A Large-scale Risk Assessment of the Biotic Integrity of Native Brook Trout Watersheds

M. Hudy[1], T. M. Thieling[2], and J. K. Whalen[3]

1 - National Aquatic Ecologist - East, USDA Forest Service, James Madison University, Harrisonburg, Virginia; 2 – Resource Information Analyst (GIS), USDA Forest Service, James Madison University, Harrisonburg, Virginia; 3 – Forest Fisheries Biologist, USDA Forest Service, Ozark-St. Francis National Forest, Russellville, Arkansas

ABSTRACT— Many physical, chemical and biological watershed level changes over the last hundred years have threatened the long-term integrity of native brook trout (*Salvelinus fontinalis*) in the eastern United States. Evaluations of the integrity of native brook trout watersheds over their native range are useful to guide decision makers, managers and publics in setting priorities for watershed level restoration, inventory and monitoring programs. Our objective was to 1) develop meaningful physical, chemical and biological metrics that could be used in watershed level risk, and prioritization assessments and 2) determine the current range of conditions for each watershed level metric to establish a benchmark to assist managers in evaluating the relative conditions of their watersheds at various scales of interest. We screened over 100 metrics and developed a multi-metric risk model (Watershed Integrity Rating – WIR) using metrics that related to watershed and water corridor; land use, sedimentation, fragmentation, air quality and human population. We tested the Watershed Integrity Rating on all 5th level watersheds in the eastern United States that contained National Forest (NFS) lands and native brook trout (current and historic). Watersheds in the Western Great Lakes region had the highest Watershed Integrity ratings while New England and the Southern Appalachians had the lowest ratings. Many individual watersheds throughout the native range appear to be at risk for brook trout survival with a high percentage of these found in the Southern Appalachians and New England.

INTRODUCTION

Many physical, chemical and biological watershed level changes over the last hundred years (Marschall and Crowder 1996; Galbreath et al. 2001) have threatened the long-term integrity of native brook trout (*Salvelinus fontinalis*) in their historic range in the eastern United States. Evaluations of the integrity of native brook trout watersheds over their native range are useful to guide decision makers, managers and publics in setting priorities for watershed level restoration, inventory and monitoring programs. Large-scale assessments for many aquatic species have been useful in identifying and quantifying: problems, information gaps, restoration priorities and funding needs (Williams et al. 1993; Davis and Simon 1995; Frissell and Bayles 1996; Warren et al. 1997; Master et al. 1998; McDougal et al. 2001). We developed a multi-metric Watershed Integrity Rating (WIR) that uses whole watershed (Moyle and Randle 1998) and water corridor variables for metrics instead of site-specific variables. Multi-metric indices can assist mangers in their evaluations of watershed health by giving an indicator of overall health when many anthropogenic factors may be contributing to a problem and by assisting in identifying key limiting factors (Barbour et al. 1999; McCormick et al. 2001). Our objective was to: 1) develop meaningful physical, chemical and biological metrics that could be used in watershed level and prioritization assessments, 2) determine the current range of conditions for each metric to establish a benchmark to assist managers in evaluating the relative conditions of their watersheds

at various scales of interest and 3) test the utility of the WIR for setting restoration priorities on National Forest lands that contain native brook trout (current and historic).

METHODS

We used 5th level Hydrologic Unit (HU) watersheds (mean size 452 km^2 $\pm$SD 248) for this assessment (Seaber et al. 1987; EPA 2002; USGS 2002b). The 5th level HU was chosen because: 1) it was the smallest size where data was currently available, 2) it is a level of great interest for land management, and 3) it is a size where plans can be developed for conservation management at a reasonable scale (Moyle and Yoshiyama 1994; Master et al. 1998). The watersheds (n = 344) in our study represent all watersheds that contained National Forest lands within the native distribution of brook trout (McCrimmon and Campell 1969; Behnke 2002). We artificially grouped the watersheds for statistical analysis into: Western Great Lakes (WGL), Eastern Great Lakes (EGL), New England (NE), Northern Southern Appalachians (NSA) and Southern Appalachians (SA)(Figure 1). If an ANOVA on the watershed groups was significant, a Tukey HSD multiple comparisons test was conducted (Sokal and Rohlf 2003). The range of the southern Appalachian strain of brook trout delineated the SA region.

The water corridor was 100 m on both sides of all streams and lakes within the watershed. The National Hydrography Dataset (NHD) (1:100,000) layers were used for streams and lakes (USGS 1994). Data on roads was developed using improved Topological Integrated Geographic Encoding and Referencing system (TIGER) data (Navtech 2001). These databases were analyzed using GIS programs that divided the National Hydrography Dataset (NHD) stream layer into gradient segments (Kendal Cikanek, Superior National Forest, personal communication). The spatial data from the 30m National Elevation Dataset (NED)(USGS 2004), 5th level HU coverage, the gradient divided NHD, human census data and the roads data were analyzed to compute metrics related to watersheds, streams, gradient, and roads. Output data included area in the watershed (total, land, and lake), stream/road crossings (total, per stream, by gradient), and road density (total, by distance from stream, by gradient).

We screened over 100 candidate metrics (Whalen 2004) for 1) completeness, 2) redundancy, 3) range, 4) variability and 5) responsiveness (Hughes et al. 1998; McCormick et al. 2001). All candidate metrics were required to have the same data resolution and definitions for all watersheds and were obtained and/or developed as a Geographic Information System (GIS) to allow for data analysis in a spatial context (Lo and Yueng 2002). Many potential databases (metrics) were eliminated from consideration because they were not available for all watersheds at the same or a suitable resolution. No direct biological metrics met the criteria. The final multi-metric index Watershed Integrity Rating (WIR) consists of five-impact categories sedimentation, fragmentation, land use, human population and air quality each with an associated indicator or surrogate for the watershed and the water corridor within that watershed (Table 1).

The range of conditions for each indicator metric was determined for all watersheds or water corridors then a percentile score was assigned for each indicator (Davis and Simon 1995; Barbour et al. 1999; Klemm et al. 2002). A scoring system is needed for standardization in the final risk assessment. The WIR scored all ten metrics on the same scoring range (0-10) based on the range of values for that indicator on all watersheds. Metrics were given a score based on the percentile in which they were found, for example if a watershed was in the 83 percentile for a particular metric it would get a score of 8.3. The final score was a summation of the ten metrics for a total range of scores from 0-100.

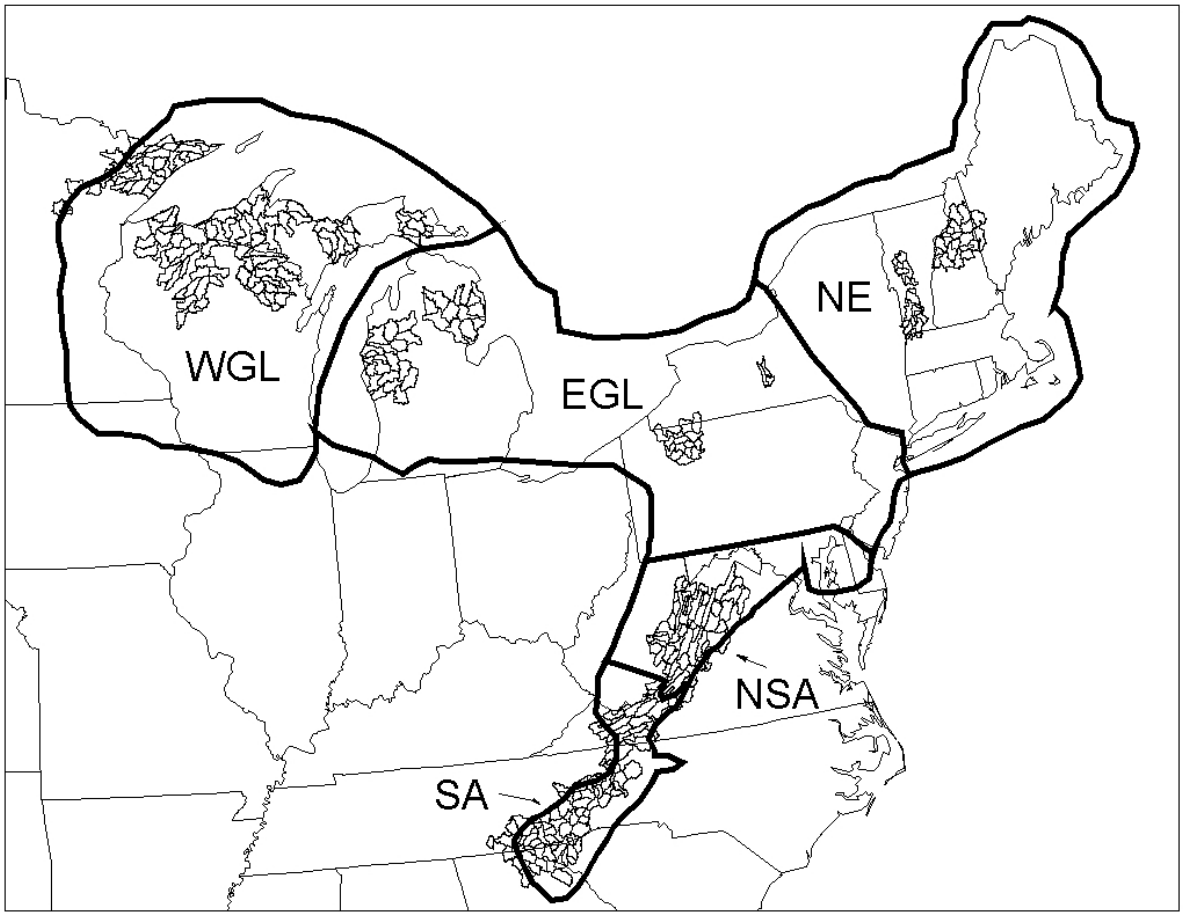

Figure 1. Historic range of brook trout in the eastern United States divided into five watershed groups; Western Great Lakes (WGL), Eastern Great Lakes (EGL), New England (NE), Northern Southern Appalachians (NSA) and Southern Appalachians (SA). The small polygons are 5th level hydrologic unit watersheds with National Forest lands within the native brook trout range.

Final Metrics (Indicators)

Sedimentation was indicated by the surrogate road density (km of road per km^2 of watershed) at the watershed level and by road density within the water corridor (Whalen 2004). Fragmentation at the watershed level was indicated by the number of dams per km^2 of watershed and was calculated from the National Inventory of Dams (NID) (United States Army Corps of Engineers 1998). Fragmentation at the water corridor level was indicated by the number of road crossings per kilometer of stream (Whalen 2004). Land use at the watershed level was indicated by the percentage of the watershed classified as human use in the National Land Cover Data (NLCD)(USGS 2002a). The NLCD was produced using satellite imagery data acquired in 30 m grid coverage. Human use includes low and high intensity residential, transitional, orchards/vines, pasture/hay, row crops, small grain crops, urban recreation, quarries/mines/gravel and commercial/industrial/transportation classifications. Land use at the water corridor level was indicated by the percentage of human land uses within the water corridor. Human population at the watershed level was indicated by a combination of the population density in 2000 and the population growth rate of that watershed since 1790 (Geolytics 2001; U.S. Census Bureau 2002; Price 2003; Whalen 2004). The water corridor level metric for human population was the percentage of the corridor that was designated as high or low residential use in the NLCD. Air

quality at the watershed level was indicated by the average 1999 nitrate and sulfate deposition (kg/ha) within the watershed (National Atmospheric Deposition Program 2003). Average deposition was based on isopleths that were developed from set sampling points. We used the average nitrate and average sulfate deposition value for each watershed as air quality watershed metric (Whalen 2004). Air quality at the stream corridor level was indicated by the buffering capacity of soils within the corridor (NRCS 2004; PSU 2004) The indicator represents the percentage of soils (upper 10 cm) in the water corridor with a buffering capacity of < 5.0 pH.

RESULTS AND DISCUSSION

The mean WIR score was 51 with a range from 14 to 96 (Table 2, Figure 2). The mean scores among the watershed groups were significantly different (ANOVA, df =344, F=130, p< 0.0001). The mean scores in all impact indicator categories were also significantly different (ANOVA, df = 344, p < 0.0001) among the watershed groups. The indicator values (actual not scored) are summarized (mean and range) in table 1.

The WGL watershed group consistently had the highest mean WIR and impact indicator scores (Table 2, Figure 2). The NE and SA watershed groups had the lowest mean WIR scores and the lowest mean indicator scores for sedimentation, fragmentation and human population. Many individual watersheds have been impacted from multi anthropogenic impacts, with a high percentage of these in the NE and SA watershed groups. These watersheds are also some of the most impacted from exotic fish introductions. We were not able to obtain data at the appropriate resolution to incorporate the impacts from exotics on native brook trout. The effects of stocked brook trout and stocked and naturalized rainbow trout and brown trout have greatly affected native brook trout populations in these regions (Larson and Moore 1985; Galbreath et al. 2001). The introductions of exotic cool and warm water species such as smallmouth bass and walleye have also affected native brook trout waters. A metric that can separate out populations of brook trout not impacted by exotics would be useful in future analysis.

This study was designed to identify the integrity of entire 5th level watersheds across the native range of brook trout in the eastern United States. The WIR is a useful starting point for answering questions appropriate to the scale of analysis. An analysis of indicators from impact categories is a second step that can help identify potential limiting factors. While the WIR and impact scores can help decision makers decide which watersheds to focus in and identify potential limiting factors, project specific restoration and conservation projects will need finer scale data and local knowledge to make wise decisions as brook trout streams in need of restoration and protection can be found in any watershed regardless of WIR score. Improvements in the data that allow for an analysis at a scale such as 6th level HU or individual stream reach are necessary to identify these important within watershed restoration or conservation projects. We used best available surrogates for many impacts because direct measurement data was not available across the range of this study. If available direct measurement data should be used for restoration decisions.

We did not run the analysis with 1:24,000 NHD stream and lake data, because it was not available for every watershed, however we conducted many watershed analyses where we had both 1:100,000 and 1:24:000 NHD data. In most cases, the metric indicator values were different but highly correlated (r > 0.90) and the relative rankings of the watersheds were not statistically different using a Spearman Rank Correlation test. There were also only small shifts in a watershed's percentile scores for each indicator. We believe our watershed and watershed group findings will be similar when the analysis can be run with a complete 1:24,000 NHD data set. We also did not conduct the analysis on all the 5th level HU within the brook trout historic range because of data gaps (primarily missing official 5th level watershed boundaries). Our experiences with working with all the National Forest watersheds (n = 991) in the eastern United States instead of a subset of brook trout only watersheds (n = 344) showed the range of conditions for

most of the indicator metrics to be similar (Whalen 2004). We believe that watersheds with National Forest lands (average ownership 56%) may have better WIR scores on average than the complete set of brook trout watersheds but the impact indicator scores will show similar trends among the watershed groups. The exception may be the NE scores where watersheds with National Forest lands are few and do not include most of the state of Maine where human population and land use indicators may score higher. An analysis for all watersheds is recommended has soon as the final 5th and 6th level HU become available.

Table 1. Final watershed and water corridor metrics used in the Watershed Integrity Rating and the mean and range of values. Water corridor is 100m either side of all streams and lakes. Each of the 10 indicators is worth 0-10 points. **Air quality score for the watershed indicator is scored 0-5 points for $N0_3$ deposition and 0-5 points $S0_4$ deposition. **Human score for watershed is scored 0-5 points for human population density in 2000 and 0-5 points for growth rate.

Impact	**Watershed indicators** (10 points each)**	**Median (range)**	**Water corridor indicators** (10 points each)	**Median (range)**
Sedimentation (20 points)	Road density (km/km^2)	1.23 (0.01 –4.89)	Road density (km/km^2)	1.53 (0.00-10.00)
Fragmentation (20 points)	# $Dams/km^2$	0.01 (0.00 – 0.11	# Road crossings/stream km	0.42 (0.00-2.08)
Land use (20 points)	% Land with human uses	8.53 (0.31 –79.81)	% Land with human uses	3.66 (0.24-30.51)
Human (20 points)	$Population/km^2$ Growth rate (1790-2000)	10 (0-281) 12 (1-25)	% Land with residential use	0.25 (0.00-14.30)
Air quality (20 points)	$N0_3$ deposition $S0_4$ deposition (kg/ha)	11 (9-18) 14 (7-21)	% Soils in water corridor with buffering capacity pH < 5.0	3.87 (0.00-100.00)

Table 2. Mean (± SE) Watershed Integrity Ranking (WIR), and impact scores for the Western Great Lakes (WGL), Eastern Great Lakes (EGL), New England (NE), Northern Southern Appalachians (NSA), Southern Appalachians (SA) and all watersheds (ALL) groups. Means followed by a common letter in a column are not statistically significantly different (ANOVA, $p < 0.001$; Tukey HSD multiple comparison test)

	WIR	Sedimentation	Fragmentation	Land use	Human	Air quality
WGL	72.5 (1.26) a	14.9 (0.31) a	14.2 (0.35) a	12.8(0.48) a	13.7(0.26) a	16.9 (0.29) a
EGL	48.4 (1.66) b	10.4 (0.52) b	10.9 (0.59) b	7.9 (0.85) b	8.0 (0.48) b	11.2 (0.87) b
NE	36.1 (2.02) c	9.8 (0.55) b	6.9 (0.64) c	7.1 (0.64) b	6.2 (0.41) c	6.1 (0.20) c
NSA	45.8 (1.65) b	9.0 (0.56) b	12.0 (0.61) b	9.1 (0.52) b	8.7 (0.54) b	7.0 (0.44) c
SA	36.4 (1.27) c	4.87 (0.37) c	6.0 (0.39) c	9.5 (0.53) b	5.4 (0.34) c	10.7 (0.33) b
All watersheds	51.2 (1.06)	10.1 (0.28)	10.4 (0.28)	10.0 (0.29)	9.1 (0.25)	11.7 (0.28)

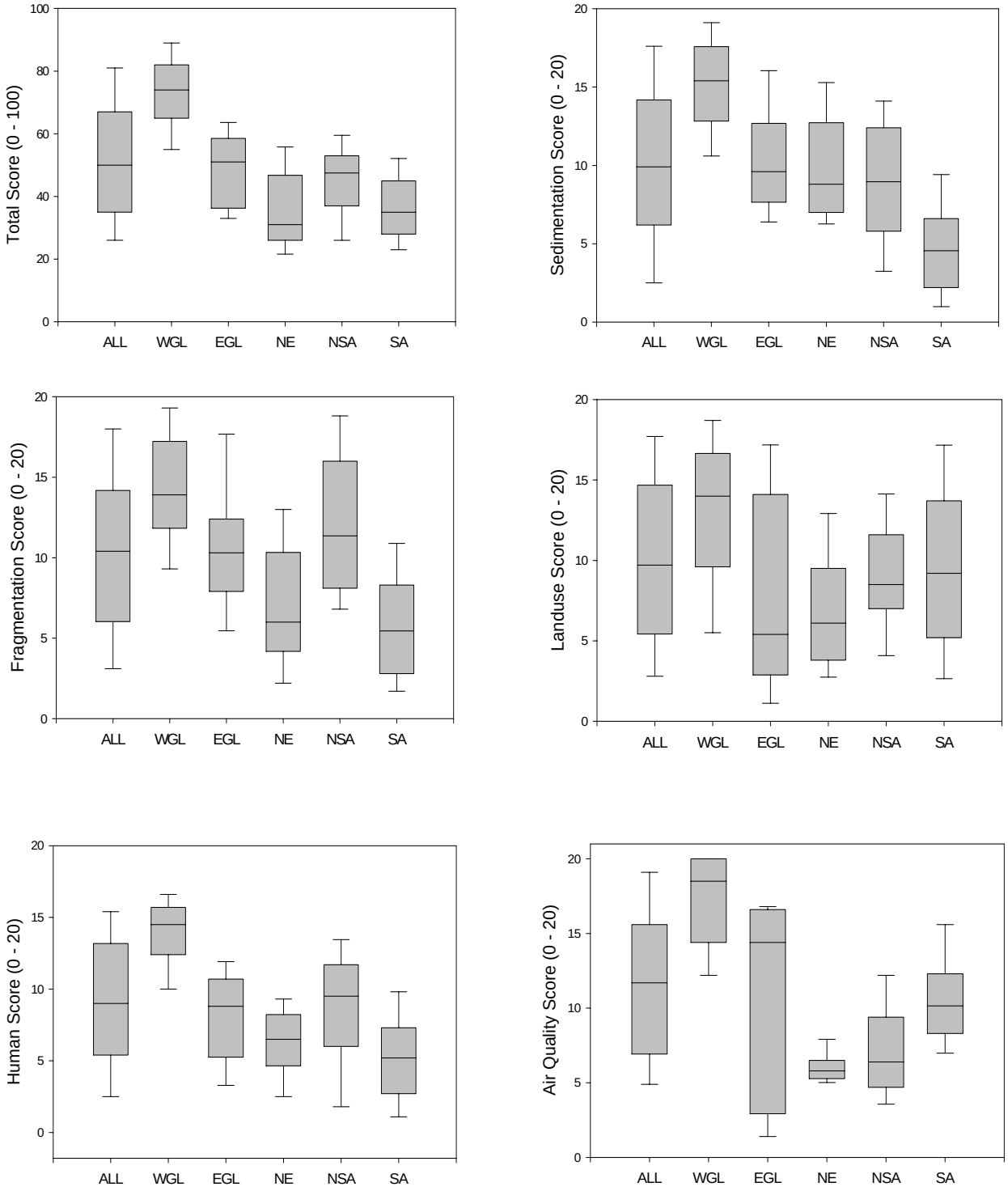

Figure 2. Range of conditions for the Watershed Integrity Rating (WIR) (total score) and individual impact indicators (sedimentation, fragmentation, land use, human population, air quality) for all watersheds (ALL), Western Great Lakes (WGL), Eastern Great Lakes (EGL), New England (NE), Northern Southern Appalachians (NSA) and Southern Appalachians (SA) watershed groups.

ACKNOWLEDGEMENTS

We would like to thank Giancarlo Cesarello for assistance in the GIS lab and Kendal Cikanek for development of programs to analyze the data. Robert Hildebrand and Eric Smith provided valuable assistance in the development and testing of the human population data.

REFERENCES

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Behnke, R.J. 2002. Trout and Salmon of North America. Free Press, Simon and Shuster, Inc. New York, New York. 359 p.

Davis, W. S. and T. P. Simon. 1995. Biological Assessment and Criteria: Tools for watershed resource planning and decision making. Lewis Publishers, Washington, D.C. Doppelt, B., M. Scurlock, C. A. Frissell, and J. Karr. 1993. Entering the watershed. Island Press, Covello, California.

Environmental Protection Agency (EPA). 2002. http://www.epa.gov/region02/gis/atlas/hucs.htm. 6 January 2003.

Frissell, C. A., and D. Bayles. 1996. Ecosystem management and the conservation of aquatic biodiversity and ecological integrity. Water Resources Bulletin 32:229-240.

Galbreath, P. F., N. D. Adams, S. Z. Guffey, C. J. Moore, and J. L. West. 2001. Persistance of Native Southern Appalachian Brook Trout Populations in the Pigeon River System, North Carolina. North American Journal of Fisheries Management 21: 927-934.

Geolytics. 2001. Census CD$^+$ Maps 1990. CD-Rom, http://www.censuscd.com.

Hughes, R. M., P. R. Kaufmann, A. T. Herlihy, T. M. Kincaid, L. Reynolds, and D. P. Larsen. 1998. A process for developing and evaluating indices of fish assemblage integrity. Canadian Journal of Fisheries and Aquatic Sciences 55: 1618-1631.

Klemm, D. J., K. A. Blocksom, W. T. Thoeny, F. A. Fulk, A. T. Herlihy, P. R. Kaufmann, and S. M. Cormier. 2002. Methods Development and Use of Macroinvertebrates as Indicators of Ecological Conditions for Streams in the Mid-Atlantic Highlands Region. Environmental Monitoring and Assessment 78: 169-212.

Larson, G.L. and S.E. Moore. 1985. Encroachment of exotic rainbow trout into stream populations of native brook trout in the southern Appalachian mountains. Transactions of the American Fisheries Society 114: 195-203.

Lo, C. P., and A. K. W. Yeung. 2002. Concepts and Techniques of Geographic Information Systems. Prentice Hall, Inc., Upper Saddle River, New Jersey.

Marschall, E. A. and L.B. Crowder. 1996. Assessing Population Responses to Multiple Anthropenic Effects: A Case Study with Brook Trout. Ecological Applications 6(1): 152-167.

Master, L. L., S. R. Flack, and B. A. Stein, editors. 1998. Rivers of Life: Critical watersheds for protecting freshwater biodiversity. The Nature Conservancy, Arlington, VA.

McCormick, F. H., R. M. Hughes, P. R. Kaufmann, D. V. Peck, J. L. Stoddard, and A. T. Herlihy. 2001. Development of an Index of Biotic Integrity for the Mid-Atlantic Highlands Region. Transactions of the American Fisheries Society 130(5): 857-877.

McCrimmon, H.R. and J.S. Campell. 1969. World distribution of brook trout, Salvelinus fontinalis. Journal of the Fisheries Research Board of Canada. 26:1699-1725.

McDougal, L. A., K. M. Russell, and K. N. Leftwich, editors. 2001. "A Conservation Assessment of Freshwater Fauna and Habitat in the Southern National Forests." USDA Forest Service, Southern Region, Atlanta Georgia. R8-TP 35 August 2001.

Moyle P. B., and P. J. Randall. 1998. Evaluating the biotic integrity of watersheds in the Sierra Nevada, California. Conservation Biology 12(6): 1318-1326.

Moyle P. B. and R. M. Yoshiyama. 1994. Protection of aquatic biodiversity in California: a five-tiered approach. Fisheries 19: 6-18.

National Atmospheric Deposition Program. 2003. NO_3 and SO_4 Isopleths. http://nadp.sws.uiuc.edu/isopleths/annualmaps.asp.

Natural Resources Conservation Service (NRCS). 2004. State soil geographic database (STATSGO). http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/index.html

Navtech. 2001. Navstreets: streets data. CD-Rom, Version 2.5. http://www.navtech.com/data/data.html

Pennsylvania State University (PSU). 2004. Earth System Science Center, Pennsylvania State University. Soil information for environmental modeling and ecosystem management. http://www.essc.psu.edu/soil_info

Price, C. 2003. 1990 population density by block group for the conterminous United States. USGS. http://water.usgs.gov/lookup/getspatial?uspopd90x10s.

Seaber, P.R., Kapinos, F.P., and Knapp, G.L. 1987. Hydrologic Unit Maps: U.S. Geological Survey Water-Supply Paper 2294.

Sokal, R.R. and F.J. Rohlf. 2003. Biometry: The principles and practice of statistics in biological research. W.H. Freeman and Company, New York, New York. 888p.

U.S. Army Corps of Engineers. 1998. National Inventory of Dams data. http://corpsgeo1.usace.army.mil/CECG/hq.html. 13 December 2002.

U.S. Census Bureau. 2002. Census 2000: Summary Files. http://www.census.gov. 2 Novemeber 2002.

U.S. Geological Survey (USGS). 1994. National Hydrography Dataset. http://nhd.usgs.gov July 7, 2004.

U.S. Geological Survey (USGS). 2002a. National Land Cover Dataset (NLCD). http://landcover.usgs.gov. 13 December 2002.

U.S. Geological Survey (USGS). 2002b. Water Resources: Hydrologic Unit Maps. http://water.usgs.gov/GIS/huc.html. 13 December 2002.

U.S. Geological Survey (USGS). 2004. National elevation data set. http://edcnts12.cr.usgs.gov/ned/

Warren, M. L., Jr., P. L. Angermeier, B. M. Burr, and W. R. Haag. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the southeastern United States. Pages 105-164 in Benz, G. W. and D. E. Collins (editors). Aquatic Fauna in Peril: The Southeastern Perspective. Special Publication 1, Southeast Aquatic Research Institute, Lenz Design and Communications, Decatur, GA.

Whalen, J.K. 2004. A risk assessment for crayfish conservation on national forest lands in the eastern U.S. Masters Thesis, James Madison University, Harrrisonburg, VA

Williams, J. D., M. L. Warren, Jr., K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9): 6-22.