Development of the Biological Condition Gradient for Fish and Headwater Fauna in High Gradient Rivers and Streams of New Jersey

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Division of Water Monitoring and Standards
Bureau of Freshwater and Biological Monitoring

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1 Introduction

The New Jersey Department of Environmental Protection (NJDEP) Bureau of Freshwater and Biological Monitoring (BFBM) performs monitoring on non-tidal freshwater streams and rivers throughout the state using fish as biological indicators of stream health. This data is used for a wide variety of purposes, including the evaluation of aquatic life use assessment for the federally required NJ Integrated Water Quality Assessment Report and the designation of Category One antidegradation classification based on exceptional ecological significance.

BFBM has established fish bioassessment protocols for three different stream types in New Jersey. The Bureau initiated Fish Index of Biotic Integrity (IBI) monitoring in 2000 following the development of the Northern Fish IBI by U.S. EPA Region 2 which was based on the EPA's Rapid Bioassessment Protocols (RBP; USEPA 1999). This, the longest fish monitoring program in the NJDEP Division of Water Monitoring and Standards (DWMS), monitors resident fish assemblages in wadable streams larger than 4-square miles in drainage area. The Southern Fish IBI was developed by BFBM in 2012 for low gradient streams in the Inner Coastal Plain eco-region of NJ. Lastly, after several years of research and analysis by the Philadelphia Academy of Natural Sciences of Drexel University and BFBM, the Headwaters IBI was completed in 2014. This program is used to monitor small first and second order streams less than 4 square miles in drainage area within the same eco-regions of Northern New Jersey as the Northern Fish IBI. The two northern programs differ not only in the size of stream monitored, but also in the assemblages monitored. The Northern Fish IBI is solely a fish-based index, whereas the Headwaters IBI uses fish, crayfish, and streamside amphibians as bio-indicators.

This report outlines the process used to develop a Biological Condition Gradient (BCG) for wadeable streams north of the fall line using fish, crayfish, and amphibian assemblage data collected as part of the Northern Fish and Headwaters IBI programs. The Bureau had previously developed a BCG for the Ambient Macroinvertebrate Network (AMNET) for describing stream condition based on macroinvertebrate assemblages in high and low gradient streams in New Jersey (Gerritsen and Leppo, 2005). The development of a NJ fish BCG and the associated rules are meant to serve several purposes: 1) further support the use of fish, crayfish, and amphibian assemblage data for aquatic life use criteria, 2) aid in the development of IBI scoring/ratings criteria and in particular the threshold between impaired and non-impaired sites, 3) serve as a weight of evidence for those stations on the edge of impairment, and 4) inform decisions regarding the regulatory use attainment.

1.1 The Biological Condition Gradient

The Biological Condition Gradient (BCG) is a conceptual and scientific framework to describe a waterbody's biological condition in tiers of impairment that deviate from natural conditions (Davies and Jackson, 2006). The BCG assigns attributes to each taxa that describe the changes in structure and function of aquatic communities in response to increasing disturbance. These attributes are evaluated for each site which is then assigned to a BCG Tier ranging from 1 (pristine) to 6 (highly impaired; Table 1). Once a BCG is developed for a specific geographic area, ecoregion, or resource category the results can be equally compared to other BCG models using the same scale of impairment. The development of a BCG model for fish and headwaters taxa will aid in providing

additional weight of evidence, and make comparing biological condition easier among difference resource categories and supplement already established IBI monitoring programs to assess the goals of the federal Clean Water Act (CWA).

Table 1. The six tiers of the Biological Condition Gradient.

BCG Tier	Description
Tier 1	Natural or pristine conditions that have not been altered
Tier 2	Minimal change in biotic structure and ecosystem function
Tier 3	Detectable change in biotic structure and ecosystem function
Tier 4	Moderate change in biotic structure and ecosystem function
Tier 5	Major changes in biotic structure and ecosystem function
Tier 6	Severe changes in biotic structure and ecosystem function

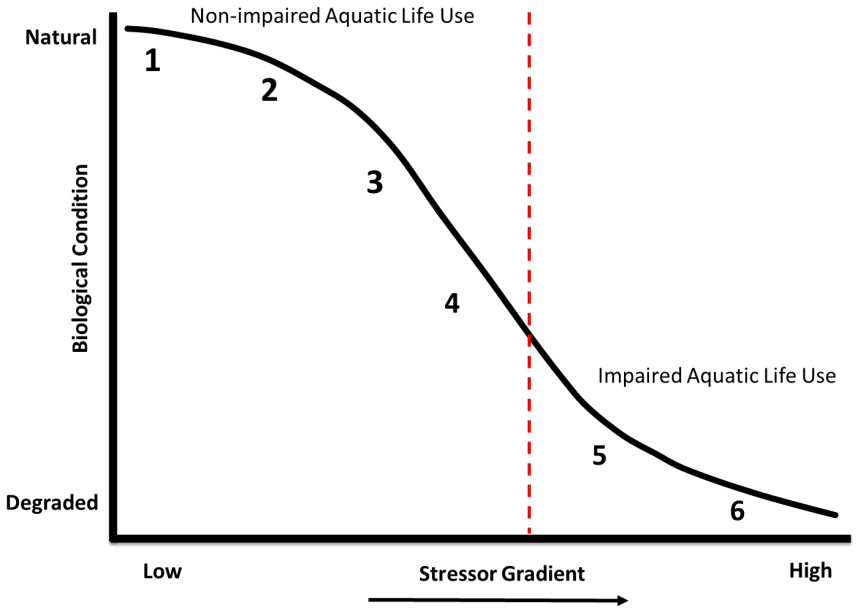

Figure 2. Conceptual diagram of the Biological Condition Gradient (modified from Davies and Jackson 2006) with impairment threshold for Aquatic Life Use (red dashed line).

2 Methods

2.1 Design

Data were collected from wadeable streams north of the fall line which runs roughly southwest to northeast from Trenton, NJ to Raritan Bay. The fall line separates the Coastal Plain from the Piedmont ecoregions. Streams in the northern part of the state are characterized as high gradient, cobble/boulder streams in the Piedmont, Highlands, and Ridge and Valley ecoregions (Figure 1).

A total of 244 unique sites from 2000-2015 were used for testing and rule development. Of this total, 149 sites were larger (northern IBI) streams and 95 were small (headwaters IBI) streams.

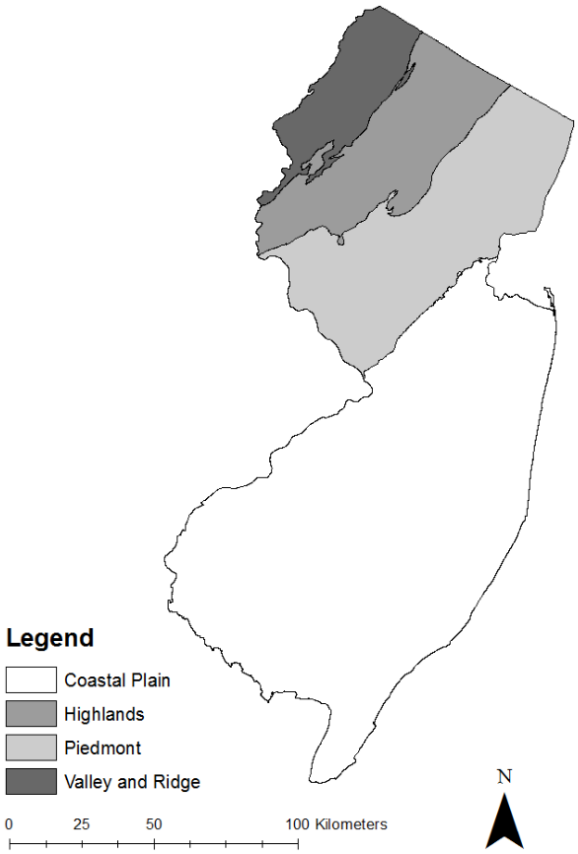

Figure 1. Map of New Jersey depicting Piedmont, Highlands, and Ridge and Valley ecoregions where Northern Fish IBI and Headwaters IBI monitoring is conducted.

Watershed size was used to separate cold (headwater) streams from larger cool/warmwater (northern IBI) streams based on cluster analysis, indicator species analysis, and linear regression analysis of northern NJ fish assemblages (Vile and Henning 2018). Results indicated 4-square miles in drainage area was the cut-off between the two monitoring programs based on the predominance of brook trout/slimy sculpin in streams less than 4-square miles. In addition, there is a higher likelihood of collecting a large enough fish sample needed for a fish-based index at sites above this drainage threshold.

2.2 Sampling Methods

Electrofishing was conducted at every site within a 150-meter stream reach to collect fish, crayfish, and amphibian samples representative of the resident assemblage and following the methods outlined in Standard Operating Procedures for the Fish Index of Biotic Integrity (NJDEP 2019). Single pass pulsed DC backpack electrofishing was employed on all headwaters and fish IBI streams. Gear ranged from 1-2 backpack units on small streams to 2-3 backpacks or

a barge unit for medium to large rivers. At headwater streams, fish, salamanders, crayfish, and frogs were collected during electrofishing, whereas only fish were collected at fish IBI streams. All biota sampled by electrofishing were identified to species and enumerated. All fish were identified to species, examined for external anomalies or DELTs (Deformities, Eroded fins, Lesions or Tumors), sport fish were measured for total length (TL; mm), and all specimens were released. Hatchery raised trout, easily identified by their numerous fin deformities, pale coloration, and missing scales/skin abrasions were not included in either dataset or analysis.

Additional sampling was conducted to target salamanders, frogs, and crayfish at each headwater stream site. The use of multiple sampling methods increases the likelihood to detect the presence of stream salamander species (Mattfeldt and Grant, 2007). The primary sampling techniques used in this study were the timed sample as recommended by Keller et. al. (2012), and the area constrained survey (ACS), which is the most cost efficient and collects the most species (Strain, 2009). With each technique, available cover (rocks, logs, debris) greater than 96 cm^2 were turned by hand and all crayfish, salamanders, and frogs encountered were captured with the aid of dip nets. All biota sampled were identified to species, enumerated, and released unless positive identification was not feasible in the field.

2.3 BCG Development

In March 2013, fisheries experts from US Environmental Protection Agency (US EPA) , United States Geological Society (USGS), Philadelphia Academy of Natural Sciences of Drexel University, NJ Department of Environmental Protection (NJDEP) Division of Science, Research, and Environmental Health, NJDEP Division of Fish and Wildlife, and NJDEP Division of Water Monitoring and Standards met to review the Biological Condition Gradient (BCG) conceptual model (Figure 2) and to discuss the feasibility of developing a New Jersey Fish BCG for high gradient streams in the Piedmont, Highlands, and Ridge and Valley Eco-regions. The first steps were to outline an approach and compile data so the workgroup could begin assigning attributes to each taxa. The workgroup set several project goals which included:

(1) To assess the different types of streams and rivers in northern New Jersey and determine the number of fish assemblages which exist in these waters based on available data

(2) To ascertain the degree to which current bioassessment data as collected by NJDEP are able to discern tiers of impairment or alterations to fish assemblages as defined in the tiered aquatic life conceptual model developed by US EPA.

(3) To identify streams and rivers in northern New Jersey which possess high biological integrity, and

(4) to define fish assemblages which characterize these waters, by assigning attributes to each fish species based on sensitivity/tolerance, range, distribution, historical presence.

BFBM staff summarized taxa data for the workgroup and presented species correlation results against various land use/land cover criteria, habitat scores, basic water chemistry parameters, and other stressor gradients. In addition, staff completed nonmetric multidimensional scaling (NMS) plots for each species collected in northern NJ (Figure 3). A total of 64 fish, 15 amphibian, and 7 crayfish species were included in attribute assignments, site evaluations, and rule development.

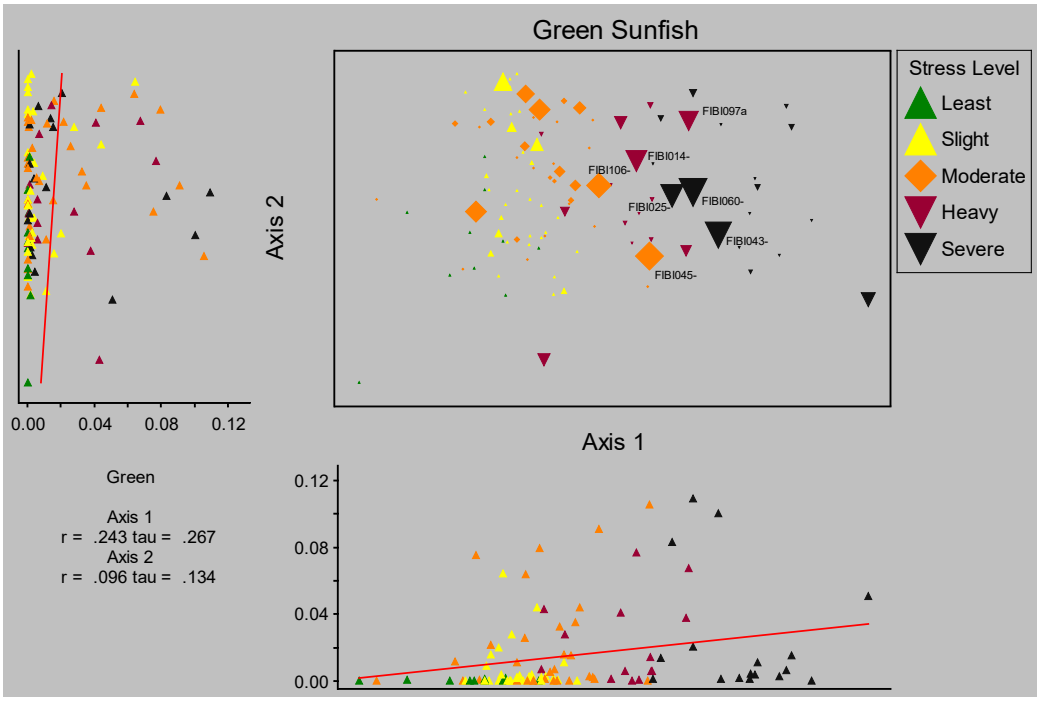

Figure 3. Example nonmetric multidimensional scaling plot.

Cluster analysis identified several distinct fish assemblages which enabled BFBM to distinguish between coldwater streams (Headwaters IBI) and larger cool/warmwater streams (Northern IBI) fish assemblages (Vile and Henning 2018). Results from cluster analysis, indicator species analysis, and linear regression, revealed the drainage area cutoff between coldwater and cool/warmwater assemblages is 4 mi^2 (Figure 4). Coldwater (Headwaters IBI) fish assemblages were dominated by brook trout *Salvelinus fontinalis*, slimy sculpin *Cottus cognatus*, blacknose dace *Rhinichthys atratulus*, and creek chub *Semotilus atromaculatus*. Northern IBI sites are broken into coolwater sites that tended to be dominated by species such as brown trout *Salmo trutta*, longnose dace *Rhinichthys cataractae*, fallfish *Semotilus corporalis*, and margined madtom *Noturus insignis* and warmwater sites that are dominated by tessellated darter *Etheostoma olmstedi* and several native and nonnative sunfish species.

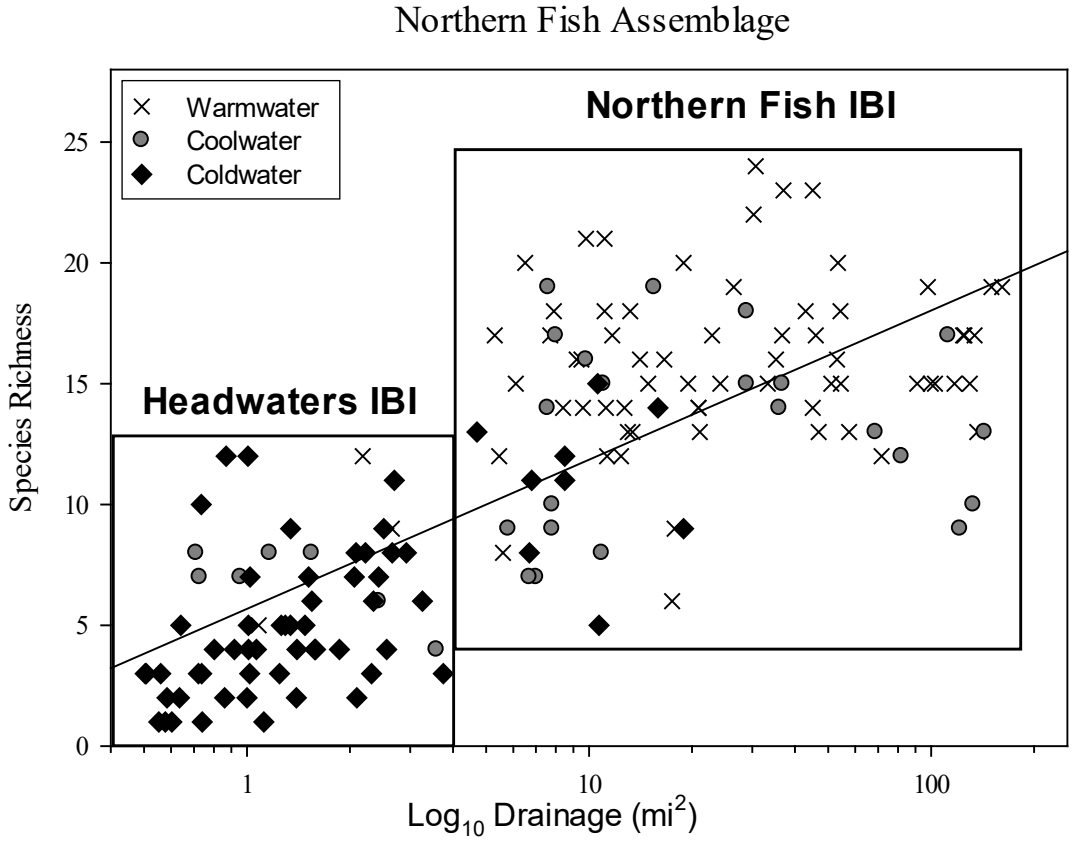

Figure 4. Linear regression of fish species richness and drainage area for New Jersey high gradient streams. New Jersey high gradient fish assemblages (warmwater, coolwater and coldwater) are derived from cluster analysis.

Following initial discussions, the workgroup reconvened in March 2014 to begin the initial steps in developing a NJ Fish BCG which included the following tasks:

(1) Assemble large fish, crayfish, salamander, and frog datasets for New Jersey (NJDEP IBI networks). The taxa data are representative of moderate to high gradient, hard bottom streams, located in the Highlands, Piedmont, and Ridge and Valley eco-regions.

(2) Review attributes assigned to the taxa by a panel of biologists in New Jersey with expertise in fish, amphibian, and aquatic ecology.

(3) Assign a set of test sites into tiers (1-6) based on the data available.

(4) Develop decision rules for assigning sites to BCG categories.

Panel biologists assigned taxa into one of the seven possible BCG attributes listed below.

I – Historically documented, sensitive, or regionally endemic taxa
II – Highly sensitive taxa (replaced sensitive and rare taxa)
II – Sensitive and common taxa (replaced sensitive and ubiquitous taxa)
IV – Taxa of intermediate tolerance
V – Tolerant taxa
VI – Non-native or intentionally introduced taxa
VII – Taxa not assigned an attribute

After initial discussions the workgroup agreed on the following revised attributes for NJ fish, amphibian, and crayfish taxa. Attribute 1 was not included in the revised list, as panelists agreed sensitive, long-lived fish, amphibian, and crayfish taxa do not occur in the study area.
II – Highly sensitive taxa (replaced sensitive and rare taxa)
III – Sensitive and common taxa (replaced sensitive and ubiquitous taxa)
IV – Taxa of intermediate tolerance
V – Tolerant taxa
VI-i – Non-native or intentionally introduced sensitive taxa
VI-m – Non-native or intentionally introduced taxa of intermediate tolerance
VI-t – Non-native or intentionally introduced tolerant taxa
(A) – Added to attribute number to represent migratory species

The workgroup reconvened and came to a consensus on attribute assignments for each fish species based on professional judgement, species correlation analysis, and NMS species plots presented to the panelists. A second attribute assessment meeting was held with staff from the Division of Fish and Wildlife, Bureau of Endangered and Nongame Species to complete the same evaluation with amphibian species.

2.4 Tier Assignments

A set of 20 northern IBI and 10 headwaters IBI sites were given to each panelist to assign into Tiers based on the fish assemblages and associated site information. Fish assemblage data included a species list, total abundance, size range, and species attribute assignment. Included with fish assemblage data was stream name, drainage size, percent forest land use/land cover, percent impervious cover, rapid bioassessment protocol habitat score, and population density within the surround watershed. Following general workgroup consensus of Tier assignments for these sites, a set of 12 anonymous sites were selected by a non-panelist. These anonymous sites were selected across the stressor gradient and only provided panelists with fish assemblage data, species attribute assignments, and summaries of the revised NJ attributes. The results of both workgroup exercises were used by BFBM staff to develop draft Tier rules.

3 BCG Rules

Staff from the Bureau of Freshwater and Biological Monitoring began the development of quantitative rules based on the consensus Tier assignments for all sites used in the Tier assignment process. Rules evaluated for inclusion included richness, percent richness, presence/absence, diversity, evenness, and percent abundance of different metrics and attribute combinations. The following is a list of attributes (II, III, etc.) and aquatic community metrics (listed by metric name) included in the final rule testing:

- Attribute II + III
- Attribute II + III + VI-i
- Attribute II + III + IV
- Attribute IV
- Attribute V
- Attribute VI-t

- Cyprinidae Taxa
- Attribute V + VI-t
- DELT Anomalies
- Migratory Species (A)
- Reproducing Salmonidae
- Reproducing Brook Trout
- Sensitive Salamander Taxa
- Common Crayfish
- Top Predator Taxa
- Amphibian Taxa
- Slimy Sculpin + Brook Trout
- Green Sunfish + Banded Killifish + Mummichog
- Dominant Taxa

Some states, such as Connecticut have elected to develop "fuzzy set" to account for sites which can be placed into several Tier assignments (Stamp and Gerritsen, 2013). Alternatively, we elected to develop a set of primary rules for each Tier assignment and alternate rules for many of the Tiers. This along with the Tier assignment procedure helps eliminate sites being placed in multiple Tiers. The Tier assignment process starts at Tier 1 and each set of data is tested against the primary and if necessary alternate rules before proceeding to the next Tier. Data must pass all primary or all alternate rules to be placed in a that particular Tier. If data from a site fails any of the primary or alternate rules, testing would move to the next sequential set of Tier rules.

3.1 Headwaters (<4 square miles)

The headwater streams rules are presented in Table 2. These rules were developed using BFBM fish, salamander, frog and crayfish data from the sites evaluated by workgroup members. The rules were calibrated to ensure proper Tier assignment of the workgroup test sites and site assignments completed by several BFBM staff. To account for variations in assemblage data, alternate rules were developed for Tiers 4-6 to ensure sites are appropriately placed in the correct Tier. Tier 4 is considered the impairment cut-off and any sites placed in Tiers 5 or 6 are considered to have impacts to assemblage structure and ecosystem function and are therefore considered impaired for aquatic life use. As a result, it was imperative that BCG rules properly placed sites with impairments for aquatic life use in Tiers 5 or 6 and non-impaired sites in Tiers 1-4.

Several rounds of testing and rule development were completed before finalized in 2015. Tier rules are applied to fish/amphibian/crayfish data in an ascending order starting with BCG 1 and proceeding through all the rules to determine if a site meets all criteria or if one proceeds to the next tier. BCG Tiers 4-6 require testing with all primary rules and if a site fails any part of the primary rule, it is tested against the alternate rule before moving to the next BCG Tier.

3.1.1 BCG Tier 1

The rules for BCG Tier 1 capture pristine unaltered conditions which the panel agreed do not exist in our current dataset and may not exist in NJ streams, but if they do, they are likely to exist in these small headwater streams. Tier 1 streams must be dominated by both native brook trout and slimy sculpin and young-of-the-year brook trout must be collected. In addition, sites must also pass all Tier 2 rules.

3.1.2 BCG Tier 2

Tier 2 is likely the highest level of unaltered conditions which exist in small coldwater streams in northern NJ. Theses streams must contain taxa from all three assemblages (fish, salamander, crayfish). Streams must support native reproducing brook trout and at least 1 sensitive salamander species (Northern dusky, mountain dusky, Northern red, Northern spring, and longtail salamander) and common crayfish. At least three attribute II+III taxa must be collected and their abundance must be greater than 30%. Attribute VI-t taxa must not be present.

3.1.3 BCG Tier 3

This Tier contains the majority of coldwater streams and are characterized by having naturally reproducing native or wild trout and contain several sensitive taxa. These streams exhibit some change in assemblage structure, but minimal change in ecosystem function. Streams in Tier 3 must contain reproducing native/wild trout and at least 2 attribute II+III+VI-i taxa which total at least 20% of the overall abundance. In addition, the community must contain a sensitive salamander (Northern dusky, mountain dusky, Northern red, Northern spring, and longtail salamander) or common crayfish.

3.1.4 BCG Tier 4

The majority of headwater streams in Tier 4 are streams transitioning from coldwater to coolwater or represent those streams with wetland dominated land use/land cover. This Tier represents the last level in which ecological function remains intact with moderate change in assemblage structure.

Primary Rule

Over 30% of the richness must be attribute II+III+IV taxa and the abundance of attribute V+VI-t taxa must be less than 40%. Streams must contain at least 1 amphibian species and abundance of Cyprinidae taxa must be at least 20% or greater.

Alternate Rule

Sites must have at least 1 vertebrate top predator, while attribute II+III+IV richness must still be over 30%. In addition, attribute VI-t richness must not exceed 2 and at least 1 amphibian species must be present.

3.1.5 BCG Tier 5

Tier 5 represent the first group with a significant break-down in assemblage structure and moderate change in ecosystem function. Sites in Tier 5 are considered to have an impaired aquatic community due to these changes in structure and function.

Primary Rule

Attribute II+III+VI-i richness is one or zero, while native cyprinidae richness must be at least one or more. In addition, abundance of attribute V+VI-t taxa must be less than 90%.

Alternate Rule

Attribute II+III+VI-i taxa must be absent and the percent richness of attribute V+VI-t taxa must be less than 90%.

3.1.6 BCG Tier 6

Streams in Tier 6 represent a complete loss of natural ecosystem structure and function. Streams in Tier 6 are considered to have a severely impaired aquatic community due to significant changes in structure and function. Pollution tolerant fish species, which include species like banded killifish, mummichog, and green sunfish are often abundant, while salamanders are absent.

Primary Rule

Attribute II+III+IV taxa are absent along with salamander taxa. Pollution tolerant species (mummichog, banded killifish, fathead minnow, green sunfish, goldfish, Western mosquitofish, and carp) must have at least 2 taxa present.

Alternate Rule

Attribute II+III+IV taxa are absent along with salamander and top predator taxa. Pollution tolerant species (mummichog, banded killifish, fathead minnow, green sunfish, goldfish, Western mosquitofish, and carp) must have at least 1 taxa present.

Table 2. Headwaters IBI Biological Condition Gradient rules

BCG Tier 1	Headwaters
Metrics	Rule
Trout Production	Naturally reproducing brook trout
Assemblage structure	Dominate two taxa must be brook trout and slimy sculpin, 3 assemblages of taxa (fish,salamander,crayfish)
Meet all rules for tier 2	
BCG Tier 2	**Headwaters**
Metrics	Rule
Trout Production	Naturally reproducing brook trout
Assemblage structure	3 assemblages of taxa (fish,salamander,crayfish)
Attribute II + III abundance	>30%
Attribute II + III richness	≥3
Attribute VI-t abundance	Absent
Sensitive salamander richness	≥1
Common crayfish richness	Present
BCG Tier 3	**Headwaters**
Metrics	Rule
Naturally reproducing native or wild trout	present
Attribute II + III + VI-i abundance	≥20%
Attribute II + III + VI-i richness	≥2
Sensitive salamander OR common crayfish	≥1

BCG Tier 4	Headwaters	
Metrics	Rule	Alternate
Vertebrate top predator	NA	≥1
Attribute II + III+ IV richness	>30%	>30%
Attribute V + VI-t abundance	<40%	NA
Attribute VI-t richness	NA	≤2
Amphibian richness	≥1	≥1
Cyprinid abundance	≥20%	NA
BCG Tier 5	**Headwaters**	
Metrics	Rule	Alternate
Attribute II + III + VI-i richness	≤1	Absent
Attribute V + VI-t abundance	<90%	NA
Attribute V + VI-t % richness	NA	<90%
Native cyprinid richness	≥1	NA
BCG Tier 6	**Headwaters**	
Metrics	Rule	Alternate
Attribute II + III + IV richness	Absent	Absent
Salamander richness	Absent	Absent
Mummichog, banded killifish, fathead minnow, green sunfish, goldfish, western mosquitofish, or carp	presence of 2 species	presence of 1 species
Top predator taxa (excluding American eel)	NA	Absent

*Sensitive salamander = N. dusky salamander, mountain dusky salamander, N. red salamander, N. spring salamander, longtail salamander

3.2 Cool/Warmwater (>4 square miles)

The cool/warmwater stream rules are presented in Table 3. These rules were developed using fish data from the sites evaluated by workgroup members. The rules were calibrated to ensure proper Tier assignment of workgroup test sites and site assignments completed by several BFBM staff. To account for variations in fish assemblage data, alternate rules were developed to appropriately place sites. Tier 4 is considered the impairment cut-off and any sites placed in Tiers 5 or 6 are considered to have impacts to assemblage structure and ecosystem function and are therefore considered impaired for aquatic life use. As a result, it was imperative that BCG rules properly placed sites with impairments for aquatic life use in Tiers 5 or 6 and non-impaired sites in Tiers 1-4. Several rounds of testing and rule development were completed before the rules were finalized in 2015. Tier rules are applied to fish data in an ascending order starting with BCG Tier 1 and proceeding through all the rules to determine if a site meets all criteria or if one proceeds to the next tier. BCG Tiers 2-6 require testing with all primary rules and if a site fails any part of the primary rule, it is tested against the alternate rule before moving to the next BCG Tier.

3.2.1 BCG Tier 1

The rules for BCG Tier 1 capture pristine unaltered conditions which the panel agreed likely does not exist in NJ streams greater than 4-square miles in drainage. These streams must be dominated by both native brook trout and slimy sculpin and young-of-the-year brook trout must be collected. In addition, sites must also pass all Tier 2 rules. As a result of land use/human activities in the surrounding watershed and environmental changes, most if not all brook trout/slimy sculpin dominated assemblages occur in smaller coldwater streams.

3.2.2 BCG Tier 2

Rules for BCG Tier 2 represent the realistic highest level for streams in this size category in NJ. Streams in Tier 2 represent minimal changes in assemblage structure and ecosystem function. These streams must have slimy sculpin or naturally reproducing trout present. At least 20% of the total abundance must be attribute II+III taxa along with at least 4 taxa from this group (attribute II+III) and nonnative tolerant taxa (attribute VI-t) must be absent.

Primary Rule

There is just one primary rule in which %abundance of attribute V taxa must be less than 20%.

Alternate Rule

Alternatively, if a site fails to meet the primary rule then the alternate rules states at least 5 or more attribute II+III+VI-i taxa must be present and attribute II taxa must be present.

3.2.3 BCG Tier 3

This Tier contains the majority of wild trout streams greater than 4 square miles, which are also characterized by having abundant minnow (Cyprinidae) populations and typically contain several sensitive taxa. These streams exhibit some change in assemblage structure, but minimal change in ecosystem function. Streams in Tier 3 must contain slimy sculpin or native/wild trout and at least 3 Cyprinidae taxa.

Primary Rule
At least 2 attribute II+III+VI-i taxa must be present and the percent abundance of attribute II+III+IV taxa must be at least 50%. In addition, the percent abundance of attribute V+VI-t taxa must be less than 30% and no more than 2 attribute VI-t taxa may be present.

Alternate Rule
At least 3 attribute II+III+VI-i taxa must be present and the percent abundance of attribute II+III+IV taxa must be at least 40%. In addition, attribute VI-t richness must be no more than 1 taxa.

3.2.4 BCG Tier 4
The majority of cool/warmwater (northern IBI) sites fall into Tier 4, as this represents the last level in which ecological function remains intact with moderate change in assemblage structure.

Primary Rule
Streams must contain at least 3 Cyprinidae species, while the % abundance of attribute V+VI-t taxa must be less than 65% and V+VI-t taxa must not represent more than half of the taxa collected.

Alternate Rule
Sites must have at least 4 Cyprinidae taxa **or** sites must have at least 2 attribute II+III+VI-i taxa along with at least 35% richness of attribute II+III+IV, no more than 70% abundance of attribute V+VI-t, and no more than 55% richness of attribute V+VI-t.

3.2.5 BCG Tier 5
Sites in Tier 5 represent the first group with a significant break-down in assemblage structure and moderate change in ecosystem function. Streams in Tier 5 are considered to have an impaired fish assemblage due to these changes in structure and function. These streams will have the most dominant taxa represent less than 65% of the total abundance.

Primary Rule
No more than 1 attribute II+III+VI-i taxa will be present and %abundance of attribute V+VI-t taxa will be less than 90%.

Alternate Rule
Sites must contain at least 2 Cyprinidae taxa and no more than 3 attribute VI-t taxa. In addition, a top predatory fish species, not including American eel, must be present.

3.2.6 BCG Tier 6
Streams in Tier 6 represent a complete loss of natural ecosystem structure and function. Streams in Tier 6 are considered to have a severely impaired fish assemblage due to significant changes in structure and function. Pollution tolerant fish species, which include banded killifish, mummichog, and green sunfish are often abundant. Sites in this category will have at least 2 of the 3 pollution tolerant species present.

Primary Rule

The percent abundance of attribute V+VI-t taxa will exceed 90%.

Alternate Rule

Cyprinid richness must be less than 2 taxa and %abundance V+VI-t taxa must be greater than 80%.

Table 3. Northern Fish IBI Biological Condition Gradient rules

BCG Tier 1		
Metrics	**Primary Rule**	**Alternate Rule**
Slimy sculpin + Brook Trout	Must be dominant 2 taxa	
Naturally reproducing brook trout	Present	
Tier 2 Rules	Must Pass All	
BCG Tier 2		
Metrics	**Primary Rule**	**Alternate Rule**
Slimy sculpin or naturally reproducing trout	Present	
%Abundance attribute II + III	>20%	
Attribute II + III richness	≥4	
Attribute VI-t taxa	Absent	
%Abundance attribute V	<20%	NA
Attribute II + III + VI-i richness	NA	≥5
Attribute II taxa	NA	Present
BCG Tier 3		
Metrics	**Primary Rule**	**Alternate Rule**
Slimy sculpin or native/wild trout	Present	
Cyprinidae richness	≥3	
Attribute II + III + VI-i richness	≥2	≥3
%Abundance attribute II + III + IV	≥50%	≥40%
%Abundance attribute V + VI-t	<30%	NA
Attribute VI-t richness	≤2	≤1

BCG Tier 4		
Metrics	**Primary Rule**	**Alternate Rule**
Cyprinidae richness	≥3	≥4
OR	NA	**OR**
Attribute II + III + VI-i richness	NA	≥2
%Richness attribute II + III + IV	NA	≥35%
%Abundance attribute V + VI-t	<65%	≤70%
%Richness attribute V + VI-t	≤50%	≤55%
BCG Tier 5		
Metrics	**Primary Rule**	**Alternate Rule**
%Abundance most dominant taxa	<65%	
Attribute II + III + VI-i taxa	≤1	NA
Cyprinidae richness	NA	≥2
%Abundance attribute V + VI-t	<90%	NA
Attribute VI-t richness	NA	≤3
Top predator taxa (Not incl. American eel)	NA	Present
BCG Tier 6		
Metrics	**Primary Rule**	**Alternate Rule**
Mummichog, banded killifish, green sunfish	2 of 3 sp. present	
Cyprinidae richness	NA	<2
%Abundance attribute V + VI-t	>90%	>80%

4 BCG Rule Performance and Use

4.1 Rule Performance

Headwaters

BCG rules correctly assigned 100% of sites into the same Tier assignment as the workgroup and BFBM testing (Table 4). A total of 95 sites were used in the rule development, testing and validation. No headwater sites were designated as Tier 1 (Table 5). Two sites (2%) did not fit into any BCG Tier. Nine sites (9%) were assigned to Tier 2, and 11 sites (12%) were assigned to Tier 3. Most of the sites (56%) fell into Tier 4. A total of 20 sites (21%) were placed into Tier 5 and 6, thus representing waters impaired for Aquatic Life Use.

Cool/Warmwater

BCG rules correctly assigned 84% of sites into the same Tier assignment as the workgroup and BFBM testing (Table 4). Sites which were not in agreement were off by one Tier assignment. These included several sites the workgroup placed in Tier 5, but the rules placed in Tier 6 and several sites the workgroup and BFBM staff assigned to Tier 4 which the rules placed higher in Tier 3. There were no sites which dropped from an impaired Tier (5 & 6) to an unimpaired Tier (2, 3 or 4) or vice versa. Overall, 149 sites were used in rule development, rule testing, and validation. Out of this total, just one site (0.8%) did not fit into any Tier. Of the 118 sites used in BFBM's rule testing and validation, just 6 sites (5.1%) did not fit into the correct Tier assignment using the rules.

Table 4. BCG panelist summary statistics for Coldwater and Cool/warmwater streams

	Rule Development	
Difference	**Headwaters**	**Cool/Warmwater**
1 Tier higher	0	3
Same Assignment	24	26
1 Tier Lower	0	2
Total No. Sites	24	31
%Correct	100%	83.9%

Out of the 118 sites used in rule testing and validation, most sites fell into Tier 4 while an almost equal number of sites were placed in Tiers 3 and 5 (Table 5). Just one site had a fish assemblage which represented the highest realistic Tier assignment (Tier 2) for coolwater/warmwater streams in New Jersey. Overall, 69% of sites had intact ecosystem function (Tiers 2-4), while 31% exhibited significant impacts to fish assemblage structure and ecosystem function (Tiers 5&6).

Table 5. BCG tier summary statistics for headwater and cool/warmwater streams

	Headwater		Cool/Warmwater	
BCG Tier	**No. Sites**	**%Sites**	**No. Sites**	**%Sites**
Tier 1	0	0%	0	0%
Tier 2	9	9%	1	1%
Tier 3	11	12%	31	26%
Tier 4	53	56%	49	42%
Tier 5	15	16%	32	27%
Tier 6	5	5%	5	4%

4.2 IBI Impairment Categories

New Fish and Headwaters IBI metrics and scoring criteria were developed in 2015 for high gradient streams north of the fall line (Vile and Henning 2018). The BCG Tier assignments were used to develop ratings breaks for each of the 5 IBI impairment categories (excellent, good, fair, poor, very poor). Scores for all sites in each BCG Tier were analyzed for natural scoring breaks. The upper bounds of the 95th confidence interval of IBI scores for sites in each Tier were used as the break point for each rating category. Both northern fish and headwater IBI sites in the excellent category represent the highest level of structure and function and are represented by BCG Tier 2 and some higher scoring sites from Tier 3. This is achieved by using the upper bound of the 95th confidence interval of IBI scores for sites in Tier 3. The same approach was used for sites in the remaining BCG Tiers. The good northern fish IBI category represents mainly sites from Tier 3 and some higher scoring Tier 4 sites. The good HIBI category represents some lower scoring Tier 2, mostly Tier 3 and some higher scoring Tier 4 sites. The fair northern fish IBI category represents mostly Tier 4 and some higher scoring Tier 5 sites. The fair HIBI category represents mostly Tier 4 and a few low scoring Tier 3 sites. The poor northern fish IBI category is represented by Tier 5 and a few high scoring Tier 6 sites, whereas the HIBI category is represented by mostly Tier 5 and low scoring Tier 4 sites. The very poor category is mainly Tier 6 sites with a few lower scoring Tier 5 sites for both IBIs. In addition, a box plot of least impaired site scores was included to further analyze the northern Fish IBI ratings breaks and further validates the scoring categories (Figure 5 and 6). Few true reference sites exist in streams over 4-square miles in New Jersey and therefore most least impaired sites are expected

to fall in the good category with a few sites stretching into the excellent and a few falling into the fair range, which is the distribution exhibited by the new rating categories.

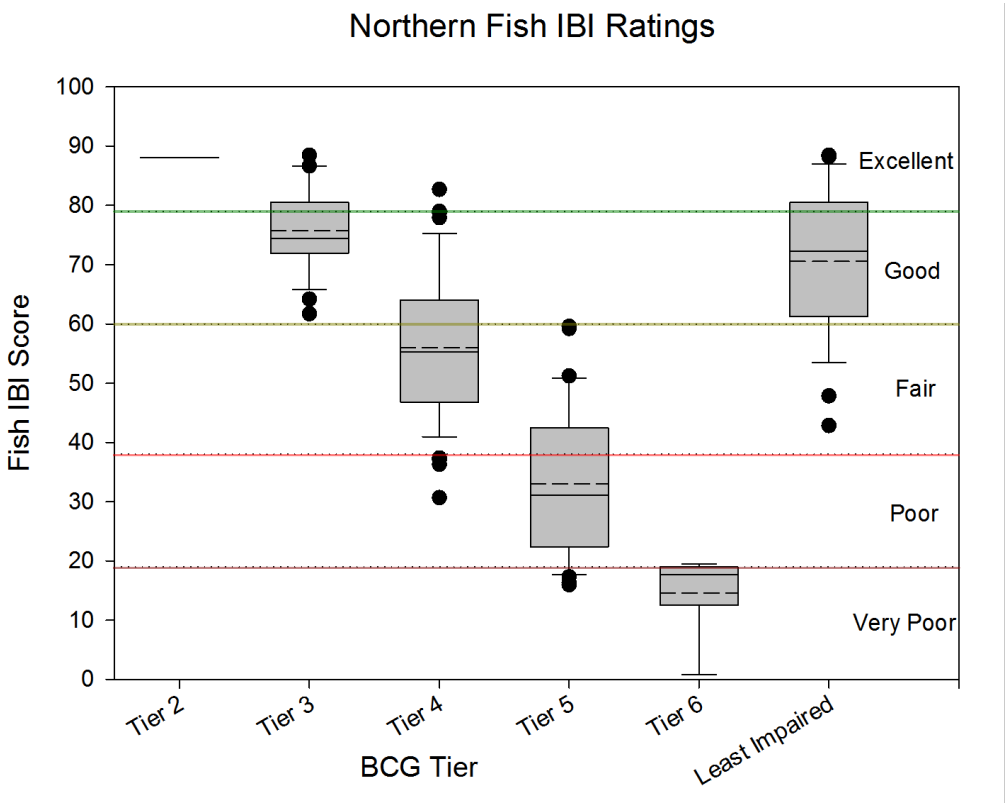

Figure 5. Northern Fish IBI score by BCG Tier

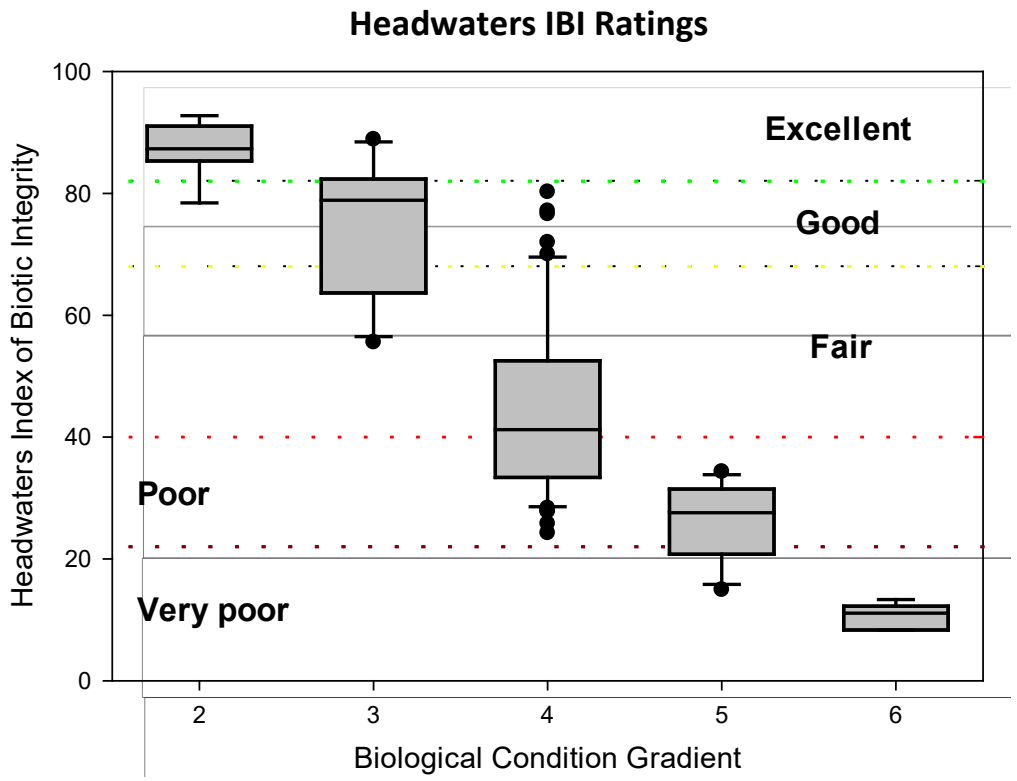

Figure 6. Headwaters IBI score by BCG Tier.

5 Discussion

The Fish BCG developed for wadeable streams above the fall line will serve to compliment the newly developed metrics for the NJ Northern Fish IBI and Headwaters IBI. These BCG rules encompass all waters from large 5th order wadeable streams all the way down to small first order fishless streams.

- The panel did not identify any Tier 1 sites in the current FIBI/HIBI dataset and if Tier 1 sites do exist, they are likely small coldwater streams (<4 miles^2).
- Non-native trout were identified as attribute VI taxa, but were given a sub-attribute identifier (i) which indicates they are non-native, but are indicators of good water quality. Many non-native species have become naturalized in NJ and have a wide range of tolerance and disturbance qualities. The sub-category permits a differentiation between sites containing several non-native species. Wild rainbow trout are far more sensitive to water chemistry and habitat degradation than many other non-natives such as green sunfish or common carp. Therefore, sites containing high percentages of non-native species should take the sensitivities of these species into account.
- Migratory species, such as American eel and sea lamprey, were given a sub-attribute identifier (A). Their presence at a site was a good indicator of connectivity in the

watershed which was included in site discussion amongst panel members, but there was not enough discriminatory value to include migratory species as a rule.

- NJ contains a number of small fishless streams in the coldwater category (<4 miles^2) which need additional data and further evaluation to develop Tier rules and aquatic life use statues.
- There was very good agreement in Tier assignments between the panelists and the BCG rules (84%-100%).
- Alternate rules were developed to account for exceptions to the primary rules.
- Stocked trout were not included in any of the datasets used to develop or test BCG rules.
- Using the new BCG rules for FIBI sites (>4 miles^2) indicate 73% of sites have intact ecosystem structure and function and therefore are considered non-impaired compared to 69% of sites which meet the goals of aquatic life use according to IBI score and rating.
- In 2012, BFBM implemented the southern fish IBI for the Inner Coastal Plain ecoregion which should be considered as the next region for BCG development, especially considering there is no fish or macroinvertebrate BCG for this area. This ecoregion presents many challenges due to the level of degradation and habitat loss in streams in this part of the state. The BCG process could potentially shed some light on these low gradient aquatic communities which could assist with future refinement of existing fish and macroinvertebrate indexes.

6 Literature Cited

Davies, S.B., and S. K. Jackson. 2006. The Biological Condition Gradient: A descriptive model for interpreting change in aquatic ecosystems. Ecological Applications 16(4):1251–1266.

Gerritsen and Leppo. 2005. Biological Condition Gradient for Tiered Aquatic Life Use in New Jersey. Prepared for U.S. EPA OST, U.S. EPA Region 2, and the New Jersey Department of Environmental Protection. Prepared by Tetra Tech, Inc., Owings Mills, MD.

Keller, D.H., R.J. Horwitz, A.M. Kreit, and P.F Overbeck. 2012. Development of Bioassessment Criteria for Headwater Streams, Phase III. The Academy of Natural Sciences of Drexel University. Philadelphia, PA.

Mattfeldt, S. D. & E. H. C. Grant, 2007. Are two methods better than one? area constrained transects and leaf litterbags for sampling stream salamanders. Herpetological Review 38: 43–45.

NJDEP, 2018. NJ Fish Monitoring Standard Operating Procedures (SOP).

Stamp, J. and J. Gerritsen 2013. A Biological Condition Gradient (BCG) assessment model for stream fish communities of Connecticut. Prepared for the U.S. EPA Office of Science and Technology and Connecticut Department of Environmental Protection. Prepared by Tetra Tech, Inc., Owings Mills, MD.

Strain, G.F., R.L. Raesly, and R.H. Hilderbrand. 2009. A comparison of techniques to sample salamander assemblages along highland streams of Maryland. Environmental Monitoring and Assessment 56:1-16.

USEPA, 1999. Rapid bioassessment protocols for use in streams and rivers: periphyton, benthic macroinverbrates, and fish. Second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency. Washington, D.C. Ch. 1–11 and appendices.

Vile, J. S., & Henning, B. F. (2018). Development of indices of biotic integrity for high-gradient wadeable rivers and headwater streams in New Jersey. Ecological Indicators, 90, 469–484. https://doi.org/10.1016/j.ecolind.2018.03.027

Appendix A: Fish, Amphibian and Crayfish BCG Attribute Assignments

Family/Common Name	Scientific Name	Historical Presence	BCG Attribute Group (1-6)
Petromyzontidae			
American Brook Lamprey	*Lethenteron appendix*	N	2
Sea Lamprey	*Petromyzon marinus*	N	4A
Anguillidae			
American Eel	*Anguilla rostrata*	N	5A
Clupeidae			
Alewife	*Alosa pseudoharengus*	N	4A
Gizzard Shad	*Drosoma cepedianum*	N	5
Salmonidae			
Rainbow Trout	*Oncorhynchus mykiss*	NN	6I
Brown Trout	*Salmo trutta*	E	6I
Brook Trout	*Salvelinus fontinalis*	N	2
Umbridae			
Eastern Mudminnow	*Umbra pygmaea*	N	5
Esocidae			
Redfin Pickerel	*Esox americanus*	N	4
Northern Pike	*Esox lucius*	NN	6M
Chain Pickerel	*Esox niger*	N	4
Cyprinidae			
Goldfish	*Carassius auratus*	E	6T
Satinfin Shiner	*Cyprinella analostana*	N	4
Spotfin Shiner	*Cyprinella spiloptera*	N	4
Common Carp	*Cyprinus carpio*	E	6T
Cutlips Minnow	*Exoglossum maxillingua*	N	3
Eastern Silvery Minnow	*Hybognathus regius*	N	4
Common Shiner	*Luxilis cornutus*	N	4
Golden Shiner	*Notemigonus crysoleucas)*	N	5
Comely Shiner	*Notropis amoenus*	N	4
Bridle Shiner	*Notropis bifrenatus*	N	2
Ironcolor Shiner	*Notropis chalybaeus*	N	2
Spottail Shiner	*Notropis husdonius*	N	4
Swallowtail Shiner	*Notropis procne*	N	4
Bluntnose Minnow	*Pimephales notatus*	NN	6T
Fathead Minnow	*Pimephales promelas*	NN	6T
Blacknose Dace	*Rhinichthys atratulus*	N	4
Longnose Dace	*Rhinichthys cataractae*	N	3
Creek Chub	*Semotilus atromaculatus*	N	4
Fallfish	*Semotilus corporalis*	N	4

Family/Common Name	Scientific Name	Historical Presence	BCG Attribute Group (1-6)
Cobitidae			
Oriental Weatherfish	*Misgurnus anguillicaudatus*	E	6T
Catostomidae			
White Sucker	*Catostomus commersonii*	N	5
Eastern Creek Chubsucker	*Erimyzon oblongus*	N	3
Northern Hog Sucker	*Hypentelium nigricans*	N	3
Ictaluridae			
White Catfish	*Ameiurus catus*	N	5
Black Bullhead	*Ameiurus melas*	NN	6T
Yellow Bullhead	*Ameiurus natalis*	N	5
Brown Bullhead	*Ameiurus nebulosus*	N	5
Channel Catfish	*Ictalurus punctatus*	NN	6M
Tadpole Madtom	*Noturus gyrinus*	N	3
Margined Madtom	*Noturus insignis*	N	3
Aphredoderidae			
Pirate Perch	*Aphredoderus sayanus*	N	4
Cyprinodontidae			
Banded Killifish	*Fundulus diaphanus*	N	5
Mummichog	*Fundulus heteroclitus*	N	5
Poeciliidae			
Western Mosquitofish	*Gambusia affinis*	NN	6T
Eastern Mosquitofish	*Gambusia holbrooki*	N	5
Moronidae			
White Perch	*Morone americana*	N	4
Striped Bass	*Morone saxatilis*	N	4A
Centrarchidae			
Rock Bass	*Ambloplites rupestris*	NN	6M
Bluespotted Sunfish	*Enneacanthus gloriosus*	N	3
Redbreasted Sunfish	*Lepomis auritus*	N	4
Green Sunfish	*Lepomis cyanellus*	NN	6T
Pumpkinseed	*Lepomis gibbosus*	N	5
Bluegill	*Lepomis macrochirus*	NN	6T
Smallmouth Bass	*Micropterus dolomieu*	NN	6M
Largemouth Bass	*Micropterus salmoides*	NN	6M
White Crappie	*Pomoxis annularis*	NN	6M
Black Crappie	*Pomoxis nigromaculatus*	NN	6M

Family/Common Name	Scientific Name	Historical Presence	BCG Attribute Group (1-6)
Percidae			
Tessellated Darter	*Etheostoma olmstedi*	N	5
Yellow Perch	*Perca flavescens*	N	4
Shield Darter	*Percina peltata*	N	3
Walleye	*Sander vitreus*	NN	6M
Cottidae			
Slimy Sculpin	*Cottus cognatus*	N	2
Ranidae			
Bullfrog	*Lithobates catesbeianus*	N	5
Green Frog	*Lithobates clamitans*	N	5
Pickerel Frog	*Lithobates palustris*	N	4
Salamandridae			
Northern Dusky Salamander	*Desmognathus fuscus*	N	3
Mountain Dusky Salamander	*Desmognathus ochrophaeus*	N	2
Northern Two-lined Salamander	*Eurycea bislineata*	N	4
Longtail Salamander	*Eurycea longicauda longicauda*	N	2
Red-spotted Newt	*Notophthalmus viridescens viridescens*	N	4
Northern Red Salamander	*Pseudotriton ruber ruber*	N	3
Northern Spring Salamander	*Gyrinophilus porphyriticus porphyriticus*	N	2
Cambaridae			
Common Crayfish	*Cambarus bartonii bartonii*	N	3
Spinycheek Crayfish	*Orconectes limosus*	N	4
Allegheny Crayfish	*Orconectes robustus*	NN	6T
Rusty Crayfish	*Orconectes rusticus*	NN	6T
Virile Crayfish	*Orconectes virilis*	NN	6T
White River Crayfish	*Procambarus acutus*	N	4
Red Swamp Crayfish	*Procambarus clarkii*	NN	6T

N=Native, NN= Nonnative (introduced), E = Exotic

6I = Nonnative Intolerant, 6M = Nonnative Intermediate tolerance, 6T = Nonnative Tolerant

A = Migratory Species