point sources, particularly in small tributaries that have limited capability to dilute and assimilate sewage, agricultural runoff, and other pollutants. In addition, the species is affected by hydrologic and water quality alterations resulting from the operation of impoundments. A variety of in-stream activities continue to threaten clubshell populations, including sand and gravel dredging, gravel bar removal, bridge construction, and pipeline construction. Coal, oil, and natural gas resources are present in a number of the watersheds that are known to support clubshell. Exploration and extraction of these energy resources can result in increased siltation, a changed hydrograph, and altered water quality even at a distance from the mine or well field. Land-based development near streams of occurrence often results in loss of riparian habitat and increased storm water runoff which combine to increase sedimentation. Because clubshell often live below the gravel surface, this species may be exceptionally sensitive to the increased siltation, which fills the spaces within the gravel, and blocks the interstitial flow of oxygen and food. Development has also resulted in an increased number of sewage treatment plants in drainages that support clubshell as well as an increase in the amount of sewage discharged from existing plants."

<u>Habitat modeling</u>

Hopkins (2009) compared the distribution of *Quadrula cylindrica*, a freshwater mussel, to environmental variables at multiple scales in the upper Green River system in Kentucky. Variables included land use/land cover pattern and composition, soil composition, and geology, at the subcatchment scale, subcatchment riparian buffer (100 m from the stream), and riparian buffer for a 100m upstream reach. Boosted regression trees found the most influential variables to be patch density at the reach scale and soil composition at the riparian scale.

Terrestrial reserves often protect important freshwater resources where aquatic considerations played a role in site selection. However, there is poor correspondence in many areas. Hydrologic regime, physical habitat, biotic composition, connectivity, and water quality need to be addressed at the watershed level. At the reach level, the material contribution zone, meander belt, active low floodplain, riparian wetlands, high floodplain, and terraces should be considered to maintain natural hydrologic and material transport processes. Aquatic conservation should encompass at least 10 fluvial kilometers, and maintain connectivity to downstream rivers.

We sought to identify suitable habitat for *P. clava* conservation or reintroduction. Our analyses, described below, were limited to coarse-scale variables at the reach and catchment scale. Microhabitat features like stream substrate or submerged vegetation might be inferred by larger scale conditions, but are best measured by field surveys.

Methods

<u>Locational data</u>

We received *P. clava* occurrence data from state Natural Heritage Programs. Some of this data was in point form and some in polygon. Spatial accuracy varied; in many cases only close enough to identify the occurrence stream reach and catchment.

We converted polygon occurrence data to points, selecting centroids, but constraining them to fall within the polygon. We merged records from all states in the NiSource study area. We omitted records with Poor viability (EO rank = "D"), Historical records (H), Failed to find (F), Extirpated (X), records prior to 1990, and subfossils.
To reduce positional errors and spatial bias, we considered stream reaches as the unit of analysis for occurrence data[1]. First, we selected NHD catchments that contained clubshells, using the locational data described earlier. Next, we identified the centroids of these catchments (using the Feature to Point tool). We ensured that these centroids fell within the catchment, selecting centroids that intersected the clubshell catchments. One centroid did not intersect a catchment[2], and was removed from further consideration. Finally, we reprojected the remaining centroids to the same coordinate system as the variable grids, used Hawth's Tools to add x-y coordinates, and convert the data to a .csv file.

Reach variables

We obtained streams, stream catchments, and flow data from NHDPlus (Bondelid et al., 2007). The NHD streams were digitized at a 1:100K scale, corresponding to a horizontal accuracy around 50 m. Because of spatial inaccuracies in the data, we did not examine potential relationships at a local (sub-reach) scale. Instead, we focused solely on the reach and catchment scales.

Table 2 lists the variables computed for each NHDPlus stream reach. We obtained surficial geology units and deposit types from Fullerton et al. (2004), compiled at a 1:1M scale. We obtained karst data from Weary (2008), believed accurate within 300 m. We obtained soil permeability from CONUS (Miller and White, 1998), selecting the value for the top layer of soil (0-5 cm; field [L1_PERM]). We obtained land cover from the 2001 National Land Cover Database (U.S. Geological Survey; see Homer et al. 2004). We obtained stream impairment data from the EPA's 303(d) list, selected only current impairments, and lumped the causes into 9 categories. To identify impounded stream reaches, we identified NHD flowlines that intersected NHD lakes, ponds, or reservoirs (not wetlands). We did not see any ponds that intersected flowlines.

Table 2. Variables computed within each NHDPlus catchment.

Variable	Definition
CAT_MAFLOWU	Mean Annual Flow - Unit Method (cfs)
CAT_MAVELU	Mean Annual Velocity - Unit Method (fps)
CAT_ELEV_CM	Mean reach elevation – smoothed (cm)
CAT_SLOPE1000	Mean channel slope (mm/m)
RCH_GEO_UNIT	Majority surficial geology unit within 60m of NHD stream reach
RCH_DEP_TYPE	Majority surficial geology deposit type within 60m of NHD stream reach
RCH_P_KARST60	Percent karst geology within 60m of NHD stream reach

[1] We previously selected one occurrence point per NHD+ catchment. We used the Identity tool with occurrence points and NHD+ catchments. The output dataset had a field [FID_catchm] that listed the FID of the NHD+ catchment the point fell within. This tool could only be used on one HUC-2 basin at a time. Where there was more than one point per catchment, we picked the most viable. If viability was the same, or unrecorded, we picked the most recent record. If records were from the same year, if there were at least 3 clustered points, we selected the middle one. If there were only two points, we picked the one furthest from others.

[2] This catchment was small (0.044 km^2).

RCH_SOILPER60	Mean soil permeability within 60m of NHD stream reach
RCH_PCTFORW60	Percent forest and wetland cover (from 2001 NLCD) within 60m of NHD stream reach
RCH_IMPOUNDED	Reach impounded? (yes/no)
RCH_AMMONIA	Reach listed as impaired for ammonia?
RCH_TOXIC_IMP	Reach listed as impaired for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_TOXIC_2	Reach listed as impaired for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_PHYSICAL	Reach listed as impaired for flow alteration; habitat alteration; temperature?
RCH_SEDIMENT	Reach listed as impaired for sediment or turbidity?
RCH_EUTROPHIC	Reach listed as impaired for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens?
RCH_BIOLOGIC	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species?
RCH_BIOLOGIC2	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants?
RCH_OTHER_IMP	Reach listed as impaired for trash or unknown reasons?
RCH_ANYIMPAIR	Reach listed as impaired for any reason? (yes/no)

Catchment variables

In addition to examining parameters at the reach scale, we assessed parameters within each cumulative catchment (i.e., the entire drainage to the end point of each stream reach, not just the subsection adjacent to the reach) using the NHDPlus Catchment Attribute Allocation and Accumulation Tool (CA3T; Horizon Systems Corporation). These included metrics like land cover (1992 and 2001), impervious surface, tree cover, alluvium, karst areas, soil permeability, and length of various stream impairments (Table 3). We defined alluvium as surficial alluvial or glacial deposits of primarily gravel or sand from Fullerton et al. (2004), chosen because of relatively high permeability.

We also calculated a Developed Land Cover Buffered Flowpath Metric: the length in meters of forest or wetland cells that a developed land cover cell flows through to reach the nearest stream; and an Agriculture Buffered Flowpath Metric; the length in meters of forest or wetland cells that an agricultural land cover cell flows through to the nearest stream (also in Table 3). These metrics, which incorporate land cover, topography and hydrology, can represent potential water pollution loads better than simple land use percentages or fixed buffer width metrics (Baker et al., 2006). We summed the inverse buffer width (1 / (buffer flow length in meters + 1)) for agriculture and developed land within each cumulative catchment, representing non-point pollution loading to the stream reach. Table 3 lists the variables computed within each cumulative NHDPlus catchment.

Table 3. Variables computed within each cumulative NHDPlus catchment.

Variable	**Definition**
CAT_AREA_KM2	Cumulative drainage area (km^2)
CAT_IBWA_KM	Cumulative sum of inverse buffer width from agriculture (1 / (buffer flow length in

	meters + 1))
CAT_IBWD_KM	Cumulative sum of inverse buffer width from developed land (1 / (buffer flow length in meters + 1))
CAT_TREE_HA	Cumulative sum of tree canopy area (ha)
CAT_TREE_PCT	Cumulative mean percent of tree canopy cover
CAT_IMPERV_HA	Cumulative sum of impervious cover area (ha)
CAT_IMPER_PCT	Cumulative mean percent of impervious cover
CAT_KARST_PCT	Cumulative mean percent of karst geology
CAT_LC01AGPCT	Cumulative area-weighted percent of agricultural land, from 2001 NLCD
CAT_LC01DEVPC	Cumulative area-weighted percent of developed land, from 2001 NLCD
CAT_LC01FORPC	Cumulative area-weighted percent of forests and wetlands, from 2001 NLCD
CAT_LC92AGPCT	Cumulative area-weighted percent of agricultural land, from 1992 NLCD
CAT_LC92DEVPC	Cumulative area-weighted percent of developed land, from 1992 NLCD
CAT_LC92FORPC	Cumulative area-weighted percent of forests and wetlands, from 1992 NLCD
CAT_PERGEOPCT	Cumulative percent of surficial alluvium
CAT_PERM_AVG	Cumulative Soil Permeability - Average
CAT_AMMON_KM	Cumulative length of reaches with ammonia impairment (km)
CAT_TOXIC_KM	Cumulative length of reaches with impairment for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_TOXIC2_KM	Cumulative length of reaches with impairment for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_PHYS_KM	Cumulative length of reaches with impairment for flow alteration; habitat alteration; temperature (km)
CAT_SEDIM_KM	Cumulative length of reaches with impairment for sediment or turbidity (km)
CAT_EUTROP_KM	Cumulative length of reaches with impairment for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens (km)
CAT_BIOIMP_KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species (km)
CAT_BIOIMP2KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants (km)
CAT_OTHER_KM	Cumulative length of reaches with impairment for trash or unknown reasons (km)

Spatial allocation of variables

We prepared variables as continuous grids. To reduce the file size below the Windows computational limits, we resampled all variable grids to 90 m cells. We then converted them to ASCII format for use in Maxent. As before, all variables we calculated at the reach and catchment scale.

Maxent model

Maximum entropy modeling (Maxent) is a machine learning technique that can be used to predict the geographic distribution of animal or plant species or other entities of interest. Maxent (using the program by Dudik et al., 2008) compares a set of samples from a distribution over a defined space, such as recorded locations of a particular species, to a set of features, such as relevant environmental variables, over that same space. Maxent estimates the spatial distribution of the species (i.e., predicts suitable habitat) by assuming nothing about that which is unknown (maximizing entropy) but matching the relationships between recorded occurrences and underlying variables. Unlike other techniques like logistic regression, maximum entropy modeling does not require reliable species absence data, which are rarely available. Maxent can also produce solutions with a small set of observations, although the larger the number of observations, the more accurate model output is likely to be. Also, the environmental variables do not need to be independent.

Output also includes the receiver operating characteristic (ROC) curve, which in this case tells the user how well the model distinguished species occurrences from random locations. The area under the ROC curve (AUC) should be as close to 1.0 as possible; an AUC of 0.5 indicates predictivity no better than random chance. Thresholds can be identified that most efficiently identify potential species habitat (fraction of occurrences included vs. the area selected). Model output also includes estimates of variable importance and graphs of predicted suitability vs. individual variables.

Based on experience with other species and natural communities, we set parameters as follows:

- Output format = logistic
- Use all possible variable relationships (linear, quadratic, product, threshold, and hinge)
- Regularization multiplier = 1
- Maximum number of background points = 10,000
- Add samples to background
- Extrapolate
- Do clamping
- Maximum number of iterations = 500
- Convergence threshold = 0.00001

<u>Spatial Maxent application – continuous grids</u>
We converted Maxent ASCII output to a floating point grid:

```
Arc: asciigrid Pleurobema_clava_avg.asc flt_P_clava float
```

We multiplied this by 100 and took the integer value:

```
Grid: P_clav_Maxent = int(flt_P_clava * 100)
```

We selected the Maxent threshold that captured the highest proportion of known clubshell occurrences, while including the least area of catchments. Generally, this corresponds to maximum sensitivity plus specificity, but we examined a number of thresholds. We identified the majority Maxent value within each NHD catchment.[3] Then, we selected those catchments corresponding to Maxent values above the test maximum sensitivity plus specificity threshold, and grouped these into spatially contiguous sections. From these, we selected those groupings that also contained catchments with Maxent values greater than the most parsimonious threshold.[4]

We then selected the NHD flow lines within those catchments[5], and calculated the length of these contiguous sections using Hawth's Tools[6]. We compared the length of each stream segment with suitable habitat to the

[3] We used the majority value because the 90 m model cells did not overlap catchment polygons exactly. We used the tool *Zonal Statistics as Table*.
[4] ArcGIS model *Identify catchments above Maxent thresholds*
[5] ArcGIS model *Identify streams above Maxent thresholds.* This buffered NHD stream reaches meeting the Maxent habitat threshold by 0.5 m (i.e., 1 m wide), dissolving overlapping buffers. We separated these shapes using the Multipart to Single Part tool.

presence of clubshells. We filtered out sections below the minimum length that contained clubshells, and thereby identified stream reaches that met both modeled habitat and length thresholds.

Results

<u>Maxent model</u>

Figure 1 shows mean model output from the Maxent model for *P. clava* using continuous grids. This model had an average test AUC for the replicate runs of 0.944.

Table 4 gives a heuristic estimate of relative contributions of the environmental variables that contributed at least 2% to the Maxent model.[7] To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda was negative. Variable contributions should be interpreted with caution.

Table 4. Individual variable contributions to the Maxent model.

Variable	Percent contribution
CATVPERGEOPCT	37.3
CATVMAFLOWU	25.7
CATVSEDIM_KM	4.7
RCHVGEO_UNIT	3.2
CATVPHYS_KM	3.0
CATVEUTROP_KM	3.0
CATVTREE_HA	2.8
CATVTOXIC_KM	2.4
RCHVDEP_TYPE	2.3
RCHVIMPOUNDED	2.2
RCHVPCTFORW60	2.1

The environmental variable CATVPERGEOPCT had the highest training and test gain when used in isolation, and therefore appeared to have the most useful information by itself. This variable also decreased the gain the most when it was omitted, and therefore appeared to have the most information that wasn't present in the other variables. It was closely followed by several other variables. Table 5 lists the values associated with higher probabilities of clubshell presence, for variables that contributed >2% to the model. Variables were inter-related, and combined in a variety of ways to create the model.

Table 5. Values associated with higher probabilities of clubshell presence, for variables that contributed >2% to the model.

Variable	Values associated with clubshell presence
CATVPERGEOPCT	Peak ~30-50%
CATVMAFLOWU	Peak ~100,000 cfs
CATVSEDIM_KM	0, with rapid suitability dropoff as this increases
RCHVGEO_UNIT	Outwash deposits, ice-contact deposits, and glacial-lake deposits; ice-contact

[6] We calculated area with Hawth's Tools in km^2; because the width was 1 m, this was the same as length in km.
[7] We chose a reporting threshold of 2% because there was a distinct break there between the top variables and the rest.

	sand and gravel; outwash sand and gravel; channel and flood-plain alluvium; loamy solifluction deposits, colluvium, and decomposition residuum
CATVPHYS_KM	0, with rapid suitability dropoff as this increases
CATVEUTROP_KM	0, with rapid suitability dropoff as this increases
CATVTREE_HA	Peak ~100,000 ha
CATVTOXIC_KM	0, with rapid suitability dropoff as this increases
RCHVDEP_TYPE	Glaciofluvial (outwash) deposits; ice-contact deposits; solifluction deposits; catastrophic glacial outburst-flood deposits
RCHVIMPOUNDED	Not impounded
RCHVPCTFORW60	100%, with suitability dropoff below this

Spatial Maxent application – continuous grids

The logistic threshold corresponding to maximum test sensitivity plus specificity was 0.1837, which captured 93% of test points, 90% of training points, and 4.98% of area on average ($p<0.001$). Other reported Maxent thresholds captured fewer test points on average and, in most cases, more area. Comparing Maxent output to clubshell occurrences, a threshold of 0.22 appeared more parsimonious (Table 6).

Table 6. Maxent values compared to clubshell occurrences.

Maxent value threshold	Number of clubshell occurrences within this range	Percent of clubshell occurrences within this range	Percent of Ohio and Tennessee basins within this range
>0.22	50	93	1.7
>0.1837	50	93	2.2
All values	54	100	100

We identified all NHD catchments with Maxent values >0.1837, and grouped these into spatially contiguous sections. From these, we selected those groupings that also contained catchments with Maxent values >0.22.[8] We then selected those NHD flow lines within those catchments[9], and calculated the length of these contiguous sections using Hawth's Tools[10]. The shortest continuous stream reach with these model values and containing clubshells[11] was 4.4 km. Rounding down to one significant digit, we selected NHD reaches within stretches of modeled suitable habitat[12] >4 km. These totaled 442 km (0.4% of the Ohio and Tennessee River basins).

Discussion

Based on available survey and environmental data, the Maxent model predicted about 0.4% of the Ohio and Tennessee River basins to be suitable habitat for *Pleurobema clava*. Some of the longer stretches of modeled habitat included the Allegheny River and some of its upper tributaries, Tippecanoe River, Great Miami River, Little Wabash River, Skillet Fork, Embarras River, Patoka River, Green River, Licking River, West Fork of Duck

[8] ArcGIS model *Identify catchments above Maxent thresholds*

[9] ArcGIS model *Identify streams above Maxent thresholds*

[10] We calculated area with Hawth's Tools in km^2; because the width was 1 m, this was the same as length in km.

[11] We selected features from Maxent_flowline_groups that are within 200 m (to account for spatial error) of Clubshell_locations_Albers83.

[12] We selected NHD flowlines that had their centroids in the selected reach buffers (Maxent_flowline_groups), and saved these as Clubshell_modeled_habitat.shp.

Creek, Little Muskingum River, Little Kanawha River, and Elk River. There were also a number of shorter stretches of modeled habitat.

Catchment geology type, stream flow, stream impairment, tree area, impoundment, and riparian forest cover were the top predictive variables. Geology can influence hydrology and water quality. Alluvial deposits, karst, and other permeable geologic formations can increase groundwater flow into streams. Arbuckle and Downing (2002) found that mussel density and species richness are higher in streams with high fractions of alluvial deposits. Such streams are more stable, with greater groundwater recharge and lower surface runoff, especially in agricultural watersheds (Arbuckle and Downing, 2002).

Clubshells preferred large streams and mid-sized rivers, not headwater streams or major rivers such as the Ohio. In general, headwater streams are more prone to drying out than larger streams, and this may be a factor. They preferred unimpounded streams in unimpaired catchments.

Nicklin and Balas (2007) found that mussel densities >1/m^2 in the middle Allegheny River, PA, were found in largely "optimal" habitat: at sites with >50% instream cover (stable habitat), 0-25% fine sediment surrounding gravel and larger rocks, at least 3 of 4 velocity/depth regimes present (including riffles and pools >0.5m deep), and little to no enlargement of islands or point bars and <10% of the bottom affected by sediment deposition. They found no mussels in poor or marginal physical habitat. A study in the Copper Creek watershed of Virginia (EPA, 2002) found that embeddedness and sedimentation were statistically significant habitat quality measures that affected the abundance and distribution of native mussel and fish species in Copper Creek, and both habitat characteristics were directly related to the amount of agricultural land use in the riparian corridor.

Clubshells also preferred stream reaches with riparian forest and wetland cover. This is consistent with other studies such as Morris and Corkum (1996), who found that Ontario rivers with riparian forest had much more diverse mussel assemblages than those without. Rivers without riparian forest were dominated by a single tolerant species. Because it contained a distinct mid-range peak, we suspect that the tree area variable was geographically correlative, not causative.

We applied a spatial filter to model output from Maxent, selecting only modeled suitable habitat >4 km. Based on other modeling, contiguous sections >10 km are preferable. As with terrestrial species, small, isolated areas of habitat may only support small, inbred populations that are doomed to local extinction. Mussel populations are now more widely separated than they were historically, leading to reduced recruitment success and declining populations, especially in the presence of stressors. EPA (2002) suggested maintaining and improving stream habitat and water quality in remaining mussel locations, and allowing populations to expand into nearby areas.

Within stream reaches, microhabitat features like substrate and bank stability may be important factors. The Maxent model applies only at the stream reach and catchment scale; management actions should be preceeded by stream surveys. We hope that the coarse-scale modeling described here can help prioritize more detailed surveys, and also emphasize the importance of catchment-scale geomorphic and land use conditions.

Federally listed species have recovery plans. 80% of all federally listed species rely on ongoing conservation efforts. Most require two or more conservation strategies. Management should not only react to present conditions, but preserve the ability of species to adapt to change, such as global warming. Propagation and culture of endangered mussels is a key component of species recovery, although there are concerns about genetic impacts. Although state and university biologists are likely to know already where the best conditions are, the Maxent model could conceivably help target reintroduction of cultured mussels. Reintroductions should be preceded by field surveys, then pilot testing of survival and recruitment.

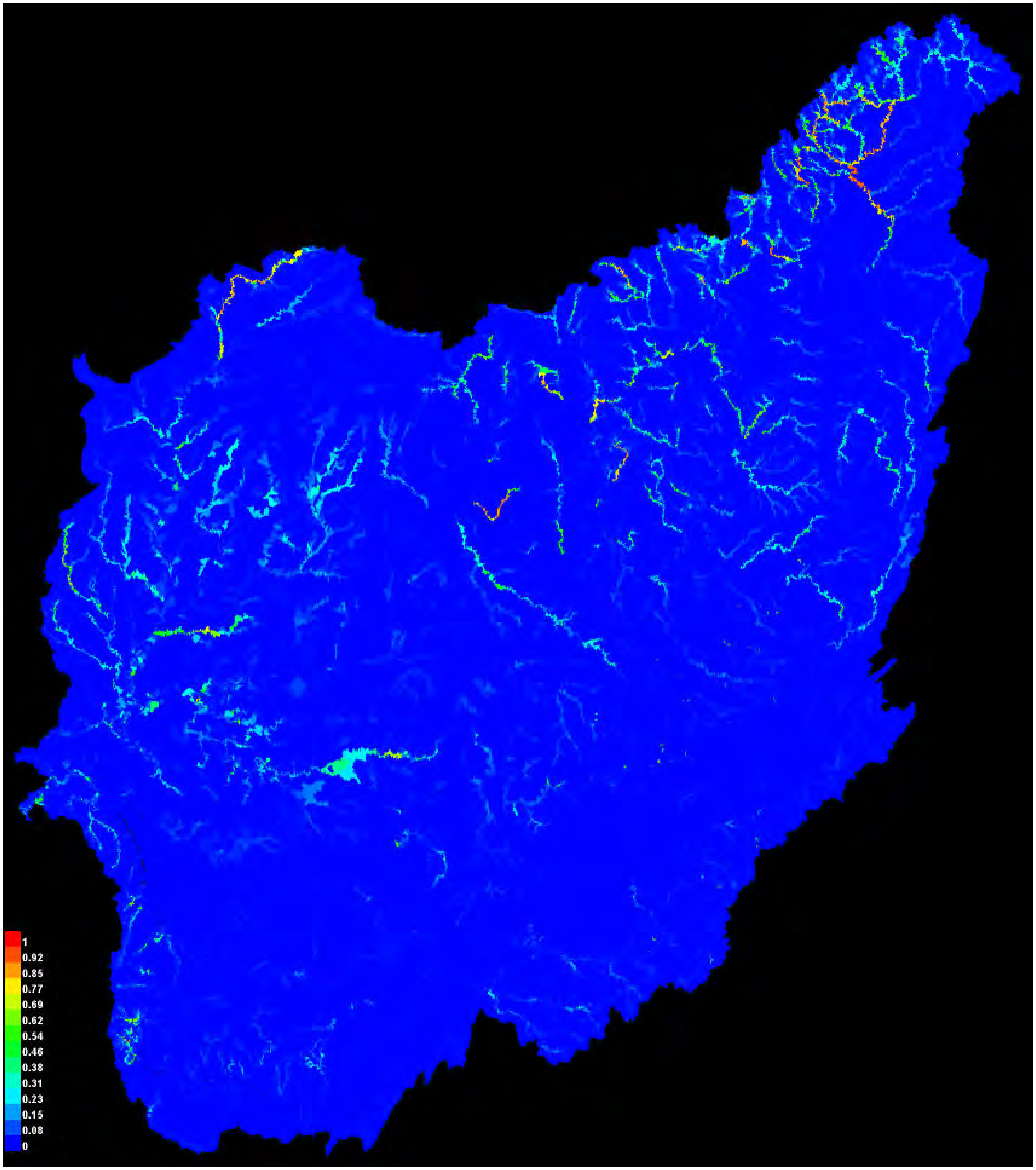

Fig. 1. Maxent output predicting suitable habitat for *Pleurobema clava*

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Coarse-Scale Modeling

Cyprogenia Stegaria (Fanshell) Habitat

(12/29/2010)

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Introduction

Overview
The Conservation Fund (TCF) is assisting the US Fish and Wildlife Service (USFWS), NiSource, and 13 affected states (DE, IN, KY, LA, MD, MS, NJ, NY, OH, PA, TN, VA, and WV) to create a multi-species, multi-state habitat conservation plan covering future construction, operation, and maintenance of NiSource natural gas pipelines and ancillary facilities. The fanshell (*Cyprogenia stegaria*), a federally endangered mussel, is one of the covered species.

North America has the highest diversity of freshwater mussels in the world. Mussels historically occurred in dense multi-species assemblages, and provide important ecosystem functions like sediment stabilization and nutrient cycling. Unfortunately, this taxa is highly imperiled; some 68% of freshwater mussel species are vulnerable, and many have gone extinct.

Habitat requirements
Cyprogenia stegaria was once widely distributed in the Ohio, Wabash, Cumberland, and Tennessee Rivers and their larger tributaries, but has been reduced to only a few stable populations (NatureServe, 2009). Most of the remaining populations are small and isolated (USFWS, 2010). According to NatureServe (2009), only three reproducing populations are known: the upper Green and Licking Rivers in Kentucky and the Clinch River in Tennessee.

Similar to other freshwater mussels, *C. stegaria* is a filter feeder, siphoning phytoplankton, diatoms, and other microorganisms from the water column (USFWS, 2010). Mussels tend to grow relatively rapidly their first few years until sexual maturity, when energy is diverted to reproduction. For freshwater mussels, fanshells have a relatively short life span, living only 6 to 26 years (USFWS, 2010).

Most mussels, including the fanshell, have separate sexes. Males expel clouds of sperm into the water column, which are drawn in by females through their incurrent siphons. Fertilization takes place internally, and the resulting zygotes develop within the gills into specialized larvae termed glochidia. Glochidia must come into contact with a specific host fish, usually within 24 hours, to survive (USFWS, 2010). Suitable host fish for *C. stegaria* include, but are probably not limited to, darters, sculpins, and logperch (NatureServe, 2009).

Glochidia parasitize the fishes' gill tissues for a few weeks; then detach to begin a free-living existence on the stream bottom. This unique method of dispersal allows freshwater mussels to colonize areas upstream as well as downstream. Unless released in suitable habitat, the released glochidia will die (USFWS, 2010). Like other mussels, the fanshell probably experiences very low annual juvenile survival. A single female's reproductive output is reduced from thousands of glochidia to less than one surviving juvenile per year (USFWS, 2010). Thus, small populations have a high risk of extirpation.

Cyprogenia stegaria. (Photo Dick Biggins, USFWS)

Dispersal barriers include climate, drainage divides, dams and other fish barriers, pollution, habitat modification (e.g., channelization), and the lack of suitable host fish. Further, dispersal rates range widely across species. Although mobile or migratory host fish may move long distances, small benthic fish like darters and sculpins may move 30 m or less. The effects of reduced migration rates are especially severe for rare species. Some populations may be functionally extinct, with no possibilities of propagation, or populations too low to persist. The long lifespan of many mussels may mask this "extinction debt" (Strayer, 2008).

Many freshwater mussels are habitat-specific; e.g., some preferring riffles, and some preferring pools. Mussels are most abundant in oxygenated, shallow waters (<2 m) of medium to large rivers and occupy a variety of stable substrates including different combinations of silt, sand, gravel, cobble, and boulders (Pennak, 1989, in Arbuckle and Downing, 2000). Rivers and larger streams, if unimpaired, generally contain more habitat niches and host fish than smaller streams. They are also less likely to dry out than smaller streams. Suitable habitat allows juveniles to settle, has substrate firm enough for support but soft enough for burrowing, is stable during floods, is wet during droughts, delivers food and essential materials (oxygen, calcium, etc.), provides favorable temperatures for growth and reproduction, povides protection from predators, and contains no toxic materials (Strayer, 2008).

According to NatureServe (2009) and USFWS (2010), *C. stegaria* inhabits the shoals and riffles of medium to large streams and rivers, in both deep and shallow water. Most findings have been in relatively deep water with sandy or gravelly substrates and a moderate to strong current (USFWS, 2010). Individuals are sensitive to pollution, siltation, habitat perturbation, inundation, and loss of fish hosts (NatureServe, 2009).

<u>Threats</u>

Stressors to freshwater mussels include stream channelization; hydrologic modifications and stream instability associated with development (e.g., impervious surfaces); lack of riparian forest; sedimentation from construction, mining, and farming; water supply withdrawals; acid mine drainage; hog farm runoff; other source pollution; dams; and other fish blockages. Mussels are more sensitive to ammonia, copper, and other metals than other aquatic organisms, and current water quality standards may be insufficient for their survival. Mussel presence and diversity indicate clean water. Coal and oil extraction can decrease downstream mussel abundance by 90%. Inadequate water flow or high-volume floods are other key stressors, with drying being the worst. Dam failure or removal can transport trapped sediment downstream and smother mussels.

USFWS (2010) identified the main threats to *C. stegaria* as declining water quality, impoundments, stream flow alterations, habitat alterations, dredging, and navigation projects affecting both the species and its host fish. Other impacts include runoff from coal mines, power plant spills, oil and gas exploration, wastewater discharges, and water supply development (USFWS, 2010).

The population in the Green River is somewhat protected within Mammoth Cave National Park, but has been threatened by runoff from oil and gas exploration and production sites and by an upstream reservoir. The steady decline of mussels in the Clinch River has been attributed to land use practices along the river, as well as impacts from coal mining and spills from a riverside coal fired power plant. The Licking River population has been threatened by wastewater discharges and plans for water supply development. Incidental take of the fanshell where it is co-located with commercially harvested mussel beds also contributes to its decline (USFWS, 2010).

<u>Habitat modeling</u>
Hopkins (2009) compared the distribution of *Quadrula cylindrica*, a freshwater mussel, to environmental variables at multiple scales in the upper Green River system in Kentucky. Variables included land use/land cover pattern and composition, soil composition, and geology, at the subcatchment scale, subcatchment riparian buffer (100 m from the stream), and riparian buffer for a 100m upstream reach. Boosted regression trees found the most influential variables to be patch density at the reach scale and soil composition at the riparian scale.

Terrestrial reserves often protect important freshwater resources where aquatic considerations played a role in site selection. However, there is poor correspondence in many areas. Hydrologic regime, physical habitat, biotic composition, connectivity, and water quality need to be addressed at the watershed level. At the reach level, the material contribution zone, meander belt, active low floodplain, riparian wetlands, high floodplain, and terraces should be considered to maintain natural hydrologic and material transport processes. Aquatic conservation should encompass at least 10 fluvial kilometers, and maintain connectivity to downstream rivers.

We sought to identify suitable habitat for *C. stegaria* conservation or reintroduction. Our analyses, described below, were limited to coarse-scale variables at the reach and catchment scale. Microhabitat features like stream substrate or submerged vegetation might be inferred by larger scale conditions, but are best measured by field surveys.

Methods

<u>Locational data</u>
We received *C. stegaria* occurrence data from state Natural Heritage Programs. Some of this data was in point form and some in polygon. Spatial accuracy varied; in many cases only close enough to identify the occurrence stream reach and catchment.

We converted polygon occurrence data to points, selecting centroids, but constraining them to fall within the polygon. We merged records from all states in the NiSource study area. We omitted records with Poor viability (EO rank = “D”), Historical records (H), Failed to find (F), Extirpated (X), records prior to 1990, and subfossils.

To reduce positional errors and spatial bias, we considered stream reaches as the unit of analysis for occurrence data[13]. First, we selected NHD catchments that contained fanshells, using the locational data described earlier. Next, we identified the centroids of these catchments (using the Feature to Point tool). We ensured that these centroids fell within the catchment, selecting centroids that intersected the fanshell catchments. One centroid did not intersect a catchment[14], and was removed from further consideration. Finally, we reprojected the remaining centroids to the same coordinate system as the variable grids, used Hawth's Tools to add x-y coordinates, and convert the data to a .csv file.

Reach variables

We obtained streams, stream catchments, and flow data from NHDPlus (Bondelid et al., 2007). The NHD streams were digitized at a 1:100K scale, corresponding to a horizontal accuracy around 50 m. Because of spatial inaccuracies in the data, we did not examine potential relationships at a local (sub-reach) scale. Instead, we focused solely on the reach and catchment scales.

Table 2 lists the variables computed for each NHDPlus stream reach. We obtained surficial geology units and deposit types from Fullerton et al. (2004), compiled at a 1:1M scale. We obtained karst data from Weary (2008), believed accurate within 300 m. We obtained soil permeability from CONUS (Miller and White, 1998), selecting the value for the top layer of soil (0-5 cm; field [L1_PERM]). We obtained land cover from the 2001 National Land Cover Database (U.S. Geological Survey; see Homer et al. 2004). We obtained stream impairment data from the EPA’s 303(d) list, selected only current impairments, and lumped the causes into 9 categories. To identify impounded stream reaches, we identified NHD flowlines that intersected NHD lakes, ponds, or reservoirs (not wetlands). We did not see any ponds that intersected flowlines.

Table 2. Variables computed within each NHDPlus catchment.

Variable	Definition
CAT_MAFLOWU	Mean Annual Flow - Unit Method (cfs)
CAT_MAVELU	Mean Annual Velocity - Unit Method (fps)
CAT_ELEV_CM	Mean reach elevation – smoothed (cm)
CAT_SLOPE1000	Mean channel slope (mm/m)
RCH_GEO_UNIT	Majority surficial geology unit within 60m of NHD stream reach
RCH_DEP_TYPE	Majority surficial geology deposit type within 60m of NHD stream reach
RCH_P_KARST60	Percent karst geology within 60m of NHD stream reach
RCH_SOILPER60	Mean soil permeability within 60m of NHD stream reach
RCH_PCTFORW60	Percent forest and wetland cover (from 2001 NLCD) within 60m of NHD stream reach
RCH_IMPOUNDED	Reach impounded? (yes/no)
RCH_AMMONIA	Reach listed as impaired for ammonia?
RCH_TOXIC_IMP	Reach listed as impaired for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB’s; pesticides; pH;

[13] We previously selected one occurrence point per NHD+ catchment. We used the Identity tool with occurrence points and NHD+ catchments. The output dataset had a field [FID_catchm] that listed the FID of the NHD+ catchment the point fell within. This tool could only be used on one HUC-2 basin at a time. Where there was more than one point per catchment, we picked the most viable. If viability was the same, or unrecorded, we picked the most recent record. If records were from the same year, if there were at least 3 clustered points, we selected the middle one. If there were only two points, we picked the one furthest from others.

[14] This catchment was small (0.044 km^2).

	radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_TOXIC_2	Reach listed as impaired for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_PHYSICAL	Reach listed as impaired for flow alteration; habitat alteration; temperature?
RCH_SEDIMENT	Reach listed as impaired for sediment or turbidity?
RCH_EUTROPHIC	Reach listed as impaired for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens?
RCH_BIOLOGIC	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species?
RCH_BIOLOGIC2	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants?
RCH_OTHER_IMP	Reach listed as impaired for trash or unknown reasons?
RCH_ANYIMPAIR	Reach listed as impaired for any reason? (yes/no)

Catchment variables

In addition to examining parameters at the reach scale, we assessed parameters within each cumulative catchment (i.e., the entire drainage to the end point of each stream reach, not just the subsection adjacent to the reach) using the NHDPlus Catchment Attribute Allocation and Accumulation Tool (CA3T; Horizon Systems Corporation). These included metrics like land cover (1992 and 2001), impervious surface, tree cover, alluvium, karst areas, soil permeability, and length of various stream impairments (Table 3). We defined alluvium as surficial alluvial or glacial deposits of primarily gravel or sand from Fullerton et al. (2004), chosen because of relatively high permeability.

We also calculated a Developed Land Cover Buffered Flowpath Metric: the length in meters of forest or wetland cells that a developed land cover cell flows through to reach the nearest stream; and an Agriculture Buffered Flowpath Metric; the length in meters of forest or wetland cells that an agricultural land cover cell flows through to the nearest stream (also in Table 3). These metrics, which incorporate land cover, topography and hydrology, can represent potential water pollution loads better than simple land use percentages or fixed buffer width metrics (Baker et al., 2006). We summed the inverse buffer width (1 / (buffer flow length in meters + 1)) for agriculture and developed land within each cumulative catchment, representing non-point pollution loading to the stream reach. Table 3 lists the variables computed within each cumulative NHDPlus catchment.

Table 3. Variables computed within each cumulative NHDPlus catchment.

Variable	Definition
CAT_AREA_KM2	Cumulative drainage area (km^2)
CAT_IBWA_KM	Cumulative sum of inverse buffer width from agriculture (1 / (buffer flow length in meters + 1))
CAT_IBWD_KM	Cumulative sum of inverse buffer width from developed land (1 / (buffer flow length in meters + 1))
CAT_TREE_HA	Cumulative sum of tree canopy area (ha)
CAT_TREE_PCT	Cumulative mean percent of tree canopy cover
CAT_IMPERV_HA	Cumulative sum of impervious cover area (ha)

CAT_IMPER_PCT	Cumulative mean percent of impervious cover
CAT_KARST_PCT	Cumulative mean percent of karst geology
CAT_LC01AGPCT	Cumulative area-weighted percent of agricultural land, from 2001 NLCD
CAT_LC01DEVPC	Cumulative area-weighted percent of developed land, from 2001 NLCD
CAT_LC01FORPC	Cumulative area-weighted percent of forests and wetlands, from 2001 NLCD
CAT_LC92AGPCT	Cumulative area-weighted percent of agricultural land, from 1992 NLCD
CAT_LC92DEVPC	Cumulative area-weighted percent of developed land, from 1992 NLCD
CAT_LC92FORPC	Cumulative area-weighted percent of forests and wetlands, from 1992 NLCD
CAT_PERGEOPCT	Cumulative percent of surficial alluvium
CAT_PERM_AVG	Cumulative Soil Permeability - Average
CAT_AMMON_KM	Cumulative length of reaches with ammonia impairment (km)
CAT_TOXIC_KM	Cumulative length of reaches with impairment for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_TOXIC2_KM	Cumulative length of reaches with impairment for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_PHYS_KM	Cumulative length of reaches with impairment for flow alteration; habitat alteration; temperature (km)
CAT_SEDIM_KM	Cumulative length of reaches with impairment for sediment or turbidity (km)
CAT_EUTROP_KM	Cumulative length of reaches with impairment for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens (km)
CAT_BIOIMP_KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species (km)
CAT_BIOIMP2KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants (km)
CAT_OTHER_KM	Cumulative length of reaches with impairment for trash or unknown reasons (km)

Spatial allocation of variables – continuous grids

We also prepared variables as continuous grids. To reduce the file size below the Windows computational limits, we resampled all variable grids to 90 m cells. We then converted them to ASCII format for use in Maxent. As before, all variables we calculated at the reach and catchment scale.

Maxent model

Maximum entropy modeling (Maxent) is a machine learning technique that can be used to predict the geographic distribution of animal or plant species or other entities of interest. Maxent (using the program by Dudik et al., 2008) compares a set of samples from a distribution over a defined space, such as recorded locations of a particular species, to a set of features, such as relevant environmental variables, over that same space. Maxent estimates the spatial distribution of the species (i.e., predicts suitable habitat) by assuming nothing about that which is unknown (maximizing entropy) but matching the relationships between recorded occurrences and underlying variables. Unlike other techniques like logistic regression, maximum entropy modeling does not require reliable species absence data, which are rarely available. Maxent can also produce solutions with a small set of observations, although the larger the number of observations, the more accurate model output is likely to be. Also, the environmental variables do not need to be independent.

Output also includes the receiver operating characteristic (ROC) curve, which in this case tells the user how well the model distinguished species occurrences from random locations. The area under the ROC curve (AUC) should be as close to 1.0 as possible; an AUC of 0.5 indicates predictivity no better than random chance. Thresholds can be identified that most efficiently identify potential species habitat (fraction of occurrences included vs. the area selected). Model output also includes estimates of variable importance and graphs of predicted suitability vs. individual variables.

Based on experience with other species and natural communities, we set parameters as follows:

- Output format = logistic
- Use all possible variable relationships (linear, quadratic, product, threshold, and hinge)
- Regularization multiplier = 1
- Maximum number of background points = 10,000
- Add samples to background
- Extrapolate
- Do clamping
- Maximum number of iterations = 500
- Convergence threshold = 0.00001

Spatial Maxent application – continuous grids

We converted Maxent ASCII output to a floating point grid:

```
Arc: asciigrid Cyprogenia_stegaria_avg.asc flt_C_steg float
```

We multiplied this by 100 and took the integer value:

```
Grid: C_steg_Maxent = int(flt_C_steg * 100)
```

We selected the Maxent threshold that captured the highest proportion of known fanshell occurrences, while including the least area of catchments. Generally, this corresponds to maximum sensitivity plus specificity, but we examined a number of thresholds. We identified the majority Maxent value within each NHD catchment.[15] Then, we selected those catchments corresponding to Maxent values above the test maximum sensitivity plus specificity threshold, and grouped these into spatially contiguous sections. From these, we selected those groupings that also contained catchments with Maxent values greater than the most parsimonious threshold.[16]

We then selected the NHD flow lines within those catchments[17], and calculated the length of these contiguous sections using Hawth's Tools[18]. We compared the length of each stream segment with suitable habitat to the presence of fanshells. We filtered out sections below the minimum length that contained fanshells, and thereby identified stream reaches that met both modeled habitat and length thresholds.

Results

[15] We used the majority value because the 90 m model cells did not overlap catchment polygons exactly. We used the tool *Zonal Statistics as Table*.

[16] ArcGIS model *Identify catchments above Maxent thresholds*

[17] ArcGIS model *Identify streams above Maxent thresholds.* This buffered NHD stream reaches meeting the Maxent habitat threshold by 0.5 m (i.e., 1 m wide), dissolving overlapping buffers. We separated these shapes using the Multipart to Single Part tool.

[18] We calculated area with Hawth's Tools in km^2; because the width was 1 m, this was the same as length in km.

Maxent model
Figure 1 shows mean model output from the Maxent model for *C. stegaria* using continuous grids. This model had an average test AUC for the replicate runs of 0.967.

Table 4 gives a heuristic estimate of relative contributions of the environmental variables that contributed at least 3% to the Maxent model.[19] To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda was negative. Variable contributions should be interpreted with caution.

Table 4. Individual variable contributions to the Maxent model.

Variable	Percent contribution
CATVTREE_HA	48.3
CATVIBWA_KM	19.5
RCHVGEO_UNIT	5.5
CATVPERM_AVG	4.2
CATVKARST_PCT	3.0

The environmental variable CATVTREE_HA had the highest training and test gain when used in isolation, and therefore appeared to have the most useful information by itself. This was followed by CATVMAFLOWU, CATVIBWA_KM, CATVAREA_KM2, and CATVIBWD_KM (gain >2.0). The environmental variable CATVKARST_PCT decreased the gain the most when it was omitted, and therefore appeared to have the most information that wasn't present in the other variables. Table 5 lists the values associated with higher probabilities of fanshell presence, for variables that contributed >3% to the model. Variables were inter-related, and combined in a variety of ways to create the model.

Table 5. Values associated with higher probabilities of fanshell presence, for variables that contributed >3% to the model.

Variable	Values associated with fanshell presence
CATVTREE_HA	~4.5 M ha, but also a peak <1 M ha.
CATVIBWA_KM	Peak ~8000 km
RCHVGEO_UNIT	Channel and flood-plain alluvium; alluvial, outwash, ice-contact, and glacial-lake deposits
CATVPERM_AVG	Peak 70-75 µm/hr
CATVKARST_PCT	Peak ~45-55%, with rapid decline <~8%

Spatial Maxent application
The logistic threshold corresponding to maximum test sensitivity plus specificity was 0.1926, which captured 96% of test points, 93% of training points, and 4.68% of area on average ($p<0.001$). Other reported Maxent thresholds captured fewer test points on average and, in most cases, more area. Comparing Maxent output to fanshell occurrences, a threshold of 0.40 appeared more parsimonious (Table 6).

Table 6. Maxent values compared to fanshell occurrences.

[19] We chose a reporting threshold of 3% because there was a distinct break there between the top variables and the rest.

Maxent value threshold	Number of fanshell occurrences within this range	Percent of fanshell occurrences within this range	Percent of Ohio and Tennessee basins within this range
>0.40	77	94	0.7
>0.1926	77	94	1.5
All values	82	100	100

We identified all NHD catchments with Maxent values >0.1926, and grouped these into spatially contiguous sections. From these, we selected those groupings that also contained catchments with Maxent values >0.40. We then selected those NHD flow lines within those catchments, and calculated the length of these contiguous sections using Hawth's Tools. The shortest continuous stream reach with these model values and containing fanshells[20] was 12 km. Rounding down to one significant digit, we selected NHD reaches within stretches of modeled suitable habitat >10 km[21], made manual additions where this automated procedure missed part of the high valued sections, and manual subtractions of tributaries that should not have been included. These totaled 1245 km (1.3% of the Ohio and Tennessee River basins).

Discussion

Based on available survey and environmental data, the Maxent model predicted about 1.3% of the Ohio and Tennessee River basins to be suitable habitat for *Cyprogenia stegaria*. Some of the longer stretches of modeled habitat included the upper Ohio River, Licking River, Wabash River, lower Tippecanoe River, East Fork of the White River, Rolling Fork, Green River, Clinch River, Elk River, Duck River, Buffalo River, the lower Sequatchie River, and a section of the Tennessee River between Pickwick Lake and Lick Creek. There were also a number of shorter stretches of modeled habitat.

Catchment tree area, drainage from agriculture, geology type, soil permeability, and geology type were the top predictive variables. Because they contained distinct mid-range peaks, we suspect that some of these variables (especially tree area and agricultural drainage) were geographically correlative, not causative. Geology can influence hydrology and water quality. Alluvial deposits, karst, and other permeable geologic formations can increase groundwater flow into streams. Arbuckle and Downing (2002) found that mussel density and species richness are higher in streams with high fractions of alluvial deposits. Such streams are more stable, with greater groundwater recharge and lower surface runoff, especially in agricultural watersheds (Arbuckle and Downing, 2002).

We applied a spatial filter to model output from Maxent, selecting only modeled suitable habitat >10 km. As with terrestrial species, small, isolated areas of habitat may only support small, inbred populations that are doomed to local extinction. Mussel populations are now more widely separated than they were historically, leading to reduced recruitment success and declining populations, especially in the presence of stressors. EPA (2002) suggested maintaining and improving stream habitat and water quality in remaining mussel locations, and allowing populations to expand into nearby areas.

[20] We selected features from Maxent_flowline_groups that are within 200 m (to account for spatial error) of Fanshell_locations_Albers83.

[21] We selected NHD flowlines that had their centroids in the selected reach buffers (Maxent_flowline_groups), and saved these as Fanshell_modeled_habitat.shp.

Within stream reaches, microhabitat features like substrate and bank stability may be important factors. The Maxent model applies only at the stream reach and catchment scale; management actions should be preceeded by stream surveys. We hope that the coarse-scale modeling described here can help prioritize more detailed surveys, and also emphasize the importance of catchment-scale geomorphic and land use conditions.

Federally listed species have recovery plans. 80% of all federally listed species rely on ongoing conservation efforts. Most require two or more conservation strategies. Management should not only react to present conditions, but preserve the ability of species to adapt to change, such as global warming. Propagation and culture of endangered mussels is a key component of species recovery, although there are concerns about genetic impacts. Although state and university biologists are likely to know already where the best conditions are, the Maxent model could conceivably help target reintroduction of cultured mussels. Reintroductions should be preceded by field surveys, then pilot testing of survival and recruitment.

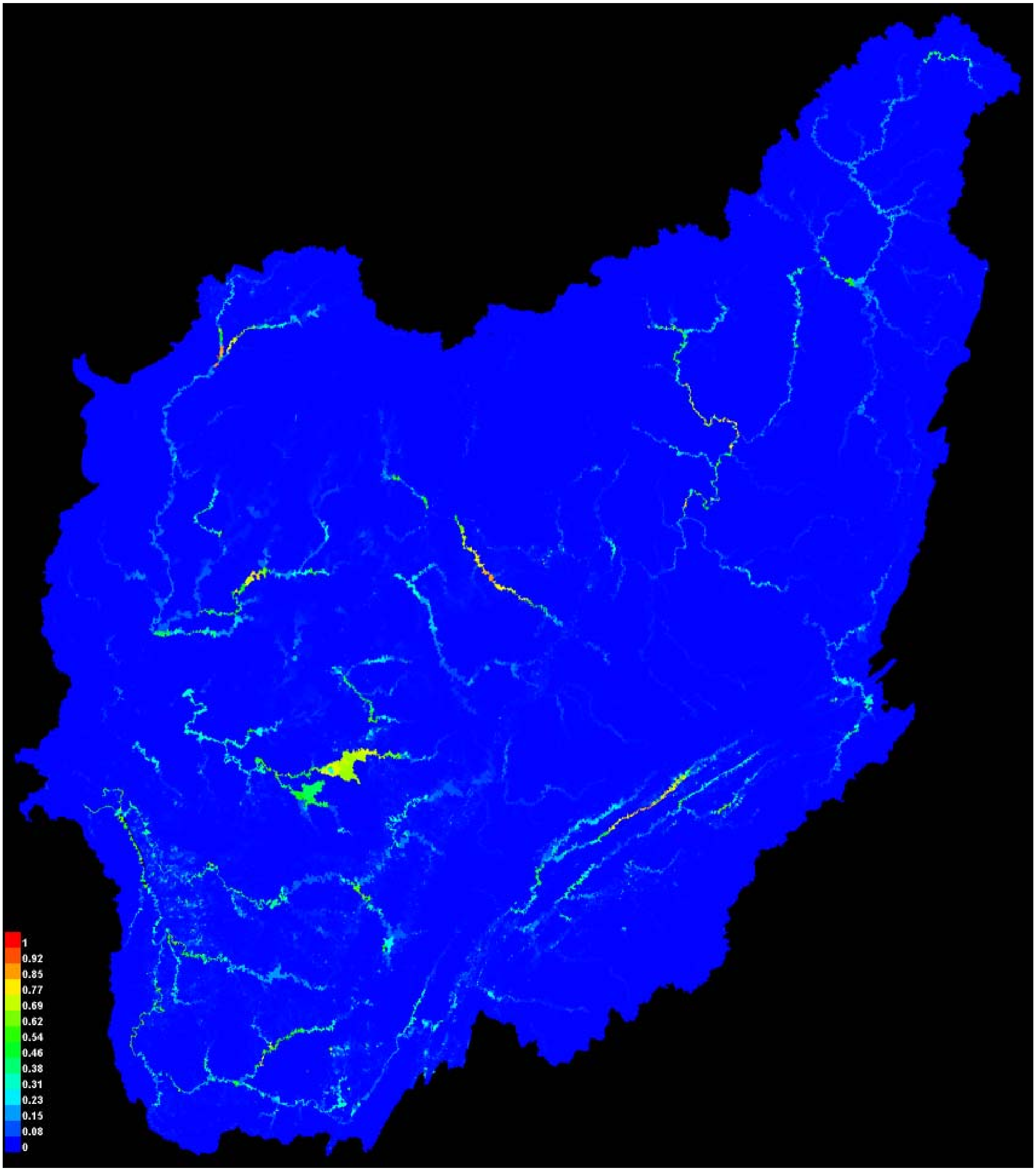

Fig. 1. Maxent output predicting suitable habitat for *Cyprogenia stegaria*

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Coarse-Scale Modeling Of *Pleurobema Collina* (James Spinymussel) Habitat

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Introduction

Overview
The Conservation Fund (TCF) is assisting the US Fish and Wildlife Service (USFWS), NiSource, and 13 affected states (DE, IN, KY, LA, MD, MS, NJ, NY, OH, PA, TN, VA, and WV) to create a multi-species, multi-state habitat conservation plan covering future construction, operation, and maintenance of NiSource natural gas pipelines and ancillary facilities. The James spinymussel (*Pleurobema collina*), a federally endangered mussel, is one of the covered species.

North America has the highest diversity of freshwater mussels in the world. Mussels historically occurred in dense multi-species assemblages, and provide important ecosystem functions like sediment stabilization and nutrient cycling. Unfortunately, this taxa is highly imperiled; some 68% of freshwater mussel species are vulnerable, and many have gone extinct.

Habitat requirements
Pleurobema collina is native to the James River system in Virginia and West Virginia, as well as the Dan and Mayo River drainages of the Roanoke River basin in North Carolina and the Tar River (NatureServe, 2009; USFWS, 2010). It is currently documented from only a few creeks and small rivers in the upper James River drainage in Virginia and the Roanoke drainage in North Carolina (USFWS, 2010).

Similar to other freshwater mussels, *P. collina* is a filter feeder, siphoning phytoplankton, diatoms, and other microorganisms from the water column (USFWS, 2010). Mussels tend to grow relatively rapidly their first few years until sexual maturity, when energy is diverted to reproduction. For freshwater mussels, James spinymussels have a relatively short life span, living only 3 to 19 years (USFWS, 2010).

Most mussels, including the James spinymussel, have separate sexes. Males expel clouds of sperm into the water column, which are drawn in by females through their incurrent siphons. Fertilization takes place internally, and the resulting zygotes develop within the gills into specialized larvae termed glochidia. Glochidia must come into contact with a specific host fish, usually within 24 hours, to survive (USFWS, 2010). Suitable host fish for *P. collina* include, but are probably not limited to, bluehead chub, rosyside dace, blacknose dace, mountain redbelly dace, rosefin shiner, satinfin shiner, stoneroller, and possibly swallowtail shiner (NatureServe, 2009).

Glochidia parasitize the fishes' gill tissues for a few weeks; then detach to begin a free-living existence on the stream bottom. This unique method of dispersal allows freshwater mussels to colonize areas upstream as well as downstream. Unless released in suitable habitat, the released glochidia will die (USFWS, 2010). Like other mussels, the James spinymussel probably experiences very low annual juvenile survival. A single female's reproductive output is reduced from thousands of glochidia to less than one surviving juvenile per year (USFWS, 2010). Thus, small populations have a high risk of extirpation.

Dispersal barriers include climate, drainage divides, dams and other fish barriers, pollution, habitat modification (e.g., channelization), and the lack of suitable host fish. Further, dispersal rates range widely across species. Although mobile or migratory host fish may move long distances, small benthic fish like darters and sculpins may move 30 m or less. The effects of reduced migration rates are especially severe for rare species. Some populations may be functionally extinct, with no possibilities of propagation, or populations too low to persist. The long lifespan of many mussels may mask this "extinction debt" (Strayer, 2008).

Many freshwater mussels are habitat-specific; e.g., some preferring riffles, and some preferring pools. Mussels are most abundant in oxygenated, shallow waters (<2 m) of medium to large rivers and occupy a variety of stable substrates including different combinations of silt, sand, gravel, cobble, and boulders (Pennak, 1989, in Arbuckle and Downing, 2000). Rivers and larger streams, if unimpaired, generally contain more habitat niches and host fish than smaller streams. They are also less likely to dry out than smaller streams. Suitable habitat allows juveniles to settle, has substrate firm enough for support but soft enough for burrowing, is stable during floods, is wet during droughts, delivers food and essential materials (oxygen, calcium, etc.), provides favorable temperatures for growth and reproduction, provides protection from predators, and contains no toxic materials (Strayer, 2008).

According to NatureServe (2009), *P. collina* is primarily found in streams of slow to moderate currents and a substrate of sand and cobble with or without boulders, pebbles, or silt. Stream width varies from 10 to 75 feet with a water depth of 0.5 to 3 feet. It is limited to unpolluted free flowing water.

<u>Threats</u>

Stressors to freshwater mussels include stream channelization; hydrologic modifications and stream instability associated with development (e.g., impervious surfaces); lack of riparian forest; sedimentation from construction, mining, and farming; water supply withdrawals; acid mine drainage; hog farm runoff; other source pollution; dams; and other fish blockages. Mussels are more sensitive to ammonia, copper, and other metals than other aquatic organisms, and current water quality standards may be insufficient for their survival. Mussel presence and diversity indicate clean water. Coal and oil extraction can decrease downstream mussel abundance by 90%. Inadequate water flow or high-volume floods are other key stressors, with drying being the worst. Dam failure or removal can transport trapped sediment downstream and smother mussels.

USFWS (2010) identified the main threats to *P. collina* as sedimentation and siltation from land use activities, competition with the Asian clam (*Corbicula fluminea*), impoundments, and pollution. Accumulations of sediments ≥0.6 cm could be lethal, and dissolved concentrations ≥600 mg/l could harm individuals (NatureServe, 2009). Increasing spatial separation of remaining populations is also a threat (USFWS, 2010).

Habitat modeling

Hopkins (2009) compared the distribution of *Quadrula cylindrica*, a freshwater mussel, to environmental variables at multiple scales in the upper Green River system in Kentucky. Variables included land use/land cover pattern and composition, soil composition, and geology, at the subcatchment scale, subcatchment riparian buffer (100 m from the stream), and riparian buffer for a 100m upstream reach. Boosted regression trees found the most influential variables to be patch density at the reach scale and soil composition at the riparian scale.

Terrestrial reserves often protect important freshwater resources where aquatic considerations played a role in site selection. However, there is poor correspondence in many areas. Hydrologic regime, physical habitat, biotic composition, connectivity, and water quality need to be addressed at the watershed level. At the reach level, the material contribution zone, meander belt, active low floodplain, riparian wetlands, high floodplain, and terraces should be considered to maintain natural hydrologic and material transport processes. Aquatic conservation should encompass at least 10 fluvial kilometers, and maintain connectivity to downstream rivers.

We sought to identify suitable habitat for *P. collina* conservation or reintroduction. Our analyses, described below, were limited to coarse-scale variables at the reach and catchment scale. Microhabitat features like stream substrate or submerged vegetation might be inferred by larger scale conditions, but are best measured by field surveys.

Methods

Locational data

We received *P. collina* occurrence data from the VA and WV Natural Heritage Programs. Some of this data was in point form (WV) and some in polygon (VA). Spatial accuracy varied; in many cases only close enough to identify the occurrence stream reach and catchment.

We converted polygon occurrence data to points, selecting centroids, but constraining them to fall within the polygon. We merged records from all states in the NiSource study area. We omitted records with Poor viability (EO rank = "D"), Historical records (H), Failed to find (F), Extirpated (X), records prior to 1990, and subfossils. This left a single WV point and 83 VA points; 70 in the James River watershed and 14 on the South Mayo River.

To reduce positional errors and spatial bias, we considered stream reaches as the unit of analysis for occurrence data. First, we selected NHD catchments that contained James spinymussels, using the locational data described earlier. Next, we identified the centroids of these catchments (using the Feature to Point tool). We ensured that these centroids fell within the catchment, selecting centroids that intersected the James spinymussel catchments. No centroids fell outside catchments. Finally, we reprojected the remaining centroids to the same coordinate system as the variable grids, used Hawth's Tools to add x-y coordinates, and convert the data to a .csv file.

Reach variables

We limited modeling to the upper half of the James River watershed; specifically, those NHD subbasins containing James spinymussels: Upper James, Maury, Rivanna, and Middle James-Buffalo. The South Mayo River population fell in an entirely separate major drainage (NHD Region 3; the James drains to the Chesapeake Bay, in Region 2).

We obtained streams, stream catchments, and flow data from NHDPlus (Bondelid et al., 2007). The NHD streams were digitized at a 1:100K scale, corresponding to a horizontal accuracy around 50 m. Because of spatial inaccuracies in the data, we did not examine potential relationships at a local (sub-reach) scale. Instead, we focused solely on the reach and catchment scales.

Table 2 lists the variables computed for each NHDPlus stream reach. We obtained surficial geology units and deposit types from Fullerton et al. (2004), compiled at a 1:1M scale. We obtained karst data from Weary (2008), believed accurate within 300 m. We obtained soil permeability from CONUS (Miller and White, 1998), selecting the value for the top layer of soil (0-5 cm; field [L1_PERM]). We obtained land cover from the 2001 National Land Cover Database (U.S. Geological Survey; see Homer et al. 2004). We obtained stream impairment data from the EPA's 303(d) list, selected only current impairments, and lumped the causes into 9 categories. To identify impounded stream reaches, we identified NHD flowlines that intersected NHD lakes, ponds, or reservoirs (not wetlands).

We used the Nonpoint-Source Pollution and Erosion Comparison Tool (N-SPECT), developed by the NOAA Coastal Services Center, to estimate relative stream sedimentation. N-SPECT uses land cover, soil characteristics, topography, and precipitation regimes to assess spatio-temporal patterns of surface water runoff processes, nonpoint source pollution, and erosion. Spatial elevation data are used to calculate flow direction and flow accumulation throughout a watershed. Land cover, soils, and precipitation data sets are processed to estimate runoff volume at both the local (pixel) and watershed scales. Coefficients representing the contribution of each land cover class to the expected pollutant load are applied to land cover data sets to approximate total pollutant loads.

As the "local" sediment and total suspended solids outputs from the N-SPECT water quality model do not account for the attenuation of these pollutants by forest and wetlands, we decided to use an inverse buffer width factor to account for this attenuation. The inverse buffer width is an index of pollution potential that incorporates the buffered flowpath length of "sources" of pollution flowing through "sinks". Sinks are areas of the landscape that attenuate pollutants/sources. For the purposes of this analysis all NLCD land cover classes except water, forest, and wetland were considered "sources", while forested and wetland areas were considered "sinks". The buffered flowpath length is the length (in map units) along a hydrologic flowpath from a given source cell to the nearest stream that is comprised of sink cells. For instance, if the flowpath from a particular source cell to the stream flows through three 30-m sink cells, the flowpath length would be 90 meters. The inverse buffer width is calculated as the reciprocal of the buffered flowpath length: IBW = 1 / (buffered flowpath length + 1). Higher values indicate higher pollution potential, e.g. an inverse buffer width value of "1" represents a source cell that is not buffered by any sink cells. Thus, multiplying the pollutant output grids by the inverse buffer width grid provides an estimate of the degree of attenuation of pollution travelling across the landscape.

Table 2. Variables computed within each NHDPlus catchment.

Variable	**Definition**
CAT_MAFLOWU	Mean Annual Flow - Unit Method (cfs)
CAT_MAVELU	Mean Annual Velocity - Unit Method (fps)
CAT_ELEV_CM	Mean reach elevation – smoothed (cm)
CAT_SLOPE1000	Mean channel slope (mm/m)
RCH_GEO_UNIT	Majority surficial geology unit within 60m of NHD stream reach
RCH_DEP_TYPE	Majority surficial geology deposit type within 60m of NHD stream reach

RCH_P_KARST60	Percent karst geology within 60m of NHD stream reach
RCH_SOILPER60	Mean soil permeability within 60m of NHD stream reach
RCH_PCTFORW60	Percent forest and wetland cover (from 2001 NLCD) within 60m of NHD stream reach
RCH_IMPOUNDED	Reach impounded? (yes/no)
RCH_AMMONIA	Reach listed as impaired for ammonia?
RCH_TOXIC_IMP	Reach listed as impaired for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_TOXIC_2	Reach listed as impaired for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_PHYSICAL	Reach listed as impaired for flow alteration; habitat alteration; temperature?
RCH_SEDIMENT	Reach listed as impaired for sediment or turbidity?
RCH_EUTROPHIC	Reach listed as impaired for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens?
RCH_BIOLOGIC	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species?
RCH_BIOLOGIC2	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants?
RCH_OTHER_IMP	Reach listed as impaired for trash or unknown reasons?
RCH_ANYIMPAIR	Reach listed as impaired for any reason? (yes/no)
RCH_SED_IBW	Mean non-cumulative catchment (i.e., reach scale) value of the product of N-SPECT sediment local effects (in grams per 900 m^2 per year) times the inverse buffer width (unit-less) of all sediment producing NLCD land cover classes. See text for more details.
RCH_TSS_IBW	Mean non-cumulative catchment (i.e., reach scale) value of the product of N-SPECT total suspended solids local effects (in grams per 900 m^2 per year) times the inverse buffer width (unit-less) of all sediment producing NLCD land cover classes. See text for more details.

<u>Catchment variables</u>

Table 3 lists the variables computed within each cumulative NHDPlus catchment. In addition to examining parameters at the reach scale, we assessed parameters within each cumulative catchment (i.e., the entire drainage to the end point of each stream reach, not just the subsection adjacent to the reach) using the NHDPlus Catchment Attribute Allocation and Accumulation Tool (CA3T; Horizon Systems Corporation). These included metrics like land cover (1992 and 2001), impervious surface, tree cover, alluvium, karst areas, soil permeability, and length of various stream impairments (Table 3). We defined alluvium as surficial alluvial or glacial deposits of primarily gravel or sand from Fullerton et al. (2004), chosen because of relatively high permeability.

We also calculated a Developed Land Cover Buffered Flowpath Metric: the length in meters of forest or wetland cells that a developed land cover cell flows through to reach the nearest stream; and an Agriculture Buffered Flowpath Metric; the length in meters of forest or wetland cells that an agricultural land cover cell flows through to the nearest stream (also in Table 3). These metrics, which incorporate land cover, topography and hydrology, can represent potential water pollution loads better than simple land use percentages or fixed buffer width metrics (Baker et al., 2006). We summed the inverse buffer width (1 / (buffer flow length in meters + 1)) for agriculture and developed land within each cumulative catchment, representing non-point pollution loading to the stream reach. We also summed models of sediment and total suspended solid loads.

Table 3. Variables computed within each cumulative NHDPlus catchment.

Variable	**Definition**
CAT_AREA_KM2	Cumulative drainage area (km^2)
CAT_IBWA_KM	Cumulative sum of inverse buffer width from agriculture (1 / (buffer flow length in meters + 1))
CAT_IBWD_KM	Cumulative sum of inverse buffer width from developed land (1 / (buffer flow length in meters + 1))
CAT_TREE_HA	Cumulative sum of tree canopy area (ha)
CAT_TREE_PCT	Cumulative mean percent of tree canopy cover
CAT_IMPERV_HA	Cumulative sum of impervious cover area (ha)
CAT_IMPER_PCT	Cumulative mean percent of impervious cover
CAT_KARST_PCT	Cumulative mean percent of karst geology
CAT_LC01AGPCT	Cumulative area-weighted percent of agricultural land, from 2001 NLCD
CAT_LC01DEVPC	Cumulative area-weighted percent of developed land, from 2001 NLCD
CAT_LC01FORPC	Cumulative area-weighted percent of forests and wetlands, from 2001 NLCD
CAT_LC92AGPCT	Cumulative area-weighted percent of agricultural land, from 1992 NLCD
CAT_LC92DEVPC	Cumulative area-weighted percent of developed land, from 1992 NLCD
CAT_LC92FORPC	Cumulative area-weighted percent of forests and wetlands, from 1992 NLCD
CAT_PERGEOPCT	Cumulative percent of surficial alluvium
CAT_PERM_AVG	Cumulative Soil Permeability - Average
CAT_AMMON_KM	Cumulative length of reaches with ammonia impairment (km)
CAT_TOXIC_KM	Cumulative length of reaches with impairment for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_TOXIC2_KM	Cumulative length of reaches with impairment for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_PHYS_KM	Cumulative length of reaches with impairment for flow alteration; habitat alteration; temperature (km)
CAT_SEDIM_KM	Cumulative length of reaches with impairment for sediment or turbidity (km)
CAT_EUTROP_KM	Cumulative length of reaches with impairment for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens (km)
CAT_BIOIMP_KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species (km)
CAT_BIOIMP2KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants (km)
CAT_OTHER_KM	Cumulative length of reaches with impairment for trash or unknown reasons (km)
CAT_SED_IBW	Accumulated sediment (kg per 900 m^2 per year) times the inverse buffer width (unit-

	less) of all sediment producing NLCD land cover classes.
CAT_SED_SC	Accumulated sediment (kg per 900 m^2 per year)
CAT_TSS_IBW	Accumulated total suspended solids (kg per 900 m^2 per year) times the inverse buffer width (unit-less) of all sediment producing NLCD land cover classes.
CAT_TSS_SC	Accumulated total suspended solids (kg per 900 m^2 per year)

Spatial allocation of variables

We prepared reach and catchment variables as continuous grids with 30m cell size, clipped to the study area. We then converted them to ASCII format for use in Maxent.

Maxent model

Maximum entropy modeling (Maxent) is a machine learning technique that can be used to predict the geographic distribution of animal or plant species or other entities of interest. Maxent (using the program by Dudik et al., 2008) compares a set of samples from a distribution over a defined space, such as recorded locations of a particular species, to a set of features, such as relevant environmental variables, over that same space. Maxent estimates the spatial distribution of the species (i.e., predicts suitable habitat) by assuming nothing about that which is unknown (maximizing entropy) but matching the relationships between recorded occurrences and underlying variables. Unlike other techniques like logistic regression, maximum entropy modeling does not require reliable species absence data, which are rarely available. Maxent can also produce solutions with a small set of observations, although the larger the number of observations, the more accurate model output is likely to be. Also, the environmental variables do not need to be independent.

Output also includes the receiver operating characteristic (ROC) curve, which in this case tells the user how well the model distinguished species occurrences from random locations. The area under the ROC curve (AUC) should be as close to 1.0 as possible; an AUC of 0.5 indicates predictivity no better than random chance. Thresholds can be identified that most efficiently identify potential species habitat (fraction of occurrences included vs. the area selected). Model output also includes estimates of variable importance and graphs of predicted suitability vs. individual variables.

Based on experience with other species and natural communities, we set parameters as follows:

- Output format = logistic
- Use all possible variable relationships (linear, quadratic, product, threshold, and hinge)
- Regularization multiplier = 1
- Maximum number of background points = 10,000
- Add samples to background
- Extrapolate
- Do clamping
- Maximum number of iterations = 500
- Convergence threshold = 0.00001
- 10-fold cross-validation

Spatial Maxent application – continuous grids

We converted Maxent ASCII output to a floating point grid:

```
Arc: asciigrid Pleurobema_collina_avg.asc flt_P_coll float
```

We multiplied this by 100 and took the integer value:

```
Grid: P_coll_Maxent = int(flt_P_coll * 100)
```

We selected the Maxent threshold that captured the highest proportion of known James spinymussel occurrences, while including the least area of catchments. Generally, this corresponds to maximum sensitivity plus specificity, but we examined a number of thresholds. We identified the majority Maxent value within each NHD catchment.[22] Then, we selected those catchments corresponding to Maxent values above the test maximum sensitivity plus specificity threshold, and grouped these into spatially contiguous sections. From these, we selected those groupings that also contained catchments with Maxent values greater than the most parsimonious threshold.[23]

We then selected the NHD flow lines within those catchments[24], and calculated the length of these contiguous sections using Hawth's Tools[25]. We compared the length of each stream segment with suitable habitat to the presence of James spinymussels. We filtered out sections below the minimum length that contained James spinymussels, and thereby identified stream reaches that met both modeled habitat and length thresholds.

Results

Maxent model

Figure 1 shows mean model output from the Maxent model for *P. collina*. This model had an average test AUC for the replicate runs of 0.803.

Table 4 gives a heuristic estimate of relative contributions of the environmental variables that contributed at least 5% to the Maxent model.[26] To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda was negative. Variable contributions should be interpreted with caution.

Table 4. Individual variable contributions to the Maxent model.

Variable	Percent contribution
RCHVGEO_UNIT	30.6
CATVSLOPE1000	14.4
CATVPERM_AVG	6.8
CATVAREA_KM2	6.8
RCH_SED_IBW	5.7
CATVELEV_CM	5.0

The environmental variable RCHVGEO_UNIT had the highest training and test gain when used in isolation, and therefore appeared to have the most useful information by itself. This was followed by CATVSLOPE1000 (gain >0.4). The environmental variable RCHVGEO_UNIT decreased the gain the most when it was omitted, and therefore appeared to have the most information that wasn't present in the other variables. Table 5 lists the

[22] We used the majority value because the 30 m model cells did not overlap catchment polygons exactly. We used the tool *Zonal Statistics as Table*.

[23] ArcGIS model *Identify catchments above Maxent thresholds*

[24] ArcGIS model *Identify streams above Maxent thresholds.* This buffered NHD stream reaches meeting the Maxent habitat threshold by 0.5 m (i.e., 1 m wide), dissolving overlapping buffers. We separated these shapes using the Multipart to Single Part tool.

[25] We calculated area with Hawth's Tools in km^2; because the width was 1 m, this was the same as length in km.

[26] We chose a reporting threshold of 5% because there was a distinct break there between the top variables and the rest.

values associated with higher probabilities of James spinymussel presence, for variables that contributed >5% to the model. Variables were inter-related, and combined in a variety of ways to create the model.

Table 5. Values associated with higher probabilities of James spinymussel presence, for variables that contributed >5% to the model.

Variable	Values associated with James spinymussel presence
RCHVGEO_UNIT	Decomposition residuum on sand and gravel beneath high stream terraces and in alluvial fans; Clayey to sandy saprolite on granite, gneiss, schist, and other felsic, mafic, and ultramafic igneous and metamorphic rocks
CATVSLOPE1000	Slope near zero; this may be geographically correlative rather than causative.
CATVPERM_AVG	~87-175 µm/hr
CATVAREA_KM2	Declines as area increases, but variability is high
RCH_SED_IBW	Declines as this increases
CATVELEV_CM	Peak around 120 m; this is more likely geographically correlative rather than causative.

Spatial Maxent application

The logistic threshold corresponding to maximum test sensitivity plus specificity was 0.2222, which captured 80% of test points (mean n=4.9), 91% of training points (mean n=44.1), and 15.8% of area on average (p=0.0134). Other reported Maxent thresholds had p > 0.05. Comparing Maxent output to James spinymussel occurrences, a threshold of 0.30 appeared more parsimonious (Table 6).

Table 6. Maxent values compared to James spinymussel occurrences.

Maxent value threshold	Number of James spinymussel occurrences within this range	Percent of James spinymussel occurrences within this range	Percent of upper James River watershed within this range
>0.30	45	92	10.1
>0.2222	45	92	13.9
All values	49	100	100

We identified all NHD catchments with Maxent values >0.2222, and grouped these into spatially contiguous sections. From these, we selected those groupings that also contained catchments with Maxent values >0.30. We then selected those NHD flow lines within those catchments, and calculated the length of these contiguous sections using Hawth's Tools. The shortest continuous stream reach with these model values and containing James spinymussels[27] was 2.7 km. Most were >10 km. We selected NHD reaches within stretches of modeled suitable habitat >10 km[28], made manual additions where this automated procedure missed part of the high valued sections, especially if they contained James spinymussels, and manual subtractions of tributaries that should not have been included. These totaled 923 km (4.1% of the upper James River watershed).

Discussion

[27] We selected features from Maxent_flowline_groups that are within 200 m (to account for spatial error) of James spinymussel_locations_Albers83.

[28] We selected NHD flowlines that had their centroids in the selected reach buffers (Maxent_flowline_groups), and saved these as James_spinymussel_modeled_habitat.shp.

Based on available survey and environmental data, the Maxent model predicted about 4% of the upper James River watershed to be suitable habitat for *Pleurobema collina*. The test AUC for *P. collina* was much lower than that of the other mussel models, but the study area was much smaller, with presumably lower variation. The environmental variables may have been geographically correlative rather than causative. The gain was low (<1) for all variables. The sediment model was consistent with stressors noted by USFWS (2010), although *P. collina* locations were more closely related to non-cumulative than cumulative sediment loads.

We applied a spatial filter to model output from Maxent, selecting only modeled suitable habitat >10 km. As with terrestrial species, small, isolated areas of habitat may only support small, inbred populations that are doomed to local extinction. Mussel populations are now more widely separated than they were historically, leading to reduced recruitment success and declining populations, especially in the presence of stressors. EPA (2002) suggested maintaining and improving stream habitat and water quality in remaining mussel locations, and allowing populations to expand into nearby areas.

Within stream reaches, microhabitat features like substrate and bank stability may be important factors. The Maxent model applies only at the stream reach and catchment scale; management actions should be preceeded by stream surveys. We hope that the coarse-scale modeling described here can help prioritize more detailed surveys, and also emphasize the importance of catchment-scale geomorphic and land use conditions.

Federally listed species have recovery plans. 80% of all federally listed species rely on ongoing conservation efforts. Most require two or more conservation strategies. Management should not only react to present conditions, but preserve the ability of species to adapt to change, such as global warming. Propagation and culture of endangered mussels is a key component of species recovery, although there are concerns about genetic impacts. Although state and university biologists are likely to know already where the best conditions are, the Maxent model could conceivably help target reintroduction of cultured mussels. Reintroductions should be preceded by field surveys, then pilot testing of survival and recruitment.

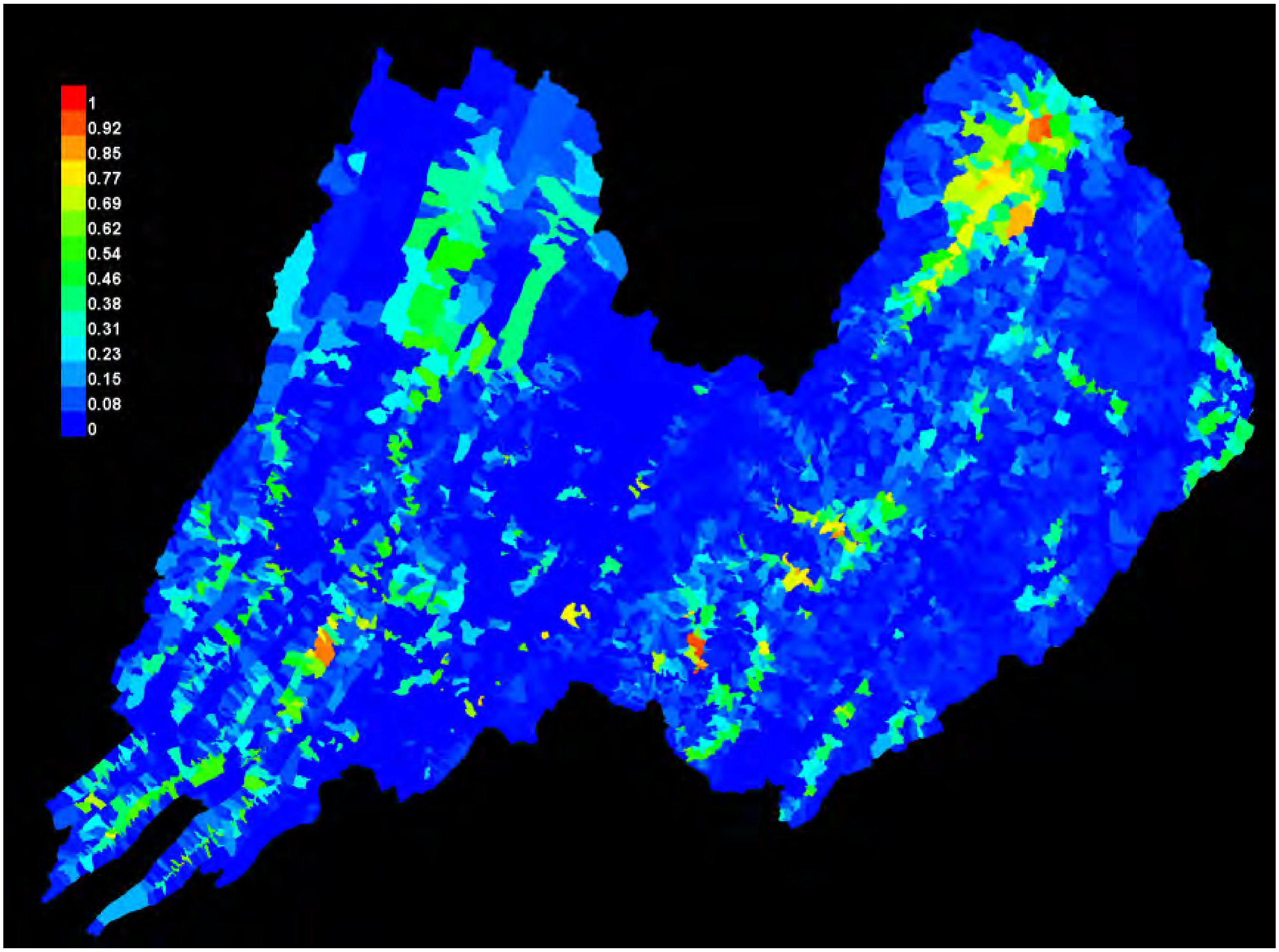

Fig. 1. Maxent output predicting suitable habitat for *Pleurobema collina*

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Coarse-Scale Modeling

Epioblasma Torulosa Rangiana (Northern Riffleshell) Habitat

(12/29/2010)

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Introduction

Overview

The Conservation Fund (TCF) is assisting the US Fish and Wildlife Service (USFWS), NiSource, and 13 affected states (DE, IN, KY, LA, MD, MS, NJ, NY, OH, PA, TN, VA, and WV) to create a multi-species, multi-state habitat conservation plan covering future construction, operation, and maintenance of NiSource natural gas pipelines and ancillary facilities. The Northern riffleshell (*Epioblasma torulosa rangiana*), a federally endangered mussel, is one of the covered species.

North America has the highest diversity of freshwater mussels in the world. Mussels historically occurred in dense multi-species assemblages, and provide important ecosystem functions like sediment stabilization and nutrient cycling. Unfortunately, this taxa is highly imperiled; some 68% of freshwater mussel species are vulnerable, and many have gone extinct.

Habitat requirements

Epioblasma torulosa rangiana is sparsely distributed within a highly restricted range, occurring in less than 5% of its former range (USFWS, 2010). The cause is uncertain, although habitat loss is suspected to be a major factor (USFWS, 2010).

Similar to other freshwater mussels, *Epioblasma torulosa rangiana* is a filter feeder, siphoning phytoplankton, diatoms, and other microorganisms from the water column (USFWS, 2010). Mussels tend to grow relatively rapidly their first few years until sexual maturity, when energy is diverted to reproduction. For freshwater mussels, Northern riffleshells have a relatively short life span, living only 7 to 15 years (USFWS, 2010).

Most mussels, including the northern riffleshell, have separate sexes. Males expel clouds of sperm into the water column, which are drawn in by females through their incurrent siphons. Fertilization takes place internally, and the resulting zygotes develop within the gills into specialized larvae termed glochidia. Glochidia must come into contact with a specific host fish, usually within 24 hours, to survive (USFWS, 2010). Suitable host fish for *E. torulosa rangiana* include, but are probably not limited to, mottled sculpin, banded darter, bluebreast darter, and brown trout (NatureServe, 2008).

Glochidia parasitize the fishes' gill tissues for a few weeks; then detach to begin a free-living existence on the stream bottom. This unique method of dispersal allows freshwater mussels to colonize areas upstream as well as downstream. Unless released in suitable habitat, the released glochidia will die (USFWS, 2010). Like other mussels, the northern riffleshell probably experiences very low annual juvenile survival. A single female's reproductive output is reduced from thousands of glochidia to less than one surviving juvenile per year (USFWS, 2010). Thus, small populations have a high risk of extirpation.

Epioblasma torulosa rangiana. (Photo USFWS)

Dispersal barriers include climate, drainage divides, dams and other fish barriers, pollution, habitat modification (e.g., channelization), and the lack of suitable host fish. Further, dispersal rates range widely across species. Although mobile or migratory host fish may move long distances, small benthic fish like darters and sculpins may move 30 m or less. The effects of reduced migration rates are especially severe for rare species. Some populations may be functionally extinct, with no possibilities of propagation, or populations too low to persist. The long lifespan of many mussels may mask this "extinction debt" (Strayer, 2008).

Many freshwater mussels are habitat-specific; e.g., some preferring riffles, and some preferring pools. Mussels are most abundant in oxygenated, shallow waters (<2 m) of medium to large rivers and occupy a variety of stable substrates including different combinations of silt, sand, gravel, cobble, and boulders (Pennak, 1989, in Arbuckle and Downing, 2000). Rivers and larger streams, if unimpaired, generally contain more habitat niches and host fish than smaller streams. They are also less likely to dry out than smaller streams. Suitable habitat allows juveniles to settle, has substrate firm enough for support but soft enough for burrowing, is stable during floods, is wet during droughts, delivers food and essential materials (oxygen, calcium, etc.), provides favorable temperatures for growth and reproduction, povides protection from predators, and contains no toxic materials (Strayer, 2008).

According to USFWS (2010), *E. torulosa rangiana* occurs in a wide variety of streams, preferring runs with a bottom composed of firmly packed sand and fine to coarse gravel. NatureServe (2008) states that they prefer riffle areas of smaller streams. They require swiftly moving, well-oxygenated water (NatureServe, 2008; USFWS, 2010). Individuals are sensitive to pollution, siltation, habitat perturbation, inundation, and loss of fish hosts (NatureServe, 2008).

<u>Threats</u>

Stressors to freshwater mussels include stream channelization; hydrologic modifications and stream instability associated with development (e.g., impervious surfaces); lack of riparian forest; sedimentation from construction, mining, and farming; water supply withdrawals; acid mine drainage; hog farm runoff; other source pollution; dams; and other fish blockages. Mussels are more sensitive to ammonia, copper, and other metals than other aquatic organisms, and current water quality standards may be insufficient for their survival. Mussel presence and diversity indicate clean water. Coal and oil extraction can decrease downstream mussel abundance by 90%. Inadequate water flow or high-volume floods are other key stressors, with drying being the worst. Dam failure or removal can transport trapped sediment downstream and smother mussels.

USFWS (2010) identified four primary factors responsible for the decline of *E. torulosa rangiana* populations: siltation, pollutants, impoundment, and instream sand and gravel mining. Both point and nonpoint sources can degrade water quality, particularly in tributaries with limited capability to dilute and assimilate sewage, agricultural runoff, and other pollutants. Exploration and extraction of coal, oil, and gas resources can alter hydrology, increase siltation, and reduce water quality, even over long distances. Land development near streams often eliminates riparian cover and increases storm water runoff, which combine to increase sedimentation. *Epioblasma* species appear to be exceptionally sensitive to the increased siltation and associated turbidity caused by land conversion. Development has also increased the number of sewage treatment plants in drainages that support northern riffleshell, and increased the amount of sewage discharged from existing plants (USFWS, 2010).

Impoundments alter hydrology and water quality. A variety of instream activities continue to threaten northern riffleshell populations, including sand and gravel dredging, gravel bar removal, bridge construction, and pipeline construction. These can change streambed configuration and result in long-lasting altered flow patterns degrading habitat, often some distance from the disturbance. Zebra mussels may also impact *E. torulosa rangiana*, particularly where northern riffleshell populations and zebra mussel habitat coincide (e.g., pools in large rivers) (USFWS, 2010).

<u>Habitat modeling</u>
Hopkins (2009) compared the distribution of *Quadrula cylindrica*, a freshwater mussel, to environmental variables at multiple scales in the upper Green River system in Kentucky. Variables included land use/land cover pattern and composition, soil composition, and geology, at the subcatchment scale, subcatchment riparian buffer (100 m from the stream), and riparian buffer for a 100m upstream reach. Boosted regression trees found the most influential variables to be patch density at the reach scale and soil composition at the riparian scale.

Terrestrial reserves often protect important freshwater resources where aquatic considerations played a role in site selection. However, there is poor correspondence in many areas. Hydrologic regime, physical habitat, biotic composition, connectivity, and water quality need to be addressed at the watershed level. At the reach level, the material contribution zone, meander belt, active low floodplain, riparian wetlands, high floodplain, and terraces should be considered to maintain natural hydrologic and material transport processes. Aquatic conservation should encompass at least 10 fluvial kilometers, and maintain connectivity to downstream rivers.

We sought to identify suitable habitat for *E. torulosa rangiana* conservation or reintroduction. Our analyses, described below, were limited to coarse-scale variables at the reach and catchment scale. Microhabitat features like stream substrate or submerged vegetation might be inferred by larger scale conditions, but are best measured by field surveys.

Methods

<u>Locational data</u>
We received *E. torulosa rangiana* occurrence data from state Natural Heritage Programs. Some of this data was in point form and some in polygon. Spatial accuracy varied; in many cases only close enough to identify the occurrence stream reach and catchment.

We converted polygon occurrence data to points, selecting centroids, but constraining them to fall within the polygon. We merged records from all states in the NiSource study area. We omitted records with Poor viability (EO rank = "D"), Historical records (H), Failed to find (F), Extirpated (X), records prior to 1990, and subfossils.

To decrease spatial bias, we only selected one occurrence point per NHD+ catchment[29]. Where there was more than one point per catchment, we picked the most viable. If viability was the same, or unrecorded, we picked the most recent record. If records were from the same year, if there were at least 3 clustered points, we selected the middle one. If there were only two points, we picked the one furthest from others.

<u>Reach variables</u>

We obtained streams, stream catchments, and flow data from NHDPlus (Bondelid et al., 2007). The NHD streams were digitized at a 1:100K scale, corresponding to a horizontal accuracy around 50 m. Because of spatial inaccuracies in the data, we did not examine potential relationships at a local (sub-reach) scale. Instead, we focused solely on the reach and catchment scales.

Table 2 lists the variables computed for each NHDPlus stream reach. We obtained surficial geology units and deposit types from Fullerton et al. (2004), compiled at a 1:1M scale. We obtained karst data from Weary (2008), believed accurate within 300 m. We obtained soil permeability from CONUS (Miller and White, 1998), selecting the value for the top layer of soil (0-5 cm; field [L1_PERM]). We obtained land cover from the 2001 National Land Cover Database (U.S. Geological Survey; see Homer et al. 2004). We obtained stream impairment data from the EPA's 303(d) list, selected only current impairments, and lumped the causes into 9 categories. To identify impounded stream reaches, we identified NHD flowlines that intersected NHD lakes, ponds, or reservoirs (not wetlands). We did not see any ponds that intersected flowlines.

Table 2. Variables computed within each NHDPlus catchment.

Variable	**Definition**
CAT_MAFLOWU	Mean Annual Flow - Unit Method (cfs)
CAT_MAVELU	Mean Annual Velocity - Unit Method (fps)
CAT_ELEV_CM	Mean reach elevation – smoothed (cm)
CAT_SLOPE1000	Mean channel slope (mm/m)
RCH_GEO_UNIT	Majority surficial geology unit within 60m of NHD stream reach
RCH_DEP_TYPE	Majority surficial geology deposit type within 60m of NHD stream reach
RCH_P_KARST60	Percent karst geology within 60m of NHD stream reach
RCH_SOILPER60	Mean soil permeability within 60m of NHD stream reach
RCH_PCTFORW60	Percent forest and wetland cover (from 2001 NLCD) within 60m of NHD stream reach
RCH_IMPOUNDED	Reach impounded? (yes/no)
RCH_AMMONIA	Reach listed as impaired for ammonia?
RCH_TOXIC_IMP	Reach listed as impaired for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_TOXIC_2	Reach listed as impaired for ammonia, unknown - fish kills; chlorine; dioxins; fish

[29] We used the Identity tool with occurrence points and NHD+ catchments. The output dataset had a field [FID_catchm] that listed the FID of the NHD+ catchment the point fell within. This tool could only be used on one HUC-2 basin at a time.

	consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_PHYSICAL	Reach listed as impaired for flow alteration; habitat alteration; temperature?
RCH_SEDIMENT	Reach listed as impaired for sediment or turbidity?
RCH_EUTROPHIC	Reach listed as impaired for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens?
RCH_BIOLOGIC	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species?
RCH_BIOLOGIC2	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants?
RCH_OTHER_IMP	Reach listed as impaired for trash or unknown reasons?
RCH_ANYIMPAIR	Reach listed as impaired for any reason? (yes/no)

Catchment variables

In addition to examining parameters at the reach scale, we assessed parameters within each cumulative catchment (i.e., the entire drainage to the end point of each stream reach, not just the subsection adjacent to the reach) using the NHDPlus Catchment Attribute Allocation and Accumulation Tool (CA3T; Horizon Systems Corporation). These included metrics like land cover (1992 and 2001), impervious surface, tree cover, alluvium, karst areas, soil permeability, and length of various stream impairments (Table 3). We defined alluvium as surficial alluvial or glacial deposits of primarily gravel or sand from Fullerton et al. (2004), chosen because of relatively high permeability.

We also calculated a Developed Land Cover Buffered Flowpath Metric: the length in meters of forest or wetland cells that a developed land cover cell flows through to reach the nearest stream; and an Agriculture Buffered Flowpath Metric; the length in meters of forest or wetland cells that an agricultural land cover cell flows through to the nearest stream (also in Table 3). These metrics, which incorporate land cover, topography and hydrology, can represent potential water pollution loads better than simple land use percentages or fixed buffer width metrics (Baker et al., 2006). We summed the inverse buffer width (1 / (buffer flow length in meters + 1)) for agriculture and developed land within each cumulative catchment, representing non-point pollution loading to the stream reach. Table 3 lists the variables computed within each cumulative NHDPlus catchment.

Table 3. Variables computed within each cumulative NHDPlus catchment.

Variable	**Definition**
CAT_AREA_KM2	Cumulative drainage area (km^2)
CAT_IBWA_KM	Cumulative sum of inverse buffer width from agriculture (1 / (buffer flow length in meters + 1))
CAT_IBWD_KM	Cumulative sum of inverse buffer width from developed land (1 / (buffer flow length in meters + 1))
CAT_TREE_HA	Cumulative sum of tree canopy area (ha)
CAT_TREE_PCT	Cumulative mean percent of tree canopy cover
CAT_IMPERV_HA	Cumulative sum of impervious cover area (ha)
CAT_IMPER_PCT	Cumulative mean percent of impervious cover
CAT_KARST_PCT	Cumulative mean percent of karst geology
CAT_LC01AGPCT	Cumulative area-weighted percent of agricultural land, from 2001 NLCD

CAT_LC01DEVPC	Cumulative area-weighted percent of developed land, from 2001 NLCD
CAT_LC01FORPC	Cumulative area-weighted percent of forests and wetlands, from 2001 NLCD
CAT_LC92AGPCT	Cumulative area-weighted percent of agricultural land, from 1992 NLCD
CAT_LC92DEVPC	Cumulative area-weighted percent of developed land, from 1992 NLCD
CAT_LC92FORPC	Cumulative area-weighted percent of forests and wetlands, from 1992 NLCD
CAT_PERGEOPCT	Cumulative percent of surficial alluvium
CAT_PERM_AVG	Cumulative Soil Permeability - Average
CAT_AMMON_KM	Cumulative length of reaches with ammonia impairment (km)
CAT_TOXIC_KM	Cumulative length of reaches with impairment for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_TOXIC2_KM	Cumulative length of reaches with impairment for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_PHYS_KM	Cumulative length of reaches with impairment for flow alteration; habitat alteration; temperature (km)
CAT_SEDIM_KM	Cumulative length of reaches with impairment for sediment or turbidity (km)
CAT_EUTROP_KM	Cumulative length of reaches with impairment for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens (km)
CAT_BIOIMP_KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species (km)
CAT_BIOIMP2KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants (km)
CAT_OTHER_KM	Cumulative length of reaches with impairment for trash or unknown reasons (km)

Spatial allocation of variables – one point per catchment

All variables were converted to a single 30 m grid cell per catchment, at locations of *E. torulosa rangiana* in catchments where these occurred, and at the centroid of catchments without occurrences. We omitted those few centroids that fell outside their catchment.

Spatial allocation of variables – continuous grids

We also prepared variables as continuous grids. To reduce the file size below the Windows computational limits, we resampled all variable grids to 90 m cells. We then converted them to ASCII format for use in Maxent. As before, all variables we calculated at the reach and catchment scale.

To reduce positional errors and spatial bias, we considered stream reaches as the unit of analysis for occurrence data. First, we selected NHD catchments that contained Northern riffleshells, using the locational data described earlier. Next, we identified the centroids of these catchments (using the Feature to Point tool). We ensured that these centroids fell within the catchment, selecting centroids that intersected the riffleshell catchments. One centroid did not intersect a catchment[30], and was removed from further consideration. Finally, we reprojected the remaining centroids to the same coordinate system as the variable grids, used Hawth's Tools to add x-y coordinates, and convert the data to a .csv file.

[30] This catchment was small (0.089 km^2).

Maxent model

Maximum entropy modeling (Maxent) is a machine learning technique that can be used to predict the geographic distribution of animal or plant species or other entities of interest. Maxent (using the program by Dudik et al., 2008) compares a set of samples from a distribution over a defined space, such as recorded locations of a particular species, to a set of features, such as relevant environmental variables, over that same space. Maxent estimates the spatial distribution of the species (i.e., predicts suitable habitat) by assuming nothing about that which is unknown (maximizing entropy) but matching the relationships between recorded occurrences and underlying variables. Unlike other techniques like logistic regression, maximum entropy modeling does not require reliable species absence data, which are rarely available. Maxent can also produce solutions with a small set of observations, although the larger the number of observations, the more accurate model output is likely to be. Also, the environmental variables do not need to be independent.

Output also includes the receiver operating characteristic (ROC) curve, which in this case tells the user how well the model distinguished species occurrences from random locations. The area under the ROC curve (AUC) should be as close to 1.0 as possible; an AUC of 0.5 indicates predictivity no better than random chance. Thresholds can be identified that most efficiently identify potential species habitat (fraction of occurrences included vs. the area selected). Model output also includes estimates of variable importance and graphs of predicted suitability vs. individual variables.

Based on experience with other species and natural communities, we set parameters as follows:

- Output format = logistic
- Use all possible variable relationships (linear, quadratic, product, threshold, and hinge)
- Regularization multiplier = 1
- Maximum number of background points = 10,000
- Add samples to background
- Extrapolate
- Do clamping
- Maximum number of iterations = 500
- Convergence threshold = 0.00001

Spatial Maxent application – one point per catchment

We converted Maxent ASCII output to a point shapefile, using the Raster to Point tool in ArcGIS. We selected the Maxent threshold that captured the highest proportion of known Northern riffleshell occurrences, while including the least number of catchments.

Spatial Maxent application – continuous grids

We converted Maxent ASCII output to a floating point grid:

```
Arc: asciigrid Epioblasma_torulosa_rangiana_avg.asc flt_ETR float
```

We multiplied this by 100 and took the integer value:

```
Grid: ETR_Maxent = int(flt_ETR * 100)
```

We selected the Maxent threshold that captured the highest proportion of known Northern riffleshell occurrences, while including the least area of catchments. Generally, this corresponds to maximum sensitivity plus specificity, but we examined a number of thresholds. We identified the majority[31] Maxent value within each

[31] The 90 m model cells did not overlap catchment polygons exactly.

NHD catchment, using Zonal Statistics as Table. Then, we selected those NHD stream reaches corresponding to Maxent values above the threshold. We also selected NHD stream reaches connecting the above reaches if they had a Maxent value greater than the maximum sensitivity plus specificity threshold.

We compared the length of each stream segment with suitable habitat to the presence of Northern riffleshell. We filtered out sections below the minimum length that contained Northern riffleshell, and thereby identified stream reaches that met both modeled habitat and length thresholds.[32]

Results

Stream reach and catchment statistics

Table 4 compares mean flow, velocity, and slope of stream reaches containing Northern riffleshell to all stream reaches in the Ohio River basin. Stream flow and velocity tended to be higher than average for Northern riffleshell. Table 5 compares the percent of impaired stream reaches, by impairment. No mussels were found in impounded reaches. Mussel presence did not appear to be impacted by 303(d) impairments. Table 6 compares catchment area and land use. Developed land more than tripled between 1992 and 2001 in the Ohio River basin, including catchments containing Northern riffleshell, at the expense of forest and agriculture. Some of this may have been actual land conversion, and some a methodology difference when classifying satellite imagery.

Table 4. Stream reach mean flow, velocity, and slope for Northern riffleshell vs. all catchments in the Ohio River basin.

Stream metric	Mean for stream reaches with N. riffleshell (n=33)	Mean for all stream reaches (n=169,443)
Mean Annual Flow (cfs)	4436	754
Mean Annual Velocity (fps)	1.8	0.9
Mean stream reach slope (%)	0.8	1.5

Table 5. Percent of impaired stream reaches containing Northern riffleshell, by impairment, vs. all catchments in the Ohio River basin.

Stream impairment	% of stream reaches with N. riffleshell (n=33)	% of all stream reaches (n=169,443)
RCH_IMPOUNDED	0	6
RCH_AMMONIA	12	3
RCH_TOXIC_IMP	39	15
RCH_TOXIC_2	39	15
RCH_PHYSICAL	12	12
RCH_SEDIMENT	12	10
RCH_EUTROPHIC	21	17
RCH_BIOLOGIC	0	2

32 We buffered NHD stream reaches meeting the Maxent habitat threshold 0.5 m (i.e., 1 m wide), dissolving overlapping buffers. We separated these shapes using Multipart to Single Part. We calculated the area with Hawth's Tools; this was the same as length in meters. We selected shapes overlapping (within 100 m of, to account for spatial error) Northern riffleshell occurrences, and identified the minimum reach length containing Northern riffleshells. Then we selected all buffer shapes above this threshold (rounded down to one significant digit). Finally, we selected NHD flowlines within these selected reach buffers, and saved this as Northern_riffleshell_modeled_habitat.shp.

RCH_BIOLOGIC2	0	2
RCH_OTHER_IMP	0	6
RCH_ANYIMPAIR	39	26

Table 6. Mean catchment area and land cover metrics for Northern riffleshell vs. all catchments in the Ohio River basin.

Stream metric	**Mean for stream reaches with N. riffleshell (n=33)**	**Mean for all stream reaches (n=169,443)**
CAT_AREA_KM2	6812	1391
CAT_IBWA_KM	442,350	187,986
CAT_IBWD_KM	120,585	54,386
CAT_TREE_HA	413,997	66,362
CAT_TREE_PCT	51	46
CAT_IMPERV_HA	5677	2568
CAT_IMPER_PCT	0.9	1.3
CAT_KARST_PCT	17	26
CAT_LC01AGPCT	32.3	33.0
CAT_LC01DEVPC	5.9	8.2
CAT_LC01FORPC	57.7	55.3
CAT_LC92AGPCT	35.8	37.6
CAT_LC92DEVPC	1.6	2.6
CAT_LC92FORPC	61.8	58.9

Maxent model – one point per catchment
The Maxent model using one point per catchment had an average test AUC for the replicate runs of 0.896.

Table 7 gives a heuristic estimate of relative contributions of the environmental variables that contributed at least 3% to the Maxent model[33]. To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda was negative. Variable contributions should be interpreted with caution.

Table 7. Individual variable contributions to the Maxent model.

Variable	**Percent contribution**
CATPPERGEOPCT	15.1
CATPMAFLOWU	14.1
CATPSEDIM_KM	13.2
CATPMAVELU	9.8
CATPIBWA_KM	7.1
RCHPDEP_TYPE	6.0
RCHPGEO_UNIT	6.0
CATVELEV_CM	4.8

[33] We chose a reporting threshold of 3% because there was a distinct break there between the top variables and the rest.

The environmental variable CATPMAFLOWU had the highest training gain when used in isolation, and therefore appeared to have the most useful information by itself. This was followed by CATPAREA_KM2, CATPTREE_HA, CATPIBWA_KM, CATPIMPERV_HA, CATPMAVELU, and CATPIBWD_KM (gain >1.5). The environmental variable CATPPERGEOPCT decreased the training gain the most when it was omitted, and therefore appeared to have the most information that wasn't present in the other variables. Table 8 lists the values associated with higher probabilities of Northern riffleshell presence, for variables that contributed >3% to the model. Variables were inter-related, and combined in a variety of ways to create the model.

Table 8. Values associated with higher probabilities of Northern riffleshell presence, for variables that contributed >3% to the model.

Variable	Values associated with Northern riffleshell presence
CATPPERGEOPCT	10-40% surficial alluvium
CATPMAFLOWU	On the order of 100,000 cfs
CATPSEDIM_KM	Close to zero; rapid decline as sediment-impaired stream length increased
CATPMAVELU	~2100-2550 fps
CATPIBWA_KM	Close to zero; rapid decline as this increased (i.e., as riparian buffering decreased in agricultural areas)
RCHPDEP_TYPE	Stream reaches through solifluction deposits, glaciofluvial deposits, and glacial outburst-flood deposits
RCHPGEO_UNIT	Outwash deposits, ice-contact deposits, and glacial-lake deposits; loamy solifluction deposits, colluvium, and decomposition residuum; channel and flood-plain alluvium
CATVELEV_CM	~300-350 m

<u>Spatial Maxent application – one point per catchment</u>
Maxent output varied between 0 and 9 (rather than 0 and 1 as is normally the case). Maxent values of 5-9 captured 91% of occurrences, but only 29% of catchments (Table 9).

Table 9. Maxent output for catchments containing Northern riffleshells, vs. all catchments in the Ohio River basin.

Maxent value	# catchments with Northern riffleshells	Cumulative %	total # catchments	Cumulative %
0	0	100%	440	100%
1	1	100%	45035	100%
2	2	97%	25693	69%
3	0	91%	18405	51%
4	0	91%	14338	39%
5	3	91%	11222	29%
6	11	82%	9248	21%
7	4	48%	8123	15%
8	11	36%	7151	9%
9	1	3%	6317	4%

TOTAL	33		145972	

Maxent model – continuous grids

Figure 1 shows mean model output from the Maxent model using continuous grids. This model had an average test AUC for the replicate runs of 0.923.

Table 10 gives a heuristic estimate of relative contributions of the environmental variables that contributed at least 3% to the Maxent model. To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda was negative. Variable contributions should be interpreted with caution.

Table 10. Individual variable contributions to the Maxent model.

Variable	Percent contribution
CATVMAFLOWU	26.8
CATVPERGEOPCT	18.1
RCHVDEP_TYPE	15.1
CATVSEDIM_KM	12.2
CATVELEV_CM	5.3
RCHVGEO_UNIT	4.2
CATVTREE_HA	3.1

The environmental variable CATVMAFLOWU had the highest training gain when used in isolation, and therefore appeared to have the most useful information by itself. This was followed by CATVTREE_HA, CATVAREA_KM2, CATVIMPERV_HA, CATVMAVELU, CATVIBWD_KM, and CATVIBWA_KM (gain >1.5). The environmental variable CATVSLOPE1000 decreased the training gain the most when it was omitted, and therefore appeared to have the most information that wasn't present in the other variables. Table 11 lists the values associated with higher probabilities of Northern riffleshell presence, for variables that contributed >3% to the model. Variables were inter-related, and combined in a variety of ways to create the model.

Table 11. Values associated with higher probabilities of Northern riffleshell presence, for variables that contributed >3% to the model.

Variable	Values associated with Northern riffleshell presence
CATVMAFLOWU	On the order of 100,000 cfs
CATVPERGEOPCT	10-40% surficial alluvium
RCHVDEP_TYPE	Stream reaches through solifluction deposits, glaciofluvial deposits, and glacial outburst-flood deposits
CATVSEDIM_KM	Close to zero; rapid decline as sediment-impaired stream length increased
CATVELEV_CM	~250-350 m
RCHVGEO_UNIT	Outwash deposits, ice-contact deposits, and glacial-lake deposits; loamy solifluction deposits, colluvium, and decomposition residuum; channel and flood-plain alluvium
CATVTREE_HA	~1E6 ha

Spatial Maxent application – continuous grids

The logistic threshold corresponding to maximum test sensitivity plus specificity was 0.1836, which captured 92% of test points, 93% of training points, and 6.89% of area on average (p=0.0013). Other reported Maxent thresholds captured <90% of test points on average, or >30% of area. Comparing Maxent output to Northern riffleshell occurrences, a threshold of 0.41 appeared more parsimonious (Table 12).

Table 12. Maxent values compared to Northern riffleshell occurrences.

Maxent value threshold	Number of Northern riffleshell occurrences within this range	Percent of Northern riffleshell occurrences within this range	Percent of Ohio River basin within this range
>0.40	35	88	0.2
>0.1836	36	90	0.6
All values	40	100	100

We selected all NHD reaches with Maxent values >0.40, and added connecting reaches with values >0.1836. The shortest continuous stream reach with these model values and containing Northern riffleshells was 1.34 km. Most such reaches were >10 km. We selected NHD reaches within stretches of modeled suitable habitat >1 km. These totaled 676 km (0.2% of the Ohio River basin).

Discussion

Based on available survey and environmental data, the Maxent model predicted about 0.2% of the stream reaches in the Ohio River basin to be suitable habitat for *Epioblasma torulosa rangiana*. The upper Allegheny River and French Creek in northwest Pennsylvania contained the majority of modeled habitat, as well as the majority of recorded occurrences. Big Darby Creek in central Ohio, the Tippecanoe River in northern Indiana, and the Olentangy River parallel to Big Darby Creek also had long stretches of modeled habitat (>10 km) and contained known occurrences. Streams with long reaches of modeled habitat (>10 km) but without recorded occurrences included Crooked Creek/Shenango River west of French Creek and Twin Creek in southwest Ohio. There were also a number of short stretches (1-10 km) of modeled habitat.

Stream flow, geology type, and sediment impairment were the top predictive variables. Northern riffleshells preferred large streams and mid-sized rivers, not headwater streams or major rivers such as the Ohio. In general, headwater streams are more prone to drying out than larger streams, and this may be a factor. Geology can influence hydrology and water quality. Alluvial deposits and other permeable geologic formations can increase groundwater flow into streams. Arbuckle and Downing (2002) found that mussel density and species richness are higher in streams with high fractions of alluvial deposits. Such streams are more stable, with greater groundwater recharge and lower surface runoff, especially in agricultural watersheds (Arbuckle and Downing, 2002).

Nicklin and Balas (2007) found that mussel densities >1/m^2 in the middle Allegheny River, PA, were found in largely “optimal” habitat: at sites with >50% instream cover (stable habitat), 0-25% fine sediment surrounding gravel and larger rocks, at least 3 of 4 velocity/depth regimes present (including riffles and pools >0.5m deep), and little to no enlargement of islands or point bars and <10% of the bottom affected by sediment deposition. They found no mussels in poor or marginal physical habitat. A study in the Copper Creek watershed of Virginia (EPA, 2002) found that embeddedness and sedimentation were statistically significant habitat quality measures that affected the abundance and distribution of native mussel and fish species in Copper Creek, and both habitat characteristics were directly related to the amount of agricultural land use in the riparian corridor.

We applied a spatial filter to model output from Maxent, selecting only modeled suitable habitat >1 km. Most suitable stream reaches identified by the model and also containing Northern riffleshells were >10 km. Stream lengths we identified between 1-10 km should be considered less suitable than lengths >10 km. As with terrestrial species, small, isolated areas of habitat may only support small, inbred populations that are doomed to local extinction. Mussel populations are now more widely separated than they were historically, leading to reduced recruitment success and declining populations, especially in the presence of stressors. EPA (2002) suggested maintaining and improving stream habitat and water quality in remaining mussel locations, and allowing populations to expand into nearby areas.

Within stream reaches, microhabitat features like substrate and bank stability may be important factors. The Maxent model applies only at the stream reach and catchment scale; management actions should be preceeded by stream surveys. We hope that the coarse-scale modeling described here can help prioritize more detailed surveys, and also emphasize the importance of catchment-scale geomorphic and land use conditions.

Federally listed species have recovery plans. 80% of all federally listed species rely on ongoing conservation efforts. Most require two or more conservation strategies. Management should not only react to present conditions, but preserve the ability of species to adapt to change, such as global warming. Propagation and culture of endangered mussels is a key component of species recovery, although there are concerns about genetic impacts. Although state and university biologists are likely to know already where the best conditions are, the Maxent model could conceivably help target reintroduction of cultured mussels. Reintroductions should be preceded by field surveys, then pilot testing of survival and recruitment.

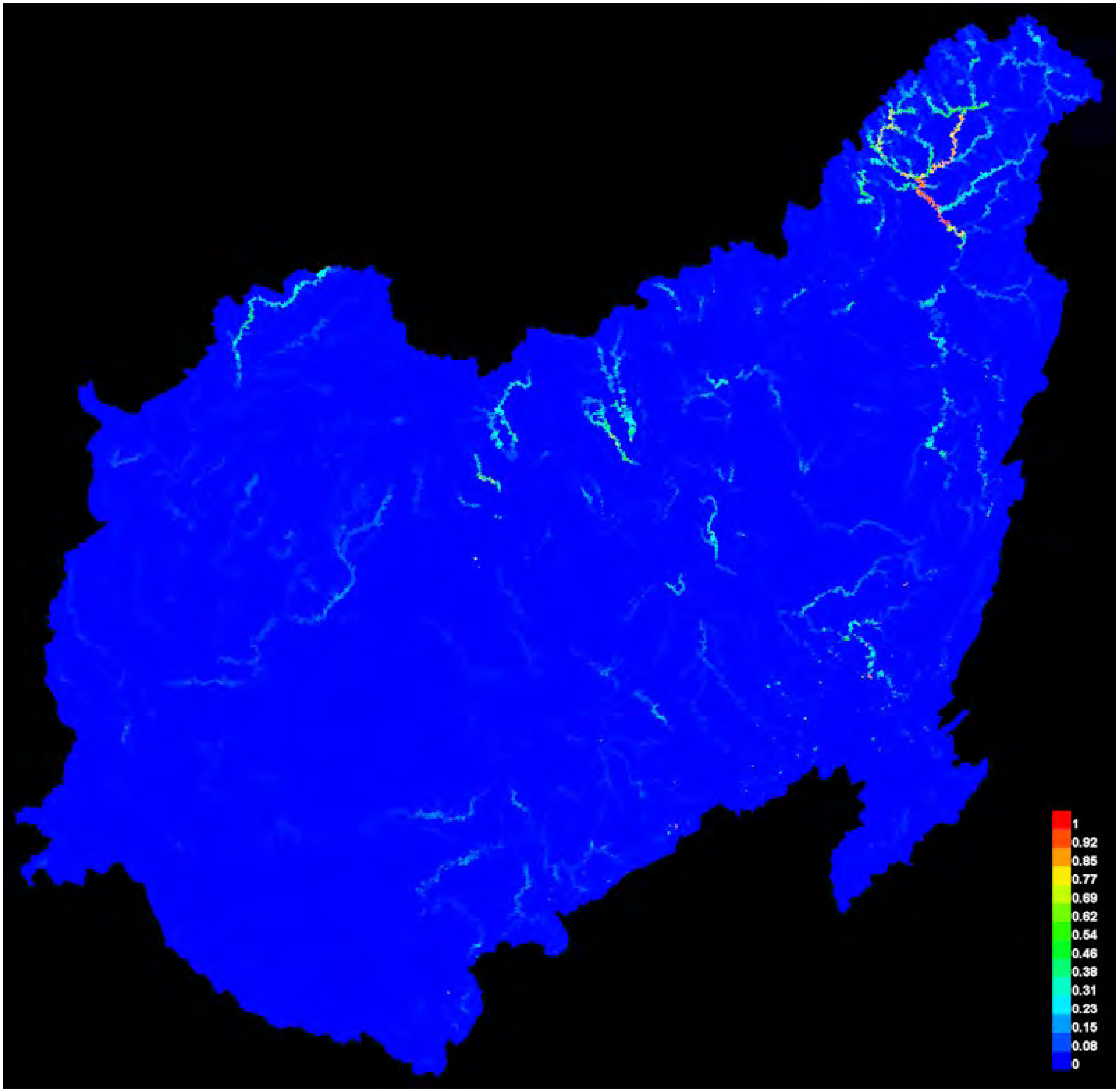

Fig. 1. Maxent output predicting suitable habitat for *Epioblasma torulosa rangiana*

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Coarse-Scale Modeling

Plethobasus Cyphus (Sheepnose) Habitat

(Draft: 12/29/2010)

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Introduction

Overview
The Conservation Fund (TCF) is assisting the US Fish and Wildlife Service (USFWS), NiSource, and 13 affected states (DE, IN, KY, LA, MD, MS, NJ, NY, OH, PA, TN, VA, and WV) to create a multi-species, multi-state habitat conservation plan covering future construction, operation, and maintenance of NiSource natural gas pipelines and ancillary facilities. The sheepnose (*Plethobasus cyphyus*), a federally endangered mussel, is one of the covered species.

North America has the highest diversity of freshwater mussels in the world. Mussels historically occurred in dense multi-species assemblages, and provide important ecosystem functions like sediment stabilization and nutrient cycling. Unfortunately, this taxa is highly imperiled; some 68% of freshwater mussel species are vulnerable, and many have gone extinct.

Habitat requirements
Plethobasus cyphyus was once widely distributed throughout much of the Mississippi River system, but has been extirpated from much of this range, and most of the remaining populations are small and geographically isolated (NatureServe, 2009). *P. cyphyus* is now found in the Mississippi, Ohio, Cumberland, Tennessee, and Ohio main stems, and scores of tributary streams (USFWS, 2010).

Similar to other freshwater mussels, *P. cyphyus* is a filter feeder, siphoning phytoplankton, diatoms, and other microorganisms from the water column (USFWS, 2010). Mussels tend to grow relatively rapidly their first few years until sexual maturity, when energy is diverted to reproduction. Sheepnose are relatively long-lived, living 20 years or more (USFWS, 2010).

Most mussels, including the sheepnose, have separate sexes. Males expel clouds of sperm into the water column, which are drawn in by females through their incurrent siphons. Fertilization takes place internally, and the resulting zygotes develop within the gills into specialized larvae termed glochidia. Glochidia must come into contact with a specific host fish, usually within 24 hours, to survive (USFWS, 2010). Suitable host fish for *P. cyphyus* include, but are probably not limited to, sauger and central stoneroller (NatureServe, 2009).

Glochidia parasitize the fishes' gill tissues for a few weeks; then detach to begin a free-living existence on the stream bottom. This unique method of dispersal allows freshwater mussels to colonize areas upstream as well as downstream. Unless released in suitable habitat, the released glochidia will die (USFWS, 2010). Like other mussels, the sheepnose probably experiences very low annual juvenile survival. A single female's reproductive output is reduced from thousands of glochidia to less than one surviving juvenile per year (USFWS, 2010). Thus, small populations have a high risk of extirpation.

Plethobasus cyphyus. (Photo Dick Biggins, U.S. Fish and Wildlife Service)

Dispersal barriers include climate, drainage divides, dams and other fish barriers, pollution, habitat modification (e.g., channelization), and the lack of suitable host fish. Further, dispersal rates range widely across species. Although mobile or migratory host fish may move long distances, small benthic fish like darters and sculpins may move 30 m or less. The effects of reduced migration rates are especially severe for rare species. Some populations may be functionally extinct, with no possibilities of propagation, or populations too low to persist. The long lifespan of many mussels may mask this "extinction debt" (Strayer, 2008).

Many freshwater mussels are habitat-specific; e.g., some preferring riffles, and some preferring pools. Mussels are most abundant in oxygenated, shallow waters (<2 m) of medium to large rivers and occupy a variety of stable substrates including different combinations of silt, sand, gravel, cobble, and boulders (Pennak, 1989, in Arbuckle and Downing, 2000). Rivers and larger streams, if unimpaired, generally contain more habitat niches and host fish than smaller streams. They are also less likely to dry out than smaller streams. Suitable habitat allows juveniles to settle, has substrate firm enough for support but soft enough for burrowing, is stable during floods, is wet during droughts, delivers food and essential materials (oxygen, calcium, etc.), provides favorable temperatures for growth and reproduction, povides protection from predators, and contains no toxic materials (Strayer, 2008).

Although *P. cyphyus* does inhabit medium-sized rivers, it generally has been considered a large-river species (NatureServe, 2009; USFWS, 2010). According to USFWS (2010), it occurs primarily in shallow shoal habitats with moderate to swift currents over coarse sand and gravel. According to NatureServe (2009), it may be associated with riffles and gravel/cobble substrates but usually has been reported from deep water (>2 m) with slight to swift currents and mud, sand, or gravel bottoms. It also appears capable of surviving in reservoirs (NatureServe, 2009). Specimens in larger rivers may occur in deep runs (NatureServe, 2009; USFWS, 2010).

<u>Threats</u>

Stressors to freshwater mussels include stream channelization; hydrologic modifications and stream instability associated with development (e.g., impervious surfaces); lack of riparian forest; sedimentation from construction, mining, and farming; water supply withdrawals; acid mine drainage; hog farm runoff; other source pollution; dams; and other fish blockages. Mussels are more sensitive to ammonia, copper, and other metals than other aquatic organisms, and current water quality standards may be insufficient for their survival. Mussel presence and diversity indicate clean water. Coal and oil extraction can decrease downstream mussel abundance by 90%. Inadequate water flow or high-volume floods are other key stressors, with drying being the worst. Dam failure or removal can transport trapped sediment downstream and smother mussels.

USFWS (2010) identified the main threats to *P. cyphyus* as impoundments, channelization, chemical contaminants, mining, and sedimentation. Accumulations of sediments ≥0.6 cm could be lethal, and dissolved concentrations ≥600 mg/l could harm individuals (NatureServe, 2009). Most remaining populations are small and isolated, which are vulnerable to extinction (USFWS, 2010).

Habitat modeling

Hopkins (2009) compared the distribution of *Quadrula cylindrica*, a freshwater mussel, to environmental variables at multiple scales in the upper Green River system in Kentucky. Variables included land use/land cover pattern and composition, soil composition, and geology, at the subcatchment scale, subcatchment riparian buffer (100 m from the stream), and riparian buffer for a 100m upstream reach. Boosted regression trees found the most influential variables to be patch density at the reach scale and soil composition at the riparian scale.

Terrestrial reserves often protect important freshwater resources where aquatic considerations played a role in site selection. However, there is poor correspondence in many areas. Hydrologic regime, physical habitat, biotic composition, connectivity, and water quality need to be addressed at the watershed level. At the reach level, the material contribution zone, meander belt, active low floodplain, riparian wetlands, high floodplain, and terraces should be considered to maintain natural hydrologic and material transport processes. Aquatic conservation should encompass at least 10 fluvial kilometers, and maintain connectivity to downstream rivers.

We sought to identify suitable habitat for *P. cyphyus* conservation or reintroduction. Our analyses, described below, were limited to coarse-scale variables at the reach and catchment scale. Microhabitat features like stream substrate or submerged vegetation might be inferred by larger scale conditions, but are best measured by field surveys.

Methods

Locational data

We received *P. cyphyus* occurrence data from state Natural Heritage Programs. Some of this data was in point form and some in polygon. Spatial accuracy varied; in many cases only close enough to identify the occurrence stream reach and catchment.

We converted polygon occurrence data to points, selecting centroids, but constraining them to fall within the polygon. We merged records from all states in the NiSource study area. We omitted records with Poor viability (EO rank = "D"), Historical records (H), Failed to find (F), Extirpated (X), records prior to 1990, and subfossils.

To reduce positional errors and spatial bias, we considered stream reaches as the unit of analysis for occurrence data[34]. First, we selected NHD catchments that contained sheepnose, using the locational data described earlier.

[34] We previously selected one occurrence point per NHD+ catchment. We used the Identity tool with occurrence points and NHD+ catchments. The output dataset had a field [FID_catchm] that listed the FID of the NHD+ catchment the point fell within. This tool could only be used on one HUC-2 basin at a time. Where there was more than one point per catchment, we picked the most viable. If viability was the same, or unrecorded, we picked the most recent record. If records were from

Next, we identified the centroids of these catchments (using the Feature to Point tool). We ensured that these centroids fell within the catchment, selecting centroids that intersected the sheepnose catchments. All centroids met this requirement. Finally, we reprojected the remaining centroids to the same coordinate system as the variable grids, used Hawth's Tools to add x-y coordinates, and convert the data to a .csv file.

Reach variables

We obtained streams, stream catchments, and flow data from NHDPlus (Bondelid et al., 2007). The NHD streams were digitized at a 1:100K scale, corresponding to a horizontal accuracy around 50 m. Because of spatial inaccuracies in the data, we did not examine potential relationships at a local (sub-reach) scale. Instead, we focused solely on the reach and catchment scales.

Table 2 lists the variables computed for each NHDPlus stream reach. We obtained surficial geology units and deposit types from Fullerton et al. (2004), compiled at a 1:1M scale. We obtained karst data from Weary (2008), believed accurate within 300 m. We obtained soil permeability from CONUS (Miller and White, 1998), selecting the value for the top layer of soil (0-5 cm; field [L1_PERM]). We obtained land cover from the 2001 National Land Cover Database (U.S. Geological Survey; see Homer et al. 2004). We obtained stream impairment data from the EPA's 303(d) list, selected only current impairments, and lumped the causes into 9 categories. To identify impounded stream reaches, we identified NHD flowlines that intersected NHD lakes, ponds, or reservoirs (not wetlands). We did not see any ponds that intersected flowlines.

Table 2. Variables computed within each NHDPlus catchment.

Variable	Definition
CAT_MAFLOWU	Mean Annual Flow - Unit Method (cfs)
CAT_MAVELU	Mean Annual Velocity - Unit Method (fps)
CAT_ELEV_CM	Mean reach elevation – smoothed (cm)
CAT_SLOPE1000	Mean channel slope (mm/m)
RCH_GEO_UNIT	Majority surficial geology unit within 60m of NHD stream reach
RCH_DEP_TYPE	Majority surficial geology deposit type within 60m of NHD stream reach
RCH_P_KARST60	Percent karst geology within 60m of NHD stream reach
RCH_SOILPER60	Mean soil permeability within 60m of NHD stream reach
RCH_PCTFORW60	Percent forest and wetland cover (from 2001 NLCD) within 60m of NHD stream reach
RCH_IMPOUNDED	Reach impounded? (yes/no)
RCH_AMMONIA	Reach listed as impaired for ammonia?
RCH_TOXIC_IMP	Reach listed as impaired for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_TOXIC_2	Reach listed as impaired for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics?
RCH_PHYSICAL	Reach listed as impaired for flow alteration; habitat alteration; temperature?

the same year, if there were at least 3 clustered points, we selected the middle one. If there were only two points, we picked the one furthest from others.

RCH_SEDIMENT	Reach listed as impaired for sediment or turbidity?
RCH_EUTROPHIC	Reach listed as impaired for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens?
RCH_BIOLOGIC	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species?
RCH_BIOLOGIC2	Reach listed as impaired for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants?
RCH_OTHER_IMP	Reach listed as impaired for trash or unknown reasons?
RCH_ANYIMPAIR	Reach listed as impaired for any reason? (yes/no)

Catchment variables

In addition to examining parameters at the reach scale, we assessed parameters within each cumulative catchment (i.e., the entire drainage to the end point of each stream reach, not just the subsection adjacent to the reach) using the NHDPlus Catchment Attribute Allocation and Accumulation Tool (CA3T; Horizon Systems Corporation). These included metrics like land cover (1992 and 2001), impervious surface, tree cover, alluvium, karst areas, soil permeability, and length of various stream impairments (Table 3). We defined alluvium as surficial alluvial or glacial deposits of primarily gravel or sand from Fullerton et al. (2004), chosen because of relatively high permeability.

We also calculated a Developed Land Cover Buffered Flowpath Metric: the length in meters of forest or wetland cells that a developed land cover cell flows through to reach the nearest stream; and an Agriculture Buffered Flowpath Metric; the length in meters of forest or wetland cells that an agricultural land cover cell flows through to the nearest stream (also in Table 3). These metrics, which incorporate land cover, topography and hydrology, can represent potential water pollution loads better than simple land use percentages or fixed buffer width metrics (Baker et al., 2006). We summed the inverse buffer width (1 / (buffer flow length in meters + 1)) for agriculture and developed land within each cumulative catchment, representing non-point pollution loading to the stream reach. Table 3 lists the variables computed within each cumulative NHDPlus catchment.

Table 3. Variables computed within each cumulative NHDPlus catchment.

Variable	Definition
CAT_AREA_KM2	Cumulative drainage area (km^2)
CAT_IBWA_KM	Cumulative sum of inverse buffer width from agriculture (1 / (buffer flow length in meters + 1))
CAT_IBWD_KM	Cumulative sum of inverse buffer width from developed land (1 / (buffer flow length in meters + 1))
CAT_TREE_HA	Cumulative sum of tree canopy area (ha)
CAT_TREE_PCT	Cumulative mean percent of tree canopy cover
CAT_IMPERV_HA	Cumulative sum of impervious cover area (ha)
CAT_IMPER_PCT	Cumulative mean percent of impervious cover
CAT_KARST_PCT	Cumulative mean percent of karst geology
CAT_LC01AGPCT	Cumulative area-weighted percent of agricultural land, from 2001 NLCD
CAT_LC01DEVPC	Cumulative area-weighted percent of developed land, from 2001 NLCD
CAT_LC01FORPC	Cumulative area-weighted percent of forests and wetlands, from 2001 NLCD
CAT_LC92AGPCT	Cumulative area-weighted percent of agricultural land, from 1992 NLCD
CAT_LC92DEVPC	Cumulative area-weighted percent of developed land, from 1992 NLCD

CAT_LC92FORPC	Cumulative area-weighted percent of forests and wetlands, from 1992 NLCD
CAT_PERGEOPCT	Cumulative percent of surficial alluvium
CAT_PERM_AVG	Cumulative Soil Permeability - Average
CAT_AMMON_KM	Cumulative length of reaches with ammonia impairment (km)
CAT_TOXIC_KM	Cumulative length of reaches with impairment for unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_TOXIC2_KM	Cumulative length of reaches with impairment for ammonia, unknown - fish kills; chlorine; dioxins; fish consumption advisory; mercury; metals (other than mercury); oil and grease; PCB's; pesticides; pH; radiation; salinity/TDS/sulfates/chlorides; taste, color and odor; total toxicity; toxic inorganics; or toxic organics (km)
CAT_PHYS_KM	Cumulative length of reaches with impairment for flow alteration; habitat alteration; temperature (km)
CAT_SEDIM_KM	Cumulative length of reaches with impairment for sediment or turbidity (km)
CAT_EUTROP_KM	Cumulative length of reaches with impairment for algal growth; noxious aquatic plants; nutrients; organic enrichment/oxygen depletion; pathogens (km)
CAT_BIOIMP_KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species (km)
CAT_BIOIMP2KM	Cumulative length of reaches with impairment for unknown - impaired biota; nuisance exotic species; nuisance native species; noxious aquatic plants (km)
CAT_OTHER_KM	Cumulative length of reaches with impairment for trash or unknown reasons (km)

<u>Spatial allocation of variables</u>

We prepared variables as continuous grids. To reduce the file size below the Windows computational limits, we resampled all variable grids to 90 m cells. We then converted them to ASCII format for use in Maxent. As before, all variables we calculated at the reach and catchment scale.

<u>Maxent model</u>

Maximum entropy modeling (Maxent) is a machine learning technique that can be used to predict the geographic distribution of animal or plant species or other entities of interest. Maxent (using the program by Dudik et al., 2008) compares a set of samples from a distribution over a defined space, such as recorded locations of a particular species, to a set of features, such as relevant environmental variables, over that same space. Maxent estimates the spatial distribution of the species (i.e., predicts suitable habitat) by assuming nothing about that which is unknown (maximizing entropy) but matching the relationships between recorded occurrences and underlying variables. Unlike other techniques like logistic regression, maximum entropy modeling does not require reliable species absence data, which are rarely available. Maxent can also produce solutions with a small set of observations, although the larger the number of observations, the more accurate model output is likely to be. Also, the environmental variables do not need to be independent.

Output also includes the receiver operating characteristic (ROC) curve, which in this case tells the user how well the model distinguished species occurrences from random locations. The area under the ROC curve (AUC) should be as close to 1.0 as possible; an AUC of 0.5 indicates predictivity no better than random chance. Thresholds can be identified that most efficiently identify potential species habitat (fraction of occurrences included vs. the area selected). Model output also includes estimates of variable importance and graphs of predicted suitability vs. individual variables.

Based on experience with other species and natural communities, we set parameters as follows:

- Output format = logistic
- Use all possible variable relationships (linear, quadratic, product, threshold, and hinge)
- Regularization multiplier = 1
- Maximum number of background points = 10,000
- Add samples to background
- Extrapolate
- Do clamping
- Maximum number of iterations = 500
- Convergence threshold = 0.00001

Spatial Maxent application – continuous grids

We converted Maxent ASCII output to a floating point grid:

```
Arc: asciigrid Plethobasus_cyphyus_avg.asc flt_P_cyph float
```

We multiplied this by 100 and took the integer value:

```
Grid: P_cyph_Maxent = int(flt_P_cyph * 100)
```

We selected the Maxent threshold that captured the highest proportion of known sheepnose occurrences, while including the least area of catchments. Generally, this corresponds to maximum sensitivity plus specificity, but we examined a number of thresholds. We identified the majority Maxent value within each NHD catchment.[35] Then, we selected those catchments corresponding to Maxent values above the test maximum sensitivity plus specificity threshold, and grouped these into spatially contiguous sections. From these, we selected those groupings that also contained catchments with Maxent values greater than the most parsimonious threshold.[36]

We then selected the NHD flow lines within those catchments[37], and calculated the length of these contiguous sections using Hawth's Tools[38]. We compared the length of each stream segment with suitable habitat to the presence of sheepnose. We filtered out sections below the minimum length that contained sheepnose, and thereby identified stream reaches that met both modeled habitat and length thresholds.

Results

Maxent model

Figure 1 shows mean model output from the Maxent model for *P. cyphyus* using continuous grids. This model had an average test AUC for the replicate runs of 0.952.

Table 4 gives a heuristic estimate of relative contributions of the environmental variables that contributed at least 3% to the Maxent model.[39] To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if

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[35] We used the majority value because the 90 m model cells did not overlap catchment polygons exactly. We used the tool *Zonal Statistics as Table*.

[36] ArcGIS model *Identify catchments above Maxent thresholds*

[37] ArcGIS model *Identify streams above Maxent thresholds.* This buffered NHD stream reaches meeting the Maxent habitat threshold by 0.5 m (i.e., 1 m wide), dissolving overlapping buffers. We separated these shapes using the Multipart to Single Part tool.

[38] We calculated area with Hawth's Tools in km^2; because the width was 1 m, this was the same as length in km.

[39] We chose a reporting threshold of 3% because there was a distinct break there between the top variables and the rest.

the change to the absolute value of lambda was negative. Variable contributions should be interpreted with caution.

Table 4. Individual variable contributions to the Maxent model.

Variable	Percent contribution
CATVIBWD_KM	33.3
CATVTREE_HA	15.9
CATVPERM_AVG	11.6
RCHVDEP_TYPE	7.1
RCHVP_KARST60	4.6
RCHVIMPOUNDED	4.5
CATVKARST_PCT	3.5

The environmental variable CATVIBWD_KM had the highest training and test gain when used in isolation, and therefore appeared to have the most useful information by itself. This was closely followed by CATVIMPERV_HA, CATVTREE_HA, CATVMAFLOWU, and CATVAREA_KM2 (gain >1.5). The variable RCHVIMPOUNDED decreased the gain the most when it was omitted, and therefore appeared to have the most information that wasn't present in the other variables. Table 5 lists the values associated with higher probabilities of sheepnose presence, for variables that contributed >3% to the model. Variables were inter-related, and combined in a variety of ways to create the model.

Table 5. Values associated with higher probabilities of sheepnose presence, for variables that contributed >3% to the model.

Variable	Values associated with sheepnose presence
CATVIBWD_KM	0 and 4,000-11,000; this was probably a geographic correlation with other variables
CATVTREE_HA	0 and >5E6 ha
CATVPERM_AVG	~60-70 µm/hr
RCHVDEP_TYPE	Primarily sheetwash alluvium and catastrophic glacial outburst-flood deposits; secondarily Eolian deposits and solution residuum
RCHVP_KARST60	Strong peak at 100%
RCHVIMPOUNDED	Unimpounded
CATVKARST_PCT	~50%

<u>Spatial Maxent application – continuous grids</u>

The logistic threshold corresponding to maximum test sensitivity plus specificity was 0.2751, which captured 91% of test points, 94% of training points, and 2.65% of area on average (p<0.001). Other reported Maxent thresholds captured fewer test points on average and, in most cases, more area. Comparing Maxent output to sheepnose occurrences, a threshold of 0.39 appeared more parsimonious (Table 6).

Table 6. Maxent values compared to sheepnose occurrences.

Maxent value threshold	Number of sheepnose occurrences within this range	Percent of sheepnose occurrences within this range	Percent of Ohio and Tennessee basins within this range
>0.39	56	95	0.7
>0.2751	56	95	1.0

All values	59	100	100

We identified all NHD catchments with Maxent values >0.2751, and grouped these into spatially contiguous sections. From these, we selected those groupings that also contained catchments with Maxent values >0.39.[40] We then selected those NHD flow lines within those catchments[41], and calculated the length of these contiguous sections using Hawth's Tools[42]. The shortest continuous stream reach with these model values and containing sheepnoses[43] was 3.3 km. Rounding down to one significant digit, we selected NHD reaches within stretches of modeled suitable habitat[44] >3 km. These totaled 860 km (0.8% of the Ohio and Tennessee River basins). Reaches >10 km were preferable.

Discussion

Based on available survey and environmental data, the Maxent model predicted about 0.8% of the Ohio and Tennessee River basins to be suitable habitat for *Plethobasus cyphyus*. The model included most of the Ohio River. Some of the other long stretches of modeled habitat were in the Allegheny River, Muskingum River, Tippecanoe River, Clinch River, Powell River, Green River, Cumberland River, and an unimpounded section of the Tennessee River. These were all sizeable rivers. There were also a number of shorter stretches of modeled habitat.

Catchment drainage from development, tree area, soil permeability, geology, and stream impoundment were the top predictive variables. The peak values for catchment drainage from development and tree area corresponded to the Ohio River, and were probably correlative rather than causative. Geology can influence hydrology and water quality. Alluvial deposits, karst, and other permeable geologic formations can increase groundwater flow into streams. Arbuckle and Downing (2002) found that mussel density and species richness are higher in streams with high fractions of alluvial deposits. Such streams are more stable, with greater groundwater recharge and lower surface runoff, especially in agricultural watersheds (Arbuckle and Downing, 2002). Lastly, sheepnose were not found in impounded streams, which is consistent with USFWS (2010).

We applied a spatial filter to model output from Maxent, selecting only modeled suitable habitat >3 km. Based on occurrence distribution, contiguous sections >10 km are preferable. As with terrestrial species, small, isolated areas of habitat may only support small, inbred populations that are doomed to local extinction. Mussel populations are now more widely separated than they were historically, leading to reduced recruitment success and declining populations, especially in the presence of stressors. EPA (2002) suggested maintaining and improving stream habitat and water quality in remaining mussel locations, and allowing populations to expand into nearby areas.

Within stream reaches, microhabitat features like substrate and bank stability may be important factors. The Maxent model applies only at the stream reach and catchment scale; management actions should be preceeded by stream surveys. We hope that the coarse-scale modeling described here can help prioritize more detailed surveys, and also emphasize the importance of catchment-scale geomorphic and land use conditions.

[40] ArcGIS model *Identify catchments above Maxent thresholds*
[41] ArcGIS model *Identify streams above Maxent thresholds*
[42] We calculated area with Hawth's Tools in km^2; because the width was 1 m, this was the same as length in km.
[43] We selected features from Maxent_flowline_groups that are within 200 m (to account for spatial error) of Sheepnose_locations_Albers83.
[44] We selected NHD flowlines that had their centroids in the selected reach buffers (Maxent_flowline_groups), and saved these as Sheepnose_modeled_habitat.shp.

Federally listed species have recovery plans. 80% of all federally listed species rely on ongoing conservation efforts. Most require two or more conservation strategies. Management should not only react to present conditions, but preserve the ability of species to adapt to change, such as global warming. Propagation and culture of endangered mussels is a key component of species recovery, although there are concerns about genetic impacts. Although state and university biologists are likely to know already where the best conditions are, the Maxent model could conceivably help target reintroduction of cultured mussels. Reintroductions should be preceded by field surveys, then pilot testing of survival and recruitment.

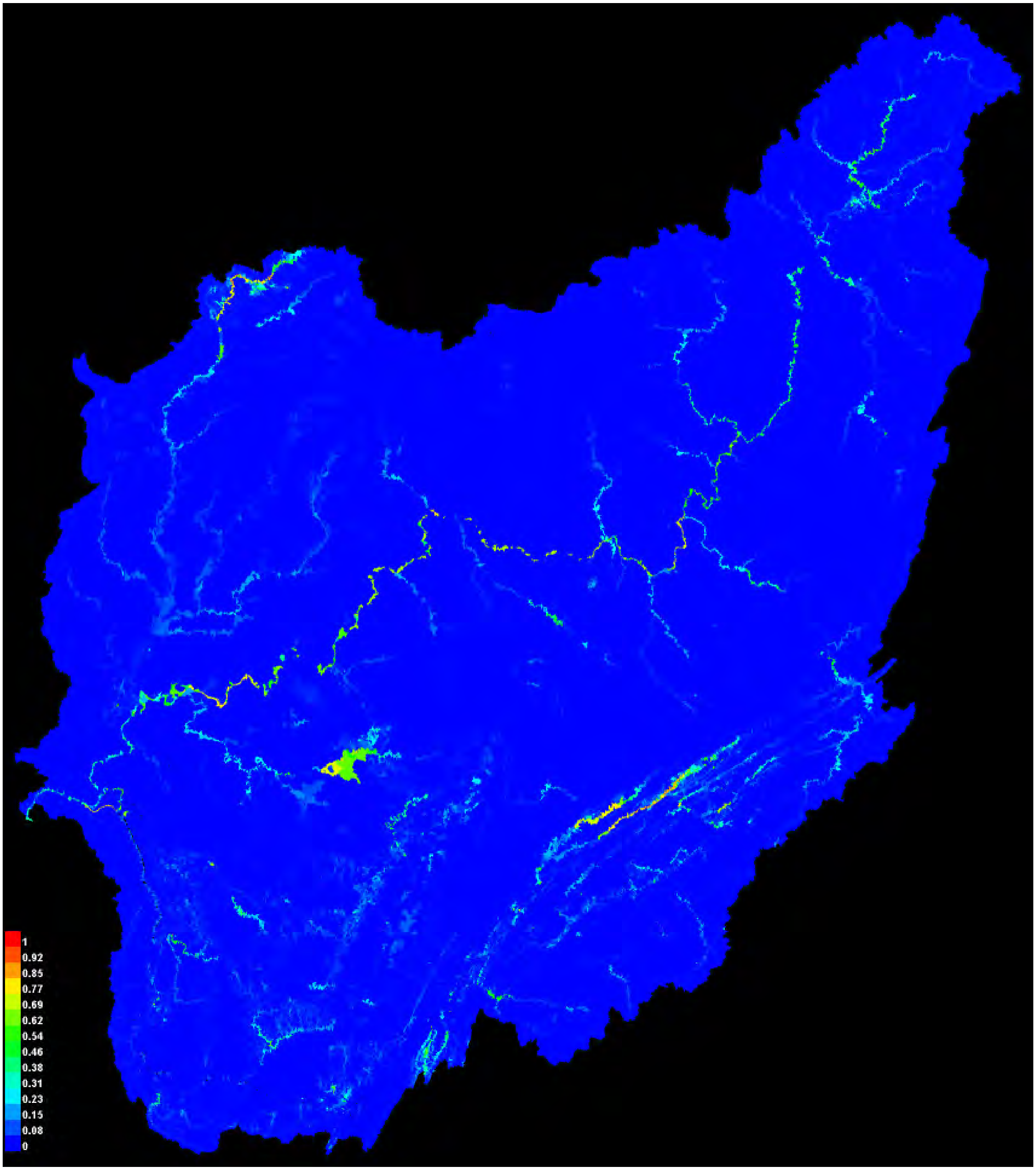

Fig. 1. Maxent output predicting suitable habitat for *Plethobasus cyphyus*

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Clubshell Summary of State Wildlife Action Plans

Indiana

Clubshell (*Pleurobema clava)*

Taxa: Mussel
Clubshell Status:
(CWCS: 29)
Federal Status: Endangered

State Status: Endangered

Species of Greatest Conservation Need (SGCN) in Aquatic Systems

Clubshell Location and Habitat Defined:
(CWCS: 78)
Species of Greatest Conservation Need (SGCN) in Ohio River/E.C.-I.P

Conservation Process – Issues and Actions for the Clubshell:
High Priority Conservation Actions for Ohio River/E.C.-I.P
Protection of adjacent buffer zone

- Promote all public and private initiatives that support the development and maintenance of vegetative (native vegetation) drainage paths and riparian corridors to maintain the ecological heath and ecological function of Ohio River/E.C.-I.P. streams.

Pollution reduction

- Develop and/or distribute BMPs that target pollution reduction to protect Ohio River/E.C.-I.P. aquatic systems that support or could support kidneyshell, little spectaclecase, purple lilliput, rayed bean mussels and wavyrayed lampmussel

Corridor development/protection

- Promote the establishment and protection of vegetated (native vegetation) riparian corridors for all Ohio River/E.C.-I.P. streams to provide suitable habitat for SGCN.

Habitat restoration incentives (financial)

- Support the implementation of existing and the development of new financial incentive programs that promote the use of BMPs for restoration of drainage paths in the Ohio River E.C.-I.P. aquatic systems to provide quality habitat for SGCN dependant on this system.

Habitat protection incentives (financial)

- Support the implementation of existing and the development of new financial incentive programs that promote the use of BMPs to protection drainage paths in the Ohio River E.C.-I.P.

Habitat protection through regulation

- Provide technical assistance (relative to the distribution, life history and ecology of SGCN and their habitat) to regulatory agencies that administer laws and rules to protect habitat.

Habitat restoration through regulation

- Provide technical assistance (relative to the habitat requirements of SGCN) to regulatory agencies that administer laws and rules that seek to avoid, minimize and mitigate habitat loss.

Habitat restoration on public lands

- Employ BMPs and develop new techniques for the restoration of Ohio River/E.C.-I.P. aquatic systems on public lands. Provide demonstration technical assistance opportunities to the public to promote restoration in other areas.

Habitat protection on public lands

- Employ BMPs and develop new techniques for the protection of Ohio River/E.C.-I.P. aquatic systems on public lands. Provide demonstration technical assistance opportunities to the public to promote protection in other areas

Artificial habitat creation (artificial reefs, nesting platforms)

- Create or protect nesting islands for least terns in appropriate areas.

Adaptive Management

- Modify survey and monitoring, research and other conservation actions and activities in response to new information to improve habitat conservation efficiency for SGCN.

Reintroduction (restoration)

- Coordinate with multi-state efforts to develop and implement restoration protocols for the northern riffleshell mussel. (This may be the only viable method of reestablishing this species now thought to be extirpated.)
- Provide for the evaluation of reintroduction efforts for any SGCN.

Habitat protection

- Cooperate with all ongoing efforts to protect the Blue River from all threats (impoundment, siltation, point source and non-point source pollution, etc) for the benefit of the hellbender and other SGCN.
- Promote the protection of clean, rocky riffles that are currently inhabited by gilt, spotted and variegate darters to help maintain their populations.

Limiting contact with pollutants/contaminants

- Maintain up-to-date, accurate records of the location of SGCN to use to avoid and minimize the placement of high risk facilities near sensitive populations.

Translocation to new geographic range

- Investigate the impact of impoundments on the distribution of species and determine the feasibility/necessity of recreating ecological assemblages in appropriate areas.

Population management

- Investigate regulatory processes for protecting the Ohio River muskellunge from take in its native range to support self-sustaining populations of this SGCN

Population enhancement (captive breeding and release)

- Support the development and implementation of practical mussel restoration and evaluation techniques for use in appropriate situations for the restoration of clubshell, rabbitsfoot, round hickorynut, sheepnose and snuffbox, mussel and other mussel species that have very limited distribution in Indiana.
- Support the long-term evaluation of population enhancement activities.

Threats reduction

- Cooperate and support efforts to identify and minimize chemical and physical alteration threats to Ohio River /E.C.-I.P. aquatic systems. Provide technical assistance to help avoid or minimize detrimental impacts to SGCN.

Exotic/invasive species control

- Cooperate with and provide technical assistance to the Aquatic Nuisance Species Program in the detection of invasive, exotic species, species control and control measure evaluation aspects of the program

Regulation of collecting

- Investigate the relationship between mudpuppy harvest and salamander mussel population viability to determine if harvest regulation might be warranted to protect the SGCN mussel.

Adaptive Management

- Modify survey and monitoring, research and other conservation actions and activities in response to new information to improve conservation efficiency for SGCN.

Kentucky

Clubshell (*Pleurobema clava*)

Taxa: Mollusk

Fanshell Status:

Federal Status	Heritage Status	GRank	SRank	GRank (Simplified)	SRank (Simplified)
LE, XN	E	G2	S1	G2	S1

G-Trend: Decreasing

G-Trend Comment: Historically, it was distributed across nine states in the Wabash, Ohio, Kanawha, Kentucky (Danglade 1922), Green, Monongahela, and Alleghany Rivers and their tributaries. Listed as occurring in the St. Peter's River in Minnesota and from Nebraska by Simpson (1914), however these records are probably in error. It is currently known from 12 streams in six states: Tippecanoe River in Indiana; Fish Creek in Ohio and Indiana; West Branch of the St. Josephs River in Ohio and Michigan; Walhonding River in Ohio; East Fork of the West Branch of the St. Josephs River in Michigan; Little Darby Creek in Ohio; French Creek in Pennsylvania and the Elk River in West Virginia. It is extirpated from Alabama, Illinois, Tennessee (U.S. Fish and Wildlife Service) and possibly New York (Strayer and Jirka 1997) (NatureServe 2004).

S-Trend: Decreasing

S-Trend Comment: Sporadic in the Upper Green River.

Clubshell Location and Habitat Defined

Habitat/ Life History: Despite the type locality of Lake Erie (apparently in error), this is a species of to medium-sized rivers and streams. Ortmann (1919) remarked that it was "a rare shell, and never found in great numbers. It is found mostly in sand and fine gravel, and is deeply buried." Hoggarth and Watters have found live individuals completely buried with the posterior shell margin facing up in sand/gravel substrate in riffle/run situations in less than 1.5 feet of water (NatureServe 2004). This seems to be the habitat of choice. Because it buries itself beneath the substrate, it is rarely found alive even in places where it is believed to occur in some numbers (NatureServe 2004). Stansbery (OSU museum curator) believed that various pesticides were at least partially responsible for the overall decrease in the fauna of areas in which P.clava was present. The introduced zebra mussel could also pose a significant threat (NatureServe 2004).

Key Habitat Locations: Upper Green River, where populations seem to be recruiting (Condition: partially supporting).

Guilds: Medium to Large Rivers.

Conservation Process – Issues and Actions for the Clubshell

Aquatic habitat degradation

- Navigational dredging/Commercial dredging. NatureServe 2004
- Construction/Operation of impoundments (migration barrier). NatureServe 2004

Biological/ consumptive uses

- Competition from introduced/invasive or native species. NatureServe 2004
- Isolated populations (low gene flow). NatureServe 2004

Point and non-point source pollution

- Acid mine drainage other coal mining impacts . NatureServe 2004
- Waste water discharge (e.g., sewage treatment). NatureServe 2004
- Agricultural runoff – including fertilizers/animal waste, herbicides, pesticides. NatureServe 2004
- Industrial waste discharge/runoff. NatureServe 2004

Top Conservation Actions for Medium to large Stream Guild

- Work with dam and hydroelectric operators to enhance and protect aquatic Habitat.
- Encourage and assist in using, developing, and implementing Best Management Practices, including revision and evaluation as applied to aquatic systems.
- Financial incentives to protect riparian corridors and watersheds.
- Develop, encourage, and initiate local watershed improvement initiative.
- Develop public aquatic education programs to inform and educate user groups.
- Work with municipalities, industries, and government agencies to reduce physical impacts of non-point and storm water runoff including Total Maximum Daily Loads (TMDL's)
- Develop priorities and technology for reintroducing and enhancing aquatic populations.
- Develop mitigation plan for impacted aquatic systems.

Ohio

Clubshell (*Pleurobema Clava*)

Taxa: Mollusks

Clubshell Status:

State list: Aquatic Species of Greatest Conservation Need (ASGCN)

Clubshell Location, Record Status and Habitat Defined:

(CWCS Section 347 of 980)
Habitat Association: Aquatic

(CWCS 337 of 980)
Species of greatest conservation need - within the Streams and Watersheds Tactical Plan

All species listed as ASGCN are native to Ohio. These species have been drawn from Ohio and federal lists of threatened and endangered species and from species having NatureServe rankings of Vulnerable, Imperiled, or Critically Imperiled for Ohio.

Conservation Process – Issues and Actions for the Clubshell:

For Streams and Watersheds Tactical Plan – See Summary for Sheepnose Mussel

Pennsylvania

Clubshell Mussel

CWCS-Priority Species (6.5 PA Fish and Boat Commission Strategic Plan and the CWCS)
Federal State Wildlife Grants (SWG) Progress for Clubshell:
(CWCS Table 10.7: SWG-Funded Progress with WAP-Priority Species)

SWG-Funded Progress with WAP-Priority Invertebrates	
Mussels	Freshwater Mussel and Fish Assemblage Habitat Use and Spatial Distributions in the French Creek Watershed – SWG ‘02 Assessment and Translocation of Mussel Fauna in the Vicinity of Carter’s Dam on the Conewango Creek - SWG '04 Freshwater Mussel (Bivalvia: Unionidae) Spatial Distributions and Habitat Use in the Navigational Pools of the Allegheny River; A Comparative Study of Two Protocols - SWG '04

Strategies for Promoting Watershed Based Resource Protection related to Clubshell:
(6.5 PA Fish and Boat Commission Strategic Plan and the CWCS)
Aquatic Stewardship
Proactive Commission involvement in reviewing and commenting on permit applications also plays an important role in ensuring the protection of the Commonwealth's aquatic resources. A number of additional focal points have also been identified for improving the Commission's resource conservation efforts.
Strategies for Promoting Watershed Based Resource Protection:

- Enhance existing partnerships with federal, state and local entities including sportsmen's clubs and conservation organizations.
- Continue active enforcement of laws and regulations designed to protect the aquatic resources.
- Establish partnerships with organizations and entities that have a stake or interest in the watersheds of the Commonwealth.

- Communicate and work with the organizations and entities that have an impact on Pennsylvania anglers, boaters and the aquatic environment, which the Commission is entrusted to protect and manage.
- Develop and implement a more comprehensive Adopt-A-Water program.
- Develop effective outreach and education programs to promote watershed-based efforts.

Sustaining Pennsylvania's Nongame Aquatic Resources
The Commission recognizes that nongame aquatic resources are important parts of Pennsylvania's ecology that warrant attention and protection. The Commission will encourage efforts to maintain and restore biological diversity and will give due consideration to this diversity in all resource management decisions. The Commission will work with conservation entities to obtain adequate and sustainable funding to preserve, protect and manage all species and organisms, which the Commission has a mandate to protect.

The large and diverse resource the Commission is charged with managing and protecting includes the Commonwealth's nongame fish, aquatic macro invertebrates, reptiles and amphibians. The PFBC is mandated to protect and manage these species, which play important ecological functions in Commonwealth waters. Due to habitat loss and degradation, however, some of these species may be at risk.

The Commission currently has management jurisdiction over 79 species of concern (endangered, threatened or candidates) including 61 species of fish, 8 species of reptiles, 4 species of amphibians, and 2 species of freshwater mussels. For some species, such as the bog turtle, coastal plain leopard frog, New Jersey chorus frog, northern riffleshell and clubshell mussels and massasauga rattlesnake, the need for increased management attention cannot be overemphasized. Sixty-one species represent 40 percent of the total fish species that exist in Pennsylvania.

Statewide Priority Conservation Actions - CWCS-Priority Species:
(CWCS 10.11 Statewide Priority Conservation Actions – CWCS - Priority Species)
Level 1 – highest priority over the next 1-5 years

- Determine Presence/Absence of Potentially Extirpated Species
- Conduct Species' Status Assessments
- Habitat Assessment and Protection
- Clarification of Genetic Issues
- Ensure Adequate State-level Protection

Level 2 – priority over the next 5-10 years

- Develop Multi-species Management Guidance
- Recovery Planning
- Long-term Monitoring

Statewide Priority Conservation Actions – Streams and Rivers:
(CWCS 15.6 Statewide Priority Conservation Actions – Streams and Rivers)
Level 1 – highest priority over the next 1-5 years

- Identify and Protect Exemplary Sites

- Support Protection of Globally-Significant Watersheds

Level 2 – priority over the next 5-10 years

- Ensure Adequate State Level Protection of Highest-Priority Riparian Habitats
- Support Protection of Critically-Important Fish Habitat
- Enhance and Restore High-Priority Lotic and Riparian Habitats
- Pursue Improved Water Quality of Priority Rivers

The Effect of Habitat Loss and Degradation related to the Clubshell:
(CWCS 11.5 The Effect of Habitat Loss and Degradation on Wildlife)
The most imperiled organisms on earth are the freshwater mussels (Wilcove et al.1998), with 34 percent of Pennsylvania's mussels endangered, threatened or extirpated.

The Importance of Private Lands in Wildlife Conservation related to the Clubshell:
(CWCS 11.7 The Importance of Private Lands in Wildlife Conservation)
The continuation of the Private Landowner Assistance Program is critical to stem the tide of declining species in Pennsylvania. Since the program's creation a little more than a year ago, RDWB's have consulted with private landowners owning more than 25,000 acres. Site-specific management plans focused on forest, wetland, riparian, and grassland habitats have been written for many of these priority properties. The RWDBs also have delivered numerous public presentations related to species of concern management and have assisted in ongoing PGC field projects relating to WAP-priority species: ospreys, northern flying squirrels, bats, Allegheny woodrats, bog turtles, and freshwater mussels.

Management of public lands also will benefit from PLAP as site evaluation tools and best management practices for species/habitats of concern are developed for this program. Conservation partners also benefit as RWDBs provide technical assistance to organizations such as conservancies, other government agencies, and watershed groups interested in managing their lands for species of concern. With further development of PLAP, there is great potential to enhance management of species of concern, thereby limiting the likelihood of these species being listed as endangered and threatened.

Landowner Incentive Program
Funding from the federal Landowner Incentive Program Tier 2 is being used by the PFBC to partner with land trusts and private entities to secure long-term conservation easements on private lands to protect and enhance important habitats for at-risk species. The program's purpose is to support on-the-ground projects that enhance, protect, or restore habitats that benefit at-risk species on private lands. The PFBC provides technical assistance to interested landowners, and evaluates and ranks proposals. High-priority projects benefit multiple at-risk species, have permanent benefits, and involve multiple project partners (Table 11.2).

Tennessee

Clubshell (*Pleurobema clava*)
Taxa: Invertebrate - Bivalve
Clubshell Status:
(Appendix A:8)
Global Ranking: G2
Federal Status:LE

State Status: E

Species of Greatest Conservation Need (SGCN): Tier 3

Widespread in the following regions:
- Cumberland River
- Tennessee River

Clubshell Location and Habitat Defined
(Appendix D)

Cumberland River Drainage
- Large Nashville Basin and Highland Rim River, origin in the Blue Ridge and Ridge and Valley
- Small Highland Rim Rivers, origin in Cumberland Plateau
- Small Highland Rim Rivers, origin in Highland Rim
- Highland Rim Streams
- Outer Highland Rim Steams

Tennessee River Drainage
- Large Ridge and Valley Rivers, origin in Blue Ridge and Ridge and Valley
- Large Nashville Basin and Highland Rim River, origin in the Blue Ridge and Ridge and Valley
- Medium Ridge and Valley River, origin in the Ridge and Valley
- Small ridge and valley rivers, origin in the Cumberland Plateau
- Small highland rim rivers, origin in the Cumberland Plateau
- Small highland rim rivers, origin in the Highland Rim
- Small Coastal Plain rivers, origin in the Highland Rim/Southern Cumberland Plateau
- Ridge and Valley Streams
- Highland Rim Streams
- Outer Highland Rim Streams
- Transitional Streams, coastal plains to Highland Rim
- Coastal Plain Streams

Conservation Process – Issues and Actions for the Clubshell:
(Appendix E: pg 32/44)
Source of Stress:
- Channelization of Rivers/Streams
- Construction of Dams/Impoundment
- Incompatible Row Crop Agricultural Practices
- Industrial Discharge
- Invasive Exotic Species
- Municipal Waterwater Treatment/Stormwater Runoff

(TNCWCS: 154)
Priority Aquatic Conservation Actions by Source of Stress:

All Sources of Stress
- Evaluate standard for review of state & federally-listed GCN species.

- Propose legislation to create dedicated funding for conservation
- Conduct scientific surveys for lesser known GCN species
- Solicit private donations to fund conservation work

Channelization of Rivers/Streams

- Develop strategic alliance with USACE, TVA, water boards, & others
- Propose legislation to expand government funded incentive programs
- Participate in environmental review procedures for construction projects
- Restore in-stream flows to channelized streams.

Construction of Dams/Impoundment

- Develop strategic alliance with USACE, TVA, water boards, & others
- Develop state standards for in-stream flows for GCN species
- Participate in environmental review procedures for construction projects
- Participate in the review of county urban growth management plans

Incompatible Row Crop Agricultural Practices

- Proposed legislation to expand government funded incentive programs.
- Develop strategic alliance with Farm Bureau, NRCS, FSA and others
- Utilize government funded incentive programs for landowners to improve/protect water quality
- Restore pastures, fields, and other agricultural lands

Industrial Discharge

- Evaluate standards for conducting environmental review of projects.
- Develop network of trained aquatic biologists to assist TDEC's monitoring
- Participate in environmental review procedures for construction projects
- Increase compliance monitoring of ARAP and other permits

Invasive Exotic Species

- Propose legislation to restrict import of invasive exotic species to TN
- Develop strategic alliance with USACE, TVA, water boards, & others
- Conduct rapid assessment of priority habitats for invasive exotics
- Implement integrated pest management practices in priority habitat

Municipal Waterwater Treatment/Stormwater Runoff

- Evaluate standards for conducting environmental review of projects
- Develop network of trained aquatic biologists to assist TDEC's monitoring
- Participate in environmental review procedures for construction projects
- Participate in the review of county urban growth management plans

West Virginia

Clubshell (*Pleurobema Clava)*

Taxa: Mussels
(CWCS 5E-Freshwater Mussels 69-72)

Clubshell Location, Record Status and Habitat Defined:
The ranks and information in the chart below indicate the rarity of the Clubshell in West Virginia. It is listed as rare and in need of conservation and its status is monitored by many groups. The Clubshell is listed as an endangered species by the US Fish and Wildlife Service.

Priority Group	Global Rank	State Rank	USFWS	IUCN Rank	CITES	NE Tech Comm	AFS	Trend
1*	G2	S1	LE	CR A1ce	App II	X	E	

The following table places known occurrences of the Clubshell into watersheds and gives site names and the ages of the records (recent is within 20 years). **Habitat:** Medium sized creeks to large flowing rivers. They are typically associated with areas of moderate flow and gravel substrates.

Watershed Site Name Record Type
West Fork River Historic
West Fork
Hackers Creek Recent
Elk River Recent
Historic
Little Kanawha Recent
Historic
Little Kanawha South Fork Hughes Recent
North Fork Hughes Historic
Middle Island Creek Recent
Middle Ohio River Valley Meathouse Fork Recent
Ohio River Historic

Decision Making Process - Needs and Actions for the Clubshell:
Each category discussed in this section is important to the conservation of the Clubshell. Because there is inadequate information on the distribution and status of the Clubshell in West Virginia, the first step in its conservation is to gain a better understanding of its distribution, habitat requirements and status. Needs and actions for each category are outlined below. **Bolded** text indicates primary actions required to identify conservation needs of the Clubshell.

Category	Need	Action
Data	Standardize data collection protocols to allow integration with other data.	**Develop and implement standardized protocols, associated forms, databases, instruction and training.**
	Legacy data from WV specimens.	**Capture museum records from WV specimens.**
	Coordinates.	**Determine coordinates for all current data.**
	Public access to data.	**Publish *Mussels of WV.***
		Provide general mussel data, such as distribution maps, on the internet.

Category	Need	Action
Surveys	Determine status at historic sites.	**A very high percentage of sites are historic. Surveys need to be conducted with priority given to sites with potential habitat and most likely to support the species, as in the Little Kanawha drainage.**
	Determine length of stream occupied at each recent occurrence.	**Conduct surveys and analyze habitat.**
	Survey additional sites.	**Analyze potential habitat statewide to determine new survey areas/sites.**

Category	Need	Action
Monitoring	Long-term monitoring sites.	**Establish long-term monitoring sites to be re-surveyed at least every 5 years.**
	Monitor habitat.	Survey to determine habitat changes and level of habitat impact through use of scour chains and measuring other stream stability parameters; if impacts occur, survey for species.

Category	Need	Action
Research	Life history	Conduct research on all life history aspects and conduct other research as impacts occur.
	Effects of mining, highways, etc.	

Conservation Process – Issues and Actions for the Clubshell:
There are conservation issues associated with the Clubshell and its habitat. This section outlines the issues and the appropriate actions to address the issues. **Bolded** actions are actions for initial implementation. Habitat loss includes effects from housing and commercial development, dam construction, road construction, mining and quarry activities, acid precipitation, utility corridors and sites, and oil and gas drilling. Water quantity and quality issues include stream channel modification, dam construction, wetland draining and filling activities, water use, acid precipitation, acid mine drainage, erosion and sedimentation, chemical pollution, nutrient loads and solid waste.

Issues	Actions
Habitat Loss	**Coordination**, Education, Management
Forest Health	
Water Quantity and Quality	**Education**, Coordination, Management
Over Collection	
Management Conflicts	
Invasive Species	
Damaging Recreation	
Data Protection	**Legislation/Regulation**

Fanshell Summary of State Wildlife Action Plans

Indiana

Fanshell (*Cyprogenia stegaria)*

Taxa: Mussel
Fanshell Status
(CWCS: 29 – listed as eastern fanshell)
Federal Status: Endangered
State Status: Endangered
Species of Greatest Conservation Need (SGCN) in Aquatic Systems.
Fanshell Location and Habitat Defined:
(CWCS: 75)

Conservation Process – Issues and Actions for the Fanshell:
High Priority Conservation Actions for Aquatic Systems

Habitat restoration incentives (financial)
- Promote the retention and development of sloughs, oxbows, and backwater habitats to benefit the banded pygmy sunfish, bantam sunfish and cypress darter in the lower Wabash River drainage.

Protection of adjacent buffer zone
- Promote the establishment and maintenance of buffers on all aquatic systems to control sedimentation and to benefit aquatic SGCN, especially the blue spotted salamander, four-toed salamander, and plains leopard frog, ellipse, swamp lymnaea, bigmouth shiner and pallid shiner.
- Provide grassy, shrubby, and/or woody riparian cover along rivers and streams for resting, denning, and loafing sites for otters.

Habitat restoration on public lands
- Create nesting islands for least terns in appropriate areas.
- Restore wetland habitats in floodplain areas to provide alternative habitats for aquatic species. Target wetlands in close proximity to rivers & streams.

Cooperative land management agreements (conservation easements)
- Promote the protection of aquatic systems for SGCN by encouraging public and private entities to enter into cooperative land management agreements and conservation easements. Provide technical assistance on the species that benefit from such protection and potential enhancement measures.

Habitat protection on public lands
- Protect nesting and foraging areas from human disturbance in order to ensure successful nesting and foraging by bald eagles, osprey, peregrine falcons, least terns, black terns, and piping plovers (potential).
- Conserve existing riparian cover along rivers & streams to provide habitat for otters.

Habitat protection incentives (financial)
- Provide technical assistance and support the use of state, federal and private incentive programs to protect aquatic habitat for the benefit of SGCN.

Managing water regimes

- Ensure appropriate water regime targets are selected in manipulated headwater streams, especially headwater streams occupied by redside dace.

Pollution reduction

- Work with state, federal and private partners to reduce point and non-point source pollution in aquatic systems to maintain and increase the distribution of the fat pocketbook, western sand darter, northern madtom and channel darter populations in the lower Wabash, White and Ohio Rivers where they are now confined.
- Maintain healthy fish and aquatic invertebrate populations with low contaminant loads in order to provide food for bald eagles, osprey, least terns, black terns, piping plovers, trumpeter swans, and other aquatic birds and species that prey on aquatic systems dependent birds such as peregrine falcons and bald eagles.
- Develop/support programs that reduce input of heavy metals, PCBs, and related contaminants into aquatic systems to benefit river otters and other SGCN.

Restrict public access and disturbance

- Develop and distribute BMPs relative to avoiding and minimizing disturbance to reptile hibernating areas (backwaters, small pools and shallow inlets to lakes and rivers) to promote the conservation of SGCN found in aquatic systems.
- Protect nesting and foraging areas from human disturbance in order to ensure successful nesting and foraging by bald eagles, osprey, peregrine falcons, least terns, black terns, and piping plovers (potential).

Corridor development/protection

- Promote the development and adoption of BMPs to protect aquatic systems shorelines and riparian corridors to minimize eutrophication to benefit pointed campeloma populations and other SGCN.

Adaptive Management

- Modify survey and monitoring, research and other conservation actions and activities in response to new information to improve habitat conservation efficiency for SGCN.

Reintroduction (restoration)

- Support the development and implementation of practical mussel restoration and evaluation techniques for use in appropriate situations for the restoration of extirpated or nearly extirpated mussel species i.e. longsolid, orangefoot pimpleback, pink mucket, pyramid pigtoe, rough pigtoe, tubercled blossom, white catspaw and white wartyback
- Monitor the abundance and distribution of newly restored aquatic system dependent species such as the river otter and osprey.

Population management

- Determine factors affecting the distribution and relative abundance of rare aquatic-based wildlife such as the river otter.
- Refine and improve survey and monitoring programs for aquatic wildlife species such as river otters, mussel species and osprey.
- Implement harvest strategies (season dates, trap set techniques, etc) to maximize take of targeted species and minimize unintentional take of otters.
- Determine age-specific reproductive parameters for river otters and mussel species.

Translocation to new geographic range

- Support the development of technical assistance materials to heighten public awareness of the dangers of releasing aquatic species in new geographical areas (even SGCN).
- Track shifts in species geographic range for correlation to global warming trends and new ecological relationships.

Protection of migration routes

- Protect shoreline areas from high human use along Lake Michigan for migrating piping plovers.
- Secure and appropriately manage sufficient aquatic areas to provide for the needs of self-sustaining populations of migrating birds.

Habitat protection

- Support programs that promote clean water and maintenance of a diverse aquatic ecosystem for the benefit of reptile and amphibian SGCN.
- Identify and secure critical spawning grounds for greater redhorse, lake sturgeon, northern brook lamprey and Tippecanoe darter to ensure maintenance of self sustaining populations.
- Develop and/or support programs that restore/maintain riparian cover along rivers and streams for the benefit of mussels and other aquatic SGCN.

Culling/selective removal

- Monitor the health of hellbenders and other aquatic SGCN and evaluate the use of selective removal of infected individuals to control the spread of contagious disease.

Threats reduction

- Cooperate with other programs to evaluate threats (contamination, gravel mining, dams, etc) to aquatic systems and provide information on impacts to SGCN.
  Native predator control
- Evaluate the use of muskrat and raccoon control in sensitive areas (where populations of SGCN are known to occur) to promote the survival and reproduction of SGCN, especially nesting turtles and mussels.
- Employ effective and appropriate predator deterrents in near least tern nesting colonies and similar vulnerable concentrations of SGCN.

Adaptive Management

- Modify survey and monitoring, research and other conservation actions and activities in response to new information to improve conservation efficiency form SGCN.

Kentucky

Fanshell (*Cyprogenia stegaria*)

Taxa: Mollusk

Fanshell Status:

Federal Status	Heritage Status	GRank	SRank	GRank (Simplified)	SRank (Simplified)
LE	E	G1	S1	G1	S1

G-Trend: Decreasing

G-Trend Comment: Historically, it was widely distributed in the Tennessee, Cumberland, and Ohio River systems, although it has become very rare in recent years. In the Ohio drainage it has been recently found in: the deep channel of the Ohio River between Cincinnati and Pittsburgh (Johnson 1980); the lower Muskingum and Walhonding Rivers, Ohio (Stansbery et al. 1982); the Salt and Licking Rivers, tributaries of the Ohio; the Green River, Kentucky (Biggins 1991) the Kanawha River, West Virginia (Stansbery, pers. comm.); the Allegheny River, Pennsylvania (Dennis 1970); and the lower Clinch River in Scott County Neves 1991, Smith 1971, NatureServe 2004).

S-Trend: Decreasing

S-Trend Comment: Generally distributed in the Licking, Rolling Fork (Salt River) and Upper Green Rivers, sporadic elsewhere (Cicerello and Schuster 2003).

Fanshell Location and Habitat Defined:

Habitat/Life History: Characteristic habitat is medium to large streams (Dennis 1984). It has been found in river habitats with gravel substrates and a strong current, in both deep and shallow water (Ortmann 1919; Parmalee 1967).
Key Habitat Locations (and their condition):1. Lower to Middle Licking River 2. Rolling Fork of Salt River 3. Upper Green River.

Guilds: Medium to large Streams

Statewide Map: fanshell.pdg

Conservation Process – Issues and Actions for the Fanshell

Aquatic habitat degradation:

- Construction/Operation of impoundments (migration barrier)
- Alteration of surface runoff patterns (flow/temp regimes)
- Biological/ consumptive uses
- Competition from introduced/invasive or native species

Point and non-point source pollution

- Waste water discharge (e.g., sewage treatment)
- Agricultural runoff – including fertilizers/animal waste, herbicides,
- Industrial waste discharge/runoff

Siltation and increased turbidity

- Agriculture

Top conservation actions for medium to large stream guild

- Work with dam and hydroelectric operators to enhance and protect aquatic habitat.
- Encourage and assist in using, developing, and implementing Best Management Practices, including revision and evaluation as applied to aquatic systems.
- Financial incentives to protect riparian corridors and watersheds.
- Develop, encourage, and initiate local watershed improvement initiative.
- Develop public aquatic education programs to inform and educate user groups.

- Work with municipalities, industries, and government agencies to reduce physical impacts of non-point and storm water runoff including Total Maximum Daily Loads (TMDL's)
- Develop priorities and technology for reintroducing and enhancing aquatic populations.
- Develop mitigation plan for impacted aquatic systems.

Ohio

Fanshell (*Cyprogenia Stegaria*)

Taxa: Taxa: Mollusks

Fanshell Status:
State list: Aquatic Species of Greatest Conservation Need (ASGCN)

Fanshell Location, Record Status and Habitat Defined:
(CWCS Section 347 of 980)
Habitat Association: Aquatic

(CWCS 337 of 980)
Species of greatest conservation need - within the Streams and Watersheds Tactical Plan

All species listed as ASGCN are native to Ohio. These species have been drawn from Ohio and federal lists of threatened and endangered species and from species having NatureServe rankings of Vulnerable, Imperiled, or Critically Imperiled for Ohio.

Conservation Process – Issues and Actions for the Fanshell:

For Streams and Watersheds Tactical Plan – See Summary for Sheepnose Mussel

Tennessee

Fanshell, *Cyprogenia stegaria*

Taxa: Mollusk
Fanshell Status
State list: Endangered
State Rank: Tier 1

Fanshell Location and Habitat Defined

Description of Essential Habitat
The fanshell is found in medium to large rivers and is associated with coarse sand and gravel substrates (Ortmann 1919; Ahlstedt 1984; Dennis 1985). It occurs in both shoals and riffles with strong current. The DGIF aquatic habitat classification was used to examine patterns in habitat use and distribution. In the

Clinch-Powell watershed, this species is found in two habitat types, very low gradient small rivers and large streams (Table 9.20).

Table 9.20. DGIF aquatic habitat types used by the fanshell in the Clinch-Powell watershed.

Aquatic Habitat Type	*Number of Reaches*
Very low gradient small river connected to another small river	12
Very low gradient large stream connected to another large stream	3

Relative Condition of Habitat

The recovery plan for the fanshell describes some issues related to past and current conditions of its habitat (USFWS 1991). The stretch of known fanshell habitat in this EDU is downstream of Stock Creek, which is considered impaired (DEQ and DCR 2004). The impairment designation is due to fish tissue contamination with PCBs from unknown sources.

Specific Threats and Trends

Historic declines of the fanshell have been caused by the impacts of impoundments, pollution, and habitat alteration (USFWS 1991). These stresses may have affected the fanshell both directly and indirectly (through the loss of its fish host). Lipford (1991) identified the degradation of water quality from a variety of sources as the greatest current threat to the species. The recovery plan also indicated that small population size is a serious threat to the viability of the species (USFWS 1991).

Mussel TAC (2004) did not identify any specific threats to the fanshell. However, they identified several threats to the Clinch and Powell drainages (Appendix H).

-

Conservation Process- Issues and Actions for the Fanshell

Lipford (1991) makes several recommendations for the recovery of the fanshell. Specific conservation actions include protecting and restoring the habitat of the species, improving water quality in the Clinch River, and implementing and enforcing BMPs for forestry and agriculture. The USFWS recovery plan also lists conservation actions as well as research and monitoring needs for the fanshell (USFWS 1991). The highest priority actions include utilizing existing legislation and regulations to protect species and its habitat and developing techniques and appropriate sites for reintroduction. Mussel TAC (2004) identified a suite of conservation actions for the Clinch and Powell drainages (Appendix I), but nothing specific to the fanshell.

Research and Monitoring Needs

Because so little is known of the fanshell, some research projects are critically needed to protect this species. One is to conduct needed species management and recovery research, including determining habitat requirements, life history and biology, and threats analysis (Lipford 1991; USFWS 1991). The second is to search for additional populations and appropriate habitat. Lipford (1991) also recommends expanding water quality monitoring stations in the Clinch River. Identification of its fish hosts may also be important. Mussel TAC (2004) identified several research or monitoring needs for the Clinch and Powell drainages (Appendix J). They did not identify anything specific to the fanshell.

West Virginia

<u>Fanshell (*Cyprogenia Stegaria)*</u>

Taxa: Mussels
5E-Freshwater Mussels 24-27

Fanshell Location, Record Status and Habitat Defined:
The ranks and information in the chart below indicate the rarity of the Fanshell in West Virginia. It is listed as rare and in need of conservation and its status is monitored by many groups. The Fanshell is listed as endangered with the US Fish and Wildlife Service.

Priority Group	Global Rank	State Rank	USFWS	Jeff Forest	IUCN Rank	NE Tech Comm	AFS	Trend
1*	G1	S1	LE	X	CR A1ce	X	E	Unknown

The following table places known occurrences of Fanshells in watersheds and gives the site names and ages of the records (recent is within 20 years).

Habitat: This species prefers large rivers and is typically found in areas of good current.
Watershed Site Name Record Type
Middle Ohio River Valley Ohio River Recent
Historic
Upper Kanawha Kanawha River Recent

Decision Making Process - Needs and Actions for the Fanshell:
Each category discussed in this section is important to the conservation of the Fanshell. Because there is inadequate information on the distribution and status of the Fanshell in West Virginia, the first step in its conservation is to gain a better understanding of its distribution, habitat requirements and status. Needs and actions for each category are outlined below. **Bolded** text indicates primary actions required to identify conservation needs of the Fanshell.

Category	Need	Action
Data	Standardize data collection protocols to allow integration with other data.	**Develop and implement standardized protocols, associated forms, databases, instruction and training.**
	Legacy data.	**Capture museum records for all WV specimens.**
	Coordinates.	**Determine coordinates for current data.**
	Public access to data.	**Publish *Mussels of WV*.**
		Provide general mussel data, such as distribution maps, on the internet.

Category	Need	Action
Surveys	Length of stream occupied at each recent occurrence needs to be determined.	**Conduct surveys and analyze habitat.**
	New and historic sites need to be surveyed.	**Revisit historic sites and conduct new surveys on sites along known river systems and their tributaries.**

Category	Need	Action
Monitoring	Long-term monitoring sites.	**Establish long-term monitoring sites to be resurveyed at least every 5 years.**
	Monitor habitat.	Visit site to determine habitat changes and level of habitat impact through use of scour chains. Measure other stream stability parameters. If impacts occur, survey for species.

Category	Need	Action
Research	Life history.	Conduct research on all life history aspects and conduct other research as impacts occur.
	Effects of mining, highways, etc.	

Conservation Process – Issues and Actions for the Fanshell:
There are conservation issues associated with the Fanshell and its habitat. This section outlines the issues and the appropriate actions to address the issues. **Bolded** actions are actions for initial implementation. Habitat loss includes effects from housing and commercial development, dam construction, road construction, mining and quarry activities, acid precipitation, utility corridors and sites, and oil and gas drilling. Water quantity and quality issues include stream channel modification, dam construction, wetland draining and filling activities, water use, acid precipitation, acid mine drainage, erosion and sedimentation, chemical pollution, nutrient loads and solid waste.

Issues	Actions
Habitat Loss	**Propagation, Coordination,** Education, Management
Forest Health	
Water Quantity and Quality	**Education**, Coordination, Management
Over Collection	
Management Conflicts	
Invasive Species	**Education**, Management
Damaging Recreation	
Data Protection	**Legislation/Regulation**

James Spiny Mussel Summary of State Wildlife Action Plan

Virginia

<u>James Spinymussel (*Pleurobema Collina)*</u>

Taxa: Mollusk
James Spinymussel Status:
(Chapter 5)
State list: Endangered

State Rank: Tier 1

James Spinymussel Location and Habitat Defined:
Chapter 5 — The Southern Appalachian Piedmont
Chapter 6 — The Blue Ridge Mountains
Chapter 7 — The Northern Ridge and Valley

Description of Essential Habitat
This species is found in unpolluted, well-oxygenated, second and third order streams of moderate hardness (CaCO > 50mg/l). It is found in runs with moderate current and with a sand, gravel, and cobble substrate (Clarke and Neves 1984). Streams containing James spinymussel range from 0.3 to 2m deep and 1 to 20m wide (Hove 1990). They seem to prefer bottom sediments of sand and cobble, with or without boulders, pebbles or silt. They are usually buried in the substrate near stagnant riffle-run flows (Hove 1990).

Extirpated populations may have occurred in larger rivers with sandy bottoms. This species was once more widely distributed throughout the James River drainage and has been significantly reduced to approximately 5-10% of its historic distribution (B. T. Watson, DGIF, pers. comm.). Neither its historic nor its current distribution in the Dan River is known. Determining the location of potential habitat was based upon the DGIF habitat classification attributes in the Dan River locations only. The DGIF aquatic habitat classification was also used to identify the diversity of habitat types used by the James spinymussel and to assess patterns of distribution (Table 5.18). Only five reaches have been identified thus far as containing this mussel. They are all small streams of low or very low gradient. However, because of the lack of information on this species in this drainage, it is difficult to thoroughly discuss its habitat preferences.

(Table 5.18)
DGIF Aquatic habitat types used by the James spinymussel in the Piedmont-Roanoke EDU.

Aquatic Habitat Type	*Number of Reaches*
Very low gradient small stream connected to another small stream	3
Low gradient small stream connected to another small stream	1
Very low gradient small stream connected to a large stream	1

The DGIF aquatic habitat classification was used to identify the habitat types used by this species and to assess patterns of distribution (Table 6.36). It has been found in six habitat types. All are small to large-sized streams with very low to low gradient.

(Table 6.36)
DGIF aquatic habitat types used by James spinymussel in the Blue Ridge-James EDU.

Aquatic Habitat Type	*Number of Reaches*
Very low gradient small streams connected to other small streams	5
Very low gradient small streams connected to large streams	4
Low gradient small streams connected to other small streams	3
Low gradient large streams connected to other large streams	2
Very low gradient large streams connected to other large streams	1
Low gradient small streams connected to large streams	1

(Table 7.68)
Aquatic habitat types used by the James spinymussel in the Ridge and Valley-James EDU.

Aquatic Habitat Type	*Number of Reaches*
Very low gradient small stream connected to another small stream	7
Low gradient small stream connected to another small stream	7
Very low gradient large stream connected to another large stream	5
Very low gradient small river connected to another small river	5
Moderate gradient small stream connected to another small stream	2
Low gradient small stream connected to a small river	1
Low gradient large stream connected to another large stream	1
Very low gradient small river connected to a large river	1
Very low gradient large river connected to another large river	1
Low gradient large river connected to another large river	1

Conservation Process – Issues and Actions for the James Spinymussel:
Chapter 5 — The Southern Appalachian Piedmont

The recovery plan for the James spinymussel identified two initial conservation actions: investigation of specific threats such as siltation, pesticides, municipal and industrial effluents, and Asian clam interactions; and assessment of projects that pose potentially negative effects on the species or its habitat (USFWS 1990). Following the implementation and assessment of these actions and monitoring actions listed below, other secondary actions should be undertaken: implement methods to control Asian clams; implement appropriate protection strategies as identified; and re-establish populations as appropriate.

Mussel TAC (2004) identified conservation actions specific to the threats outlined above (in no particular order):

- Dam removal and/or installation of fish passage for necessary fish host migration and habitat restoration
- Stormwater management
- More efficient use of water
- Education of regional and county planning administrators
- Education of homeowners regarding the use of fertilizers and pesticides (especially molluscicides)

- Work with VDOT to develop possible solutions to salt application and subsequent runoff
- Implementation of appropriate best management practices for agriculture and stormwater management
- Augment population where possible
- Increase hazardous materials response to spills
- Improve enforcement of existing water quality and permitting regulations

Research and Monitoring Needs:
The recovery plan for the James spinymussel identified the following research or monitoring needs: determination of essential habitat; threats monitoring; life history and ecology studies to establish the feasibility and methods to re-introduce this species to its historic range; and monitoring of existing and introduced populations (USFWS 1990). Mussel TAC (2004) listed other research needs tied to stress reduction. These include: researching and subsequently implementing minimum flow requirements; investigating the amount of sediment reduction needed to see a positive effect on mussel community; researching the impacts of biocide runoff from residents, investigating the toxicity of creosote contamination from wood bridges and road salts.

Northern Riffleshell Summary of State Wildlife Action Plans

Indiana

Northern Riffleshell (*Epioblasma torulosa rangiana)*

Taxa: Mussel
Northern Riffleshell Status:
(CWCS: 30)
Federal Status: Endangered

State Status: Endangered

Species of Greatest Conservation Need (SGCN) in Aquatic Systems

Northern Riffleshell Location and Habitat Defined:
(CWCS: 78)
Species of Greatest Conservation Need (SGCN) in Ohio River/E.C.-I.P

Conservation Process – Issues and Actions for the Northern Riffleshell:
High Priority Conservation Actions for Ohio River/E.C.-I.P
Protection of adjacent buffer zone

- Promote all public and private initiatives that support the development and maintenance of vegetative (native vegetation) drainage paths and riparian corridors to maintain the ecological heath and ecological function of Ohio River/E.C.-I.P. streams.

Pollution reduction

- Develop and/or distribute BMPs that target pollution reduction to protect Ohio River/E.C.-I.P. aquatic systems that support or could support kidneyshell, little spectaclecase, purple lilliput, rayed bean mussels and wavyrayed lampmussel

Corridor development/protection

- Promote the establishment and protection of vegetated (native vegetation) riparian corridors for all Ohio River/E.C.-I.P. streams to provide suitable habitat for SGCN.

Habitat restoration incentives (financial)

- Support the implementation of existing and the development of new financial incentive programs that promote the use of BMPs for restoration of drainage paths in the Ohio River E.C.-I.P. aquatic systems to provide quality habitat for SGCN dependent on this system.

Habitat protection incentives (financial)

- Support the implementation of existing and the development of new financial incentive programs that promote the use of BMPs to protection drainage paths in the Ohio River E.C.-I.P.

Habitat protection through regulation

- Provide technical assistance (relative to the distribution, life history and ecology of SGCN and their habitat) to regulatory agencies that administer laws and rules to protect habitat.

Habitat restoration through regulation

- Provide technical assistance (relative to the habitat requirements of SGCN) to regulatory agencies that administer laws and rules that seek to avoid, minimize and mitigate habitat loss.

Habitat restoration on public lands

- Employ BMPs and develop new techniques for the restoration of Ohio River/E.C.-I.P. aquatic systems on public lands. Provide demonstration technical assistance opportunities to the public to promote restoration in other areas.

Habitat protection on public lands

- Employ BMPs and develop new techniques for the protection of Ohio River/E.C.-I.P. aquatic systems on public lands. Provide demonstration technical assistance opportunities to the public to promote protection in other areas

Artificial habitat creation (artificial reefs, nesting platforms)

- Create or protect nesting islands for least terns in appropriate areas.

Adaptive Management

- Modify survey and monitoring, research and other conservation actions and activities in response to new information to improve habitat conservation efficiency for SGCN.

Reintroduction (restoration)

- Coordinate with multi-state efforts to develop and implement restoration protocols for the northern riffleshell mussel. (This may be the only viable method of reestablishing this species now thought to be extirpated.)
- Provide for the evaluation of reintroduction efforts for any SGCN.

Habitat protection

- Cooperate with all ongoing efforts to protect the Blue River from all threats (impoundment, siltation, point source and non-point source pollution, etc) for the benefit of the hellbender and other SGCN.
- Promote the protection of clean, rocky riffles that are currently inhabited by gilt, spotted and variegate darters to help maintain their populations.

Limiting contact with pollutants/contaminants

- Maintain up-to-date, accurate records of the location of SGCN to use to avoid and minimize the placement of high risk facilities near sensitive populations.

Translocation to new geographic range

- Investigate the impact of impoundments on the distribution of species and determine the feasibility/necessity of recreating ecological assemblages in appropriate areas.

Population management

- Investigate regulatory processes for protecting the Ohio River muskellunge from take in its native range to support self-sustaining populations of this SGCN

Population enhancement (captive breeding and release)

- Support the development and implementation of practical mussel restoration and evaluation techniques for use in appropriate situations for the restoration of clubshell, rabbitsfoot, round hickorynut, sheepnose and snuffbox, mussel and other mussel species that have very limited distribution in Indiana.
- Support the long-term evaluation of population enhancement activities.

Threats reduction

- Cooperate and support efforts to identify and minimize chemical and physical alteration threats to Ohio River /E.C.-I.P. aquatic systems. Provide technical assistance to help avoid or minimize detrimental impacts to SGCN.

Exotic/invasive species control

- Cooperate with and provide technical assistance to the Aquatic Nuisance Species Program in the detection of invasive, exotic species, species control and control measure evaluation aspects of the program

Regulation of collecting

- Investigate the relationship between mudpuppy harvest and salamander mussel population viability to determine if harvest regulation might be warranted to protect the SGCN mussel.

Adaptive Management

- Modify survey and monitoring, research and other conservation actions and activities in response to new information to improve conservation efficiency for SGCN.

Kentucky

Northern Riffleshell (***Epioblasma torulosa rangiana)***

Federal Status	Heritage Status	GRank	SRank	GRank (Simplified)	SRank (Simplified)
LE	E	G2T2	S1	G2	S1

G-Trend: Decreasing

G-Trend Comment: Historically occurred throughout much of the Ohio River watershed but range has been dramatically reduced to eight to ten populations scattered over four states and one province with only three that are considered viable (NatureServe 2004). The species has experienced greater than a 95% range reduction (U.S. Fish and Wildlife Service 1993; Staton et al. 2000)). The northern riffleshell was listed as a federally endangered species in February of 1993. It was also considered to be Endangered by the freshwater mussel subcommittee of the endangered species committee of the American Fisheries Society (Williams et al. 1993). In the Midwest, the northern riffleshell was widely distributed and relatively common in some of the headwater streams in the Wabash and Ohio River drainages. Endangered in Indiana, Michigan, and Ohio. Extirpated from Illinois. See Staton et al. (2000) for trend information. Global Inventory Needs: Historical records exist from the Mahoning and Little Mahoning rivers in Ohio and Pennsylvania and may still harbor populations and should be investigated. Additional work needs to be done on the Tippecanoe River in Indiana, the Elk River in West Virginia, and the Green River in Kentucky where fresh-dead shells have been found in recent years (Watters 1994). An inventory of existing museum records should be compiled to provide information on historical sites and potential new ones.

S-Trend: Decreasing

S-Trend Comment : Possibly extirpated. Formerly in the Ohio and Green River to the Licking River.

Northern Riffleshell Location and Habitat Defined:

Habitat Life History: Small to large rivers in sand and gravel (Cicerello and Schuster 2003). Ortmann (1919:334) reported that this species was "always found...on riffles, on a bottom of firmly packed and rather fine gravel, in swiftly flowing, shallow water or coarse gravel" and Clarke (1981) gave its habitat as "highly oxygenated riffle". Preferred habitat appears to require swiftly moving water. Lowered dissolved oxygen content and elevated ammonia levels (frequently associated with agricultural runoff and sewage discharge) have been shown to be lethal to some species of freshwater naiads (Horne and McIntosh 1979). Dredging of streams has an immediate effect on existing populations by physically removing and destroying individuals.

Key Habitat Locations (and their condition): Possibly extirpated. Green River in Hart County (Condition: fully supporting (80%) in the Green River).

Guilds: Medium to large streams.

Conservation Process – Issues and Actions for Northern Riffleshell
Aquatic habitat degradation

- Navigational dredging/Commercial dredging
- Gravel/sand removal or quarrying (e.g., mineral excavation)
- Construction/Operation of impoundments (migration barrier)

Biological/ consumptive uses

- Competition from introduced/invasive or native species
- Incidental mortality due to commercial fishing/musseling (mortality and over harvest)

Point and non-point source pollution

- Waste water discharge (e.g., sewage treatment)
- Agricultural runoff – including fertilizers/animal waste, herbicides,
- Industrial waste discharge/runoff

Siltation and increased turbidity

- Agriculture
- Road construction
- Urbanization/Development General Construction

Top Conservation Actions for Medium to Large Stream Guild

- Work with dam and hydroelectric operators to enhance and protect aquatic habitat.
- Encourage and assist in using, developing, and implementing Best Management Practices, including revision and evaluation as applied to aquatic systems.
- Financial incentives to protect riparian corridors and watersheds.
- Develop, encourage, and initiate local watershed improvement initiative.
- Develop public aquatic education programs to inform and educate user groups.
- Work with municipalities, industries, and government agencies to reduce physical impacts of non-point and storm water runoff including Total Maximum Daily Loads (TMDL's)
- Develop priorities and technology for reintroducing and enhancing aquatic populations.
- Develop mitigation plan for impacted aquatic systems.

Ohio

Northern Riffleshell (*Epioblasma Torulosa Rangiana*)

Taxa: Taxa: Mollusks

Northern Riffleshell Status:
State list: Aquatic Species of Greatest Conservation Need (ASGCN)

Northern Riffleshell Location, Record Status and Habitat Defined:
(CWCS Section 347 of 980)

Habitat Association: Aquatic

(CWCS 337 of 980)
Species of greatest conservation need - within the Streams and Watersheds Tactical Plan

All species listed as ASGCN are native to Ohio. These species have been drawn from Ohio and federal lists of threatened and endangered species and from species having NatureServe rankings of Vulnerable, Imperiled, or Critically Imperiled for Ohio.

Conservation Process – Issues and Actions for the Northern Riffleshell:

For Streams and Watersheds Tactical Plan – See Summary for Sheepnose Mussel

Pennsylvania

Clubshell Mussels and Northern Riffleshell

CWCS-Priority Species (6.5 PA Fish and Boat Commission Strategic Plan and the CWCS)
Federal State Wildlife Grants (SWG) Progress for Northern Riffleshell:
(CWCS Table 10.7: SWG-Funded Progress with WAP-Priority Species)

SWG-Funded Progress with WAP-Priority Invertebrates	
Mussels	Freshwater Mussel and Fish Assemblage Habitat Use and Spatial Distributions in the French Creek Watershed – SWG ‘02 Assessment and Translocation of Mussel Fauna in the Vicinity of Carter’s Dam on the Conewango Creek - SWG '04 Freshwater Mussel (Bivalvia: Unionidae) Spatial Distributions and Habitat Use in the Navigational Pools of the Allegheny River; A Comparative Study of Two Protocols - SWG '04

Strategies for Promoting Watershed Based Resource Protection related to Northern Riffleshell:
(6.5 PA Fish and Boat Commission Strategic Plan and the CWCS)
Aquatic Stewardship
Proactive Commission involvement in reviewing and commenting on permit applications also plays an important role in ensuring the protection of the Commonwealth's aquatic resources. A number of additional focal points have also been identified for improving the Commission's resource conservation efforts.

Strategies for Promoting Watershed Based Resource Protection:

- Enhance existing partnerships with federal, state and local entities including sportsmen's clubs and conservation organizations.
- Continue active enforcement of laws and regulations designed to protect the aquatic resources.
- Establish partnerships with organizations and entities that have a stake or interest in the watersheds of the Commonwealth.

- Communicate and work with the organizations and entities that have an impact on Pennsylvania anglers, boaters and the aquatic environment, which the Commission is entrusted to protect and manage.
- Develop and implement a more comprehensive Adopt-A-Water program.
- Develop effective outreach and education programs to promote watershed-based efforts.

Sustaining Pennsylvania's Nongame Aquatic Resources

The Commission recognizes that nongame aquatic resources are important parts of Pennsylvania's ecology that warrant attention and protection. The Commission will encourage efforts to maintain and restore biological diversity and will give due consideration to this diversity in all resource management decisions. The Commission will work with conservation entities to obtain adequate and sustainable funding to preserve, protect and manage all species and organisms, which the Commission has a mandate to protect.

The large and diverse resource the Commission is charged with managing and protecting includes the Commonwealth's nongame fish, aquatic macro invertebrates, reptiles and amphibians. The PFBC is mandated to protect and manage these species, which play important ecological functions in Commonwealth waters. Due to habitat loss and degradation, however, some of these species may be at risk.

The Commission currently has management jurisdiction over 79 species of concern (endangered, threatened or candidates) including 61 species of fish, 8 species of reptiles, 4 species of amphibians, and 2 species of freshwater mussels. For some species, such as the bog turtle, coastal plain leopard frog, New Jersey chorus frog, northern riffleshell and clubshell mussels and massasauga rattlesnake, the need for increased management attention cannot be overemphasized. Sixty-one species represent 40 percent of the total fish species that exist in Pennsylvania.

Statewide Priority Conservation Actions - CWCS-Priority Species:

(CWCS 10.11 Statewide Priority Conservation Actions – CWCS - Priority Species)

Level 1 – highest priority over the next 1-5 years

- Determine Presence/Absence of Potentially Extirpated Species
- Conduct Species' Status Assessments
- Habitat Assessment and Protection
- Clarification of Genetic Issues
- Ensure Adequate State-level Protection

Level 2 – priority over the next 5-10 years

- Develop Multi-species Management Guidance
- Recovery Planning
- Long-term Monitoring

Statewide Priority Conservation Actions – Streams and Rivers:

(CWCS 15.6 Statewide Priority Conservation Actions – Streams and Rivers)

Level 1 – highest priority over the next 1-5 years

- Identify and Protect Exemplary Sites

- Support Protection of Globally-Significant Watersheds

Level 2 – priority over the next 5-10 years

- Ensure Adequate State Level Protection of Highest-Priority Riparian Habitats
- Support Protection of Critically-Important Fish Habitat
- Enhance and Restore High-Priority Lotic and Riparian Habitats
- Pursue Improved Water Quality of Priority Rivers

The Effect of Habitat Loss and Degradation related to Northern Riffleshell:
(CWCS 11.5 The Effect of Habitat Loss and Degradation on Wildlife)
The most imperiled organisms on earth are the freshwater mussels (Wilcove et al.1998), with 34 percent of Pennsylvania's mussels endangered, threatened or extirpated.

The Importance of Private Lands in Wildlife Conservation related to Northern Riffleshell:
(CWCS 11.7 The Importance of Private Lands in Wildlife Conservation)
The continuation of the Private Landowner Assistance Program is critical to stem the tide of declining species in Pennsylvania. Since the program's creation a little more than a year ago, RDWB's have consulted with private landowners owning more than 25,000 acres. Site-specific management plans focused on forest, wetland, riparian, and grassland habitats have been written for many of these priority properties. The RWDBs also have delivered numerous public presentations related to species of concern management and have assisted in ongoing PGC field projects relating to WAP-priority species: ospreys, northern flying squirrels, bats, Allegheny woodrats, bog turtles, and freshwater mussels.

Management of public lands also will benefit from PLAP as site evaluation tools and best management practices for species/habitats of concern are developed for this program. Conservation partners also benefit as RWDBs provide technical assistance to organizations such as conservancies, other government agencies, and watershed groups interested in managing their lands for species of concern. With further development of PLAP, there is great potential to enhance management of species of concern, thereby limiting the likelihood of these species being listed as endangered and threatened.

Landowner Incentive Program
Funding from the federal Landowner Incentive Program Tier 2 is being used by the PFBC to partner with land trusts and private entities to secure long-term conservation easements on private lands to protect and enhance important habitats for at-risk species. The program's purpose is to support on-the-ground projects that enhance, protect, or restore habitats that benefit at-risk species on private lands. The PFBC provides technical assistance to interested landowners, and evaluates and ranks proposals. High-priority projects benefit multiple at-risk species, have permanent benefits, and involve multiple project partners (Table 11.2).

West Virginia

Northern Riffleshell (*Epioblasma Torulosa Rangiana)*

Taxa: Mussels
(CWCS 5E-Freshwater Mussels-39)

Fanshell Location, Record Status and Habitat Defined:

The ranks and information in the chart below indicate the rarity of the Northern Riffleshell in West Virginia. It is listed as rare and in need of conservation and its status is monitored by many groups. The Northern Riffleshell is listed as endangered by the US Fish and Wildlife Service.

Priority Group	Global Rank	State Rank	USFWS	CITES	NE Tech Comm	AFS	Trend
1*	G2T2	S1	LE	App II	X	E	Unknown

The following table places known occurrences of the Northern Riffleshell into watersheds and gives the site names and ages of the records (recent is within 20 years).

Habitat: The Northern Riffleshell prefers riffles in medium to large rivers.
Watershed Site Name Record Type
West Fork West Fork River Historic
Upper Kanawha Kanwaha River Historic
Elk Elk River Recent

Decision Making Process - Needs and Actions for the Northern Riffleshell:
Each category discussed in this section is important to the conservation of the Northern Riffleshell. Because there is inadequate information on the distribution and status of the Northern Riffleshell in West Virginia, the first step in its conservation is to gain a better understanding of its distribution, habitat requirements and status. Needs and actions for each category are outlined below. **Bolded** text indicates primary actions required to identify conservation needs of the Northern Riffleshell.

Category	Need	Action
Data	Standardize data collection protocols to allow integration with other data.	**Develop and implement standardized protocols, associated forms, databases, instruction and training.**
	Legacy data.	**Capture museum records for all WV specimens.**
	Coordinates.	**Determine coordinates for current data.**
	Public access to data.	**Publish *Mussels of WV*.**
		Provide general mussel data, such as distribution maps, on the internet.

Category	Need	Action
Surveys	Status at historic sites needs to be determined.	**Conduct surveys in the Upper Kanawha River.**
	Length of stream occupied at each recent occurrence needs to be determined.	Conduct surveys and analyze habitat.
	New and historic sites need to be surveyed.	Revisit historic sites and conduct new surveys on sites along known river systems and their tributaries. Priority will be given to Upper Kanawha River.

Category	Need	Action
Monitoring	Long-term monitoring sites.	Only two individuals have been found in recent years, if a new population is found, set-up long term monitoring site.

Category	Need	Action
Research	Life history.	Conduct research on all life history aspects and conduct other research as impacts occur.
	Effects of mining, highways, etc.	

Conservation Process – Issues and Actions for the Northern Riffleshell:
There are conservation issues associated with the Northern Riffleshell and its habitat. This section outlines the issues and the appropriate actions to address the issues. **Bolded** actions are actions for initial implementation. Habitat loss includes effects from housing and commercial development, dam construction, road construction, mining and quarry activities, acid precipitation, utility corridors and sites, and oil and gas drilling. Water quantity and quality issues include stream channel modification, dam construction, wetland draining and filling activities, water use, acid precipitation, acid mine drainage, erosion and sedimentation, chemical pollution, nutrient loads and solid waste.

Issues	Actions
Habitat Loss	**Propagation, Coordination**, Education, Management
Forest Health	
Water Quantity and Quality	**Education**, Coordination, Management
Over Collection	
Management Conflicts	
Invasive Species	
Damaging Recreation	
Data Protection	**Legislation/Regulation**

Sheepnose Summary of State Wildlife Action Plans

Indiana

Sheepnose (*Plethobasus Cyphyus)*

Taxa: Mussel
Sheepnose Status:
(CWCS: 31)
Federal Status: Candidate for Federal listing

State Status: Endangered

Species of Greatest Conservation Need (SGCN) in Aquatic Systems

Sheepnose Location and Habitat Defined:
(CWCS: 78)
Species of Greatest Conservation Need (SGCN) in Ohio River/E.C.-I.P

Conservation Process – Issues and Actions for the Sheepnose:
High Priority Conservation Actions for Ohio River/E.C.-I.P
Protection of adjacent buffer zone

- Promote all public and private initiatives that support the development and maintenance of vegetative (native vegetation) drainage paths and riparian corridors to maintain the ecological heath and ecological function of Ohio River/E.C.-I.P. streams.

Pollution reduction

- Develop and/or distribute BMPs that target pollution reduction to protect Ohio River/E.C.-I.P. aquatic systems that support or could support kidneyshell, little spectaclecase, purple lilliput, rayed bean mussels and wavyrayed lampmussel

Corridor development/protection

- Promote the establishment and protection of vegetated (native vegetation) riparian corridors for all Ohio River/E.C.-I.P. streams to provide suitable habitat for SGCN.

Habitat restoration incentives (financial)

- Support the implementation of existing and the development of new financial incentive programs that promote the use of BMPs for restoration of drainage paths in the Ohio River E.C.-I.P. aquatic systems to provide quality habitat for SGCN dependent on this system.

Habitat protection incentives (financial)

- Support the implementation of existing and the development of new financial incentive programs that promote the use of BMPs to protection drainage paths in the Ohio River E.C.-I.P.

Habitat protection through regulation

- Provide technical assistance (relative to the distribution, life history and ecology of SGCN and their habitat) to regulatory agencies that administer laws and rules to protect habitat.

Habitat restoration through regulation

- Provide technical assistance (relative to the habitat requirements of SGCN) to regulatory agencies that administer laws and rules that seek to avoid, minimize and mitigate habitat loss.

Habitat restoration on public lands

- Employ BMPs and develop new techniques for the restoration of Ohio River/E.C.-I.P. aquatic systems on public lands. Provide demonstration technical assistance opportunities to the public to promote restoration in other areas.

Habitat protection on public lands

- Employ BMPs and develop new techniques for the protection of Ohio River/E.C.-I.P. aquatic systems on public lands. Provide demonstration technical assistance opportunities to the public to promote protection in other areas

Artificial habitat creation (artificial reefs, nesting platforms)

- Create or protect nesting islands for least terns in appropriate areas.

Adaptive Management

- Modify survey and monitoring, research and other conservation actions and activities in response to new information to improve habitat conservation efficiency for SGCN.

Reintroduction (restoration)

- Coordinate with multi-state efforts to develop and implement restoration protocols for the northern riffleshell mussel. (This may be the only viable method of reestablishing this species now thought to be extirpated.)
- Provide for the evaluation of reintroduction efforts for any SGCN.

Habitat protection

- Cooperate with all ongoing efforts to protect the Blue River from all threats (impoundment, siltation, point source and non-point source pollution, etc) for the benefit of the hellbender and other SGCN.
- Promote the protection of clean, rocky riffles that are currently inhabited by gilt, spotted and variegate darters to help maintain their populations.

Limiting contact with pollutants/contaminants

- Maintain up-to-date, accurate records of the location of SGCN to use to avoid and minimize the placement of high risk facilities near sensitive populations.

Translocation to new geographic range

- Investigate the impact of impoundments on the distribution of species and determine the feasibility/necessity of recreating ecological assemblages in appropriate areas.

Population management

- Investigate regulatory processes for protecting the Ohio River muskellunge from take in its native range to support self-sustaining populations of this SGCN

Population enhancement (captive breeding and release)

- Support the development and implementation of practical mussel restoration and evaluation techniques for use in appropriate situations for the restoration of clubshell, rabbitsfoot, round hickorynut, sheepnose and snuffbox, mussel and other mussel species that have very limited distribution in Indiana.
- Support the long-term evaluation of population enhancement activities.

Threats reduction

- Cooperate and support efforts to identify and minimize chemical and physical alteration threats to Ohio River /E.C.-I.P. aquatic systems. Provide technical assistance to help avoid or minimize detrimental impacts to SGCN.

Exotic/invasive species control

- Cooperate with and provide technical assistance to the Aquatic Nuisance Species Program in the detection of invasive, exotic species, species control and control measure evaluation aspects of the program

Regulation of collecting

- Investigate the relationship between mudpuppy harvest and salamander mussel population viability to determine if harvest regulation might be warranted to protect the SGCN mussel.

Adaptive Management

- Modify survey and monitoring, research and other conservation actions and activities in response to new information to improve conservation efficiency for SGCN.

Kentucky

<u>Sheepnose (*Plethobasus Cyphyus*)</u>

Taxa: Mollusk

Sheepnose Status:

Federal Status	Heritage Status	GRank (Simplified)	SRank	GRank	SRank (Simplified)
N	E	G3	S1	G3	S1

G-Trend: Decreasing

G-Trend Comment: Historically occurred throughout much of the Mississippi River system wit the exception of the upper Missouri River system and most lowland tributaries in the lower Mississippi River system. Known from 77 streams historically in 15 states in the Mississippi, Ohio, Cumberland, Tennessee, and Ohio main stems, and scores of tributary streams rangewide.

S-Trend: Decreasing

S-Trend Comment: Sporadic nearly statewide.

Sheepnose Location and Habitat Defined:

Habitat/Life History: Although it does inhabit medium-sized rivers, this mussel generally has been considered a large-river species. It may be associated with riffles and gravel/cobble substrates but usually has been reported from deep water (>2 m) with slight to swift currents and mud, sand, or gravel bottoms. It also appears capable of surviving in reservoirs, such as upper Chickamauga Reservoir immediately below Watts Bar Dam. This species is critically imperiled throughout all of its range.

Key Habitat Locations (and their condition): Green River from Mammoth Cave upstream to Hart County (Condition: fully supporting).

Guilds: Large rivers in current.

Statewide Map: Sheepnose.pdf

Conservation Process – Issues and Actions for the Sheepnose:

Aquatic Habitat Degradation:

- Navigational dredging/Commercial dredging
- Gravel/sand removal or quarrying (e.g., mineral excavation)
- Construction/Operation of impoundments (migration barrier)
- Stream channelization/ditching

Point and Non-point Source Pollution:

- Waste water discharge (e.g., sewage treatment)
- Toxic chemical spills
- Agricultural runoff – including fertilizers/animal waste, herbicides,
- Urban runoff
- Chemical spills and contaminants (applied and accidental)

Siltation and Increased Turbidity:

- Agriculture

Top Conservation Actions for Large Rivers in Current:

- Work with dam and hydroelectric operators to enhance and protect aquatic habitat.
- Encourage and assist in using, developing, and implementing Best Management Practices, including revision and evaluation as applied to aquatic systems.
- Financial incentives to protect riparian corridors and watersheds.
- Develop public aquatic education programs to inform and educate user groups.
- Develop, encourage, and initiate local watershed improvement initiative.
- Work with municipalities, industries, and government agencies to reduce physical impacts of non-point and storm water runoff including Total Maximum Daily Loads (TMDL's)
- Develop mitigation plan for impacted aquatic systems.
- Develop priorities and technology for reintroducing and enhancing aquatic populations.

Mississippi

Sheepnose Mussel (*Plethobasus Cyphyus*)
Taxa: Mollusk

Sheepnose Mussel Status:
(Chapter 2:40)
State list: Endangered

State Rank: Critically imperiled in Mississippi because of extreme rarity or because of some factor(s) making it vulnerable to extirpation.

Tier 1 - Species that are in need of immediate conservation action and/or research because of extreme rarity, restricted distribution, unknown or decreasing population trends, specialized habitat needs and/or habitat vulnerability. Some species may be considered critically imperiled and at risk of extinction/extirpation.

Sheepnose Mussel Location and Habitat Defined:
(Appendix 8:379)(Chapter 3:68)
Mississippi River Alluvial Plain Ecoregion:

- Agriculture Fields, Hay and Pasture Lands, Old Fields,

- Prairies, Cedar Glades and Pine Plantations
- Bottomland Hardwood Forests
- Riverfront Forests/Herblands/Sandbars
- Inland Freshwater Marshes
- Swamp Forests
- Lacustrine Communities
- Streams
- Urban and Suburban Lands

Conservation Process – Issues and Actions for the Sheepnose Mussel:
(Appendix 13: 401)
The following is a preliminary prioritized (high, medium, low) list of species related research and survey recommendations compiled from expert surveys:
PLETHOBASUS CYPHYUS (SHEEPNOSE)
HIGH Additional survey work: surveys in large Delta rivers (e.g.Coldwater)

(Chapter 5:308-309)
Lotic and Lentic Systems Survey and Research Needs
Mussels:

- Conduct status surveys for riverine mussels to determine range and abundance for smaller streams in the state (especially within Tombigbee drainage), Bayou Pierre drainage, large Delta rivers (i.e. Coldwater River), the lower Pearl River and headwater streams.
- Monitor known populations for evidence of decline or recovery. Monitoring is recommended specifically for larger streams.
- Conduct phylogenetic analysis of *Lampsilis cardium/satura* complex.
- Determine effects of poor water quality on a statewide basis, but especially for streams that support a high diversity of mussel species.
- Assess and monitor the effects of agriculture usage of ground water on the Mississippi Delta streams especially in the Sunflower River basin streams.
- Assess and monitor the effects of industrial water withdrawals especially the Tennessee-Tombigbee drainage.
- Phylogenetic analysis is recommended for *Strophitus* sp., *Uniomerus* sp., the *cardium/satuna* complex, the *Obovaria subrotunda/unicolor/jacksoniana* complex, and several Delta mussels.
- It is recommended that captive propagation be implemented for some mussel species (i.e. *Quadrula metanevra*) to enable their reintroduction into stream systems where previously extirpated.

(Chapter 4: 78)
High Priority Lotic (Streams) and Lentic (Lacustrine) Systems

1. Tombigbee Drainage
2. Northeast Hills, Tennessee River Drainage
3. Ephemeral Ponds
4. Pascagoula Drainage
5. Lower Coastal Plain, Pearl Drainage

Ohio

Sheepnose Mussel (*Plethobasus Cyphyus*)

Taxa: Mollusk

Sheepnose Mussel Status:

Aquatic Species of Greatest Conservation Need (ASGCN)

Sheepnose Mussel Location, Record Status and Habitat Defined:

(CWCS Section 347 of 980)

Habitat Association: Aquatic

(CWCS 337 of 980)

Species of greatest conservation need - within the Streams and Watersheds Tactical Plan

All species listed as ASGCN are native to Ohio. These species have been drawn from Ohio and federal lists of threatened and endangered species and from species having NatureServe rankings of Vulnerable, Imperiled, or Critically Imperiled for Ohio.

Conservation Process – Issues and Actions for the Sheepnose Mussel:

Streams and Watersheds Tactical Plan

(CWCS 337-346 of 980)

Goal: To use a watershed approach in protecting and managing riparian habitats to enhance aquatic wildlife abundance and diversity, and increase recreational opportunities in Ohio's Focus Watersheds.

Introduction

Streams and riparian habitats are the most biologically diverse aquatic systems in Ohio. The structural variability of streams creates highly diverse habitats that are inhabited by many aquatic species, including over 153 fishes, 63 mussels, 14 amphibians and thousands of crustaceans and insects. Almost all of Ohio's state-listed threatened and endangered aquatic species are primarily stream-dwelling. Unfortunately, the rich diversity of streams is imperiled by a multitude of stressors.

As Ohio's population continues to increase, development of rural land and resulting fragmentation of wildlife habitat threatens many streams, which are Ohio's most biologically diverse aquatic habitats. Habitat loss and degradation, changes to hydrology, excessive sedimentation, channelization, and loss of floodplain connectivity all impact aquatic communities. Additionally, aquatic invasive species threaten to further impact native species and degrade habitats. Resource agencies and conservation groups realize that habitat protection and restoration must be done at the watershed level to be most effective.

The DOW realizes that to effectively implement watershed approaches requires collaboration with other agencies and NGO's that share common goals regarding the status and function of watersheds. The DOW must form broad coalitions to ensure effective planning, maximize resources, and efficiently implement conservation and restoration programs. The recurrent theme of partnerships throughout this document is intentional and critically important for achieving our goals.

Focus Watersheds

Focus Watersheds were drawn from the ODNR Candidate Streams for Protection and Restoration (see Section 8.3.1). This rates Ohio watersheds by integrating measures of physical and biological integrity, biodiversity, and recreational opportunity. All watersheds received a prioritization score which ranks their relative importance for protection and restoration activities.

The DOW has identified eleven Focus Watersheds to concentrate efforts related to aquatic portion of its CWCS. These include the highest scoring watersheds in Ohio. Watersheds in both the Lake Erie and Ohio River drainages representing all of Ohio's major ecoregions have been included. All have diverse habitat types with high use designations and excellent biodiversity.
Most are Ohio Scenic Rivers.

Focus Watersheds for Ohio's Aquatic CWCS

Watershed*	Prioritization Score	Ohio Drainage (mi^2)
Little Miami River	14	1755
Grand River	11	705
Scioto River	11	6510
Paint Creek	11	
Big Darby Creek	13	
Little Darby	10	
Muskingum River	11	8038
Kokosing River	9	
Walhonding River	9	
Great Miami River	10	3948
Stillwater River	6	
Cuyahoga River	8	425
Ohio Brush Creek	8	435
Little Beaver Creek	7	510
Maumee River	6	4862
Sandusky River	6	1420
Chagrin River	4	264
	Total:	28872
	Ohio (land area):	40953
Percentage of Ohio covered by Focus Watersheds:		71%

*Italicized are important sub-watersheds of the Focus Watershed

Implementation of Streams and Watersheds Strategic Plan Strategies

Dam Removal and Fish Passage

Strategy:

- Remove dams that are no longer needed or justified.

Habitat Protection and Restoration on Private Lands

Strategies:

- Protect and restore forested riparian corridors, floodplains, and wetlands through conservation easements, acquisition, and landowner programs and incentives.
- Develop and support programs and incentives that encourage and maintain good stewardship practices for riparian and in-stream habitat

- Through partnerships, collaboration, and coordination, participate in and support stream and watershed efforts by other agencies, nongovernmental organizations (NGOs), and other groups
- Develop and implement a Private Lands Aquatic Program.

Habitat Protection and Restoration on Public Lands
Strategy:

- Develop and implement stream protection best management practices on Division of Wildlife and other state-owned land.

Biological and Habitat Assessment and Monitoring
Strategies:

- Protect high quality stream habitats and restore others based on the presence of a high aquatic diversity, rare and endangered species, good sport fishing, biological integrity, and other related criteria.
- Collect baseline stream habitat data using quantitative and qualitative methods for the purpose of restoration and monitoring change over time.

Restoration and Maintenance of Hydrologic Functions
Strategies:

- Protect and restore natural flow regimes including important ground water recharge areas, floodplains, wetlands, and stormwater retention areas.
- Participate in and support (e.g., technical assistance and funding) regional land use planning efforts in Ohio.
- Help develop model stream protection guidelines (e.g., generic conservation easements, a riparian protection ordinance).
- Review existing Division, state, and federal laws and regulations on stream habitat and propose new polices, rules, and laws where needed to strengthen statewide stream habitat protection initiatives and/or regulations.

Educating Ohio's Citizens Regarding the Value of Steams and Watersheds
Strategy:

- Develop and provide stream education to landowners, the general public, schools, and public officials.

Funding for a Streams and Watersheds Program
Strategy:

- Seek additional funding for the Streams and Watersheds Habitat Program.

Tennessee

Sheepnose *(Plethobasus Cyphyus*)
Taxa: Invertebrate - Bivalve
Sheepnose Status:
(Appendix A:8)
Global Ranking: G3

Federal Status:

State Status:

Species of Greatest Conservation Need (SGCN): Tier 1

Widespread in the following regions:
- Mississippi River
- Cumberland River
- Tennessee River

Sheepnose Location and Habitat Defined
(Appendix D)

Mississippi River Drainage
- Medium Gulf Coast Plain Rivers, origin in the Coastal Plain
- Coastal Plain Streams
- Coastal Plain Streams, loess veneer over stand

Cumberland River Drainage
- Large Nashville Basin and Highland Rim River, origin in the Blue Ridge and Ridge and Valley
- Small Ridge and Valley Rivers, origin Blue Ridge/Piedmont
- Small Highland Rim Rivers, origin in Cumberland Plateau
- Small Highland Rim Rivers, origin in Highland Rim
- Highland Streams

Tennessee River Drainage
- Large Ridge and Valley Rivers, origin in Blue Ridge and Ridge and Valley
- Large Nashville Basin and Highland Rim River, origin in the Blue Ridge and Ridge and Valley
- Medium Ridge and Valley rivers, origin in the Blue Ridge
- Medium Ridge and Valley River, origin in the Ridge and Valley
- Small ridge and valley rivers, origin in ridge and valley
- Small ridge and valley rivers, origin in the Cumberland Plateau
- Small ridge and valley rivers, origin in the Blue Ridge/Piedmont
- Small Coastal Plain rivers, origin in the Highland Rim/Southern Cumberland Plateau
- Small Coastal Plain rivers, origin in Coastal Plain
- Ridge and Valley Streams
- Transitional streams, Cumberland plateau to ridge and valley, escarpment
- Ridge and valley streams, few headwaters in plateau sandstone
- Transitional streams southern Cumberland plateau to Highland River
- Highland Rim Stream
- Transitional Streams, Blue Ridge to Ridge and Valley
- Transitional Streams, coastal plains to Highland Rim
- Coastal Plain Streams

Conservation Process – Issues and Actions for the Sheepnose:
(Appendix E: pg 17/44)
Source of Stress:

- Channelization of Rivers/Streams
- Construction of Dams/Impoundment
- Incompatible Grazing/Pasture Management Practices
- Incompatible mining
- Incompatible Row Crop Agricultural Practices
- Industrial Discharge
- Invasive Exotic Species
- Municipal Waterwater Treatment/Stormwater Runoff
- Operation of Dams/Reservoirs

(TNCWCS: 154)
Priority Aquatic Conservation Actions by Source of Stress:

All Sources of Stress
- Evaluate standard for review of state & federally-listed GCN species.
- Propose legislation to create dedicated funding for conservation
- Conduct scientific surveys for lesser known GCN species
- Solicit private donations to fund conservation work

Channelization of Rivers/Streams
- Develop strategic alliance with USACE, TVA, water boards, & others
- Propose legislation to expand government funded incentive programs
- Participate in environmental review procedures for construction projects
- Restore in-stream flows to channelized streams.

Construction of Dams/Impoundment
- Develop strategic alliance with USACE, TVA, water boards, & others
- Develop state standards for in-stream flows for GCN species
- Participate in environmental review procedures for construction projects
- Participate in the review of county urban growth management plans

Incompatible Grazing/Pasture Management Practices
- Propose legislation to expand government funded incentive programs
- Coordinate planning for easement acquisition among agencies and NGOs
- Utilize government-funded incentive programs for landowners to improve and protect water quality
- Develop formal management agreements with landowners

Incompatible mining
- Propose legislation to designate priority habitat as unsuitable for mining
- Encourage the Office of Surface Mining to designate priority habitats as lands unsuitable for mining
- Reclaim abandoned coal mines
- Participate in the review of county urban growth management plans

Incompatible Row Crop Agricultural Practices
- Proposed legislation to expand government funded incentive programs.
- Develop strategic alliance with Farm Bureau, NRCS, FSA and others
- Utilize government funded incentive programs for landowners to improve/protect water quality
- Restore pastures, fields, and other agricultural lands

Industrial Discharge
- Evaluate standards for conducting environmental review of projects.

- Develop network of trained aquatic biologists to assist TDEC's monitoring
- Participate in environmental review procedures for construction projects
- Increase compliance monitoring of ARAP and other permits

Invasive Exotic Species

- Propose legislation to restrict import of invasive exotic species to TN
- Develop strategic alliance with USACE, TVA, water boards, & others
- Conduct rapid assessment of priority habitats for invasive exotics
- Implement integrated pest management practices in priority habitat

Municipal Waterwater Treatment/Stormwater Runoff

- Evaluate standards for conducting environmental review of projects
- Develop network of trained aquatic biologists to assist TDEC's monitoring
- Participate in environmental review procedures for construction projects
- Participate in the review of county urban growth management plans

Operation of Dams/Reservoirs

- Develop strategic alliance with USACE, TVA, water boards, & others
- Develop state standards for in-stream flows for GCN species
- Encourage USACE and TVA to review operations of dams and structure
- Participate in the environmental review procedures for construction projects.