Development of a Headwaters Index of Biotic Integrity (HIBI) for high-gradient streams in New Jersey

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Pinelands Research Series

Presentation overview

- Intro to IBI and NJDEP Biological Monitoring
- Headwater streams 101
- Pilot study and methods development
- Index development
- Headwaters (HIBI) Monitoring program

What is an Index of Biotic Integrity(IBI)?

- Using biological assemblages (fish, macroinvertebrates, periphyton, amphibians, etc.) to assess the overall health of an ecosystem (Karr 1981, Karr et al. 1986)
- A scoring system based on multiple attributes (metrics) of a biological assemblage
- Individual metrics are summed and overall score used to determine health of a resource
- Metrics selected based on how well they indicate anthropogenic stressors



Biological Monitoring in NJDEP

Bureau of Freshwater and Biological Monitoring

1992 - Benthic macroinvertebrates (AMNET) , 3 regional Indices

- **HGMI-(high gradient, Northern NJ),**
- **CPMI- (low gradient, Coastal Plain excluding the Pinelands)**
- **PMI – Pinelands**

Pinelands Research Series: Dean Bryson – "Development and Application of a Benthic Macroinvertebrate Index for Pinelands Rivers and Streams" February 2013

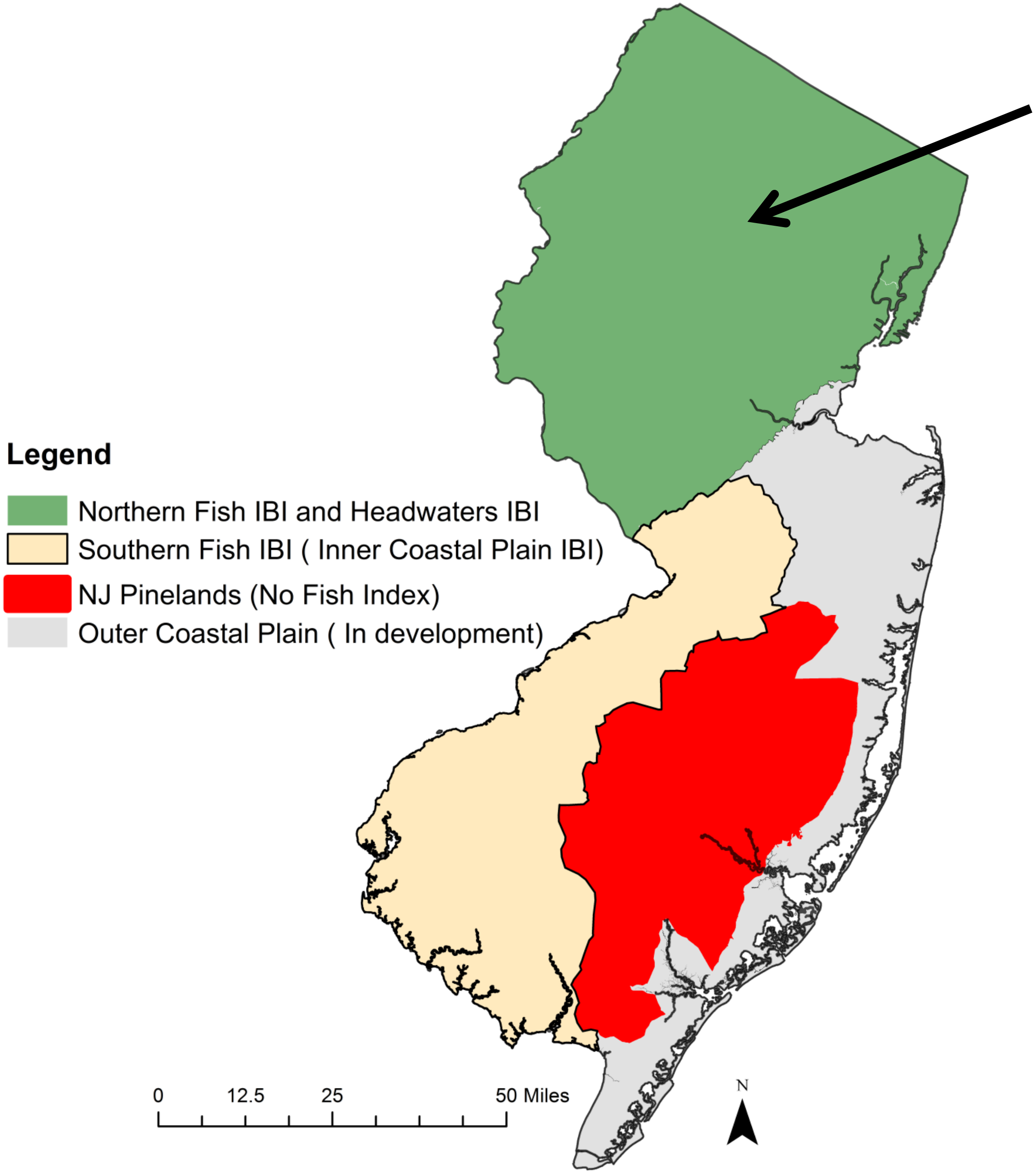
2000 - Fish Index of Biological Integrity (FIBI) :

- **High gradient >4 mi² catchment area (Northern NJ)**
  previously >5mi² catchment area
- **(2012) Low gradient (Inner Coastal Plain, Southern NJ)**

Pinelands Research Series: John Vile – "The NJ Inner Coastal Plain Fish IBI" April 2013

2013 -Headwater Index of Biotic Integrity (HIBI)
(High gradient, <4 mi² catchment area)
(Northern NJ)

New Jersey Fish IBIs



Streams < 5 miles^2 in drainage area unassessed by vertebrate IBI prior to development of Headwaters IBI

Why Do We Need a Headwater IBI?

Expand Biological Monitoring and fill in monitoring gaps!

- Northern Fish IBI metrics were not applicable to headwater streams
    - Need at least 5 species and 100 individuals at reference sites for a solely fish based IBI
    - Needed to add taxa (salamanders, crayfish, frogs) to IBI due to low fish richness in small streams
- HIBI created to compliment existing FIBI network (HIBI samples streams <4mi^2 drainage, FIBI samples >4mi^2)
- **All non-tidal wadeable river miles north of the fall line can now be assessed with a vertebrate IBI (FIBI or HIBI)**

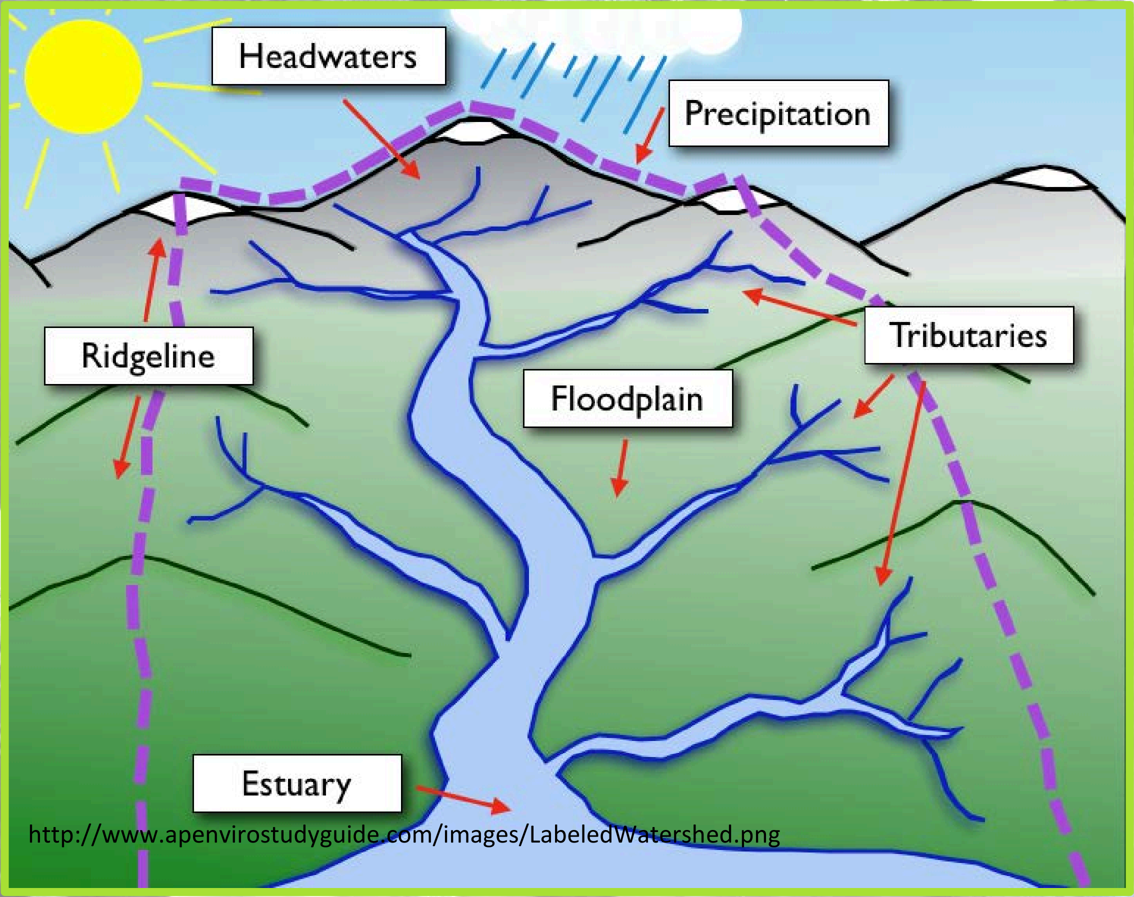
Data Uses

- Support Clean Water Act, Aquatic Life Use, fishable waters
- Support trout status classifications (trout production(TP), trout maintenance (TM) and non-trout (NT))
- Category One designations
- Report threatened and endangered species observed to NJDEP Division of Fish and Wildlife

Headwater Streams

What is a headwater stream?

- Smallest tributaries in a watershed
- A spring, intermittent, or perennial source of water that is the origin of a river network
- Predominantly first, second, and small third Strahler order streams



http://www.apenvirostudyguide.com/images/LabeledWatershed.png

Why Monitor Headwater Streams?

Abundance

- Comprise greater than 70% of the total stream length in the United States
- Approximately 80% of the non-tidal stream miles in northern New Jersey, of which 38% are listed as anti-degradation waters

Ecological Services

- Provide water, support groundwater recharge, transport sediment and organic matter, cycle nutrients and provide habitat for flora and fauna
- Headwater streams dictate downstream water quality and are essential to watershed health

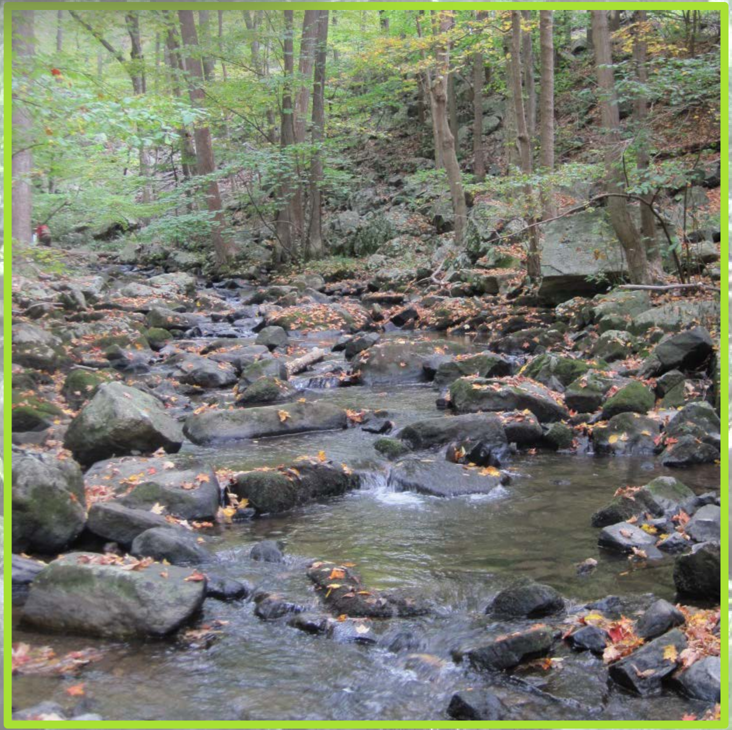
Vulnerability

- Human disturbance (e.g. land development, logging, road construction, acidification, storm water management, piping and stream burial)
- Discharge and withdrawals
- Drought

Headwaters Research

Academy of Natural Science at Drexel University (ACNSDU) Pilot Study (2004-2012)

- Sampled 66 sites
- Determined best bioindicators to use
- Tested various sampling collection techniques
- Proposed preliminary metrics



NJDEP (2013)

- Sampled 30 sites
- Validated sampling techniques
- Sampled additional reference sites

Biological Indicators

Crayfish

Fish

Frogs

Salamanders (streamside)

Why are streamside salamanders good ecological indicators?

Trophic status

- Top predator (carnivore) in fish-less streams

Life history

- Aquatic larval stages up to 4 years

Physiology

- Lungless, moist permeable skin

Abundance

- Stable populations, small home range

Ubiquity

- Found in almost all streams but the most perturbed

Sensitive to multiple stressors

- Contaminants
- Drought
- Flooding
- Acid mine drainage
- Logging
- Development

NJ Streamside Salamanders

Headwaters Sampling Methods

Headwater Monitoring Methods

Electrofishing

- A stream reach of 150 m is electrofished moving upstream sampling all available cover using one or two backpack electrofishing units

Area Constrained Survey

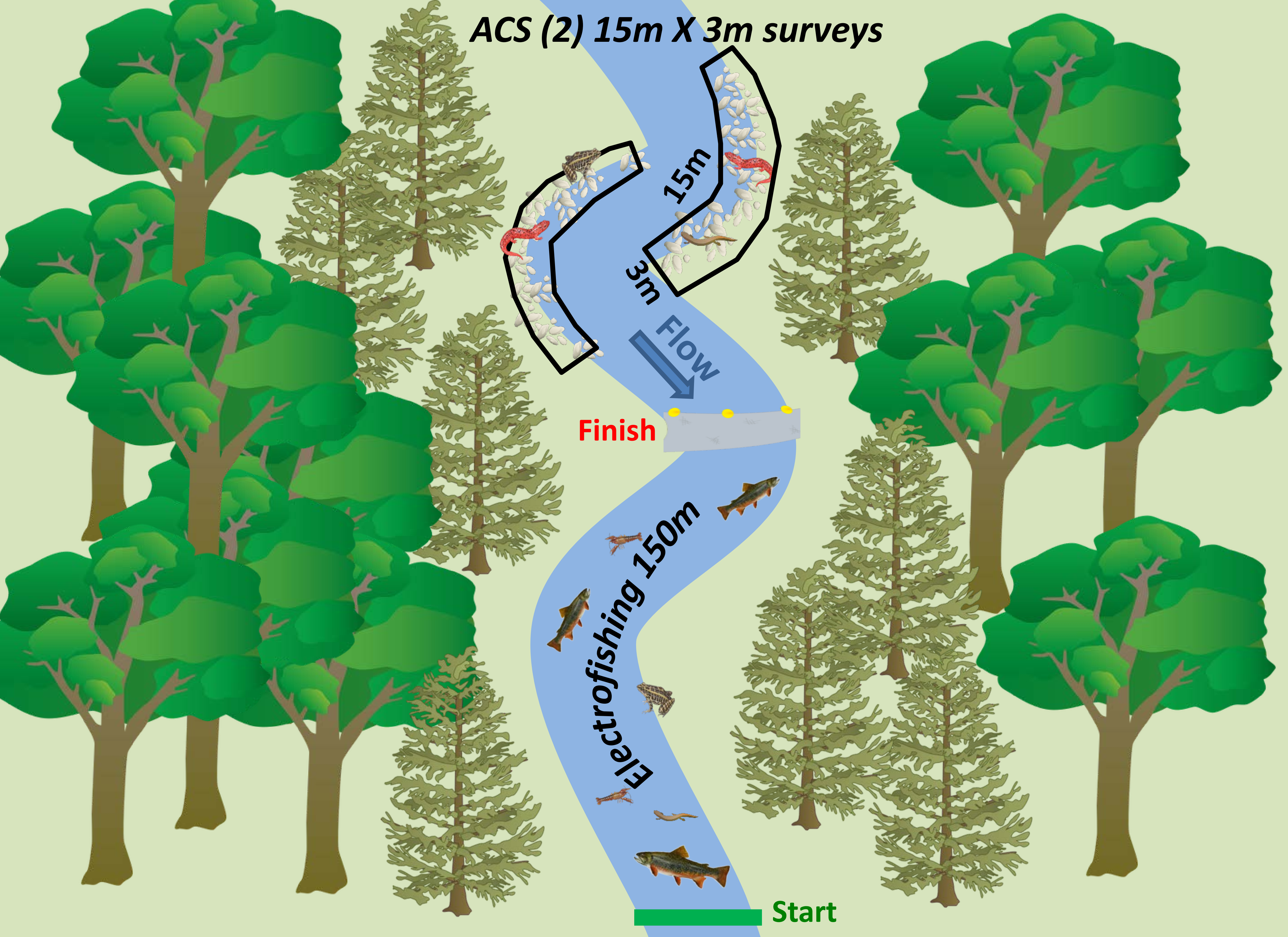
- An area of 90 m^2 (2 transects measuring 15 x 1 m in the water and a 15 x 2 m area along the bank) is sampled by area constrained survey (ACS) by a crew of two individuals flipping all available cover(rocks, logs, debris). All crayfish, salamanders and frogs are captured with the aid of dip nets

Habitat Survey

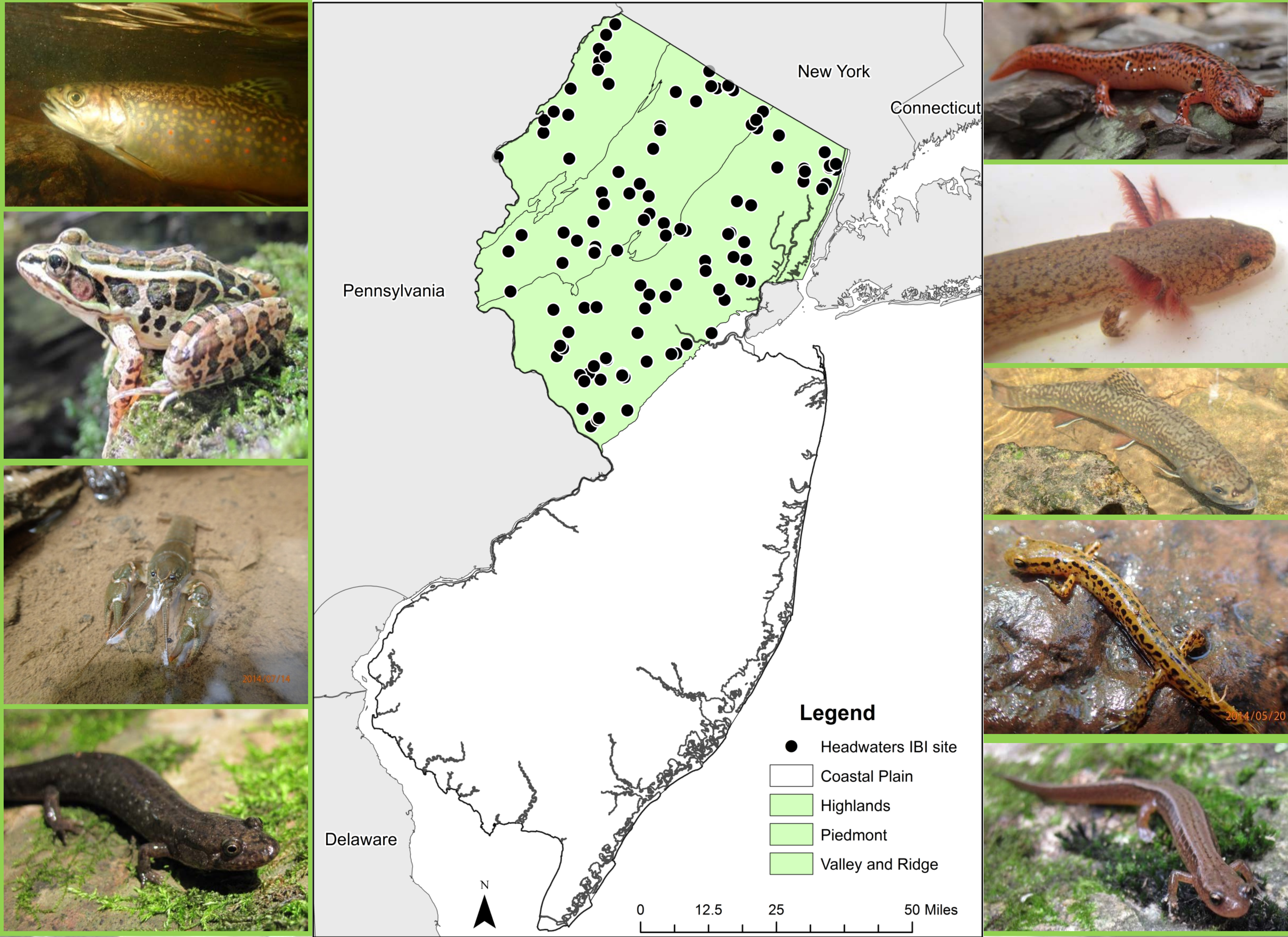
- Gradient, canopy cover, wetted width
- EPA's Rapid Habitat Assessment:
  epifaunal substrate, embeddedness, velocity/depth regimes, sediment deposition, channel flow status, channel alteration, frequency of riffles, bank stability, bank vegetative protection, and riparian vegetative zone width.

Water Quality

- Ambient water quality parameters (dissolved oxygen (DO; mg/L), DO (% saturation), pH, temperature and conductivity)



ACS (2) 15m X 3m surveys
15m
3m
Flow
Finish
Electrofishing 150m
Start


New York
Connecticut
Pennsylvania
Delaware
Legend
Headwaters IBI site
Coastal Plain
Highlands
Piedmont
Valley and Ridge
N
0
12.5
25
50 Miles
2014/07/14
2014/05/20

Development of a Headwater Index of Biotic Integrity

Vile, J. S., and B.F. Henning. (In prep). Development of indices of biotic integrity for high-gradient wadeable rivers and headwater streams in New Jersey.

Northern NJ Fish Assemblages (Thermal classifications)

Cluster Analysis
Pooled all northern NJ Fish assemblage data (FIBI and HIBI)

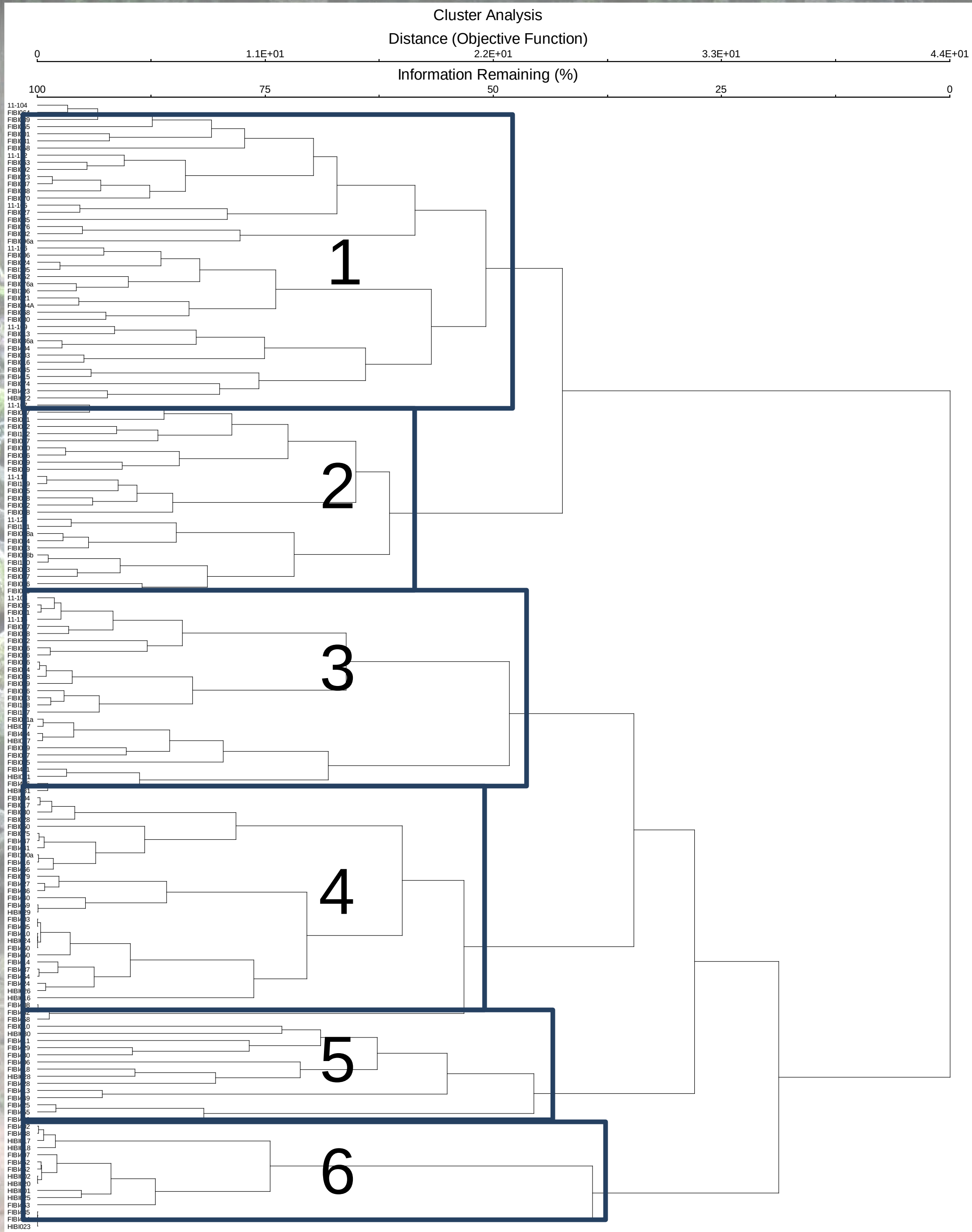
Warmwater

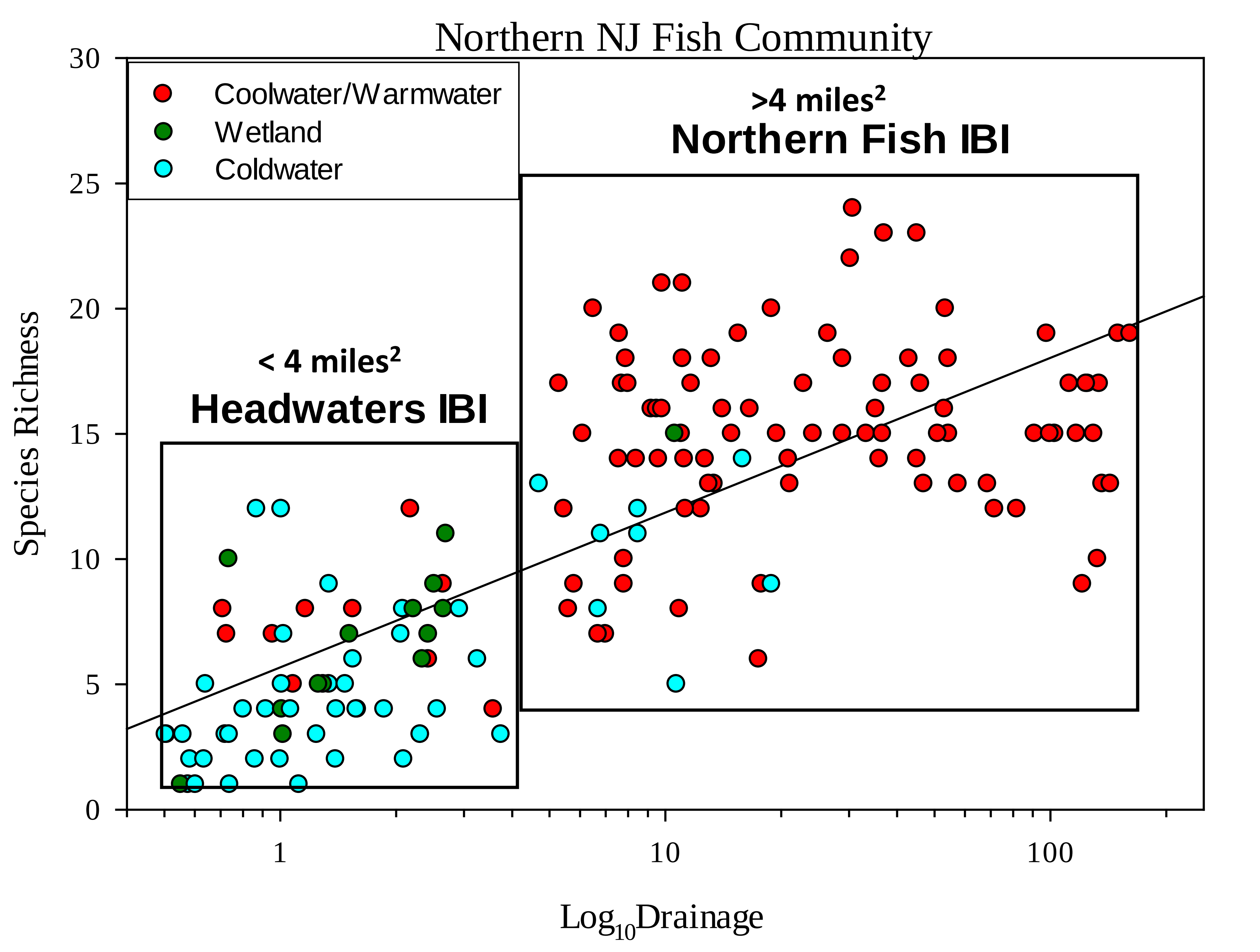
Coolwater

Coldwater

Wetlands

Coldwater





Northern NJ Fish Community
Coolwater/Warmwater
Wetland
Coldwater
>4 miles²
Northern Fish IBI
< 4 miles²
Headwaters IBI
Species Richness
0
5
10
15
20
25
30
1
10
100
Log10Drainage

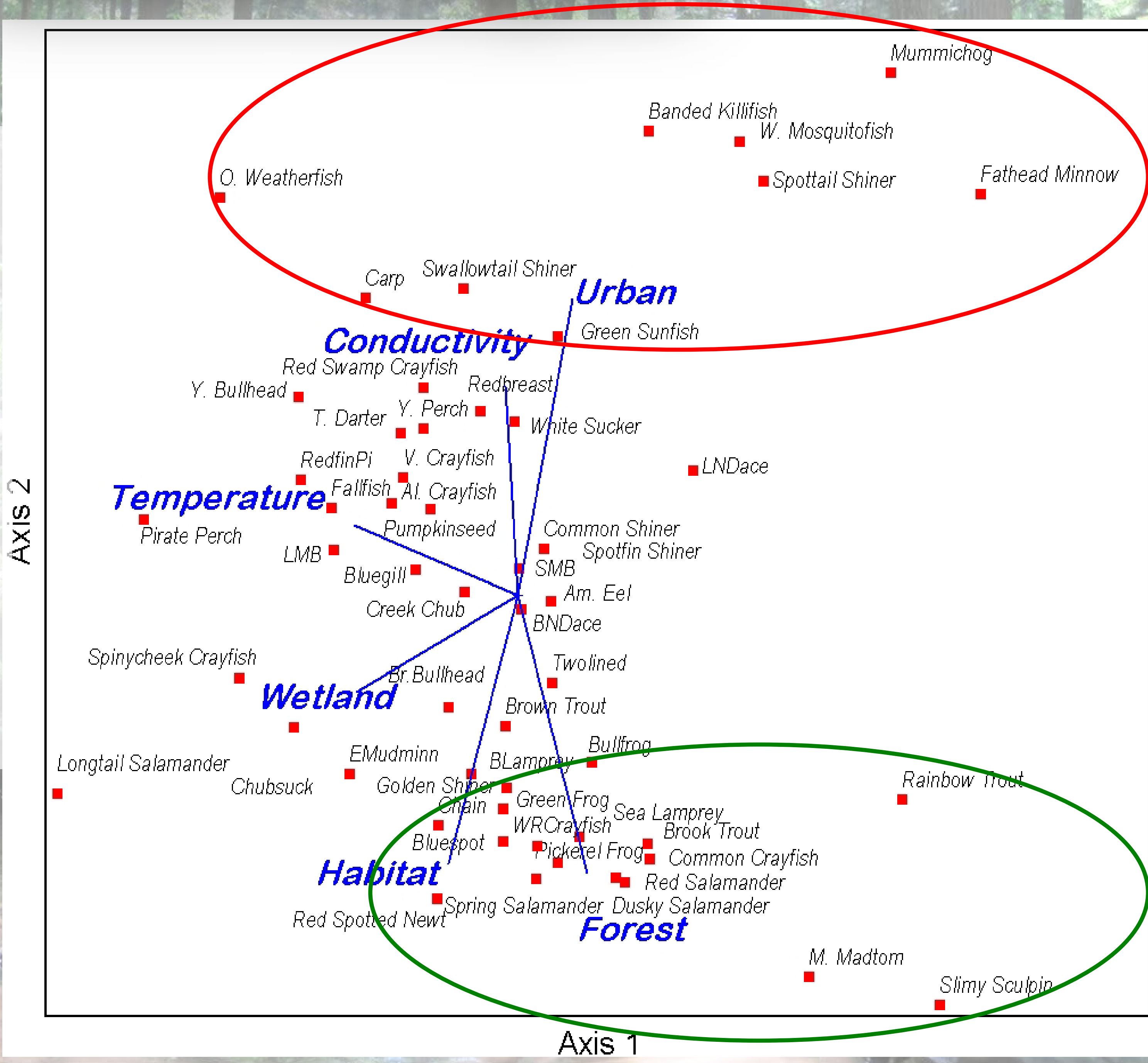
Headwaters Assemblage CCA

Canonical Correspondence Analysis

We used to identify species sensitivity to anthropogenic stressors

Species tolerant to anthropogenic stress

Species intolerant to anthropogenic stress



Structured Approach to IBIs

Whittier, T.R., Hughes, R.M., Stoddard, J.L., Lomnicky, G.A., Peck, D.V., Herlihy, A.T.,2007. A structured approach for developing indices of biotic integrity: three examples from western USA streams and rivers. Trans. Am. Fish. Soc. 136, 718–735.

- Developed set of tests to evaluate and select metrics in a streamlined manner that is less subjective

- When a metric fails a test, it is eliminated

1. Range Test
2. Signal to noise
3. Correlation with natural gradients (drainage size, gradient)
4. Responsiveness test
5. Redundancy
6. Metric scoring and evaluation

TABLE 1.—Metric classes used to develop indices of biotic integrity in the western USA.

Class	Description
Habitat	Preferred habitat for each vertebrate species (e.g., benthic, water column, or hider)
Tolerance	General tolerance to common anthropogenic, physical, and chemical stressors (sensitive, intermediate, tolerant, or very tolerant)
Trophic	Primary source of nutrition for each vertebrate species as an adult (herbivore, invertivore, invertivore–piscivore, piscivore, or omnivore)
Reproductive	Reproductive habit for each vertebrate species (e.g., lithophil, nest builder, or crevice spawner)
Composition	The representation of different taxonomic groups (e.g., family) in the assemblage
Richness	The number of different kinds of taxa
Life history	The general life history strategy for each vertebrate species (e.g., migrating [vagile], long-lived, etc.)
Aliens	Whether each vertebrate species is native or introduced in the region where it was collected
Abundance	The number of individuals of an assemblage, taxonomic group, or guild collected

NJ Metric Evaluation Process

1. Range Test for metric values
    - Eliminated metrics with < 3 species (Richness metrics only)
    - Eliminated metrics with >75% zero values or identical values
2. Signal to noise - ratio of variance among sites (signal) to the variance of repeated visits to the same site (noise)
    - Eliminated metrics with S:N values less than 3
3. Correlation with natural gradients (drainage size, gradient)
    - Metrics with R^2 >.25 were adjusted
    - Predicted value = $m*\log_{10}$(drainage area)+b
    - Adjusted value = mean of reference + observed- predicted
4. Responsiveness to human disturbance
    - Correlation coefficients with land use, habitat, water chemistry variables
    - One -way ANOVA (Least Impaired vs. Most Impaired)
    - Metrics listed in order of highest F-value
5. Redundancy
    - Eliminated metrics with Pearson Correlation coefficients >0.75
6. Metric scoring and evaluation
    - Metrics with the highest F-value that passed all screening tests were selected
    - Scored metrics scaled to range from 0-100 (continuous scoring)
    - Metric values decrease with stress: Score = 100 x Metric Value/95th Percentile
    - Metric values Increase with stress: Score = 100 x (95th Percentile – Metric Value)/(95th Percentile – 5th Percentile)
    - Total HIBI scores were the averages of their composite metric scores, with a potential range of 0–100.

Site Classification Categories

	N=35	N=20
Criteria	**Least Impaired**	**Most Impaired**
% Forest + %Wetland	>70%	<30%
% Urban	<20%	>70%
% Impervious cover	<5%	>20%
Total Habitat Score	Optimal or Suboptimal	Marginal or Poor

Intermediate sites (N=41) were classified as those that did not fit the above criteria

68 Candidate Metrics Tested

Taxonomic Richness

- Number of top carnivore fish species
- Number of intolerant fish species
- Number of coldwater fish species
- Number of fluvial specialist fish species
- Number of intermediate fish species
- Number of lithophilic fish spawners
- Number of minnow species
- Number of native lithophilic fish spawners
- Number of native fish species
- Number of benthic invertivore fish species
- Number of coolwater fish species
- Number of total fish species
- Number of macro-habitat generalist fish species
- Number of warmwater fish species
- Number of general feeder fish species
- Number of fluvial dependent fish species
- Number of tolerant fish species
- Number of vertebrate species
- Number of native vertebrate species
- Number of intolerant vertebrate species
- Number of tolerant vertebrate species
- Number of top carnivore vertebrate species

Thermal

- Percent of coldwater fish individuals
- Percent of coolwater fish individuals
- Percent of warmwater fish individuals

Trophic

- Percent of top carnivore fish individuals
- Percent of benthic invertivore fish individuals
- Percent of general feeder fish individuals
- Percent of vertebrate top carnivore individuals
- Proportion of vertebrate richness as top carnivore
- Proportion of non-tolerant vertebrate species as top carnivore

Tolerance

- Percent of intolerant fish individuals
- Percent of intermediate fish individuals
- Percent of tolerant fish individuals
- Percent of vertebrate intolerant individuals
- Percent of vertebrate tolerant individuals
- Tolerance Index

Stream flow

- Percent of fluvial specialist individuals, except blacknose dace
- Percent lithophils
- Percent native lithophils
- Percent of fluvial specialist individuals
- Percent of macro-habitat generalist fish individuals
- Percent of fluvial dependent fish individuals
- Percent rheophilic species
- Percent rheophilic species (excluding blacknose dace)

Non-native

- Percent of non-native top carnivore fish individuals
- Percent of non-native macrohabitat generalist fish individuals
- Percent of non-native vertebrate individuals
- Percent of non-native individuals (fish and crayfish)
- Percent of non-native general feeder fish individuals
- Percent of non-native warmwater fish individuals
- Proportion of vertebrate species as non-native
- Proportion of total richness as native non tolerant species
- Proportion of total richness as native

Indicator species and Composition

- Percent of pioneer fish individuals
- Percent of most abundant species
- Percent of brook trout individuals
- Percent of blacknose dace individuals
- Percent Family Rhinichthys individuals
- Percent of individuals of the most abundant species
- Percent of white sucker individuals
- Number of Native Crayfish Species
- Percent Native Crayfish
- CPUE Common Crayfish
- Number Salamander and Sensitive Frog Species
- Number Salamander and Sensitive Frog Species minus Two lined salamander
- Brook trout density (#individuals/100 m^2)
- Number of brook trout size classes

Results

Metric	Ecological Class	Response to stress	S:N	F-value	Mann-Whitney (p value)	% DE
Intolerant Vertebrate Richness	Taxonomic Richness	Decrease	14.3	38.8	0.000	95
Proportion of Vertebrate Richness as Top Carnivore	Trophic	Decrease	17.8	25.0	0.000	79
% Tolerant Fish Individuals	Tolerance	Increase	31.2	31.0	0.000	89
Proportion of Total Richness as Native	Non-Native	Decrease	3.1	30.4	0.001	89
% Native Crayfish	Composition	Decrease	3.2	43.1	0.000	100
Brook Trout Density (individuals/100m^2)	Composition /Indicator Species	Decrease	1.6*	7.1	0.002	**

*Brook trout density metric failed S/N , but passed all other tests. Limited number of repeat site visit to streams containing brook trout

**The 25th percentile for least disturbed sites was 0.00 for metric

Discrimination efficiency (DE) is the capacity of the biological metric or index to detect stressed conditions. It is measured as the percentage of stressed sites that have values lower than the 25th percentile of reference values (Stribling et al. 2000).

Metric Correlation with Landuse

Metric	% Forested N=96	% Urban N=96	% Impervious cover N=56
Intolerant Vertebrate Richness	0.658	-0.614	-0.592
Proportion of Vertebrate Richness as Top Carnivore	0.444	-0.454	-0.501
% Tolerant Fish Individuals	-0.497	0.591	0.77
Proportion of Total Richness as Native	0.498	-0.517	-0.582
% Native Crayfish	0.542	-0.541	-0.522
Brook Trout Density (individuals/100m^2)	0.297	-0.307	-0.322

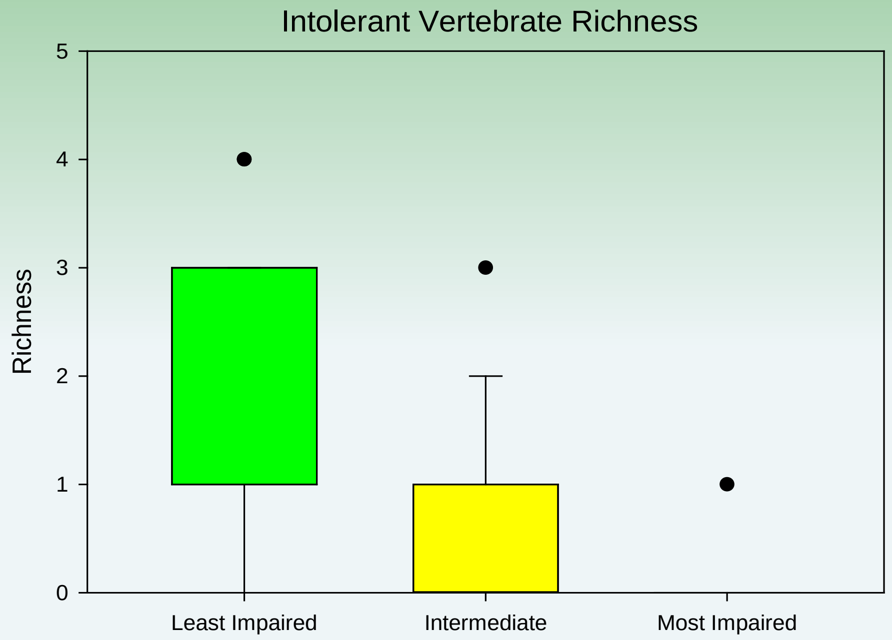
Richness

1. Number of Intolerant Vertebrate Species

Response to stress ↓

American Brook Lamprey, Brown Trout, Rainbow Trout, Brook Trout, Cutlips Minnow, Northern Hog Sucker, Shield Darter, Slimy Sculpin, Margined Madtom, Northern Dusky Salamander, Longtail Salamander, Northern Red Salamander, Northern Spring Salamander

Metric Score = (# Intolerant Vertebrates ÷ 3)*100



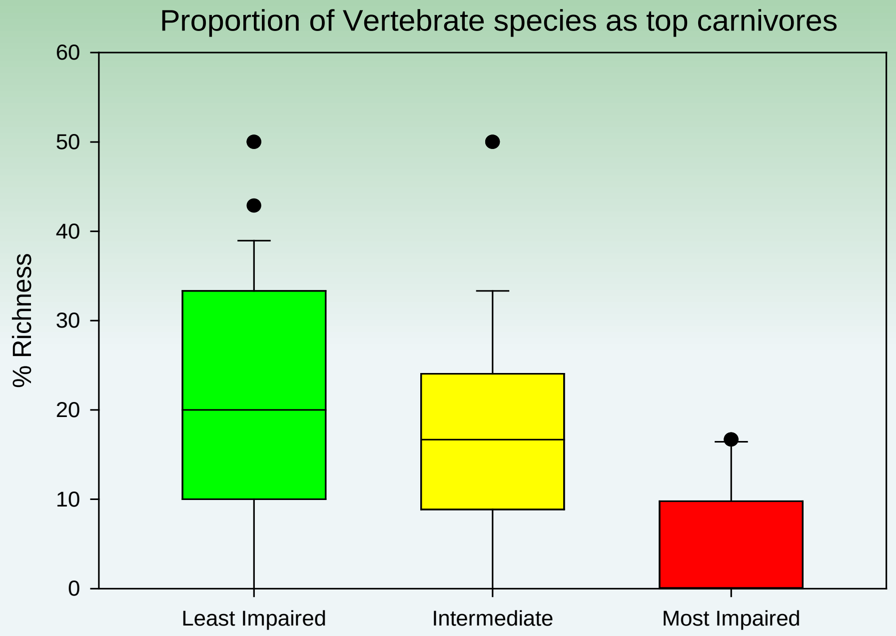
Trophic

2. Proportion of Vertebrate species as top carnivores

Response to stress ↓

Black Crappie, Brown Trout, Rainbow Trout, Brook Trout, Chain Pickerel, Largemouth Bass, Northern Pike, Redfin Pickerel, Rock Bass, Smallmouth Bass, Striped Bass, Walleye, White Catfish, White Crappie, White Perch, Yellow Perch, Bullfrog, Northern Red Salamander, Northern Spring Salamander

Metric Score = (Proportion of Vertebrate species as top carnivores ÷ 38.0)*100



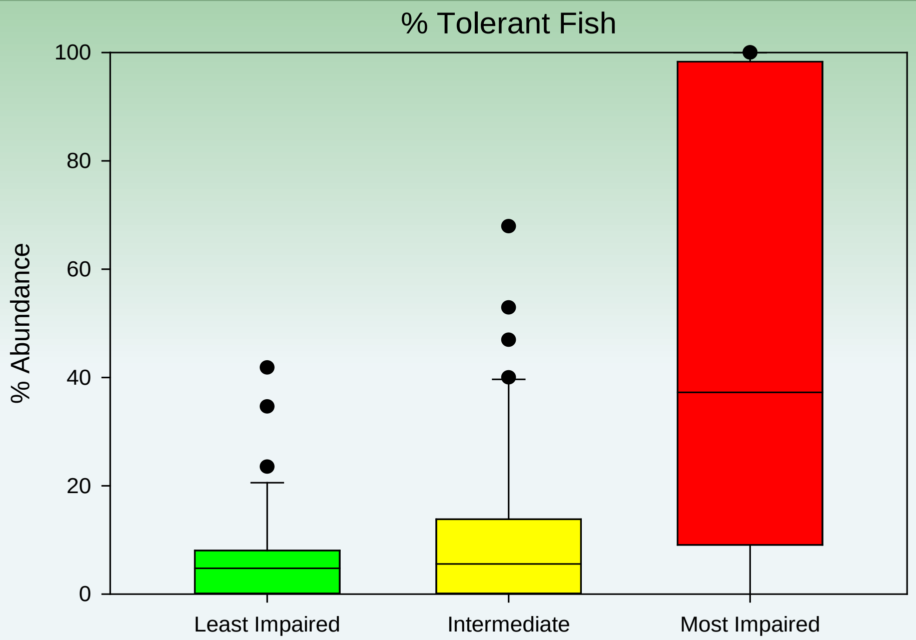
Tolerance

3. Percent Tolerant Fish

Response to stress ↑

American Eel, Green Sunfish, White Sucker, Banded Killifish, Mummichog, Common Carp, Fathead Minnow, Goldfish, Pumpkinseed, Western Mosquitofish

Metric Score = (96.1- % tolerant fish)/(96.1-0) *100



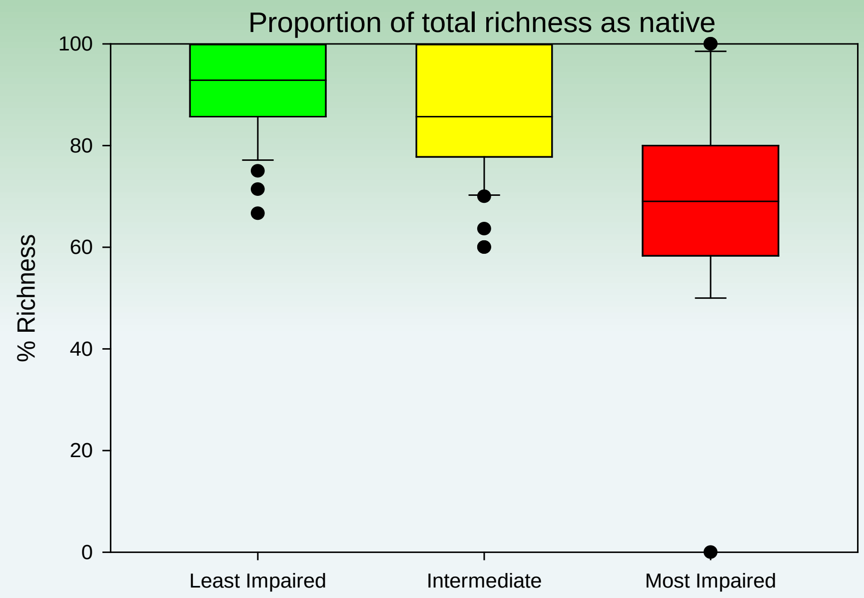
<u>Non-native</u>

4. Proportion of total richness as native

Response to stress ↓

<u>Excludes</u>: Black crappie, Bluegill, Brown trout, Common carp, Fathead minnow, Goldfish, Green sunfish, Largemouth bass, Northern Pike, Northern Snakehead, Oriental Weatherfish, Rock Bass, Smallmouth bass, Walleye, Western Mosquitofish, White Crappie, Rainbow Trout, Allegheny Crayfish, Rusty Crayfish, Virile Crayfish, Red Swamp Crayfish

Metric Score = (Proportion of species richness as native ÷ 100)*100



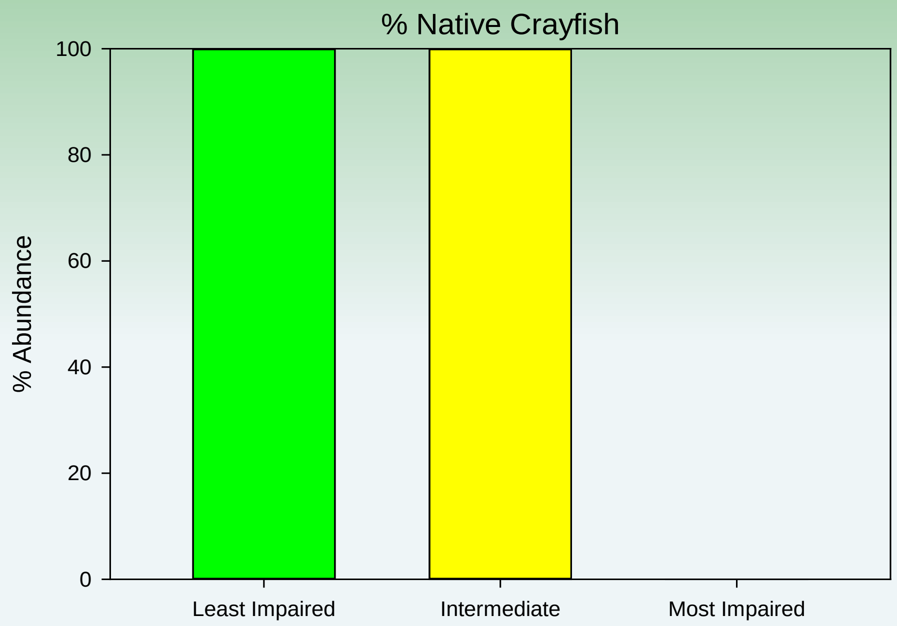
Composition

5. % Native crayfish

Response to stress ↓

Common Crayfish, Spinycheek Crayfish, White River Crayfish

Metric Score = (% native crayfish ÷ 100)*100

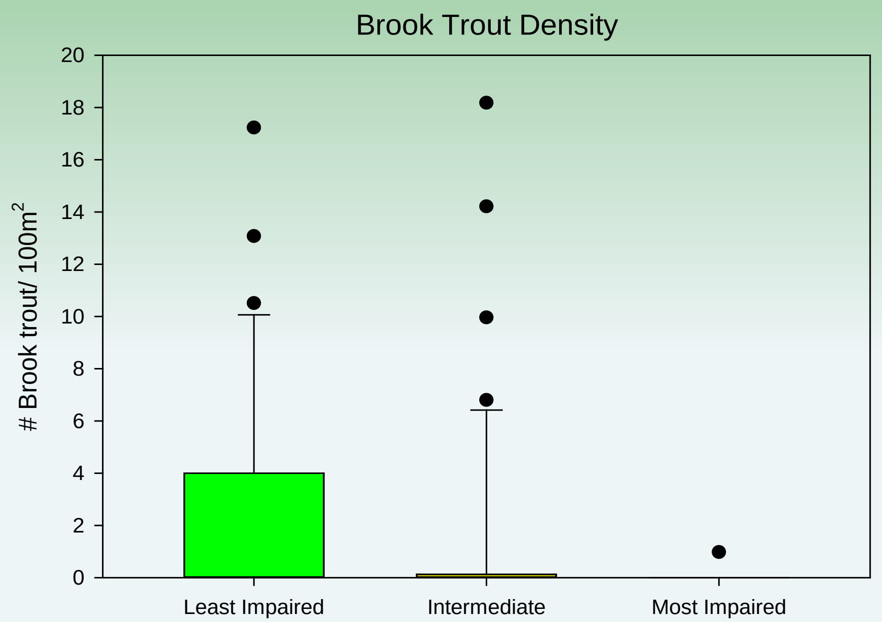


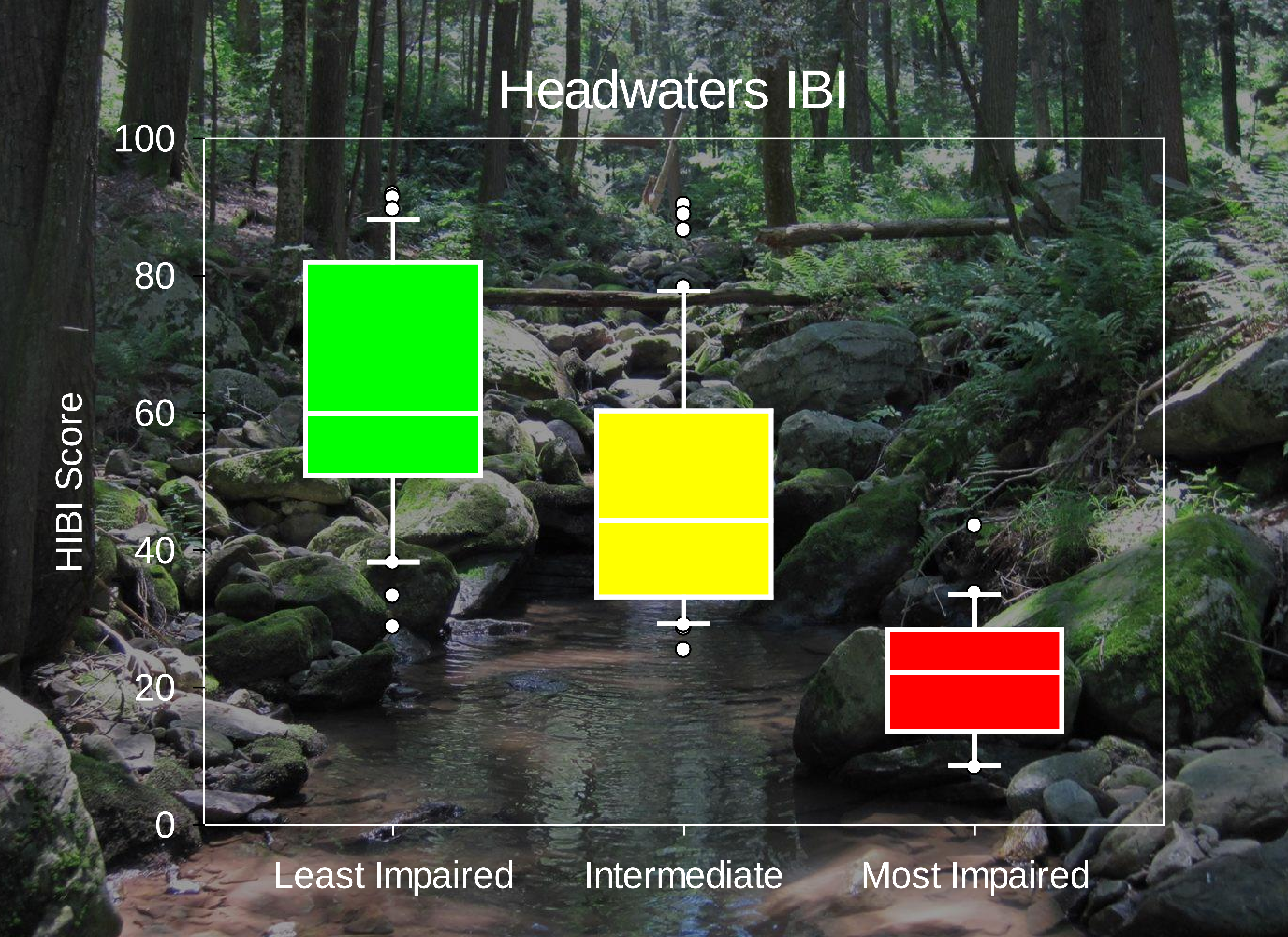
Composition/Indicator Species

6. Brook trout density (individuals/100m^2)

Response to stress ↓

Metric Score = (# Brook trout /100m^2 ÷ 10.1)*100




Headwaters IBI
HIBI Score
100
80
60
40
20
0
Least Impaired
Intermediate
Most Impaired

HIBI Scores and Ratings

Assessment Rating	HIBI Score
Excellent	82-100
Good	51-81
Fair	29-50
Poor	13-28
Very poor	0-12


Healthy Headwater Assemblage
Reproducing brook trout
Top Carnivores
Intolerant (sensitive) fish
Native taxa
Intolerant (sensitive) salamanders
Native crayfish

Beerskill

Drainage area= 1.46 mi^2

Species	Quantity
Brook Trout	77
Blacknose Dace	68
Slimy Sculpin	30
Northern Two-lined Salamander	19
American Eel	10
Green Frog	6
Northern Dusky Salamander	3
Common Crayfish	2
Golden Shiner	2
Pickerel Frog	1

HIBI Score

87.3

Rating: Excellent

Metric	Score
Intolerant vertebrate richness	100.0
Proportion of vertebrate species as top carnivore	29.2
% Tolerant Fish	94.4
Proportion of total richness as native	100.0
% Native crayfish	100.0
Brook trout density	100.0
HIBI Score	**87.3**


Impaired Headwater Assemblage
Top Carnivores Absent
Tolerant salamanders or none
Tolerant fish
Non-native taxa

Peach Orchard Brook

Drainage area= 2.85 mi^2

HIBI Score

6.4

Rating: Very Poor

Species	Quantity
Banded Killifish	471
Green Sunfish	95
Mummichog	38
Pumpkinseed	24
Brown Bullhead	6
Golden Shiner	3
Red Swamp Crayfish	2

Metric	Score
Intolerant vertebrate richness	0.0
Proportion of vertebrate species as top carnivore	0.0
% Tolerant Fish	0.0
Proportion of total richness as native	38.5
% Native crayfish	0.0
Brook trout density	0.0
HIBI Score	**6.4**

Headwaters Monitoring Network

Fixed Sites N=50

- Rotating basin design (Northwest, Northeast, and Raritan) Revisit every 5 years, track trends

Sentinel Sites N=9

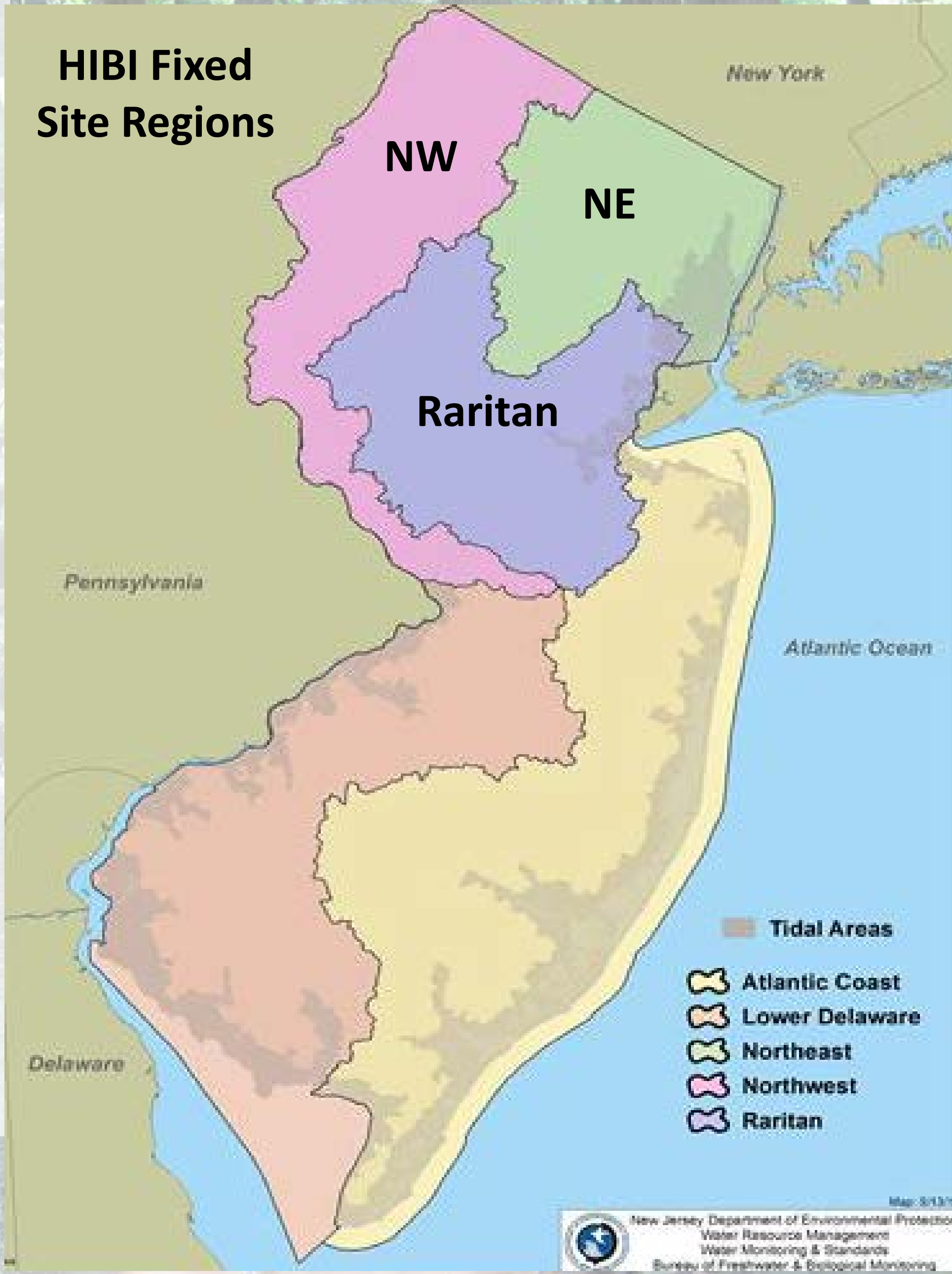
- Sentinel sites were selected based on the following criteria: 1) contain at least three sensitive taxa
- 2) designated by NJDEP Surface Water Quality Standards as FW1-TP waters (nondegradation waters) or category one (C1) waters with trout production status
- 3) <10% Urban Land Cover within the stream's drainage

Probabilistic Sites N=35

- Probabilistic sites were generated using a Generalized Random Tessellation Stratified (GRTS) survey design to provide a statistical Statewide survey of the Fish Index of Biotic Integrity Network.

U.S.EPA Regional Monitoring Network N=3

- RMN sites have minimal or low levels of upstream human-related disturbance
- Biological, thermal, and hydrologic data are collected to quantify and monitor changes in baseline conditions, including climate change effects



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Questions?
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