A MID-ATLANTIC STREAM SUITABILITY INDEX FOR BROOK TROUT (*SALVELINUS FONTINALIS*)

by

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Environmental Science and Public Policy

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DEDICATION

This body of work is dedicated to my wonderful family who have supported me throughout this endeavor.

ACKNOWLEDGEMENTS

I give thanks to my committee members, Dr. Chris Parsons, Dr. Gregory Foster and Dr. Gregory Perrier, for all their efforts and guidance. I give special thanks to my advisor, Dr. Dann Sklarew, who willingly accepted me as an advisee. His wisdom and positive outlook have often been the only inspiration that kept me moving forward with my research.

A special thanks is extended to the Maryland Department of Natural Resources and associated state agencies for providing much of the data and field methodology described in this document.

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LIST OF ABREVIATIONS AND SYMBOLS

AESTHET.. Aesthetic value
DIST_RD... Distance to the nearest dirt or paved road (m) in catchment upstream of site
DO_FLD.. Dissolved oxygen (mg/L)
EPI_SUB.. Epifaunal substrate
FIBI...Fish Index of Biological Indicators
IBI...Index of Biological Indicators
Instantaneous threshold...........................A scientific, socio-political or economic barrier
LOG_RD... Log normalized DIST_RD data
MD DNR...Maryland Department of Natural Resources
Minitab 16.........................The primary statistical software package utilized in this study
PCA...Principal component analysis
PC...Principal components (unitless)
%Ag............................ Percentage of agricultural land use in catchment upstream of site
%forest............................. Percentage of forested land use in catchment upstream of site
RIFFQUAL.. Riffle Run Quality
RIP_WID.. Riparian wideness (m)
TEMP_FLD.......................... Spring time (March through April) water temperature (˚C)
VA DEQ...Virginia Department of Environmental Quality

Further explanation of the above and additional abbreviations and symbols, specific to MDNR database coding and parameters, are provided as Appendix B.

ABSTRACT

A MID-ATLANTIC STREAM SUITABILITY INDEX FOR BROOK TROUT (*SALVELINUS FONTINALIS)*

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A Mid-Atlantic multimetric index provides a quick and cost effective assessment of brook trout streams or potential brook trout streams in the Mid-Atlantic United States. Using five core metrics--three in-stream metrics (riffle/run quality, dissolved oxygen content and water temperature) and two watershed metrics (percent land use in agriculture and distance to the nearest road from the survey site), the index can be calculated in the field by professional natural resource managers or trained volunteers. The index should be used in concert with other assessment tools, including a classification model designed to allow resource managers to quickly screen a given stream reach in order to determine its potential for supporting sustainable populations of brook trout. Used in tandem, the classification model could provide a preliminary assessment of a stream, followed by a secondary assessment using an index rating to further evaluate stream quality and potential.

CHAPTER 1

Introduction

Native eastern brook trout (*Salvelinus fontinalis*) populations are declining in their native range in the Eastern United States (EBTJV, 2007). The species is the only indigenous trout within the region. Sensitive to degrading environmental conditions or rapidly altering habitat, brook trout appear to be ideal bioindicators of headwater biodiversity in coolwater watersheds of the Eastern United States (Stranko, Hilderbrand, Morgan II, et al., 2008). Meyer et al. (2007) reveal the deep importance of headwaters in protection of biodiversity. This is where the terrestrial/aquatic interface is most active. Headwaters act as great buffers between land and water while also providing critical habitat for a variety of biota, both plant and animal.

Brook trout are endemic to the eastern portion of the United States and Canada. The natural range for brook trout consists of the cool and cold water rivers and streams of the eastern portions of North America. Figure 1 shows the historical range of brook trout, including a 50 km buffer around the range. Today, many of the historic populations are threatened by environmental degradation, mostly of anthropogenic origin

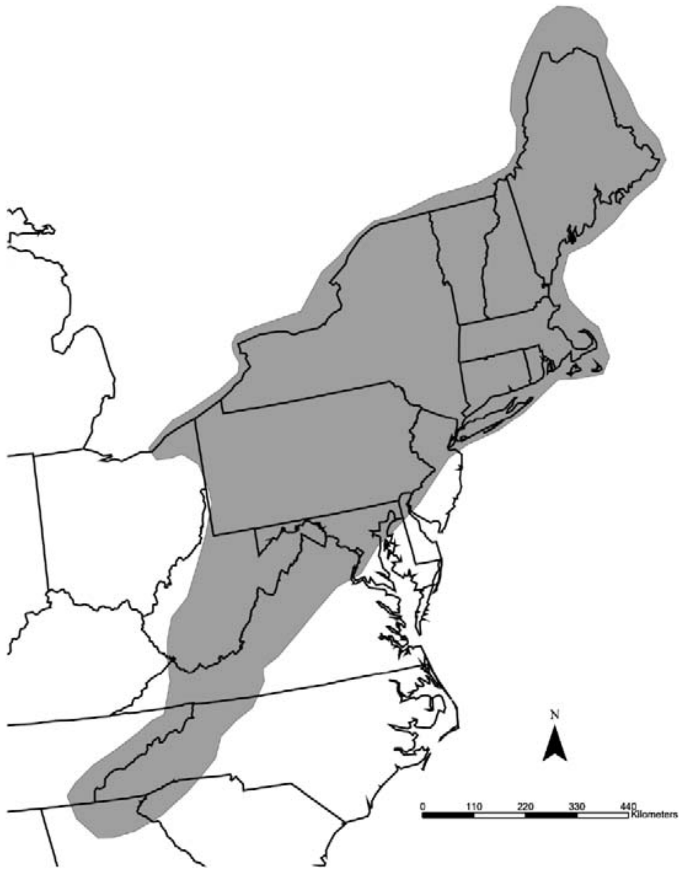

Figure 1. Historical U.S. range of brook trout (Hudy, Thieling, Gillespie, and Smith, 2008a).

(Hudy et al., 2008). Only 5% of the original brook trout populations in the United States, all of which are in Maine, remain at or near their historic numbers. Upon examination of figure 2, it appears there may be a relation between threatened brook trout populations and latitude with the southern latitudes showing the most threatened populations. Figure 2 also reveals the severity of fragmentation between populations compared to the historical range of the species. Increased human activity (e.g., farming, timber harvesting, residential development) in the Eastern United States provides for various and numerous stressors to brook trout populations. Data from the U.S. Census Bureau indicate an increase of approximately 90 million people from 1800 to 1900 (Census Bureau, 2002) within the historic range of the brook trout. Unlike the 20th century, most of the population expansion during the 19th century was in rural and outlying areas where forests were cut and farming developed (Dale et al., 2000).

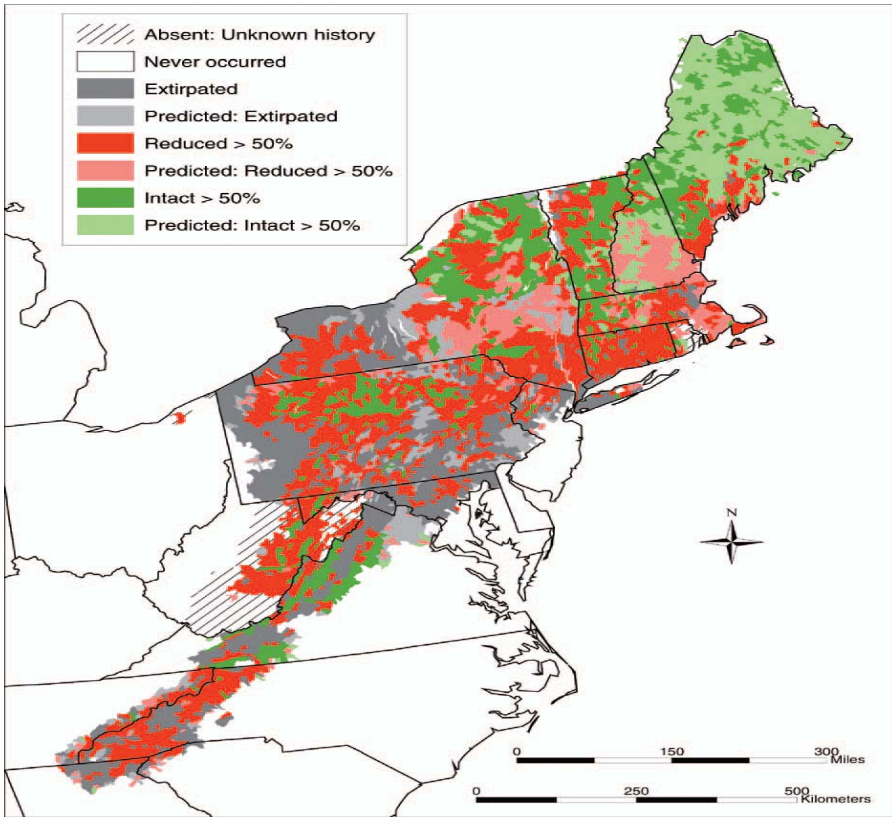

Figure 2. Distribution of brook trout status classifications in subwatersheds throughout the species' Eastern U.S. range (Hudy, Thieling, Gillespie, and Smith, 2008a).

The very presence of brook trout in the streams serves as an indicator of a healthy stream system while declining populations may indicate declining health of the stream ecosystem (Venture, 2007). Evidence for such measures of sensitivity is revealed in figure 2 which shows intact populations of brook trout are largely in sparsely populated rural areas or on federal lands, both which incur relatively little impact from human activity. Declining brook trout populations have been attributed to several anthropogenic origins. Hartman and Hakala (2006) suggest fine sediment loading from logging practices could be the main detriment to brook trout recruitment. Fine sediments (<0.063 mm) decrease stream biodiversity by smothering eggs and larval brook trout thereby depriving them of oxygen. It is also suggested these fine sediments alter stream biodiversity by covering the habitat necessary for many macroinvertebrate species. Hartman and Hakala (2006) conclude sediment loading may be the most important factor determining stream health. Furthermore, Utz and Hartman (2007) indicate brook trout survival is largely dependent on terrestrial insect abundance. Baldigo et al., (2005) report high mortality rates of brook trout in streams where poor timber harvest methods practiced near riparian zones result in increased siltation and surface water temperatures.

Healthy brook trout trophy fisheries exist in Maine and Canada where brook trout can attain large size and survive for many years (Venture, 2007). For various reasons, brook trout are often forced out of their natural range in most of the Eastern United States and resort to survival in headwater streams with limited nutrient resources (Venture, 2007). Brook trout 20 inches long were caught in Western Maryland streams in the 1800s (Maryland, 2006). The loss of growth potential can be attributed to inability to access food sources in second order and higher streams due to the presence of non-indigenous species, such as smallmouth bass, which may prey on brook trout and non-indigenous trout which outcompete brook trout for forage and spawning locations (Venture, 2007). Consequently brook trout are forced into the headwaters where they are isolated from other populations of brook trout. The pockets of isolation contribute to fragmented gene pools within the species. The inability to maintain genetic diversity within a species has been reported as one of the first stages of extinction (Wilcox and Murphy, 1985).

Analysis of Factors Affecting Brook Trout Biodiversity

Habera and Moore (2005) described the severity of brook trout fragmentation in its southern range. Their findings indicate brook trout have been forced into the headwaters of most rivers and streams due to competition from exotic species, primarily rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) and for need of cooler water found at higher altitudes. The geographical isolation of the trout decreases genetic diversity within the overall trout population, a significant complication in species preservation (Lande, 1995). Isolated populations may later be subjected to an extreme environmental condition (e.g. drought, heat wave, landslide) and have no exit potential and would have no remote replacement population in which they could recruit more fish.

Although exotic species may outcompete brook trout, many agree poor land management is the primary threat to healthy brook trout populations (EBTJV, 2007; Hudy, Thieling, Gillespie, and Smith, 2008; Stranko, Hilderbrand, Morgan, et al., 2008). Primarily, improper land use by agriculture has a compounding effect on sustainable brook trout populations. The mid-Atlantic region (MD, VA and WV) and the southern range of the brook trout appear to be most affected by poor agriculture practices while northeast brook trout are largely subjected to sedimentation and temperature elevation, both from poor land management (Venture, 2007). Unabated livestock use of streams and rivers has a compounding deleterious impact on brook trout habitat. Grazing on the stream banks can lead to erosion and sediment loading. Livestock grazing will also prevent or impair the growth of riparian vegetation. Overhanging vegetation decreases solar radiation from heating up the water while also providing terrestrial insects as a food source for trout (Utz et al., 2010). Additionally, livestock wading in streams alters substrate, potentially displacing aquatic insects and damaging spawning beds. The overall impact of agriculture on brook trout populations is apparent in a study by Hudy et al., (2008).

While rainbow trout and brown trout are relatively tolerant to perturbations in water quality, (browns and rainbows competing in the Mid-Atlantic are not really an issue in brook trout conservation), sustainable brook trout populations require excellent water quality, especially low water temperatures. Higher water temperatures appear to increase metabolism. Trout restricted to smaller headwater tributaries, with limited food sources, are largely malnourished, especially in warmer water environments (Utz and Hartman, 2007).

Methods for Assessing Brook Trout Habitat

A trout stream assessment tool that has been utilized for over three decades was first developed by Binns and Eiserman (1979) for the Wyoming Game and Fish Department. Binns and Eiserman's model effectively combines habitat characteristics in one overall management assessment tool. The Binns and Eiserman model was later refined and evolved into the Wyoming Habitat Assessment Methodology (WHAM) (Quist et al., 2006). WHAM incorporates 11 different water quality and habitat metrics in a multilinear regression model. The model was specifically designed to aid resource managers in their attempts to predict trout standing crop in Wyoming streams. The model was gradually modified through the years to include a three prong approach, including separate assessments. Level I of the assessment focuses on watershed characteristics. Level II focuses on in-stream water quality and habitat parameters at the stream reach and channel-unit scales. Finally, Level III provides a mechanism where managers can incorporate consideration for site-specific parameters into the decision making process. Such unusual considerations may include bridges, dams, Native American land, waterfalls, etc. (Quist et al., 2006).

WHAM's effectiveness as an assessment tool is evident due to it enduring nature--still in use for over three decades. A tool similar to WHAM may enhance brook trout resource management in the Eastern United States in efforts to conserve the species.

In developing WHAM, Binns and Eiserman (1979) chose 22 field attributes to sample, all which characterized fluvial habitat for trout. Of the 22, only 11 were significantly correlated with trout standing crop (correlation coefficients greater than 0.20). Table 1 below outlines the 11 habitat criteria and minimum rating characteristics for each.

Table 1.
Stream habitat attributes used in the Habitat Quality Index. "R" values are from multiple regression analyses in relation to trout standing crop. (Binns and Eiserman, 1979).

Attribute	Symbol	R	Rating characteristics	
			0 (worst)	1
Late summer stream flow	X_1	0.36	Inadequate to support trout (CPF < 10% ADF)	Very limited: potential for trout support is sporadic (CPF 10–15% ADF)
Annual stream flow variation	X_2	0.80*	Intermittent stream	Extreme fluctuation, but seldom dry; base flow very limited
Maximum summer stream temperature (C)	X_3	0.28	<6 or >26.4	6–8 or 24.2–26.3
Nitrate nitrogen (mg/liter)	X_4	0.69*	<0.01 or >2.0	0.01–0.04 or 0.91–2.0
Fish food abundance (number/0.1 m²)	X_5	0.57*	<25	26–99
Fish food diversity (D_s)[a]	X_6	0.57*	<0.80	0.80–1.19
Cover (%)[b]	X_7	0.55*	<10	10–25
Eroding banks (%)[c]	X_8	0.45*	75–100	50–74
Substrate	X_9	0.44*	SAV lacking	Little SAV
Water velocity (m³/second)[d]	X_{10}	0.38*	<8 or >122	8–15.4 or 106.6–122
Stream width (m)	X_{11}	0.38*	<0.6 or >46	0.6–2.0 or 23–46

The Maryland Department of Natural Resources (2006) lists flow fluctuation, maximum water temperature, bank erosion and riparian cover as apparent habitat attributes impacting brook trout populations.

The U.S. Fish and Wildlife Service developed an index model for brook trout in 1982 (Raleigh, 1982). The model includes several key in-stream components for consideration of brook trout suitability. However, the model lacks watershed characteristics key to predicting future impacts on in-stream water quality. Raleigh (1982) does not justify the metrics utilized in the model, only implying the components included in the model appear to be those of highest importance according to scientific literature. One model feature utilizes temporal measurements where possible. Temporal consideration incorporates watershed impacts over time but does not identify the source of positive or negative watershed features. Without knowledge of watershed characteristics, resource managers may under appreciate or fail to identify impacts a given watershed may contribute to surface water quality within the watershed.

Organizers within the Eastern Brook Trout Joint Venture and Trout Unlimited recognized a need for a mechanism to rate or assess a subwatershed's suitability for sustainable populations of brook trout. Williams et al., (2007a) developed "The Conservation Success Index" or CSI for the sole purpose of analyzing the status of native salmonid populations. The index facilitates protection, restoration, reintroduction and monitoring efforts by providing a multimetric rating system for conservation managers. The index is comprehensive and thorough yet is specific to subwatersheds where trout populations presently exist. It does not allow resource managers to gauge the potential of subwatersheds presently devoid of trout nor is it specific to any particular species of trout or char. The CSI scoring is useful for prioritizing management schemes for planning purposes by allowing managers to focus on deficiencies revealed in the tabulation.

An index similar to the CSI could be developed to specifically focus on brook trout population sustainability while also allowing managers to evaluate all potential subwatersheds and not just those presently harboring trout. Such a tool is lacking and would be especially useful for volunteer and citizen action groups who lack the necessary scientific expertise to gauge a stream's ability to sustain brook trout populations. The index would also be useful in targeting specific problems in a given watershed thereby providing direction for restoration efforts.

The indices as described above are insufficient to specifically determine brook trout population status in the Mid-Atlantic United States. Raleigh's (1982) model, although dated, actually provides a user friendly approach to assessing any given environment and it is also specific to brook trout. However, Raleigh's model was developed based on individual metrics independent of multimetric interaction. Also, it was developed for use in the Western United States in areas where brook trout are non-indigenous. Williams et al.'s (2007a) is not specific to brook trout nor is it specific to a given geographic location. It has been well documented that environmental dynamics involved between the northern and southern range of brook trout are significantly different (Venture, 2007).

An initial step in developing an index is to determine whether or not a few environmental metrics can be used to measure the quality of potential brook trout habitat.

Such key metrics should be able to discern optimum conditions where brook trout populations are sustainable from degraded conditions unsuitable for trout. Multivariate discriminant analysis provides a method where environmental metrics can be utilized in two separate classification linear regression equations, one equation for each environmental condition in question (Fisher, 1936). Findings within the present study establish a discriminant analysis model useful in determining favorable conditions for sustaining brook trout.

Material and Methods

The geographic area of concern for selecting streams in the Mid-Atlantic encompassed the state of Maryland and the northwest part of Virginia (Figure 3 and Figure 4). In order to develop a discriminant analysis tool, historical data from various federal and state agencies in the region were obtained and reviewed for suitability. After an extensive search, it was determined Maryland Department of Natural Resources (MDNR) possessed the most comprehensive database where watershed, in-stream and fish population parameters were collected at the same time or at least tabulated in a fashion where correlations could readily be derived through data manipulation.

Maryland DNR provides annual data through a public website, http://www.dnr.state.md.us/streams/publications.asp where viewing access is provided. Before using any of the data, steps were taken to ensure proper protocols for quality assurance and quality control were adhered to. MDNR implements a *Quality Assurance/Quality Control Plan* (Maryland, 2009) described in its 106 Ambient Water

Quality Monitoring project as requested by the U.S. Environmental Protection Agency. The process was originally initiated in 1972 and first implemented in 1974. Maryland DNR lists 151 streams with viable brook trout populations. Various data on the conditions of these streams and the brook trout populations therein have been compiled and analyzed for management purposes (Maryland, 2006). Virginia stream data specific to brook trout populations is limited. Virginia's Department of Environmental Quality's Probabilistic Monitoring program provided the only stream water quality database generated through random sampling of surface waters throughout the state. Unfortunately, very few sites within the program contain brook trout. Therefore Maryland appears to be the best source for data to build a Mid-Atlantic model.

Developing a Model

Utilizing the combined data on Maryland's 151 brook trout streams, 120 *a priori* reference stream reaches (Appendix A) were chosen. Efforts to include representative streams from each of the four provinces which harbor native brook trout populations (Figure 3) were enhanced by utilizing stratified random sampling with proportional allocation. Independent sampling events on the same stream or watershed were entered as separate data entries.

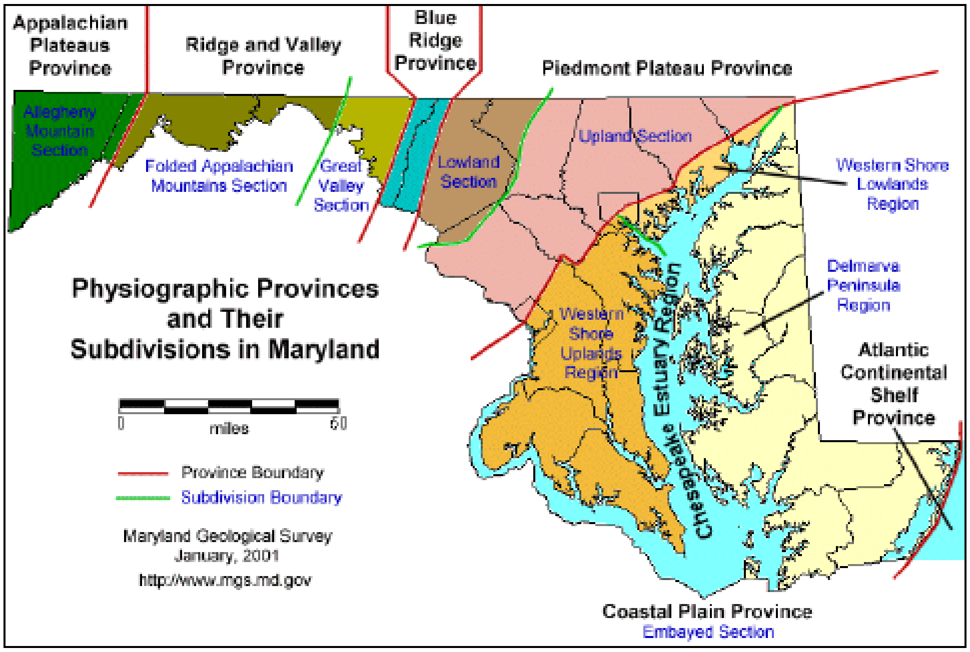

Figure 3. Map of Maryland's physiographic provinces (USGS, 2001). Historical native brook trout range is considered to be west of the fall line, the red separating Piedmont Plateau Province from the Western Shore (Maryland, 2006).

Figure 4. Map of Virginia showing approximate geographic coverage included in the validation analysis here – i.e., parts of Virginia west and north of the red line. (Original image from Maps.com).

Site Classification Strata

Watershed characteristics were evaluated at the reference site locations with particular emphasis on a set of core variables (e.g., percent forest cover, percent agriculture, percent urban, distance to the nearest road) described by Hudy et al., (2008). Available data for watersheds largely depended upon United States 2000 census results. In order to maximize correlations between in-stream habitat measurements and watershed use, most model reference data were from 2000 to 2004. Metrics were chosen based on available reference site watershed characteristics which correlate with brook trout populations as documented in scientific findings (Maryland, 2006; Thieling, 2006a; Williams, Haak, Gillespie, and Colyer, 2007a; Stranko, Hilderbrand, Morgan, et al., 2008; Hudy, Thieling, Gillespie, and Smith, 2008b). Several in-stream habitat quality metrics have been utilized in numerous statistical models and indices and have been well documented in the literature (Binns and Eiserman, 1979; Raleigh, 1982; Kozel et al., 1989; Beauchamp et al., 1992; Larscheid and Hubert, 1992; Schmitt et al., 1993; Hawkins et al., 1993; Binns, 1994; Baldigo et al., 2005; Thieling, 2006a; Astin, 2007; Whittier et al., 2007; Stranko, Hilderbrand, Morgan II, et al., 2008; Hudy, Thieling, Gillespie, and Smith, 2008a). In the present study, metrics evaluated for brook trout in-stream habitat quality were based on significant historical correlations as indicated in the literature cited above (e.g. dissolved oxygen and water temperature) and availability as determined by compiled data on 84 Maryland reference sites (each site consists of a 75 meter long reach), reviewing 45 different parameters (Appendix B). All metrics are measured during the spring sampling season of March and April.

Quality Evaluation and Final Selection of Metrics.

Each metric was evaluated for its effectiveness for discriminant analysis, first by reviewing Pearson correlation coefficients and identifying metrics that correlated with brook trout populations with R values greater than 0.20 (Binns and Eiserman, 1979) and $p \leq 0.05$.

A first quality check of the selected metrics subjected them to cluster analysis, using an average linkage dendrogram (Gauch, 1982), in order to determine if any given metric may bias results. At this stage, a small group of metrics were identified as possible indicators of brook trout populations. To further evaluate the metrics for suitability, the selected subset of metrics were evaluated for collinearity in order to eliminate metrics that appear to be statistically similar to each other ($R > 0.69$), potentially indicative of a model that could inaccurately weigh the predictive value of certain characteristics in the watershed or stream (Burton and Gerritsen, 2003). Examination of principal component eigenvector metric loadings provided a third and final quality check. Metrics that may have been collinear, as determined by the Pearson correlation coefficients, were further evaluated by the graphical proximity of their corresponding eigenvectors. A high R value ($R > 0.69$) and less than 20 degrees separation within a principal component analysis (PCA) loading graphic provide substantial evidence for collinearity.

Discriminant Analysis Model and Cross Validation

As a result of the above metric quality review, an even smaller subset of metrics were chosen for developing a discriminant analysis model to determine whether or not given Mid-Atlantic streams, within the original range of eastern brook trout, have potential to sustain brook trout populations. Eighty-four of the original 120 reference streams had sufficient data for the selected key metrics. This small subset of metrics was evaluated for effectiveness in discriminating between reference sites with brook trout and those sites devoid of fish. A *post hoc* multivariate discriminant analysis model was developed on MINITAB 16 statistical software utilizing chosen metrics (Hall et al., 2002) with the 84 reference streams. Since metric values were derived from the same 84 reference streams, results were cross-validated within the same model development.

To investigate the potential for expanding the geographic range of the model, additional validation using *a priori* data from six Virginia stream reaches was conducted. These reaches were selected from the list of randomly selected reference sites within Virginia's Department of Environmental Quality's Probabilistic Monitoring Program (Virginia DEQ, 2006). Utilizing the list of reference sites, a stratified random sample of the reference sites was generated from all the brook trout containing streams (three identified) in the northwest portion of the state. Other nearby reference sites devoid of brook trout were utilized for comparison.

Results and Discussion

Upon examination of Appendix B, very few parameters met or exceeded the benchmark R = 0.20 or greater. Table 2 is a list of 11 metrics chosen based on analysis of Pearson correlations as described in Binns and Eiserman (1979) and also based on field knowledge.

Table 2.
Potential discriminating metrics in Mid-Atlantic upland streams.

Potential Discriminating Environmental Metrics. N = 120 for in-stream parameters; N = 84 for land-use parameters	Pearson correlations with # of brook trout at site locations; p values in parentheses; CI = 95%
Distance from sample site to the nearest road (DIST_RD)	0.319 (0.000)
% Forest land cover in the watershed (%forest)	0.301 (0.004)
% Agriculture land cover in the watershed (%Ag)	-0.298 (0.004)
Water temperature (TEMP_FLD)	-0.291 (0.002)
Riffle quality (RIFFQUAL)	0.290 (0.002)
In-stream habitat (INSTRHAB)	0.275 (0.003)
Epifaunal substrate (EPI_SUB)	0.258 (0.005)
Riparian wideness (RIP_WID)	0.232 (0.020)
Aesthetic value (AESTHET)	0.202 (0.027)
Dissolved oxygen (DO_FLD)	0.189 (0.043)
# of Ephemerella sampled at site (Ephemerella)	-0.121 (0.186)

The mayfly genus *Ephemerella,* was not well correlated with numbers of brook trout (R = -0.121); however, cursory review of the data produced suspicion of a possible relationship. Except for dissolved oxygen (R = 0.189), Pearson correlation values (R) for all other metrics in Table 2 have a magnitude of R = 0.20 or above.

Cluster analysis results in figure 5 below indicate small but insignificant overall model bias among the 11 metrics with respect to year sampled, stream order or province location of stream reach site . There does appear to be some bias for province with respect to % forest cover in the watersheds. Such bias appears logical since the eastern part of Maryland is more urban than the western part of the state. Interestingly, the bias does not exist for % Agriculture in a province. There appears to be very little significant bias for year sampled.

The loading plot of the principal components derived from 11 metrics described above was examined (Figure 6) for metric quality. The graphic reveals possible collinearity between riffle/run quality, in-stream habitat and epifaunal substrate quality and dissolved oxygen due to their close proximity. Upon checking for collinearity, re-examination of Pearson correlation data reveals P values nearing 0.70 for all three in-stream habitat metrics but not with dissolved oxygen.

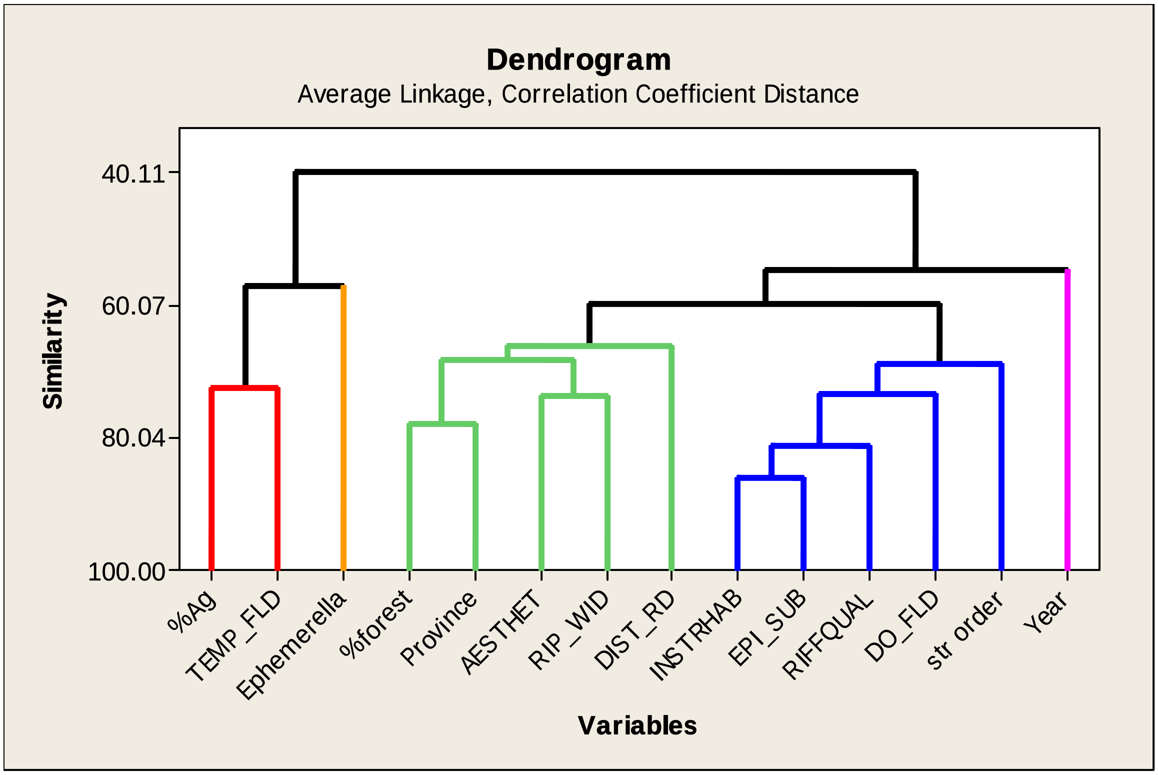

Figure 5. Cluster analysis of 11 diagnostic metrics and 3 model constraints

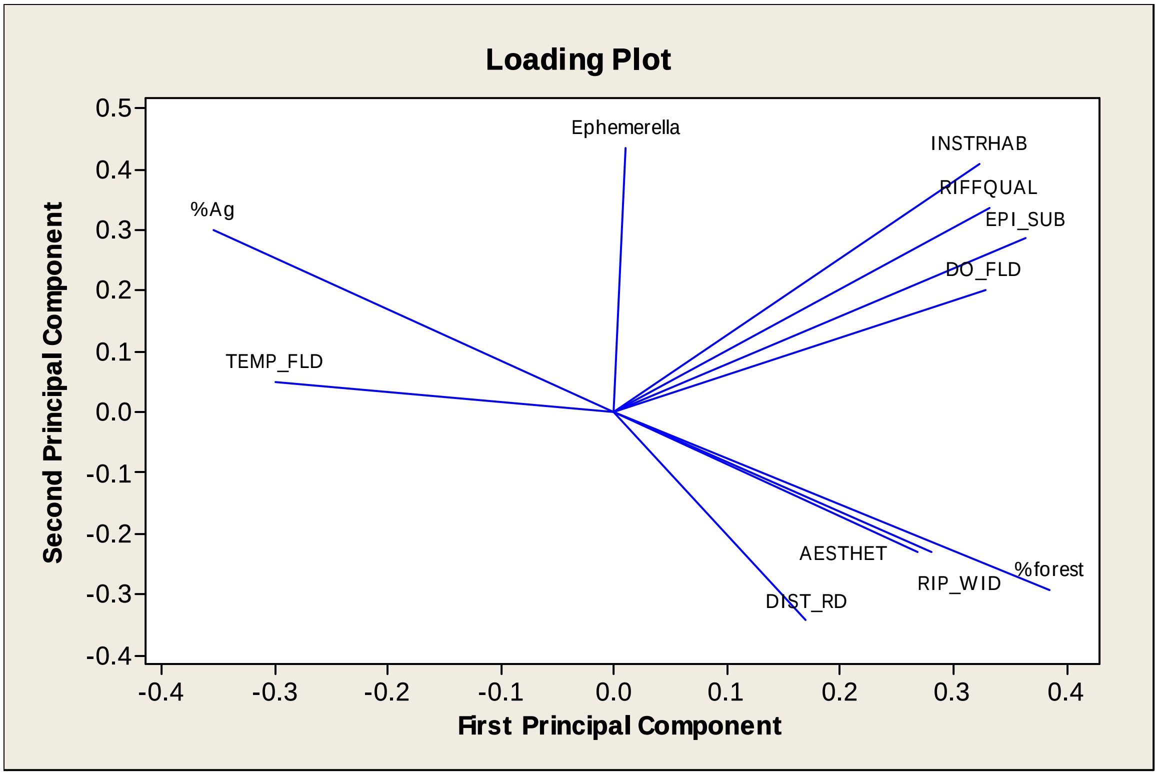

Figure 6. Loading plot of eigenvector spatial significance for 11 potential discriminating metrics.

Figure 6 also reveals RIP_WID, AESTHET, DIST_RD and %forest may have some collinearity features. However, since DIST_RD has a much higher Pearson correlation with the number of brook trout at test sites, it was selected as the best metric within the group.

A final subgroup of metrics were selected based on thorough examination of Pearson correlations, principal component analysis and Eigenvector loading and multiple trials using MINITAB discriminant analysis. Key metrics selected for discriminant analysis of 84 Maryland stream reaches, 42 with brook trout populations and 42 without, include: % agriculture land use in the watershed (%Ag), riffle/run quality at the survey site (RIFFQUAL), the log transformed distance to the nearest road from the survey site (LOG_RD), water temperature at the survey site (TEMP_FLD) and dissolved oxygen content at the survey site (DO_FLD). Final model metrics and the principal component analysis (PCA) are revealed in Table 3.

Results of the analysis along with cross-validation results are presented in Figure 7. The classification equations derived from the discriminant analysis and corresponding suitability statistic (S) are provided in Table 4.

Table 3. Final key metrics with corresponding principal component analysis.

Principal Component Analysis:

Eigenanalysis of the Correlation Matrix
84 cases used, 36 cases contain missing values

Eigenvalue	2.2339	1.0504	0.7414	0.5517	0.4226
Proportion	0.447	0.210	0.148	0.110	0.085
Cumulative	0.447	0.657	0.805	0.915	1.000

Variable	PC1	PC2	PC3	PC4	PC5
%Ag	-0.447	0.317	-0.621	0.476	-0.295
RIFFQUAL	0.473	0.192	-0.572	-0.589	-0.256
TEMP_FLD	-0.537	-0.054	-0.293	-0.448	0.650
DO_FLD	0.533	0.154	-0.264	0.454	0.646
LOG_RD	0.065	-0.915	-0.362	0.144	-0.085

Discriminant Analysis

```
Linear Method for Response: bkt present

Predictors (metrics): TEMP_FLD, DO_FLD, %Ag, RIFFQUAL, LOG_RD

Group       no       yes
Count       42        42

84 cases used, 36 cases contain missing values

Summary of classification
                 True Group
Put into Group     no    yes
no                 31      7
yes                11     35
Total N            42     42
N correct          31     35
Proportion      0.738  0.833

N = 84           N Correct = 66           Proportion Correct = 0.786

Summary of Classification with Cross-validation

                 True Group
Put into Group     no    yes
no                 30      8
yes                12     34
Total N            42     42
N correct          30     34
Proportion      0.714  0.810

N = 84           N Correct = 64           Proportion Correct = 0.762

Squared Distance Between Groups

       no      yes
no   0.00000  2.38415
yes  2.38415  0.00000

Linear Discriminant Function for Groups

             no      yes
Constant  -78.239  -79.016
TEMP_FLD    5.173    4.772
DO_FLD      6.849    7.153
%Ag        -0.028   -0.006
RIFFQUAL    0.374    0.558
LOG_RD      2.477    3.586
```

Figure 7. Results of a *post hoc* discriminant analysis and corresponding cross-validation of potential Maryland brook trout streams.

Table 4.
Smith-Sklarew classification equations and corresponding suitability statistic (S) for determining habitat suitability for sustainable brook trout populations.

S(bkt_sp) = -79.02 + 4.77 (TEMP_FLD) + 7.15 (DO_FLD) + 0.56 (RIFFQUAL) + -0.01 (%Ag) + 3.59 (LOG_RD)

S(no_bkt_sp) = -78.24 + 5.17 (TEMP_FLD) + 6.85 (DO_FLD) + 0.37 (RIFFQUAL) + -0.03 (%Ag) + 2.48 (LOG_RD)

Combining the two equations we derive an equation for the suitability statistic (S)

S = S(bkt_sp) – S(no_bkt_sp)

S = -0.78 + -0.4 (TEMP_FLD) + 0.3 (DO_FLD) + 0.19 (RIFFQUAL) + 0.02 (%Ag) + 1.11 (LOG_RD)

If S > 0 then stream exhibits characteristics suitable for sustaining brook trout

If S < 0 then stream most likely lacks conditions to sustain brook trout

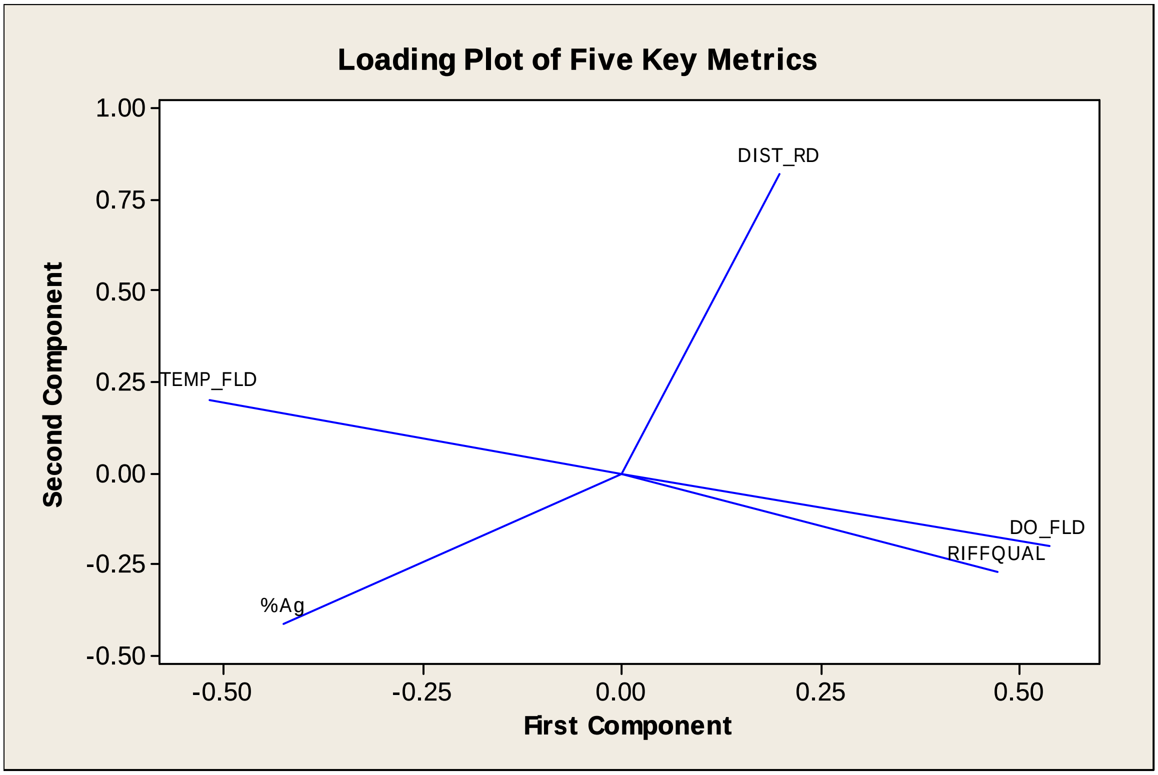

Figure 8. Loading plot of 5 key watershed/in-stream metrics.

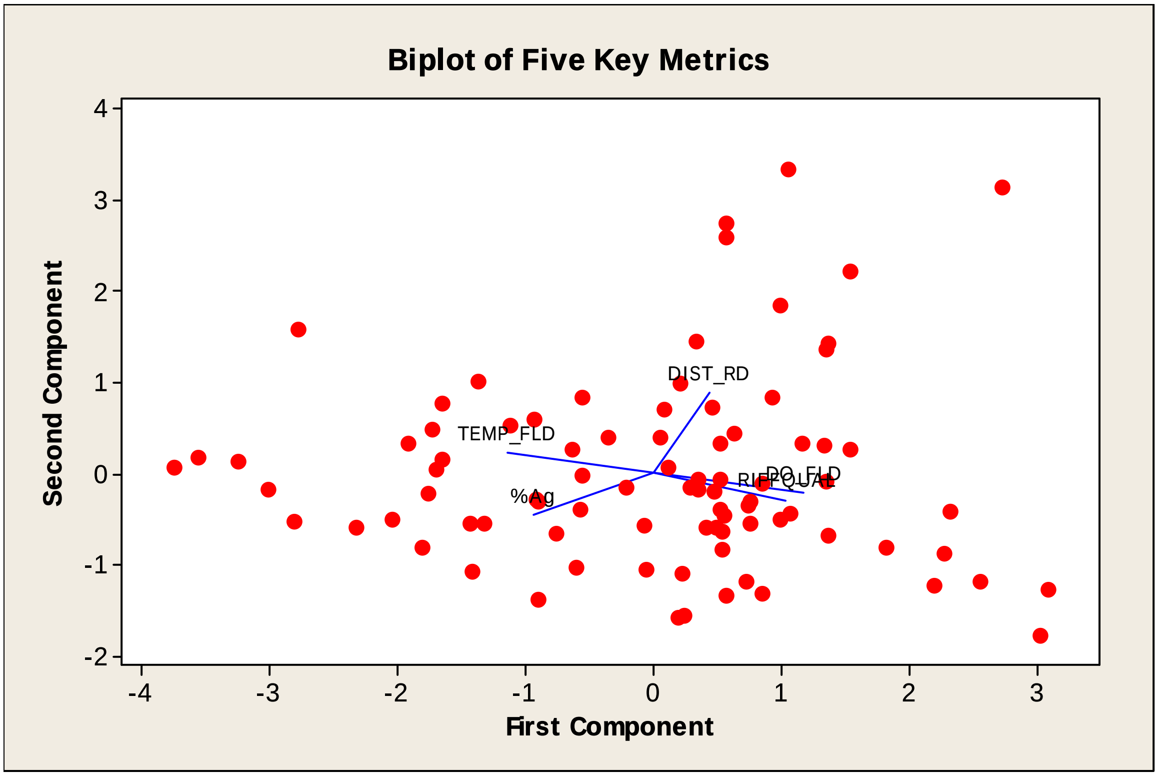

Figure 9. Biplot representation of principal component analysis of 5 key watershed/in-stream metrics.

Table 5.

Validation of the model using 6 Virginia stream reaches with two groups – "yes" group with brook trout observed, "no" group without – across three stream orders each. Sites selected from Virginia Department of Environmental Quality Probabilistic Monitoring Sites (Hill, 2006).

Observation	StationID	StreamName	Order	Basin	# bkt	% Ag	LOG_RD	DO_FLD	TEMP_FLD	RIFFQUAL	S
1	1BNTH046.56	North River	2	Shenandoah	3	0	2.74273	11.9	6.6	19	6.80
2	2-PRS003.23	SF Piney River	1	James	112	0	0.47712	11.1	8.3	19	3.37
3	2-STV000.48	Shawvers Run	3	James	4	1	3.22427	11.1	6.8	20	7.22
4	2-BCC001.90	Back Creek	1	James	0	20	3.23401	12.9	12.9	19	5.18
5	1BSMT009.08	Smith Creek	3	Shenandoah	0	57	2.92324	8	20.2	10	-0.18
6	2-BFL011.64	Taylor Creek	2	James	0	4.47	0.00000	11.6	13.7	18	0.73

Prediction for Test Observations

Observation	Pred. Group	From Group	Squared Distance	Probability	Actual Group
1	yes				yes
		no	32.838	0.001	
		yes	19.370	0.999	
2	yes				yes
		no	21.578	0.036	
		yes	14.986	0.964	
3	yes				yes
		no	35.035	0.001	
		yes	20.735	0.999	
4	yes				no
		no	22.032	0.004	
		yes	11.056	0.996	
5	no				no
		no	3.206	0.533	
		yes	3.468	0.467	
6	yes				no
		no	12.878	0.340	
		yes	11.549	0.660	

Maryland Department of Natural Resources (MD DNR) and Virginia's Department of Environmental Quality (VDEQ or DEQ) have both utilized data collected from their water quality and biological monitoring programs to produce biological indices for lotic systems within their states (Roth et al., 1998; Hill, 2006; Southerland et al., 2007; Stranko, Hilderbrand, Morgan, et al., 2008). The models are useful over a broad geographic range within their respective states. However, the models are not specific to any particular species and, as presented, are models which ultimately assess water quality. Taking the exact opposite approach, results from the present study produce a model which uses water quality and watershed information to predict the suitability of lotic systems for a particular species, the eastern brook trout with 76% accuracy.

Appendix B displays the results of correlation analysis of brook trout abundance with 45 stream and watershed parameters. In addition, macroinvertebrate data was examined. Unfortunately, macroinvertebrate data from MD DNR is tabulated inconsistently. Some sites identified specimens down to the genus while other survey sites identified specimens to the family. As such, the data was deemed unreliable for use in its present form. However, visual examination of the data revealed a possible correlation between *Ephemerella* abundance and brook trout abundance. Therefore, the *Ephemerella* numbers were entered into the correlation matrix but the correlation did not prove evident ($R = -0.12$; $p = 0.19$).

Correlations between brook trout abundance and 11 metrics are revealed in Table 2. Riffle/Run quality ($R = 0.29$), in-stream habitat quality ($R = 0.28$), distance to the nearest road (R = 0.32) and water temperature (R = -0.29) had the highest Pearson correlations with brook trout abundance. There was fairly significant collinearity (0.669) between riffle/run quality and in-stream habitat quality. Further evidence of collinearity between the two metrics is demonstrated by their close proximity in Figure 6. After further examination of the sampling criteria, riffle/run quality was selected over in-stream habitat quality because most of the on-site measurements for riffle/run quality are quantitative in nature whereas, in comparison, many of the criteria for in-stream habitat were subjective (Maryland, 2009).

Examination of PCA (Table 3) for the five key metrics highlights TEMP_ FLD as the feature metric in the first component followed by DIST_RD in the second component and %Ag in the third. Review of PCA results of all 11 preliminary metrics featured %Ag in the fourth PCA indicating an influential component within the watershed (Appendix D).

Figure 7 suggests measurements of five key metrics within selected stream reach survey sites in the described Mid-Atlantic region would allow resource managers to predict, with 79% accuracy, the viability of that stream to sustain brook trout populations. However, results from a *post hoc* model should legitimately be based on the cross-validation percentage, in this case 76%.

Since Pearson correlations are based on two dimensional linear relationships, such models appear to be useful as initial information when searching for environmental indicators but, in the present case, lack precision provided via a multivariate three dimensional discriminant analysis approach. A multi-dimensional analytical approach, such as principal component analysis (Table, 3), aid in explaining why some Pearson correlations with smaller R values could possibly result in better model metrics. Such is the case with DO_FLD (R = 0.19) and DOC_LAB (R = -0.24) (Annex A).

Further exploration of PCA results reveal a loading plot displaying a radiant eigenvector arrangement within the sample population (Figure 8). The significance of the encompassing "spider-web" loading graphic suggests the model's ability to encompass a multidimensional space while the biplot displays basic trends along the first two principal components in a two dimensional space (Figure 9). The first two principal components account for 66% of the sample population environmental variability (Table, 3).

Utilizing results summarized in figure 7, two classification equations were established (Table, 4) to aid resource managers in their management efforts. Such information coupled with other on-site knowledge (e.g. sedimentation, summertime temperature spikes, exotic competitors, etc.) empowers resource managers in their management decision making process.

An additional cross-validation using data from six Virginia streams was conducted (Table 5) in order to examine the predictability potential of the model. Unfortunately, the small sample size does not allow for full appreciation of the predictability power provided via the discriminant analysis tool. However, the 66% predictability rate demonstrates a potential viable tool. Looking at summary of classification results in both Figures 7 and Table 4, it appears predictability of the model is more successful for favorable brook trout streams (81% in Maryland, 100% in

Virginia). One possibility for the slight skew toward favorable streams could be explained by the model indicating brook trout could thrive in a given stream, they just aren't there or were not found during the survey. Such indications should be considered a positive attribute of the model. It is possible many of the streams that presently do not harbor sustainable brook trout populations could indeed harbor them in their present state. In other words, brook trout populations could potentially be established in these streams without any stream remediation or restoration. Therefore, based on results from the cross-validation trial and validation using data from selected Virginia streams,,the predictability of the model should strictly be viewed as an indication of a stream's potential to harbor sustainable brook trout populations.

Conclusion

Brook trout populations, especially in the southern half of the species' range, are diminishing and becoming increasingly fragmented as shown in figure 2 (Hudy, Thieling, Gillespie, and Smith, 2008a). Efforts to restore or remediate brook trout streams can be assisted with an analytical method to gage any stream's potential to harbor sustainable brook trout populations. Classification equations (Table 4), produced through a discriminant analysis model presented herein, provide such a tool for resource efforts in the Mid-Atlantic region of the United States. The five key metrics, % agriculture land use in the watershed (%Ag), riffle/run quality at the survey site (RIFFQUAL), the log transformed distance to the nearest road from the survey site (LOG_RD), water temperature at the survey site (TEMP_FLD) and dissolved oxygen content at the survey site (DO_FLD) are useful as predictors of stream quality. With very little evidence of substantial model bias, applications of the classification equations may be broad reaching. Additionally, the key metrics can easily be measured with professionally trained volunteers at minimal costs. Although the model may be most useful employed within the State of Maryland, cross-validation results using Virginia stream data suggest the same classification equations may be applicable in certain Virginia geographic regions. Further exploration into model applications within Virginia and possibly West Virginia streams is warranted. Additional exploration into development of a brook trout stream suitability index is also warranted based on the discriminating features of the five key metrics. Using Virginia stream data, in Table 5 the suitability statistic (S) suggests some streams (e.g. Back Creek) may not presently harbor brook trout but may be suitable in their present state to do so. Therefore, the more positive the S values, the more likely a given stream's habitat is compatible with brook trout sustainability. Conversely, streams that do not score well should not be discarded immediately. Taylor Creek (Table 5) did not score well (S = 0.73) but only displayed one poor metric measurement--the distance to the nearest road. Resource managers should review all metric measurements along with S values in order to form an initial just assessment of particular stream reach or sub-watershed.

Obvious limitations of the model are revealed in the metrics themselves. It is likely there are degraded streams in urban and suburban areas yet these areas may have little or no agriculture within the watershed. Also, suburban watersheds may produce low water temperatures and high dissolved oxygen content in the spring when sampling occurs but summer water temperatures may be limiting along with low dissolved oxygen concentrations (Raleigh, 1982). The classification equations presented may be applied over the four geographic provinces within Maryland and possibly similar geographic terrain within Virginia but better classification equations might be developed specific to each province or perhaps, more specifically, each ecoregion. Since the main goal of the present study was to identify key metrics useful for discriminating conditions throughout the Mid-Atlantic region, no effort was taken to create a tool specific to any given province across the entire Maryland geographic range. Without prior knowledge of any given watershed or stream or possible instantaneous thresholds which may be detrimental to brook trout sustainability, the suitability statistic (S) should be viewed as a screening indicator.

While traditional environmental indices are largely based on results of two dimensional linear regression as expressed in Pearson correlation (R) values (Binns and Eiserman, 1979; Raleigh, 1982; Burton and Gerritsen, 2003; Whitman et al., 2004), it appears a multidimensional approach using correlations as a screening tool first followed by multivariate discriminating techniques (e.g., PCA, cluster analysis and predictive discriminant analysis) as described in the present study, may produce a product with broader application and utility (Hall et al., 2002; Wagner and Fernandez-Gimenez, 2009). By extending the approach taken by Hall et al. (2002) in which Maryland streams were classified based on their physical habitat features, it is possible to further refine the classification to identify conditions suitable for brook trout.

CHAPTER 2

Introduction

In 2007, Eastern Brook Trout Joint Venture (EBTJV) and Trout Unlimited (TU) organizers recognized the need for a mechanism to rate or assess a subwatershed's suitability for sustainable populations of salmonids. Williams et al. (2007) developed a "Conservation Success Index," or CSI, for the sole purpose of analyzing the status of native salmonid populations. The index facilitates protection, restoration, reintroduction and monitoring efforts by providing a multimetric rating system for conservation managers. It does not allow resource managers to gauge the potential of subwatersheds presently devoid of trout nor is it specific to any particular species of trout or char. The CSI scoring is useful for prioritizing management schemes for planning purposes by allowing managers to focus on deficiencies revealed in the tabulation. Collecting the necessary data for the CSI appears to be time consuming, costly and requires considerable expertise. With over 5000 subwatersheds within the historical brook trout range still containing sustainable populations of the species (Hudy, Thieling, Gillespie, and Smith, 2008a), implementation of the CSI over the described geographical area does not appear to be practical. Additionally, the CSI is also not tailored to capture the specific habitat needs of brook trout.

An index similar to the CSI could be developed to specifically focus on brook trout population sustainability, while also allowing managers to evaluate all potential subwatersheds, not just those presently harboring trout. Such a tool does not yet exist. It would be especially useful for volunteer and citizen action groups, like many local TU chapters, who lack the necessary scientific expertise to gauge a stream's ability to sustain brook trout populations. The index would also be useful in targeting specific habitat deficiencies in a given watershed, thereby providing direction for restoration efforts. Perhaps an abbreviated index encompassing many CSI measurement goals but is more volunteer/field friendly, less subjective and labor intensive, may be more practical and cost-effective. As of December 2010, there appears to have been no such index in use in the Mid-Atlantic region (Matt Sell, Maryland Department of Natural Resources, personal communication).

The indices described above are insufficient to specifically determine brook trout population status in the Mid-Atlantic United States. Raleigh's (1982) model, although dated, provides a user-friendly approach to assessing any given habitat and it is also specific to brook trout. However, Raleigh's model was developed based on individual metrics, independent of multimetric interaction. Also, it was developed for use in areas of the Western United States where brook trout are non-indigenous. The CSI of Williams et al. (2007) is not specific to brook trout nor is it specific to a given geographic location. By contrast, environmental dynamics involved in sustaining brook trout in its northern range compared to its southern range are considered distinct (Venture, 2007).

A discriminant analysis (DA) model was developed to predict whether certain streams are suitable for sustaining brook trout populations (Chapter One). The model was developed using 120 stream reach sites surveyed in spring by the Maryland Department of Natural Resources from the year 2000 to 2008. Suitable sites were chosen within all four geological provinces harboring sustainable populations of brook trout in the state. A stratified random selection of sites was used, based on having a equal amount of sites with (60 sites) and without (60 sites) brook trout populations, while also attempting to include as much of the area of the state as possible. The discriminant analysis was specifically designed to determine which environmental predictors performed best as ecological barometers in predicting stream suitability for sustaining brook trout populations.

The Smith-Sklarew classification functions were derived after analysis of 45 parameters using Pearson correlations and principal component analysis. Eleven metrics were identified as potentially predictive indicators. Distinct combinations of the 11 metrics were subjected to discriminant analysis modeling using Minitab version 16. The analysis resulted in the establishment of five key metrics and two multimetric classification equations (Table 4) utilized to determine the suitability of upland Mid-Atlantic streams in Maryland and Northwestern Virginia for sustaining brook trout populations..

While the model proved 76% accurate in predicting streams with and without brook trout populations via cross-validation of the sample streams, it does not provide detailed information on stream condition, nor does it provide much indication whether or not certain in-stream habitat qualities prevail or are degraded. It simply provides a "yes" or "no" indication as to whether or not any given stream may be a good candidate for sustaining brook trout.

The result of the analysis led to the development of a suitability statistic (S) (Table 6) which would enable resource managers to use values for the five key metrics in a simple algebraic equation to determine whether or not a given stream might be suitable for sustainable brook trout populations.

Table 6.
Smith-Sklarew classification of MD stream/watershed suitability (S) for sustaining brook trout populations. The five key metrics:

TEMP_FLD	Springtime water temperature (˚C) at the site
DO_FLD	Dissolved oxygen concentration (mg/L)
RIFFQUAL	Riffle run quality based on a 0 - 20 grading scale; 20 = best
%Ag	Land-use percentage of watershed catchment upstream of site in agriculture
LOG_RD	Log of distance (m) to the nearest road in the catchment upstream of the site

As Suitability statistic (S) increases above zero, habitat should be increasingly suitable for brook trout, where –

$$S = -0.78 + -0.4\,(TEMP\_FLD) + 0.3\,(DO\_FLD) + 0.19\,(RIFFQUAL) + 0.02\,(\%Ag) + 1.11\,(LOG\_RD).$$

The five metrics included two watershed parameters (percentage of watershed in Agriculture (%Ag) and distance from the sample site to the nearest road (LOG_RD)) and three in-stream parameters (riffle/run quality rating (RIFFQUAL), dissolved oxygen concentration (DO_FLD) and water temperature (TEMP_FLD)) (Table 6).

These environmental metrics appear to adequately envelope key environmental components which have significant impact on Mid-Atlantic brook trout streams. Principal component (PC) analysis in Table 3 reveals importance of all five metrics: principal component 1 (PC1) shows all metrics as having similar explanatory value (circa 0.5), except for "distance to the nearest road" (LOG_RD, at about 0.05). For PC2, LOG_RD has nearly 3 times more weight (over 0.9) than then next important metric. Therefore, all metrics display explanatory power, thus should be treated as valuable when assessing stream suitability. They might also be useful combined into a multimetric index for assessing a given stream's condition as potential brook trout habitat.

Similar indices have been well documented: The U.S. Fish and Wildlife Service developed an index model for brook trout in 1982 (Raleigh, 1982). The model includes several key in-stream components for considering brook trout suitability. However, the model lacks watershed characteristics key to predicting future impacts on in-stream water quality. Raleigh (1982) does not justify the metrics utilized in the model, only implying the components included in the model appear to be those of highest importance according to scientific literature. Without knowledge of watershed characteristics, resource managers may not fully appreciate how the landscape of a watershed impacts surface water quality and brook trout habitat.

The proposed model presented below is a modified approach used in the modern version of WHAM (Quist et al., 2006), utilizing a strategic subset of CSI indicators. It was developed through the incorporation of 2000 to 2008 data compiled by Maryland's Department of Natural Resources (MDNR), revealing metrics specific to sustainable brook trout populations of the Mid-Atlantic region. Model results are presented in the form of a unit-free multimetric index value, on a scale from 0 (poor condition) to 100 (best value). Since key metrics have already been identified and evaluated for redundancy, and they represent different aspects or impact different aspects of the brook trout's habitat, an index was developed from metric measurements within 120 reference streams. Standardizing the five metric values to a common 100-point scale allows resource managers to combine each metric into an overall combined multimetric index with each metric having equal weight within the index (Burton and Gerritsen, 2003). Averaging all the scores produces the final multimetric index score for a particular stream reach.

Material and Methods

Using the five key metrics in Table 6, a multimetric brook trout stream suitability index (BKTI) was developed using spring time data from the same population of 120 sites selected for the discriminant analysis. Three of the metrics (riffle/run quality, dissolved oxygen and distance to the nearest road) are positively correlated with sustainable brook trout populations. Water temperature and percentage of land use in agriculture are negatively correlated with sustainable brook trout populations (Table 7).

In order to determine whether or not each metric is an adequate indicator for brook trout stream suitability, box and whisker plots (box plots) for each metric were developed showing how streams with brook trout differ from steams without. This follows the similar approach of Hall et al. (2002) in their discriminant analysis (DA) model of Maryland upland streams. Metrics that failed to clearly separate with box plots according to DA categories were further evaluated according to the index of biological indicator (IBI) ratings for each of the sample population stream reaches, where appropriate (Hall et al., 2002; Burton and Gerritsen, 2003). Box plots were developed for those metrics according to how the actual metric values vary along the IBI continuum with good streams classified as those with IBI ratings 4.0 and higher and poor streams with ratings less than 3.0.

Most fish indices (FIBI) lack a more definitive delineation found with benthic indices of biological integrity (BIBI, most commonly listed as IBI) (Roth et al., 2000; Hill, J., 2011). Therefore, strict separation between high quality brook trout streams and poor quality streams may not be possible for each of the individual five key metrics within the test population of stream reaches. It is important to measure ecological integrity in a manner that is broad-based in an attempt to encapsulate as many aspects of environmental influence as possible. For this reason, all five metrics were included in a multimetric index. The resulting index integrates these to provide a rating or score in the range of 0-100, facilitating ease of use and interpretation for resource managers and other conservationists.

Table 7.
Key metrics for assessing Mid-Atlantic upland streams. See Appendix B for units of measure and metric descriptions.

Key Metrics. N = 120 for in-stream parameters; N = 84 for land-use parameters	Pearson correlations with # of brook trout at site locations; p values in parentheses; CI = 95%
Distance (m) from sample site to the nearest road (DIST_RD)	0.319 (0.000)
% Agriculture land cover in the watershed (%Ag)	-0.298 (0.004)
Water temperature ˚C (TEMP_FLD)	-0.291 (0.002)
Riffle quality (0 - 20) (RIFFQUAL)	0.290 (0.002)
Dissolved oxygen (mg/L) (DO_FLD)	0.189 (0.043)

Index Development

Principal component scores for each of the 84 sites were evaluated using a normal probability plot and the Ryan-Joiner normality test to ensure multivariate normality (McGarigal et al., 2000). Any of the principal component scores that failed the normality test were further examined for skewness. A skewness score greater than +1 or less than -1 were considered highly skewed (Bulmer, 1979). Should any of the principal component scores fail for normality and skewness, then the set of five key metrics discovered in the discriminant analysis model described in Chapter One would not be suitable for the multimetric index and a new combination of metrics would have to be considered.

The 95th percentile of each metric exhibiting positive correlation with brook trout populations was indentified. This measure was considered the maximum brook trout stream suitability quality rating (best value). Likewise, for negatively correlated metrics, the 5th percentile was identified and considered the maximum quality rating (best value). The 95th and 5th percentiles were chosen in order to reduce excessive weighting by outliers (Burton and Gerritsen, 2003).

Each metric value was normalized as follows:

Equation 1: score = 100 x (Field measurement/X_{95th}),

where X95 = the 95th percentile of this metric's values in all samples as listed in Appendix A, and

any score better than the 95th percentile is set to 100.

Equation 2: score = 100 x [(Maximum - Field measurement)/(Maximum - X_{5th})],

where Maximum = the maximum possible value for a field measurement as listed in Appendix A or an instantaneous threshold value.

X5 = the 5th percentile of this metric's values in all samples as listed in Appendix A , and

any score better than the 5th percentile is set to 100.

Any field temperature equal to or higher than 20 ˚C was given a value of 19.99˚C as to avoid the recording of a zero.

Justification for avoiding a temperature index score of "zero" is to dissuade organizations from uniformly disregarding streams on the bases of surpassing the temperature instantaneous threshold of 20˚C. Should temperature be the only limiting factor preventing sustainable brook trout populations, often riparian zones can easily be revegetated to provide future shading and subsequent lower surface water temperatures (Petty et al., 2005). This is especially true for areas where cold-water springs exist.

Results from the above calculations can be readily tabulated in the field in order to facilitate "real time" assessment following the actual survey. A brook trout stream suitability index (BKTI) score or rating for a stream reach will be obtained by averaging all the unitless metric scores.

Results and Discussion

Box plots for each key metric are shown in Figures 10 through 14.

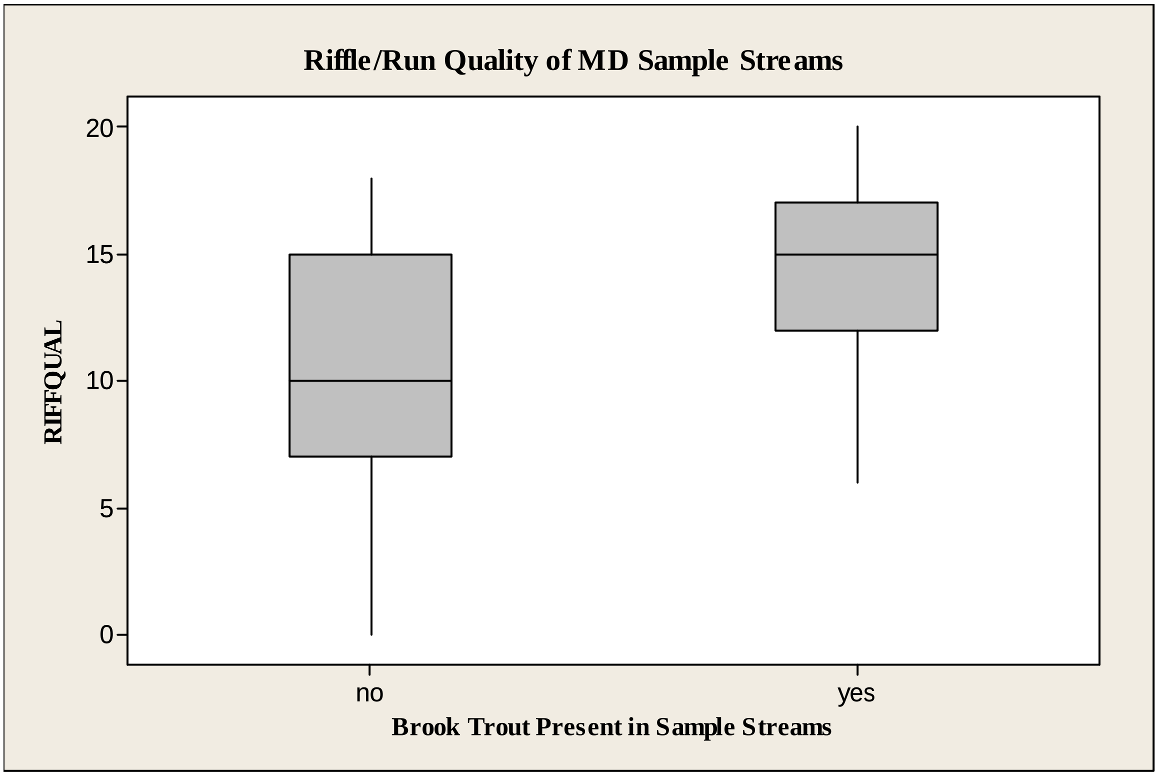

Figure 10. Box plots of riffle/run quality of Maryland sample streams. Top and bottom of each box represents the first and third quartile of the metric population. Confidence bars show central 95% of the sample population. Outliers are designated with an asterisk and represent data points that are more than 1.5 times the range between the central 50% of data.

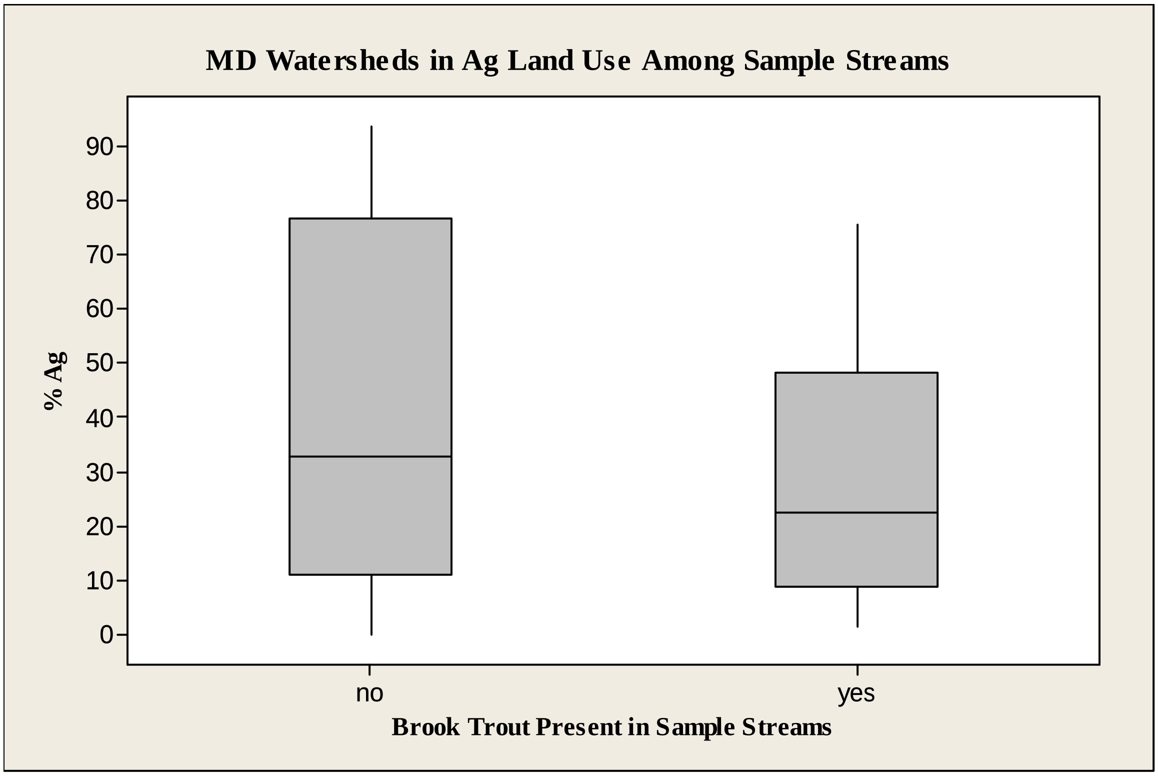

Figure 11. Box plots of percentage of the watershed land use in Agriculture and presence of brook trout.

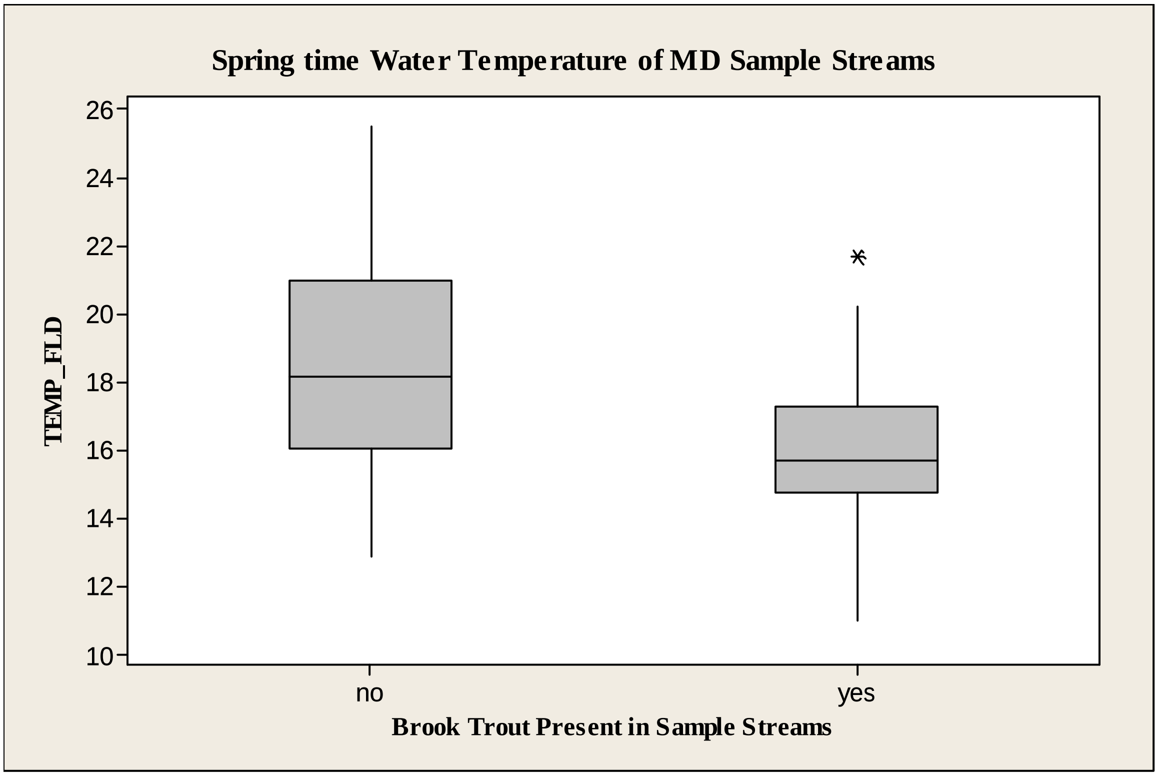

Figure 12. Box plots of water temperature in selected Maryland streams and presence of brook trout.

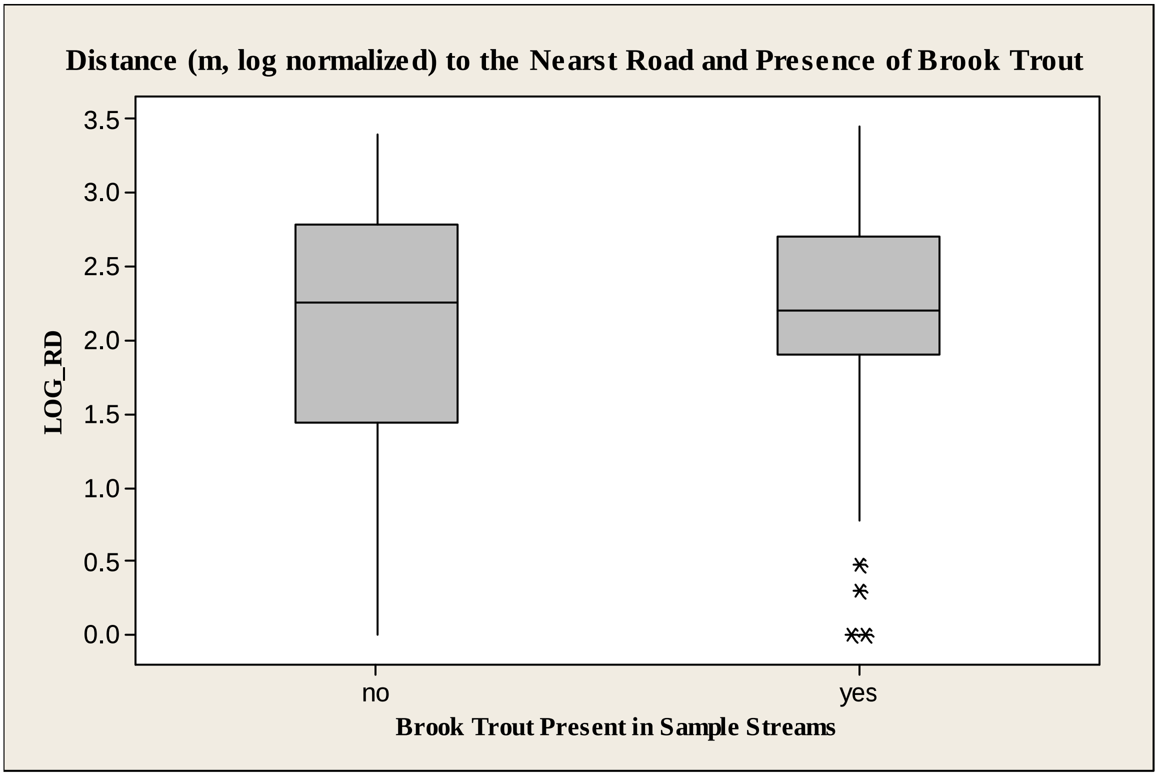

Figure 13. Box plots of distance to the nearest road (meters) in selected Maryland streams and presence of brook trout. The distance has been log normalized.

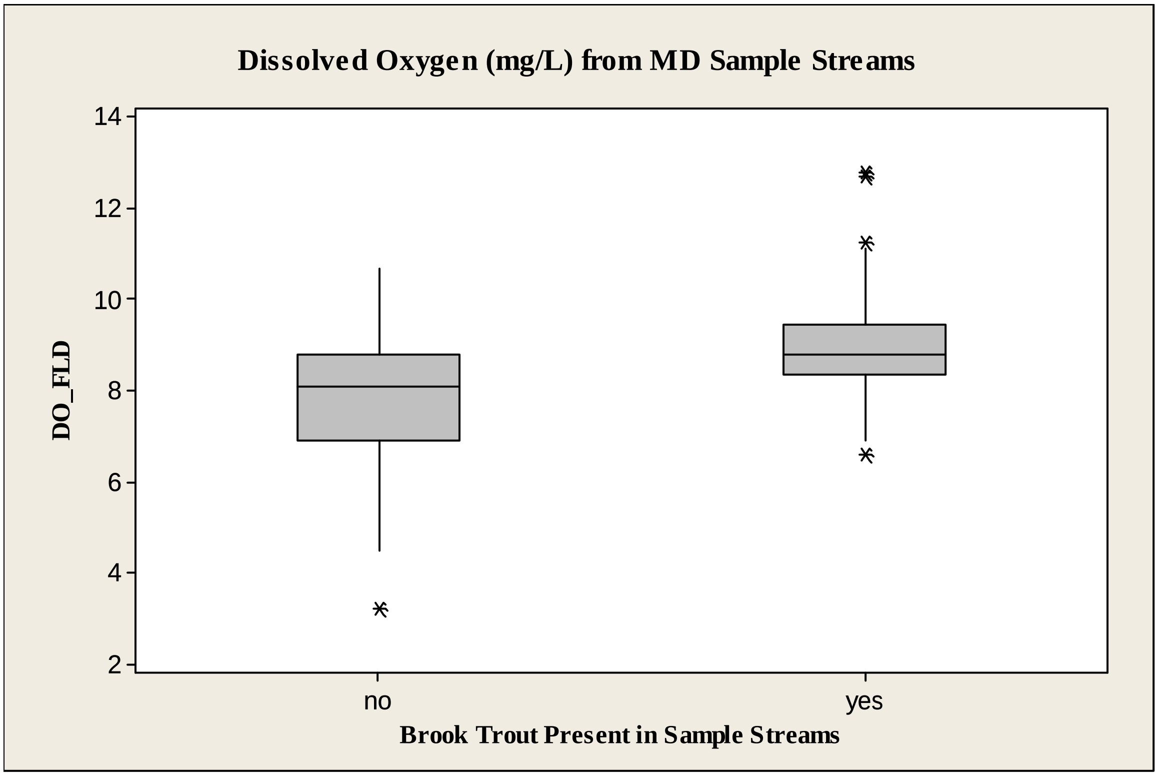

Figure 14. Box plots of dissolved oxygen content (mg/L) in selected Maryland streams and presence of brook trout.

Box plots of two of the metrics, % Ag (Figure 11) and distance to the nearest road (LOG_RD) (Figure 13), were not distinguishable when watersheds with brook trout were compared to watersheds devoid of brook trout. However, Pearson correlations between habitat metrics and book trout counts (-0.30 ($p<0.05$) %Ag; 0.32 ($p<0.05$) LOG_RD, CI = 95%) support predictions of the final classifications. Ambiguous box plots use binary classification (brook trout presence/absence) whereas correlations are based on quantity of brook trout present and not simple categorization of presence or absence. Therefore, correlations provided a more nuanced description of the relationship between the metric and brook trout.

Roth et al. (Roth et al., 2000)) described classification of good and poor along the IBI continuum in Maryland streams. Instead of using categories of brook trout present or absent, categories of good streams (IBI ≥4.0) and poor streams (IBI <3.0) were used. Both % Ag and LOG_ RD metrics were also examined within the IBI continuous scale to determine whether further distinctions could be achieved. Figures 15 and 16 show a more refined separation for %Ag and LOG_RD when evaluated based on sample stream IBI ratings. Although the separation is not ideal, it is comparable to other Mid-Atlantic FIBIs (Pirhalla, 2004; Hill, J., 2011)

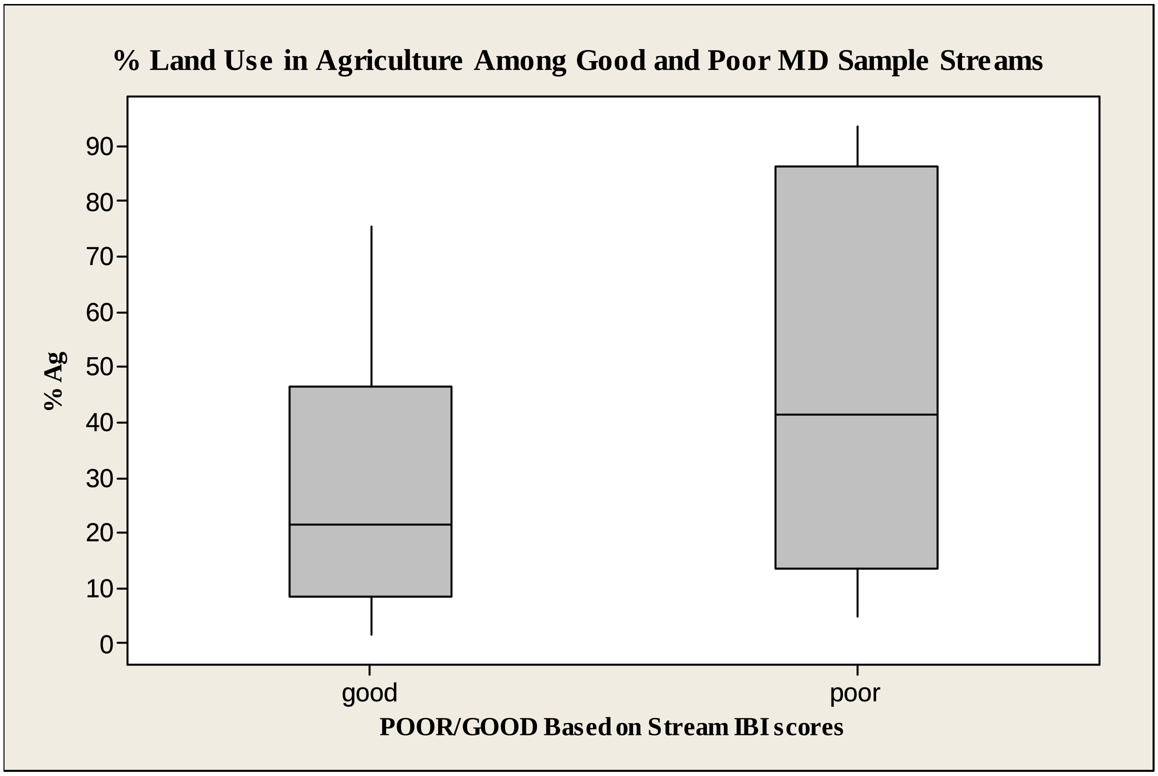

Figure 15. Box plots of good streams and poor streams with corresponding % agriculture land use upstream from selected Maryland streams.

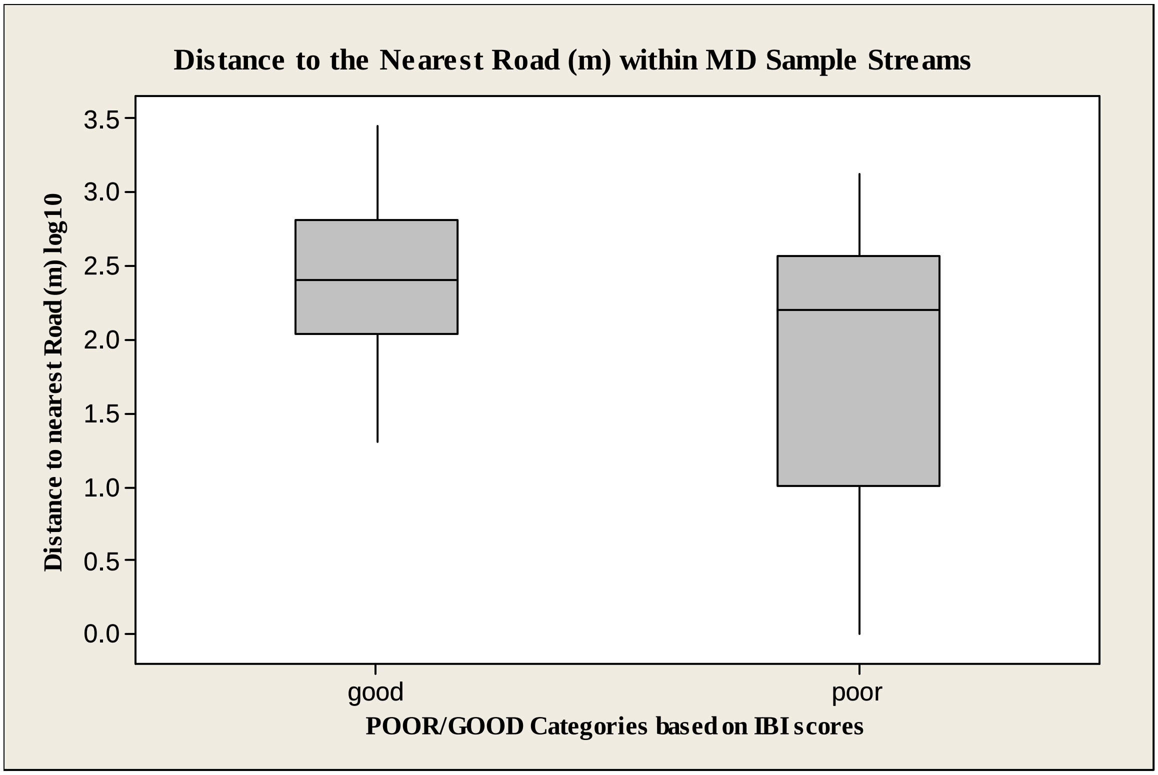

Figure 16. Box plots of good streams and poor streams with corresponding distances to the nearest road (dirt or paved) from selected Maryland streams.

Due to the limited sample size of 84 stream reaches with data for every metric used in the model, the population of scores for each principal component was examined for multivariate normality Normal probability plots are shown in Figures 17 - 21. Additional tests for skewness were necessary for the second and third principal component scores since they did not pass the Ryan-Joiner normality test at $p = 0.05$. Skewness results are shown in Figures 22 and 23. Neither set of scores surpassed the threshold values of less than -1 or greater than +1. therefore, they are not considered to be highly skewed (Bulmer, 1979).

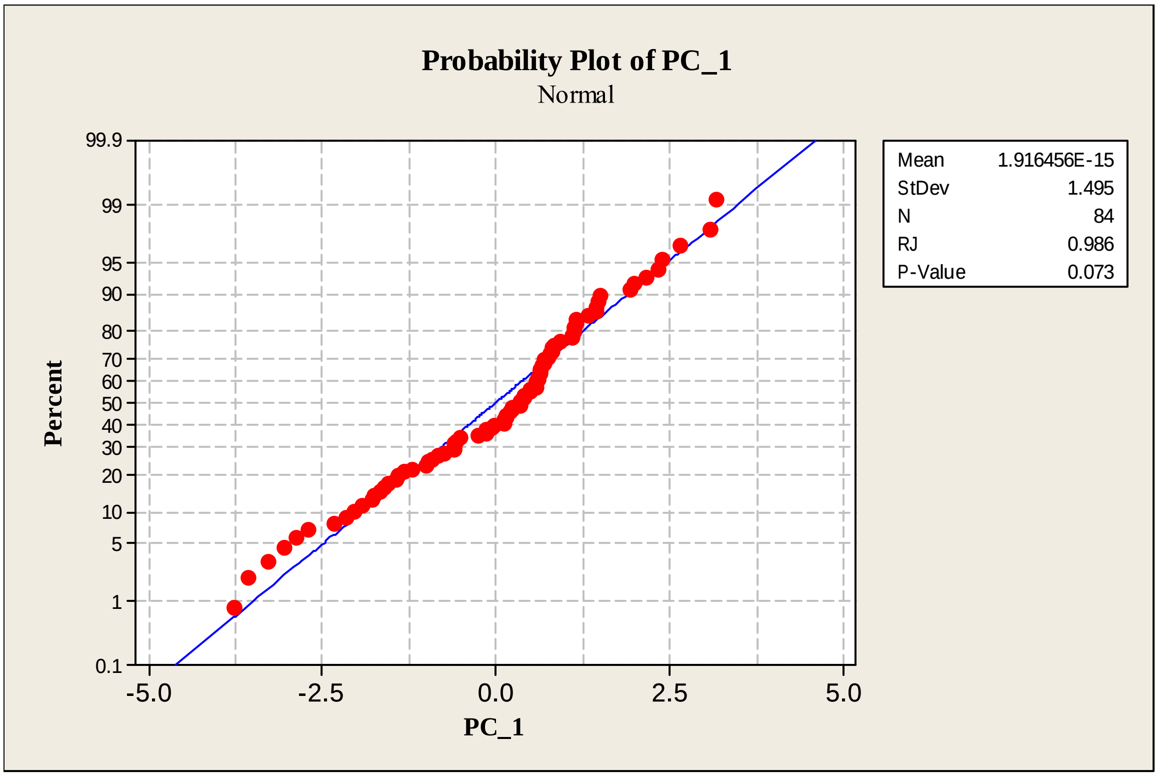

Figure 17. Normal distribution plot for scores from the first principal component.

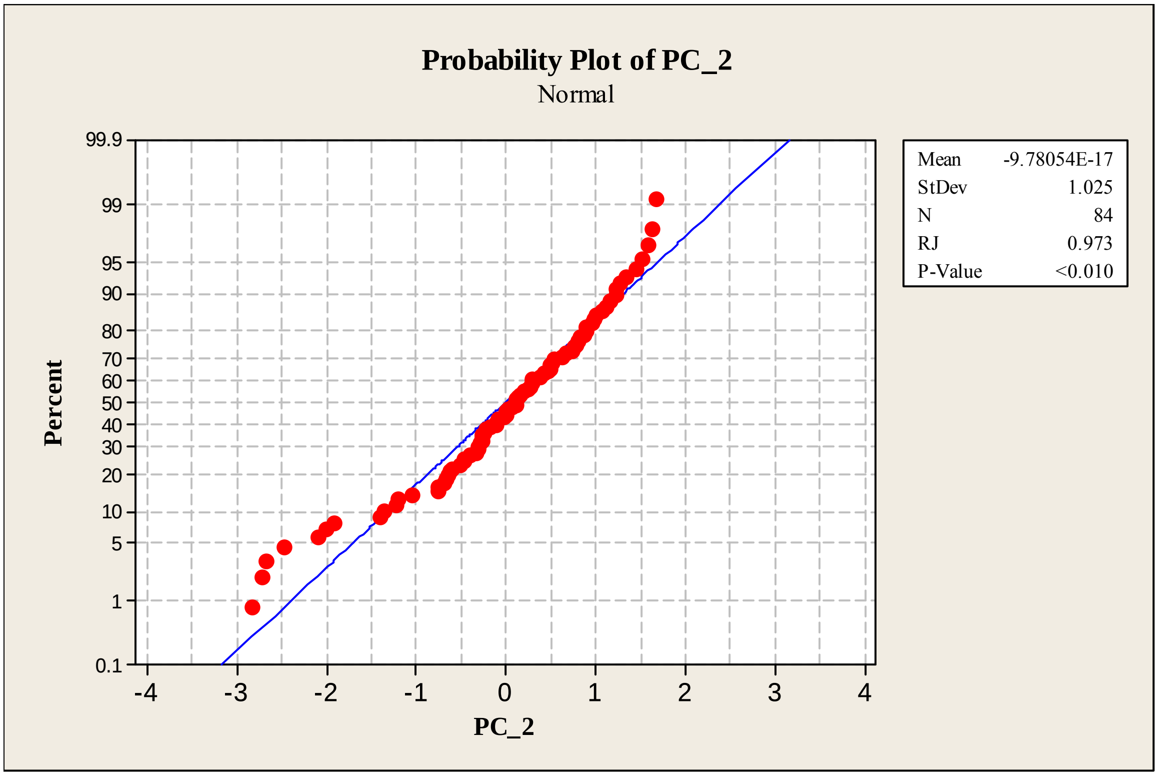

Figure 18. Normal distribution plot for scores from the second principal component.

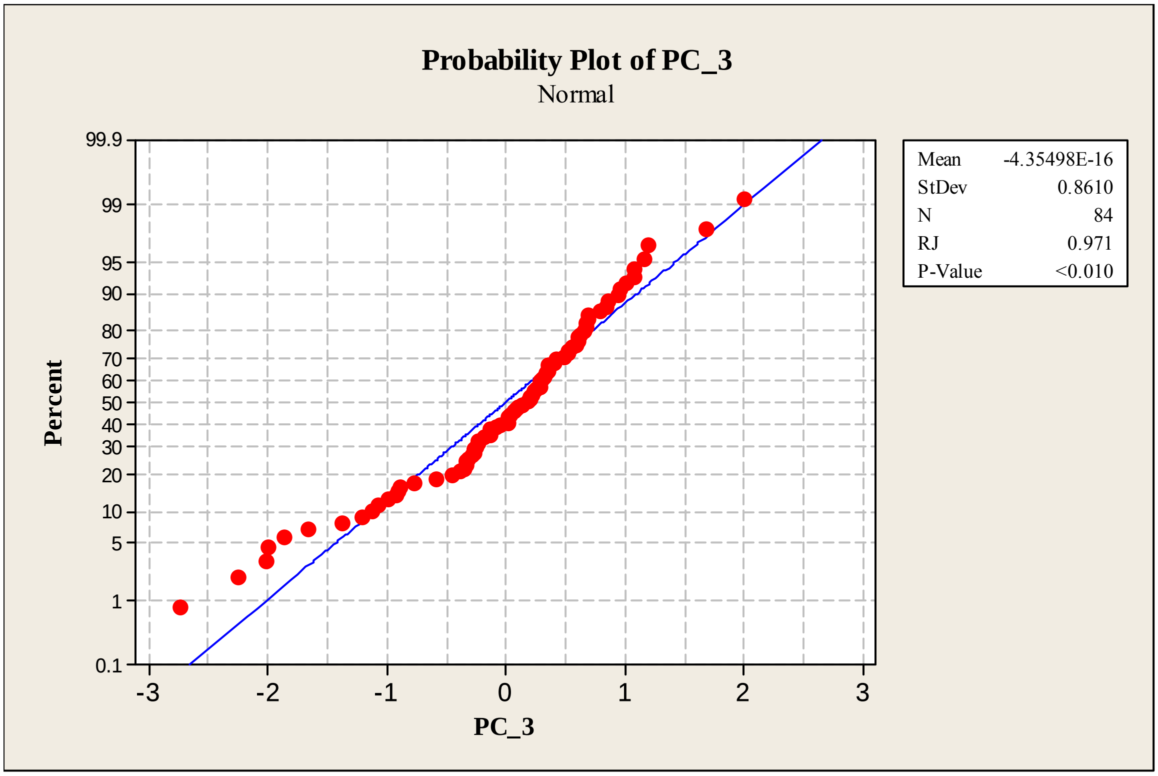

Figure 19. Normal distribution plot for scores from the third principal component.

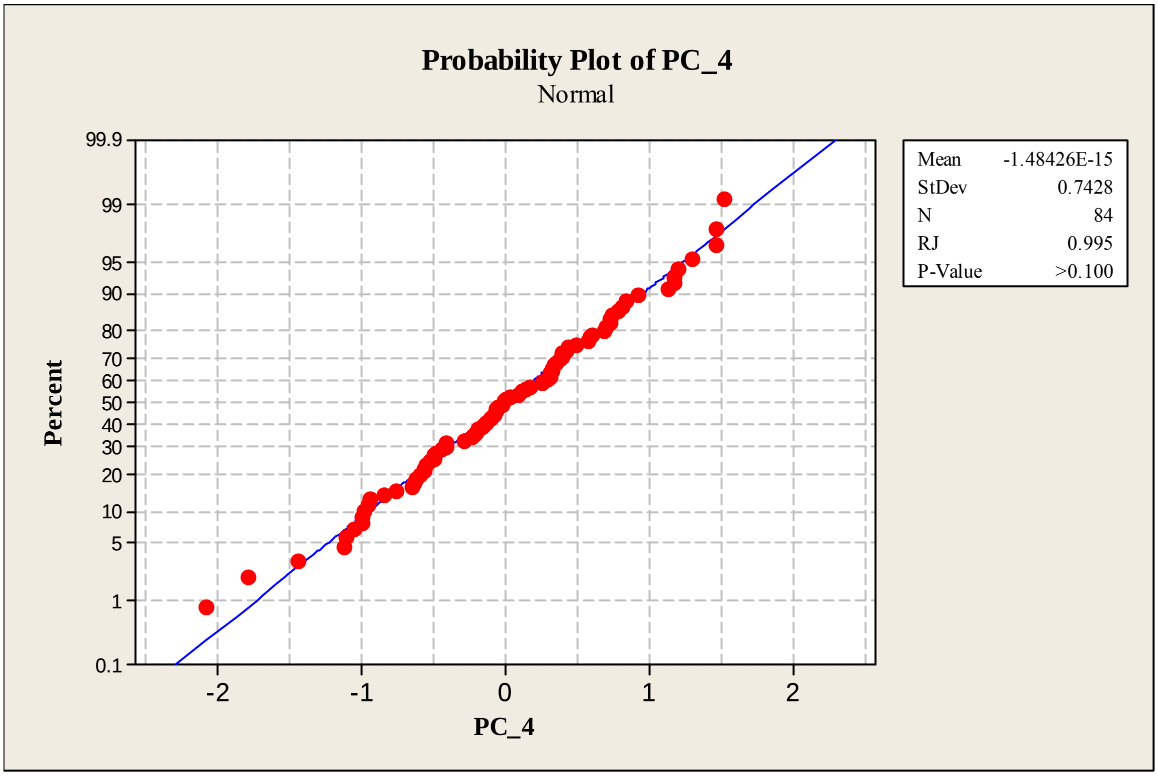

Figure 20. Normal distribution plot for scores from the fourth principal component.

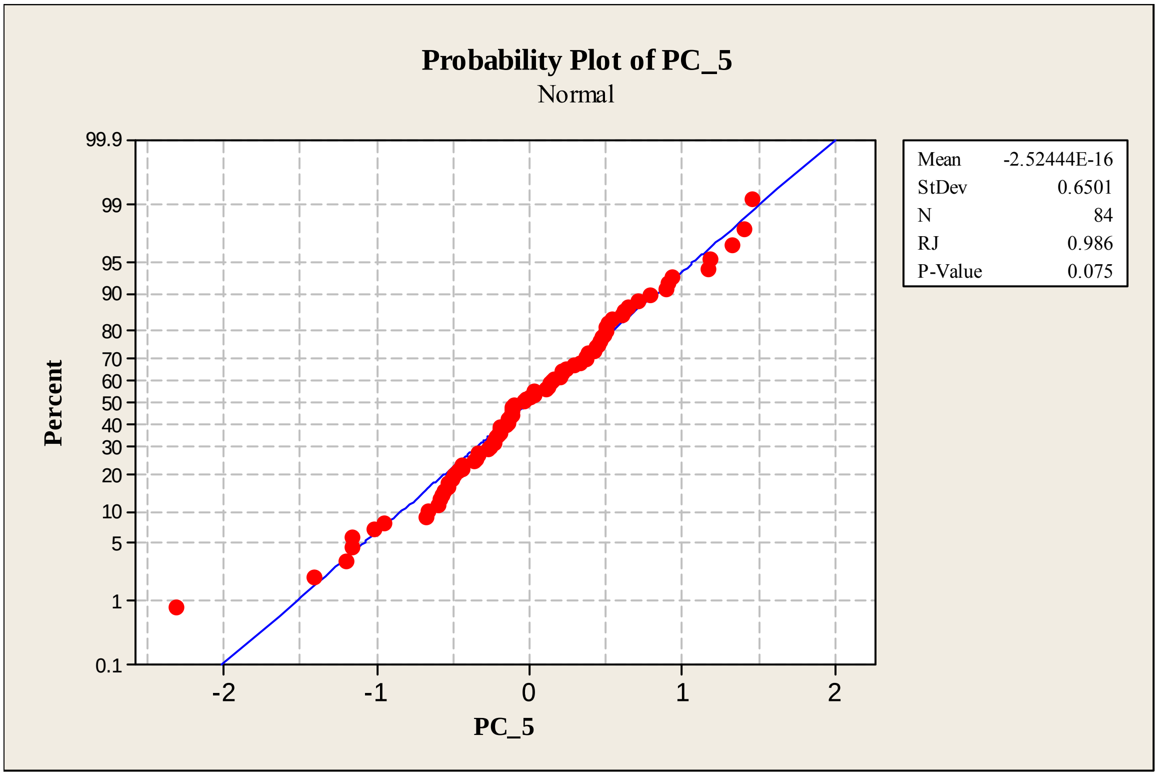

Figure 21. Normal distribution plot for scores from the fifth principal component.

Table 8.

Tabulated form of a multimetric index (BKTI) for rating stream suitability for sustainable brook trout populations in the Mid-Atlantic United States. Final index score for a site is determined by averaging the site's five unitless standardized metric scores, using a maximum metric score of 100 for any metric whose individual score at a site exceeded 100 (Burton and Gerritsen, 2003). Best value scores were derived from the original data found in Appendix A. Xmax for temperature of 20.0˚C is the instantaneous threshold value for brook trout (Raleigh, 1982). Any field temperature measurement above 20.0˚C is assigned a value of 19.99. Data from all 120 stream reach sites were considered for the in-stream metrics while watershed best values originated from the 84 test sites used in the classification model.

	Standard (best value)	X_{min}	**Standardization equation**
Metrics that increase with increasing #s of bkt	X_{95}		*(X in this column = metric value measured in the field)*
Dissolved Oxygen (mg/L)	10.8	0	Score = 100 x (X/10.8)
Distance (m) from nearest road (log 10)	3.2	0	Score = 100 x (X/3.2)
Riffle/Run quality	19	0	Score = 100 x (X/19)
(0 = worst to 20 = best)			
	Standard (best value)	X_{max}	**Standardization equation**
Metrics that decrease with increasing #s of bkt	X_5		*(X in this column = metric value measured in the field)*
Water temperature (˚C)	12.9	20.0	Score = 100 x [(20.0 - X)/(20.0 - 12.9)]
% Ag land use above site	0.56	100	Score = 100 x [(100 - X)/(100 - 0.56)]

Illustration of Combining Stream Classification with Index Rating

One possible application of the Mid-Atlantic brook trout stream index is to combine it with results from initial assessments of stream classification described in Chapter 1. Below is an example of such an application. Three stream reach assessments from Appendix A were chosen to illustrate possible outcomes produced by implementation of both methods in tandem.

Table 9
Sample data for illustrating stream classification and index rating application

SITEYR	bkt	%Ag	RIFFQUAL	LOG_RD	TEMP_FLD	DO_FLD
PRUN-205-R-2001	34	11.66	20	2	12.8	10.2
LOCH-101-R-2002	0	89.22	7	2.544068	18.1	3.2
SAVA-116-R-2002	0	7.68	7	3.278754	18.9	9.7

Inserting metric results from each site into the Smith-Sklarew classification equations of table 6, produce the following for each reach:

Table 10
Suitability prediction in selected Virginia streams versus observations for the presence of brook trout. (Note, suitability statistic based on reference streams from MD. Additional data is needed to definitively determine whether the same coefficients in the equation would apply in Virginia.)

Stream Reach	S	Predict as Suitable (S>0)	Trout Observed
PRUN	3.4	YES	YES
LOCH	-1.2	NO	NO
SAVA	-0.3	NO	NO

Results disclosed in Table 10 above agree with results observed in the field. However, stream reaches from the LOCH and SAVA sites produced similar scores in the two different classifications so resource managers may want to further investigate the suitability of these two watersheds in order to determine whether or not they would be candidate sites for re-establishing sustainable brook trout populations. Before moving forward, resource managers may want to evaluate whether instantaneous thresholds exist which would nullify any quantitative results. For instance, since water temperature measurements are taken in the spring, it may be known that summer water temperatures for a given stream reach exceed the lethal limit of 20 degrees Celsius. Because numerous instantaneous thresholds exist and may be watershed specific, resource managers should familiarize themselves with the dynamics of each watershed before moving forward with field surveys.

In the absence of instantaneous thresholds that may delay or prevent further action, resource managers could conduct field surveys, obtaining metric data for the 5 key metrics utilized in the multimetric brook trout stream suitability index. Data collection methodology should be consistent across all geographic localities within the Mid-Atlantic region and in accordance with sampling guidelines provided in Appendix B.

Using data already obtained for the LOCH and SAVA sample sites described in table 9, followed by tabulation of index scores using table 8, a multimetric, unitless index score was obtained for each in order to produce an initial stream reach assessment or to determine if low index values may exist for individual metrics. Results are tabulated in Table 11.

Table 11.
Brook trout stream suitability multimetric index results for three sample streams presented above. Brook trout index score (BKTI) obtained by averaging all individual unitless metric scores.

Site	%Ag	RIFFQUAL	LOG_RD	TEMP_FLD	DO_FLD	BKTI
PRUN	89.4	100	62.5	100	94.5	89.3
LOCH	10.9	36.8	79.4	26.8	29.6	36.7
SAVA	92.8	36.8	100	15.5	89.8	67.0

Multimetric index scores from Table 11 reveal index scores that are considerably different. The high BKTI score of 89.3 for PRUN is consistent with observed brook trout populations. Coupled with the classification results, an index score of 36.7 for the LOCH site suggests it would not be an ideal candidate stream for restoration. Conversely, metric data from the SAVA site produced a multimetric rating nearly double that of the LOCH site with high metric ratings for %Ag, LOG_RD and DO_FLD. Poor water temperature and riffle/run quality scores suggest a possible lack of adequate riparian buffer. Further examination of the raw data for the site reveals a riparian wideness measurement of 22 meters which is less than half of MD DNR's maximum value of 50 meters.

The above is only one application example of using the Smith-Sklarew Suitability statistic (S) in tandem with the BKTI. It's important that resource managers do not entirely disregard the potential of a stream based strictly on the S statistic. In the case described above, restoration at the SAVA site may involve something as simple as planting riparian vegetation. Other applications may include implementation of a standard approach by regional resource managers in an effort to obtain baseline assessments for streams of interest. Yearly follow-up assessments may help gauge success of restoration efforts. Other resource managers may want to determine whether or not changes in watershed land-use has impacted a stream's BKTI rating by tracking yearly assessments over time.

Conclusion

The multimetric index presented in Table 8 provides natural resource managers with a useful field tool for rating current brook trout streams in the Mid-Atlantic United States while also providing a useful assessment device for determining the potential of other streams. All of the metrics in the index are easily measured by professionals or trained volunteers. Any particular 75 meter reach could be rated with the index in a matter of a couple of hours. With field survey results in hand and access to the online USGS Multi-Resolution Land Characteristic Consortium (MRLC) website (http://gisdata.usgs.gov/website/mrlc/) and Google Earth (http://maps.google.com/maps?hl=en&tab=wl) it may be possible to compute an index rating for a 75m stream reach in much less than an hour. Resource managers may also employ the multimetric index in evaluating stream restoration efforts or, through routine monitoring, determine long-term trends in brook trout habitat quality within a given stream.

The index does not explicitly identify instantaneous threshold values such as lethal water temperatures (Raleigh, 1982) substrate sediment coverage (Hartman and Hakala, 2006) or percent impervious surface coverage (Stranko, Hilderbrand, Morgan, et al., 2008) as others have reported. Additionally, streams in suburban areas may incur favorable index ratings for percent land use in agriculture, but such attribute would not be appropriate. Considering the suburban land uses, percent of the watershed in forest was also examined as a possible alternative index component since it has a collinear R value (-0.961) but results from cross-validation in the discriminant analysis model were less favorable. Thus, there may be reason to adjust indices according to particular attributes in a given watershed.

The index as presented in the present study is intended to assist resource conservationists and should not be used as a "stand-alone" mechanism for assessing particular watersheds or even a particular stream reach. In its present form, the index may be most useful as a preliminary assessment device, designed for rapid, cost effective analysis or screening of Mid-Atlantic upland streams, specifically for brook trout habitability. Resource managers may also employ the index to assess long term trends within a watershed or to gauge success of watershed/instream restoration projects.

Although there have been many effective biological indices developed and used in the Mid-Atlantic United States (Roth et al., 1998; Jones and Kelso, 1999; Kelso et al., 2001; Burton and Gerritsen, 2003; Astin, 2007), none are specifically designed for assessing brook trout habitat in the region. While several trout multimetric indices exist, their applications may be too broad-based to have local geographical significance (Thieling, 2006b; Williams, Haak, Gillespie, and Colyer, 2007b; Hudy, Thieling, Gillespie, and Smith, 2008a) or may have significance in a remote geographical location (Binns and Eiserman, 1979; Schmitt et al., 1993). Maryland's FIBI does document brook trout streams in a manner that provides statistical significance for high quality streams sustaining brook trout populations, but the index is still not a stand alone index for the species (Roth et al., 2000; Vølstad et al., 2003). The same can be said for the physical habitat index for Maryland streams (Hall et al., 2002).

The multimetric index presented herein provides a quick and cost effective assessment of brook trout streams or potential brook trout streams in the Mid-Atlantic United States. Using five core metrics--three in-stream metrics (riffle/run quality, dissolved oxygen content and water temperature) and two watershed metrics (percent land use in agriculture and distance to the nearest road from the survey site), the index can be calculated in the field by professional natural resource managers or trained volunteers. The index should be used in concert with other assessment tools, including the classification model described in Chapter 1, designed to enhance resource managers ability to quickly screen a given stream reach in order to determine its potential for supporting sustainable populations of brook trout.

DISCUSSION

While many environmental indices have been developed through the years, most aquatic indices in the United States are linked to water quality assessment or monitoring as provided through certain provisions of the Clean Water Act. Therefore, the use of biological indicators is an extension of traditional physico-chemical methods used for assessment and monitoring conditions of water quality, largely for human use. To a lesser degree, indices have been developed specifically to assist in the management of fish and wildlife. Because many state governments segregate their fisheries management from basic water quality monitoring, priorities are often misaligned or poorly coordinated. As a consequence, trends in environmental degradation or improvement may occur unbeknownst to one agency while increase or decrease in species abundance may occur unbeknownst to the other agency.

The brook trout stream suitability index (BKTI) presented herein is not only a statistically sound approach for assessing Mid-Atlantic upland streams, but is also a thrifty, efficient tool that provides rapid results for the trained volunteer or professional resource manager in the field. Such a tool bypasses much of the bureaucratic convolution described above. Its lack of sophistication should facilitate volunteer involvement without sacrificing quality in the information it provides. In the present governmental budgetary climate in 2011, such a tool should be welcomed by all involved in managing eastern brook trout populations in the Mid-Atlantic region of the United States.

It's important to note the BKTI was formulated with data provided by MD DNR and the index developed with the application specific to the Mid-Atlantic region. There is some evidence the index may be effective in northwestern Virginia (Figure 4 and Table 5), however, additional data or field surveys will be necessary to determine the geographical extent of the index's application. While the index was designed for brook trout restoration management, it may also indirectly measure conditions favorable for other organisms as well. Additional investigation is needed to determine if coexisting species are inadvertently monitored through application of the index. Since the index is based on a one-time sampling sortie in the spring, there may be other stream/watershed characteristics evident at other times of the year that may significantly alter in-stream habitat. Resource managers and conservationists are encouraged to thoroughly research watershed characteristics, including socio-political aspects, before embarking on a direction based solely on one index evaluation developed during the spring when stream conditions are typically at their best.

While the Smith-Sklarew classification model and corresponding S statistic have shown to be over 76% accurate via cross-validation, there's evidence its accuracy may be conservative. Since the model was developed using reference streams with known populations of brook trout, it's possible some of the streams devoid of brook trout have the potential to harbor brook trout in their present condition. Brook trout may be absent due to a detrimental historical event (e.g. logging, agriculture) or disturbances which temporarily led to an environment uninhabitable by brook trout. It is possible some of those streams may have recovered naturally but are still devoid of brook trout simply because trout were never re-introduced. For this reason, a critical evaluation of the S statistic should include further investigation should a stream rate positive for an S statistic score yet is devoid of brook trout. Theoretically, the more positive the S statistic score, the more brook trout compatible the habit. Conversely, some of the streams with high S statistic values may have one or several instantaneous thresholds which prevent re-establishing brook trout populations.

Because of the uncertainty involved with interpreting the data, interpretation of BKTI and S statistic results should only be undertaken by professionals or trained scientists. It has been my personal experience that many professionals shy away from user-friendly field assessments, stating their simplicity produces meaningless results. During side conversations, what I'm really hearing is they fear for their job security if volunteers are eventually able to replace them. The above two tools, the S statistic and the BKTI require highly trained scientists to adequately interpret the results. Volunteers may be able to collect the data but interpretation requires the experienced scientist to look for "why" the values look the way they do and "what" factors come into consideration for causation and remedy. Additionally, professionals are absolutely imperative for quality control purposes. A pure volunteer effort without professional or third-party oversight may lack proper protocols or proper field technique. All considered, the two above methods almost necessitate professional scientist oversight, training, standardization, implementation and interpretation.

One possible extension for future research may include the search for environmental ecotones. Traditional ecological studies have often described ecotones in the context of landscape transition zones. However, research in the present study suggests there may be multi-dimensional statistical ecotones in waterscapes as well. While instantaneous environmental thresholds have been described for certain species with respect to single environmental stressors, defining thresholds in a multivariate or multidimensional fashion has not been well defined for fauna. Figure 22 below suggests an environmental ecotone may exist for Mid-Atlantic populations of brook trout. Perhaps such an abrupt transition may have gone unnoticed in other studies of species because those species may be less sensitive to environmental perturbations. But in Figure 22 it is clearly evident brook trout populations demonstrate a response within a relatively small gradient noted between 0 and -1 along the first principal component axis. Further study is needed as the data used to generate the graphics were not entirely statistically sound. Should future research prove such an ecotone exists, one might look at certain species as not just indicator or keystone species but more specifically, principal indicator species. While traditional keystone species exhibit sensitivity to changes in one ecosystem, principal indicator species may uniquely be able to exhibit sensitivity to changes in two ecosystems as their existence thrives on the border of both. Implications of such findings in future research may provide a new paradigm within the understanding of ecosystem dynamics.

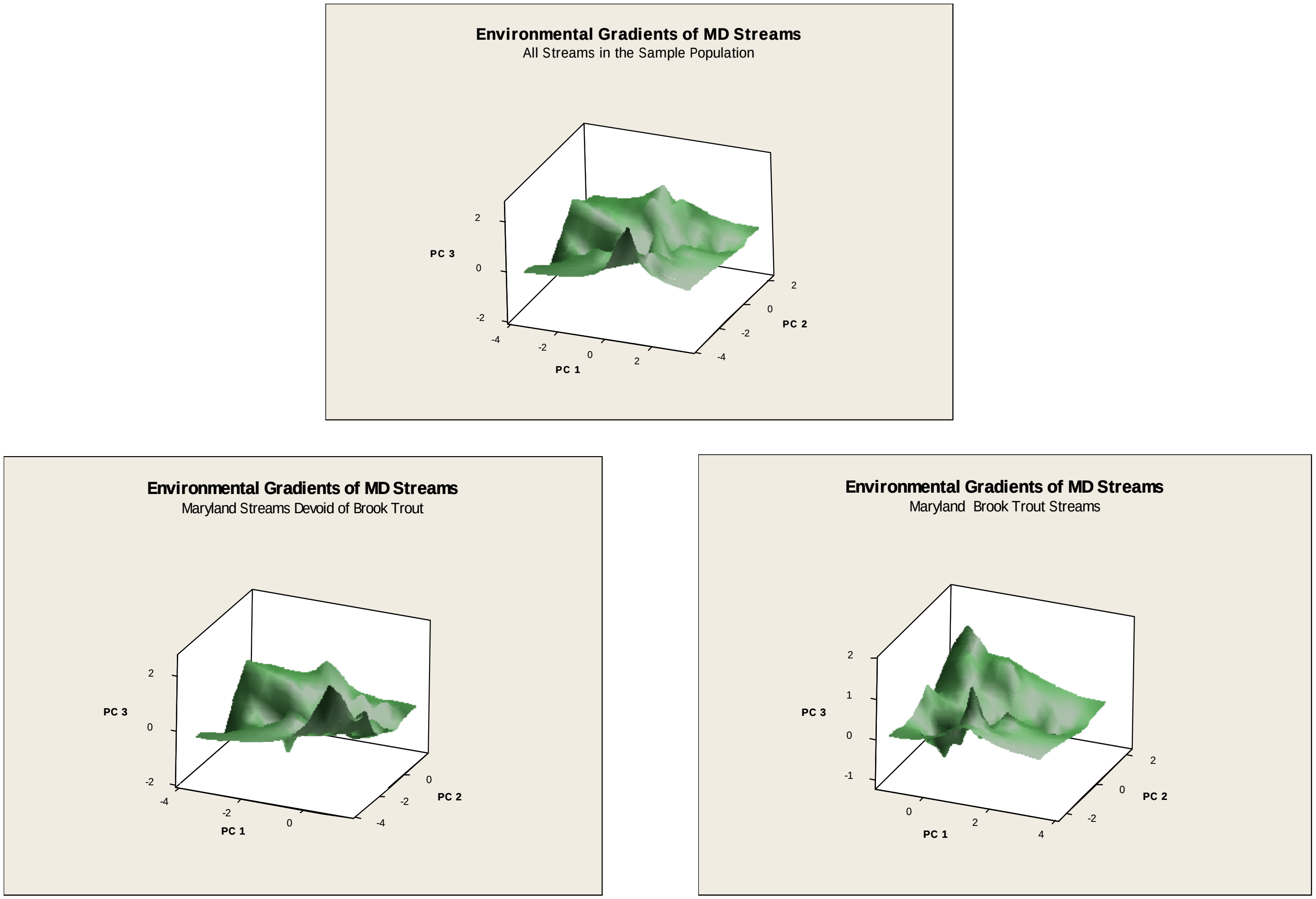

Figure 22. An exhibit of possible environmental gradients within Mid-Atlantic brook trout populations.

APPENDIX A: MARYLAND REFERENCE STREAMS

Data in this section were obtained from MDNR publicly accessible database: http://www.dnr.state.md.us/streams/publications.asp .

SITEYR	bkt	%Ag	RIFFQUAL	LOG_RD	TEMP_FLD	DO_FLD
ANTI-113-R-2003	3	26.12	16	2	17.2	8.5
CASS-104-R-2000	10	21.36	13	2.041393	15.9	8.6
CASS-105-R-2008	6		17	2.243038	19	8.6
CASS-106-R-2000	4	21.47	15	2.39794	15.8	8.4
CASS-110-R-2000	6	43.85	8	1.90309	17.8	7.9
CASS-202-R-2008	1		16	1.69897	16.7	9.9
DEER-106-R-2001	6	55.05	10	2.39794	18.9	8.2
DEER-113-R-2001	28	39.57	15	2.39794	16.6	9
DEER-115-R-2004	1		16	0	17.3	9
DEER-117-R-2001	4		8	2	15.2	8.8
DEER-121-R-2004	4		10	1	17.8	7.2
DEER-126-R-2004	2		15	2.60206	16.6	8.7
EVIT-101-R-2004	65		16	0.477121	12.6	9.1
GEOR-107-R-2003	12	3.77	17	2	12.7	9.9
GEOR-114-R-2003	3	1.56	15	2.676694	17	7.7
LIBE-129-R-2003	2	32.97	14	2.69897	16.6	8.7
LIBE-212-R-2000	18	50	11	2.342423	16.5	8.8
LIGU-102-R-2001	7	48.21	15	0	14.6	9.4
LIGU-109-R-2001	1	75.32	11	2.041393	17.6	9.1
LYOU-103-R-2004	3		6	2.944483	15.7	7.7
PRET-102-R-2008	1		15	1.361728	15.6	9.2
PRET-104-R-2000	13	66.65	15	2.176091	14.4	9.1
PRET-108-R-2000	25	68.8	12	2.30103	15.3	9.5
PRET-111-R-2000	22		14	0.845098	14.8	9.1
PRUN-102-R-2001	71	9.75	13	2.812913	17.1	11.1
PRUN-103-R-2001	131	3	19	3.113943	15.6	7
PRUN-107-R-2001	131	3.05	19	3.130334	15.6	7
PRUN-108-R-2007	16		17	2.079181	14.23	11.25
PRUN-205-R-2001	34	11.66	20	2	12.8	10.2
PRUN-210-R-2001	23	11.97	18	2.176091	13.5	12.7
WILL-110-R-2004	14		12	1	14.8	8.8
WILL-120-R-2004	12		12	0.30103	15.7	9.9

SITEYR	bkt	%Ag	RIFFQUAL	LOG_RD	TEMP_FLD	DO_FLD
WILL-212-R-2004	22		19	0.778151	16.8	8.5
WILL-219-R-2004	18		20	2.20412	12.9	8.5
WILL-404-R-2004	1		19	2.477121	11	10.3
LOCH-101-R-2002	0	89.22	7	2.544068	18.1	3.2
LOCH-102-R-2002	0	4.85	7	0.477121	17.9	7.5
LOCH-102-R-2007	0		10	1	15.9	9.2
LOCH-102-S-2000	35	42.91	14	2.176091	15.3	8.8
LOCH-104-R-2007	0			0		
LOCH-107-R-2002	0	83.21	6	2.30103	22.2	4.8
LOCH-109-R-2002	0	67.56	10	2.113943	21.2	9
LOCH-111-R-2002	0	86.86		2.60206		
LOCH-112-R-2002	0	61.72	11	2.146128	18.1	8.3
LOCH-114-R-2002	0	47.87	7	2.342423	20.3	7.5
LOCH-115-R-2002	0	11.61	6	2.176091	20.8	6.6
LOCH-121-R-2002	6	71.42	10	2.778151	21.7	7.2
LOCH-122-R-2002	0	85.09	7	2.079181	23.7	5
LOCH-123-R-2002	0	4.8	9	2.255273	18.2	7.7
LOCH-209-S-2000	0	43.59	17	1.30103	16.3	9.2
LOCH-213-R-2002	1	62.79	10	2.255273	20.2	6.9
LOCH-216-R-2002	32	39.05	12	1.90309	19.4	8.4
LOCH-224-R-2002	0	74.38	16	0.69897	25.2	8.5
LOCH-305-R-2002	0	62.82	13	1.954243	21.9	8
LOCH-403-R-2007	0		0	2.176091	15.5	10
LOCH-404-R-2002	0	59.78	17	2.60206	24.5	7.1
LOCH-405-R-2007	0		18	2.39794	23.5	9.2
LOCH-443-R-2002	0	16.41	16	0	12.9	10.7
PRLN-104-R-2003	0		10	2.60206	15.1	7.4
PRLN-104-R-2007	0			3.20412		
PRLN-105-R-2003	0	1.08	10	2.511883	13.7	7.1
PRLN-107-R-2003	0	1.45	8	0	15.6	8.6
PRLN-122-R-2003	0	0	15	3.255273	16.1	8.4
PRLN-201-R-2003	0	3.34	11	0	16.1	8.1
PRLN-302-R-2007	0		11	3.09691	17.2	9.5
PRLN-305-R-2007	0		11	2.935507	21.5	6.3
PRLN-306-R-2003	0	10.86	13	3.39794	18.6	8.7
PRLN-316-R-2003	0	10.67	12	2.90309	18.4	8.2
PRLN-318-R-2003	0	10.79	13	2.845098	18.4	8.7
PRLN-321-R-2003	0	3.16	16	1.845098	18	8
SAVA-102-R-2007	0		8	3.123852	13.78	9.6
SAVA-103-R-2002	80	55.43	9	2.69897	18.5	9.1
SAVA-104-R-2002	86	4.83	18	1.653213	15	9.7
SAVA-104-R-2007	33		16	3.1959	12.3	7.5
SAVA-105-R-2002	80	1.54	14	2.477121	15.7	9.5
SAVA-105-R-2007	50		15	2.20412	13.9	8.8
SAVA-115-R-2002	0	55.94		0		
SAVA-116-R-2002	0	7.68	7	3.278754	18.9	9.7

SITEYR	bkt	%Ag	RIFFQUAL	LOG_RD	TEMP_FLD	DO_FLD
SAVA-117-R-2002	103	6.29	8	3.255273	17	8.4
SAVA-119-R-2002	46	6.25	6	1.740363	18.3	6.6
SAVA-120-R-2002	49	8.36	12	3.176091	17.6	9.2
SAVA-206-R-2002	21	43.8	10	3.176091	17.7	9.4
SAVA-308-R-2002	12	16.05	18	2	17.4	8.4
SAVA-312-R-2002	124	10.4	15	3.447158	15.5	10.9
SAVA-401-R-2002	26	30.07	20	1.778151	13.5	12.8
SAVA-410-R-2002	48	10.57	19	2.69897	15.5	10.9
SAVA-414-R-2002	46	10.39	19	2	16.3	9
UMON-101-R-2000	0	16.2	7	1.30103	21.5	6.8
UMON-103-R-2000	0	86.7	8	1	20.9	6
UMON-106-R-2000	0	93.4	7	1.845098	15	7.2
UMON-115-R-2000	0	0	6	2.579784	18.5	9.6
UMON-117-R-2000	0	83.7	8	1.69897	19.2	6.3
UMON-119-R-2000	19	0.5	15	2	18.4	7.3
UMON-128-R-2000	0	0		3.181844		
UMON-131-R-2000	0	90.4	4	2.255273	21.5	6.9
UMON-132-R-2000	0	0.7	0	2.230449	15.5	5.7
UMON-134-R-2000	0	0.3	14	1	17.8	9.2
UMON-201-R-2007	0		15	2.30103	23	8.3
UMON-203-R-2007	0		12	2.944483	24.9	6.9
UMON-207-R-2000	0	4.8	17	1.90309	20.5	8.6
UMON-322-R-2000	0	12.3	18	2.845098	17.1	8.6
UMON-402-R-2007	0		10	2.700704	25.5	4.5
UMON-413-R-2000	0	20.8	16	1.477121	17.3	8.2
YOUG-101-R-2001	0	19.11	6	2.623249	14.3	7.9
YOUG-102-R-2001	0	69.69	9	0	20.3	6.9
YOUG-103-R-2007	0		6	0	15.7	9.5
YOUG-106-R-2001	48	9.9	16	2.477121	15.7	7.8
YOUG-107-R-2001	0	22.41	13	2.20412	15.3	8.2
YOUG-110-R-2001	0	52.01	15	0	17	8.3
YOUG-112-R-2001	0	21.35	14	2.113943	17.9	7.2
YOUG-117-R-2001	61	23.01	12	2.30103	14.7	9.5
YOUG-118-R-2001	0	10.1	0	2.477121	20.7	4.8
YOUG-123-R-2001	15	12.93	16	2.255273	15.9	8.8
YOUG-127-R-2001	119	7.89	18	2.832509	14.5	7.5
YOUG-201-R-2007	0		18	3.041393	15.6	8.1
YOUG-208-R-2001	11	40.31	16	3.113943	16.2	8.6
YOUG-208-R-2007	11		17	2.763428	12.6	8.3
YOUG-214-R-2001	0	28.78	0	2.778151	17.3	9.8
YOUG-219-R-2001	0	32.75	16	2.778151	20.8	6.2
YOUG-221-R-2001	1	18.3	19	1.69897	15.4	8.8

APPENDIX B: MDNR DATABASE CODING AND PARAMETER DESCRIPTIONS

Catchment Land Use Information

use	*description*
Percent Urban	Percentage of urban land use in catchment upstream of site.
Percent Agriculture	Percentage of agricultural land use in catchment upstream of site.
Percent Forest	Percentage of forested land use in catchment upstream of site.
Percent Impervious	Percentage of impervious covered land use in catchment upstream of site.

Water Chemistry Information

parameter code	*parameter defined with units*
Closed pH	Lab pH, sampled in the spring.
Specific Cond.	Specific Conductivity (μmho/cm).
ANC	Acid Neutralizing Capacity (μeq/L).
Cl	Chloride (mg/L).
Nitrate-N	Nitrate Nitrogen (mg/L).
SO4	Sulfate (mg/L).
P-P	Particulate Phosphorus (mg/L).
TD-P	Total Dissolved Phosphorus (mg/L).
Ortho-P	Orthophosphate (mg/L).
Nitrite	Nitrite Nitrogen (mg/L).
Ammonia	Ammonia (mg/L).
TD-N	Total Dissolved Nitrogen (mg/L).
P-N	Particulate Nitrogen (mg/L).
P-C	Particulate Carbon (mg/L)
DOC	Dissolved Organic Carbon (mg/L).
DO_FLD	Dissolved Oxygen as measured in the field (mg/L).
TEMP_FLD	water temperature as measured in the field (˚C).
Turbidity	Turbidity (NTUs).

Physical Habitat Condition

habitat	*description*
Riparian Buffer Width Left	Width of the riparian buffer on the left bank (meters)
Riparian Buffer Width Right	Width of the riparian buffer on the right bank (meters).
Adjacent Cover Left	Type of adjacent land cover on the left bank
Adjacent Cover Right	Type of adjacent land cover on the right bank

Additional field codes and abbreviations within the database are listed below

Variable	*Description (Transformation)*
TACRE	Watershed area (common log)
FORLU	Adjacent forested land use
SINUOUS	Sinuosity
MAXDEPTH	Maximum depth
WETWID	Wetted width
THADEP	Thalweg depth
WIDDEP	Wetted width/Thalweg depth
VELDEP	Velocity/depth quality
POOLQUAL	Pool quality
RIFFQUAL	Riffle quality
EMBEDDED	Embeddedness
TBANKSTAB	Transformed bank stability (square root)
WOOD	Instream Wood
INSTRHAB	Instream Habitat
EPISUB	Epibenthic substrate
SUBSTR	Substrate
HAB	Habitat
TSHAD	Transformed percent shading (arc-sine square-root)
RIPWID	Riparian width
REMOTE	Remoteness
AESTHET	Aesthetics
DIST_RD	Distance to the nearest road (paved or dirt) in meters

Physical Habitat Sampling Protocols

Physical habitat assessments conducted by MBSS are intended to represent the habitat conditions available to the organisms living in the streams and to report on the extent to which certain anthropogenic factors may be affecting Maryland's streams. MBSS Habitat assessment protocols are based on a combination of metrics modified and adapted from USEPA's Rapid Bioassessment Protocols (RBP) and Ohio EPA's Qualitative Habitat Evaluation Index (QHEI). Although EPA's RBP habitat assessment protocols differentiate between riffle-run and pool-glide stream types, all metrics selected for the MBSS are scored at all MBSS sample sites to allow direct comparisons across physiographic regions and summaries of conditions on a statewide basis. Certain MBSS physical habitat variables are recorded based on counts, measurements, or estimates made in the field. These variables include distance from nearest road to site, width of riparian buffer, stream gradient, width, depth, velocity, culvert width and length, extent and height of eroded bank, numbers of woody debris and root wads, extent of channelization, percent embeddedness, and percent shading. The quality of five habitat assessment metric variables along with the severity of bank erosion, buffer breaks, and bar formation are rated using standardized MBSS rating methods. The collection of data on certain other habitat variables are based on the observation (or not) of certain conditions such as buffer breaks,land use types, and evidence of channelization. Based on observations at sites, the absence, presence or extensive presence of stream character and bar substrate is recorded. The type and relative size of riparian vegetation and the type of land cover adjacent to the buffer are reported using standard MBSS codes. The method used for collecting data in the field for each variable differs based on the expected use of each variable as well as optimizing the time required to collect useable information.

The following variables are scored on the following scale:

0-5 Poor
6-10 Marginal
11-15 Sub-optimal
16-20 Optimal

Instream Habitat Structure: Scored based on the value of instream habitat to the fish community

Epifaunal Substrate: Scored based on the amount and variety of hard, stable substrates used by benthic macroinvertebrates

Velocity/Depth Diversity: Scored based on the variety of velocity/depth regimes present at a site

Pool/Glide/Eddy Quality: Scored based on the variety and complexity of slow or still water habitat present at a site

Riffle Run Quality: Scored based on the depth, complexity, and functionality of riffle/run habitat present at a site

Extent of Pools: The extent of pools, glides, and eddies present at a site (meters).

Extent of Riffles: The extent of riffles and runs present at a site (meters).

Embeddedness: Scored as a percentage (0-100) based on the fraction of surface area of larger particles surrounded by finer sediments.

Shading: Scored as a percentage (0-100) based on estimates of the degree and duration of shading of sites during the summer.

Trash Rating: Scored base on the visual appeal of the site and the presence/absence of human refuse. Results from this rating appear under AESTHET (Aesthetics) in the database.

Maximum Depth: Maximum depth of the stream (centimeters).

Physical Habitat Modifications

Buffer Breaks?: Presence/absence of breaks in the riparian buffer, either right or left bank (Y/N).

Surface Mine?: Surface Mine present at the site (Y/N).

Landfill?: Landfill present at the site (Y/N).

Channelization: Stream channelization evident at the site (Y/N).

Erosion Severity Left - Severity of erosion on left bank (Severe, Moderate, Mild, or None).

Erosion Severity Right - Severity of erosion on right bank.

Bar Formation - Extent of bar formation in stream (Severe, Moderate, Mild, or None).

Field Information Management

Each MBSS site is assigned a unique identification code. The code is recorded at the top of all MBSS data sheets. The unique code is made up of four parts.

1) Watershed code. The appropriate four letter code indicating the eight digit watershed containing the site (watershed codes listed below).

2) Segment. Three numbers are used to designate the segment. These three letters begin with the stream order and the next two letters refer to the order in which the site was selected. For random sites, the order in which the sites were collected can be important as sites lower in order being sampled indicate less probability of bias (i.e. in being representative of watershed conditions) compared to having many sites with higher order sampled.

3) Type. A one letter code is used to designate the site type. Site type codes that were used during the Round Two MBSS and are likely to be used during the Round Three MBSS include "R" for random sites, "S" for sentinel sites, "X" for special study sites and "T" for targeted sites.

4) Year. The last four digits in the site identification are the calendar year during which sampling occurred.

Watershed	Abbreviation	Province
Antietam Creek	ANTI	Ridge and Valley
Casselman River	CASS	Appalachian Plateau
Deer Creek	DEER	Piedmont Plateau
Evitts Creek	EVIT	Ridge and Valley
Georges Creek	GEOR	Appalachian Plateau
Liberty Reservoir	LIBE	Piedmont Plateau
Little Gunpowder Falls	LIGU	Piedmont Plateau
Loch Raven Reservoir	LOCH	Piedmont Plateau
Little Youghiogheny	LYOU	Appalachian Plateau
Prettyboy Reservoir	PRET	Piedmont Plateau
Potomac River Lower North Br	PRLN	Ridge and Valley
Potomac River Upper North Br	PRUN	Appalachian Plateau
Savage River	SAVA	Appalachian Plateau
Upper Monocacy River	UMON	Blue Ridge
Wills Creek	WILL	Blue Ridge
Youghiogheny River	YOUG	Appalachian Plateau

(Information within Appendix B was obtained from Maryland's Department of Natural Resources publicly accessible database:
http://www.dnr.state.md.us/streams/publications.asp).

APPENDIX C: CORRELATIONS OF BROOK TROUT ABUNDANCE WITH 45 PARAMETERS FROM 120 MARYLAND REFERENCE STREAM REACHES

	bkt	%urban	%Ag	%forest
%urban	-0.087			
	0.507			
%Ag	-0.298	0.191		
	0.004	0.147		
%forest	0.301	-0.245	-0.961	
	0.004	0.061	0.000	
%imperv	-0.034	0.982	0.246	-0.298
	0.844	0.000	0.148	0.078
INSTRHAB	0.275	0.251	-0.261	0.294
	0.003	0.055	0.014	0.006
EPI_SUB	0.258	0.215	-0.399	0.443
	0.005	0.102	0.000	0.000
VEL_DPTH	0.104	0.343	-0.203	0.191
	0.270	0.008	0.059	0.077
POOLQUAL	0.091	0.278	-0.184	0.172
	0.332	0.033	0.087	0.112
RIFFQUAL	0.290	0.071	-0.259	0.315
	0.002	0.591	0.016	0.003
CHAN_ALT	0.172	-0.029	-0.003	0.067
	0.092	0.829	0.981	0.541
BANKSTAB	0.227	0.052	-0.390	0.426
	0.025	0.703	0.000	0.000
EMBEDDED	-0.240	-0.198	0.376	-0.350
	0.010	0.136	0.000	0.001
SHADING	0.131	0.045	-0.242	0.220
	0.162	0.732	0.024	0.041
DIST_RD	0.319	-0.142	-0.297	0.324
	0.000	0.282	0.005	0.002
AESTHET	0.202	-0.271	-0.291	0.421
	0.027	0.036	0.005	0.000

WOOD_DEB	0.009	0.108	-0.024	0.037
	0.927	0.423	0.827	0.736
NUMROOT	0.008	0.152	-0.029	0.014
	0.935	0.259	0.791	0.896
INSTREAMWOOD	0.020	*	*	*
	0.938	*	*	*
DEWATERWOOD	0.296	*	*	*
	0.232	*	*	*
INSTREAMROOT	-0.112	*	*	*
	0.659	*	*	*
DEWATERROOT	0.143	*	*	*
	0.572	*	*	*
RIP_WID	0.232	-0.183	-0.429	0.482
	0.020	0.169	0.000	0.000
RV_WID_L	0.212	-0.204	-0.498	0.484
	0.021	0.118	0.000	0.000
RV_WID_R	0.201	0.070	-0.527	0.497
	0.028	0.596	0.000	0.000
MAXDEPTH	-0.057	0.352	-0.167	0.146
	0.547	0.006	0.123	0.177
AVGWID	-0.032	0.225	-0.210	0.234
	0.734	0.087	0.050	0.029
AVGTHAL	-0.057	0.214	-0.118	0.118
	0.545	0.104	0.276	0.274
AVG_VEL	0.098	-0.066	-0.127	0.170
	0.300	0.619	0.241	0.114
Ephemerella	-0.121	0.050	0.099	-0.059
	0.186	0.705	0.354	0.581
PH_LAB	-0.044	0.214	0.226	-0.307
	0.634	0.100	0.032	0.003
COND_LAB	-0.081	0.120	0.145	-0.313
	0.381	0.361	0.172	0.003
ANC_LAB	-0.163	0.166	0.109	-0.318
	0.077	0.204	0.308	0.002
DOC_LAB	-0.251	0.100	0.361	-0.379
	0.006	0.449	0.000	0.000
CL_LAB	-0.028	0.068	0.061	-0.152
	0.766	0.606	0.570	0.152
SO4_LAB	0.033	-0.059	-0.209	0.134
	0.720	0.656	0.048	0.206

TN	-0.160	0.130	0.803	-0.796
	0.081	0.322	0.000	0.000
TP	-0.108	0.085	0.379	-0.365
	0.242	0.520	0.000	0.000
O_PHOS	-0.074	0.057	0.341	-0.328
	0.424	0.666	0.001	0.002
NH3	-0.136	0.052	0.334	-0.323
	0.140	0.695	0.001	0.002
NO2	-0.156	0.240	0.537	-0.538
	0.091	0.064	0.000	0.000
NO3_LAB	-0.137	0.107	0.763	-0.757
	0.138	0.416	0.000	0.000
TEMP_FLD	-0.291	-0.039	0.369	-0.389
	0.002	0.767	0.000	0.000
DO_FLD	0.189	0.088	-0.272	0.299
	0.043	0.506	0.011	0.005
PH_FLD	-0.039	0.232	0.197	-0.255
	0.676	0.078	0.067	0.017
COND_FLD	-0.119	0.177	0.065	-0.210
	0.205	0.179	0.552	0.051
TURB_FLD	-0.076	-0.123	0.247	-0.233
	0.419	0.353	0.021	0.030
LOG_RD	0.238	-0.254	-0.199	0.236
	0.009	0.050	0.060	0.025

	%imperv	INSTRHAB	EPI_SUB	VEL_DPTH
INSTRHAB	0.152			
	0.376			
EPI_SUB	0.194	0.684		
	0.257	0.000		
VEL_DPTH	0.219	0.711	0.422	
	0.200	0.000	0.000	
POOLQUAL	0.148	0.705	0.360	0.810
	0.390	0.000	0.000	0.000
RIFFQUAL	0.115	0.669	0.518	0.652
	0.502	0.000	0.000	0.000
CHAN_ALT	0.215	0.086	0.134	-0.023
	0.208	0.401	0.190	0.827
BANKSTAB	0.183	0.087	0.172	0.029
	0.285	0.397	0.093	0.778

EMBEDDED	-0.220	-0.515	-0.707	-0.359
	0.198	0.000	0.000	0.000
SHADING	0.107	0.050	0.159	-0.105
	0.535	0.595	0.090	0.266
DIST_RD	-0.191	-0.004	0.110	-0.144
	0.272	0.968	0.244	0.126
AESTHET	-0.400	0.091	0.237	-0.089
	0.016	0.333	0.011	0.342
WOOD_DEB	-0.201	0.234	0.140	0.152
	0.239	0.021	0.172	0.138
NUMROOT	-0.208	0.312	0.108	0.244
	0.224	0.002	0.292	0.016
INSTREAMWOOD	*	0.135	-0.052	-0.208
	*	0.593	0.839	0.409
DEWATERWOOD	*	0.185	0.267	-0.084
	*	0.462	0.284	0.740
INSTREAMROOT	*	0.319	0.321	0.326
	*	0.197	0.195	0.186
DEWATERROOT	*	0.504	0.490	0.169
	*	0.033	0.039	0.503
RIP_WID	-0.384	0.213	0.239	0.078
	0.021	0.037	0.019	0.448
RV_WID_L	-0.337	0.265	0.324	0.157
	0.044	0.004	0.000	0.095
RV_WID_R	0.125	0.294	0.353	0.126
	0.467	0.001	0.000	0.179
MAXDEPTH	0.070	0.539	0.248	0.745
	0.684	0.000	0.007	0.000
AVGWID	-0.019	0.471	0.259	0.563
	0.913	0.000	0.005	0.000
AVGTHAL	0.035	0.472	0.144	0.601
	0.838	0.000	0.125	0.000
AVG_VEL	-0.055	0.418	0.196	0.517
	0.748	0.000	0.036	0.000
Ephemerella	0.005	0.148	0.203	0.151
	0.979	0.115	0.030	0.107
PH_LAB	0.145	0.254	0.083	0.301
	0.399	0.006	0.379	0.001
COND_LAB	0.142	0.017	-0.302	0.135
	0.409	0.859	0.001	0.152

ANC_LAB	0.330	-0.108	-0.246	0.061
	0.050	0.251	0.008	0.517
DOC_LAB	-0.041	-0.238	-0.090	-0.228
	0.814	0.010	0.341	0.014
CL_LAB	0.100	0.036	-0.160	0.024
	0.563	0.703	0.088	0.797
SO4_LAB	-0.112	0.146	-0.240	0.261
	0.514	0.120	0.010	0.005
TN	0.229	-0.200	-0.271	-0.078
	0.179	0.032	0.003	0.406
TP	0.072	-0.356	-0.326	-0.185
	0.676	0.000	0.000	0.048
O_PHOS	-0.085	-0.114	-0.018	-0.120
	0.623	0.227	0.849	0.201
NH3	0.033	-0.298	-0.274	-0.191
	0.850	0.001	0.003	0.041
NO2	0.590	-0.220	-0.200	-0.143
	0.000	0.018	0.032	0.126
NO3_LAB	0.196	-0.185	-0.257	-0.065
	0.252	0.048	0.005	0.492
TEMP_FLD	-0.106	-0.193	-0.104	-0.155
	0.539	0.039	0.269	0.099
DO_FLD	0.053	0.384	0.338	0.355
	0.760	0.000	0.000	0.000
PH_FLD	0.125	0.346	0.164	0.294
	0.468	0.000	0.081	0.001
COND_FLD	0.248	0.074	-0.190	0.196
	0.145	0.429	0.042	0.036
TURB_FLD	-0.201	-0.282	-0.340	-0.103
	0.240	0.002	0.000	0.275
LOG_RD	-0.507	0.066	0.102	-0.073
	0.002	0.481	0.280	0.437

	POOLQUAL	RIFFQUAL	CHAN_ALT	BANKSTAB
RIFFQUAL	0.418			
	0.000			
CHAN_ALT	-0.075	0.112		
	0.464	0.275		
BANKSTAB	0.039	0.156	0.186	
	0.706	0.127	0.068	
EMBEDDED	-0.219	-0.478	0.034	-0.146
	0.019	0.000	0.739	0.157
SHADING	-0.080	0.001	-0.091	0.187
	0.393	0.996	0.374	0.066
DIST_RD	-0.134	0.021	-0.071	0.133
	0.156	0.823	0.490	0.197
AESTHET	-0.021	0.061	-0.002	0.220
	0.822	0.514	0.987	0.031
WOOD_DEB	0.216	-0.008	-0.115	-0.182
	0.034	0.940	0.262	0.075
NUMROOT	0.240	0.183	-0.161	0.030
	0.018	0.073	0.116	0.767
INSTREAMWOOD	0.352	-0.584	*	*
	0.152	0.011	*	*
DEWATERWOOD	-0.023	0.045	*	*
	0.928	0.861	*	*
INSTREAMROOT	0.352	0.300	*	*
	0.152	0.226	*	*
DEWATERROOT	0.473	0.079	*	*
	0.048	0.755	*	*
RIP_WID	0.030	0.153	-0.082	0.197
	0.768	0.135	0.426	0.054
RV_WID_L	0.066	0.160	-0.106	0.181
	0.483	0.088	0.304	0.076
RV_WID_R	0.117	0.213	-0.069	0.253
	0.212	0.022	0.500	0.013
MAXDEPTH	0.873	0.274	-0.037	0.062
	0.000	0.003	0.719	0.544
AVGWID	0.519	0.356	0.017	0.086
	0.000	0.000	0.866	0.401
AVGTHAL	0.674	0.236	0.064	0.052
	0.000	0.011	0.535	0.611

AVG_VEL	0.288	0.647	0.261	0.075
	0.002	0.000	0.010	0.466
Ephemerella	0.066	0.056	0.040	-0.143
	0.485	0.555	0.697	0.162
PH_LAB	0.231	0.183	-0.108	-0.306
	0.013	0.050	0.292	0.002
COND_LAB	0.108	-0.040	-0.091	-0.273
	0.251	0.668	0.377	0.007
ANC_LAB	0.015	-0.197	-0.067	-0.329
	0.873	0.035	0.514	0.001
DOC_LAB	-0.095	-0.301	-0.066	0.018
	0.313	0.001	0.521	0.864
CL_LAB	0.070	-0.043	-0.173	-0.169
	0.460	0.647	0.090	0.099
SO4_LAB	0.167	0.213	0.106	-0.033
	0.074	0.022	0.303	0.750
TN	-0.128	-0.130	0.114	-0.288
	0.172	0.165	0.264	0.004
TP	-0.188	-0.207	-0.104	-0.260
	0.044	0.027	0.310	0.010
O_PHOS	-0.141	-0.190	0.042	-0.011
	0.131	0.042	0.685	0.914
NH3	-0.229	-0.260	0.030	-0.108
	0.014	0.005	0.769	0.291
NO2	-0.072	-0.235	-0.069	-0.207
	0.444	0.012	0.504	0.042
NO3_LAB	-0.118	-0.119	0.110	-0.286
	0.209	0.205	0.283	0.005
TEMP_FLD	-0.103	-0.296	-0.170	-0.227
	0.274	0.001	0.096	0.025
DO_FLD	0.184	0.409	-0.015	0.163
	0.049	0.000	0.884	0.110
PH_FLD	0.294	0.148	-0.182	-0.272
	0.001	0.113	0.074	0.007
COND_FLD	0.124	0.067	-0.131	-0.228
	0.185	0.477	0.201	0.025
TURB_FLD	-0.112	-0.108	-0.075	-0.277
	0.235	0.253	0.464	0.006
LOG_RD	-0.027	-0.007	-0.118	-0.038
	0.777	0.941	0.248	0.712

	EMBEDDED	SHADING	DIST_RD	AESTHET
SHADING	-0.278			
	0.003			
DIST_RD	-0.134	0.183		
	0.156	0.052		
AESTHET	-0.125	0.185	0.425	
	0.185	0.048	0.000	
WOOD_DEB	-0.099	-0.018	0.017	0.130
	0.336	0.863	0.869	0.203
NUMROOT	-0.229	0.186	-0.046	0.000
	0.025	0.069	0.657	0.998
INSTREAMWOOD	0.392	0.184	-0.086	0.182
	0.108	0.465	0.735	0.470
DEWATERWOOD	-0.220	0.596	0.227	0.354
	0.380	0.009	0.364	0.150
INSTREAMROOT	-0.525	0.255	0.097	0.254
	0.025	0.307	0.702	0.310
DEWATERROOT	-0.136	0.507	-0.184	0.231
	0.591	0.032	0.464	0.356
RIP_WID	-0.177	0.338	0.337	0.475
	0.084	0.001	0.001	0.000
RV_WID_L	-0.339	0.288	0.239	0.339
	0.000	0.002	0.009	0.000
RV_WID_R	-0.253	0.438	0.272	0.348
	0.007	0.000	0.003	0.000
MAXDEPTH	-0.115	-0.195	-0.115	-0.074
	0.224	0.037	0.222	0.433
AVGWID	-0.114	-0.190	-0.057	0.013
	0.226	0.042	0.547	0.890
AVGTHAL	0.073	-0.336	-0.137	-0.081
	0.441	0.000	0.147	0.387
AVG_VEL	-0.131	-0.234	-0.221	-0.137
	0.166	0.012	0.018	0.145
Ephemerella	-0.141	0.045	-0.160	-0.045
	0.135	0.631	0.083	0.624
PH_LAB	-0.015	-0.255	-0.178	-0.404
	0.873	0.006	0.054	0.000
COND_LAB	0.143	-0.047	-0.229	-0.402
	0.129	0.617	0.013	0.000

ANC_LAB	0.139	-0.115	-0.182	-0.542
	0.142	0.219	0.049	0.000
DOC_LAB	0.105	0.053	-0.006	-0.192
	0.268	0.575	0.949	0.037
CL_LAB	0.034	0.075	-0.162	-0.135
	0.717	0.429	0.080	0.143
SO4_LAB	0.128	-0.070	-0.073	-0.197
	0.175	0.458	0.433	0.032
TN	0.325	-0.267	-0.276	-0.281
	0.000	0.004	0.003	0.002
TP	0.302	-0.261	-0.056	-0.071
	0.001	0.005	0.548	0.444
O_PHOS	0.004	0.010	-0.084	-0.107
	0.963	0.914	0.367	0.245
NH3	0.192	-0.055	-0.085	-0.120
	0.041	0.556	0.359	0.192
NO2	0.145	-0.141	-0.103	-0.223
	0.124	0.134	0.269	0.015
NO3_LAB	0.318	-0.268	-0.270	-0.257
	0.001	0.004	0.003	0.005
TEMP_FLD	0.126	-0.121	-0.028	-0.039
	0.182	0.197	0.769	0.680
DO_FLD	-0.282	0.014	0.050	0.090
	0.002	0.886	0.594	0.341
PH_FLD	-0.125	-0.192	-0.144	-0.322
	0.185	0.040	0.127	0.000
COND_FLD	0.057	-0.154	-0.198	-0.347
	0.546	0.101	0.034	0.000
TURB_FLD	0.314	-0.313	-0.065	-0.014
	0.001	0.001	0.490	0.884
LOG_RD	-0.035	0.163	0.689	0.454
	0.708	0.082	0.000	0.000

	WOOD_DEB	NUMROOT	INSTREAMWOOD	DEWATERWOOD
NUMROOT	0.100			
	0.332			
INSTREAMWOOD	*	*		
	*	*		
DEWATERWOOD	*	*	0.364	
	*	*	0.137	

INSTREAMROOT	* *	* *	-0.093 0.713	0.255 0.308
DEWATERROOT	* *	* *	0.517 0.028	0.575 0.012
RIP_WID	-0.031 0.761	0.149 0.147	* *	* *
RV_WID_L	0.076 0.459	0.071 0.487	0.200 0.426	0.372 0.129
RV_WID_R	0.054 0.596	0.148 0.148	0.225 0.369	0.490 0.039
MAXDEPTH	0.202 0.048	0.189 0.064	0.292 0.240	-0.243 0.332
AVGWID	0.289 0.004	0.104 0.308	0.632 0.005	-0.107 0.673
AVGTHAL	0.197 0.054	0.100 0.328	0.696 0.001	-0.152 0.546
AVG_VEL	0.119 0.246	0.044 0.669	-0.033 0.896	-0.169 0.504
Ephemerella	-0.007 0.945	0.082 0.427	0.656 0.003	0.234 0.351
PH_LAB	0.056 0.586	0.100 0.329	-0.051 0.840	-0.397 0.103
COND_LAB	-0.107 0.295	0.163 0.110	0.019 0.940	-0.256 0.305
ANC_LAB	-0.050 0.627	0.062 0.546	-0.026 0.918	-0.476 0.046
DOC_LAB	-0.030 0.767	0.007 0.943	0.056 0.826	0.182 0.470
CL_LAB	-0.056 0.586	0.149 0.146	0.116 0.646	0.113 0.656
SO4_LAB	-0.130 0.206	0.138 0.178	-0.260 0.298	-0.398 0.102
TN	-0.072 0.486	-0.118 0.249	0.043 0.865	-0.425 0.079
TP	-0.078 0.449	-0.095 0.354	0.243 0.331	-0.332 0.178
O_PHOS	-0.057 0.581	-0.007 0.948	-0.024 0.925	-0.386 0.113
NH3	-0.052 0.611	-0.114 0.266	0.753 0.000	0.272 0.275

NO2	0.075	-0.096	0.321	-0.256
	0.463	0.352	0.194	0.304
NO3_LAB	-0.072	-0.121	0.044	-0.420
	0.481	0.239	0.864	0.083
TEMP_FLD	-0.117	0.068	-0.193	-0.339
	0.252	0.508	0.443	0.169
DO_FLD	0.143	-0.003	0.209	0.006
	0.162	0.973	0.405	0.982
PH_FLD	0.234	0.179	0.066	-0.370
	0.021	0.079	0.794	0.131
COND_FLD	-0.044	0.191	-0.095	-0.376
	0.666	0.061	0.706	0.124
TURB_FLD	-0.083	-0.063	-0.331	-0.064
	0.417	0.538	0.179	0.800
LOG_RD	0.020	0.070	0.038	0.186
	0.845	0.493	0.881	0.460

	INSTREAMROOT	DEWATERROOT	RIP_WID	RV_WID_L
DEWATERROOT	0.227			
	0.364			
RIP_WID	*	*		
	*	*		
RV_WID_L	0.199	0.265	0.736	
	0.428	0.288	0.000	
RV_WID_R	-0.105	0.187	0.729	0.611
	0.680	0.458	0.000	0.000
MAXDEPTH	0.164	0.180	-0.013	0.022
	0.515	0.474	0.897	0.814
AVGWID	-0.070	0.387	0.080	0.088
	0.782	0.113	0.438	0.350
AVGTHAL	-0.258	0.260	0.022	0.032
	0.302	0.297	0.829	0.731
AVG_VEL	-0.120	-0.036	-0.021	0.066
	0.635	0.887	0.841	0.480
Ephemerella	-0.097	0.171	-0.091	0.004
	0.701	0.499	0.366	0.968
PH_LAB	-0.223	-0.047	-0.248	-0.197
	0.373	0.854	0.013	0.032
COND_LAB	-0.036	-0.139	-0.114	-0.094
	0.888	0.582	0.258	0.308

ANC_LAB	-0.365	-0.280	-0.232	-0.121
	0.136	0.261	0.020	0.190
DOC_LAB	0.512	-0.003	-0.255	-0.302
	0.030	0.991	0.010	0.001
CL_LAB	0.233	0.152	-0.004	0.008
	0.353	0.546	0.969	0.933
SO4_LAB	0.011	-0.352	0.034	-0.058
	0.965	0.152	0.734	0.532
TN	-0.315	-0.397	-0.382	-0.408
	0.203	0.103	0.000	0.000
TP	-0.507	-0.168	-0.256	-0.313
	0.032	0.505	0.010	0.001
O_PHOS	-0.254	-0.307	-0.077	-0.139
	0.309	0.216	0.446	0.131
NH3	0.304	0.427	-0.196	-0.238
	0.220	0.077	0.050	0.009
NO2	-0.286	-0.038	-0.279	-0.333
	0.249	0.881	0.005	0.000
NO3_LAB	-0.306	-0.394	-0.341	-0.363
	0.217	0.106	0.001	0.000
TEMP_FLD	0.343	-0.118	-0.121	-0.168
	0.164	0.642	0.239	0.072
DO_FLD	-0.120	0.246	0.141	0.176
	0.635	0.326	0.169	0.059
PH_FLD	-0.263	-0.138	-0.231	-0.119
	0.292	0.585	0.023	0.205
COND_FLD	-0.111	-0.270	-0.065	-0.053
	0.660	0.278	0.529	0.570
TURB_FLD	0.235	0.176	-0.184	-0.230
	0.348	0.485	0.072	0.014
LOG_RD	0.245	0.128	0.488	0.328
	0.328	0.614	0.000	0.000

	RV_WID_R	MAXDEPTH	AVGWID	AVGTHAL
MAXDEPTH	0.050			
	0.593			
AVGWID	0.019	0.543		
	0.839	0.000		
AVGTHAL	0.046	0.760	0.681	
	0.626	0.000	0.000	

AVG_VEL	0.031	0.238	0.466	0.386
	0.745	0.010	0.000	0.000
Ephemerella	-0.028	0.072	0.083	0.095
	0.760	0.443	0.375	0.313
PH_LAB	-0.177	0.219	0.412	0.271
	0.054	0.019	0.000	0.003
COND_LAB	0.017	0.071	0.027	0.140
	0.858	0.450	0.777	0.135
ANC_LAB	-0.071	0.028	-0.005	0.081
	0.444	0.769	0.955	0.388
DOC_LAB	-0.137	-0.063	-0.056	-0.115
	0.137	0.506	0.554	0.221
CL_LAB	0.081	0.036	-0.012	0.035
	0.379	0.701	0.901	0.707
SO4_LAB	0.067	0.101	0.107	0.222
	0.472	0.285	0.255	0.017
TN	-0.360	-0.104	-0.064	0.006
	0.000	0.271	0.494	0.945
TP	-0.303	-0.150	-0.098	-0.083
	0.001	0.110	0.295	0.375
O_PHOS	-0.100	-0.087	-0.139	-0.148
	0.280	0.356	0.137	0.113
NH3	-0.237	-0.188	-0.109	-0.089
	0.010	0.044	0.246	0.343
NO2	-0.265	-0.044	0.031	-0.005
	0.004	0.644	0.738	0.955
NO3_LAB	-0.324	-0.096	-0.059	0.012
	0.000	0.306	0.529	0.898
TEMP_FLD	-0.183	-0.108	-0.023	-0.092
	0.051	0.249	0.810	0.327
DO_FLD	0.126	0.206	0.276	0.207
	0.180	0.027	0.003	0.027
PH_FLD	-0.153	0.284	0.324	0.273
	0.102	0.002	0.000	0.003
COND_FLD	-0.019	0.087	0.135	0.146
	0.840	0.358	0.150	0.118
TURB_FLD	-0.229	-0.103	-0.070	-0.020
	0.014	0.275	0.459	0.832
LOG_RD	0.315	-0.026	0.027	-0.065
	0.000	0.784	0.775	0.487

	AVG_VEL	Ephemerella	PH_LAB	COND_LAB
Ephemerella	0.065			
	0.490			
PH_LAB	0.232	0.154		
	0.013	0.095		
COND_LAB	0.082	-0.096	0.447	
	0.385	0.301	0.000	
ANC_LAB	-0.072	-0.040	0.504	0.705
	0.446	0.667	0.000	0.000
DOC_LAB	-0.284	-0.072	0.077	0.024
	0.002	0.438	0.404	0.796
CL_LAB	-0.046	-0.073	0.228	0.824
	0.623	0.429	0.013	0.000
SO4_LAB	0.399	-0.141	0.225	0.505
	0.000	0.127	0.014	0.000
TN	0.035	0.148	0.230	0.212
	0.711	0.107	0.012	0.021
TP	-0.108	-0.045	-0.035	0.039
	0.250	0.623	0.705	0.671
O_PHOS	-0.144	0.146	0.050	0.003
	0.124	0.114	0.589	0.975
NH3	-0.143	-0.009	-0.031	0.090
	0.126	0.919	0.739	0.328
NO2	-0.110	-0.009	0.151	0.136
	0.241	0.926	0.101	0.140
NO3_LAB	0.040	0.161	0.238	0.202
	0.668	0.080	0.009	0.027
TEMP_FLD	-0.375	0.130	0.322	0.123
	0.000	0.165	0.000	0.189
DO_FLD	0.400	0.123	0.020	-0.148
	0.000	0.189	0.836	0.115
PH_FLD	0.163	0.168	0.746	0.404
	0.081	0.074	0.000	0.000
COND_FLD	0.220	-0.087	0.428	0.638
	0.018	0.354	0.000	0.000
TURB_FLD	-0.011	-0.068	0.004	0.044
	0.905	0.471	0.964	0.637
LOG_RD	-0.173	-0.175	-0.197	-0.134
	0.065	0.055	0.032	0.146

	ANC_LAB	DOC_LAB	CL_LAB	SO4_LAB
DOC_LAB	0.142			
	0.123			
CL_LAB	0.333	0.004		
	0.000	0.969		
SO4_LAB	0.190	-0.110	0.147	
	0.039	0.234	0.110	
TN	0.274	0.073	0.085	-0.094
	0.003	0.432	0.355	0.308
TP	0.026	0.279	0.035	-0.047
	0.776	0.002	0.703	0.613
O_PHOS	0.031	0.273	-0.002	-0.071
	0.742	0.003	0.980	0.445
NH3	0.071	0.354	0.082	-0.009
	0.443	0.000	0.373	0.921
NO2	0.149	0.507	0.085	-0.035
	0.105	0.000	0.357	0.703
NO3_LAB	0.273	0.005	0.070	-0.091
	0.003	0.953	0.451	0.326
TEMP_FLD	0.205	0.342	0.109	-0.128
	0.028	0.000	0.246	0.172
DO_FLD	-0.198	-0.333	-0.116	0.052
	0.034	0.000	0.215	0.582
PH_FLD	0.354	0.014	0.319	0.115
	0.000	0.880	0.001	0.220
COND_FLD	0.518	0.076	0.371	0.538
	0.000	0.420	0.000	0.000
TURB_FLD	-0.005	0.097	-0.012	0.125
	0.957	0.302	0.899	0.182
LOG_RD	-0.151	0.046	-0.033	-0.090
	0.101	0.621	0.724	0.330

	TN	TP	O_PHOS	NH3
TP	0.306			
	0.001			
O_PHOS	0.299	0.367		
	0.001	0.000		
NH3	0.236	0.778	0.615	
	0.010	0.000	0.000	
NO2	0.407	0.547	0.430	0.566
	0.000	0.000	0.000	0.000

NO3_LAB	0.986	0.206	0.247	0.102
	0.000	0.024	0.007	0.269
TEMP_FLD	0.183	0.252	0.306	0.295
	0.050	0.007	0.001	0.001
DO_FLD	-0.160	-0.330	-0.217	-0.334
	0.089	0.000	0.020	0.000
PH_FLD	0.178	-0.033	0.073	-0.003
	0.057	0.723	0.435	0.978
COND_FLD	0.091	0.028	0.028	0.103
	0.333	0.764	0.768	0.272
TURB_FLD	0.156	0.934	0.057	0.419
	0.096	0.000	0.544	0.000
LOG_RD	-0.206	0.030	-0.061	-0.005
	0.024	0.750	0.509	0.957

	NO2	NO3_LAB	TEMP_FLD	DO_FLD
NO3_LAB	0.342			
	0.000			
TEMP_FLD	0.337	0.179		
	0.000	0.056		
DO_FLD	-0.354	-0.143	-0.524	
	0.000	0.126	0.000	
PH_FLD	0.085	0.176	0.212	0.169
	0.367	0.060	0.023	0.070
COND_FLD	0.129	0.087	0.119	-0.106
	0.166	0.355	0.206	0.259
TURB_FLD	0.299	0.149	0.179	-0.251
	0.001	0.113	0.055	0.007
LOG_RD	0.008	-0.204	0.068	-0.085
	0.929	0.026	0.468	0.367

	PH_FLD	COND_FLD	TURB_FLD
COND_FLD	0.343		
	0.000		
TURB_FLD	-0.041	0.088	
	0.667	0.348	
LOG_RD	-0.201	-0.147	0.004
	0.032	0.115	0.965

Cell Contents: Pearson correlation
P-Value

APPENDIX D: EIGENANALYSIS OF THE CORRELATION MATRIX

Eigenanalysis of the Correlation Matrix
83 cases used, 37 cases contain missing values

Eigenvalue	4.1516	1.8486	1.1799	0.9008	0.7230	0.6676	0.5228	0.3904
Proportion	0.377	0.168	0.107	0.082	0.066	0.061	0.048	0.035
Cumulative	0.377	0.545	0.653	0.735	0.800	0.861	0.909	0.944

Eigenvalue	0.3484	0.2351	0.0318
Proportion	0.032	0.021	0.003
Cumulative	0.976	0.997	1.000

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
%Ag	-0.355	-0.302	0.275	-0.429	-0.062	0.206	0.021	0.033
%forest	0.385	0.292	-0.183	0.410	0.063	-0.102	0.096	0.021
INSTRHAB	0.323	-0.410	0.097	-0.143	0.254	-0.220	-0.055	-0.204
EPI_SUB	0.365	-0.287	0.200	0.044	0.141	-0.243	-0.029	-0.440
RIFFQUAL	0.332	-0.338	-0.028	-0.190	0.118	-0.187	0.175	0.743
DIST_RD	0.170	0.344	0.410	-0.201	-0.592	-0.461	-0.121	0.142
AESTHET	0.269	0.229	0.439	-0.103	0.065	0.399	0.691	-0.103
RIP_WID	0.281	0.231	0.345	-0.048	0.312	0.424	-0.659	0.183
Ephemerella	0.010	-0.438	0.247	0.648	-0.384	0.283	-0.015	0.203
TEMP_FLD	-0.300	-0.051	0.517	0.271	0.168	-0.318	-0.048	-0.112
DO_FLD	0.328	-0.201	-0.181	-0.206	-0.516	0.268	-0.163	-0.305

Variable	PC9	PC10	PC11
%Ag	0.120	-0.079	-0.674
%forest	-0.097	0.057	-0.726
INSTRHAB	0.134	0.722	-0.020
EPI_SUB	0.246	-0.640	-0.001
RIFFQUAL	-0.254	-0.201	0.039
DIST_RD	0.197	0.086	-0.007
AESTHET	-0.048	0.065	0.116
RIP_WID	-0.004	-0.029	0.011

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CURRICULUM VITAE

Albert "Kirk" Smith grew up in Fairfax County, VA in the 1960s and 70s fishing in many of the local ponds and streams near his home in Oakton, VA. In the early 1970s Kirk often caught brook trout in Little Difficult Run near his house. His admiration of the species as a young child has led to this dissertation forty years later. Kirk graduated from Oakton High School in 1978 and then studied freshwater ecology and fisheries management at Virginia Tech. After graduating in 1983, he entered graduate school at James Madison University where he evaluated the effects of acid precipitation on rainbow trout plasma protein concentrations. While at Virginia Tech and James Madison, Kirk often took 4 to 6 month appointments working for various natural resource agencies around the country. After nearly 20 years of working in the environmental field and studying science, Kirk decided to contribute to the next generation of scientists by teaching at a local high school and community college in Northern Virginia.