Development of the Inner Coastal Plain Fish IBI for Southern New Jersey

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Background

In 2000, the Bureau of Freshwater Fisheries (BFF) initiated a pilot project to assess the feasibility of developing a Fish Index of Biotic Integrity (IBI) in New Jersey's Inner Coastal Plain eco-region. This fish IBI would use fish as bio-monitors to assess aquatic life use, similarly to the NJ Fish IBI Program developed for the northern part of the state by the U.S. Environmental Protection Agency (USEPA) Region 2 in 2000 and later refined by the Bureau of Freshwater and Biological Monitoring (BFBM) in 2005. This pilot study was being conducted on wadeable Delaware River draining streams/rivers which were outside the Pinelands boundary and south of the fall line (Figure 1).

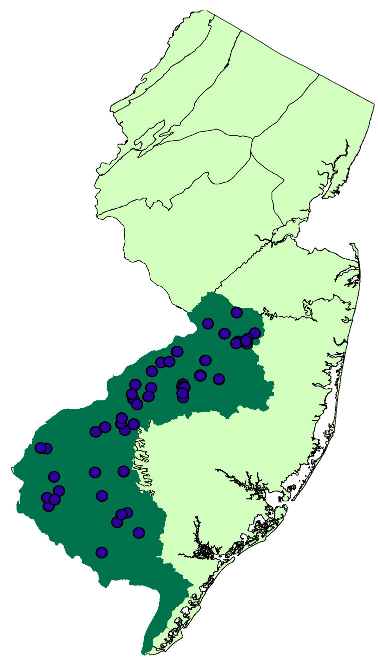

Figure 1. Outline of study area.

In June 2006, the results of the pilot study were presented to members of the Fish IBI workgroup, which includes staff from US Geological Survey, US EPA Region 2, DEP's Office of Science, Water Monitoring and Standards, and the Philadelphia Academy of Natural Sciences of Drexel University. BFBM took over the responsibility of future refinement and finalizing this monitoring program. In February 2007, BFBM received fish data from BFF and began an evaluation of the pilot study to determine the steps needed to finalize the program and initiate long-term monitoring. After a thorough assessment of the data and pilot project, it was determined further refinements were necessary to ensure the program met all six criteria of a valid index of biotic integrity (Karr et al. 1986) in particular, criterion five and six:

Criterion 1. The measure must be biological

Criterion 2. The measure must be interpretable at several trophic levels to provide a connection to other organisms not directly involved in the monitoring.

Criterion 3. The measure must be sensitive to the environmental conditions being monitored

Criterion 4. The response range of the measure must be suitable for the intended application

Criterion 5. The measure must be reproducible and precise within defined and acceptable limits for data collected over space and time

Criterion 6. Variability of the measure must be low.

In 2008, the Bureau began taking steps to recalibrate the IBI to ensure a valid index was being developed which could be used by the Department to assess the waters of the state 305(b), identify impaired water bodies 303(d), and identify waters in need of special protection through the Category One process. An extensive literature and information search was conducted on historical fish distributions within the Inner Coastal Plain. This research indicated fish assemblages and conditions within the Inner Coastal Plain historically resemble that of least impacted sites in this eco-region of New Jersey and other nearby states.

Several Atlantic coast states have developed or are in the process of developing Coastal Plain Fish IBI's and have similar stream conditions and fish assemblages as NJ. The North Carolina Division of Water Quality has been conducting Fish IBI monitoring since the early 1990's and is currently revising the index used for coastal plain streams. Several NC fish metrics were evaluated and two trophic metrics (%Insectivores and %Piscivores) are being used for the NJ index. Maryland Department of Natural Resources, in cooperation with Versar, Inc., completed a refinement and validation of their coastal plain Fish IBI in 2000 and completed a refinement in 2005. Maryland has the most refined coastal plain IBI and has very similar coastal streams and fish assemblages as NJ. Typical coastal fish species such as creek chubsucker, tadpole madtom, banded sunfish, Bluespotted sunfish, and mud sunfish are also found in Maryland's coastal plain streams. As such, the Maryland index was used as a template for developing/refining metrics for NJ and for establishing thresholds for reference/degraded conditions.

Site Selection

Geographic Information System (GIS) was used to identify potential "least impaired" and "most impaired" sites based on 2002 and 2007 land use/land cover. The main criteria used for impact classification was %forest/wetland, %urban, %impervious cover, and pH. Instream habitat, fish abundance, and species richness were used post sampling to accept or eliminate least impaired sites (Table 1). As true reference conditions do not exist in NJ's Inner Coastal Plain, it was imperative that least impacted sites have minimal anthropogenic stressors. A key component of this was to ensure enough fish and fish species were collected in a sample reach to accurately characterize reference condition. Any site meeting the least impacted land use/land cover criteria which did not contain at least 100 fish and 5 species was eliminated from the analysis, as studies have shown it to be impossible to accurately characterize reference conditions with fewer than 100 fish and 5 species (Roth et al. 2000).

Table 1. Impact Classification.

Condition	Least Impacted Sites N=21	Most Impacted Sites N=24
%Forest/Wetland	>50%	<35%
%Urban	<20%	>60%
%Impervious Cover	<5%	>19%
pH	>5.5	None
Instream Habitat	Optimal or Sub-optimal	None
Fish Abundance	>100	None
Fish Richness	>5	None

Methods

See standard operating procedures (SOP) for information regarding Fish IBI field methods (http://www.nj.gov/dep/wms//bfbm/ibireports.html).

Metric Development

In 2008, BFBM began an intensive sampling effort targeting sites identified as potential least impacted and most impacted. In 2009, a total of 29 least impacted/most impacted sites along with 64 other sites were used to develop and assess low gradient fish metrics using the methods and analysis outlined by Maryland DNR. In 2012, an additional 14 least impaired/most impaired sites were added for final analysis. The final dataset consisted of 45 least impacted/most impacted and 111 total sites. Coastal plain fish metrics from Maryland, North Carolina, Virginia, and Georgia were tested along with standard fish metrics developed by Karr (1986) and NJ high gradient fish metrics used in the northern part of the state. In total, over 40 metrics were tested against various stressor gradients.

Development and final metric testing consisted of analyzing all data for general trends with various stressors and land use/land cover using Pearson's correlation. Mann-Whitney analysis was used to test for significant differences in medians between least impaired and most impaired sites (Table 2). A Kolmogorov-Smirnov test was used to compare distributions of least impaired and most impaired data. Metrics were selected for further analysis based on results from the three screening analyses. Regression analysis was performed to compare raw metric data versus forest/wetland and urban land use land cover, impervious cover, habitat score, and drainage size.

Table 2. Results of Mann-Whitney (M-W), Kolmogorov-Smirnov (K-S), and Pearson Correlation Analysis. Significant results are in bold ($p < 0.05$).

	2012 Reference n = 21 Impaired n = 24		2012 n = 111 Pearson Correlation	
Metric	M-W	K-S	Urban	Forest
Native Sp.	***P* < 0.001**	***P* < 0.001**	**-0.29**	**0.39**
Benthic Sp.	***P* < 0.001**	***P* < 0.001**	**-0.48**	**0.35**
Intolerant Sp.	***P* < 0.001**	***P* < 0.001**	**-0.41**	**0.46**
% Tolerants	***P* < 0.001**	***P* = 0.001**	**0.47**	**-0.27**
% Insectivores	***P* < 0.001**	***P* < 0.001**	**-0.48**	**0.30**
% Piscivores	***P* = 0.002**	***P* = 0.001**	-0.18	**0.24**
Abundance	***P* < 0.001**	***P* = 0.001**	**-0.21**	0.07

The final group of metrics which passed screening analysis were compared for significant metric redundancy using Pearson's correlation analysis. Metrics with a correlation greater than 0.75 were re-evaluated and one of the two was eliminated (Emery et al. 2003). Two metrics which measured overall species richness and native species richness exhibited significant redundancy ($r = 0.97$) and as a result of better performance in the screening analysis, the native richness metric was selected and the species richness metric was eliminated.

In spring 2009, metric results and testing methodology were presented to fisheries staff from Maryland DNR, Versar, Inc. and USEPA Regions 2 and 3 for review and comment. All comments were positive and all parties involved agreed with the overall approach and results/conclusions. Minor comments were addressed prior to the May 2009 IBI Workgroup meeting.

On May 27, 2009, the revised Southern Fish IBI was presented to members of the Fish IBI Workgroup. Members of the workgroup agreed that additional work was needed on the pilot Inner Coastal Plain Index and there was a consensus with the redevelopment following the methodology utilized by Maryland DNR and North Carolina Division of Water Quality. Based on feedback from the workgroup meeting, it was determined the metrics should be validated using an n-1 statistical approach, along with additional monitoring.

Validation

A jackknife analysis was used on the least impaired/most impaired dataset (n = 45) to remove a single data point prior to running the non-parametric Mann-Whitney analysis. This process was repeated until each point had been removed and analyses run. The goal of this analysis was to detect outliers in the dataset to determine bias and standard error. All 45 pairwise comparisons among least impaired and most impaired sites were significant at $P < 0.05$ for each of the first seven metrics. The DELT anomalies metric, which is a measure of abnormalities in fish, was significant for only 7 of 33 cases. This metric typically is only reliable when water quality is severely impaired, but can be an important component of an ibi for those situations.

Metrics were also validated using bootstrapping analysis which randomly selects a subset of the dataset to run the non-parametric analysis, replaces those sites and randomly selects a new subset to analyze. A random subset of 35 sites was selected from the least impacted/most impacted dataset. The bootstrap dataset and subsequent non-parametric Mann-Whitney pairwise comparison was repeated 45 times for each metric. All 45 cases for the first seven metrics were significant at $P < 0.05$ when comparing least impaired and most impaired data. The DELT anomalies metric comparisons were significant for 10 of 33 cases.

Metrics were further evaluated for performance using coefficient of variability (CV) and percent discriminatory efficiency (DE) (Table 3). The CV, which compares the standard deviation to the mean ranged from 16.6 to 126.9. Seven of 8 metrics had CV's below 44.3, while the %Piscivore metric was high (126.9) indicating high variability among sites. The %DE, which is used to calculate the percentage of impaired sites below the 25^{th} percentile of least impaired ranged from 70.8% to 91.7% for 7 of the 8 metrics. The percent DELT anomalies metric had a 46.2% DE, as this metric if effective at discriminating severe water quality impairments.

Table 3. Results of Coefficient of Variability and Discrimination Efficiency analysis.

Metric	Coefficient of Variability (CV)	Discrimination Efficiency (DE)
Native Sp.	16.6	87.50%
Benthic Sp.	19.8	83.30%
Intolerant Sp.	44.3	91.70%
% Tolerants	24.4	70.80%
% Insectivores	35.0	83.30%
% Piscivores	126.9	70.80%
Abundance	39.4	75.00%
DELTs	32.3	46.20%

<u>Scoring</u>

Several metric scoring techniques were evaluated including: Fausch maximum species richness (MSR) plots, Lyons modified MSR plots, Maryland DNR discrete scoring, Klemm continuous scoring, Tetra Tech continuous scoring, and a modified continuous scoring technique (Blocksom 2003). Scoring techniques were evaluated by comparing discrimination efficiencies, coefficient of variability, and overall scores among least impacted and most impacted sites. Based on results of the analysis and the desire to conform Fish IBI scoring criteria to that of the Ambient

Biological Monitoring Program (AMNET), the continuous scoring method developed by Tetra Tech was selected.

All richness metrics had significant relationships with drainage size which required scoring adjustments, as the number of fish species collected tends to increase with a stream's drainage size (Table 4). Metrics exhibiting a strong relationship ($r^2 > 0.25$) with drainage were adjusted using the linear regression model of the least impaired dataset and the following adjustment:

adjusted value = mean reference + observed – predicted

where predicted value= m * $\log_{10}$ (drainage area in mi^2) + b (Tetra Tech, Inc. 2007).

Table 4. Metric adjustments for catchment size.

Number of Native Species	11.05 + x - [Log_{10}(Drainage Area * 2.7828) + 8.6142]
Number of Benthic Insectivores	2.29 + x - [Log_{10}(Drainage Area * 0.6293) + 1.7354]
Number of Intolerant Species	1.38 + x - [Log_{10}(Drainage Area * 0.7737) + 0.7043]

Each metric was scored on a continuous scale using the 95^{th} percentile of reference and impaired data as the upper threshold and zero as the lower threshold for metrics which decrease with an increase in stress (Table 5):

$$Score = 100 \times Metric\ Value/95^{th}\ Percentile$$

Metrics which increase with an increase in stressor levels were scored using the 5^{th} percentile of reference as the upper limit using the formula:

$$Score = 100 \times (95^{th}\ Percentile – Metric\ Value)/(95^{th}\ Percentile – 5^{th}\ Percentile)$$

Table 5. Fish IBI metrics and scoring criteria.

Metric	Response	Scoring
Native Richness	↓	100 * X /15
Benthic Richness	↓	100 * X /3
Intolerant Richness	↓	100 * X /2
% Tolerants	↑	100 * (93.5 – X) /93.5
% Insectivores	↓	100 * X /61.2
% Piscivores	↓	100 * X /31.8
Abundance	↓	100 * X /299
DELTs	↑	100 * (3.4 - X) /3.4

Network Development
In order to expand the Fish IBI to new waters not currently assessed, while at the same time being able to track trends over time, and monitor reference sites for long term changes in the environment, the Fish IBI network was redesigned in 2012 to mimic the network developed by the Maryland Biological Stream Survey (MBSS). To meet these goals, while also building toward the long-term goal of a 200 site network, the redesigned statewide Fish IBI network consists of 90 fixed, 50 probabilistic, and 10 sentinel stations.

Probabilistic Network
Probabilistic sites were selected in cooperation with USEPA using a Generalized Random Tessellation Stratified (GRTS) survey design for a linear resource from a 1:24 K coverage of non-tidal streams outside of the Pinelands. A total of 50 probabilistic sites were selected for the two fish IBI networks (35 N_IBI sites and 15 S_IBI sites).

Northern sites were stratified to include only streams greater than 5 square miles, north of the fall line, and located more than one mile downstream of any impoundment. Coastal sites were south of the fall line, outside the Pinelands, and were greater than 2.0 square miles. Streams ranged in orders from 1 through 6, with most applicable sites falling in orders 3 and 4. Sites will be sampled over a 5-year period and as a result 10 sites (8 N_IBI and 2 S_IBI) will be sampled each year.

Sentinel Network
Sentinel sites are a group of reference sites which will be monitored on a continuous basis to evaluate environmental changes, such as global warming. A total of 10 sites (8 N_IBI and 2 S_IBI) were selected with 5 sites sampled each year. The criteria for selecting sentinel sites are as follows:

- Sites must have scored in the “good” or “excellent” Fish IBI rating range
- Recent site data must contain at least 2 intolerant species, and stocked trout are not to be included (data has shown intolerants are sensitive to change and are the first species to disappear as a result of degradation
- The most recent habitat score must be above 150
- If stocked trout were collected at the site, wild trout must have also been collected at that site
- Percent urban land use must be less than 20%
- Site should have some level of protection i.e. Wildlife Management Area

Fixed Network
The fixed network is comprised of sites which have been previously sampled by the Fish IBI Program and are important for assessing long-term trends. Sites selected as sentinel sites were not included in the fixed site network. Access to the stream will also be considered, as several streams have been dropped from the network in recent years as a result of losing landowner permission. A greater emphasis will be placed on sites with public access. In addition, overall score will be considered to achieve a good distribution of scores among network sites to ensure

the continued collection of data across a range of disturbance gradients in order to re-evaluate metrics in the future. The number of sites selected from each water region was based on the area. The fixed network for the northern fish IBI consists of 55 sites divided into each of the three water regions: Upper Delaware (19 sites), Raritan (21 sites), and Northeast (15 sites). The fixed network for the southern fish IBI consists of 35 sites divided between the Inner Coastal Plain (26 sites) and the Outer Coastal Plain (9 sites).

Current Southern IBI Monitoring

Sampling at probabilistic sites was initiated in 2011 and to date, 6 random sites have been sampled (Table 6). In addition, 5 sentinel sites were sampled to evaluate fish assemblage and habitat criteria. Additional sentinel sites will be evaluated in the future including Ivanhoe Brook FIBI213.

Table 6. Probabilistic and Sentinel sites sampled in 2011 and 2012.

Site ID	Stream	Network	Stratum	2011	2012
NJS11-137	Lower Alloways Creek	Probabilistic	S_IBI	X	
NJS11-138	Toms River	Probabilistic	S_IBI	X	
NJS11-141	Pleasant Run	Probabilistic	S_IBI	X	
NJS11-142	Salem River	Probabilistic	S_IBI		X
NJS11-149	North Branch Rancocas Creek	Probabilistic	S_IBI		X
NJS11-222	Great Ditch	Probabilistic	S_IBI		X
FIBI211	Lahaway Creek	Sentinel	S_IBI	X	
FIBI217	SB Rancocas Creek	Sentinel	S_IBI	X	
FIBI224	NB Rancocas Creek	Sentinel	S_IBI	X	
FIBI225	Lahaway Creek	Sentinel	S_IBI	X	
FIBI211	Lahaway Creek	Sentinel	S_IBI		X

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