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Statewide analysis of brook trout (*Salvelinus fontinalis*) population status and reach-scale conservation priorities in West Virginia Watersheds

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Statewide Analysis of Brook Trout (*Salvelinus fontinalis*) Population Status and Reach-Scale
Conservation Priorities in West Virginia Watersheds

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Master of Science
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Abstract

Statewide Analysis of Brook Trout (*Salvelinus fontinalis*) Population Status and Reach-Scale Conservation Priorities in West Virginia watersheds

Jason W. Clingerman

The Eastern Brook Trout Joint Venture (EBTJV) was formed to implement range-wide strategies that sustain healthy, fishable brook trout populations. Hudy et al. (2006) recently completed a comprehensive analysis of eastern brook trout distributions representing a critical first step towards fully integrating brook trout conservation efforts in this region. This study was designed to supplement and complement existing data on brook trout distributions and status within West Virginia. We examined recently obtained data for the entire state to update the EBTJV distributional map published in Hudy et al. (2006). We then used fish sample data along with GIS-acquired landscape data to create models to predict and extrapolate brook trout distributions and population types within the historical distribution of brook trout within West Virginia. We also used these data to identify critical reach scale priorities for brook trout protection, restoration and enhancement.

Executive Summary

Introduction

Brook trout (*Salvelinus fontinalis*) in the Appalachians have a long history of decline and range reduction from physical, chemical, and biological alterations of habitat due to anthropogenic perturbations (Marschall and Crowder 1996, Yarnell 1998, Boward et al. 1999). In the Appalachians, many contributing impacts have combined to cause reduction in brook trout populations and distribution (Marschall and Crowder 1996). Habitat fragmentation (Belford and Gould 1989, Gibson et al. 2005, Poplar-Jeffers 2005), sedimentation (Curry and MacNeill 2004), increased water temperature (Johnson and Jones 2000, Curry et al. 2002), agriculture and forestry practices (King 1938, Curry et al. 2002, Nislow and Lowe 2003, Baldigo et al. 2005), acid rain (Baker et al. 1996, Van Sickle et al. 1996, Baldigo and Murdoch 1997, Driscoll et al. 2001, Baldigo et al. 2005), acid mine drainage, urbanization, poor riparian habitat/management, and the introduction of exotics (King 1938, Larson and Moore 1983, Waters 1983, Larson et al. 1995, Southerland et al. 2005) have all contributed to declines in native brook trout across their native range.

Recently, studies by Hudy et al. (2005), and Theiling (2006) analyzed eastern brook trout populations at the “subwatershed” scale. A subwatershed was a 12-digit Hydrologic Unit Code (HUC). These large watersheds (average size = 86.3 km²) provided coarse-scale population status for the entire region, but lacked the resolution necessary to provide detailed information about brook trout population status.

Dunning et al. (1992) emphasized the development of intermediate or landscape scale studies. They define a landscape as a mosaic of habitat patches in which a particular patch (focal patch) is embedded. Landscapes would be of different sizes for different organisms, but would

be of a size between an organism's normal home range and the species' regional distribution (Dunning et al. 1992). This scale of study links local microscale studies with large regional or global assessments. A study of this scale focusing on brook trout could give managers essential information on the viability and status of populations across this landscape scale. For the brook trout this could enable further development of management and restoration strategies as well as pinpoint strategic areas to implement these methods for maximum recovery of the landscape-scale population.

In order to more effectively address recovery of brook trout populations, we must address the differences in brook trout populations across the landscape scale. Petty et al. (2005) studied spatio-temporal variation in the distribution of brook trout within the upper Shavers Fork, a 12-digit HUC located in east-central West Virginia found that throughout the study watershed, population structure differed from reach to reach. They found that small, alkaline tributaries were nonsubstitutable, source habitats (Schlosser and Angermeier 1995) that acted as spawning areas where abundances of juvenile brook trout were high and seasonally stable. They found that large adult brook trout were substantially more mobile and utilized the larger stream habitats during spring and summer but moved back into small streams to spawn. Understanding these processes and identifying population types across the landscape are critical steps to fully understand brook trout population dynamics and for restoration at a landscape scale.

Given the above concerns, we designed this study to supplement and complement existing data on brook trout distributions and status within West Virginia. We decided to use landscape-scale variables to assess and predict brook trout status at the local (reach) scale. We assessed brook trout population types, presence/absence, densities, and conservation priorities.

Methods

First, we examined recently obtained data for 265 sites from across the entire state to update the EBTJV distributional map published in Hudy et al. (2005). We then used this fish sample data along with GIS-acquired landscape data (landcover, geology, drainage area, elevation) to create models to predict and extrapolate brook trout distributions and population types within the historical distribution of brook trout within West Virginia. We also analyzed landscape data to detect thresholds important in determining brook trout presence/absence. Lastly, we also used these data to identify critical reach scale priorities for brook trout protection, restoration and enhancement.

Results

EBTJV Status Update

We found that the majority of the time, the EBTJV status was correct, but were able to reclassify 9 of the 29 subwatersheds we sampled that were previously deemed extirpated. For the remaining 20 subwatersheds, we confirmed that brook trout were indeed extirpated. From this sampling, we conclude that of the original 454 subwatersheds believed to have supported brook trout populations historically, brook trout are now extirpated from 281, present at highly reduced levels in 144, present in reduced levels in 19, and intact in only 5 subwatersheds. We used the results of this study to produce a final updated map of brook trout population status at the 12-digit HUC scale throughout the state of West Virginia.

Brook Trout Population Status

We found that we were able to correctly classify brook trout presence/absence in approximately 75% of independently sampled streams. Cross-validated models predicting brook trout population types and densities were also effective. The model predicting population types

had a 61% average cross-validated misclassification rate, but had a cross-validated error rate of less than 1 (0.973) which indicates the model improved up choosing population types at random. The density models had explained 18.8 – 94% of the variation in the data; the average variance explained was 47.1%.

Threshold Analysis

We analyzed landscape data and found the following threshold ranges important in determining brook trout presence/absence: > 80 – 92% forest, < 2 – 12% agriculture, < 5 – 7% developed, < 45 km² drainage area, > 400 – 700 m minimum elevation, and < 4% mining intensity.

Brook Trout Conservation Priorities

We found that 15% of the study area was assigned a protection priority, 3% was assigned a restoration priority and <1% of the study area was classified as a reintroduction priority. We also assessed the amount of these priorities that occurred on public land. We found that there were 2,914 reaches on public land that had a protection priority, 621 reaches were classified as restoration priorities, and 55 reaches were classified as reintroduction priorities.

Discussion

We found that the original EBTJV classifications of subwatersheds were true the majority of the time. However, we were able to reclassify all of the unknown subwatersheds to match one of the previously defined categories. The Hudy et al. (2006) document classified subwatersheds based solely on interviews with local game managers. The local game managers based their classifications on a combination of field data and reports of brook trout presence within each subwatershed. With the nature of the data in Hudy et al. (2006), we would assume that the

majority of the subwatersheds would be correct, but would expect a small number of misclassifications, as we reported here.

Discussion

Predictive modeling has become a large part of fisheries research and conservation. Landscape variables have been used to successfully predict fish abundances (Feist et al. 2003, Pess et al. 2002), densities (Creque et al. 2005), and distributions (Theiling 2006). The use of landscape variables allows data to be collected within a GIS, and does not require labor intensive sampling, a critical benefit for research to be effective. The use of classification and regression trees as the statistical method for predictive modeling has become quite prevalent in ecological studies. Multivariate classification and regression trees have advantages over traditional modeling methods. Their multivariate nature eliminates the need for normalized data and allows the use of highly correlated variables. Classification and regression trees, by their nature and design, allow for patterns within independent data to be easily assessed, and also indicate potential mechanisms important in structuring the response variables. Classification trees have been used to correctly predict distribution of lichens (Edwards et al. 2006), macroinvertebrate communities (Merovich et al. 2007), presence and absence of coral species (De'ath and Fabricius 2000) and most recently brook trout distributions (Theiling 2006) to name a few. Regression trees have been used to predict prairie greenness index (Michaelsen et al. 1994), abundance of plant species (Larsen and Speckman 2004), and smallmouth bass (*Micropterus dolomieu*) nesting sites (Rejwan et al. 1999). Multivariate regression trees have also been shown to be a powerful technique for modeling community responses to environmental factors (De'ath 2002). The majority of these studies was either at spatial scales too large to provide detailed population dynamic information (Theiling 2006), or was built using variables only obtained on site (De'ath

and Fabricius 2000, Rejwan et al 1999). The remaining studies listed above did use landscape or GIS-derived variables to predict smaller scale ecological responses. To our knowledge, there has not been a similar study on fish at this scale and extent, especially not brook trout. Theiling (2006) described and predicted brook trout population status at the subwatershed (HUC-12) level for the entire range of the eastern brook trout, but did not have the scale necessary to provide more than coarse-scale population distributions. By predicting brook trout at the reachshed scale with landscape variables, it allowed us to make predictions about brook trout populations at a smaller scale, and to be able to easily extrapolate those predictions to the remaining portions of the study area. The results of these predictions gives a hypothesis of brook trout distribution at the reach scale based on the best available information which can be refined through additional sampling to give the most accurate assessments of brook trout populations.

Our population type predictions give valuable insight into the spatial dynamics of brook trout populations. These predictions and their extrapolations allow us to spatially examine patterns of population types. We see from our analysis that population structure is highly variable from stream to stream and especially among major drainage regions. There also seems to be evidence that at the watershed scale there is population supplementation/complementation occurring. Our data indicates this population structure is potentially occurring throughout West Virginia and is not limited only to the Shavers Fork watershed where Petty et al. (2005) documented and described it previously. Our population type predictions follow their results that small streams (natal population type) in close proximity to larger streams (marginal population type) act as non-substitutable sources, while the larger more productive streams act as supplemental habitat in the form of productive sinks. Overall the population productivity of the watershed is maximized when these two types of streams/population types are in close proximity

to on another (Petty et al. 2005). Our results also indicate that high density population types tend to be isolated in rare, optimal habitat streams. These streams fit the following criteria most often: intermediate size, nearly 100% forest cover, alkaline geology, and intermediate elevation. This fits current knowledge of brook trout life history; the intermediate elevation, especially, provides the optimum combination of flow stability and water temperature for maximum growth and survival. It is only with this type of information will managers be able to more accurately assess current populations and be able to identify critical areas for brook trout protection and enhancement. These types of maps can also identify areas where certain spatial population dynamics may be in play, which could result in informative studies in the future.

We were able to identify thresholds for key variables (% forest, % agriculture, elevation, % developed, drainage area, and mining intensity) that structured brook trout presence and absence. Theiling (2005) and Hudy et al. (2008) recently performed a similar analysis on brook trout, but at a much larger scale. Their scales of study were the HUC-12 watershed, and the extent of their study was the entire range of the eastern brook trout. These linked studies found that for watersheds with intact brook trout populations, forest cover was generally greater than 70% and agricultural land use was less than 15% (using approximately the 90th percentile). Our thresholds, while predicting a different but similar response variable, are somewhat similar. We found that the 90th percentile threshold for forest cover was higher, at 80 - 92%, while the same level threshold for agricultural land use was similar to what these studies found at 12%. Our higher forest threshold is most likely due to difference in scale of the studies. Our higher forest threshold for a smaller watershed size indicates that forest cover becomes more of a limiting factor for smaller watersheds than for structuring populations at the large HUC-12 watershed. The remainder of the variables they used did not match any of the variables we used in our study.

We also noted marked differences in thresholds among drainages for several variables. Minimum elevation and drainage area were the most highly variable among drainages. The elevation for both streams with and without brook trout was highest in the Kanawha drainage and lowest in the Potomac drainage. This indicates that the overall average elevation of these drainages could be causing these differences in thresholds, as the Kanawha lies mostly upon the Allegheny Plateau, while the Potomac drainage mostly covers the lower elevation ridge and valley province. It could also indicate that relative elevation within a drainage basin could be an important variable. The importance of the differences in thresholds could also be muddled by correlated variables undetermined in this study.

Drainage area was the other highly variable threshold we found. Brook trout were found in streams of much larger drainage area in the Monongahela drainage when compared with the other two drainage regions (approximately 40 km² compared to 15 km²). This drainage could simply be the area of the state where there are larger streams capable of supporting brook trout. Both streams with and without brook trout had a larger drainage areas, which could indicate that this difference could be a relict of sampling slightly larger drainage area streams within this drainage.

Predicting size class abundance generally did not provide any more information as to actual status of brook trout populations within the study area. These predictions did allow us, through evaluations of the predictive trees, to determine critical thresholds and important variables in determining abundances of different size classes of brook trout. The abundance of all size classes increases with an increase in elevation, forest cover, and sandstone geology. The abundance of adults (both small and large adult classes) increases with a decrease in mining intensity, and is maximized in the basin area range of approximately 2.5 – 20.0 km² (small adults

maximized range is 2.3 – 11.7 km²; large adults maximized at 5.6 – 20.1 km²). Young-of-year abundances increase also with a basin area size of less than 10.3 km², a reduction in agriculture, and an increase in limestone.

The presence/absence models predictions provided distributional data important for managing brook trout. By analyzing the presence/absence models trees, we can see that basin area, mining intensity, elevation, forest cover, and geologies were most important in determining presence and absence of brook trout. Basin area was important in nearly all models, and generally smaller basin areas have a higher probability of presence. Elevation was also very important in nearly all models, and probability of presence increases as elevation increases. Forest cover is another important variable in many of the models predicting presences and absences; with an increase in forest cover brook trout presence is more likely. Several geologies (limestone, shale, and sandstone) were important in one or more models, but due to great geologic differences among regions, broad generalizations about geologies are difficult to make.

Differences in predictor variables among modeled regions are especially important to note. This demonstrates what we would expect: specific environmental factors structure brook trout populations in specific areas. For example forest cover and elevation were most important in the Potomac drainage where water quality is generally high, and the limiting factor is most likely stream temperature. Forest cover and elevation, therefore work together to keep streams cool. In the Monongahela drainage, where water quality issues are more important than stream temperature, forest cover and elevation were generally not as important as the mining intensity index which has been linked to water quality (Petty and Merovich 2005). This demonstrates the fact that when predicting ecological responses at small scales, the models themselves cannot

cover too broad of a geographic area, the risk therein lies in the misclassification rates becoming too high as a result of over-generalizations.

The results from the presence absence extrapolations indicate the majority of presences occur in the highest elevation areas along the spine of the Appalachians. This fits current knowledge about brook trout in WV. The majority of presences fall within the EBTJV's brook trout distributional areas (Hudy et al. 2006). Brook trout across much of their range have been relegated to high elevation, headwater streams (Hudy et al. 2006, Larson and Moore 1985). The area within the state with the highest occurrences of presences is the highest elevation area, generally containing headwater streams. This fits current knowledge on ecology and life history of brook trout. Brook trout require cold water, and higher elevation areas have lower average temperatures, thus providing cooler in-stream temperatures for brook trout. Ample forest cover to provide stream shading allows for brook trout to thrive outside of the highest elevation areas. This is evident, especially within the eastern panhandle, where low elevation reachsheds with high forest cover are classified as high probability of presence. Within the state, though, water temperature is not the only factor controlling brook trout populations. Water chemistry issues, mainly acidification from acid mine drainage or acid rain, can cause many streams to be toxic for brook trout. These water chemistry issues are mainly confined the west of the Allegheny Front (Monongahela and the majority of the Kanawha drainages). In the Monongahela drainage, where we had a mining intensity index and included it in the landscape models, it was always the most important variable in determining brook trout presence. The mining intensity index takes into account acidification from mining, but does not account for acid precipitation. Since bedrock geology is important in determining buffer capacity of streams, percentages of bedrock should account for this process within models.

From the population type predictions along with the predictions of distribution, we can see several important issues concerning brook trout within West Virginia. The core brook trout populations are characterized by juxtaposition of small natal streams and larger marginal streams, most likely acting in a complementary/supplementary state. Outside of the core distribution, populations are highly scattered and generally isolated, especially in the Potomac drainage. These populations also tend to be highly variable in quality. When analyzing populations at a broader scale, we can see that extirpation at the HUC-12 scale occurs in watersheds that are highly isolated from core populations.

The priority predictions followed the pattern we expected, in the majority of protection and restoration priorities occurred along the high elevation spine of the state. The spatial pattern of priorities we see in the predictions follows current knowledge on brook trout ecology and population dynamics, specifically metapopulation theory and source-sink dynamics (Liller 2005, Petty et al. 2005). In many areas, we see a pattern where smaller tributaries are given a protection priority (based on their predicted population type, “natal”), but the larger streams are classified as priorities for restoration. We know that currently these larger streams do not produce many brook trout via instream reproduction, but that large adults will use these streams as food availability is high (Liller 2005, Petty et al. 2005). The smaller tributaries produce large amounts of young of the year brook trout, and are therefore critical habitats to protect, while these larger streams could potentially be restored to allow all size classes of fish to once again use these areas.

Management Implications

From this research we found that it was possible to accurately predict brook trout populations from landscape variables with good success. We were able to extrapolate results to

areas that were unsampled. This indicates that predictive models are effective for predicting brook trout distributions in areas that are unsampled. Predictive modeling is a method that could allow managers to make large-scale predictions of species distributions with minimal data, an economically-friendly method. We were also able to identify population types and predict them across the landscape at the reach scale. This data allows managers to easily identify potential brook trout habitat for enhancement or protection. It also allows managers to more clearly visualize population structure across the landscape, which would be critical information for general management of brook trout populations. We were also able to identify critical thresholds for landscape variables that are important in determining brook trout presence/absence. These thresholds can provide critical information for managers as well. This information can be used to identify limiting factors for brook trout populations. Managers should analyze the focal landscape variables (% forest, % agriculture, % developed, minimum elevation, mining intensity, and basin area) to determine which variable could potentially be limiting any given stream.

From this analysis it is clear that future decisions surrounding brook trout management should address the following issues: protect core populations; create maximum interconnectedness of streams with core populations; identify reintroduction priorities; and to restore populations by building off the core populations. The core population should especially try to be expanded in the upper Greenbrier and upper Potomac watersheds where brook trout populations could expand downstream if water temperature was lowered by increasing forest cover, especially in the riparian zone. These areas have excellent water quality as much of their watersheds are located on limestone or shale geologies. This give these streams high buffering capacity for acid load as creating highly alkaline streams, another important factor for highly productive brook trout populations, especially for spawning (Petty et al. 2005).

These data can also be utilized by managers that are currently in the process of classifying trout streams within West Virginia. The data collected has been provided to the WVDNR and WVDEP so they can propose known brook trout streams to be classified into the highest protection classification. The data and analysis from this study can also be used to generate presumptive lists of remaining streams that would contain brook trout populations. Follow-up sampling could then be performed to verify presence of brook trout in these streams where predictive models indicate brook should be present.

Limitations

One major limitation to this study is the lack of multiple-year data. These models are essentially predicting the population status and type during a single “snapshot” in time. This limitation is accounted for somewhat since the Potomac and Kanawha drainages were sampled in different years and the Monongahela drainage was sampled for several years, but each individual sample still only reflects the brook trout population at that particular time. Studies have shown that brook populations can vary (Marschall and Crowder 1995) because of temporal environmental variation, and that they also vary seasonally (Petty et al. 2005) as brook trout move spatially in accordance to life history.

Another limitation is the limited dataset we used. While we had enough data to create effective predictive models, we did extrapolate models built from 265 sites to over 45,000 reachsheds. With these models, an increased amount of construction data will only reduce the amount of misclassifications in the classification and regression trees. Our misclassification rates averaged approximately 25% when validating on an independent dataset, which falls within the range found by Thieling (2006), where misclassification rates for cross-validated models ranged from 17 – 35%.

There were also a couple very important issues that were beyond the scope of this project. Acid precipitation (Baker et al. 1996, Van Sickle et al. 1996, Baldigo and Murdoch 1997, Driscoll et al. 2001, Baldigo et al. 2005), and non-native exotic salmonids (King 1938, Larson and Moore 1983, Waters 1983, Larson et al. 1995, Southerland et al. 2005) have been previously shown to be detrimental to brook trout populations. We did not address these issues directly in this study; the scale at which these variables determine brook trout populations is much more localized than this study could predict. We did account for changes in bedrock geology, which is tied to buffering capacity, and therefore the amount of acid reaching the stream. This was done in an attempt to remove error from the model because of acid rain susceptibility. We also discussed sample points with members of the WVDNR in order to avoid sampling streams where encountering stocked trout, especially stocked brook trout could be likely. We also made every effort to exclude any brook trout that were taken in samples if we suspected them of being stocked, although this occurred very infrequently.

Local habitat measurements were unable to be extrapolated to each stream reach and were therefore not part of any analysis performed. Local measures such as water quality measures (pH, alkalinity, temperature), habitat complexity, substrate size, and flow variability are examples of the local measures important to brook trout that we were unable to assess. Since we analyzed the entire watershed's land cover and geology, water quality should have been accounted for the predictive models. The other local habitat variables could not be accounted for by any of the variables we included in our models. These local habitat variables could prove critical in explaining remaining variance not explained by models, and for describing misclassification occurring in predictive landscape models. The results from our analysis should

be combined with local habitat measures when available to give the most accurate representation of limiting factors important in structuring brook trout populations.

Future Work

Additional studies on this subject should focus on obtaining additional fish sample points to increase the predictive power of the models by reducing misclassifications. Also analysis of multiple year data at sites would allow for broad scale analysis of the variation in brook trout populations from year to year. Future studies should also utilize up-to-date landscape scale GIS data to account for as many variables affecting brook trout as possible. The mining intensity value was such a strong predictor of brook trout where it was available; it would be important to digitize mining features throughout the remainder of the state to allow the mining intensity value to be calculated throughout. Also, recent advances in GIS technologies have allowed for analyses of proximity of certain landscape feature to others. This will allow us to obtain distances along flow paths rather than straight-line distances. These would allow one to gain information on flow path distance to nearest features of interest (mines, springs, population types, etc.) Using these values in predictive modeling could allow for these ecological characteristics of brook trout populations to be accounted for when predicting population status, as well as potentially incorporating population dynamic theories into these models.

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Chapter 3

Figure 1. Generalized classifications of brook trout conservation categories as they pertain to local and regional brook trout conditions.

Figure 2. Illustration indicating the scheme used to determine regional brook trout enhancement priorities. Tier 1 priorities are the highest priorities while Tier 3 priorities are the lowest level assigned for brook trout enhancement.

Figure 3. Map of priorities for brook trout enhancement within West Virginia. Protection priorities are shown in green and are areas predicted to have good brook trout population that need preserved. Restoration priorities are shown in blue where brook trout populations have the best potential for enhancement. Reintroduction priorities are shown in red and are high potential areas in extirpated subwatershed. Subwatersheds indicated as priorities for protection are shown with a red outline.

Figure 4. Map of priorities for brook trout enhancement within public lands. Protection priorities are shown in green and are areas predicted to have good brook trout population that need preserved. Restoration priorities are shown in blue where brook trout populations have the best potential for enhancement. Reintroduction priorities are shown in red and are high potential areas in extirpated subwatershed.

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Appendix 1. Site names and easting and northing coordinates (NAD 83, UTM Zone 17) for all sites used for modeling brook trout populations

Appendix 2. Fish data collected during sampling.

Appendix 3. Local habitat variables recorded during fish sampling. Local habitat variables were not available for all sites sampled.

Chapter 1

An Updated Map of Brook Trout (*Salvelinus fontinalis*) Distributions at the 12-Digit HUC Scale in West Virginia¹

Abstract

A recent assessment performed by Hudy et al. (2006) in support of the Eastern Brook Trout Joint Venture (EBTJV) indicated a lack of brook trout distributional data for many regions of West Virginia. In an effort to update and validate the initial EBTJV distributional map, we systematically sampled 265 streams (1st through 3rd order) throughout West Virginia. We found that in the majority of cases, the EBTJV status was correct. However, we were able to reclassify 9 highly reduced subwatersheds that were previously classified as extirpated as having brook trout. An additional 20 subwatersheds were confirmed as extirpated. From this sampling, we conclude that of the original 454 subwatersheds believed to have supported brook trout populations historically, brook trout are now extirpated from 281 (61.9%), present at highly reduced levels in 144 (31.7%), present in reduced levels in 19 (4.2%), and intact in 5 subwatersheds (1.1%). We used the results of this study to produce a final updated map of brook trout population status at the 12-digit HUC scale throughout the state of West Virginia.

¹ Report to be submitted to the EBTJV

Introduction

Brook trout (*Salvelinus fontinalis*) in the Appalachians have a long history of decline and range reduction from physical, chemical, and biological alterations of habitat due to anthropogenic perturbations (Marschall and Crowder 1996, Yarnell 1998, Boward et al. 1999). In the Appalachians, many contributing impacts have combined to cause reduction in brook trout populations and distribution (Marschall and Crowder 1996). Habitat fragmentation (Belford and Gould 1989, Gibson et al. 2005, Poplar-Jeffers et al. IN PRESS), sedimentation (Curry and MacNeill 2004), increased water temperature (Johnson and Jones 2000, Curry et al. 2002), agriculture and forestry practices (King 1938, Curry et al. 2002, Nislow and Lowe 2003, Baldigo et al. 2005), acid rain (Baker et al. 1996, Van Sickle et al. 1996, Baldigo and Murdoch 1997, Driscoll et al. 2001, Baldigo et al. 2005, Petty et al. 2005, Petty and Thorne 2005, McClurg et al. 2007), acid mine drainage, urbanization, poor riparian habitat/management, and the introduction of exotics (King 1938, Larson and Moore 1983, Waters 1983, Larson et al. 1995, Southerland et al. 2005) have all contributed to declines in native brook trout across their native range.

The final report to the Eastern Brook Trout Joint Venture (Hudy et al. 2006) indicated there was a lack of recent data on brook trout distribution throughout much of West Virginia; (MacCrimmon and Campbell 1969, Jenkins and Burkhead 1993). Within the upper Potomac River and lower New River drainages there is little known about the current distribution and status of brook trout. Consequently, the main objective of this study was to assess brook trout distribution and population status in each of these regions within West Virginia. Specifically we:

- 1) conducted extensive field sampling throughout each of these geographic areas to gather knowledge on brook trout distribution and relative abundance, and
- 2) we examined existing data

gathered in a similar fashion for the remaining portions of the state to identify any potential misclassifications in the original EBTJV report (Hudy et al. 2006).

Methods

To evaluate the original EBTJV classifications, we performed two seasons of extensive sampling across much of the range of brook trout within West Virginia. Sampling occurred during summer 2006 (Potomac drainage), summer 2007 (Kanawha drainage), and summers 2001-2007 (Monongahela drainage). We followed a protocol established to effectively and efficiently sample brook trout where they had not recently been documented. We used the output from initial predictive models we developed to predict brook trout presence.

GIS Framework and Landscape Attributes

Current landcover data was obtained from the 2001 National Landcover Dataset (NLCD), obtained from MRLC data distribution website at 30-meter cell size resolution (<http://seamless.usgs.gov>). In order to account for the problems with over-specificity of the cover types as described in Thogmartin et al. (2004), we reclassified the NLCD raster into six classes (Table 1). Geology data was obtained from the West Virginia GIS Tech Center website (www.wvgis.wvu.edu) and was originally digitized at the 1:24,000 scale based on statewide geologic maps from the West Virginia Geologic Survey. Geology data was classified into four types: limestone, sandstone, shale, or other. All categories were previously designated in the original dataset with the exception of the “other” category. This category was a combination of alluvium, quartzite, and phyllite, each of which occurred at low frequency throughout the study area. Elevation data was obtained from MRLC data distribution website at 30-meter cell size resolution (<http://seamless.usgs.gov>).

A stream reach was defined as a segment of stream into which no mapped tributaries enter (streams and reaches are defined by the 1:24K USGS topographic maps). Each stream reach has an associated watershed, or reachshed (Michael Strager, unpublished data). ArcGIS 9.2 (ESRI, Redlands, CA) was used to tabulate area of each landcover class and each geology type within each reachshed for the study area. The same software was used to find zonal statistics (mean, maximum, minimum) for elevation data within each reachshed. Data for each of these was added to the attribute table for each reachshed.

Using the “shed tools” extension (Strager et al. unpublished data) for ArcView 3.3 (ESRI, Redlands, CA) and flow tables obtained from the WV Natural Resources Analysis Center (NRAC), we were able to accumulate landcover, geology and basin area data for each reachshed. This data gave us cumulative totals for these variables for each reachshed.

Site Selection

We developed an initial predictive model to determine which subwatersheds and stream reaches should be sampled in the Potomac and Kanawha drainages. There were a total of 267 sites sampled; 113 in the Monongahela drainage and 76 sites in both the Kanawha and Potomac drainages (Figure 1). The accumulated landscape data described above was used as the independent variables in the model. For the Potomac drainage, we used brook trout presence/absence data collected by the West Virginia Division of Natural Resources (WVDNR) in the past 10 years. There were 71 sites for the Potomac drainage and 76 for the Kanawha. Presence/absence status was the dependent variable, and was joined into the reachshed attributes. The attribute table, now containing presence/absence status and all landscape variables was then exported to be analyzed in a statistical program. The statistical method we used was a non-parametric classification tree model within the statistical program R (R Core Development Team

2006). These models were then validated using a small independent subset (25%) of the initial data.

For both models, the output was a probability of brook trout presence for each reachshed within the each region (Figures 2 and 3). These probabilities were then grouped into three categories: high probability (probability of presence > 0.75), intermediate probability (probability of presence $0.25 - 0.75$), and low probability (probability of presence < 0.25).

For the Potomac drainage predictive model, 15 landscape variables were included (Table 2). Only five variables were used in the final model, and included maximum elevation within the reachshed, minimum elevation within the reachshed, cumulative total area of upstream forest land cover, cumulative percentage of upstream developed land cover, and cumulative area of upstream agricultural land cover (Table 2, Figure 4). When verifying this model on construction data, overall correct classification rate was 76.4% (23.6 % total error, 5.5% omission error, 18.1% commission error). Once sampling was completed, we validated this model on this independent dataset; which had an overall correct classification rate of 72% (28% total error, 14.7 omission error, 13.3 commission error). In the Potomac drainage, 91% of the reachsheds were predicted as low probability of presence, and 6% of reachsheds were predicted as intermediate probability, and 3% of reachsheds were predicted as high probability of presence (Figure 2).

For the Kanawha drainage predictive model, 23 landscape variables were included (Table 2), but only 3 variables were used in the final model. The variables used in the model were: minimum elevation within the reachshed, cumulative area of agriculture, and cumulative percentage of agriculture (Table 3, Figure 5). For this model, there was no validation data, so to evaluate the effectiveness of the model, we used a cross-validated model. Null misclassification

rate was 37.5%, the model misclassification rate was 6.5% (this is same as the total misclassification rate when verifying on the construction data as above), and the average cross-validated misclassification rate was 7.6%. When extrapolating this model to the entire region, 53% of the reachsheds were predicted as high probability, and 46% were predicted as low probability, while only 1% of reachsheds were predicted as intermediate probability (Figure 3).

Since the EBTJV distributional map was done at such a large scale and there was a lack of sound data for many areas, we chose 8 of the approximately 75 extirpated subwatersheds that we deemed most likely to contain reproducing populations of brook trout to sample. A subwatershed was targeted as likely to contain reproducing populations of brook trout based on one of the following criteria: one or more stream reaches within the subwatershed were on a list obtained from the West Virginia Division of Natural Resources that included presumed or likely brook trout streams, conversations with local residents indicated the presence of reproducing brook trout, or the basic predictive model indicated a large number of stream reaches as likely to contain brook trout. Once a subwatershed was targeted for sampling, we sampled the five reaches with the highest probability of presence within that subwatershed. If brook trout were not found after these five highest probability sites were sampled, we considered the subwatershed to be confirmed as extirpated. If brook trout were found within the subwatershed, we reclassified the subwatershed as greatly reduced in the EBTJV classification scheme.

In addition to the Potomac and Kanawha drainages, which we sampled over two seasons, we analyzed a large existing dataset from the Monongahela drainage. The Monongahela drainage covers the remaining portion of the range of brook trout within West Virginia. Over the past seven years, other researchers from West Virginia University have collected fish survey data

across this drainage; we examined this data to determine if there were any misclassifications in the EBTJV publication that we could identify.

All sites consisted of small to medium sized wadable streams (drainage area < 270 km²) throughout each of the three major drainages. Fish collection was performed using one to three backpack electrofishing units utilizing pulsed DC electrical current. Single-pass electrofishing commenced at a riffle and proceeded upstream a distance of 40 times mean stream width with a minimum length of 150 meters and a maximum site length of 300 meters (Barbour et al. 1999). We used single pass electrofishing methods described in Freund and Petty (2007). Capture efficiency of brook trout has been shown to be high ($\hat{p} = 0.69$, SE = 0.015 for adults and $\hat{p} = 0.77$, SE = 0.013 for juveniles) and relatively constant over time and among sites.(Hense 2007). Each site represented at least two riffle/run/pool combinations (Barbour et al. 1999). Fish were collected with dipnets and held in buckets or livewells until they were counted and weighed. Clove oil at a concentration of 40 mg/L (Woody et al. 2002) was used to anesthetize fish before handling. For trout species, all individuals were weighed (± 0.1 g), measured (± 1 mm) and counted. For non-trout species, only species presence was noted to assess species assemblage. All fish were then released back into the stream.

Results

We sampled 29 subwatersheds that were previously classified as extirpated (Extirpated, Unknown: No Data, or Unknown History from Hudy et al. 2006). We found extant, reproducing brook trout populations within 9 of these subwatersheds through sampling (Figure 6). We confirmed that brook trout were extirpated from the other 20 subwatersheds (Figure 6). For the remaining 229 subwatersheds, we infer that brook trout are extirpated given their original classification in Hudy et al. (2006) and the lack of high quality reaches in our predictive models

(Table 3). We were also able to determine that one subwatershed previously classified as greatly reduced had been extirpated. Finally, we updated the EBTJV map for the entire state using the same categories Hudy et al. (2006) developed (Figure 7). From this update, there is now a total of 281 (61.9%) extirpated subwatersheds, five (1.1%) present: qualitative subwatersheds, five (1.1%) present: intact subwatersheds, 19 (4.2%) present: reduced subwatersheds, and 144 (31.7%) present: greatly reduced.

Discussion

We found that the original EBTJV classifications of subwatersheds was true the majority of the time. However, we were able to reclassify all of the unknown subwatersheds to match one of the previously defined categories. The Hudy et al. (2006) document classified subwatersheds based solely on interviews with state fish biologists. These biologists based their classifications on a combination of field data and reports of brook trout presence within each subwatershed. With the nature of the data in Hudy et al. (2006), we would assume that the majority of the subwatersheds would be correct, but would expect a small number of misclassifications, as we reported here.

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Table 1. Reclassification scheme used for conversion from 2001 National Land Cover Dataset (NLCD) data to the raster data used for analysis.

2001 NLCD Value	2001 NLCD LULC Original Name	Reclassified Name
11	Open Water	Open Water
41	Deciduous Forest	Forest
42	Evergreen Forest	Forest
43	Mixed Forest	Forest
90	Woody Wetlands	Forest
52	Shrub/Scrub	Agricultural
71	Grassland/Herbaceous	Agricultural
81	Pasture/Hay	Agricultural
82	Cultivated Crops	Agricultural
	Emergent Herbaceous	
95	Wetlands	Wetlands
21	Developed, Open Space	Developed
22	Developed, Low Intensity	Developed
23	Developed, Medium Intensity	Developed
24	Developed, High Intensity	Developed
31	Barren Land	Barren

Table 2. List of variables included in non-parametric classification trees for the initial predictive presence/absence models.

Variable Description	Potomac Model		Kanawha Model	
	Included	Used	Included	Used
Minimum Elevation (m)	•	•	•	•
Maximum Elevation (m)	•	•	•	
Drainage Area (km ²)	•		•	
Surface Water (km ²)	•		•	
Forest Area (km ²)	•	•	•	
Agricultural Area (km ²)	•	•	•	•
Wetland Area (km ²)	•		•	
Developed Area (km ²)	•		•	
Barren Area (km ²)	•		•	
% Surface Water	•		•	
% Forest	•		•	
% Agriculture	•		•	•
% Wetland	•		•	
% Developed	•	•	•	
% Barren	•		•	
Limestone (km ²)			•	
Sandstone (km ²)			•	
Shale (km ²)			•	
Other Geology (km ²)			•	
% Limestone			•	
% Sandstone			•	
% Shale			•	
% Other Geology			•	

Table 3. Updated EBTJV classifications of subwatersheds within West Virginia.

Updated EBTJV Status	Updated # of Subwatersheds
Presumed Extirpated	230
Confirmed Extirpated	60
Present: Qualitative	5
Present: Intact	5
Present: Reduced	19
Present: Greatly Reduced	144
Confirmed Present: Greatly Reduced	9

Figure 1. This map shows the distribution of sites where samples were taken. Sites used to make the initial predictive model for the Potomac model are shown in red.

Figure 2. Initial predictive model used to sample from for the Potomac drainage.

Figure 3. Initial predictive model used to sample from for the Kanawha drainage.

Figure 4. Initial predictive model for Potomac drainage built to maximize field sampling efficiency. Probabilities given are probability of brook trout presence. Present or absent status based on probabilities greater than or less than 0.50, respectively.

Figure 5. Initial predictive model for Kanawha drainage built to maximize field sampling efficiency. Lengths of vertical branches increase with increasing importance to overall model. Probabilities given are probability of brook trout presence. Present or absent status based on probabilities greater than or less than 0.50, respectively.

Figure 6. Updated EBTJV distributional map for West Virginia.

Figure 7. Updated EBTJV status map for West Virginia.

Chapter 2

Landscape Thresholds and a Statewide Assessment of Brook Trout Population Status in West Virginia

Abstract

The overall objective of this study was to provide a comprehensive, reach-scale view of brook trout distribution and population status throughout the state of West Virginia. To accomplish this goal, we addressed the following specific objectives: 1) to identify brook trout population types; 2) to construct and validate landscape models capable of predicting brook trout population status (presence, density, and population type) at the reach scale; and 3) to identify critical thresholds of landscape variables that are important in determining brook trout presence/absence. We used sample data from 265 sites distributed across the Potomac, Monongahela, and Kanawha drainages to identify four distinct types of brook trout populations: high density, intermediate density adult, natal, and marginal. We found that we were able to correctly classify brook trout presence/absence in approximately 75% of validation sites. Cross-validated models predicting brook trout population types and densities were also effective. The model predicting population types had a 61% average cross-validated misclassification rate, but had a cross-validated error rate of less than 1 (0.973). Population density models explained 18.8 – 94% of the variation in the data; the average variance explained was 47.1%. Our analysis identified the following threshold ranges important in determining brook trout presence/absence: > 80 – 92% forest, < 2 – 12% agriculture, < 5 – 7% developed, < 45 km² drainage area, > 400 – 700 m minimum elevation, and < 4% mining intensity. The predictions of brook trout population status give fine-scale resolution distributional maps which can be used by managers to make informed management decisions. The thresholds can also help managers in determining limiting factors for brook trout populations and to identify conservation priorities at both multiple scales.

Introduction

Literature Search

Brook trout (*Salvelinus fontinalis*) in the Appalachians have a long history of decline and range reduction due to physical, chemical, and biological alterations of their habitat (Marschall and Crowder 1996, Yarnell 1998, Boward et al. 1999). In the Appalachians, many contributing anthropogenic disturbances have combined to cause reduction in brook trout populations and distribution (Marschall and Crowder 1996). Habitat fragmentation (Belford and Gould 1989, Gibson et al. 2005, Poplar-Jeffers et al. IN PRESS), sedimentation (Curry and MacNeill 2004), increased water temperature (Johnson and Jones 2000, Curry et al. 2002), agriculture and forestry practices (King 1938, Curry et al. 2002, Nislow and Lowe 2003, Baldigo et al. 2005), acid rain (Baker et al. 1996, Van Sickle et al. 1996, Baldigo and Murdoch 1997, Driscoll et al. 2001, Baldigo et al. 2005), acid mine drainage, urbanization, poor riparian habitat/management, and the introduction of exotics (King 1938, Larson and Moore 1983, Waters 1983, Larson et al. 1995, Southerland et al. 2005) have all contributed to declines in native brook trout across their native range.

Few studies have addressed the cumulative effects of multiple stressors on brook trout, with the exception of Marschall and Crowder (1996). They assessed population level responses to siltation (sedimentation), acidification, introduction of a competing non-native salmonid (rainbow trout, *Oncorhynchus mykiss*), and fishing pressure via a size-classified matrix population model. They determined that multiple effects would have cumulative negative impacts on brook trout populations, especially when catastrophic environmental events (floods and droughts) were included. They determined that the most detrimental factors to brook trout populations were those that decreased the survival of large juveniles and small adults. This type

of research is essential in understanding the complex population dynamics when a population is affected by multiple stressors, but lacks the spatial aspect crucial to understanding population response at the landscape level. Such landscape level models have been developed to predict abundance of chinook salmon (*Oncorhynchus tshawytscha*) (Feist et al. 2003) and coho salmon (*O. kisutch*) (Pess et al. 2002). During comparative studies, it has been shown that landscape-scale habitat data was a better predictor of fish abundance (Feist et al. 2003) and density (Creque et al. 2005) across the landscape than was site-scale habitat data.

Recently as part of the Eastern Brook Trout Joint Venture (EBTJV), a study was done by Thieling (2006), to predict brook trout distribution in the eastern United States. The model used in this study was created to be generally applicable over the entire eastern United States and was based on several broad watershed characteristics: percentage forested lands, percentage agriculture lands, combined nitrate (NO_3^-) and sulfate (SO_4^{2-}) deposition, road density, and percentage riparian mixed forested lands in the water corridor. The classification tree model developed was able to correctly classify subwatershed (12 Digit HUC) brook trout status a majority of the time (51-79 % correct classification rate in the final model). This model was very applicable in assessing range-wide population perturbations on brook trout distribution, but lacks the resolution necessary to analyze population status within these fairly large (average size: 8633 ha) 12 Digit HUC subwatersheds.

Rather than the large regional assessment of Thieling (2006) or the smaller microscale population models such as Marschall and Crowder (1996), Dunning et al. (1992) emphasized the development of intermediate or landscape scale studies. They define a landscape as a mosaic of habitat patches in which a particular patch (focal patch) is embedded. Landscapes would be of different sizes for different organisms, but would be of a size between an organism's normal

home range and the species' regional distribution (Dunning et al. 1992). This scale of study links local microscale studies with large regional or global assessments. A study of this scale focusing on brook trout could give managers essential information on the viability and status of populations across this landscape scale. For the brook trout this could enable further development of management and restoration strategies as well as pinpoint strategic areas to implement these methods for maximum recovery of the landscape-scale population.

In order to more effectively address recovery of brook trout populations, we must address the differences in brook trout populations across the landscape scale. Petty et al. (2005) studied spatio-temporal variation in the distribution of brook trout within the upper Shavers Fork, a 12-digit HUC subwatershed located in east-central West Virginia and found that throughout the study watershed, population structure differed from reach to reach. They also found that small, alkaline tributaries were nonsubstitutable, source habitats (Schlosser and Angermeier 1995) that acted as spawning areas where abundances of juvenile brook trout were high and seasonally stable. They found that large adult brook trout were substantially more mobile and utilized the larger stream habitats during spring and summer but moved back into small streams to spawn. Understanding these processes and identifying population types across the landscape are critical steps to fully understand brook trout population dynamics and for restoration at a landscape scale.

Objectives

The overall objective of this study was to provide a comprehensive, segment-scale resolution, assessment of brook trout distribution and population status throughout the state of West Virginia. To accomplish this goal, we addressed the following specific objectives:

- 1) To identify brook trout population types;

- 2) To construct and validate landscape models capable of predicting brook trout population status (presence, density, and population type) at the reach scale throughout watersheds of West Virginia; and
- 3) Identify critical thresholds of landscape variables that are important in determining brook trout presence/absence.

Methods

Study Area

This study was conducted across the historic range of brook trout within West Virginia as defined by MacCrimmon and Campbell (1969) (Figure 1). We did not model populations in watersheds that did not cover substantial areas within West Virginia (James and Youghieny River drainages). Also, following what Jenkins and Burkhead (1994) stated on historical distribution of brook trout, we did not model several other drainages (Coal, Guyandotte, and Little Kanawha River drainages) where they did not think brook trout were historically present. For all sampling and analyses, we divided the state into three regions based on major drainage divides: Potomac, Monongahela, and the lower New River drainages (Figure 2).

The Potomac River drainage was the first region of study. Most of Potomac River drainage within West Virginia falls within the ridge and valley province, and drains from the eastern slope of the Allegheny Front. Much of this system is typified by long, linear, low gradient rivers meandering through wide valleys fed by higher gradient tributaries, a typical trellised drainage pattern. Agriculture dominates much of lowland areas of this region, which has caused extensive damage to much of the riparian zones of streams. This area of West Virginia has largely avoided the detriments associated with coal mining, as much of the drainage is dominated by shale and limestone geologies. The North Branch of the Potomac River drains a

small portion of the Allegheny Plateau, where coal-bearing sandstone dominates and is the only region affected by mining within the Potomac drainage.

The second region included in this study is the Monongahela River drainage. This region drains from the western side of the Allegheny Front and lies within the Allegheny Plateau province. Much of this region tends to be more dendritic in nature, although many headwater rivers exhibit a trellised pattern as well. Coal mining was a major historic perturbation, and its affects can still be seen throughout the region in the form of acid mine drainage. Acid precipitation in this region's poorly buffered sandstone geologies also causes acid problems in many streams (Petty and Thorne 2005, McClurg et al. 2007).

The last region of study for this project lies within the lower New River drainage in the southeastern portion of West Virginia. The Allegheny Front divides this region. On the east side of the Allegheny Front, this basin resembles the Potomac drainage, and falls within the ridge and valley province. On the western side of the Allegheny Front, this drainage resembles the Monongahela drainage, and lies within the Allegheny plateau province. The major perturbations in this basin are similar to either the Potomac or Monongahela drainages, depending on the portion of the drainage.

We also modeled brook trout by physiographic province (Figure 3). This was to model features specific to those individual regions, rather than simply those within drainages. Hughes et al. (1987) found that both aquatic ecoregions and river drainages were useful in describing ichthyogeographic distributions in Oregon. The Allegheny Front was used as the major divider, dividing what we termed the "Plateau" and "Ridge and Valley" provinces. We also included a third area where mining intensity data was available. We termed this area "Mined Plateau" and modeled it separately from the other two regions. Both the ridge and valley and plateau

provinces cover parts of the Potomac and Kanawha drainages. The plateau province also covers portions of the Monongahela drainage. The mined plateau province falls entirely within the remaining portion of the Monongahela drainage.

GIS Framework and Landscape Attributes

Current landcover data was the 2001 National Landcover Dataset (NLCD), which was obtained from MRLC data distribution website at 30-meter cell size resolution (<http://seamless.usgs.gov>). In order to account for the problems with over-specificity of the cover types as described in Thogmartin et al. (2004), we reclassified the NLCD raster into six classes (Table 1). Geology data was obtained from the West Virginia GIS Tech Center website (www.wvgis.wvu.edu) and was originally digitized at the 1:24,000 scale based on statewide geologic maps from the West Virginia Geologic Survey. Geology data was classified into four types, limestone, sandstone, shale, or other. All categories were previously designated in the original dataset with the exception of the “other” category. This category was a combination of alluvium, quartzite, and phyllite, each of which occurred at low frequency throughout the study area. Elevation data was obtained from MRLC data distribution website at 30-meter cell size resolution (<http://seamless.usgs.gov>).

A stream reach was defined as a segment of stream into which no tributaries enter (streams and reaches are defined by the 1:24K USGS topographic maps). Each stream reach has an associated watershed, or reachshed (Michael Strager, unpublished data) (Figure 4). ArcGIS 9.1 or ArcGIS 9.2 (ESRI, Redlands, CA) was used to tabulate area of each landcover class and each geology type within each reachshed for the study area. The same software was used to find zonal statistics (mean, maximum, minimum) for elevation data within each reachshed. Data for each of these was added to the attribute table for each reachshed.

Using the “shed tools” extension (Strager et al. unpublished data) for ArcView 3.3 (ESRI, Redlands, CA) and flow tables obtained from the WV Natural Resources Analysis Center (NRAC), we were able to accumulate landcover, geology and basin area data for each reachshed. This data gave us cumulative totals for these variables for each reachshed.

Site Selection

We developed an initial predictive model to determine which subwatersheds and stream reaches should be sampled in the Potomac and Kanawha drainages. The accumulated landscape data described above was used as the independent variables in the model. For the Potomac drainage, we used brook trout presence/absence data collected by the West Virginia Division of Natural Resources (WVDNR) in the past 10 years. Presence/absence status was the dependent variable, and was joined into the reachsheds attributes. The attribute table, now containing presence/absence status and all landscape variables was then exported to be analyzed in a statistical program. The statistical method we utilized was a non-parametric classification tree model within the statistical program R (R Core Development Team, 2006). These models were then validated using a small independent subset (25%) of the initial data.

For both models, the output was a probability of brook trout presence for each reachshed within the each region. These probabilities were then grouped into three categories: high probability (probability of presence > 0.75), intermediate probability (probability of presence $0.25 - 0.75$), and low probability (probability of presence < 0.25).

The sample sites were chosen from the following protocol. First we examined the current EBTJV classification of the subwatersheds (6th level Hydrologic Unit watersheds, 12-Digit HUC) within the study area. All of the subwatersheds classified as “intact” ($> 90\%$ of historic habitat occupied with self-sustaining populations) and as “reduced” (50-90 % of historic habitat

occupied by self-sustaining populations) were sampled due to the small number of these subwatersheds within the study area. Within the next level of classification, “greatly reduced” (1-49% of historic habitat occupied by self-sustaining populations), approximately 35% of the sub-watersheds (33 of the 94 within the study area) were chosen at random and sampled (Figure 5).

The remaining subwatersheds had several classifications in the EBTJV document based on historical presence, but for this study we classified all remaining as “extirpated.” Since the EBTJV distributional map was done at such a large scale and there was a lack of sound data for many areas, we chose 33 of 178 subwatersheds that we deemed most likely to contain reproducing populations of brook trout to sample. A subwatershed was targeted as likely to contain reproducing populations of brook trout based on one of the following criteria: one or more stream reaches within the subwatershed were on a list obtained from the West Virginia Division of Natural Resources that included presumed or likely brook trout streams, conversations with local residents indicated the presence of reproducing brook trout, or the basic predictive model indicated a large number of stream reaches as likely to contain brook trout.

For each level of classification above we used a different sampling strategy within the subwatersheds. For both “intact” and “reduced” subwatersheds, one stream reach falling into each of the predicted categories (high, intermediate, and low) was sampled at random within each of the four subwatersheds carrying these classifications. For “greatly reduced” subwatersheds, one “high” stream reach and one of either “intermediate” or “low” probability was sampled. This was done in order to make sure there was a sufficient number of sites sampled containing brook trout, allowing variability in density and abundance to be included in the final model

For the subwatersheds classified as “extirpated” we used a different sampling approach. We sampled the five highest probability sites within that subwatershed. If after this sampling, no brook trout were collected, we inferred that the “extirpated” classification was indeed appropriate. If brook trout were collected in any of the five sites, the classification essentially changed from “extirpated” to “greatly reduced” and the sampling protocol described above was followed. We sampled as many of these sites as possible given time constraints during the summers of 2006 (Potomac region) and 2007 (Kanawha region).

Site selection within the Monongahela drainage was slightly different, but the sites consisted of streams that fell within the same basin area range and were chosen to capture variation across a range of landscape variables for the drainage basin: stream size, geology, and mining intensity. For this drainage 35% of the greatly reduced and 5% of the extirpated were sampled compared to 31% and 18.5%, respectively, for the remainder of the study area. Given the distribution of sites within this watershed as compared to the other two we sampled, we are confident that this data is comparable to the other data, and will be treated accordingly for the remainder of the analyses.

Brook Trout Population Sampling

All sites consisted of small to medium sized wadable streams (drainage area < 270 km²) throughout each of the three drainage basins. There were a total of 267 sites sampled; 113 in the Monongahela drainage and 76 sites in both the Kanawha and Potomac drainages (Figure 6). Fish collection was performed using one to three backpack electrofishing units utilizing pulsed DC electrical current. Single-pass electrofishing commenced at a riffle and proceeded upstream a distance of 40 times mean stream length with a minimum length of 150 meters and a maximum site length of 300 meters (Barbour et al. 1999). We used single pass electrofishing methods

described in Freund and Petty (2007). Capture efficiency of brook trout has been shown to be high (p-hat = 0.69, SE = 0.015 for adults and p-hat = 0.77, SE = 0.013 for juveniles) and relatively constant and with little variability among sites (Hense 2007). Each site represented at least two riffle/run/pool sequences (Barbour et al. 1999). Fish were collected with dipnets and held in buckets or livewells until they were counted and weighed. Clove oil at a concentration of 40 mg/L (Woody et al. 2002) was used to anesthetize fish before handling. For trout species, all individuals were weighed (± 0.1 g), measured (± 1 mm) and counted. For non-trout species, only species presence was noted to assess species assemblage. All fish were then released back into the stream.

Identifying Brook Trout Population Types

Within program R and the “cluster” package (Maechler et al. 2006), we performed a cluster analysis using the Bray-Curtis distance method with Ward’s agglomeration method to produce clusters of similar sites based on the brook trout population structure (density of young of year, small adults, and large adults). The cluster dendrogram was pruned to seven groups. We felt that this number of groups was a number large enough to provide differentiation between groups without over specificity. To determine the legitimacy of groups, we used a multivariate analysis of variance (MANOVA) with a post-hoc tukey test to analyze if there were any groups that did not differ significantly ($\alpha = 0.05$) among all three variables (young-of-year density, small adult density, large adult density). Before performing the MANOVA, these variables were transformed using a LOG + 1 transformation, after which they approached normality so that the more robust parametric tests could be used. Any groups that were not significantly different from one another among each size class were combined into a new group. We then used box and whisker plots to examine differences in young-of-year, small adult, large adult, and total

standardized relative abundance (density in fish/meter * 150 meters) among groups. We used this data to describe and name groups that remained.

Landscape Models

We created models predicting population types, presence/absence, and density of brook trout. For each drainage basin, a model was created to give a prediction for each reachshed within the study area. We also created models by physiographic region for each reachshed. The independent variables in all of these models were the landscape variables we had available at the reachshed level (Table 2). The dependent variables were population types from cluster analysis, probability of brook trout presence, and the standardized relative abundance (fish/150 meters of stream) of each size class of brook trout. Model results were then averaged (unweighted) from both models (i.e. drainage model and province model) for each reachshed to give a final probability of presence taking into account both models. This was true for both presence/absence and density modeling. For predicting population types, we created one model for the entire state. We did this due to the small number of sample points available for model creation.

The modeling method we used was a non-parametric, cross-validated classification tree (population type and presence/absence models) or regression tree (density model) using the statistical program R (R Core Development Team 2006) and the “mvpart” function within the “mvpart” package (Therneau et al. 2006). To maximize the predictive effectiveness of the models for the study area, we used all the available data to create the models. We then verified the models’ accuracy by analyzing the cross-validated misclassification rates. For the presence/absence models we validated them on an independent WVDNR dataset, where misclassification rates were again analyzed.

Once models were validated, the results were extrapolated to the remaining unsampled reachsheds throughout the entire study area. Tables with predicted values were exported from program R using the “MASS” package (Venables and Ripley 2002). These tables also contained a unique identification number which allowed us to join them back to the original reachshed shapefile. Once the table was joined, the reachsheds were color coded based on the predicted values from the created models.

In an attempt to identify critical thresholds in landscape variables as they relate to brook trout populations, we examined a series of box-and-whisker plots. Hudy et al. (IN PRESS) used the same method to describe important thresholds for brook trout at the subwatershed (HUC-12) level. We used these methods to identify critical thresholds in landscape variables at the reach level as they pertain to brook trout presence.

Results

General Results

Across the entire study area, there were a total of 55,465 reaches and reachsheds that were modeled. Reachsheds averaged 71.4 ha in size, and had an average stream reach length of approximately 700 meters (Table 2). Elevation ranged from 76 – 1490 m, with an average elevation of 617 m. We found that 80% of the study area was forested, 12% of the study area was agricultural, and 7% was developed (Table 3). Geology types differed among regions and drainages, but for the entire study area, shale was most common occurring across 47% of the area, while sandstone occurred on 43% of the study area. Limestone was most common in the Potomac drainage and ridge valley province, and consisted of only 8% of the study area (Table 3).

A total of 265 sites were sampled statewide between 2001 and 2007, 76 in the Potomac, 76 in the Kanawha and 113 in the Monongahela drainage. Brook trout were present in 109 out of the 265 sites (41%). Brook trout were present in 40% of streams in the Potomac drainage, 34% of streams in the Kanawha drainage, and 47% of the streams sampled in the Monongahela drainage. Appendix 1 summarizes fish data gathered at each sample site. Appendix 2 summarizes the remaining data collected at each site, although it was not used in this study.

Brook Trout Population Types

Cluster analysis produced seven groups (Table 4). MANOVA indicated that there were significant differences (d.f. = 5, $p < 0.0001$) in size class structure among the seven groups. However, post-hoc tukey tests indicated that three groups should be combined into one group, because they did not differ significantly ($p > 0.01$) in numbers of young of year, small adult or large adults. After combining these groups, there were a total of four groups that remained. We then used box and whisker plots to further examine differences among groups for total abundance, young-of-year abundance, small adult abundance, and large adult abundance (Figure 7). This allowed us to describe and name each group produced from cluster analysis. Group names were as follows: high density (HD), intermediate density adult (IDA), natal (N), and marginal large adult (MLA). Table 4 shows the full description for each group.

Presence/Absence Models

For each drainage (Potomac, Kanawha, and Monongahela) and province (Plateau, Mined Plateau, Ridge and Valley), a separate classification tree model was created predicting brook trout presence and absence on the basis of landscape variables (Table 5).

The model for the Potomac drainage contained four variables (% forest, drainage area, minimum elevation, and % shale) and six terminal nodes (Table 4, Figure 8). The null

misclassification rate for this data was 39.5%. The model had an internal misclassification rate of 14.5%. The cross validated misclassification rate was 36.5%, which gives a calculated cross-validation error rate of 0.924. This was an improvement from the null misclassification rate indicating the model is more effective at predicting presence and absence than choosing at random. When validating this model on independent data, the misclassification rate was 34.3% (omission misclassification = 14.3%, commission misclassification = 20%).

When creating the classification tree model for the Kanawha drainage, the model contained four variables (minimum elevation, % sandstone, % forest, and drainage area) and six terminal nodes (Table 5, Figure 9). The null misclassification rate for this data was 34.2%. The model had an internal misclassification rate of 9.2%, and the cross-validated misclassification rate was 24.2%. This gave a calculated cross-validation error rate of 0.708, again indicating this model improved upon choosing a classification at random. When validating this model upon independent data the total misclassification rate was 19.4% (omission misclassification rate = 7%, commission misclassification rate = 12.4%).

The classification tree model for the Monongahela drainage contained two variables (mining intensity and drainage area) and three terminal nodes (Table 5, Figure 10). The misclassification rate for this set of data was 46.9%. The model had an internal misclassification rate of 23.9%, and had a cross-validated misclassification rate of 23.3%. The cross-validation error rate was equal to 0.831, meaning the model improved upon choosing classification at random. Using the independent dataset to validate, the total misclassification rate was 26.7% (omission misclassification rate = 13%, commission misclassification rate = 13.7%).

For the Ridge and Valley province, the classification tree used three variables (minimum elevation, % sandstone, and drainage area) and contained five terminal nodes (Table 5, Figure

11). The null misclassification rate for this set of data was 33.9%, and classification tree had an internal misclassification rate of 14.3%. When cross-validating this model, the misclassification rate was 23.3%, giving a cross-validation error rate of 0.687, indicating this model performed well at correctly classifying presences and absences for this region. The misclassification rate for the independent validation dataset was 18.6% (omission misclassification rate = 4.7%, commission misclassification rate = 13.9%).

The classification tree model for the Plateau province included five variables (% agriculture, minimum elevation, drainage area, % barren, and % shale) and seven terminal nodes (Table 5, Figure 12). The null misclassification rate for this set of data was 47.1%, and the model had an internal misclassification rate of 21.6%. Upon cross-validation, the misclassification rate was 46.7%. While this rate is somewhat high, the cross-validation error, 0.992, is still less than one indicating that this model performs slightly better than choosing at random. When validating this model on independent data, the misclassification rate was 32.3% (omission misclassification rate = 12.5%, commission misclassification rate = 19.8%).

The last province modeled was the mined plateau region. The model here included only one variable (mining intensity) and two terminal nodes (Table 5, Figure 13). The null misclassification rate was 33.3%, and the model had an internal misclassification rate of 17.6%. The cross-validated misclassification rate was 24%, producing a cross-validation error rate of 0.722. The misclassification rate was 22.9% (omission misclassification rate = 8.4%, commission misclassification rate = 14.5%) when validating the model on independent data.

After the creation of all of models, each reachshed had two values for probability of presence, one from the drainage basin model, and one for the province model. The average of the two probabilities was used to remove extreme values from predictions, and this average was

used as the final probability of presence for each reachshed. When examining the validation data (N = 401 sites) for the new values averaged from the previous models, misclassification of presence/absence occurred on 25.2% of the sites. Omission misclassification accounted for 11.5% of the misclassifications, while commission misclassification represented the remaining 13.7% of the misclassifications (Table 6).

Population Type Models

With the final brook trout population type groups, (high density, natal, intermediate density adult, and marginal) we created a model to predict these groups based on landscape variables. Twelve variables were included into the model creation, but only two variables were used in the model, minimum elevation and basin area (Figure 14). We had no data for model validation, but used internal cross-validation to verify the model. The null misclassification rate for this data was 62.9%, and model had an internal misclassification rate of 37.1%. The average cross-validated misclassification rate was 61.2%, which gave a cross-validated error rate of 0.973, indicating that this model improved upon choosing groups at random.

Abundance Models

Regression tree models were created for each size class of fish (young-of-year, small adult, large adult) as well as for the total abundance for each region. Percent variation explained by these models ranged from 18.8 to 94.3% and averaged 47.1% (Table 7). Percentage of variation explained by the drainage and province models was 44.6% and 49.5%, respectively. Table 8 describes the variables included and used in each model. Regression trees for total abundance (Figures 15 – 20), young-of-year abundance (Figures 21 – 26), small adult abundance (Figures 27 – 32), and adult abundance (Figures 33 – 38) show the expected mean values for each terminal node of the tree.

Extrapolations

Each of the models created with landscape variables (presence/absence, population type, and abundances) were extrapolated to a portion of, or the entire study area. Approximately 50,000 reachsheds were present across the entire study area, and were available for extrapolation. For the presence/absence model and the abundance models, the results from the province and drainage modeling were averaged. For the population type extrapolations, we only extrapolated to the 6,500 reachsheds where the predicted probability of presence was greater than or equal to 0.50.

When extrapolating the presence/absence model, we only extrapolated to 30,389 reachsheds that fell within subwatersheds where brook trout are known to exist. We removed reachsheds within 12-digit HUC subwatersheds where brook trout are known to be extirpated. Of these reachsheds, 6,486 (21%) had a probability of presence greater than or equal to 0.50, and 2,181 (7%) of the reachsheds had a probability of presence greater than or equal to 0.75 (Figure 39).

The extrapolations for the population type prediction showed that the natal class was predicted most often with 4,810 reachsheds (74%) being predicted as such. The marginal class was predicted for 1062 reachsheds (16%), while high density was predicted in only 9% of the reachsheds and the intermediate density adult class was predicted on less than 1% of the reachsheds (Figure 40). The key aspect of the extrapolation of this model is the juxtaposition of natal streams and marginal streams in the core regions of brook trout distribution.

Each size class, as well as total abundance was predicted for all reachsheds within the study area. Regression tree models gave a predicted abundance (fish per 150 meter stream length) at each node. Abundance values were averaged for the province and drainage models to

reduce extreme values. For the total abundance models, the average response was 11.9 fish per 150-meter stream length, with a minimum response of zero and a maximum response of 145.46 fish. Only 2,544 reachsheds (6%) had a predicted abundance of over 25 fish/150 m (Figure 41). For the young-of-the-year abundance model, the average response was 5 young-of-year fish/150m, with the minimum response being zero and the maximum response 55 young-of-year fish/150m. There were 2,220 reachsheds (5%) with a predicted young-of-year response greater than or equal to 15 fish/150 m (Figure 42). The average response for the small adult abundance models was 4 fish/150 m; the minimum response was zero and the maximum response was 86 fish/150 m. Only 701 reachsheds (2%) were predicted to have 15 or more small adult fish within each 150-meter section (Figure 43). The average response for the large adult abundance model was 2 fish/150 m, with the minimum being zero and the maximum response being 33 large adult fish per 150-meter section. There were 1,012 reachsheds (2%) predicted to have 10 or more large adult brook trout per 150 meters (Figure 44).

Threshold Identification

Boxplots were developed for six critical landscape variables that were used most often in the landscape models (% forest, % agriculture, % developed, minimum elevation, drainage area, and mining intensity). These plots were examined separately for each major drainage basin (Figure 49). We identified the 75th, 90th, and 95th percentiles as thresholds for each variable. By choosing three thresholds, we were able to identify conservative, moderate, and liberal thresholds (Table 9). The 90th percentile threshold for forest cover was from 80 – 92%, depending on the drainage (Table 9, Figure 45). For all sites, 75% of streams containing brook trout had 90% or greater forest landcover values.

Percentage of agricultural landcover was another important variable for determining brook trout presence; the 90th percentile threshold for streams containing brook trout was 12% agriculture landcover. Agricultural landcover thresholds differed greatly between drainages, the 90th percentile thresholds for this variable ranged from 1% in the Kanawha drainage to 16% in the Potomac drainage.

Percent of developed land upstream was an important variable for determining brook trout presence and the threshold was relatively similar for all drainages. The 90th percentile threshold was 7%, and the 75th percentile threshold was 5% for the entire study area combined.

Drainage area was an important parameter, but surprisingly, the critical threshold was highly variable among drainages. Overall 90% of streams with brook trout present had a drainage area less than 47 km². The 90th percentile threshold was 58 km² for the Monongahela drainage, 27 km² for the Kanawha drainage, and 37 km² for the Potomac drainage.

Elevation was another important variable; overall 90% of all streams containing brook trout had a minimum elevation of greater than 406 m, although the thresholds were highly variable among drainages. For the Monongahela drainage, the 90th percentile threshold was 447 meters, 645 meters for the Kanawha drainage, and 318 meters for the Potomac drainage.

For the Monongahela, where mining intensity values were available, a mining intensity value of approximately 3.5 was a critical threshold.

Discussion

Predictive modeling has become a large part of fisheries research and conservation. Landscape variables have been used to successfully predict fish abundances (Feist et al. 2003, Pess et al. 2002), densities (Creque et al. 2005), and distributions (Theiling 2006). The use of landscape variables allows data to be collected within a GIS, and does not require labor intensive

sampling, a critical benefit for research to be effective. The use of classification and regression trees as the statistical method for predictive modeling has become quite prevalent in ecological studies. Multivariate classification and regression trees have advantages over traditional modeling methods. Their multivariate nature eliminates the need for normalized data and allows the use of highly correlated variables. Classification and regression trees, by their nature and design, allow for patterns within independent data to be easily assessed, and also indicate potential mechanisms important in structuring the response variables. Classification trees have been used to correctly predict distribution of lichens (Edwards et al. 2006), macroinvertebrate communities (Merovich et al. 2007), presence and absence of coral species (De'ath and Fabricius 2000) and most recently brook trout distributions (Theiling 2006) to name a few. Regression trees have been used to predict prairie greenness index (Michaelsen et al. 1994), abundance of plant species (Larsen and Speckman 2004), and smallmouth bass (*Micropterus dolomieu*) nesting sites (Rejwan et al. 1999). Multivariate regression trees have also been shown to be a powerful technique for modeling community responses to environmental factors (De'ath 2002). The majority of these studies was either at spatial scales too large to provide detailed population dynamic information (Theiling 2006), or was built using variables only obtained on site (De'ath and Fabricius 2000, Rejwan et al 1999). The remaining studies listed above did use landscape or GIS-derived variables to predict smaller scale ecological responses. To our knowledge, there has not been a similar study on fish at this scale and extent, especially not brook trout. Theiling (2006) described and predicted brook trout population status at the subwatershed (HUC-12) level for the entire range of the eastern brook trout, but did not have the scale necessary to provide more than coarse-scale population distributions. By predicting brook trout at the reachshed scale with landscape variables, it allowed us to make predictions about brook trout populations at a

smaller scale, and to be able to easily extrapolate those predictions to the remaining portions of the study area. The results of these predictions gives a hypothesis of brook trout distribution at the reach scale based on the best available information which can be refined through additional sampling to give the most accurate assessments of brook trout populations.

Our population type predictions give valuable insight into the spatial dynamics of brook trout populations. These predictions and their extrapolations allow us to spatially examine patterns of population types. We see from our analysis that population structure is highly variable from stream to stream and especially among major drainage regions. There also seems to be evidence that at the watershed scale there is population supplementation/complementation occurring. Our data indicates this population structure is potentially occurring throughout West Virginia and is not limited only to the Shavers Fork watershed where Petty et al. (2005) documented and described it previously. Our population type predictions follow their results that small streams (natal population type) in close proximity to larger streams (marginal population type) act as non-substitutable sources, while the larger more productive streams act as supplemental habitat in the form of productive sinks. Overall the population productivity of the watershed is maximized when these two types of streams/population types are in close proximity to on another (Petty et al. 2005). Our results also indicate that high density population types tend to be isolated in rare, optimal habitat streams. These streams fit the following criteria most often: intermediate size, nearly 100% forest cover, alkaline geology, and intermediate elevation. This fits current knowledge of brook trout life history; the intermediate elevation, especially, provides the optimum combination of flow stability and water temperature for maximum growth and survival. It is only with this type of information will managers be able to more accurately assess current populations and be able to identify critical areas for brook trout protection and

enhancement. These types of maps can also identify areas where certain spatial population dynamics may be in play, which could result in informative studies in the future.

We were able to identify thresholds for key variables (% forest, % agriculture, elevation, % developed, drainage area, and mining intensity) that structured brook trout presence and absence. Theiling (2005) and Hudy et al. (2008) recently performed a similar analysis on brook trout, but at a much larger scale. Their scales of study were the HUC-12 watershed, and the extent of their study was the entire range of the eastern brook trout. These linked studies found that for watersheds with intact brook trout populations, forest cover was generally greater than 70% and agricultural land use was less than 15% (using approximately the 90th percentile). Our thresholds, while predicting a different but similar response variable, are somewhat similar. We found that the 90th percentile threshold for forest cover was higher, at 80 - 92%, while the same level threshold for agricultural land use was similar to what these studies found at 12%. Our higher forest threshold is most likely due to difference in scale of the studies. Our higher forest threshold for a smaller watershed size indicates that forest cover becomes more of a limiting factor for smaller watersheds than for structuring populations at the large HUC-12 watershed. The remainder of the variables they used did not match any of the variables we used in our study.

We also noted marked differences in thresholds among drainages for several variables. Minimum elevation and drainage area were the most highly variable among drainages. The elevation for both streams with and without brook trout was highest in the Kanawha drainage and lowest in the Potomac drainage. This indicates that the overall average elevation of these drainages could be causing these differences in thresholds, as the Kanawha lies mostly upon the Allegheny Plateau, while the Potomac drainage mostly covers the lower elevation ridge and valley province. It could also indicate that relative elevation within a drainage basin could be an

important variable. The importance of the differences in thresholds could also be muddled by correlated variables undetermined in this study.

Drainage area was the other highly variable threshold we found. Brook trout were found in streams of much larger drainage area in the Monongahela drainage when compared with the other two drainage regions (approximately 40 km² compared to 15 km²). This drainage could simply be the area of the state where there are larger streams capable of supporting brook trout. Both streams with and without brook trout had a larger drainage areas, which could indicate that this difference could a relict of sampling slightly larger drainage area streams within this drainage.

Predicting size class abundance generally did not provide any more information as to actual status of brook trout populations within the study area. These predictions did allow us, through evaluations of the predictive trees, to determine critical thresholds and important variables in determining abundances of different size classes of brook trout. The abundance of all size classes increases with an increase in elevation, forest cover, and sandstone geology. The abundance of adults (both small and large adult classes) increases with a decrease in mining intensity, and is maximized in the basin area range of approximately 2.5 – 20.0 km² (small adults maximized range is 2.3 – 11.7 km²; large adults maximized at 5.6 – 20.1 km²). Young-of-year abundances increase also with a basin area size of less than 10.3 km², a reduction in agriculture, and an increase in limestone.

The presence/absence models predictions provided distributional data important for managing brook trout. By analyzing the presence/absence models trees, we can see that basin area, mining intensity, elevation, forest cover, and geologies were most important in determining presence and absence of brook trout. Basin area was important in nearly all models, and

generally smaller basin areas have a higher probability of presence. Elevation was also very important in nearly all models, and probability of presence increases as elevation increases. Forest cover is another important variable in many of the models predicting presences and absences; with an increase in forest cover brook trout presence is more likely. Several geologies (limestone, shale, and sandstone) were important in one or more models, but due to great geologic differences among regions, broad generalizations about geologies are difficult to make.

Differences in predictor variables among modeled regions are especially important to note. This demonstrates what we would expect: specific environmental factors structure brook trout populations in specific areas. For example forest cover and elevation were most important in the Potomac drainage where water quality is generally high, and the limiting factor is most likely stream temperature. Forest cover and elevation, therefore work together to keep streams cool. In the Monongahela drainage, where water quality issues are more important than stream temperature, forest cover and elevation were generally not as important as the mining intensity index which has been linked to water quality (Petty and Merovich 2005). This demonstrates the fact that when predicting ecological responses at small scales, the models themselves cannot cover too broad of a geographic area, the risk therein lies in the misclassification rates becoming too high as a result of over-generalizations.

The results from the presence absence extrapolations indicate the majority of presences occur in the highest elevation areas along the spine of the Appalachians. This fits current knowledge about brook trout in WV. The majority of presences fall within the EBTJV's brook trout distributional areas (Hudy et al. 2006). Brook trout across much of their range have been relegated to high elevation, headwater streams (Hudy et al. 2006, Larson and Moore 1985). The area within the state with the highest occurrences of presences is the highest elevation area,

generally containing headwater streams. This fits current knowledge on ecology and life history of brook trout. Brook trout require cold water, and higher elevation areas have lower average temperatures, thus providing cooler in-stream temperatures for brook trout. Ample forest cover to provide stream shading allows for brook trout to thrive outside of the highest elevation areas. This is evident, especially within the eastern panhandle, where low elevation reachsheds with high forest cover are classified as high probability of presence. Within the state, though, water temperature is not the only factor controlling brook trout populations. Water chemistry issues, mainly acidification from acid mine drainage or acid rain, can cause many streams to be toxic for brook trout. These water chemistry issues are mainly confined the west of the Allegheny Front (Monongahela and the majority of the Kanawha drainages). In the Monongahela drainage, where we had a mining intensity index and included it in the landscape models, it was always the most important variable in determining brook trout presence. The mining intensity index takes into account acidification from mining, but does not account for acid precipitation. Since bedrock geology is important in determining buffer capacity of streams, percentages of bedrock should account for this process within models.

From the population type predictions along with the predictions of distribution, we can see several important issues concerning brook trout within West Virginia. The core brook trout populations are characterized by juxtaposition of small natal streams and larger marginal streams, most likely acting in a complementary/supplementary state. Outside of the core distribution, populations are highly scattered and generally isolated, especially in the Potomac drainage. These populations also tend to be highly variable in quality. When analyzing populations at a broader scale, we can see that extirpation at the HUC-12 scale occurs in watersheds that are highly isolated from core populations.

Management Implications

From this research we found that it was possible to accurately predict brook trout populations from landscape variables with good success. We were able to extrapolate results to areas that were unsampled. This indicates that predictive models are effective for predicting brook trout distributions in areas that are unsampled. Predictive modeling is a method that could allow managers to make large-scale predictions of species distributions with minimal data, an economically-friendly method. We were also able to identify population types and predict them across the landscape at the reach scale. This data allows managers to easily identify potential brook trout habitat for enhancement or protection. It also allows managers to more clearly visualize population structure across the landscape, which would be critical information for general management of brook trout populations. We were also able to identify critical thresholds for landscape variables that are important in determining brook trout presence/absence. These thresholds can provide critical information for managers as well. This information can be used to identify limiting factors for brook trout populations. Managers should analyze the focal landscape variables (% forest, % agriculture, % developed, minimum elevation, mining intensity, and basin area) to determine which variable could potentially be limiting any given stream.

From this analysis it is clear that future decisions surrounding brook trout management should address the following issues: protect core populations; create maximum interconnectedness of streams with core populations; identify reintroduction priorities; and to restore populations by building off the core populations. The core population should especially try to be expanded in the upper Greenbrier and upper Potomac watersheds where brook trout populations could expand downstream if water temperature was lowered by increasing forest cover, especially in the riparian zone. These areas have excellent water quality as much of their

watersheds are located on limestone or shale geologies. This give these streams high buffering capacity for acid load as creating highly alkaline streams, another important factor for highly productive brook trout populations, especially for spawning (Petty et al. 2005).

These data can also be utilized by managers that are currently in the process of classifying trout streams within West Virginia. The data collected has been provided to the WVDNR and WVDEP so they can propose known brook trout streams be classified into the highest protection classification. The data and analysis from this study can also be used to generate presumptive lists of remaining streams that would contain brook trout populations. Follow-up sampling could then be performed to verify presence of brook trout in these streams where predictive models indicate brook should be present.

Limitations

One major limitation to this study is the lack of multiple-year data. These models are essentially predicting the population status and type during a single “snapshot” in time. This limitation is accounted for somewhat since the Potomac and Kanawha drainages were sampled in different years and the Monongahela drainage was sampled for several years, but each individual sample still only reflects the brook trout population at that particular time. Studies have shown that brook populations can vary (Marschall and Crowder 1995) because of temporal environmental variation, and that they also vary seasonally (Petty et al. 2005) as brook trout move spatially in accordance to life history.

Another limitation is the limited dataset we used. While we had enough data to create effective predictive models, we did extrapolate models built from 265 sites to over 45,000 reachsheds. With these models, an increased amount of construction data will only reduce the amount of misclassifications in the classification and regression trees. Our misclassification

rates averaged approximately 25% when validating on an independent dataset, which falls within the range found by Thieling (2006), where misclassification rates for cross-validated models ranged from 17 – 35%.

There were also a couple very important issues that were beyond the scope of this project. Acid precipitation (Baker et al. 1996, Van Sickle et al. 1996, Baldigo and Murdoch 1997, Driscoll et al. 2001, Baldigo et al. 2005), and non-native exotic salmonids (King 1938, Larson and Moore 1983, Waters 1983, Larson et al. 1995, Southerland et al. 2005) have been previously shown to be detrimental to brook trout populations. We did not address these issues directly in this study; the scale at which these variables determine brook trout populations is much more localized than this study could predict. We did account for changes in bedrock geology, which is tied to buffering capacity, and therefore the amount of acid reaching the stream. This was done in an attempt to remove error from the model because of acid rain susceptibility. We also discussed sample points with members of the WVDNR in order to avoid sampling streams where encountering stocked trout, especially stocked brook trout could be likely. We also made every effort to exclude any brook trout that were taken in samples if we suspected them of being stocked, although this occurred very infrequently.

Local habitat measurements were unable to be extrapolated to each stream reach and were therefore not part of any analysis performed. Local measures such as water quality measures (pH, alkalinity, temperature), habitat complexity, substrate size, and flow variability are examples of the local measures important to brook trout that we were unable to assess. Since we analyzed the entire watershed's land cover and geology, water quality should have been accounted for the predictive models. The other local habitat variables could not be accounted for by any of the variables we included in our models. These local habitat variables could prove

critical in explaining remaining variance not explained by models, and for describing misclassification occurring in predictive landscape models (see Appendix 3). The results from our analysis should be combined with local habitat measures when available to give the most accurate representation of limiting factors important in structuring brook trout populations.

Future Work

Additional studies on this subject should focus on obtaining additional fish sample points to increase the predictive power of the models by reducing misclassifications. Also analysis of multiple year data at sites would allow for broad scale analysis of the variation in brook trout populations from year to year. Future studies should also utilize up-to-date landscape scale GIS data to account for as many variables affecting brook trout as possible. The mining intensity value was such a strong predictor of brook trout where it was available; it would be important to digitize mining features throughout the remainder of the state to allow the mining intensity value to be calculated throughout. Also, recent advances in GIS technologies have allowed for analyses of proximity of certain landscape feature to others. This will allow us to obtain distances along flow paths rather than straight-line distances. These would allow one to gain information on flow path distance to nearest features of interest (mines, springs, population types, etc.) Using these values in predictive modeling could allow for these ecological characteristics of brook trout populations to be accounted for when predicting population status, as well as potentially incorporating population dynamic theories into these models.

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Table 1. Reclassification scheme used for conversion from 2001 National Land Cover Dataset (NLCD) data to the raster data used for analysis.

2001 NLCD Value	2001 NLCD LULC Original Name	Reclassified Name
11	Open Water	Open Water
41	Deciduous Forest	Forest
42	Evergreen Forest	Forest
43	Mixed Forest	Forest
90	Woody Wetlands	Forest
52	Shrub/Scrub	Agricultural
71	Grassland/Herbaceous	Agricultural
81	Pasture/Hay	Agricultural
82	Cultivated Crops	Agricultural
	Emergent Herbaceous	
95	Wetlands	Wetlands
21	Developed, Open Space	Developed
22	Developed, Low Intensity	Developed
23	Developed, Medium Intensity	Developed
24	Developed, High Intensity	Developed
31	Barren Land	Barren

Table 2. Elevation and reachshed attributes summarized by drainage and province.

		Number	Mean	Mean	Min	Max
Region		Reachsheds	Reachshed Size (ha)	Elevation (m)	Elevation (m)	Elevation (m)
Province	Ridge and Valley	18959	71.1	584	76	1490
	Plateau	26832	67.3	664	184	1489
	Mined Plateau	9311	82.9	508	214	1334
Drainage	Potomac	13076	70.7	488	76	1490
	Kanawha	28768	68	685	163	1485
	Monongahela	13603	79.3	616	214	1490
Entire Study Area		55465	71.4	617	76	1490

Table 3. Geology and land cover data GIS data summarized by drainage and province.

		Geology Type Percentage					Landcover Type Percentage				
	Region	Limestone	Sandstone	Shale	Other	Surface Water	Forested	Agriculture	Wetlands	Developed	Barren
Province	Ridge and Valley	19	18	60	3	1	75	18	0	6	0
	Plateau	1	62	36	1	1	86	6	0	6	1
	Mined Plateau	1	57	40	2	1	79	12	0	7	1
Drainage	Potomac	18	21	57	4	1	73	19	0	7	0
	Kanawha	6	53	40	1	1	84	8	0	6	1
	Monongahela	2	45	50	2	1	83	9	0	6	1
Entire Study Area		8	43	47	2	1	81	11	0	6	1

Table 4. Descriptions of brook trout population type groups created from cluster analysis and NMDS, as well as the descriptions of the groups combined for predictive modeling.

Grouping Scheme	Group Name	Group Abbreviation	Group Description
Original Cluster Groups	High Density	HD	High overall density, high YOY and Small adult density especially
	High Quality Natal	HQN	High quality natal streams, dominated by YOY, intermediate density
	Intermediate Quality Natal	IQN	Intermediate quality natal streams, dominated by YOY, low density
	Intermediate Density Adult	IDA	Intermediate to low density dominated by adults, generally small adults
	Low Density General	LDG	Low density, not dominated by any one size class
	Marginal Large Adult	MLA	Marginal streams, generally only Large adults present, very low density
	Marginal Natal	MN	Marginal streams, generally only YOY present, very low density
Groups for Predictive Modeling	High Density	HD	High overall density, high YOY and Small adult density especially
	Natal	N	Combination of HQN and IQN, dominated by YOY, moderate densities
	Intermediate Density Adult	IDA	Intermediate to low density dominated by adults, generally small adults
	Marginal	M	Combination of LDG, MLA, and MN, low to very low density

Table 5. Variables included in presence absence models for each region. Numbers indicate variable importance in each model.

Variable Type	Variable Description	Potomac		Kanawha		Monongahela		Ridge and Valley		Plateau		Mined Plateau	
		Included	Rank	Included	Rank	Included	Rank	Included	Rank	Included	Rank	Included	Rank
Land Cover Classification	Drainage Area (km ²)	•	2	•	4,5	•	2	•	3,4	•	3,4	•	
	Mining Intensity Index					•	1					•	1
	Minimum Elevation Within Reachshed (m)	•	3	•	1	•		•	1	•	2	•	
	% Surface Water	•		•		•		•		•		•	
	% Forest	•	1,5	•	3	•		•		•		•	
	% Agriculture	•		•		•		•		•	1	•	
	% Wetland	•		•		•		•		•		•	
	% Developed	•		•		•		•		•		•	
Dominant Bedrock Geology	% Barren	•		•		•		•		•	5	•	
	% Limestone	•		•				•		•		•	
	% Sandstone	•		•	2	•		•	2	•		•	
	% Shale	•	4	•		•		•		•	6	•	
	% Other Geology	•		•		•		•		•		•	

Table 6. Complete summary of misclassification rates when validating predictive presence absence models on independent WVDNR data (N = 401 sites).

Dataset	Model Description	Omission Misclassification (%)	Commission Misclassification (%)	Total Misclassification (%)
Drainage	Potomac average	11	19	30
	Potomac drainage	14	20	34
	Potomac province	6	17	23
	Kanawha average	9	11	20
	Kanawha drain	7	12	19
	Kanawha province	7	20	26
	Monongahela average	12	14	26
	Monongahela drain	13	14	27
	Monongahela province	13	15	28
Province	Ridge valley average	9	13	22
	Ridge valley drain	11	13	23
	Ridge valley province	5	14	19
	Plateau average	13	14	27
	Plateau drain	11	15	26
	Plateau province	13	20	32
	Mined average	8	15	23
	Mined drain	15	11	25
	Mined province	8	15	23
Totals	Overall average	12	14	25
	Overall drainage	12	14	25
	Overall province	10	17	27

Table 7. Regression tree effectiveness shown as percent variation explained by the model for each region and population metric predicted.

Variable Predicted (Standardized abundances)	% Variation Described By Regression Tree						
	Potomac	Kanawha	Monongahela	Ridge Valley	Plateau	Mined	Averages
Young-of-year	47.0	39.7	37.4	19.4	12.0	60.7	36.0
Small Adult	66.5	44.1	52.7	60.3	35.0	49.3	51.3
Large Adult	60.2	21.4	56.4	46.2	43.2	87.0	52.4
Total Population	56.6	18.8	34.7	45.0	42.0	94.3	48.6
Averages	57.6	31.0	45.3	42.7	33.1	72.8	47.1

Table 8. Variables included in each regression tree model predicting standardized abundances and their overall importance rank within the model. YOY = young-of-the-year, SMAD = small adult, LGAD = large adult, TOT = total population.

Variable Type	Variable Description	Total	Potomac			Total	Kanawha			Total	Monongahela		
			YOY	SMAD	LGAD		YOY	SMAD	LGAD		YOY	SMAD	LGAD
Land Cover Classification	Drainage Area (km ²)	2	2	2	2		2,3	1	3,4	1	1		3
	Mining Intensity Index											1	
	Minimum Elevation (m)					1							2
	Maximum Elevation (m)								1				
	% Surface Water												
	% Forest	1	1	1	1							5	
	% Agriculture						1		2				
	% Wetland												
	% Developed												
	% Barren												
Dominant Bedrock Geology	% Limestone											3,4	1
	% Sandstone							3			2		
	% Shale			3				2		2		2	
	% Other Geology												

Table 8. Continued

Variable Type	Variable Description	Total	Ridge and Valley			Total	Plateau			Total	Mined Plateau		
			YOY	SMAD	LGAD		YOY	SMAD	LGAD		YOY	SMAD	LGAD
Land Cover Classification	Drainage Area (km ²)	2,3		3,4,5	2	1,3				3			4
	Mining Intensity Index									1			1
	Minimum Elevation (m)			1,2							1	2	
	Maximum Elevation (m)					5	1	1	4				
	% Surface Water												
	% Forest	1	1		3								
	% Agriculture				1	2,4		2	1,2			5	
	% Wetland												
	% Developed												
	% Barren												
Dominant Bedrock Geology													
	% Limestone		2		4			3				1,3	
	% Sandstone								3,5	2	2		3
	% Shale											4	2
	% Other Geology												

Table 9. Thresholds of landscape variables for streams where brook trout were present. Thresholds are indicated by 95th, 90th, 75th, and 50th percentiles. For percent forest and minimum elevation, threshold values are the variable values above which the given percentage of sites fall. For remaining variables, threshold values are the variable values below which the given percentage of sites fall.

Drainage	Percentile	Landscape Variables					Mining Intensity
		Elevation (m)	% Forest	% Agriculture	% Developed	Drainage Area (km ²)	
Potomac	95th	307	68	26.2	6	42.72	N/A
	90th	318	80	15.9	5.1	36.91	N/A
	75th	405	86	8.5	4	17.81	N/A
	Median	469	94	3	3	8.64	N/A
Kanawha	95th	588	91	1.8	6.8	37.81	N/A
	90th	645	92	1	6	27.41	N/A
	75th	728	94	0	4	14.8	N/A
	Median	821	96	0	2	10.25	N/A
Monongahela	95th	429	72	18.2	8.4	88.77	7.76
	90th	447	80	11.8	7.8	57.52	3.58
	75th	505	88	6	6	38.58	0.99
	Median	601	92	2	4	16.29	0
Total	95th	353	74	19.8	7.6	60.86	N/A
	90th	406	82	12.2	7	47.17	N/A
	75th	480	90	5	5	25.73	N/A
	Median	662	94	1	4	11.7	N/A

Figure 1. Approximate historical distribution of brook trout within West Virginia according to MacCrimmon and Campbell (1969).

Figure 2. Major drainages within West Virginia. Specified are the drainages that were modeled in this study.

Figure 3. Delineation of the physiographic provinces used as analysis units for modeling.

Figure 4. An example of how reachsheds were delineated. Each stream segment as defined by the 1:24,000 USGS topographic map has a corresponding reachshed.

Figure 5. Original Eastern Brook Trout Joint Venture status map. The bolded 12-Digit HUCs were the watersheds where samples were taken.

Figure 6. Distribution of sample sites.

Figure 7. Box-and-whisker plots showing differences in numbers of each size class for each population type.

Figure 8. Final classification tree model predicting presence and absence for the Potomac drainage. This model explained 63.3% of the variation of brook trout presence on the construction data.

Figure 9. Classification tree model predicting brook trout presence and absence for the Kanawha drainage. This model described 73.1% of the variation in brook trout presences on the construction data.

Figure 10. Classification tree model predicting brook trout presence and absence for the Monongahela drainage. This model described 49.1% of the variation in brook trout presences on the construction data.

Figure 11. Classification tree model predicting brook trout presence and absence for the Ridge and Valley province. This model described 57.9% of the variation in brook trout presences on the construction data.

Figure 12. Classification tree model predicting brook trout presence and absence for the Plateau province. This model described 54.2% of the variation in brook trout presences on the construction data.

Figure 13. Classification tree model predicting brook trout presence and absence for the mined province. This model described 47.1% of the variation in brook trout presences on the construction data.

Figure 14. Classification tree model predicting brook trout population types; it describes 42% of the variation in population type data. At each terminal node the predicted class is shown, along with the probability of that class. Inside parentheses is shown the number of correctly classified sites and the total number of sites at that node.

Figure 15. Regression tree predicting total abundance for the Potomac drainage; this model describes 56.6% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 16. Regression tree predicting total abundance for the Kanawha drainage; this model describes 18.8% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 17. Regression tree predicting total abundance for the Monongahela drainage; this model describes 34.7% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 18. Regression tree predicting total abundance for the ridge and valley province; this model describes 45.0% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 19. Regression tree predicting total abundance for the plateau province; this model describes 42.0% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 20. Regression tree predicting total abundance for the mined province; this model describes 94.3% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 21. Regression tree predicting young-of-year abundance for the Potomac drainage; this model describes 47.0% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 22. Regression tree predicting young-of-year abundance for the Kanawha drainage; this model describes 39.7% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 23. Regression tree predicting young-of-year abundance for the Monongahela drainage; this model describes 37.4% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 24. Regression tree predicting young-of-year abundance for the ridge and valley province; this model describes 19.4% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 25. Regression tree predicting young-of-year abundance for the plateau province; this model describes 12.0% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 26. Regression tree predicting young-of-year abundance for the mined province; this model describes 60.7% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 27. Regression tree predicting small adult abundance for the Potomac drainage; this model describes 66.5% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 28. Regression tree predicting small adult abundance for the Kanawha drainage; this model describes 44.1% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 29. Regression tree predicting small adult abundance for the Monongahela drainage; this model describes 52.7% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 30. Regression tree predicting small adult abundance for the ridge and valley province; this model describes 60.3% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 31. Regression tree predicting small adult abundance for the Plateau province; this model describes 35.0% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 32. Regression tree predicting small adult abundance for the mined province; this model describes 49.3% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 33. Regression tree predicting large adult abundance for the Potomac drainage; this model describes 60.2% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 34. Regression tree predicting large adult abundance for the Kanawha drainage; this model describes 21.4% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown..

Figure 35. Regression tree predicting large adult abundance for the Monongahela drainage; this model describes 56.4% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 36. Regression tree predicting large adult abundance for the ridge and valley province; this model describes 46.2% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 37. Regression tree predicting large adult abundance for the plateau province; this model describes 43.2% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown.

Figure 38. Regression tree predicting large adult abundance for the mined province; this model describes 87.0% of the variation in the data. At each node, the total number sites, the mean response (predicted abundance), and the mean-square error rate is shown

Figure 39. Extrapolated presence absence model results for the entire study area. Areas where brook trout are known to be extirpated are omitted from this map. Unit of prediction is probability of presence at the reachshed scale.

Figure 40. Population type prediction are shown for the study area; only reachsheds with a predicted probability of presence greater than 0.50 were predicted.

Figure 41. Predicted total brook trout abundances are shown for the entire study area. Abundances are derived from densities and are reported as the number of fish per 150-meter length of stream.

Figure 42. Predicted young of year brook trout abundances are shown for the entire study area. Abundances are derived from densities and are reported as the number of fish per 150-meter length of stream.

Figure 43. Predicted small adult brook trout abundances are shown for the entire study area. Abundances are derived from densities and are reported as the number of fish per 150-meter length of stream.

Figure 44. Predicted large adult brook trout abundances are shown for the entire study area. Abundances are derived from densities and are reported as the number of fish per 150-meter length of stream.

Figure 45. Box and whisker plots of selected landscape variables. Shaded boxes are streams where brook trout were present while the white boxes indicate streams where brook trout were absent. Boxes show the middle 50th percentile of observations, with the median shown as the line across the box. Whiskers extend to the 10th and 90th percentile range. The symbol “+” indicates the maximum and minimum values, if this is not shown, it falls outside of the plotted view.

Chapter 3

Establishing priorities for brook trout protection, restoration and reintroduction in West Virginia watersheds

Abstract

We used EBTJV classifications along with reach-scale predicted brook trout population metrics to assign restoration and protection priorities for West Virginia streams. This provided regional and local scale brook trout population measures to assess spatially, the reaches that would most benefit both local and regional brook trout populations. We found that 15% of the study area was assigned a protection priority, 3% was assigned a restoration priority and <1% of the study area was classified as a reintroduction priority. We also assessed the amount of these priorities that occurred on public land. We found that there were 2,914 reaches on public land that had a protection priority, 621 reaches were classified as restoration priorities, and 55 reaches were classified as reintroduction priorities. These restoration priorities will provide wildlife and land managers with critical information necessary for meaningful brook trout enhancement projects in the state of West Virginia.

Introduction

Due to increased levels of human alterations in land use and to aquatic habitats, restoration of aquatic habitats has become prevalent in managing aquatic systems (NRC 1992). Restoration has historically revolved around local/site scale manipulations, but there are several key issues such as barriers to colonization, temporal changes in habitat use, introduced species, long-term and large-scale processes, and inappropriate scales of restoration that localized efforts cannot address (Bond and Lake 2003). Landscape and watershed restoration principles have recently emerged to address many of these types of issues (Kershner 1997, Bohn and Kershner 2002, Petty and Thorne 2005). Landscape restoration has evolved, but mainly as a theoretical science (Holl et al. 2003). Landscape restoration for recovering aquatic communities generally involves assessing land use, riparian issues, and how they relate to aquatic populations over the entire catchment in question (Bohn and Kershner 2002). Studies have demonstrated and emphasized the importance of landscape-scale processes on aquatic communities (Taylor et al 1993, Fausch et al 2002, Lowe 2002), therefore it is critical to assess important relationships of landscape-level processes to the local communities (Bohn and Kershner 2002).

Brook trout restoration in the eastern United States has come to the forefront since the assessment performed by Hudy et al. (2006) as part of the Eastern Brook Trout Joint Venture (EBTJV). Hudy et al. (2006) specified a variety of practices and issues that have been detrimental to brook trout populations, as indicated from local wildlife managers across the entire range of the brook trout. They indicated high water temperature, agriculture, urbanization, exotic species, and riparian habitat as the most often reported major degradations. However, in West Virginia agriculture, acid mine drainage, mining, acid precipitation, and forestry were the most reported impacts. Riparian zones have been identified as critical areas for nutrient control,

stream shading, and sediment reduction into streams (Naiman and Decamps 1997, Storey and Cowley 1997, Ewel et al. 2001), and are therefore critical to brook trout populations as well.

Brook trout presence has been linked to large scale landscape characteristics (Petty and Thorne 2005, Hudy et al. 2006, Theiling 2006). Brook trout are also highly mobile and will use several different stream reaches throughout their lifetime (Liller 2006, Petty et al. 2005). Given their reliance upon land use practices and their mobile nature, brook trout would be a good candidate for a landscape-level restoration study.

Recently, Trout Unlimited applied their Conservation Success Index (CSI) to eastern brook trout (Williams et al. 2007), using much of the data collected by Hudy et al. (2006) at the HUC-12 scale. They used four categories of indicator variables: range-wide condition, population integrity, habitat integrity, and future security. These variables allowed for identification of subwatersheds (HUC-12) for restoration, reintroduction, and protection of brook trout populations. The extensive numbers of variables they used accounted for many of the issues facing brook trout, but the scale at which they performed the study is too coarse to allow managers to pinpoint individual stream reaches for enhancement practices. The coarse nature of the EBTJV data they used was also highly variable within categories, for example the “greatly reduced” category contains subwatersheds that have from 1 – 50% of the historic habitat currently occupied with brook trout. The range of 1 – 50% is quite wide, and the within group variance in brook trout status must be quite large. Williams et al. (2007) even state that “for finer scale applications, such as stream reach projects, CSI data needs to be augmented with more local information.”

In this assessment we assigned restoration priorities for brook trout at the reach scale by using landscape and watershed scale inputs, adding to the assessment performed by Williams et

al. (2007). Specifically, this assessment will pinpoint spatially explicit reaches that would be priorities for 1) restoration, 2) protection, and 3) reintroduction and would enhance local and regional brook trout populations.

The objectives of this study are two-fold. First, we used an updated EBTJV subwatershed status (Chapter 1) along with predicted brook trout population metrics (Chapter 2) to establish protection and restoration priorities for brook trout for the state of West Virginia at the reach scale. We then calculated subwatershed brook trout condition score, and used this score to assess which reaches would be most beneficial to restore or protect to return the largest regional increase in brook trout population status. This will provide useful, functional priorities at the reachshed scale for West Virginia based on local and regional brook trout population status as well as current knowledge of brook trout ecology and population dynamics. This information can then be used by fisheries managers and land managers to guide restoration activities and will identify critical areas for protection.

Methods

Reach-Scale Enhancement Classifications

For each reachshed within the study area, we obtained the following data: 1) updated EBTJV status for the subwatershed the reachshed falls within (extirpated, reduced, greatly reduced, intact), predicted population type for the reachshed (HD, IDA, MLA, N), and predicted probability of presence for the reachshed (ranging from 0 – 1.0). The updated EBTJV status was the outcome of recent work where we analyzed large datasets in order to improve the accuracy of Hudy et al. (2006) (See Chapter 1). The predicted population type resulted from previous work where cluster analysis and MANOVA tests indicated four distinct brook trout population types within the study area. We then used landscape variables to predict the population type for each

reachshed within the study area (See Chapter 2). The predicted probability of presence was obtained during previous research as well; landscape variables were used to predict brook trout presence/absence at the reach-scale (See Chapter 2). The EBTJV status provided relative regional brook trout population status (Table 1).

The predicted population type furnished insight as to the structure of the population, and therefore to the value of that particular stream to the overall population residing in the local drainage network (Petty et al. 2005). The predicted probability of presence provided valuable information as to whether or not brook trout would be likely to inhabit that particular reachshed, and therefore gives a good indication of the local condition. Probability of presence was classified into three categories: low (0 – 0.33), intermediate (0.34 – 0.66), and high (0.67 – 1.00).

We then created a set of rules based on the above data that would establish priorities for each reachshed (Table 2). We based these rules on existing knowledge of the life history and ecology of the brook trout (Figure 1). There were four potential outcomes from these rules, and they were: protection, restoration, reintroduction, or no action. Protection was assigned to reachsheds that were identified as areas where brook trout were highly likely to occur and where their populations need to be maintained (Figure 1). This occurred in reachsheds that were part of an existing intact regional population or reachsheds that were a high quality population type remaining in an area where the regional population had declined. Restoration priority was given to reachsheds where brook trout populations had been reduced both regionally and locally (Figure 1). More specifically this was the outcome when a reachshed had a high probability of presence and was within a regional population that had been reduced, but had a low quality predicted population type (Table 2). Reintroduction was the outcome when reachsheds were

identified as having a high probability of presence, but fell within subwatersheds where brook trout are currently extirpated (Figure 1). This would identify the most suitable habitats in areas where brook trout were most likely to be successful if reintroduced. Any other combination of the input variables results in “no action.” In subwatersheds where brook trout are extant, this classification is given to reachsheds that are low probability of presence for brook trout. In subwatersheds where brook trout are extirpated, the “no action” class was given to all but the highest probability reaches where reintroduction was a possibility.

A note on the difference of reintroduction and restoration: restoration is the classification given to reachsheds within subwatersheds where brook trout are still extant, but “on-the-ground” actions may require actual reintroductions via stream stockings. Reintroduction is the outcome we used in areas where brook trout are known or thought to be extirpated and any work to enhance brook trout populations would definitely require reintroductions via stream stockings.

For both the protection and restoration classifications, the classes were further broken down into two subclasses, primary priority and secondary priority. This was done by analyzing the probability of brook trout presence for each reach. In reachsheds where the predicted probability of presence was high, the highest level of priority was given. In reachsheds that had an intermediate probability of presence, these were secondary priorities. This allowed more accurate identification of the most favorable of conditions for enhancements, without ruling out the areas covered by secondary priorities.

Regional Priority Establishment

Once local classifications of enhancement (protection, restoration, and reintroduction) were completed we wanted to establish priorities also based on regional conditions. To do this, we calculated regional (HUC-12 level) brook trout condition scores. For each stream reach, we

multiplied the length of the reach by the predicted probability of brook trout presence, which gave a length measure weighted by probability of presence. We then added all weighted lengths and actual lengths within each subwatershed. We then divided the total weighted length by the total actual length to give a measure of relative brook trout condition for each subwatershed. The subwatershed brook trout condition score ranged from 0 – 1 and essentially gives the probability that a randomly selected stream reach within the subwatershed will contain brook trout.

For regional priority establishment, we classified the score into three categories: a score of 0 – 0.33 was considered poor, 0.34 – 0.66 was considered fair, and 0.67 – 1.0 was considered good. In order to account for the assessments done by Hudy et al. (2006), we also considered any subwatersheds they classified as intact brook trout populations to have a “good” subwatershed brook trout condition score, even if our calculated condition score did not fall into that category. We considered any HUC-12 subwatershed with a “good” brook trout condition score to be a priority for protection at the subwatershed scale. For the reach-scale priorities, we used Figure 2 to assign priorities based on the reach-scale classifications and the HUC-12 brook trout condition score.

Lastly, using a shapefile obtained from the West Virginia GIS Tech Center website (www.wvgis.wvu.edu) depicting West Virginia public lands, we assessed how many enhancement priorities fell within currently held public land. This will easily allow wildlife managers to see critically important areas within lands they currently manage that would benefit most from protection and restoration activities as they pertain to brook trout populations.

Results

When applying our priority rules to the study area (~45,000 reachsheds), we found that 36,031 reachsheds (81%) received “no action” classification, 6,701 reachsheds (15%) received a protection priority, 1,457 reachsheds (3%) received a restoration priority, and 400 reachsheds (<1%) received reintroduction priority (Figure 3). Within the protection classification, 30% of those results were Tier 1 protection priorities, while the remaining 70% were either Tier 2 or 3 protection priorities. For restoration classification, 51% of this classification was deemed as Tier 1 restoration priority, while only the remaining 49% was classified as a Tier 2 or 3 restoration priorities.

The majority of protection priorities were located along the high elevation spine of the Allegheny Mountains where brook trout population strongholds exist. Most Tier 1 protection priorities were located in areas where larger, more intact populations are known to exist, the headwaters of the Greenbrier, Shavers Fork of the Cheat and Gauley rivers. There was some Tier 1 protection priorities found in the headwaters of the North Fork of the Potomac river drainage. Tier 2 and 3 protection priorities were more extensive, and were most prevalent in the Cheat and Tygart watersheds (Monongahela basin). There were also some areas as protection priorities identified in the headwaters of the Potomac basin as well.

The majority of Tier 1 restoration priorities were identified within and among the areas indicated for Tier 1 protection. Most of these areas indicated for Tier 1 restoration were larger rivers within areas containing more intact populations. There were also some Tier 2 and 3 restoration priorities identified along the fringes of the core brook trout populations.

There were a very limited number of reachsheds classified as reintroduction priorities. The reaches identified as having high potential for reintroduction were generally very isolated

and were scattered mainly to the west of the core brook trout populations. There were a very limited number of stream networks identified as having good potential for reintroduction. These would be the areas most likely to support brook trout if they were restocked into those networks because complementary and adjacent habitats would increase the regional probability of persistence.

On public lands within West Virginia, there were a total of 3,695 reachsheds that were given a priority for reintroduction, restoration, or protection (Figure 4). There were only 55 reachshed on public land classified as a reintroduction priority, most of which were scattered and isolated. There were a total of 2,914 reaches on public lands that had classifications as a protection priority, 1,363 of these were Tier 1 priorities. Lastly, there were 621 reachsheds within public land boundaries that were identified as restoration priorities. Of these, 439 were classified as Tier 1 restoration priorities.

Discussion

Restoration priorities, to be effective must address several key elements. Characterization, issues and key questions, current conditions, reference conditions, identification of objectives, synthesis and interpretation, summary of conditions, and recommendations (Regional Ecosystem Office 1995, Kersner 1997). We have addressed nearly all of these points in our analysis. We characterized and identified the key issues in the watershed, as well as described the current conditions by predicting brook trout population status variables using landscape variables. Reference conditions as they pertain to our study would be the historic range of brook trout, and while the range is somewhat disputed, MacCrimmon and Campbell (1969) along with Jenkins and Burkhead (1993) describe the range of the eastern brook trout. Our objectives are clearly defined, and synthesis and interpretation of our results are

analyzed below along with the summary of conditions for the study area. Our recommendations follow below as well.

When analyzing predicted presences in areas that remain classified as extirpated in the updated EBTJV distributional status (reintroduction priorities), we find only a limited number of areas where there are clusters of predicted presences. The majority of these clusters occur in the low elevation areas of the Tygart drainage (part of the Monongahela basin). In this region, mining intensity was such a strong predictor of brook trout presences that no other variables were included in the predictive models. These areas, while they lack detrimental impacts related to mining, probably do not have the elevation and/or forest cover necessary to support a sustaining population of brook trout. When analyzing results from other regions of the state, we can see that upstream forest cover needs to be approximately 80% or more unless a stream is at especially high elevation in order to support brook trout and this is simply not the case for the majority of these areas. The elevation of these areas range from 277 – 590 m, but cumulative forest cover averages only 70%.

The priority predictions followed the pattern we expected, with the majority of protection and restoration priorities occurring along the high elevation spine of the state. The spatial pattern of priorities we see in the predictions follows current knowledge on brook trout ecology and population dynamics, specifically metapopulation theory and source-sink dynamics (Liller 2005, Petty et al. 2005). In many areas, we see a pattern where smaller tributaries are given a protection priority (based on their predicted population type, “natal”), but the larger streams are classified as priorities for reintroduction. We know that currently these larger streams do not produce many brook trout via instream reproduction, but that large adults will use these streams as food availability is high (Liller 2005, Petty et al. 2005). The smaller tributaries produce large

amounts of young of the year brook trout, and are therefore critical habitats to protect, while these larger streams could potentially be restored to allow all size classes of fish to once again use these areas.

While there are populations of brook trout within the state that are quite isolated, generally brook trout thrive in areas where there is a network of stream segments that are suitable (Taylor et al. 1993, Fagan 2002). The areas classified as possible reintroductions were very isolated and scattered. This could be a result of the above mentioned metapopulation and source-sink population dynamics at work. These high quality isolated segments could probably support brook trout currently, but have been extirpated in the past and have no source populations nearby for recolonization. Another possible explanation is that in these areas the suitable habitat has been reduced to areas so small that the population can no longer be supported internally.

Our assessment of critical areas for brook trout enhancement on public lands will allow those managing those lands to easily identify areas without extensive population and land use assessments. For agencies managing these lands (i.e. USDA National Forests, WVDNR) with brook trout management as a goal, these results would be critical for providing protection within their boundaries. Restoration activities are also much easier to perform on public lands, and these results indicate there are ample opportunities within public lands for such activities without having to convince private landowners that brook trout enhancement is a worthwhile venture.

Limitations

Restoration activities are time consuming and costly. Funding is limiting in most, if not all situations, and therefore those performing restoration activities must produce the largest results for the least amount of cost. While the classifications produced from this paper provide critical assignments of priorities spatially for both restoration and protection, it does not specify

which type restoration activity should be performed. Managers can use the information presented here to pinpoint areas for both restoration and protection within West Virginia, but it will then be necessary to perform more rigorous assessments of both land use of the watershed and instream habitat. This will allow managers to more accurately assess the limiting factors for brook trout.

The protection priorities set forth from this assessment pinpoint areas critical to sustain brook trout at the current level. Without these habitats, populations regionally would decline and eventually fail. The identification of these areas is now simplistic, although actually protecting these areas can be problematic. Future work would include identifying areas where brook trout can be protected (public lands, cooperation of landowners). Restoring the areas identified as such would also be problematic and those performing these actions would have to assess each individual situation more in depth, but this assessment identifies the areas most likely to benefit from these activities.

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Table 1. Subwatershed classification scheme descriptions from Hudy et al. 2006. Categories 5.0 and 6.0 were combined due to small sample size of category 6.0. For all analyses we ran, classifications 1.0, 1.1, 2.0, and 3.0 were considered extirpated.

Classification categories	Summary Characteristics
Classification 1.0 Unknown	No data or not enough data to classify further.
Classification 1.1 Absent: unknown history	Brook trout currently not in watershed; historic status unknown.
Classification 2.0 Never occurred	Historic self-sustaining populations never known to occur.
Classification 3.0 Extirpated	All historic self-sustaining populations extirpated.
Classification 4.0 Present: Qualitative	No quantitative data; qualitative data show presence.
Classification 5.0 Present: Intact large	High percentage (>90%) of historic habitat occupied by self-sustaining populations, populations greater than 5,000 individuals or 500 adults.
Classification 6.0 Present: Intact small	High percentage (>90%) of historic habitat occupied by self-sustaining populations, populations less than 5,000 individuals or 500 adults.
Classification 7.0 Present: Reduced	Reduced percentage (50% to 90%) of historic habitat occupied by self-sustaining brook trout.
Classification 8.0 Present: Greatly reduced	Greatly reduced percentage (1% to 49%) of historic habitat occupied by self-sustaining brook trout.

Table 2. Combinations resulting in indicated priorities for WV subwatersheds. Any remaining combinations not listed here resulted in a “no action” classification.

PRIORITY OUTCOME	EBTJV STATUS	POPULATION TYPE	PROBABILITY PRESENCE
REINTRODUCTION	Extirpated	HD	High
	Extirpated	N	High
	Extirpated	IDA	High
	Extirpated	M	High
RESTORATION	Greatly Reduced	M	Intermediate
	Greatly Reduced	M	High
	Greatly Reduced	IDA	Intermediate
	Greatly Reduced	IDA	High
	Reduced	M	Intermediate
	Reduced	M	High
	Reduced	IDA	Intermediate
	Reduced	IDA	High
PROTECTION	Greatly Reduced	N	Intermediate
	Greatly Reduced	N	High
	Greatly Reduced	HD	Intermediate
	Greatly Reduced	HD	High
	Reduced	N	Intermediate
	Reduced	N	High
	Reduced	HD	Intermediate
	Reduced	HD	High
	Intact	M	Intermediate
	Intact	M	High
	Intact	IDA	Intermediate
	Intact	IDA	High
	Intact	N	Intermediate
	Intact	N	High
	Intact	HD	Intermediate
	Intact	HD	High

Regional Condition	Good	Restoration	Protection	Protection
	Fair	Restoration	Restoration	Protection
	Poor	No Action	Restoration	Protection
	Extirpated	No Action	No Action	Reintroduction
		Poor	Fair	Good
		Local Condition		

Figure 1. Generalized classifications of brook trout enhancement categories as they pertain to local and regional brook trout conditions.

Regional Condition	Good	Tier 1	Tier 1
	Fair	Tier 2	Tier 1
	Poor	Tier 3	Tier 2
		Secondary	Primary

**Reach-Scale
Protection/Restoration
Classification**

Figure 2. Illustration indicating the scheme used to determine regional brook trout enhancement priorities. Tier 1 priorities are the highest priorities while Tier 3 priorities are the lowest level assigned for brook trout enhancement.

Figure 3. Map of priorities for brook trout enhancement within West Virginia. Protection priorities are shown in green and are areas predicted to have good brook trout population that need preserved. Restoration priorities are shown in blue where brook trout populations have the best potential for enhancement. Reintroduction priorities are shown in red and are high potential areas in extirpated subwatershed. Subwatersheds indicated as priorities for protection are shown with a bolded red outline.

Figure 4. Map of priorities for brook trout enhancement within public lands. Protection priorities are shown in green and are areas predicted to have good brook trout population that need preserved. Restoration priorities are shown in blue where brook trout populations have the best potential for enhancement. Reintroduction priorities are shown in red and are high potential areas in extirpated subwatershed.

Appendix 1. Site names and easting and northing coordinates (NAD 83, UTM Zone 17) for all sites used for modeling brook trout populations.

Reachshed ID	Drainage	Province	Site Name	Easting	Northing	Sampled Length	Stream Width
154770	Kanawha	Plateau	Bear Creek of Camp Creek	488361	4153038	150	2.3
113386	Kanawha	Plateau	Big Laurel Creek Gauley Camden	540123	4241683	150	2.8
107145	Kanawha	Plateau	Big Run of Gauley	565615	4253449	150	3.6
163230	Kanawha	Plateau	Big Spring Branch of East River	491396	4128096	150	2.5
136902	Kanawha	Plateau	Buffalo Creek	498171	4196310	150	2
155517	Kanawha	Plateau	Camp Creek	488513	4150749	250	6.3
117281	Kanawha	Plateau	Hunter Run of NF Cherry	547202	4233162	164	4.1
105437	Kanawha	Plateau	Laurel Creek of Elk	541938	4257382	150	3.5
134919	Kanawha	Plateau	Laurel Creek of Manns	509628	4201237	150	3.1
139843	Kanawha	Plateau	Laurel Creek of New	496112	4189378	150	3.8
126540	Kanawha	Plateau	LF Anglins	520017	4217522	150	3.6
150411	Kanawha	Plateau	Little Bluestone River	501069	4163024	150	2.8
132147	Kanawha	Plateau	Manns Creek of New	504929	4206134	150	3.4
155589	Kanawha	Plateau	Mash Fork of Camp Creek	487392	4150504	150	3.7
122319	Kanawha	Plateau	Middle Branch of Hominey Creek	521567	4225323	150	2
108383	Kanawha	Plateau	Middle Fk of Gauley	567087	4251560	150	2.3
127562	Kanawha	Plateau	NF Big Clear Creek	535197	4215429	150	2.9
120273	Kanawha	Plateau	North Fork Cherry	554923	4228480	180	4.4
117987	Kanawha	Plateau	Panther Creek	529850	4233266	180	4.5
144281	Kanawha	Plateau	Pinch Creek	496278	4179562	150	3.2
151272	Kanawha	Plateau	Pipestem Creek	507457	4161196	150	2.7
103774	Kanawha	Plateau	Poplar Run of Birch River	524096	4260982	150	2.6
107708	Kanawha	Plateau	Props Run of Slatyfork	575817	4252567	150	3
126737	Kanawha	Plateau	RF Anglins	519956	4217359	150	3
111470	Kanawha	Plateau	Rockcamp Run	533404	4244780	150	1.8
108591	Kanawha	Plateau	South Fk of Gauley	566588	4251442	150	3.1
150973	Kanawha	Plateau	Suck Creek	501303	4162037	150	2.2
112982	Kanawha	Plateau	Trib of MF Williams	554544	4243128	150	3
98447	Kanawha	Plateau	UNT 1 of Bk Fk Elk	569300	4270031	150	3.3
99612	Kanawha	Plateau	UNT 2 of Bk Fk Elk	568883	4269145	150	3.6
111712	Kanawha	Plateau	UNT 2 of Williams River	559751	4245368	150	3.3

Reachshed ID	Drainage	Province	Site Name	Easting	Northing	Sampled Length	Stream Width
126052	Kanawha	Plateau	UNT of NF Big Clear Creek	535051	4215829	150	2.5
110370	Kanawha	Plateau	UNT of Williams River	561739	4247615	150	3.1
106254	Kanawha	Plateau	Upper Birch River	537016	4255706	152	3.8
106464	Kanawha	Plateau	Upper Laurel Creek of Elk	540177	4255176	150	2.3
96719	Kanawha	Ridge Valley	Abes Run	614983	4274931	150	3.4
139076	Kanawha	Ridge Valley	Alum Rock Hollow	535670	4191751	150	2.1
140868	Kanawha	Ridge Valley	Big Draft	563357	4187391	150	1
124272	Kanawha	Ridge Valley	Bruffey Creek	562446	4221079	150	3.1
126600	Kanawha	Ridge Valley	Cochran Creek of Knapps Creek	590586	4217564	150	1.4
95314	Kanawha	Ridge Valley	Cove Run of WF Greenbrier	604062	4276275	150	1.3
137576	Kanawha	Ridge Valley	Dobson Branch of Greenbrier	558463	4195023	150	2
125486	Kanawha	Ridge Valley	Douthat Creek	586914	4219360	150	3
154955	Kanawha	Ridge Valley	Dropping Lick Creek	539098	4150718	160	4
142899	Kanawha	Ridge Valley	Dry Creek of Howards	562963	4181670	150	3.9
94734	Kanawha	Ridge Valley	East Fork Greenbrier Headwaters	617046	4278938	160	4.2
149758	Kanawha	Ridge Valley	Forest Run	552924	4164342	150	0.3
146037	Kanawha	Ridge Valley	Harts Run Headwaters	555946	4174585	150	1.5
144398	Kanawha	Ridge Valley	Harts Run in State Forest	556866	4178730	150	3
121019	Kanawha	Ridge Valley	Hills Creek Above Falls	559046	4226421	176	4.4
143141	Kanawha	Ridge Valley	Howards Creek below WSS	554929	4180768	230	5.7
152385	Kanawha	Ridge Valley	Kitchen Creek	553449	4157768	150	3.6
124131	Kanawha	Ridge Valley	Laurel Creek of Knapps Creek	590073	4221311	180	4.5
148315	Kanawha	Ridge Valley	Laurel Creek of Second Creek	555034	4169173	150	2.5
126984	Kanawha	Ridge Valley	Laurel Run of Greenbrier near Hil	568713	4216052	180	4.4
133848	Kanawha	Ridge Valley	Laurel Run of Lower Greenbrier	561861	4202635	150	2.2
149516	Kanawha	Ridge Valley	Little Laurel Creek Headwaters	555858	4165577	150	1.1
102381	Kanawha	Ridge Valley	Little River East Fork of Greenbr	611411	4263572	150	4.4
98885	Kanawha	Ridge Valley	Long Run of East Fork of Greenbri	613104	4270546	150	3
131202	Kanawha	Ridge Valley	Meadow Creek above Lake				
			Sherwood	587646	4207881	150	2.5
145782	Kanawha	Ridge Valley	Middle Tuckahoe Run	561890	4175353	150	3.8
110127	Kanawha	Ridge Valley	Moses Spring Run	593117	4247637	150	2.4
96210	Kanawha	Ridge Valley	Mullenox Run	614436	4275674	165	4.1
107090	Kanawha	Ridge Valley	NF Deer Creek Headwaters	608674	4253247	200	5
107659	Kanawha	Ridge Valley	NF of Deer Creek at Rt 28 crossing	600347	4252499	280	7

Reachshed ID	Drainage	Province	Site Name	Easting	Northing	Sampled Length	Stream Width
127771	Kanawha	Ridge Valley	Panther Camp Ck of Spring Creek	552464	4215085	166	4.4
140489	Kanawha	Ridge Valley	Pond Lick Run of Howards	566432	4187353	150	1.8
128785	Kanawha	Ridge Valley	Spring Creek of Greenbrier	556031	4212374	150	3.3
107872	Kanawha	Ridge Valley	Sutton Run of NF Deer Creek	607878	4252675	150	2.3
146208	Kanawha	Ridge Valley	Tuckahoe Run	560055	4174213	150	2.4
131821	Kanawha	Ridge Valley	Two Mile Run	576372	4205861	150	2.4
156604	Kanawha	Ridge Valley	UNT of Rock Camp	535900	4148344	150	2.2
139920	Kanawha	Ridge Valley	Upper Howards Creek	566115	4189726	150	2.4
91212	Kanawha	Ridge Valley	Upper West Fork of Greenbrier	606112	4285427	150	3.2
142148	Kanawha	Ridge Valley	Wades Creek of Howards	563120	4184136	150	2.7
155707	Kanawha	Ridge Valley	Wallace Hollow of Dropping Creek	539969	4150536	150	2
31225	Monongahela	Mined	Barnes Run	621177	4392091	160	4
33486	Monongahela	Mined	Beaver Creek	619867	4387318	200	5
33903	Monongahela	Mined	Beaver Creek above McCarty	620852	4386913	240	6
90611	Monongahela	Mined	Birch Fork	580164	4286684	200	5
29637	Monongahela	Mined	Blaney Hollow	601478	4395619	160	4
41182	Monongahela	Mined	Brains Creek	598567	4369849	240	6
44621	Monongahela	Mined	Cooks Run	597632	4361825	150	3
30146	Monongahela	Mined	Darnell Hollow	601059	4394731	160	4
40083	Monongahela	Mined	Daugherty Run at Headwaters	622633	4372827	160	4
39658	Monongahela	Mined	Daugherty Run at Mouth	620138	4372416	160	4
40806	Monongahela	Mined	Elsey Run	619469	4370428	160	4
56357	Monongahela	Mined	Glade Run NF Blackwater	628666	4339026	150	3
30377	Monongahela	Mined	Hog Run	624489	4392845	150	3
64987	Monongahela	Mined	Hunter Fork	594520	4325953	240	6
72807	Monongahela	Mined	Island Run	589670	4314414	150	3
77162	Monongahela	Mined	Laurel Creek of Middle Fork	579428	4307811	240	6
32366	Monongahela	Mined	Laurel Run at 73 Bridge	609925	4389538	300	8
33144	Monongahela	Mined	Laurel Run of Big Sandy at Mouth	611665	4388433	300	10
43821	Monongahela	Mined	Laurel Run of Three Fork	595029	4364015	300	12
87354	Monongahela	Mined	Left Fork Buckhannon River	567854	4292867	300	12
89664	Monongahela	Mined	Left Fork of Right Fork Buckhannon R	567115	4288639	300	8
32336	Monongahela	Mined	Little Laurel Run	608916	4389967	160	4
33425	Monongahela	Mined	Little Sandy Creek at 4H Camp	618251	4387952	300	12

Reachshed ID	Drainage	Province	Site Name	Easting	Northing	Sampled Length	Stream Width
31953	Monongahela	Mined	Little Sandy Creek at Barnes Cabin	622669	4390180	300	8
33603	Monongahela	Mined	Little Sandy Creek at Rt 26 Bridge	616163	4387642	300	15
82703	Monongahela	Mined	Long Run	579145	4299677	160	4
42628	Monongahela	Mined	Martins Run	598687	4366443	150	3
84587	Monongahela	Mined	Middle Fork at Cassity	583251	4297015	300	12
29295	Monongahela	Mined	Morgan Run of Cheat Lake	599980	4395998	200	5
35448	Monongahela	Mined	Muddy Creek at Cuzzart	623844	4382879	200	5
36596	Monongahela	Mined	Muddy Creek at Headwaters	626364	4379899	200	5
35489	Monongahela	Mined	Muddy Creek Brandonville Pike	620350	4382709	300	8
36194	Monongahela	Mined	Muddy Creek Million Bridge	618377	4380208	300	10
36134	Monongahela	Mined	Muddy Creek Tack shop	619960	4381639	300	8
66654	Monongahela	Mined	Pecks Run	575399	4323120	200	5
89092	Monongahela	Mined	Right Fork Buckhannon River	566328	4289944	300	15
92742	Monongahela	Mined	Right Fork Buckhannon River Upper	565603	4282472	300	10
39470	Monongahela	Mined	Roaring Creek at Mouth	616880	4373741	300	12
37829	Monongahela	Mined	Roaring Creek downstream Lick Run	620308	4375876	200	5
38194	Monongahela	Mined	Roaring Creek One	621769	4376637	160	4
45258	Monongahela	Mined	Saltlick Creek at Bridge	597632	4361825	240	6
69865	Monongahela	Mined	Sand Run	574786	4318298	300	12
50815	Monongahela	Mined	Sandy Creek Lower	596171	4350478	300	8
52578	Monongahela	Mined	Sandy Creek Upper	598245	4348115	160	4
90986	Monongahela	Mined	Trout Run	570345	4286202	160	4
40815	Monongahela	Mined	UNT Fields Stony Run	600333	4370313	160	4
43798	Monongahela	Mined	UNT Laurel of Three Fork	594028	4363558	160	4
42683	Monongahela	Mined	Upper Laurel Run of Three Forks	593890	4366093	240	6
33784	Monongahela	Mined	Webster Run	616057	4387214	160	4
32050	Monongahela	Mined	Whites Run	597548	4390719	160	4
48241	Monongahela	Mined	York Run	599278	4355295	150	3
93421	Monongahela	Plateau	Beckys Creek	587218	4281144	240	6
69999	Monongahela	Plateau	Big Run	629814	4318226	150	3
49809	Monongahela	Plateau	Buffalo Creek at Mouth	613062	4352856	280	7
52089	Monongahela	Plateau	Buffalo Creek Upper	609247	4348557	240	6
59000	Monongahela	Plateau	Clover Run at Mouth	611120	4335926	300	8
99130	Monongahela	Plateau	Conley Run	584717	4269832	150	3

Reachshed ID	Drainage	Province	Site Name	Easting	Northing	Sampled Length	Stream Width
83624	Monongahela	Plateau	Daniels Run	614070	4297930	200	5
87791	Monongahela	Plateau	Dry Fork	618977	4290076	150	3
88508	Monongahela	Plateau	East Fork Gladly Fork	612474	4290609	240	6
89837	Monongahela	Plateau	East Fork Gladly Fork	609973	4288212	240	6
90875	Monongahela	Plateau	East Fork Gladly Fork	609734	4286619	240	6
68947	Monongahela	Plateau	Elklick Run	627750	4320241	160	4
97152	Monongahela	Plateau	Elkwater Fork	583271	4273492	240	6
89583	Monongahela	Plateau	Five Lick Run	614497	4288777	160	4
85542	Monongahela	Plateau	Gandy Creek Lower Site	625056	4295124	300	0
87781	Monongahela	Plateau	Gandy Creek Upper Site	623643	4291988	300	0
83775	Monongahela	Plateau	Gladly Fork Lower Site	612714	4297883	300	0
83810	Monongahela	Plateau	Gladly Fork Upper Site	613049	4298600	300	0
81679	Monongahela	Plateau	Halfway Run	613129	4301321	150	3
56600	Monongahela	Plateau	Hile Run	620116	4339419	150	3
58629	Monongahela	Plateau	Horseshoe Run at Maxwell	619307	4336384	300	14
58900	Monongahela	Plateau	Horseshoe Run Lower Repeated	617913	4335468	300	15
56303	Monongahela	Plateau	Horseshoe Run Upper	623392	4339965	300	10
86655	Monongahela	Plateau	Jones Run	594329	4293525	160	4
71600	Monongahela	Plateau	Laurel Fork at Mouth	625439	4316054	300	14
57264	Monongahela	Plateau	Laurel Run of Horseshoe	622861	4338872	160	4
74213	Monongahela	Plateau	Leading Lower Creek	599424	4311578	300	14
56248	Monongahela	Plateau	Leadmine Run	624489	4340203	200	5
62249	Monongahela	Plateau	Left Fork Clover Run One	608942	4330360	300	8
62010	Monongahela	Plateau	Left Fork Clover Run Upper	605964	4330883	200	5
84267	Monongahela	Plateau	Left Fork of Flies Creek	601192	4297627	200	5
49842	Monongahela	Plateau	Little Buffalo Creek	613863	4351966	150	3
71639	Monongahela	Plateau	Loglick Run	603510	4315946	150	3
53742	Monongahela	Plateau	Louse Camp Run	609774	4345137	150	3
49629	Monongahela	Plateau	Madison Run	616792	4352976	150	3
58626	Monongahela	Plateau	Maxwell Run	621050	4335555	150	3
81336	Monongahela	Plateau	McCray Creek	616904	4301236	160	4
93176	Monongahela	Plateau	Mill Creek at Kumbrabow	582048	4281429	240	6
60362	Monongahela	Plateau	Mill Run	616919	4333432	160	4
58440	Monongahela	Plateau	Minear Run Lower Repeated	612893	4336429	200	5

Reachshed ID	Drainage	Province	Site Name	Easting	Northing	Sampled Length	Stream Width
57314	Monongahela	Plateau	Minear Run Middle	615178	4338581	200	5
90923	Monongahela	Plateau	Narrow Ridge	621969	4285323	150	3
73693	Monongahela	Plateau	Panther Camp Run	621307	4313095	150	3
59541	Monongahela	Plateau	Right Fork Clover Run	609571	4334109	160	4
45258	Monongahela	Plateau	Saltlick Creek Repeated	618412	4360618	200	5
46881	Monongahela	Plateau	Saltlick Mouth	616047	4357255	300	8
102830	Monongahela	Plateau	Shavers Fork at Ryans Bend	591494	4261500	300	12
89555	Monongahela	Plateau	Shavers Run	594441	4288157	200	5
88214	Monongahela	Plateau	Swallow Rock Run	626680	4290606	150	3
89777	Monongahela	Plateau	Tingler Run	613751	4287735	150	3
55013	Monongahela	Plateau	Twelvemile Run	623539	4343314	150	3
99628	Monongahela	Plateau	Tygart Valley River at Valley Head	584133	4268303	300	10
67613	Monongahela	Plateau	UNT Dry Fork	624233	4321393	150	3
68320	Monongahela	Plateau	UNT Dry Fork	627280	4320758	150	3
69423	Monongahela	Plateau	UNT Dry Fork	624553	4318707	150	3
73627	Monongahela	Plateau	UNT Dry Fork	628148	4313089	150	3
73884	Monongahela	Plateau	UNT Dry Fork	628555	4312580	150	3
74284	Monongahela	Plateau	UNT Dry Fork	630463	4311613	150	3
73978	Monongahela	Plateau	UNT Gladly Fork	620014	4312325	150	3
91085	Monongahela	Plateau	Warner Run	619639	4285535	150	3
88537	Monongahela	Plateau	West Fork Gladly Fork	608713	4290728	200	5
101031	Monongahela	Plateau	Windy Run	584122	4266555	160	4
51821	Potomac	Plateau	Difficult Run	645517	4348549	200	5
47993	Potomac	Plateau	Emory Creek of Abrams Creek	658994	4355850	150	1.8
53797	Potomac	Plateau	Red Oak Creek	638368	4346105	150	1
45815	Potomac	Plateau	UNT of Abrams Creek	657051	4359335	150	1.1
55537	Potomac	Plateau	UNT of NB Potomac	635627	4342392	150	3.5
95218	Potomac	Ridge Valley	Back Run	624987	4277196	150	3.5
85199	Potomac	Ridge Valley	Brushy Run	634938	4295437	170	4.2
84147	Potomac	Ridge Valley	Brushy Run of N Mill Creek	653675	4298025	150	1.5
87923	Potomac	Ridge Valley	Camp Run Hdwaters	665851	4291015	150	0.7
68551	Potomac	Ridge Valley	Cove Run of Waites Run	707431	4320715	150	3.5
80759	Potomac	Ridge Valley	Cullers Run Below Forks	679741	4302671	150	2.5
81329	Potomac	Ridge Valley	Cullers Run near mouth	684597	4301900	150	2.5

Reachshed ID	Drainage	Province	Site Name	Easting	Northing	Sampled Length	Stream Width
83376	Potomac	Ridge Valley	Dry Hollow of SB at Eagle Rock	648011	4298899	150	2
50670	Potomac	Ridge Valley	Eliber Run	678328	4351675	150	2
45957	Potomac	Ridge Valley	Elk Branch near Engle	777708	4359621	150	1.3
46256	Potomac	Ridge Valley	Elks Run Halltown	775856	4358849	150	0.5
53911	Potomac	Ridge Valley	Furnace Run	774937	4345932	150	3
90843	Potomac	Ridge Valley	Hammer Run	647050	4286187	150	3.5
90317	Potomac	Ridge Valley	Hammer Run Hdwaters	643913	4287294	150	1.4
97923	Potomac	Ridge Valley	Haves R. Upstream of Brandywine L	656937	4272689	150	3.7
60136	Potomac	Ridge Valley	Hawk Run	715752	4333260	150	3.1
74923	Potomac	Ridge Valley	High Ridge Run	646732	4311022	150	2.2
71325	Potomac	Ridge Valley	Johnson R. of Mill Creek Petersburg	661648	4316743	150	2.6
88345	Potomac	Ridge Valley	Kettle Creek	662730	4291478	150	2.4
104242	Potomac	Ridge Valley	LF of Big Stony Run of SF	650613	4259886	150	2
97139	Potomac	Ridge Valley	LF of Haves Run	656584	4274267	150	2.6
82072	Potomac	Ridge Valley	LF of UNT of Stroder Run	633278	4300822	150	0.7
102534	Potomac	Ridge Valley	Lick Run of Little EK of SF	649783	4263588	150	0.9
102229	Potomac	Ridge Valley	Little Fork of SF	651167	4263852	150	2.3
76726	Potomac	Ridge Valley	Long Run	638544	4305843	200	5
77770	Potomac	Ridge Valley	Long Run of SB	650448	4306762	150	1.3
78333	Potomac	Ridge Valley	McIntosh Run	633916	4304366	150	2
38934	Potomac	Ridge Valley	Meadow Branch above SCL	743373	4375246	150	2.2
31783	Potomac	Ridge Valley	Meadow Branch Below Park	747965	4391041	160	4
58304	Potomac	Ridge Valley	Middle Fork Patterson Creek	664441	4336819	150	3.4
96078	Potomac	Ridge Valley	Middle Ridge Hollow	622429	4275219	150	2.2
48624	Potomac	Ridge Valley	Mill Creek of Patterson	670450	4354858	150	2.6
51579	Potomac	Ridge Valley	Mill Run of SB at Nathaniel WMA	693811	4348004	150	3.6
60614	Potomac	Ridge Valley	Moore's Run	707998	4330138	150	3.5
34773	Potomac	Ridge Valley	Mountain Run	743053	4384685	150	2
81508	Potomac	Ridge Valley	N Mill Creek	653620	4301651	150	1.8
51965	Potomac	Ridge Valley	New Creek	662090	4349387	150	3.5
57220	Potomac	Ridge Valley	NF Patterson	662424	4338032	150	3.5
97772	Potomac	Ridge Valley	Owl Knob Hollow	620200	4272384	150	3.5
57140	Potomac	Ridge Valley	Patterson Creek near NF mouth	668910	4339557	180	4.5
88504	Potomac	Ridge Valley	Reeds Creek	645027	4291143	150	3

Reachshed ID	Drainage	Province	Site Name	Easting	Northing	Sampled Length	Stream Width
95369	Potomac	Ridge Valley	Road Run of SF at West End Rd	658352	4277319	150	3
38979	Potomac	Ridge Valley	Roaring Run above SCL	743429	4375196	150	1
37364	Potomac	Ridge Valley	Rock Gap Run	733674	4378454	150	2
53726	Potomac	Ridge Valley	Rosser Run	665436	4345443	150	1.5
70896	Potomac	Ridge Valley	Samuel Run	648684	4315052	150	3
79378	Potomac	Ridge Valley	Sawmill Run	643788	4304686	150	1.7
81026	Potomac	Ridge Valley	Seneca Creek Above Strader Run	632900	4302264	300	10.4
77233	Potomac	Ridge Valley	Shafter Run	645808	4306605	150	2.5
81173	Potomac	Ridge Valley	Shipe Hollow Run of Cullers R	678285	4301857	150	1
92432	Potomac	Ridge Valley	Sinkhole Run UNT of Reeds Creek	639583	4283131	150	0.7
104644	Potomac	Ridge Valley	South Fork River	644363	4258442	300	8
83274	Potomac	Ridge Valley	Stony Creek of N Mill	652050	4299378	150	1.4
94627	Potomac	Ridge Valley	Stony Run of SF below Brandywine	658426	4279241	150	3
31085	Potomac	Ridge Valley	Swim Run at CR8	746214	4392928	150	0.8
54844	Potomac	Ridge Valley	Thorn Run of Patterson	664920	4343385	150	2.4
55642	Potomac	Ridge Valley	Thorn Run of Patterson at Martin Rd	668818	4342114	150	2.8
72911	Potomac	Ridge Valley	Trout Pond Run	696395	4314150	150	1.3
68125	Potomac	Ridge Valley	Trout Run	702019	4320445	150	3.6
33888	Potomac	Ridge Valley	UNT of Back Creek	756839	4386908	150	1.4
97555	Potomac	Ridge Valley	UNT of Dry Run of Upper NF	628608	4273442	150	1.1
97945	Potomac	Ridge Valley	UNT of Haves R upstrm of Brandyw	656977	4272689	150	2.6
71591	Potomac	Ridge Valley	UNT of Johnson Run	662222	4316195	150	2.5
96320	Potomac	Ridge Valley	Unt of Teeter Camp	622716	4275678	150	1.7
91337	Potomac	Ridge Valley	Waggy Run UNT to Reeds Creek	640605	4284931	150	1.2
31874	Potomac	Ridge Valley	Warm Springs Run	738661	4391533	150	3.5
80709	Potomac	Ridge Valley	Wetzel Hollow of Cullers Run	678799	4302676	150	2.1
51998	Potomac	Ridge Valley	Whip Gap Run	666804	4348455	150	1.8
51166	Potomac	Ridge Valley	Whip Run	669394	4350769	150	2.4
56233	Potomac	Ridge Valley	Williamsport Run of Patterson	670372	4340877	150	2.5
76888	Potomac	Ridge Valley	Zeke Run	645162	4308027	150	2.6

Appendix 2. Fish data collected during sampling.

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Abes Run	150	3.4	7	23	477	0	20	3	0	0	1	75
Alum Rock Hollow	150	2.1	6	0	0	0	0	0	0	0	0	0
Back Run	150	3.5	2	82	1758	20	39	23	0	0	0	0
Barnes Run	160	4	3	0	0	0	0	0	0	0	0	0
Bear Creek of Camp Creek	150	2.3	2	0	0	0	0	0	1	260	0	0
Beaver Creek	200	5	3	0	0	0	0	0	0	0	0	0
Beaver Creek above McCarty	240	6	5	0	0	0	0	0	0	0	0	0
Beckys Creek	240	6	14	0	0	0	0	0	0	0	0	0
Big Draft	150	1	1	0	0	0	0	0	0	0	0	0
Big Laurel Creek												
Gauley Camden	150	2.8	3	21	300	10	6	5	0	0	0	0
Big Run	150	3	2	0	0	0	0	0	0	0	0	0
Big Run of Gauley	150	3.6	1	45	479	28	13	4	0	0	0	0
Big Spring Branch of East River	150	2.5	9	0	0	0	0	0	0	0	1	16
Birch Fork	200	5	8	97	2005	50	29	18	0	0	0	0
Blaney Hollow	160	4	3	0	0	0	0	0	0	0	0	0
Brains Creek	240	6	6	2	580	0	0	2	0	0	0	0
Bruffey Creek	150	3.1	3	0	0	0	0	0	0	0	0	0
Brushy Run	170	4.2	2	289	5127	146	92	51	0	0	0	0
Brushy Run of N Mill Creek	150	1.5	9	0	0	0	0	0	0	0	0	0
Buffalo Creek	150	2	1	85	2534	48	2	35	0	0	0	0
Buffalo Creek at Mouth	280	7	19	18	2886	0	0	18	2	997	0	0
Buffalo Creek Upper	240	6	16	6	706	1	0	5	0	0	0	0
Camp Creek	250	6.3	13	0	0	0	0	0	1	241	1	220
Camp Run												
Hdwaters	150	0.7	1	0	0	0	0	0	0	0	0	0
Clover Run at	300	8	10	1	40	0	0	1	2	214	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Mouth												
Cochran Creek of												
Knapps Creek	150	1.4	7	0	0	0	0	0	0	0	0	0
Conley Run	150	3	5	1	3	1	0	0	0	0	0	0
Cooks Run	150	3	4	0	0	0	0	0	0	0	0	0
Cove Run of												
Waites Run	150	3.5	8	27	640	0	21	6	0	0	0	0
Cove Run of WF												
Greenbrier	150	1.3	4	0	0	0	0	0	0	0	0	0
Cullers Run Below												
Forks	150	2.5	9	0	0	0	0	0	0	0	0	0
Cullers Run near												
mouth	150	2.5	9	0	0	0	0	0	0	0	0	0
Daniels Run	200	5	9	1	1	1	0	0	0	0	0	0
Darnell Hollow	160	4	2	0	0	0	0	0	0	0	0	0
Daugherty Run at												
Headwaters	160	4	4	18	327	2	12	4	0	0	0	0
Daugherty Run at												
Mouth	160	4	18	2	6	2	0	0	0	0	0	0
Difficult Run	200	5	6	35	679	11	15	9	0	0	0	0
Dobson Branch of												
Greenbrier	150	2	4	0	0	0	0	0	0	0	0	0
Douthat Creek	150	3	9	0	0	0	0	0	0	0	0	0
Dropping Lick												
Creek	160	4	10	0	0	0	0	0	53	2570	0	0
Dry Creek of												
Howards	150	3.9	9	0	0	0	0	0	0	0	0	0
Dry Fork	150	3	2	0	0	0	0	0	0	0	0	0
Dry Hollow of												
South Branch at												
Eagle	150	2	4	76	1358	34	26	16	0	0	0	0
East Fork Gladys												
Fork	240	6	4	34	367	22	8	4	0	0	0	0
East Fork Gladys												
Fork	240	6	9	14	189	12	0	2	0	0	0	0
East Fork Gladys	240	6	7	4	34	3	0	1	0	0	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Fork												
East Fork												
Greenbrier												
Headwaters	160	4.2	8	17	435	2	9	6	0	0	13	767
Eliber Run	150	2	5	0	0	0	0	0	0	0	0	0
Elk Branch near												
Engle	150	1.3	5	0	0	0	0	0	0	0	0	0
Elklick Run	160	4	1	0	0	0	0	0	0	0	0	0
Elks Run Halltown	150	0.5	4	0	0	0	0	0	0	0	0	0
Elkwater Fork	240	6	15	0	0	0	0	0	0	0	1	181
Elsey Run	160	4	4	17	1058	11	0	6	0	0	0	0
Emory Creek of												
Abrams Creek	150	1.8	0	0	0	0	0	0	0	0	0	0
Five Lick Run	160	4	6	7	235	4	0	3	0	0	0	0
Forest Run	150	0.3	2	0	0	0	0	0	0	0	0	0
Furnace Run	150	3	11	0	0	0	0	0	0	0	0	0
Gandy Creek												
Lower Site	300	0	10	2	573	0	0	2	0	0	2	418
Gandy Creek												
Upper Site	300	0	14	14	921	0	1	13	0	0	3	246
Glade Run NF												
Blackwater	150	3	5	0	0	0	0	0	0	0	0	0
Glady Fork Lower												
Site	300	0	16	1	307	0	0	1	1	260	0	0
Glady Fork Upper												
Site	300	0	22	3	422	0	0	3	0	0	0	0
Halfway Run	150	3	0	40	108	39	1	0	0	0	0	0
Hammer Run	150	3.5	10	28	1824	3	8	17	2	138	0	0
Hammer Run												
Hdwaters	150	1.4	2	0	0	0	0	0	0	0	0	0
Harts Run												
Headwaters	150	1.5	6	0	0	0	0	0	0	0	0	0
Harts Run in State												
Forest	150	3	7	0	0	0	0	0	0	0	0	0
Haves Run												
Upstream of	150	3.7	1	0	0	0	0	0	0	0	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Brandywine L												
Hawk Run	150	3.1	3	11	306	2	4	5	0	0	0	0
High Ridge Run	150	2.2	2	63	2017	14	17	32	0	0	0	0
Hile Run	150	3	9	0	0	0	0	0	0	0	0	0
Hills Creek Above Falls	176	4.4	3	0	0	0	0	0	0	0	0	0
Hog Run	150	3	6	0	0	0	0	0	0	0	0	0
Horseshoe Run at Maxwell	300	14	18	4	218	3	0	1	0	0	1	2
Horseshoe Run Lower Repeated	300	15	18	0	0	0	0	0	22	354	0	0
Horseshoe Run Upper	300	10	17	3	13	3	0	0	0	0	0	0
Howards Creek below WSS	230	5.7	10	0	0	0	0	0	0	0	0	0
Hunter Fork	240	6	11	0	0	0	0	0	0	0	0	0
Hunter Run of NF Cherry	164	4.1	1	22	725	4	10	8	0	0	0	0
Island Run	150	3	4	0	0	0	0	0	0	0	0	0
Johnson Run of Mill Creek												
Petersburg	150	2.6	16	0	0	0	0	0	0	0	0	0
Jones Run	160	4	13	0	0	0	0	0	0	0	0	0
Kettle Creek	150	2.4	10	10	344	7	1	2	0	0	0	0
Kitchen Creek	150	3.6	5	0	0	0	0	0	0	0	0	0
Laurel Creek of Elk	150	3.5	7	0	0	0	0	0	1	217	6	2399
Laurel Creek of Knapps Creek	180	4.5	14	0	0	0	0	0	0	0	0	0
Laurel Creek of Manns	150	3.1	4	0	0	0	0	0	0	0	0	0
Laurel Creek of Middle Fork	240	6	10	1	89	0	0	1	5	20	1	160
Laurel Creek of New	150	3.8	16	0	0	0	0	0	0	0	10	1072
Laurel Creek of	150	2.5	5	0	0	0	0	0	0	0	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Second Creek												
Laurel Fork at Mouth	300	14	10	0	0	0	0	0	0	0	0	0
Laurel Run at 73 Bridge	300	8	17	1	21	0	1	0	9	149	0	0
Laurel Run of Big Sandy at Mouth	300	10	8	0	0	0	0	0	0	0	6	972
Laurel Run of Greenbrier near Hil	180	4.4	10	0	0	0	0	0	0	0	0	0
Laurel Run of Horseshoe	160	4	10	63	1158	15	38	10	0	0	1	256
Laurel Run of Lower Greenbrier	150	2.2	5	120	1828	5	114	1	0	0	0	0
Laurel Run of Three Fork	300	12	6	0	0	0	0	0	0	0	7	954
Leading Lower Creek	300	14	16	0	0	0	0	0	0	0	0	0
Leadmine Run	200	5	9	69	1673	27	21	21	0	0	0	0
Left Fork Buckhannon River	300	12	12	0	0	0	0	0	0	0	0	0
Left Fork Clover Run One	300	8	16	2	284	0	0	2	1	525	0	0
Left Fork Clover Run Upper	200	5	8	28	589	18	5	5	0	0	20	931
Left Fork of Flies Creek	200	5	12	3	57	0	2	1	1	118	6	135
Left Fork of Right Fork Buckhannon R	300	8	13	0	0	0	0	0	3	713	0	0
LF Anglins	150	3.6	4	1	30	0	0	1	0	0	0	0
LF of Big Stony Run of SF	150	2	4	43	972	10	22	11	0	0	0	0
LF of Haves Run	150	2.6	1	0	0	0	0	0	0	0	0	0
LF of UNT of Stroder Run	150	0.7	0	0	0	0	0	0	0	0	0	0
Lick Run of Little	150	0.9	4	0	0	0	0	0	0	0	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
EK of SF												
Little Bluestone River	150	2.8	6	0	0	0	0	0	0	0	0	0
Little Buffalo Creek	150	3	5	0	0	0	0	0	0	0	0	0
Little Fork of SF	150	2.3	3	173	3425	61	69	43	0	0	0	0
Little Laurel Creek Headwaters	150	1.1	4	0	0	0	0	0	0	0	0	0
Little Laurel Run	160	4	3	2	112	0	0	2	0	0	0	0
Little River East Fork of Greenbr	150	4.4	7	19	866	2	4	13	0	0	13	946
Little Sandy Creek at 4H Camp	300	12	16	0	0	0	0	0	7	420	15	1316
Little Sandy Creek at Barnes Cabin	300	8	12	0	0	0	0	0	2	23	12	113
Little Sandy Creek at Rt 26 Bridge	300	15	19	0	0	0	0	0	0	0	1	8
Loglick Run	150	3	7	0	0	0	0	0	0	0	0	0
Long Run	160	4	10	9	396	1	1	7	0	0	0	0
Long Run	200	5	3	99	4853	33	15	51	0	0	0	0
Long Run of East Fork of Greenbri	150	3	5	21	502	3	13	5	0	0	6	101
Long Run of SB	150	1.3	2	0	0	0	0	0	0	0	0	0
Louse Camp Run	150	3	4	20	195	15	3	2	0	0	0	0
Madison Run	150	3	8	5	690	1	1	3	0	0	0	0
Manns Creek of New	150	3.4	6	0	0	0	0	0	0	0	0	0
Martins Run	150	3	2	0	0	0	0	0	0	0	0	0
Mash Fork of Camp Creek	150	3.7	9	0	0	0	0	0	0	0	1	61
Maxwell Run	150	3	2	126	2774	59	31	36	0	0	0	0
McCray Creek	160	4	6	6	458	1	0	5	0	0	0	0
McIntosh Run	150	2	0	0	0	0	0	0	0	0	0	0
Meadow Branch above SCL	150	2.2	11	0	0	0	0	0	0	0	0	0
Meadow Branch	160	4	13	0	0	0	0	0	0	0	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Below Park Meadow Creek above Lake Sherwood	150	2.5	6	4	77	1	1	2	0	0	0	0
Middle Branch of Hominey Creek	150	2	6	12	17	12	0	0	0	0	1	2
Middle Fk of Gauley	150	2.3	2	44	488	28	11	5	0	0	1	3
Middle Fork at Cassity	300	12	12	0	0	0	0	0	0	0	2	303
Middle Fork Patterson Creek	150	3.4	15	0	0	0	0	0	0	0	0	0
Middle Ridge Hollow	150	2.2	0	0	0	0	0	0	0	0	0	0
Middle Tuckahoe Run	150	3.8	6	0	0	0	0	0	0	0	0	0
Mill Creek at Kumbrabow	240	6	3	50	1411	19	16	15	0	0	0	0
Mill Creek of Patterson	150	2.6	3	117	1725	68	36	13	0	0	0	0
Mill Run	160	4	4	11	480	2	3	6	0	0	0	0
Mill Run of SB at Nathaniel WMA	150	3.6	3	143	2760	37	71	35	0	0	0	0
Minear Run Lower Repeated	200	5	11	2	96	0	0	2	0	0	1	162
Minear Run Middle	200	5	7	13	272	1	11	1	0	0	0	0
Moore's Run	150	3.5	12	1	63	0	0	1	0	0	0	0
Morgan Run of Cheat Lake	200	5	21	0	0	0	0	0	0	0	0	0
Moses Spring Run	150	2.4	3	29	797	5	11	13	0	0	0	0
Mountain Run	150	2	4	0	0	0	0	0	0	0	0	0
Muddy Creek at Cuzzart	200	5	8	7	816	0	0	7	0	0	13	1616
Muddy Creek at Headwaters	200	5	6	6	252	1	0	5	0	0	5	408

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Muddy Creek Brandonville Pike	300	8	6	0	0	0	0	0	1	23	0	0
Muddy Creek Million Bridge	300	10	6	0	0	0	0	0	27	741	12	1520
Muddy Creek Tack shop	300	8	8	0	0	0	0	0	5	120	2	375
Mullenox Run	165	4.1	5	39	562	8	27	4	0	0	0	0
N Mill Creek	150	1.8	20	0	0	0	0	0	0	0	0	0
Narrow Ridge	150	3	3	33	601	16	13	4	0	0	0	0
New Creek	150	3.5	6	53	1007	40	3	10	0	0	0	0
NF Big Clear Creek	150	2.9	9	2	76	0	1	1	2	407	12	332
NF Deer Creek Headwaters	200	5	4	121	4172	33	41	47	0	0	0	0
NF of Deer Creek at Rt 28 crossing	280	7	12	0	0	0	0	0	0	0	0	0
NF Patterson	150	3.5	18	0	0	0	0	0	47	745	2	232
North Fork Cherry	180	4.4	5	46	374	28	14	4	0	0	0	0
Owl Knob Hollow	150	3.5	1	63	1230	4	47	12	0	0	0	0
Panther Camp Ck of Spring Creek	166	4.4	8	3	88	0	1	2	0	0	2	376
Panther Camp Run	150	3	3	55	598	27	26	2	0	0	27	26
Panther Creek	180	4.5	5	1	75	0	0	1	0	0	0	0
Patterson Creek near NF mouth	180	4.5	19	0	0	0	0	0	0	0	0	0
Pecks Run	200	5	10	0	0	0	0	0	0	0	0	0
Pinch Creek	150	3.2	7	0	0	0	0	0	1	155	3	437
Pipestem Creek	150	2.7	6	0	0	0	0	0	0	0	0	0
Pond Lick Run of Howards	150	1.8	4	0	0	0	0	0	0	0	0	0
Poplar Run of Birch River	150	2.6	13	0	0	0	0	0	0	0	0	0
Props Run of Slatyfork	150	3	6	15	253	1	12	2	131	353	1	37
Red Oak Creek	150	1	5	33	787	14	10	9	0	0	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Reeds Creek	150	3	6	12	163	7	3	2	1	11	0	0
RF Anglins Right Fork	150	3	3	0	0	0	0	0	0	0	0	0
Buckhannon River Right Fork	300	15	17	1	243	0	0	1	4	843	2	328
Buckhannon River Upper	300	10	10	4	166	0	1	3	0	0	3	662
Right Fork Clover Run	160	4	11	0	0	0	0	0	1	32	0	0
Road Run of SF at West End Rd	150	3	1	0	0	0	0	0	0	0	0	0
Roaring Creek at Mouth	300	12	23	1	4	1	0	0	0	0	0	0
Roaring Creek downstream Lick Run	200	5	3	27	585	3	20	4	0	0	0	0
Roaring Creek One	160	4	3	67	1825	5	39	23	0	0	0	0
Roaring Run above SCL	150	1	0	0	0	0	0	0	0	0	0	0
Rock Gap Run	150	2	8	0	0	0	0	0	0	0	0	0
Rockcamp Run	150	1.8	5	0	0	0	0	0	0	0	0	0
Rosser Run	150	1.5	3	0	0	0	0	0	0	0	0	0
Saltlick Creek at Bridge	240	6	16	3	87	2	0	1	0	0	0	0
Saltlick Creek Repeated	200	5	14	12	439	0	5	7	0	0	0	0
Saltlick Mouth	300	8	19	0	0	0	0	0	0	0	0	0
Samuel Run	150	3	6	41	556	20	17	4	11	66	0	0
Sand Run	300	12	18	0	0	0	0	0	0	0	0	0
Sandy Creek Lower	300	8	15	0	0	0	0	0	0	0	0	0
Sandy Creek Upper	160	4	10	0	0	0	0	0	0	0	0	0
Sawmill Run	150	1.7	7	18	412	7	8	3	1	77	0	0
Seneca Creek	300	10.4	10	184	7744	39	74	71	177	9617	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Above Strader Run												
Shafter Run	150	2.5	2	6	169	1	2	3	0	0	0	0
Shavers Fork at Ryans Bend	300	12	16	11	261	2	5	4	8	223	1	22
Shavers Run	200	5	10	0	0	0	0	0	0	0	0	0
Shipe Hollow Run of Cullers R	150	1	4	0	0	0	0	0	0	0	0	0
Sinkhole Run UNT of Reeds Creek	150	0.7	0	0	0	0	0	0	0	0	0	0
South Fk of Gauley	150	3.1	4	45	411	31	10	4	0	0	5	84
South Fork River	300	8	22	2	327	0	0	2	0	0	0	0
Spring Creek of Greenbrier	150	3.3	2	0	0	0	0	0	0	0	0	0
Stony Creek of N Mill	150	1.4	14	0	0	0	0	0	0	0	0	0
Stony Run of SF below Brandywine	150	3	1	0	0	0	0	0	0	0	0	0
Suck Creek	150	2.2	6	0	0	0	0	0	0	0	0	0
Sutton Run of NF												
Deer Creek	150	2.3	4	83	1117	42	29	12	0	0	0	0
Swallow Rock Run	150	3	2	35	605	14	13	8	0	0	0	0
Swim Run at CR8	150	0.8	13	0	0	0	0	0	0	0	0	0
Thorn Run of Patterson	150	2.4	2	0	0	0	0	0	0	0	0	0
Thorn Run of Patterson at Martin Rd	150	2.8	12	0	0	0	0	0	0	0	0	0
Tingler Run	150	3	1	2	32	1	0	1	0	0	0	0
Trib of MF Williams	150	3	1	4	49	0	4	0	0	0	0	0
Trout Pond Run	150	1.3	1	39	749	7	25	7	0	0	0	0
Trout Run	160	4	6	86	1309	58	14	14	0	0	0	0
Trout Run	150	3.6	18	4	723	0	0	4	0	0	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
Tuckahoe Run	150	2.4	5	0	0	0	0	0	0	0	0	0
Twelvemile Run	150	3	4	37	374	29	5	3	0	0	0	0
Two Mile Run	150	2.4	6	0	0	0	0	0	0	0	0	0
Tygart Valley River at Valley Head	300	10	16	1	56	0	0	1	0	0	0	0
UNT 1 of Bk Fk Elk	150	3.3	2	0	0	0	0	0	0	0	0	0
UNT 2 of Bk Fk Elk	150	3.6	4	13	165	8	2	3	0	0	4	368
UNT 2 of Williams River	150	3.3	0	0	0	0	0	0	0	0	0	0
UNT Dry Fork	150	3	1	17	483	12	2	3	0	0	0	0
UNT Dry Fork	150	3	5	26	314	22	0	4	0	0	0	0
UNT Dry Fork	150	3	0	0	0	0	0	0	0	0	0	0
UNT Dry Fork	150	3	0	0	0	0	0	0	0	0	0	0
UNT Dry Fork	150	3	0	0	0	0	0	0	0	0	0	0
UNT Dry Fork	150	3	1	0	0	0	0	0	0	0	0	0
UNT Fields Stony Run	160	4	2	0	0	0	0	0	0	0	0	0
UNT Glady Fork	150	3	2	17	165	11	5	1	0	0	0	0
UNT Laurel of Three Fork	160	4	3	0	0	0	0	0	0	0	0	0
UNT of Abrams Creek	150	1.1	1	3	52	1	1	1	0	0	0	0
UNT of Back Creek	150	1.4	9	0	0	0	0	0	0	0	0	0
UNT of Dry Run of Upper NF	150	1.1	4	0	0	0	0	0	0	0	0	0
UNT of Haves Run upstream of Brandyw	150	2.6	1	0	0	0	0	0	0	0	0	0
UNT of Johnson Run	150	2.5	7	0	0	0	0	0	0	0	0	0
UNT of NB Potomac	150	3.5	5	0	0	0	0	0	0	0	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH SPECIES RICHNESS	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
UNT of NF Big Clear Creek	150	2.5	5	21	885	5	1	15	0	0	2	89
UNT of Rock Camp	150	2.2	2	0	0	0	0	0	61	1532	0	0
Unt of Teeter Camp	150	1.7	1	1	71	0	0	1	0	0	0	0
UNT of Williams River	150	3.1	0	0	0	0	0	0	0	0	0	0
Upper Birch River	152	3.8	5	0	0	0	0	0	0	0	3	697
Upper Howards Creek	150	2.4	6	0	0	0	0	0	0	0	0	0
Upper Laurel Creek of Elk	150	2.3	3	0	0	0	0	0	0	0	2	581
Upper Laurel Run of Three Forks	240	6	5	0	0	0	0	0	0	0	2	323
Upper West Fork of Greenbrier	150	3.2	7	0	0	0	0	0	0	0	0	0
Wades Creek of Howards	150	2.7	6	0	0	0	0	0	0	0	0	0
Waggy Run UNT to Reeds Creek	150	1.2	0	0	0	0	0	0	0	0	0	0
Wallace Hollow of Dropping Creek	150	2	2	0	0	0	0	0	22	663	0	0
Warm Springs Run	150	3.5	12	0	0	0	0	0	0	0	0	0
Warner Run	150	3	4	39	329	23	14	2	0	0	0	0
Webster Run	160	4	4	0	0	0	0	0	0	0	0	0
West Fork Gladys Fork	200	5	8	9	316	4	2	3	0	0	0	0
Wetzel Hollow of Cullers Run	150	2.1	5	0	0	0	0	0	0	0	0	0
Whip Gap Run	150	1.8	6	68	3159	16	13	39	0	0	0	0
Whip Run	150	2.4	10	0	0	0	0	0	0	0	0	0
Whites Run	160	4	2	0	0	0	0	0	0	0	0	0
Williamsport Run of Patterson	150	2.5	1	0	0	0	0	0	83	2022	0	0

SITE_NAME	REACH LENGTH	WETTED WIDTH	FISH	# SAFO	SAFO WGT	# YOY	# SMAD	# LGAD	# ONMY	ONMY WGT	# SATR	SATR WGT
			SPECIES RICHNESS									
Windy Run	160	4	11	2	102	0	0	2	0	0	1	288
York Run	150	3	5	0	0	0	0	0	0	0	0	0
Zeke Run	150	2.6	2	19	912	6	2	11	0	0	0	0

Appendix 3. Local habitat variables recorded during fish sampling. Local habitat variables were not available for all sites sampled.

SITE NAME	SAMPLE DATE	H ₂ O TEMP (°C)	H ₂ O PH	SPECIFIC CONDUCT.	TOTAL HARDNESS (mg/L)	CALCIUM HARDNESS (mg/L)	STREAM GRADIENT (PCT)	RIFFLE: POOL RATIO	MAX. DEPTH (m)	PCT. CANOPY	RVHA
New Creek	8/18/2006	12.64	8.48	91	60	40	2	4	0.6	0.7	185
Mullenox Run	6/13/2007	13	.	25	.	.	3	4	0.6	0.7	172
UNT of Rock Camp	8/2/2007	13.49	8.22	229	160	120	5	4	0.5	0.7	179
Middle Ridge Hollow	7/14/2006	13.6	8.28	39	40	20	12	5	0.5	0.9	179
Williamsport Run of Patterson	8/15/2006	13.61	8.07	563	340	260	4.3	5	0.4	0.8	182
Trib of MF Williams	7/13/2007	13.63	4.77	28	40	20	3.33	3	0.5	0.8	183
UNT of Williams River	7/13/2007	13.83	4.61	30	20	20	8.33	2	0.8	0.8	190
UNT 2 of Williams River	7/13/2007	13.9	4.97	26	20	20	5	5	0.6	0.8	185
Long Run of East Fork of Greenbri	6/13/2007	14.14	.	25	.	.	3.33	7	0.4	0.8	183
Unt of Teeter Camp	7/14/2006	14.23	7.29	37	40	20	14.7	5	0.4	0.9	180
Abes Run	6/13/2007	14.34	.	31	.	.	4	5	0.5	0.7	161
Mill Creek of Patterson	8/9/2006	14.61	8.41	446	280	200	3	4	0.4	0.7	151
Two Mile Run	6/12/2007	14.63	.	41	.	.	2.67	4	0.7	0.7	172
NF Deer Creek Headwaters	6/27/2007	14.68	6.9	37	20	20	1.5	3	1.1	0.6	179
Little River East Fork of Greenbr	6/14/2007	14.81	.	49	.	.	2.33	3	1	0.6	179
Middle Fk of Gauley	7/6/2007	14.83	6.93	45	20	20	7.33	1	1.8	0.9	196
UNT of Haves Run upstream of Brandyw	7/27/2006	14.84	6.78	48	40	20	6.7	3	0.8	0.8	182
LF of UNT of Stroder Run	7/11/2006	14.9	8	302	220	180	29.3	8	0.2	0.9	166
East Fork Greenbrier Headwaters	6/14/2007	14.99	10.03	22	.	.	2	5	0.5	0.6	165
Wallace Hollow of Dropping Creek	8/2/2007	15.01	8.16	192	140	100	4.33	5	0.3	0.7	183

SITE NAME	SAMPLE DATE	H ₂ O TEMP (°C)	H ₂ O PH	SPECIFIC CONDUCT.	TOTAL HARDNESS (mg/L)	CALCIUM HARDNESS (mg/L)	STREAM GRADIENT (PCT)	RIFFLE: POOL RATIO	MAX. DEPTH (m)	PCT. CANOPY	RVHA
South Fk of Gauley Laurel Run of	7/6/2007	15.11	7.01	32	20	20	4.67	3	0.6	0.8	190
Greenbrier near Hil	6/15/2007	15.12		37			2	3	0.5	0.6	163
Samuel Run	6/30/2006	15.13	7.23	102	80	40	8	3	0.8	0.6	175
Laurel Run of											
Lower Greenbrier	6/28/2007	15.19	7.19	34	20	20	1.33	3	0.8	0.8	169
Dry Hollow of South											
Branch at Eagle	7/20/2006	15.21	8.47	178	100	100	8.7	2	0.6	0.6	186
NF Big Clear Creek	7/8/2007	15.22	7.54	82	40	40	1.67	2	1	0.7	164
Haves Run											
Upstream of											
Brandywine L	7/27/2006	15.24	7.55	45	40	20	3.7	4	0.6	0.8	186
Hunter Run of NF											
Cherry	7/5/2007	15.31	5.48	25	20	20	3.67	2	1.4	0.8	179
Whip Gap Run	8/9/2006	15.37	8.46	202	120	120	4	3	1.1	0.7	150
McIntosh Run	7/13/2006	15.43	8.26	190	120	120	12.5	3	0.7	0.7	162
Back Run	7/12/2006	15.54	8.15	111	80	60	11.5	3	0.5	0.9	175
UNT of NF Big											
Clear Creek	7/8/2007	15.62	7.73	97	40	40	1.67	3	0.5	0.8	169
Difficult Run	6/29/2006	15.67	7.34	72	60	20	4	3	1.3	0.7	154
Zeke Run	7/7/2006	15.68	8.05	105	60	60	5.7	4	0.9	0.7	168
Shafter Run	7/7/2006	15.69	8.02	135	100	60	6	4	0.4	0.7	167
Big Run of Gauley	7/6/2007	15.71	5.37	26	20	20	4.33	5	0.6	0.7	173
Tuckahoe Run	8/3/2007	15.72	7.8	87	40	40	2.67	4	0.4	0.7	172
Owl Knob Hollow	7/19/2006	15.84	7.97	54	40	20	5.7	4	0.4	0.8	180
Mill Run of SB at											
Nathaniel WMA	7/6/2006	15.96	7.92	57	60	40	3.7	6	0.6	0.9	187
Road Run of SF at											
West End Rd	7/27/2006	15.96	6.95	58	40	20	4.3	4	0.5	0.8	184
Middle Branch of											
Hominey Creek	7/27/2007	16.09	6.74	32	20	20	2.67	2	1.7	0.7	176
Long Run	7/17/2006	16.18	7.28	60	40	20	5.3	2	1	0.7	172
Sutton Run of NF											
Deer Creek	6/27/2007	16.21	7.05	49	20	20	2.33	3	0.6	0.6	163
High Ridge Run	6/30/2006	16.22	7.65	95	80	40	5.3	5	1.4	0.8	185

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UNT 1 of Bk Fk Elk Dropping Lick Creek	7/17/2007	16.23	6	22	20	20	3.67	3	0.6	0.8	180
Little Fork of SF	8/2/2007	16.34	8.22	216	140	100	3.33	3	0.8	0.5	172
Stony Run of SF below Brandywine	7/21/2006	16.37	8.04	50	40	20	2.3	3	0.8	0.3	182
Dobson Branch of Greenbrier	7/26/2006	16.37	8.2	63	40	20	3	3	0.3	0.8	179
LF of Big Stony Run of SF	6/28/2007	16.42	7.07	142	60	60	3.33	4	1.2	0.8	165
North Fork Cherry	7/25/2006	16.42	7.58	48	40	20	4.3	3	0.5	0.7	179
Hammer Run	6/11/2007	16.49		35			1.5	2	0.9	0.6	149
Big Laurel Creek	7/19/2006	16.5	8.29	314	160	160	1.7	10	0.4	0.1	141
Gauley Camden	7/7/2007	16.74	6.97	33	20	20	2	3	0.5	0.8	173
UNT 2 of Bk Fk Elk	7/17/2007	16.8	6.71	44	20	20	2	4	0.6	0.8	187
LF of Haves Run	7/26/2006	16.82	7.4	152	60	40	4.3	3	0.3	0.9	166
Panther Creek	7/7/2007	16.86	6.95	56	20	20	2.75	4	0.7	0.7	181
Stony Creek of N Mill	8/17/2006	17.01	7.72	446	200	160	0.7	1	0.6	0.6	119
Middle Tuckahoe Run	8/3/2007	17.03	7.44	65	40	20	2	2	1	0.6	177
Brushy Run	7/17/2006	17.09	6.72	58	40	20	6	2	0.7	0.6	183
Bruffey Creek	7/5/2007	17.12	7.77	110	60	60	3	3	0.3	0.6	179
Bear Creek of Camp Creek	7/31/2007	17.14	7.6	41	40	20	6.67	4	0.5	0.7	184
LF Anglins	7/19/2007	17.17	8.02	224	160	120	2.33	3	0.5	0.8	177
Roaring Run above SCL	6/21/2006	17.2	6.3	48	20	20	4.7	4	0.4	0.9	175
RF Anglins	7/19/2007	17.21	7.76	32	20	20	2.33	3	0.5	0.8	183
Cove Run of WF Greenbrier	6/26/2007	17.3	7.19	33	20	20	2.33	5	0.3	0.7	171
Moses Spring Run	7/30/2007	17.32	8.01	203	120	100	5.33	3	0.6	0.8	184
Cochran Creek of Knapps Creek	6/29/2007	17.43	6.74	45	20	20	1	1	1	0.7	167
Props Run of Slatyfork	7/17/2007	17.47	7.02	42	20	20	2.67	2	0.7	0.6	193

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Reeds Creek	7/12/2006	17.5	8.95	190	100	100	1.3	2	0.7	0.5	158
UNT of Abrams Creek	8/11/2006	17.56	7.49	580	300	220	6.3	3	0.3	0.4	151
Hills Creek Above Falls	7/5/2007	17.59	7.61	57	20	20	2	3	0.3	0.8	175
Douthat Creek	6/29/2007	17.68	7.26	55	40	20	1.67	2	0.3	0.6	175
Mash Fork of Camp Creek	7/31/2007	17.74	7.73	66	40	20	4	2	1	0.7	185
Meadow Branch above SCL	6/21/2006	17.8	8.72	55	20	20	0.7	0.5	0.8	0.9	159
Sinkhole Run UNT of Reeds Creek	7/12/2006	17.84	8.53	102	60	60	18	4	0.4	0.9	181
Camp Run	7/28/2006	17.94	7.18	87	60	40	8.3	1	0.3	0.9	170
Hdwaters	7/25/2007	18.12	7.36	99	60	40	1.67	3	0.5	0.7	153
Poplar Run of Birch River	8/30/2006	18.19	7.62	172	100	80	6.7	2	0.4	0.6	159
Red Oak Creek	8/11/2006	18.2	4.45	687	280	160	5	2	0.5	0.7	188
Emory Creek of Abrams Creek	6/29/2006	18.2	7.15	72	40	40	4	4	0.7	0.8	170
Hawk Run	8/1/2007	18.22	7.98	288	120	100	3.67	3	0.5	0.8	177
Alum Rock Hollow	7/24/2006	18.31	7.44	90	60	40	3.3	4	1.2	0.3	180
Seneca Creek	8/1/2007	18.44	7.21	59	40	20	3.33	2	0.5	0.7	190
Above Strader Run	6/23/2006	18.5	7.78	410	280	200	0.7	2	0.6	0.7	159
Pond Lick Run of Howards	8/8/2006	18.56	8.45	342	220	200	4	5	0.3	0.7	165
Rock Gap Run	7/19/2006	18.6	7.16	112	20	20	11.7	3	0.3	0.5	147
Rosser Run	6/12/2007	18.76		121			6.67	2	0.8	0.5	177
Waggy Run UNT to Reeds Creek	8/9/2006	18.83	8.48	471	340	240	8	2	1	0.5	153
Buffalo Creek	7/31/2007	18.92	8.28	517	240	180	2.33	3	0.5	0.5	177
Eliber Run	7/20/2006	18.96	7.92	229	140	100	4.3	1	0.4	0.7	165
Big Spring Branch of East River	6/26/2007	19.01	7.43	49	40	20	1.67	2	0.4	0.3	159
Long Run of SB											
Upper West Fork of Greenbrier											

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Harts Run Headwaters	8/7/2007	19.02	7.02	134	80	60	2.33	0	0.5	0.6	99
Elk Branch near Engle	6/20/2006	19.22	7.65	616	440	280	1.3	2	0.4	0.4	120
Sawmill Run	7/5/2006	19.22	7.75	249	140	140	6	3	0.5	0.6	153
Laurel Creek of Elk	8/15/2007	19.25	8.2	199	120	80	1.33	4	0.4	0.7	165
Upper Laurel Creek of Elk	8/15/2007	19.28	8.18	230	120	80	2.33	3	0.5	0.5	125
NF Patterson	8/7/2006	19.4	8.45	362	240	200	1	4	0.7	0.7	177
Upper Birch River	8/16/2007	19.45	8.21	1129	400	340	2	4	0.6	0.6	170
Pinch Creek	8/9/2007	19.48	7.8	172	80	40	3	2	1	0.9	192
Moores Run	8/2/2006	19.57	7.79	269	160	160	0.7	5	0.5	0.6	169
Laurel Creek of Knapps Creek	6/29/2007	19.69	7.32	66	40	20	1	1	0.6	0.7	179
Laurel Creek of Manns	7/16/2007	19.69	6.36	48	20	20	0.33	0	0.8	0.3	137
Little Laurel Creek Headwaters	8/7/2007	19.81	7.3	43	20	20	3	2	0.5	0.8	147
Laurel Creek of Second Creek	8/7/2007	19.84	7.77	58	20	20	1.67	2	0.3	0.7	177
Brushy Run of N Mill Creek	8/17/2006	19.89	7.88	4	180	120	1.3	1	0.3	0.8	154
Meadow Branch Below Park	6/22/2006	19.9	8.08	58	40	20	1	4	0.6	70	177
Panther Camp Ck of Spring Creek	6/28/2007	19.91	7.36	61	40	20	2.67	4	1.3	0.2	170
Forest Run	8/13/2007	20.01	7.52	239	160	120	2.33	0	0.2	0.8	141
Thorn Run of Patterson	8/8/2006	20.01	8.6	334	260	180	3.3	5	0.3	0.8	167
Lick Run of Little EK of SF	7/27/2006	20.03	7.15	61	40	20	1.7	1	0.2	0.6	162
Meadow Creek above Lake											
Sherwood	8/10/2007	20.04	6.55	18	20	20	2	3	0.4	0.9	163
Camp Creek	7/31/2007	20.17	7.55	132	40	40	2	5	0.5	0.5	176
Wetzel Hollow of	8/1/2006	20.17	7.34	98	100	20	2.3	5	0.2	0.4	148

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Cullers Run											
UNT of Dry Run of Upper NF	7/18/2006	20.26	8.1	352	240	220	6	4	0.4	0.4	148
Harts Run in State Forest	8/7/2007	20.28	7.72	63	40	20	1	1	0.4	0.7	147
Cullers Run Below Forks	8/1/2006	20.29	7.5	135	60	40	2	3	0.6	0.8	171
South Fork River UNT of NB	7/25/2006	20.32	8.61	225	120	120	1.3	2	0.6	0.2	158
Potomac	8/30/2006	20.36	7.37	143	80	60	1.3	4	0.4	0.2	168
Kettle Creek	7/27/2006	20.42	6.92	103	60	40	1.3	3	0.6	0.5	164
Rockcamp Run	7/7/2007	20.43	7.77	283	120	80	4	3	0.5	0.6	173
UNT of Back Creek	6/19/2006	20.44	7.13	184	120	60	0.3	0	0.3	50	130
Shipe Hollow Run of Cullers R	7/31/2006	20.54	7.36	140	80	40	3.7	3	0.4	0.8	156
Manns Creek of New	7/16/2007	20.7	6.9	129	60	40	0.33	1	0.7	0.6	144
Trout Pond Run	8/1/2006	20.77	8.25	41	40	20	6.3	2	0.6	0.8	168
Warm Springs Run	6/22/2006	20.86	7.93	326	240	160	0.7	1	1.5	60	156
Big Draft	8/1/2007	20.88	7.27	136	120	40	1.33	3	0.4	0.2	147
Johnson Run of Mill Creek Petersburg	8/17/2006	20.98	8.26	563	300	240	0.7	2	0.4	0.3	148
N Mill Creek	8/17/2006	21.01	7.78	355	180	120	0.3	1	0.6	0.3	137
Suck Creek	8/8/2007	21.02	7.92	232	120	100	3.67	3	0.4	0.8	157
Cove Run of Waites Run	8/2/2006	21.08	7.32	53	40	20	4	3	0.7	0.7	183
Swim Run at CR8	6/22/2006	21.32	8.02	227	120	80	0.7	0	0.6	30	138
Patterson Creek near NF mouth	8/8/2006	21.4	8.63	300	200	200	1	2	0.6	0.7	173
Upper Howards Creek	8/1/2007	21.41	7.63	124	80	60	2.33	2	0.3	0.5	160
Dry Creek of Howards	8/3/2007	21.42	7.56	164	80	60	0.33	3	0.4	0.6	159
Trout Run	8/1/2006	21.69	8.18	135	60	60	1	4	1.8	0.4	175
Elks Run Halltown	6/21/2006	21.7	6.3	656	460	320	0.3	0	0.3	0.4	86
UNT of Johnson	8/17/2006	21.83	8.7	383	240	160	1.3	2	0.4	0.8	161

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Run											
Mountain Run	6/22/2006	21.9	6.79	203	120	100	4	2	0.3	0.4	139
Wades Creek of Howards	8/3/2007	22.02	7.24	388	160	120	1.67	3	0.5	0.6	152
Whip Run	8/15/2006	22.03	8.43	211	140	100	2	3	0.3	0.7	150
Thorn Run of Patterson at Martin Rd	8/15/2006	22.04	8.48	311	180	140	0.7	1	0.8	0.6	162
Laurel Creek of New	8/16/2007	22.1	8.43	173	100	60	2	4	0.5	0.7	166
NF of Deer Creek at Rt 28 crossing	6/27/2007	22.19	7.56	63	40	20	1	2	0.5	0.4	174
Cullers Run near mouth	7/31/2006	22.22	7.4	170	100	60	1.3	3	0.5	0.6	158
Little Bluestone River	8/8/2007	22.34	7.88	153	80	60	1.67	2	0.8	0.6	160
Hammer Run Hdwaters	7/19/2006	23	8.35	428	300	220	2.3	10	0.2	0.5	152
Spring Creek of Greenbrier	6/28/2007	23.15	8.38	94	60	40	2.33	1	0.3	0.5	159
Kitchen Creek	8/13/2007	23.5	9.1	208	140	100	2	2	1	0.6	156
Middle Fork Patterson Creek	8/8/2006	23.82	8.63	335	180	160	0.3	1	0.5	0.4	150
Pipestem Creek	8/8/2007	23.99	8.52	221	120	100	1.67	1	0.7	0.5	151
Furnace Run	6/19/2006	24.16	7.64	96	60	20	0.7	3	0.5	60	151
Howards Creek below WSS	8/17/2007	24.5	8.42	480	240	160	0.8	2	0.8	0.4	151