GEOLOGICAL SURVEY OF ALABAMA

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WATER INVESTIGATIONS PROGRAM

DELINEATION OF ICHTHYOREGIONS IN ALABAMA FOR USE WITH THE INDEX OF BIOTIC INTEGRITY

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by

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ABSTRACT

A comprehensive database of 855 fish community samples, compatible for use in the Index of Biotic Integrity (IBI), was compiled from several institutional sources. Samples in the database were georeferenecd for use with GIS (Geographic Information System) software and the scientific nomenclature was standardized. Multivariate statistical analyses were used to determine the most favorable groupings of the collections within the confines of ecoregions and river drainages. Five ichthyoregions were delineated that were geographically consistent and that contained a homogeneous fish fauna. The analysis produced a classification with two major regions, one for ecoregions above the Fall Line (uplands) and one for ecoregions below the Fall Line (lowlands). The analysis further divided the upland region into three clusters and the lowland region into two clusters. These five cluster groups are the basis of our ichthyoregion classification and illustrate the spatial relationships between level IV ecoregions and major drainages, and between combinations of drainages and ecoregions. As more data are collected during this project, these preliminary ichthyoregion boundaries may be refined as necessary to better reflect the natural organization of fish communities and to assist in the assignment of all the state's waters to designated water-use classifications.

The Geological Survey of Alabama (GSA) 30+2 sampling method for collecting fish community samples was further evaluated in the Alabama Coastal Plain. The Coastal Plain, or lowland, sampling data were compared to sampling data previously collected for upland streams. Lowland streams required fewer sampling efforts per habitat compared to upland streams. For some metrics (percent insectivorous cyprinids, percent sunfish, total species, catch, and the IBI) significantly less sampling effort was required for lowland streams. The remaining metrics for lowland streams (percent omnivores, percent top carnivores, number of darter species, number of minnow species, number of sucker species, and number of sunfish species) were not significantly different than upland streams, but lowland metric means were always less than upland metric means. Although fewer efforts appear to be adequate for collecting an IBI-compatible sample in the Alabama Coastal Plain, it is recommended that the

30+2 method be applied to all streams sampled in the state to maintain a consistent sampling protocol between all sampling crews.

INTRODUCTION

The Geological Survey of Alabama (GSA), in cooperation with the Office of Education and Outreach (OEO) of the Alabama Department of Environmental Management (ADEM) and the Wildlife and Freshwater Fisheries Division (WFFD) of the Alabama Department of Conservation and Natural Resources (ADCNR), has initiated a multi-year research effort to develop and calibrate a comprehensive fish community bioassessment tool, known as the Index of Biotic Integrity (IBI), for the state of Alabama. This tool will be useful in helping agencies assign designated water-use classifications for all the state's waters to manage water quality more efficiently and effectively, understand aquatic resources more broadly and in greater depth, better manage aquatic habitat, and communicate to the public more clearly the need for and benefits of strong water resources protection and management.

The ADEM has recently revised its process for assessment of surface waters in Alabama relative to their designated uses and the procedures that it will use for listing and reporting waters under sections 305(b) and 303(d) of the Clean Water Act. The process used to categorize Alabama's waters and determine if they support their designated uses begins with the collection and evaluation of water-quality data, including biological assessments. The data must be qualitatively and quantitatively adequate to provide an accurate indication of water-quality conditions, since decisions based on the data can have substantial economic implications and long-term regulatory consequences. The newly revised Use-Support Assessment Process of ADEM has a goal of placing all waters of the state into one of five categories:

Category 1 - Waters that are attaining all applicable water-quality standards.
Category 2 - Waters that meet some, but not all, applicable water-quality standards and insufficient data are available to determine if remaining standards are met.

Category 2a - High potential for impairment based on available data.

Category 2b - Low potential for impairment based on available data.

Category 3 - Waters for which there are no data to determine if applicable water-quality standards are met.

Category 4 - Waters in which one or more standards are not met but establishment of a total maximum daily load (TMDL) is not required.

Category 4a - Waters for which an approved TMDL exists.

Category 4b - Waters for which other required control measures are expected to attain applicable water-quality standards in a reasonable period of time.

Category 4c - Waters for which the impairment is not caused by a pollutant.

Category 5 - Waters in which a pollutant has caused or is suspected of causing impairment. Waters in Category 5 comprise the State's 303(d) list.

The water-quality assessment process for each of Alabama's seven designated uses (Outstanding Alabama Water, Public Water Supply, Swimming, Shellfish Harvesting, Fish & Wildlife, Limited Warmwater Fishery, Agricultural & Industrial Water Supply) is different because each use classification is protected by specific numeric and narrative criteria. Therefore, the methodology for assigning a water to one of the categories will have different data requirements. Information that can be considered in the assessment process includes water chemistry data such as chemical concentrations, land use land cover data, physical data such as temperature and sediment measurements, habitat evaluations, bacteriological data, and biological data such as macroinvertebrate and fish community assessments.

The most widely used approach for biological assessment is sampling and analysis of the macroinvertebrate community using the rapid bioassessment protocol (RBP-III) methodology (Plafkin and others, 1989; Barbour and others, 1999) or some variation thereof. Another, less widely used, approach for conducting bioassessments is through sampling and analysis of the fish community. Assessing the biological condition of streams using the fish community has distinct advantages over the use of other aquatic groups.

> Fishes occupy the full range of positions throughout the food chain including herbivores, carnivores, piscivores, omnivores, insectivores, and planktivores, thereby integrating a variety of watershed functions and conditions into their community trophic structure.
>
> Fishes are generally present in all but the most polluted waters.
>
> Because fishes are relatively long-lived compared to macroinvertebrates and generally spawn for a restricted period in a year, their population numbers and fluctuations are more stable over longer periods of time.
>
> Fishes are relatively easy to identify compared to diatoms and macroinvertebrates. Species identification is possible for practically all individuals collected; and, if desired, individuals can be identified by a trained biologist and released in the field. Samples returned to the laboratory can be sorted and identified, and data sheets can be prepared relatively quickly allowing several samples to be processed in a day.
>
> Environmental requirements of fishes are relatively well known for a majority of species. Life history information is extensive for many species, and detailed distributional information is becoming more available with time.

Water-quality standards, legislative mandates, and public opinion are more directly related to the status of a lake or stream as a fishery resource. One goal of the Clean Water Act is to make waters “fishable and swimmable,” a directly measurable and attainable concept. Public perception of streams, pollution, and water-quality monitoring is linked closely with fishes because of their value as a food source and as a recreational resource.

The process of biological assessment is a systems approach for evaluating water resources that focuses on the actual condition of the resource, assessing chemical and physical water quality, biotic interactions, hydrology, energy and trophic interactions, and habitat structure. The extensively used chemical/physical and whole-effluent toxicity water regulatory approach only measures certain components of a water resource and, as such, are only indirect indicators of biological community integrity. Ultimately, it is the measurable performance of the natural biological system relative to a reference condition that is the goal for determining whether or not regulatory programs have successfully maintained or improved water quality. Biological assessments, whether macroinvertebrate based or fish community based, directly measure the biological performance of a water body.

Biological assessments can now be used with confidence for water resource evaluation for several reasons. First, technical support for the use of standardized techniques and methods has increased during the last decade (Karr and others, 1986; Plafkin and others, 1989; Barbour and others, 1999). Second, field and laboratory techniques have been refined and modified for use within a regulatory scheme. Third, a practical, working definition of biological integrity has been developed (Karr and Dudley, 1981) from which the process of biological assessment can be defended and biological performance measured. And finally, the concept of using data from ecoregional reference watersheds has been incorporated into the evaluation process compensating for the natural variation inherent in biological populations and systems (U.S. Environmental Protection Agency -USEPA, 2005). Full integration of the chemical-specific, toxicity, and biological water-quality assessment approaches is essential for a broad-based, technically sound, and cost-effective system for regulating and managing water resources.

One of the many assets of the IBI method is its ability to reduce very complex ecological processes into simple terms that managers, industry and business representatives, regulators, and the public can understand. Application of the IBI to fishery management problems and water-quality issues can be done with confidence because the science behind the IBI method is extensive and peer reviewed. The GSA applied the IBI to a large regional watershed, the Cahaba River, in 1997 (Shepard and others, 1997), developing metrics and associated scoring criteria for the first time in an Alabama watershed. Later, in conjunction with ADEM, GSA developed another application of the IBI for streams in the Black Warrior River system (O'Neil and Shepard, 2000). Since these studies, the GSA has applied the IBI to the Locust Fork system (Shepard and others, 2004), the Mulberry Fork system (Shepard and others, 2002), the Cahaba River system again (O'Neil, 2002), and the Hatchet Creek system (O'Neil and Shepard, 2004). The IBI sampling methodology was refined and the new procedure applied in a study of streams in the Coosa and Tallapoosa River systems in general and the Terrapin Creek watershed in particular (O'Neil and others, 2006).

Although the IBI is routinely used for water-quality regulation in other states and has been successfully applied in selected drainages in Alabama, it is underutilized in Alabama as an assessment tool. Several needs have been identified if the IBI biomonitoring method is to be applied statewide for assessing streams and other aquatic habitats.

A standardized wadeable stream sampling protocol must be created and adopted for use. Future research will be needed to explore lake, reservoir, and nonwadeable river sampling protocols.

The IBI has not been calibrated statewide to Alabama's high fish biodiversity and variable ecological and physiographic regions. Ecoregional and(or) drainage-specific scoring criteria (ichthyoregions) still need to be determined for most of Alabama's waters. This aspect of IBI implementation will require long-term cooperation among participating agencies.

Application of the IBI requires accurate species identifications by well-trained individuals. Any organization applying the IBI in Alabama must take this requirement into account because of Alabama's high fish biodiversity. The benefits of “green” sampling (i.e. non-destructive sampling), which means identifications are made on site and individuals are returned to the stream, should also be given a priority. A QA/QC system for fish identification within agencies should be established.

All organizations, agencies, and colleges using the IBI in Alabama need to collectively adopt a list of standardized ecological and tolerance designations for all species of fishes in the state. GSA has created such a list that should be peer reviewed by fisheries biologists, fish ecologists, and ichthyologists familiar with the state’s fishes.

Ecoregional and (or) drainage reference sites should be established and sampled systematically over time. ADEM has already established ecoregional reference sites for their macroinvertebrate program, and these sites need to be sampled for fishes on a prescribed basis.

Several of these needs have been met and research is ongoing on others. The GSA, in conjunction with WFFD, recently developed a standardized stream sampling protocol during a 3-year study in the Terrapin Creek watershed (O’Neil and others, 2006) for use with the IBI. This sampling protocol is now being used for all IBI fish bioassessments by ADEM, WFFD, and GSA. Additionally, IBI metrics and scoring criteria were re-evaluated for streams in the Coosa and Tallapoosa River systems resulting in improved procedures. Also, the practicality and usefulness of the IBI in a small watershed investigation (Terrapin Creek) was demonstrated. Results of the Terrapin Creek study provided a solid basis for IBI implementation statewide. The ADEM is currently applying the IBI on a limited basis in their statewide stream assessment program and the WFFD has recognized that additional stream and reservoir assessment tools will be needed by their department in future years for managing habitat quality and stream resources to benefit fish populations in the State.

In the more than 30 years since the Clean Water Act was passed, there has been considerable progress in the science of aquatic ecology and in the development of biological monitoring and assessment techniques. Biological goals adopted into state water-quality standards as designated aquatic life uses in the 1970s were general in definition and intent (e.g., “aquatic life as naturally occurs”) given the state of biomonitoring science and the limited data available to define aquatic life uses. Although such general use classifications met the requirements of the Clean Water Act, they were only the beginning, rather than the end point, of appropriate use designations. Improved application and integration of bioassessment methodologies into the water resource management process will result in a more efficient and effective regulatory system capable of realizing the expected goals of “swimmable and fishable” waters that the public expects. As the concept of tiered aquatic life uses is also implemented into water-quality management (USEPA, 2005), we will be able to better define and develop more precise, scientifically defensible, aquatic life uses that account for the natural differences between waterbodies and should result in more appropriate and practical levels of protection for specific waterbodies.

ACKNOWLEDGMENTS

Several individuals and institutions provided assistance with this study, and we sincerely appreciate their time and contributions. Fred Leslie, Chris Johnson, Lynn Sisk, and Norm Blakey of ADEM were involved in designing this project, discussing many aspects of project implementation, and in providing partial funding under Section 319 of the Clean Water Act. Steve Rider and Stan Cook of WFFD were also instrumental in designing the project, providing funding and encouragement for implementing this study and field assistance when needed. Cal Johnson, Anne Wynn, and Brett Smith of the Geological Survey of Alabama assisted with field collections, data entry, and data analysis.

OBJECTIVES

The objectives of this study were to continue the statewide IBI development process in Alabama by (1) delineating natural ichthyoregions in the state based on established ecoregions and river drainages and (2) evaluating the 30+2 IBI sampling protocol in Alabama’s Coastal Plain.

METHODS

The distribution of Alabama's 300+ species of freshwater fishes is controlled to some extent by ecologic factors related to stream and river drainage patterns as well as natural geographic variation. This high biodiversity and variability in distribution have been well established and documented in two recently published books about fishes in the state (Mettee and others, 1996 and Boschung and Mayden, 2004). High biodiversity and differential distribution provide strong support for the use of fish communities as a water-quality monitoring and assessment tool. They also make efforts to standardize and calibrate measures used for biological monitoring more difficult, particularly in light of Alabama's high ecoregional diversity (29 level IV ecoregions, fig. 1), 17 river systems (fig. 1), and unique distribution patterns of freshwater fishes.

A key to using ecoregions and drainages for interpreting and calibrating the IBI is to synthesize and reduce their inherent variability into a smaller number of reasonably consistent geographical regions with homogeneous fish fauna, which are termed "ichthyoregions." Compton and others (2003) have successfully applied the ichthyoregion concept to the IBI in Kentucky illustrating its use in a state with high fish biodiversity and high ecoregion and drainage diversity.

Several tasks were identified as necessary for developing a preliminary statewide ichthyoregion map.

Task 1 - A database of historical fish community samples taken from level IV ecoregions in the state should be created for use in classifying and delineating ichthyoregions. These samples should have been collected using similar sampling methods, or parts thereof, as outlined in the GSA 30+2 method, the samples should have been collected by field biologists and ichthyologists familiar with sampling wadeable streams, and identifications should have been made by researchers familiar with the southeastern fish fauna.

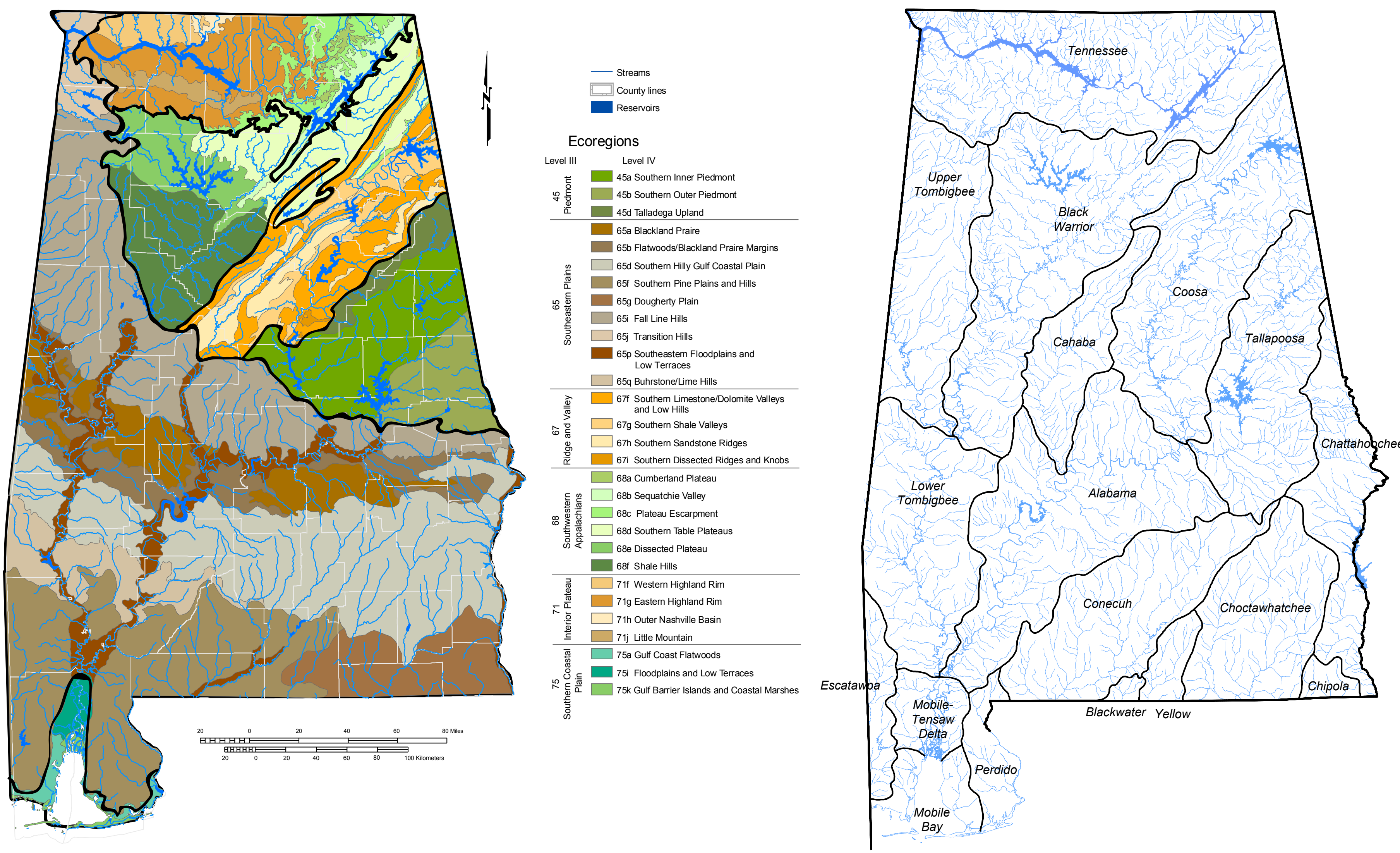

Figure 1. Ecoregions and river systems in Alabama.

Task 2 - Relationships within fish community data should be explored using cluster analysis to identify regions of similar faunal composition and relate to these regions to unique combinations of landscape features such as ecoregions and drainages.

Task 3 - Ichthyoregions should be delineated using results of the analyses in combination with best professional judgment to yield reasonably consistent geographical regions containing a homogeneous fish fauna suitable for IBI criteria development. These preliminary ichthyoregions should be zoogeographically consistent with known distributions of fishes, have fish communities that are similar in both species composition and ecological function, and be similar geographically reflecting similar geologic and hydrologic characteristics.

A database of 855 samples, compatible for use with the IBI and containing records for 229 species, was compiled from existing institutional fish collection records. These data were found in collections or graduate research studies from the GSA, Auburn University Museum (AUM), ADEM, ADCNR, Florida Museum of Natural History, Troy State University (Morris, 2002), Tulane University, the University of Alabama Ichthyological Collection (UAIC), and personal collection data of J. Malcolm Pierson (JMP). Data were initially compiled into individual drainage spreadsheets with species as rows, collections as columns, and number of individuals of a particular species in a collection as cell entries. These drainage spreadsheets were later combined into a master spreadsheet of all species and collections. Each collection location was georeferenced and its level IV ecoregion determined through application of GIS software.

All statistical analyses, including multivariate techniques, were conducted with SYSTAT software. Spreadsheet data were transposed with collections (cases) as rows and species (variables) as columns, imported to SYSTAT, and, because the abundance data generally varied by orders of magnitude for some species, the spreadsheet cells were converted to a comparable basis by performing a standard deviation z-score transformation. A hierarchical clustering approach was selected, using an unweighted pair-group method in SYSTAT. Clusters were joined using average linkage, and distances were calculated using the Pearson metric.

RESULTS AND DISCUSSION

About 67 percent of the 855 samples in the database were from GSA files followed by samples from the UAIC (8.1 percent), AUM (5.6 percent), personal collections of J. Malcolm Pierson (4.7 percent), and ADEM (4.6 percent) (table 1). Samples were well distributed across the state representing all drainages and almost all level IV ecoregions (fig. 2). The number of samples within level IV ecoregions was approximately proportional to the number of samples predicted by relative ecoregion areas (table 2). Predicted number of samples was determined by multiplying ecoregion area, as a fraction of total area, times the total number of samples in the database (855). Table 2 also shows the distribution of actual and predicted number of samples relative to the broader level III ecoregions. Table 3 is a similar analysis for major river drainages in the state. These three comparisons demonstrate that samples were reasonably well stratified relative to level III and IV ecoregion areas and drainage areas in the state.

Cluster analysis was used to explore similarities of fish community composition between drainages and ecoregions. The average abundance of each species, for all samples, within a drainage or level IV ecoregion was used as input for the cluster analyses. A cluster analysis by major drainages in the state delineated three distinct regions: coastal drainages, the Mobile River basin, and the Tennessee River drainage (fig. 3). The coastal drainage region contained three unique clusters: the Escatawpa River, the Mobile-Tensaw-Perdido Rivers group, and the Blackwater/Yellow-Conecuh-Choctawhatchee-Chattahoochee River group. The Mobile River basin region contained two unique clusters; the Alabama-Tombigbee cluster and the Coosa-Black Warrior-Cahaba-Tallapoosa cluster. The Alabama-Tombigbee cluster occurs almost exclusively below the Fall Line, the Black Warrior-Coosa subcluster is predominantly above the Fall Line with limited area below, while the Tallapoosa-Cahaba subcluster is about split

Table 1. Institutions from which collection data were obtained.

Institution	Number of collections	Percent
Geological Survey of Alabama	573	67.02
Auburn University Museum	48	5.61
Alabama Department of Environmental Management	39	4.56
Wildlife and Freshwater Fisheries Division	2	0.23
Florida State Museum of Natural History	4	0.47
Troy University graduate thesis	47	5.5
Tulane University	33	3.86
University of Alabama Ichthyological Collection	69	8.07
Personal collections of J. Malcolm Pierson	40	4.68

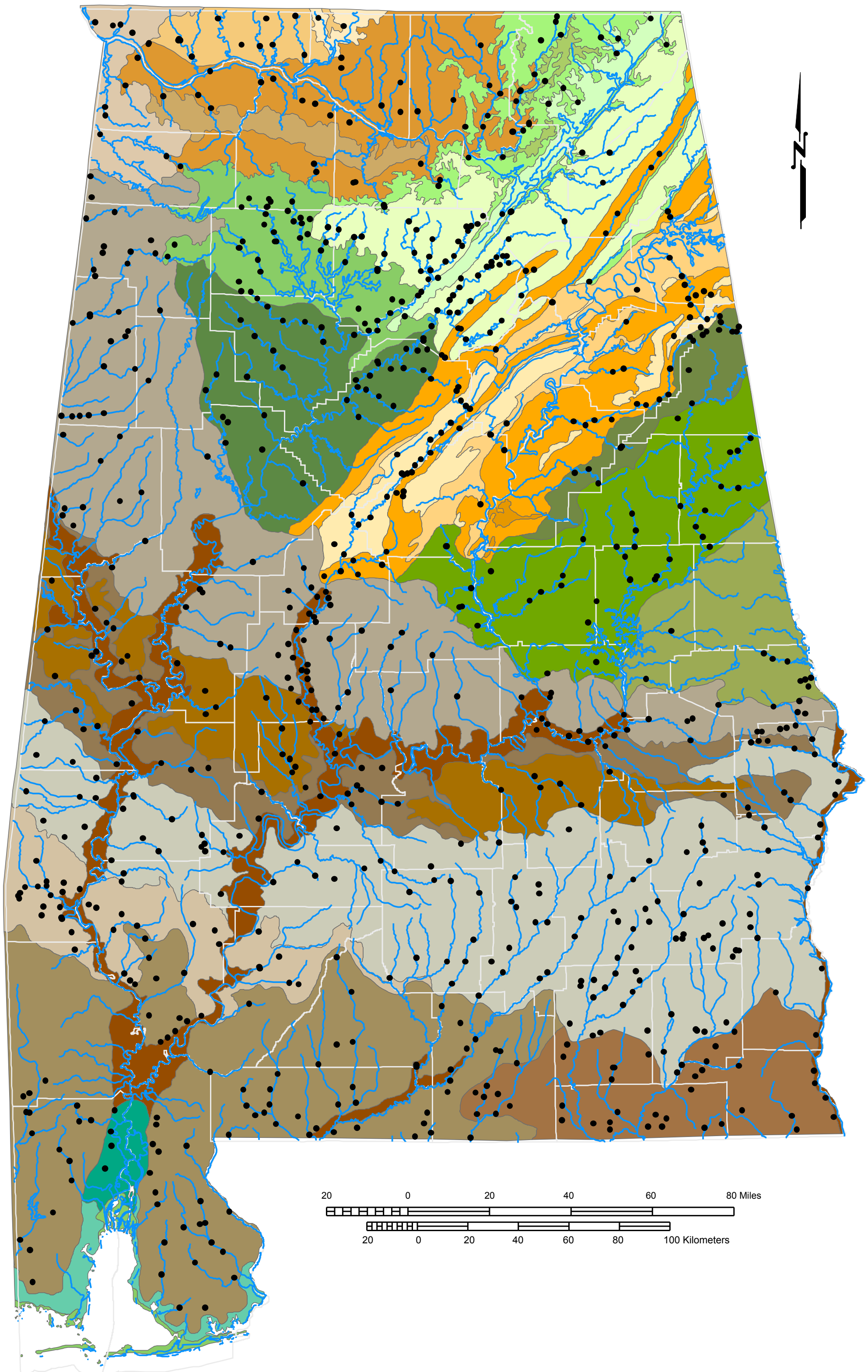

Figure 2. Sampling stations included in the database. See figure 1 for key to ecoregions

Table 2. Distribution of samples within ecoregions.

Ecoregion level IV	Area		Number of samples	
	Sq miles	Percent	Predicted	Actual
45a	2,818	5.45	47	37
45b	1,388	2.68	23	11
45d	624	1.21	10	15
65a	2,101	4.06	35	22
65b	1,951	3.77	32	42
65d	7,522	14.55	125	134
65f	5,992	11.59	100	88
65g	1,979	3.83	33	41
65i	6,558	12.68	108	82
65j	677	1.31	11	13
65p	2,468	4.77	41	36
65q	1,533	2.96	25	36
67f	2,427	4.69	40	52
67g	1,057	2.04	17	7
67h	955	1.85	16	23
67i	36	0.07	1	0
68a	104	0.20	2	0
68b	503	0.97	8	10
68c	1,076	2.08	18	10
68d	2,280	4.41	38	50
68e	1,407	2.72	23	48
68f	2,187	4.23	36	38
71f	504	0.97	8	11
71g	2,302	4.45	38	43
71h	110	0.21	2	3
71j	418	0.81	7	0
75a	324	0.63	5	0
75i	271	0.52	4	3
75k	143	0.28	2	0
Total	51,715		855	855

Ecoregion level III	Area		Number of samples	
	Sq miles	Percent	Predicted	Actual
45	4,830	9.34	80	63
65	30,780	59.52	509	494
67	4,473	8.65	74	82
68	7,556	14.61	125	156
71	3,336	6.45	55	57
75	740	1.43	12	3
Total	51,715		855	855

Table 3. Distribution of samples within river drainages.

River drainages	Area		Number of samples	
	Sq miles	Percent	Predicted	Actual
Tennessee River drainage	6,826	13.2	112	92
Apalachicola River basin				
Chattahoochee	2,573	4.98	42	47
Chipola	258	0.5	4	3
Coastal drainages				
Blackwater/Yellow	654	1.27	11	15
Perdido	670	1.29	11	11
Perdido Bay tributaries	171	0.33	3	1
Choctawhatchee	3,130	6.05	52	79
Conecuh	3,849	7.44	64	56
Miss Sound tributaries	119	0.23	2	0
Mobile River basin				
Coosa	5,400	10.44	89	76
Tallapoosa	4,022	7.78	67	44
Alabama	6,023	11.65	100	68
Cahaba	1,818	3.52	30	67
Black Warrior	6,288	12.16	104	148
Tombigbee	7,693	14.88	127	117
Mobile-Tensaw	962	1.86	16	17
Mobile Bay tributaries	491	0.95	8	4
Pascagoula River basin				
Escatawpa	767	1.48	13	10
Totals	51,715		855	855

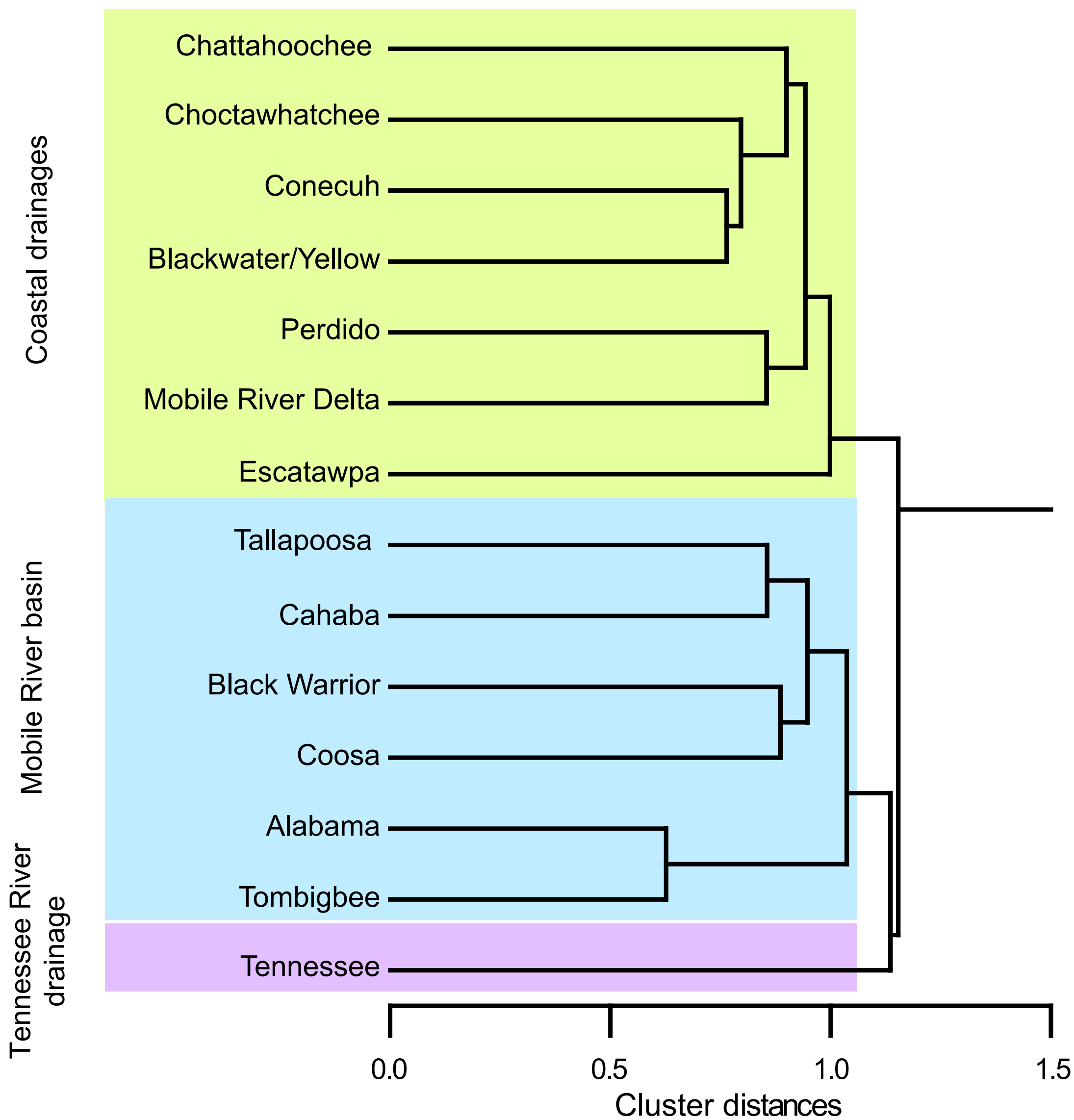

Figure 3. Hierarchical cluster analysis for major drainages in Alabama based on fish communities.

equally above and below the Fall line. The Tennessee cluster was unique to itself but was aligned most closely to the Mobile River basin region (fig. 3). This analysis highlights the fact that fish faunas in the state are not uniquely defined by or confined solely within drainage boundaries. For example, the Mobile River delta drainage (part of the Mobile River basin) clustered with drainages of the coastal group and was most similar to the Perdido River fauna. Although the structure of drainages in the state provides a convenient framework for delineating regions for IBI criteria development, they are poor predictors of regional fauna similarity.

Another drainage cluster analysis was performed but this time a different framework was imposed on the data. Major drainages were similarly used as in figure 3 but in addition, some were split into two parts, an above Fall Line “drainage” unit and a below Fall Line unit. For example, the Cahaba River is bisected by the Fall Line into two unique geographic units that are each faunally distinct. Each of these units was considered a unique drainage unit for the analysis. The addition of the Fall Line distinction into the dataset resulted in a cluster analysis that appears to better reflect faunal similarities within and between drainages. Four regions were identified (fig. 4) by the analysis: coastal drainages, Mobile River basin above the Fall Line, Mobile River basin below the Fall Line, and the Tennessee River drainage. The Tennessee drainage was again found to be a unique region unto itself. In the coastal region we observed a similar cluster pattern as in figure 3 but with the addition of a unique Chattahoochee cluster. The analysis identified two clusters in the Mobile River basin below the Fall Line region, a Cahaba-Tallapoosa group and an Alabama-Tombigbee-Black Warrior group. Two clusters were identified in the Mobile River basin above the Fall Line region, a Coosa-Cahaba-Black Warrior group and a Tallapoosa group. These results show that relationships between Alabama’s fish faunal regions are better defined when using both drainages and other geographical features such as the Fall Line.

Results in figures 3 and 4 demonstrate that other geographic controls beyond drainage boundaries are also important for determining the community structure and faunal composition of fish communities in the state. Within the Mobile River basin we see drainages, or parts of drainages, below the Fall Line grouping together in a unique cluster and the same for drainages, or parts of drainages, above the Fall Line (fig. 4). It

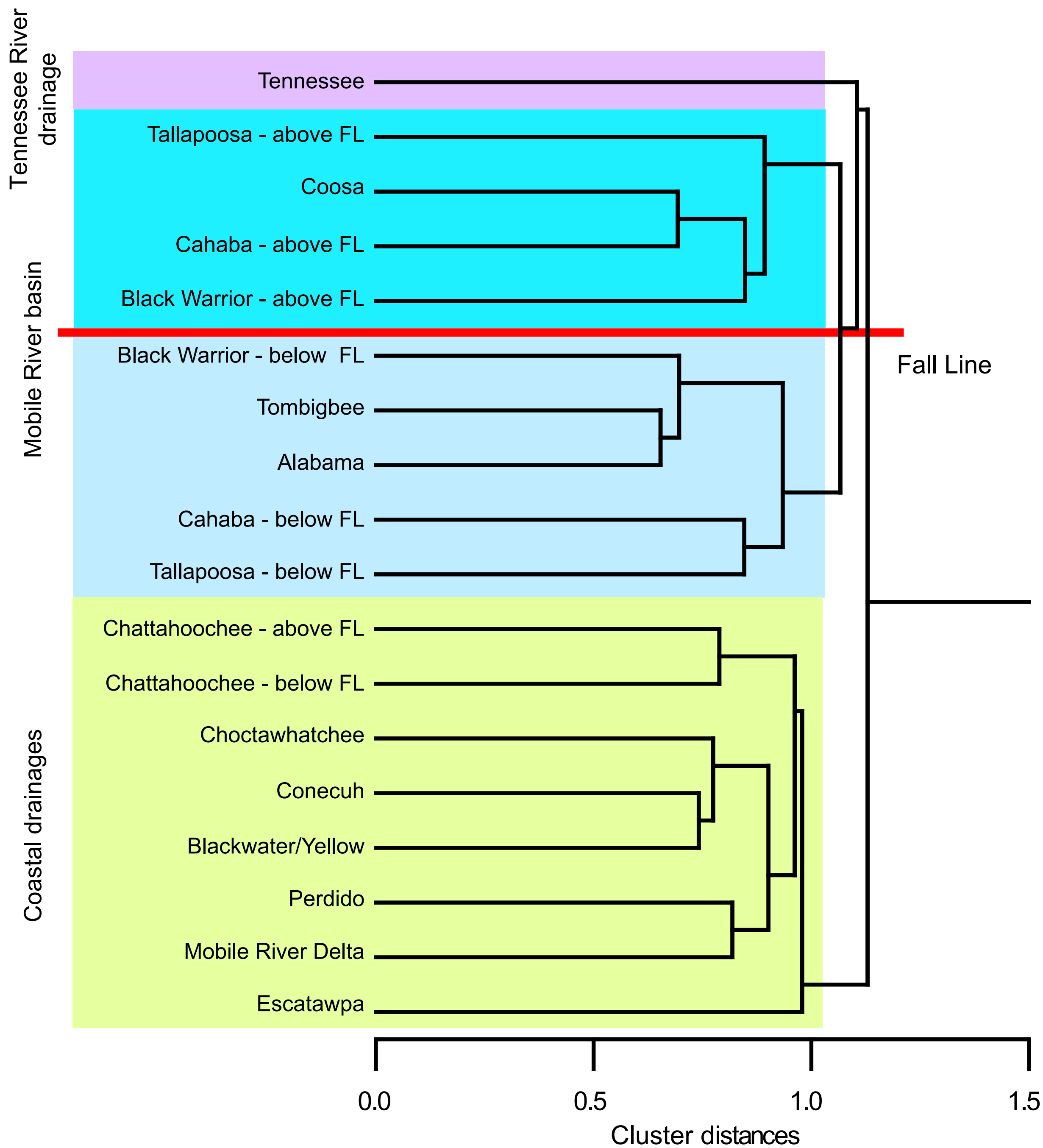

Figure 4. Hierarchical cluster analysis for major drainages in Alabama, including a Fall Line stratification, based on fish communities.

is difficult to determine the relative degree of influence of drainage versus other geographic factors in determining faunal similarity. In some instances drainages work well in defining a fauna (for example, Tennessee River drainage) while in other instances geographic features combined with drainages may play a larger role (for example, Mobile River basin above the Fall Line). Drainage boundaries considered exclusively appear to be an inadequate geographic framework for partitioning faunal variation particularly when other geographic features such as the Fall Line are considered.

By definition, ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources (Griffith and others, 2001). Ecoregions are delineated through the analysis of the spatial patterns and the composition of biotic and abiotic phenomena that reflect differences in ecosystem quality and integrity including geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Wiken, 1986; Omernik, 1987, 1995). In practice, the ecoregion concept as applied in Alabama has a strong geographic component, with ecoregion boundaries corresponding closely to physiographic regions (Sapp and Emplaincourt, 1975).

A final cluster analysis of ecoregions was undertaken to examine the ability of this geographic framework to define natural faunal groupings of fishes throughout the state. This analysis (fig. 5) resulted in a significant improvement of faunal clusters compared to either the strict drainage analysis or the drainage analysis coupled with the Fall Line distinctions. The analysis produced a classification with two major regions, one for ecoregions above the Fall Line (uplands) and one for ecoregions below the Fall Line (lowlands). The analysis further divided the upland region into three clusters while it divided the lowland region into two clusters (fig. 5). These five cluster groups form the basis of our ichthyoregion classification and illustrate the spatial relationships between level IV ecoregions, major drainages, and between combinations of drainages and ecoregions.

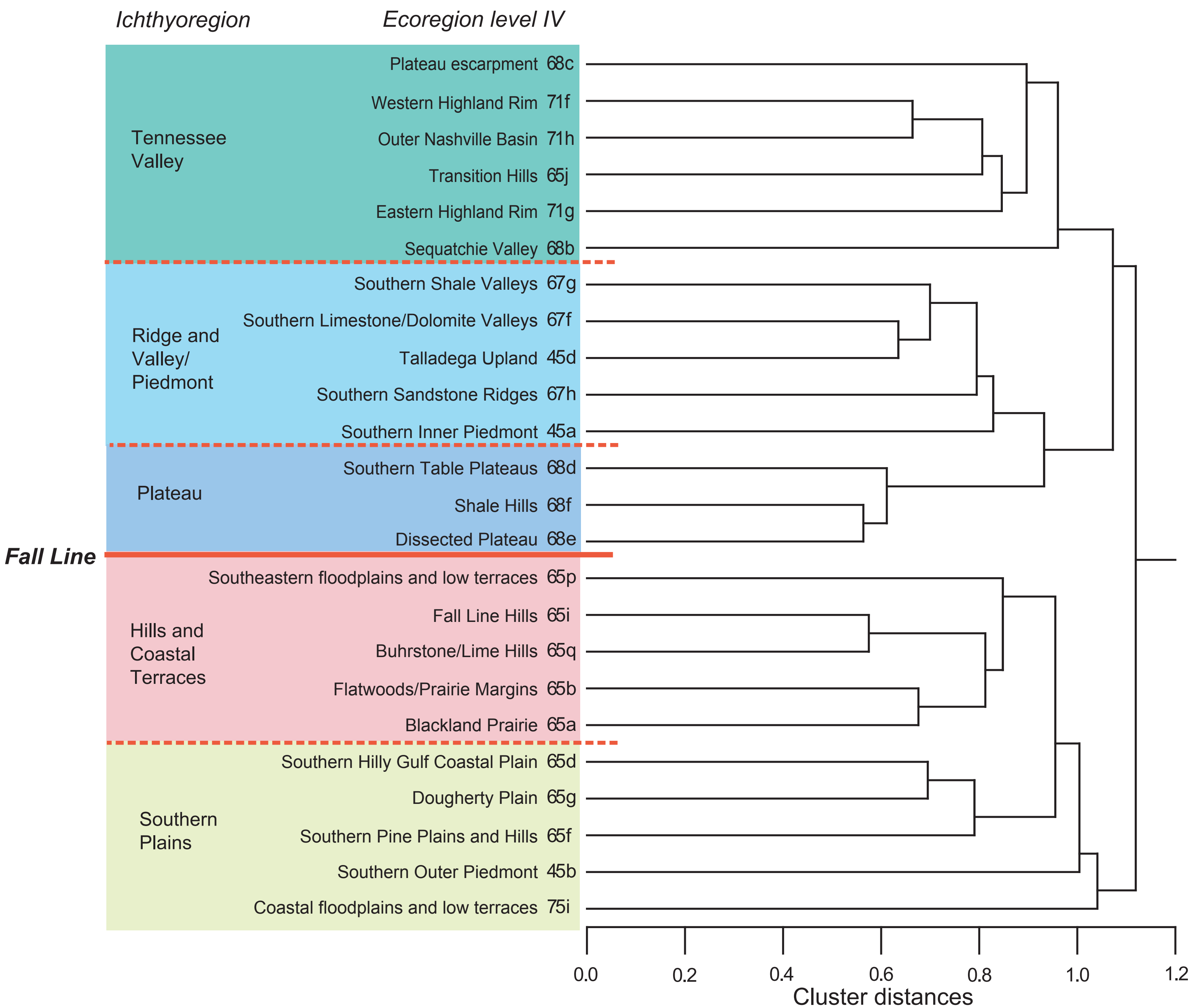

Figure 5. Hierarchical cluster analysis of level IV ecoregions based on fish communities.

ICHTHYOREGIONS

TENNESSEE VALLEY

The Tennessee Valley ichthyoregion includes most river and stream systems draining into the Tennessee River. It includes six level IV ecoregions (fig. 5): 65j-Transition Hills, 68b-Sequatchie Valley, 68c-Plateau Escarpment, 71f-Western Highland Rim, 71g-Eastern Highland Rim, and 71h-Outer Nashville Basin. Ecoregions 71f, 71g, 71h, and 65j in the western Tennessee River valley of Alabama form a cluster group, whereas ecoregions 68b and 68c each formed unique groups. Although ecoregion 65j is geographically below the Fall Line, the analysis clustered it with the other Tennessee Valley ecoregions, illustrating the strong drainage influence in this case. Stream systems in the eastern part of the Tennessee River drainage in Alabama are classified in the Southwestern Appalachians ecoregion (68) and, although resolved into the Tennessee Valley ichthyoregion, they are somewhat problematic for criteria development. The Paint Rock system (68c), because of its high fish biodiversity, is inconsistent with other Tennessee Valley stream systems and may require a special set of criteria. Streams in the Sequatchie Valley (68b) may also require separate IBI criteria because their biodiversity appears unusually low compared to other Tennessee Valley streams. Further work will be needed in these two ecoregions to determine if separate scoring criteria will be needed. Species highly likely to be encountered in relatively large numbers across the Tennessee Valley ichthyoregion include *Campostoma oligolepis, Luxilus chrysocephalus, Lythrurus fasciolaris, Lepomis macrochirus, Lepomis megalotis, Cottus carolinae, Etheostoma rufilineatum, Etheostoma duryi, Lepomis cyanellus, Lepomis auritus,* and *Hypentelium nigricans* (table 4).

RIDGE AND VALLEY/PIEDMONT

The Ridge and Valley/Piedmont ichthyoregion includes the Cahaba, Coosa, and most of the Tallapoosa River systems upstream of the Fall Line. It encompasses ecoregions 67f-Southern Limestone/Dolomite Valleys, 67g-Southern Shale Valleys, 67h-Southern Sandstone Ridges, 45a- Southern Inner Piedmont, and 45d-Talladega Upland. Two clusters were defined in this region (fig. 5). One cluster includes the Ridge and Valley ecoregions (67f, 67g, 67h) plus one ecoregion from the Piedmont (45d), and

Table 4. Relative abudance and encounter of core species in five Alabama ichthyoregions.

Tennessee Valley

Species	RA	E	RAxE
Campostoma oligolepis	0.2241	0.8636	0.1935
Luxilus chrysocephalus	0.0947	0.7500	0.0710
Lythrurus fasciolaris	0.0875	0.5682	0.0497
Lepomis macrochirus	0.0394	0.8750	0.0345
Lepomis megalotis	0.0285	0.8864	0.0252
Cottus carolinae	0.0331	0.7159	0.0237
Etheostoma rufilineatum	0.0548	0.3977	0.0218
Etheostoma duryi	0.0221	0.7614	0.0168
Lepomis cyanellus	0.0165	0.8182	0.0135
Lepomis auritus	0.0233	0.5455	0.0127
Hypentelium nigricans	0.0167	0.6818	0.0114
Percina caprodes	0.0130	0.6477	0.0084
Etheostoma tennesseensis	0.0208	0.3977	0.0083
Cyprinella spiloptera	0.0186	0.3750	0.0070
Etheostoma caeruleum	0.0165	0.4205	0.0069
Hybopsis amblops	0.0199	0.3409	0.0068
Gambusia affinis	0.0100	0.6364	0.0064
Notropis telescopus	0.0281	0.2159	0.0061
Fundulus olivaceus	0.0089	0.6477	0.0058
Etheostoma flabellare	0.0196	0.2386	0.0047
Pimephales notatus	0.0106	0.4091	0.0043
Cyprinella galactura	0.0183	0.1932	0.0035
Micropterus salmoides	0.0051	0.6591	0.0033
Moxostoma erythrurum	0.0069	0.4432	0.0030
Etheostoma blennoides	0.0075	0.3409	0.0025
Clinostomus funduloides	0.0128	0.1591	0.0020
Lepomis microlophus	0.0046	0.4318	0.0020
Rhinichthys atratulus	0.0106	0.1818	0.0019
Ambloplites rupestris	0.0039	0.3977	0.0016
Semotilus atromaculatus	0.0041	0.3068	0.0013
Moxostoma duquesnei	0.0043	0.2727	0.0012
Fundulus catenatus	0.0049	0.2386	0.0012
Notropis boops	0.0097	0.1136	0.0011
Etheostoma nigripinne	0.0033	0.3295	0.0011
Lepomis gulosus	0.0026	0.3977	0.0010
Hemitremia flammea	0.0063	0.1591	0.0010

Plateau

Species	RA	E	RAxE
Campostoma oligolepis	0.1699	0.8750	0.1486
Notropis stilbius	0.1589	0.6618	0.1052
Cyprinella venusta	0.1184	0.7353	0.0870
Percina nigrofasciata	0.0772	0.7868	0.0608
Cyprinella callistia	0.0791	0.5147	0.0407
Lepomis macrochirus	0.0388	0.7279	0.0282
Lepomis megalotis	0.0321	0.7868	0.0252
Lepomis cyanellus	0.0203	0.5735	0.0116
Notropis asperifrons	0.0282	0.2794	0.0079
Luxilus chrysocephalus	0.0260	0.3015	0.0078
Micropterus punctulatus	0.0145	0.5221	0.0075
Etheostoma artesiae	0.0168	0.4412	0.0074
Pimephales vigilax	0.0353	0.1912	0.0068
Hypentelium etowanum	0.0100	0.5147	0.0052
Etheostoma stigmaeum	0.0155	0.3235	0.0050
Fundulus olivaceus	0.0114	0.4118	0.0047
Etheostoma douglasi	0.0183	0.2279	0.0042
Percina kathae	0.0092	0.4412	0.0041
Lythrurus bellus	0.0133	0.2426	0.0032
Cyprinella whipplei	0.0263	0.0735	0.0019
Moxostoma poecilurum	0.0063	0.2868	0.0018
Lepomis auritus	0.0088	0.1176	0.0010

Ridge and Valley/Piedmont

Species	RA	E	RAxE
Campostoma oligolepis	0.1811	0.9462	0.1713
Cyprinella callistia	0.0790	0.7154	0.0565
Cottus carolinae	0.0750	0.5462	0.0410
Cyprinella trichroistia	0.0811	0.4692	0.0381
Hypentelium etowanum	0.0425	0.8538	0.0363
Lepomis megalotis	0.0328	0.7308	0.0240
Lepomis macrochirus	0.0304	0.7769	0.0236
Percina nigrofasciata	0.0313	0.7154	0.0224
Notropis stilbius	0.0361	0.5692	0.0206
Etheostoma jordani	0.0458	0.4308	0.0197
Lepomis auritus	0.0266	0.5308	0.0141
Lepomis cyanellus	0.0190	0.6308	0.0120
Luxilus chrysocephalus	0.0262	0.4231	0.0111
Percina palmaris	0.0210	0.4000	0.0084
Cyprinella venusta	0.0155	0.5077	0.0079
Etheostoma stigmaeum	0.0126	0.6154	0.0078
Micropterus coosae	0.0108	0.6538	0.0071
Notropis xaenocephalus	0.0256	0.2385	0.0061
Cyprinella gibbsi	0.0267	0.1692	0.0045
Etheostoma coosae	0.0128	0.3154	0.0040
Gambusia affinis	0.0111	0.3077	0.0034
Notropis chrosomus	0.0161	0.1538	0.0025
Phenacobius catostomus	0.0071	0.3231	0.0023
Fundulus olivaceus	0.0068	0.3308	0.0022
Noturus leptacanthus	0.0080	0.2308	0.0018
Semotilus atromaculatus	0.0089	0.2000	0.0018
Percina kathae	0.0042	0.4077	0.0017
Micropterus punctulatus	0.0041	0.3923	0.0016
Moxostoma duquesnei	0.0044	0.3308	0.0014
Notropis asperifrons	0.0082	0.1385	0.0011

RA - Relative abundance.

E - Encounter, proportion of samples in which a species was found.

Table 4. Relative abudance and encounter of core species in five Alabama ichthyoregions.

Hills and Coastal Terraces			
Species	RA	E	RAxE
Cyprinella venusta	0.1212	0.6759	0.0820
Notropis baileyi	0.1137	0.5556	0.0632
Lythrurus bellus	0.0702	0.7315	0.0514
Notropis ammophilus	0.0750	0.5602	0.0420
Notropis texanus	0.0465	0.5926	0.0275
Lepomis megalotis	0.0320	0.8241	0.0263
Luxilus chrysocephalus	0.0440	0.5972	0.0262
Percina nigrofasciata	0.0307	0.7130	0.0219
Pimephales notatus	0.0456	0.3657	0.0167
Fundulus olivaceus	0.0192	0.7361	0.0141
Gambusia affinis	0.0323	0.4213	0.0136
Etheostoma stigmaeum	0.0199	0.4861	0.0097
Lepomis macrochirus	0.0149	0.6019	0.0090
Campostoma oligolepis	0.0202	0.4352	0.0088
Notropis amplamala	0.0147	0.4074	0.0060
Nocomis leptacanthus	0.0136	0.4213	0.0057
Pimephales vigilax	0.0229	0.2269	0.0052
Etheostoma rupestre	0.0187	0.2731	0.0051
Noturus leptacanthus	0.0088	0.4722	0.0042
Etheostoma lachneri	0.0136	0.3009	0.0041
Notropis volucellus	0.0163	0.1620	0.0026
Lepomis cyanellus	0.0047	0.3657	0.0017
Hybognathus nuchalis	0.0101	0.1435	0.0014
Etheostoma artesiae	0.0052	0.2685	0.0014
Micropterus salmoides	0.0034	0.3843	0.0013
Etheostoma nigrum	0.0047	0.2731	0.0013
Etheostoma ramseyi	0.0069	0.1852	0.0013
Semotilus atromaculatus	0.0058	0.2037	0.0012
Notropis uranoscopus	0.0150	0.0648	0.0010

Southern Plains			
Species	RA	E	RAxE
Notropis texanus	0.0857	0.6630	0.0569
Cyprinella venusta	0.0998	0.5616	0.0561
Percina nigrofasciata	0.0607	0.7754	0.0471
Notropis longirostris	0.0633	0.3478	0.0220
Notropis amplamala	0.0403	0.5362	0.0216
Fundulus olivaceus	0.0240	0.6848	0.0164
Notropis baileyi	0.0744	0.1703	0.0127
Lythrurus atrapiculus	0.0397	0.3043	0.0121
Lepomis megalotis	0.0209	0.5254	0.0110
Lepomis macrochirus	0.0185	0.5616	0.0104
Pteronotropis hypselopterus	0.0290	0.2283	0.0066
Gambusia holbrooki	0.0184	0.3442	0.0063
Lythrurus bellus	0.0354	0.1594	0.0056
Noturus leptacanthus	0.0108	0.4928	0.0053
Lepomis miniatus	0.0107	0.4420	0.0047
Notropis ammophilus	0.0295	0.1522	0.0045
Pimephales notatus	0.0205	0.1522	0.0031
Hybopsis sp cf winchelli	0.0140	0.2174	0.0031
Etheostoma colorosum	0.0128	0.2174	0.0028
Aphredoderus sayanus	0.0070	0.3696	0.0026
Luxilus chrysocephalus	0.0116	0.1848	0.0021
Lythrurus roseipinnis	0.0232	0.0797	0.0018
Esox americanus	0.0050	0.3514	0.0018
Pteronotropis signipinnis	0.0165	0.1014	0.0017
Etheostoma swaini	0.0059	0.2645	0.0015
Lepomis gulosus	0.0047	0.2754	0.0013
Nocomis leptacanthus	0.0082	0.1413	0.0012
Semotilus thoreauianus	0.0076	0.1486	0.0011
Etheostoma stigmaeum	0.0069	0.1413	0.0010

RA - Relative abundance.
E - Encounter, proportion of samples in which a species was found.

encompasses streams principally in the Coosa and Cahaba River systems. The other cluster is an exclusive Piedmont ecoregion (45a) and includes streams in the Tallapoosa River system plus a few lower Coosa River tributaries. The fish communities throughout this ichthyoregion have a similar species composition, and streams in this ichthyoregion have similar hydrologic patterns, habitat structure, and bottom substrates of carbonate and metamorphic rocks. Although ecoregion 45b, Southern Outer Piedmont, clustered with the Southern Plains ichthyoregion, we have at this time included it as part of the Ridge and Valley/Piedmont ichthyoregion. This was done based on similarities in habitat structure and hydrologic characteristics between ecoregion 45b and the other Ridge and Valley/Piedmont streams. Ecoregion 45b is drained principally by Chattahoochee River tributaries above the Fall Line. It may ultimately be determined that it does need to be included as part of the Southern Plains ichthyoregion but, until further work is completed, we think that the Fall Line is a significant barrier to fish dispersal and that 45b should be classified in the Ridge and Valley/Piedmont ichthyoregion, or perhaps a subpart with different IBI scoring criteria. Species likely to be encountered in high numbers in the Ridge and Valley/Piedmont ichthyoregion include *Campostoma oligolepis, Cyprinella callistia, Cottus carolinae, Cyprinella trichroistia, Hypentelium etowanum, Lepomis megalotis, Lepomis macrochirus, Percina nigrofasciata, Notropis stilbius, Etheostoma jordani, Lepomis auritus, Lepomis cyanellus,* and *Luxilus chrysocephalus* (table 4).

PLATEAU

The Plateau ichthyoregion encompasses all of the Black Warrior River drainage upstream of the Fall Line (ecoregions 68e-Dissected Plateaus, 68f-Shale Hills, and 68d-Southern Table Plateaus) and parts of the Tennessee River drainage in ecoregion 68d. Separate IBI scoring criteria may be required for ecoregion 68d because it includes streams from both the Mobile River basin and Tennessee River drainage. Species likely to be encountered in high numbers include *Campostoma oligolepis, Notropis stilbius, Cyprinella venusta, Percina nigrofasciata, Cyprinella callistia, Lepomis macrochirus, Lepomis megalotis,* and *Lepomis cyanellus* (table 4).

HILLS AND COASTAL TERRACES

This ichthyoregion is comprised of two separated areas in the Coastal Plain below the Fall Line and includes streams principally in the Mobile River basin in ecoregions 65a- Blackland Prairie, 65b- Flatwoods and Prairie Margins, 65q- Buhrstone Hills and Lime Hills, 65i- Fall Line Hills, and 65p- Southeastern floodplains and low terraces (fig. 5). Two clusters were identified in this ichthyoregion. One includes streams in the Blackland Prairies and Flatwoods (65a, 65b) noted for their low flow sustainability during dry periods, and the other cluster includes streams in the Fall Line Hills and Lime Hills (65i, 65q) which are known for their very hilly and sometimes rugged topography. Species likely to be encountered in high numbers include *Cyprinella venusta, Notropis baileyi, Lythrurus bellus, Notropis ammophilus, Notropis texanus, Lepomis megalotis, Luxilus chrysocephalus, Percina nigrofasciata, Pimephales notatus, Fundulus olivaceus,* and *Gambusia affinis* (table 4).

SOUTHERN PLAINS

The Southern Plains ichthyoregion is large and comprises a combination of stream systems in the lower Mobile River basin including the lower Tombigbee and Alabama River systems (excluding those occurring in the Hills and Coastal Terraces ichthyoregion), streams of the Mobile-Tensaw River Delta, and streams draining directly into Mobile Bay. It also includes all coastal river systems in Alabama: the Escatawpa, Perdido, Escambia-Conecuh, Blackwater, Yellow, Choctawhatchee-Pea, Chipola, and Chattahoochee. Ecoregions included in this ichthyoregion were 65d- Southern Hilly Gulf Coastal Plain, 65g- Dougherty Plain, 65f- Southern Pine Plains and Hills, and 75i- Coastal floodplains and low terraces (fig. 5). This is a large ichthyoregion with streams of similar hydrologic patterns and habitat structure. Streams draining the low coastal terraces in Mobile and Baldwin Counties will require further study and may require unique scoring criteria. Species likely to be encountered in high numbers include *Notropis texanus, Cyprinella venusta, Percina nigrofasciata, Notropis longirostris, Notropis amplamata, Fundulus olivaceus, Notropis baileyi, Lythrurus atrapiculus, Lepomis megalotis,* and *Lepomis macrochirus* (table 4).

EVALUATION OF 30+2 SAMPLING METHOD IN THE ALABAMA COASTAL PLAIN

The GSA 30+2 sampling protocol (O’Neil and others, 2006) was developed using samples collected in upland streams of the Coosa and Tallapoosa Rivers. Upland streams generally have a full suite of basic habitat types: riffles, runs, pools, and shorelines. Lowland streams below the Fall Line typically have pools, runs (or glides), and shoreline but often lack rocky riffles as found in upland streams. Debris snags and glide pools may dominate some of these habitats and in some ecoregions (65a, 65b, and 65q) bedrock may be exposed and true rocky riffle habitat may be present. We were interested in further evaluation of the 30+2 method in Alabama Coastal Plain streams to determine if the method was sufficient for collecting a sample suitable for IBI analysis.

Twelve stream stations were sampled in the Alabama Coastal Plain (fig. 6) that represented a variety of watershed sizes (9.9 mi^2 to 277 mi^2 in area) with varying levels of human disturbance. Stations were collected so that 10 sampling efforts were completed in each habitat zone (10 riffle efforts, 10 run efforts, and 10 pool efforts), in addition to two shoreline efforts for a total of 32 efforts based on the 30+2 sampling recommendations in O’Neil and others (2006). If rocky riffles were not present, then the 10 efforts assigned to riffles were allotted to extra pools and(or) runs. Species data were hand recorded on paper and later transferred to spreadsheets in the office. The basic data file for each station consisted of abundance counts for each species collected in each effort for each habitat zone. For analytical purposes, the first sampling unit was created by combining two shoreline efforts with one pool, one riffle, and one run effort randomly selected from the basic data file. Another pool, riffle, and run effort was then selected randomly and added to sampling unit 1 to create sampling unit 2. Each sequential sampling unit represented the cumulative total of all previous units plus the addition of one randomly selected pool, run, and riffle effort. This procedure was repeated until 10 sampling units had been created, depleting all sampling efforts in the basic data file. This random resampling process without replacement was replicated 15 times to create a dataset sufficient in size to evaluate sampling effort statistically.

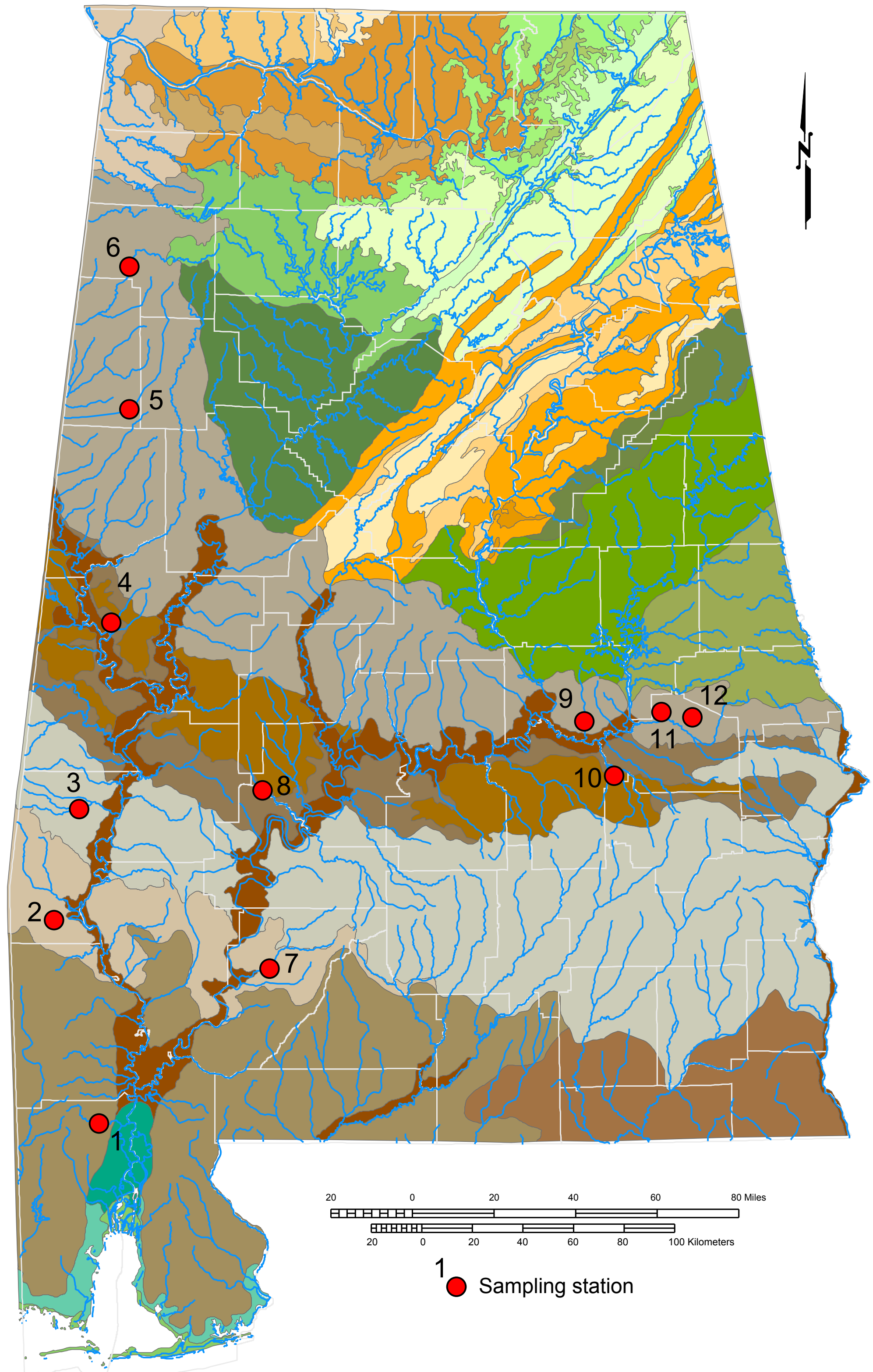

Figure 6. Stations for sampling method evaluation in Alabama's Coastal Plain.

The resulting data were evaluated to determine the number of sampling units required for the metric value versus sampling unit curves to reach a critical asymptote. Metric values at 10 sampling units were assumed to be representative of the true population condition in the sampled stream reach. This population value was represented as the metric value at 10 sampling units +/- 5 percent of this value. For example, if the cumulative number of species equaled 30 at 10 sampling units, then the population value for the metric falls in the range 28.5 to 31.5 (30 +/- [.05x30]). These two end points are the critical asymptotes for a metric at a particular station. The number of sampling units needed for two standard errors (SE) of the metric mean value to reach this critical asymptote was determined for the 12 sampling stations (table 5).

The sampling depletion data in table 5 were further evaluated by calculating the mean and 95 percent confidence interval for several metrics and the IBI and comparing these values to similar measures calculated for upland stream samples (fig. 7) from an earlier study (O'Neil and others, 2006). In general, lowland streams required fewer efforts per habitat compared to upland streams. For some metrics (percent insectivorous cyprinids, percent sunfish, total species, catch and the IBI) lowland streams required significantly less sampling effort than upland streams. The remaining metrics (percent omnivores, percent top carnivores, number of darter species, number of minnow species, number of sucker species, and number of sunfish species) were not significantly different, but metric means of lowland streams were always less than upland streams.

From this analysis we can conclude that the 30+2 sampling protocol is generally sufficient to collect a sample in Coastal Plain streams adequate for IBI calculation. These results likely relate to the fact that lowland streams generally lacked riffle habitat and the additional pool and run efforts were substituted for riffle efforts into the analysis. As such, lowland streams, at least statistically, required less effort to reach an asymptote for any given metric. It is tempting to adopt a protocol that requires less sampling for lowland streams given this result, but we still recommend that the 30+2 method be applied in lowland as well as upland streams. Most lowland streams do not have rock riffles, but the majority do have some form of snag-type habitat that can mimic the structure of riffles. As such, we suggest that it is more prudent to oversample

Table 5. Number of sampling units required for metric value to reach asymptote.

Station	Station no.	Area mi²	IBI metrics [1] Percent InsCyp	Percent Omni	Percent TopCarn	Percent Sun	Number DarSp	Number MinSp	Number SukSp	Number SunSp	Total Species	Catch	IBI
Bassetts Creek	1	136	3	1	2	8	6	3	1	4	7	5	1
Souwilpa Creek	2	38.9	2	4	6	4	5	7	7	6	7	1	1
Tuckabum Creek	3	115	1	4	10	9	6	4	6	7	7	3	1
Trussels Ctreek	4	69	5	4	1	9	3	4	4	1	5	2	3
Luxapallila Creek	5	205	2	1	7	7	4	4	5	6	7	1	1
Buttahatchee River	6	277	3	1	7	4	7	7	1	1	7	1	1
Big Flat Creek	7	247	3	2	1	9	8	7	6	1	7	1	7
Chilatchee Creek	8	90	2	3	5	6	3	6	4	5	7	1	1
Chubbehatchee Creek	9	61.6	7	2	7	8	1	6	8	1	7	8	1
Line Creek	10	75	3	3	9	9	5	6	1	1	7	3	1
Wauxamaca Creek	11	9.9	4	2	7	8	8	2	1	1	2	6	1
Choctafaula Creek	12	55.6	4	4	9	8	4	5	1	1	6	5	1
Mean			3.25	2.58	5.92	7.42	5.00	5.08	3.75	2.92	6.33	3.08	1.67
Sample size			12	12	12	12	12	12	12	12	12	12	12
Standard deviation			1.6026	1.2401	3.0883	1.8320	2.1320	1.6765	2.6671	2.4664	1.4975	2.3916	1.7753
Standard error			0.4626	0.3580	0.8915	0.5288	0.6155	0.4840	0.7699	0.7120	0.4323	0.6904	0.5125
95% Confidence Interval			2.3433	1.8817	4.1693	6.3801	3.7937	4.1348	2.2409	1.5211	5.4861	1.7302	0.6622
			4.1567	3.2850	7.6641	8.4532	6.2063	6.0319	5.2591	4.3122	7.1806	4.4365	2.6711

[1] - InsCyp-insectivorous cyprinids, Omni-omnivores, TopCarn-top carnivores,Sun-sunfish, DarSp-darter species, MinSp-minnow speci
SukSp-sucker species, SunSp=sunfish species

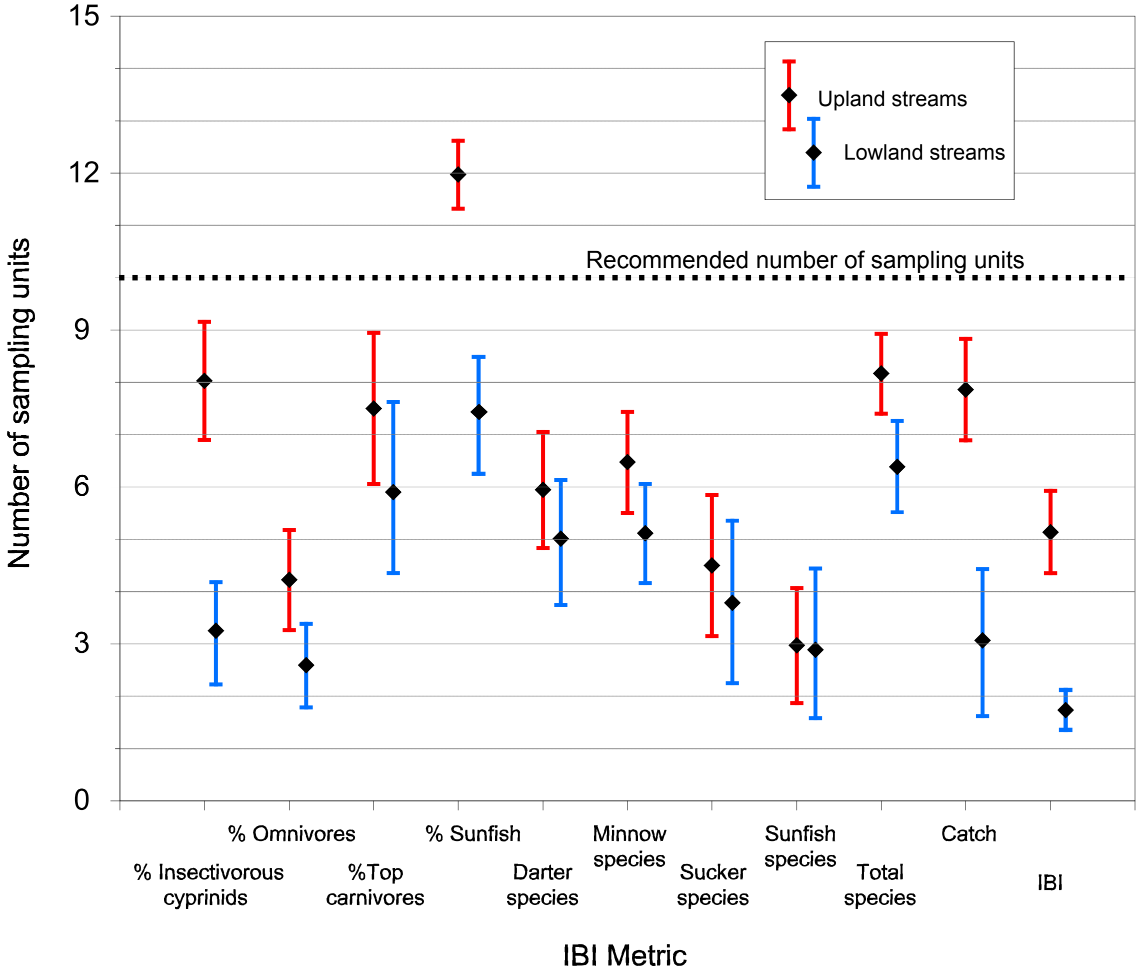

Figure 7. Comparison of sampling depletion results between lowland and upland streams for selected IBI metrics.

rather than undersample and risk not representing biodiversity adequately and incorrectly estimating trophic structure proportions that do not reflect true fish community structure. These errors will result in an unrepresentative IBI score.

CONCLUSIONS

The work plan for 2007-08 includes three tasks. The first task will be to initiate work on developing the field data logging protocol. A tablet computer has been purchased and the Tennessee Valley Authority has agreed to provide a copy of their data entry software. This program will require modification for the GSA 30+2 sampling protocol and to the IBI metrics and criteria for Alabama streams. The second task will be to initiate IBI sampling in Gulf slope drainages. Sampling will be conducted jointly with ADCNR and ADEM personnel for the purpose of collecting samples to be used in developing IBI scoring criteria appropriate for these streams. The Tennessee River drainage was originally scheduled for this year but due to the extended drought conditions in the Tennessee Valley ADEM personnel decided to move the sampling effort to Alabama's Gulf slope drainages. For the third task we will begin to evaluate methods for sampling unwadeable rivers and lakes and ways to adapt the IBI to these aquatic conditions.

REFERENCES CITED

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1997, Revision to rapid bioassessment protocols for use in streams and rivers: U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, D.C., EPA 841-D-97-002.

Boschung, H.T., and Mayden, R.M., 2004, Fishes of Alabama: Washington, Smithsonian Books, 736 p.

Compton, M.C., Pond, G.J., and Brumley, J.F., 2003, Development and application of the Kentucky Index of Biotic Integrity (KIBI): Frankfort, Kentucky, Kentucky Department for Environmental Protection, Division of Water, 45 p.

Griffith, G.E., Omernik, J.M., Comstock, J.A., Lawrence, S., Martin, G., Goddard, A., Hulcher, V.J., and Foster, T., 2001, Ecoregions of Alabama and Georgia, (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,700,000).

Karr, J.R., and Dudley, D.R., 1981, Ecological perspectives on water-quality goals: Environmental Management, v. 5, p. 55-68.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., and Schlosser, I.J., 1986, Assessing biological integrity in running waters: a method and its rationale: Illinois Natural History Survey Special Publication 5, 28 p.

Mettee, M.F., O'Neil, P.E., and Pierson, J.M., 1996, Fishes of Alabama and the Mobile Basin: Birmingham, Alabama, Oxmoor House, Inc., 820 p.

Morris, C.C., 2002, Development of watershed indicators and status of wadeable streams in the Alabama portion of the Choctawhatchee-Pea River watershed using fish communities: Troy, Alabama, Troy State University, unpublished MS. thesis, 32 p.

Omernik, J.M., 1987, Ecoregions of the conterminous United States (map supplement): Annals of the Association of American Geographers, v. 101, no. 1, p. 118-125.

Omernik, J.M., 1995, Ecoregions - a framework for environmental management, *in* Davis, W.S., and Simon, T.P., eds., Biological assessment and criteria-tools for water resource planning and decision making: Boca Raton, Florida, Lewis Publishers, p. 49-62.

O'Neil, P.E., 2002, A biological assessment of selected sites in the Cahaba River system, Alabama: Alabama Geological Survey contract report to the U.S. Environmental Protection Agency, Atlanta, Georgia,Contract no. 2R-0117-NAGF, 48 p.

O'Neil, P.E., and Shepard, T.E., 2000, Application of the Index of Biotic Integrity for assessing biological condition of wadeable streams in the Black Warrior River system, Alabama: Alabama Geological Survey Bulletin 169, 71 p.

O'Neil, P.E., and Shepard, T.E., 2004, Hatchet Creek regional reference watershed study: Alabama Geological Survey Open-File Report 0509, 48 p.

O'Neil, P.E., Shepard, T.E., and Cook, M.R., 2006, Habitat and biological assessment of the Terrapin Creek watershed and development of the Index of Biotic Integrity for the Coosa and Tallapoosa River systems: Alabama Geological Survey Open-File Report 0601, 210 p.

Plafkin, J.L., Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M., 1989, Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish: Washington, D.C., U.S. Environmental Protection Agency, Office of Water Regulations and Standards, EPA 440-4-89-001.

Sapp, C.D., and Emplaincourt, J., 1975, Physiographic regions of Alabama: Alabama Geological Survey Special Map 168.

Shepard, T.E., O'Neil, P.E., McGregor, S.W., and Henderson, W.P., 2002, Biomonitoring in the Mulberry Fork watershed, 1999-2001: Alabama Geological Survey contract report to Alabama Department of Conservation and Natural Resources, 60 p.

Shepard, T.E., O'Neil, P.E., McGregor, S.W., Mettee, M.F., and Harris, S.C., 1997, Biomonitoring and water-quality studies in the upper Cahaba River drainage of Alabama, 1989-94: Alabama Geological Survey Bulletin 165, 255 p.

Shepard, T.E., O'Neil, P.E., McGregor, S.W., and Mettee, M.F., 2004, Biomonitoring in the Locust Fork watershed, Alabama: Alabama Geological Survey Bulletin 175, 61 p.

U.S. Environmental Protection Agency, 2005, Use of biological information to better define designated aquatic life uses in state and tribal water quality standards: Tiered Aquatic Life Uses (DRAFT): U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, EPA - 822-R-05-001, 188 p.

Wiken, E., 1986, Terrestrial ecozones of Canada: Ottawa, Environment Canada, Ecological Land Classification Series no. 19, 26 p.

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