ACT Aquatic Gap and water quality monitoring

Final Report

Prepared by:

Elise Irwin[1], Gareth Turner[2], Katie Mickett,[2] and Taconya Piper[2]

[1]USGS, Alabama Cooperative Fish and Wildlife Research Unit, 108 M. White Smith Hall, Auburn University, Alabama, irwiner@.auburn.edu

[2]Alabama Cooperative Fish and Wildlife Research Unit

Prepared for:

Mr. Jim McHugh
Alabama Department of Conservation and Natural Resources
Division of Wildlife and Freshwater Fisheries
Montgomery, Alabama

March 2007

TABLE OF CONTENTS

INTRODUCTION

The Southeastern Aquatic GAP project was initiated to identify conservation areas in river basins where aquatic biodiversity and endemism are higher than other temperate rivers. As part of a regional assessment of the ACT/ACF basins, we have developed techniques to incorporate geospatial data to analyze aquatic species distribution in relation to local and landscape features and identify conservation potential of specific subwatersheds. Three portions of the ACT/ACF (Upper Coosa and Tallapoosa, and Flint basins) were completed under contract with U.S. Geological Survey; these projects were instrumental in development of methodologies which have proved effective for model construction (Peterson et al. 2003a; Turner et al. 2004; Irwin et al. 2004). Faunal groups that have been modeled include fishes, mussels, snails and crayfishes. This report incorporates models developed for the remainder of the ACT basin. The primary purpose of the project was to create databases and maps of aquatic species distributions in portions of the Alabama-Coosa-Tallapoosa (ACT) River Basins by developing predictive models relating species distribution to local and landscape-level features.

The ACT basin spans broad ranges of physiographic settings and harbors exceptionally high levels of species richness and endemism, providing ideal opportunities for testing and refining approaches to predict species occurrences and community attributes in relation to physical variables. The ACT basin (58,708 km^2) originates in the Blue Ridge province of the Southern Appalachian Mountains in Georgia and Tennessee, drains extensive portions of the Valley and Ridge and Piedmont provinces in west Georgia and east Alabama, and of the Coastal Plan in lower Alabama. Physiographic and climatic diversity, with a geologic history of isolation punctuated by interbasin dispersal, and protection from Pleistocene glaciation, have fostered development in the ACT of the some of the highest levels of aquatic faunal diversity and endemism recorded in temperate freshwaters. At least 203 freshwater, diadromous, and marine invading fishes occur natively in the ACT (Warren et al. 2000; Freeman et al. 2005). The Coosa River system alone contains at least 15 endemic fishes as well as remnants of an exceptionally diverse molluscan fauna (Bogan et al. 1995; Burkhead et al. 1997 Neves et al. 1997).

The need for an Aquatic GAP application in these river systems is no less than urgent. Ten ACT fishes are Federally listed and an additional 29 fish species are listed as imperiled (Freeman et al. 2005). Levels of species imperilment likely underestimate the actual extent of loss for unique stream types with high water quality and faunal integrity. Conversion of forest to agriculture, urban growth and river impoundment for hydropower and navigation, have altered stream and river habitat throughout much of the basins. For example, dams and reservoirs impound approximately 44 % of the ACT mainstem rivers. In addition to the well documented effects of impoundments on riverine fauna, dams also have caused a decline in diadromous and migratory species, led to decreased species richness in flow-modified fragments of rivers downstream from dams, and isolated populations in tributary systems (Freeman et al. 2005). Presently, parts of the region are experiencing among the highest population growth rates in the nation, bringing urban sprawl, impervious surface proliferation, and increasing pressures on streams for water supply. At least 16 water supply reservoirs are in planning phases for construction on streams in the Coosa, Tallapoosa, Chattahoochee and Flint systems in Georgia (R. Goodloe, USFWS, *personal communication*). Georgia, Florida, and Alabama are locked in an interstate controversy over water use in these systems and water allocation to downstream states. The intense and growing competition for water in these systems - to support population growth, expanding agriculture, for industry and hydropower, and to provide for healthy stream communities - reflects the urgency with which scientifically sound tools are needed to facilitate landscape-level planning and biodiversity conservation.

Protocols for stream segment classification and the analysis of biological distributions have been established by both The Nature Conservancy and MORAP, however, these techniques have yet to be tested by alternative approaches. Nor have these organizations tested the scale at which aquatic faunal assemblages can be predicted. We propose alternate approaches to modeling and predicting aquatic species distribution in relation to landscape features at various scales in the ACT basin. Our project is based on the fundamental assumption that watershed characteristics (e.g., soils, vegetation, elevation, relief, land use) and geomorphic history directly influence stream structure and function and that these, in turn, influence the aquatic community. These influences, however, occur in systems with high natural variability that must be assessed and quantified. Further, we assume that the ultimate goal of this project will be to develop products that can be used by natural resource managers for decision-making; hence, they should include quantifiable measures of uncertainty (Lindley 1985; Clemen 1996). Therefore, we will develop probabilistic models using historic and current (empirical) data on the distribution of aquatic species in the basin to ultimately provide a decision support system for resource managers.

Objectives

Conserving aquatic fauna will require addressing detrimental effects of land use practices, water management regimes and habitat fragmentation (Irwin and Freeman 2002; Freeman et al. 2005; Mirarchi et al. 2004). Our goal for this project was to use existing methods to develop models to assess distribution of aquatic fauna in relation to landscape features in the ACT basin (Alabama). Our specific objectives were to:

1) Build and test predictive models for aquatic fauna distribution using empirical species distributional data;
2) Test the feasibility of incorporating water quality models based on land use for selection of areas for restoration/protection; and
3) Develop a decision support system to assist resource managers with conservation scenarios for fauna (http://www.SoutheasternAquaticGAP.org).

STUDY AREA

ACT Basin

The Alabama-Coosa-Tallapoosa (ACT) river system drains approximately 59,000 km^2, including substantial portions of northwest Georgia, east-central Alabama, and a small area of southeastern Tennessee (Figure 1). Physiographic diversity of the system creates a mosaic of lotic habitats that, prior to construction of large dams, formed a fluvial continuum from the mountains to the Gulf. The northernmost headwaters of the Coosa River system dissect the southern terminus of the Blue Ridge, Valley and Ridge, and upland Piedmont along the southern bend of Appalachia. These headwater rivers derive their distinctiveness from the varied lithography and soil horizons of these provinces in northwestern Georgia and northeastern Alabama (Wharton 1978). The main stem of the Coosa River (460 km in length) originates in the relatively open Great Valley subsection of the Valley and Ridge, at Rome, Georgia. The upper most Coosa River watershed is not included in the study area; faunal models can be found in Peterson et al. (2003a). The lower third of the Coosa River main stem historically cascaded through a series of large virtually unnavigable bedrock shoals (Jackson 1995). The shoals abruptly disappear just below the fall line where the Alabama River is formed by the junction of the Coosa River with the Tallapoosa River near Montgomery, Alabama. The Tallapoosa River has similar physiographic diversity, flowing 415 km from Piedmont uplands in west Georgia and east Alabama, crossing the fall line in another set of large falls (i.e., prior to impoundment), and continuing across the coastal plain to join the Coosa River to form the mainstem Alabama River. The Alabama River main stem winds 500 km across the coastal plain, joining with the Tombigbee River approximately 72 km from Mobile Bay.

METHODS

Database construction

Data layers were built at various scales for the use in the development of faunal distribution models. In addition to using existing layers produced for Alabama and Georgia GAP projects, supplemental layers were constructed and used in predictive models of aquatic species distribution. All data were entered into a Geographic Information System (GIS) using ArcView 3.2a®, ArcGIS 9.2®, ArcInfo® and ERDAS Imagine 8.7®.

Taxa and reach level characters. Available records for taxa in the basin were compiled from recent and historical records. Sample sites were georeferenced and entered into the geographic information system. The location, genus, and species of each taxa were verified for accuracy. Locations of taxa were defined as the reaches containing sample sites. Reaches were defined as the stream segment bounded by tributary junctions following (Frissell et al. 1986). Mean elevation, gradient (slope), aspect, stream order (Strahler 1957), link magnitude (Shreve 1966), and downstream link magnitude (Osborne and Wiley 1992) were calculated for each reach containing a sample site.

Subwatersheds. We used 12-digit U.S. Geological Survey (USGS) hydrologic units (approximately 7,800 hectares) (Table 2), hereafter defined as subwatersheds, as the basic land unit for model fitting and prediction. The subwatersheds were delineated by hand, based on digital raster graph (DRG) images and digital elevation models (DEM) of 1:24,000. Subwatersheds for the Georgia portion of the basin were obtained from the USGS via the Georgia Data Clearinghouse. Subwatersheds for the Alabama portion of the basin were obtained from the Natural Resource Conservation Service (NRCS) in a beta version. The data were checked for accuracy within the ACT Basin.

Landscape and stream characteristics. - Subwatershed characteristics used during species distribution model-fitting and prediction included landuse/landcover, geologic features, physiographic region, road density, drainage density, and number of impoundments. Stream reach characteristics included mean elevation, slope, aspect, stream order, link magnitude, downstream link magnitude, location relative to the fall line, and isolation. We also evaluated the influence of adjacent populations by estimating the percent of occupied subwatersheds for each species as the percent of sampled subwatersheds within a subbasin (8- digit USGS hydrologic unit) that contained the species.

Landscape variables were determined for each subwatershed. The land use/land cover coverage was obtained from the USGS National Land Cover Dataset (Table 2; NLCD; USGS 2001). The original dataset included 15 land use/land cover (LU/LC) classes. However, each of the following were combined: woody and emergent herbaceous wetland classes (wetland); shrub/scrub and grassland/herbaceous classes (rangeland); and pasture/hay and row crops (agricultural). Urban classes (high- and low-intensity residential and commercial/industrial/transportation) were also combined. Likewise, forest classes (deciduous, evergreen, and mixed) were not combined. Two classes, “water” and “barren” were also included, but needed no reclassifying from the NLCD dataset; therefore, a final total of nine classes were used for model construction (Table 3). For each subwatershed, landuse/landcover classes were expressed as the percentage of the total subwatershed area. For the Tallapoosa River basin, the land use/land cover coverage was obtained from the USGS National Land Cover Dataset (Table 2; NLCD; USGS 1992). The original dataset included 17 land use/land cover

(LU/LC) classes. Woody and emergent herbaceous wetland classes were combined into "wetland"; quarries/strip mines and transitional classes into "barrenland"; grasslands/herbaceous, and urban/recreational grasses into "rangeland"; and pasture/hay and row crops into "agricultural". Urban classes (high- and low-intensity residential and commercial/industrial/transportation) were considered individually and combined into an "Urban" class. Likewise, forest classes (deciduous, evergreen, and mixed) were considered individually along with a combined "Forest" class. A class named "water" was also included, but needed no reclassifying from the NLCD dataset. For each subwatershed, landuse/landcover classes were expressed as the percentage of the total subwatershed area. For each subwatershed, landuse/landcover classes were expressed as the percentage of the total subwatershed area (Table 4).

Road data were obtained from the U.S. Census Bureau's 2000 TIGER/Line Files (Table 2). For each subwatershed, road density was estimated by summing the total length of roads and dividing by the area of the subwatershed. Similarly, stream drainage density was estimated by summing the total length of streams at a scale of 1:100,000 (see hydrography below) and dividing by the subwatershed area.

Geological features used during model-fitting included physiographic province and district, and the parent geomorphic material (Table 2). Physiographic province and district for the Alabama portion of the basin were obtained from the Alabama Agricultural Experiment Station (Mount 1986) and the Georgia portion was obtained from the Physiographic Map of Georgia (Clark and Zisa 1976). Due to inconsistencies between state boundaries, the geomorphic data were obtained from the USGS (Digital Data Series 11, Release 2, 1997) at a scale of 1:2,500,000. Geologic data were expressed as a percentage of the total subwatershed area. Geologic percentages within each subwatershed were obtained using the same methods to obtain the aforementioned landuse/landcover percentages.

Stream network (hydrography) data were obtained from the USGS National Hydrography Dataset (Table 2; NHD; USGS 2001a). Hydrography data for individual subbasins (USGS 8-digit hydrologic units) at a scale of 1:100,000 were combined to create stream networks for each study basin. The NHD data was used to calculate stream density. An additional stream network, used for quantifying stream order (Strahler

1957), link magnitude (Shreve 1956) and downstream link magnitude (d-link) (Osborne and Wiley 1992) was created from a DEM. The creation of this stream network involved several steps. First, using ArcGIS's hydrologic analysis, problematic areas (sinks) in the DEM were filled using the "SINK" function. Sinks are problematic in a DEM because any water that flows into them cannot flow out. After all sinks were filled, the "FLOW DIRECTION" tool was used to determine the direction that water would flow out of each cell. Once the flow direction had been calculated, data was able to be input into the "FLOW ACCUMULATION" function. "FLOW ACCUMULTION" calculated the number of upslope cells flowing to a location. A threshold was set to the output of the "FLOW ACCUMULATION". All cells with more than 200 cells flowing into them were classified as part of the stream network.

Tributary reaches were categorized as "isolated" if separated from the mainstem river or the major tributaries (identified for each subbasin above) by a downstream impoundment using lake and reservoir data from the NHD dataset (Figure 3). The mean elevation, slope, and aspect of each sample reach were derived from the National Elevation Dataset (USGS 1999), which contained a 1:24,000 digital elevation model for the conterminous United States.

Statistical Analyses

Estimating species detection probabilities

Determination of species presence is only absolutely certain for when a species is detected or captured (assuming species are identified correctly). If a species is not detected in a survey, there are two alternatives. First, it is possible the species was truly absent. Second, it is possible the species is present, but it was not detected during the survey (i.e., a false absence). The ability to detect a species is a function of the number of vulnerable individuals and the ability to capture the species (i.e., probability of capture; Bayley and Peterson 2001), which vary with habitat characteristics. Thus, models of species presence/absence can be influenced (biased) by the factors that affect abundance and capture probabilities.

The influence of false absences on species presence models can be minimized using species detection probability estimates as weighting factors during model fitting

(Peterson 2003a). Detection probabilities for each species were quantified using program MARK (White and Burnham 1999) that incorporated the likelihood-based methods outlined in MacKenzie et al. (2002) and field demonstration of these methods from Bailey et al. (2004).

Detection probabilities were estimated using data from sites that were sampled on at least 3 occasions from multiple research projects (Costley 1998; Peyton and Irwin 1997; Hayer and Irwin unpublished data). We estimated species specific detection probabilities (Table 2), except for the following; *Ameiurus natalis*, *Cyprinella trichoroistia, Etheostoma artesiae, E. coosae, E. ditrema, Fundulus stellifer, Lythurus lirus, Notropis asperifrons, N. buccatus, N. chrosomus, N. xaenocephalus, Pimepales notatus* and *Semotilis thoreauianus*. In these cases, detection probabilities were assigned from con-generic (i.e., similar) species. This approach was similar to the group detection probability estimation reported by Peterson et al. (2003a) for Aquatic GAP in the Flint River Basin. Detection probabilities then were used as weights during model fitting and for estimating probabilities of species presence, as described below.

Modeling species distributions

Pearson correlations were calculated for all pairs of predictor variables (i.e., sample reach and subwatershed characteristics; Table 3) prior to analyses. To avoid multicollinearity, a subset uncorrelated predictor variables ($r^2 < 0.36$ and > -0.36) was selected for inclusion in our candidate models. Peterson et al. (2003) evaluated several methods for analysis of Aquatic GAP faunal and landscape data. They concluded that non-parametric K-nearest neighbor (KNN) models were much more accurate than both hierarchical and nonhierarchical logistic regression models.

Non-parametric methods- When modeling species occurrences, biological responses are usually approximated assuming some predefined statistical distribution. Therefore, model accuracy is influenced by how faithfully the distribution approximates the biological response. Nonparametric techniques do not require statistical distribution assumptions and are generally more accurate than parametric techniques (Haas et al. 1999; Olden and Jackson 2002). Therefore, we used a nonparametric technique, K-nearest neighbor classification (KNN), to model species presence at the sample reach and subwatershed scales and compared the accuracy of these models to the nonhierarchical and hierarchical logistic regression models, respectively.

KNN classification is relatively a flexible, nonparametric statistical technique that is used to predict the response of an observation using a nonparametric estimate of the response distribution of its K nearest (i.e., in predictor space) neighbors (Hand 1982). Model selection was accomplished via cross-validation (Hjorth 1994; Haas et al. 1999), which is asymptotically equivalent to AIC (Shao 1997) and is therefore, useful for selecting the simplest, best fitting model. Similar to the logistic regression models described above, we fit all possible subsets of the global model for each species via KNN for values of *K* from 2- 30. We considered the best fitting model as that in which *K*, the number of predictors, and model error rate were minimized. During model fitting, weights were assigned using the WEIGHT option in SAS PROC DISCRIM (SAS Institute 2001).

Evaluation of model accuracy

The most relevant measure of model performance is the expected error rate (EER), which is the error rate of the model averaged over all possible patterns of responses at the design points (Efron 1983). That is, the EER is the error rate of a particular model when it is applied to new circumstances (e.g., predicting species occurrence at currently unknown locations). Cross validation estimates are nearly unbiased estimators of EER (Funkunaga and Kessel 1971) and provide a measure of overall predictive ability of models without excessive variance (Efron 1983). Therefore, we evaluated the predictive ability of our best fitting models via leave-one-out cross validation. During this procedure, one sample (e.g., subwatershed) was left out of the data, the model was fit with the remaining observations, and the probability of presence estimated for the held out observation. We then classified the sample reach (or subwatershed) as occupied if the probability $\geq$ 0.5, otherwise unoccupied. This procedure was repeated for each observation and the known and predicted classifications compared. Classification error rates were defined as the proportion of sites that were assigned the incorrect status (e.g., an occupied site that was classified as unoccupied).

Predicting species occurrence

Samples were not collected from many of the subwatersheds within each study basin. For these subwatersheds, we estimated the probability of presence for each species using the most accurate models as determined by the cross validation process (described above). In addition, we assumed that an observed absence may be due non-detection rather than absence. To account for non-detection, we estimated posterior probabilities of presence for watersheds with ‘observed’ absences following Bayley and Peterson (2001) as:

$$P(F \mid Co) = \frac{(1-d)\,p_e}{(1-d)p_e + (1-p_e)}, \qquad (1)$$

where $P(F|Co)$ is the posterior probability of presence, given no detection, (1-d) is the probability of not detecting a species in a sample reach ($d = d_s$ from [1] above) or subwatershed ($d = d_w$ from [2] above), given it is present, and p_e is the cross-validated probability of presence from the most accurate model. That is, p_e is the estimated probability of presence when that observation was left out of the dataset during cross-validation.

Soil and Water Assessment Tools (SWAT)

We used a Soil and Water Assessment Tool (SWAT) model to simulate biophysical processes to estimate the impacts of various land uses in one of the most urbanized part of the study area: Saugahatchee Creek watershed (570 km^2; Figure 4) and evaluated change in environmental parameters between 1992 and 2001, coincident with National Land Cover Data (USGS 1992). SWAT, along with Geographic Information Systems (GIS), integrated available input data, such as soil type, land use, crops, topography, weather, nutrient and pesticide loading to predict the long-term impact of land use/management decisions (DiLuzio et al. 2002).

The study area was subdivided into 216 homogeneous subbasins called hydrologic response units or HRUs. Each HRU had unique soil and landscape use properties. Input information for each HRU was grouped into categories of weather, unique areas of land cover, soil, and management within the HRU. The loading and movement of runoff, sediment, nutrient, and pesticide loadings to the main channel in each HRU was simulated considering the effect of several physical processes that influenced the hydrology. Two separate SWAT models were run, one using the 1992 NLCD and the other using the 2001 NLCD (Table 10). The models were run over a 17-year period (1989-2006) with daily and yearly results computed. A 5-year average was also computed (1990-1994 for the 1992 NLCD and 1999-2003 for the 2001 NLCD) which provided more realistic results. Output from the two models was compared.

RESULTS

ACT Basin

Fish samples used for the modeling were derived from over 1,800 collections in the ACT since 1970; these collections were comprised of over 37,300 individual records and were from approximately 1,085 unique reaches (Figure 5). The number of collections varied greatly among HUCs and watersheds in the ACT basin (Figure 6). Although a total of 190 fish species were recorded from the ACT Basin, we constructed models on 79 (41%) with sufficient (>20) occurrences for model power (Table 5). Detection probabilities were calculated for each species and are reported in Table 5. In addition, we provide a summary of records for the species of greatest conservation need (GCN species; Table 6; ADCNR/DWFF 2005).

HUC models.-The total study area included 349 12-digit HUCs (Table 3). Predictions at the subwatershed level were conducted using the best model for each species. Maps depicting probability of presence were generated for each species; in all instances different models for each main watershed were used to compile maps. Example maps are illustrated in Figures 7-9 and the full set of maps are located on the Web Page (http://www.SoutheasternAquaticGap.org). Individual watershed results are reported below.

Alabama Basin- Thirty species were modeled in the Alabama Basin (Table 7). The species-specific models of species presence within sample reaches in the Alabama Basin were relatively accurate with classification error rates for presence, absence, and across categories (overall error) averaging 14.3.2%, 25.4%, and 22.3%, respectively. The variables important for predicting species occurrence varied substantially among species (Table 7). However, there were a few general patterns. Reach and HUC level measures such as stream order, stream density, road density and reach elevation, were important for predicting the presence of 17 species. The influence of the juxtaposition of habitats as measured by percent adjacent occupied subwatersheds, degree of isolation, and the link magnitude of the nearest downstream reach also were important to predicting the presence of 18 species. Inclusion of both reach level and juxtaposition variables in models occurred for 27 species. Watershed-level measures such as the amount of rangeland and forested lands, and urban were significant variables for predicting the presence of 15 or more species. Parent geology occurred as predictive variables in models for 19 species. Physiographic province occurred as predictive variables in 13 models.

Coosa Basin- Forty-three species were modeled in the Coosa Basin (Table 8). The species-specific models of species presence within sample reaches in the Tallapoosa Basin were relatively accurate with classification error rates for presence, absence, and across categories (overall error) averaging 16.8%, 27.3%, and 25.3%, respectively (Table 8). The variables important for predicting species occurrence varied substantially among species (Table 8). However, there were a few general patterns. Reach and HUC level measures such as stream order, reach gradient, elevation and stream and road density were important for predicting the presence of 31 species. The influence of the juxtaposition of habitats as measured by percent adjacent occupied subwatersheds, degree of isolation, and the link magnitude of the nearest downstream reach also were important to predicting the presence of 25 species. Inclusion of both reach level and juxtaposition variables in models occurred for at least 41 species. Watershed-level measures such as the amount of row crop agriculture, forested lands, water and wetland were significant variables for predicting the presence of 28 or more species. Parent geology occurred as predictive variables in models for all but 17 species; whereas, physiographic province occurred in 25 species models.

Tallapoosa Basin—Sixty species were modeled in the Tallapoosa Basin (Table 9). The species-specific models of species presence within sample reaches in the Tallapoosa Basin were relatively accurate with classification error rates for presence, absence, and across categories (overall error) averaging 16.2%, 21.5%, and 20.5%, respectively (Table 9). However, models for the entire study area had much higher error rates. The variables important for predicting species occurrence varied substantially among species (Table 9).

However, there were a few general patterns. Reach level measures such as stream order, reach gradient, and reach elevation were important for predicting the presence of 36 or more species. The influence of the juxtaposition of habitats as measured by percent adjacent occupied subwatersheds, degree of isolation, and the link magnitude of the nearest downstream reach also were important to predicting the presence of 46 or more species. Inclusion of both reach level and juxtaposition variables in models occurred for at least 21 species. Watershed-level measures such as the amount of row crop agriculture, forested lands, and water were significant variables for predicting the presence of 43 or more species. Parent geology occurred as predictive variables in models for all but 13 species; whereas physiographic province occurred in only 11 models.

SWAT Modeling

Land use changed between the two time periods that SWAT models were compiled. Developed land increased by 13.3% and forested land decreased by 18.7% (Table 10). The SWAT model predicted increases in several environmental parameters that ultimately affect water quality. Most apparent were a 30% increase in total N runoff (kg/ha), a 21% increase in total P runoff (kg/ha) and a 212% increase in total sedimentation (tons). In addition, total water yield increased by only 6%; whereas, surface runoff increased by 42%.

DISCUSSION

The goal of the Gap Analysis Program is to provide natural resource managers with information to facilitate land management decision-making. Land managers, however, can only be effective at conserving biodiversity if they are informed as to the nature and extent of potential impacts on ecosystems. For aquatic systems, achievement of this goal then will require multiple approaches, including the identification and conservation of existing high-quality habitats and the reduction or elimination of potential threats to aquatic communities. Failure to correctly identify critical habitats and significant threats could lead to further declines in aquatic populations and the waste of scarce management resources. Previous and current aquatic GAP efforts (e.g., MORAP) have focused on the development of classification systems based on the perceived importance of landscape and stream characteristics. Specific habitat (landscape) classes then are selected for specific conservation efforts. Although useful, these approaches cannot be used to identify key factors influencing the structure of communities and species persistence, or for developing tools for estimating the condition of aquatic communities in unsampled areas because they rely almost entirely on unquantified 'expert' opinion. Furthermore, these approaches cannot be used to quantify the potential impact and uncertainty of proposed activities, which limits their usefulness for land management planning, resource allocation, and decision-making (e.g., basin planning, risk assessment).

We believe that, when feasible, empirical modeling is superior to contemporary classification approaches for three reasons. First, empirical models provide insights into the factors influencing species distribution and persistence. These insights then can be used during the development of quantitative decision support tools. Second, empirical models have a strong theoretical basis for formal, statistically-valid evaluations of model accuracy and precision. Third, empirical models provide an objective basis for expressing and incorporating uncertainty in decision-making. Note that uncertainty can be incorporated in expert (opinion) models via subjective probability. However, it places a heavy burden of proof on the decision-maker (Morgan and Henrion 1990). In what follows, we discuss the implications of our species distribution models and outline the next steps toward developing quantitative decision support tools.

We found that the presence of multiple (20) fish species was significantly related to stream reach isolation, which was consistent with our previous study of at-risk taxa in the Upper Tallapoosa River Basin, Georgia (Freeman et al. 2003) and in the Flint River Basin (Peterson et al. 2003b). Peterson et al. (2003a) reported similar error rates for KNN models built at the subwatershed scale. At the broader scale (subwatersheds), fish species presence was significantly, positively related to the presence of conspecifics in nearby subwatersheds in the Flint River Basin. At the HUC scale in the ACT Basin, juxtaposition of adjacent colonized subwatersheds was important in describing presence for 18 species. We believe that these patterns are a reflection of the factors influencing species persistence. Lotic communities are known to exhibit a high degree of elasticity and can recover from natural or anthropogenic disturbances relatively quickly (Peterson and Bayley 1993). For example, warmwater stream fishes can recolonize defaunated streams in a matter of weeks through relatively discrete, large-scale movements, such as seasonal migrations (Bayley and Osborne 1993; Peterson et al. 2002). To successfully recolonize, lotic organisms must be present in unimpacted streams and must have access to impacted reaches following disturbance (Peterson and Bayley 1993). Stream isolation prevents recolonization of disturbed streams by obligate lotic species and can eliminate demographic support for resident populations, placing them at greater risk of local extinction (e.g., Dunham and Rieman 1999). Similarly, the presence of conspecifics in close proximity to disturbed streams or extant populations represents the likely sources of colonists or immigrants, respectively. The importance of refounding (colonization) and demographic support suggested here and in other studies (e.g., Dunham and Rieman 1999) highlights the importance of explicitly incorporating these factors into natural resource decision-making.

Species presence was related to reach characters, such as site elevation stream order, link magnitude and downstream link magnitude. For several endemic fish species, link magnitude alone explained significant variation in abundance (Peyton and Irwin 1997). Freeman et al. (2003) reported KNN models for 5 endemic fishes in the Upper Tallapoosa Basin. Each species was related to either position in the watershed (stream order, link magnitude) or degree of isolation. When we rebuilt the models with data from the rest of the basin (and somewhat different landscape variables), the new models were similar and in all but one case (*Cyprinella gibbsi*), models included the same variables as those reported in Freeman et al. (2003). This suggests that these models are robust and can be used for conservation efforts. One species, *Etheostoma chuckwachatte*, is currently being considered as a candidate for the Endangered Species List. Our models (see Figure 9) can help identify critical habitats and subwatersheds to maintain populations. The other five GCN species for which we had adequate data for model building were *Hybopsis lineapunctata*, *Macrhybopsis aestivalis*, *Fundulus bifax*, *Etheostoma ditrema*, and *Percina smithvanizi* (Tallapoosa River, “muscadine darter”).. Of these, all their distributions were related to reach characters (e.g., stream density, stream order) and juxtaposition of habitats (e.g., isolation, link magnitude). These models can be applied to any stream reach (potential sampling site) within the historic distribution to predict probability of occurrence.

Other landscape characters, such land use and geologic features were also important predictors of species presence. These relations, however, likely represent complex mechanisms influencing the stream habitat "template" (*sensu* Southwood 1977). For example, the presence of granitic rocks may influence instream habitats, such as rocky shoals. The relation between various parent geologic forms and the presence of certain fish species may represent the influence of granitic parent material on shoal habitats. In addition, many species are restricted in their distribution to above the fall line (Boshung and Mayden 2004) and are distributed (on the reach level) in habitats with coarse substrata (e.g.., *E. chuckwachatte*, *Micropterus coosae*, *P. palmaris*). In these examples, each underlying mechanism (habitat type or geographic distribution) could have profoundly different implications for management decision-making. If the relation between species presence and granitic parent material were due to the latter's effect on the shoal habitat availability, then increased habitat fragmentation and impoundment of shoals may have a negative effect on that species. In contrast, if distribution is related to other factors (not habitat availability) then decreases in rocky habitats may not affect species presence or distribution. In the case of each of the examples above, distribution in relation to the fall line (Piedmont for *P. palmaris* in Coosa), stream order, and %agriculture, range or low intensity urban were significant predictors of species presence. Quantitative decision models should not rely exclusively on simple correlative models, such as our species presence models, to determine model structure and parameter estimates. Rather, models should have a strong theoretical and empirical basis to be useful for natural resource decision-making (Williams et al. 2002). In this sense, models of species presence are used to identify potential mechanisms influencing species distribution and persistence and guide decision model development.

Land Use/Land Cover variables were significant predictors in many species models. These variables are unfortunately the most likely to change temporally; however, change in these variables can be measured and if maintenance of specific land cover is needed for species conservation, those specifics could be incorporated into conservation plans. Our SWAT models of the urbanized section of Saugahatchee Creek watershed illustrated how rapidly (9 years). Saugahatchee Creek watershed is located in eastern Alabama (Tallapoosa River basin), is currently facing a number of environmental issues due to changes in the area. Specific concerns that are affecting the water quality in the watershed include population growth, wastewater treatment runoff, sediment runoff, quarries and mining, and increased impervious surfaces. In addition, total maximum daily load (TMDLs) metrics have been imposed on Saugahatchee Creek for both nutrients and sediment (Bill Deutch, personal communication). The Auburn-Opelika metropolitan statistical area (MSA) is located in the portion of the watershed where SWAT estimated a 212% increase in sediment runoff and a 21 and 30% increase in total P and N runoff, respectively. Because the MSA is predicted to experience unprecedented growth in the next decade, this watershed can provide insights into how these changes will affect faunal components. Fortunately, thus far, there are no GCN fish species in the Saugahatchee Creek watershed. We recently acquired a water quality data set that we can use to calibrate the SWAT model (Alabama Water Watch, unpublished data; Santhi et al. 2001); we believe that SWAT can be a useful tool for evaluation of certain land practices and their effects on aquatic fauna.

We compared our models with those of Peterson et al. (2003a) and of the 30 species for which both studies considered only 10% did not have similar predictive variables. Forty-three percent of the species had the same (or similar) predictive variables in the respective models. The remaining species (47%) were similar in that parent geology predicted presence in respective models. Because there were differences in geology between the Flint River Basin and the ACT Basin, investigation of similarities between specific models are needed. These comparisons may allow us to expand models to include regional inputs.

Our models were relatively accurate with cross validation error rates that averaged less than 23%. We probably could have obtained greater accuracy using nonparametric classifiers, such as neural networks and genetic algorithms (Chambers and Hastie 1992). These techniques, however, do not estimate the degree of uncertainty in a prediction, whereas other techniques (e.g., KNN, logistic regression, classification trees) estimate uncertainty in the form of a probability (i.e., the probability of presence). This allows managers to incorporate uncertainty in decision-making. For example, consideration a situation where a manager needs to choose 1 of 3 possible headwater streams for establishing a reserve to conserve a particular species. A hypothetical neural network model of species presence predicts that the species occurs in all 3 locations and provides no basis for discriminating among sites. In contrast, a hypothetical KNN model predicts that the probability presence in one location is 0.95 and for the other two, 0.5, which suggests that one location may be superior. Our models allowed us to avoid arbitrary cutoff values for determining presence and allowed us to incorporate uncertainty. The uncertainty in species presence estimates also can be directly incorporated into decision models (e.g., see Rieman et al. 2001). Peterson and Dunham (2003) also detail methods for incorporating models and sampling data to improve estimates of species presence and provide more accurate estimates for better decision-making at lower costs. Clearly, the quantification and incorporation of uncertainty in estimates of species presence and also community composition is crucial to land management decision-making (Conroy and Noon 1996).

One of the limitations of our approach was that empirical models are fairly data intensive; therefore, many species were not included in our modeling efforts. Surprisingly, this list included not only rare fishes, but common fishes as well. As we compiled and corrected the faunal database it became apparent that common species were absent and were potentially released in the field. Although individuals may have recorded data in personal collection notes, occurrence of common species (e.g. *Notropis edwardraneyi*, Alabama River basin) were often not recorded in the two museum databases. If we noted occurrence in a "comments section" we included the species as present at the site. Rare species, if detected, are sometimes not accessioned immediately (if at all) because of the need to investigate and compile life history or systematic information regarding the species. In addition, individual investigators, including State and Federal researchers, do not (or have not) accession(ed) fishes at either of the two main Ichthyologic collections in Alabama. Consequently, important distribution data on rare fishes is lacking and compromises predictive model building for GCN species. For rare fishes, we sent out a request to numerous researchers in the State for additional records on GCN species and received one reply that updated data that we already had access to. If conservation of GCN species is a priority, data must be made available for planning purposes. We intend to continue the search for additional GCN records and will likely relax the “pre-1970” and “>20 records” constraints in order to develop models for the remaining GCN species.

An additional outcome of compiling presence/absence data is that status information for specific species may be illustrated. One example of this is *Esox niger*. Both Mettee et al. (1996) and Boshung and Mayden (2004) indicate stable populations of *E. niger* throughout its range. When compiling data for models, we were interested that there were only six post-1970 records for *E. niger* (3 sites) in the Alabama River basin, and 31 records (16 sites) in the Tallapoosa River basin (see next paragraph); consequently, we did not construct models for this species in these basins based on our *a priori* constraints. A quick search for pre-1970 data in both UAIC and AUM databases indicated only 12 additional records. Unless there are more and recent distribution data for this species, we would contend that more survey work is needed for this species, particularly in wetland type habitats where it occurs. Incidentally, the Coosa River basin model for *E. niger* included wetland and reach elevation as significant predictive variables (see Table 8). Wetland habitats are probably some of the least surveyed habitats for fishes.

Another use of our Aquatic GAP database compilation was the analysis of where sampling efforts are lacking. Figure 5 illustrates the number of sites (stream reaches) within HUCs, and also indicates where no post-1970 data (zero sites within a HUC) were recorded from the databases we used; 27% of the HUCs in the study basins did not include data for our models. The Alabama River basin had the fewest sampling sites per HUC (ratio = 1:1) yet it has the most HUCs in the ACT (132). The Coosa and Tallapoosa river basins had more sites sampled per HUC; 365 (site/HUC ratio = 3.8:1) and 594 (site/HUC ratio = 4.8:1), respectively. In addition, some individual HUCs were sampled more than others. Subbasins with 11-16 sites were Waxahatchee Creek and Camp Branch, Cedar Creek and the Coosa River (one HUC), Chocolocco Creek (2 HUCS), Shoal Creek, an upper, middle and two lower Tallapoosa River HUCs, and one Uphapee Creek HUC. With the exception of Beach Creek in Georgia (Tallapoosa River Basin), subbasins with 17-24 sites were mostly located in the lower portion of the Tallapoosa River and Coosa River basins (one). These included two more Uphapee

Creek HUCs, Chewacla Creek and Loblockee Creek HUCs. The authors presume that these lower HUCs have been sampled extensively based on their proximity to Auburn University. For example, the 16 sites where *E. niger* occurred in the Tallapoosa River basin were all within 20 miles of Auburn University. This non-random pattern of sample site "selection" introduces bias in faunal distribution data.

Next steps.- Our modeling efforts have provided valuable insight into the factors influencing species distribution and community structure in portions of the ACF and ACT Basins (This study; Freeman et al. 2003; Peterson et al. 2003a). The results of this and other studies (e.g., Albertson and Torak 2002; Peterson et al. 2002; Peterson et al. 2003a) suggest that the future structure of aquatic communities in reaches of the ACT (and the Flint River basin) is influenced by the physical habitat template, refounding and demographic support from nearby communities, and the current community structure. These factors, in turn, are influenced by management actions (e.g., land use, water impoundment), channel morphology, stream hydrology, geologic features, and local climate. It is apparent that for GCN species, additional distributional data are needed to develop robust probability of presence models. In addition, data are almost complete to develop models for mollusks in the basin (Jim Williams, personal communication).

Our website (www.southeastaquaticgap.org) will be the source of data by which decisions can be made and it will be updated with new information as it is available. Next, our decision models will be parameterized using data collected over relatively short time periods and limited areas and are likely to be have substantial uncertainty (e.g., variability) associated with them. To improve these models, we will develop empirical Bayes techniques for incorporating future data into the model building and refinement process. For example, sensitivity analysis will be performed on these models to identify the key uncertainties, which will allow managers to prioritize information needs for monitoring or future studies. The final models will provide spatially explicit estimates of changes in fish population metrics or community structure in response to management actions, such as the establishment of alternative stream flows, the construction of flow augmentation reservoirs, wetland restoration activities, and/or the purchase of conservation lands in the Basins.

ACKNOWLEDGEMENTS

This grant was funded through the Alabama State Wildlife Grants program administered through the Alabama Department of Conservation of Natural Resources, Wildlife and Freshwater Fish Division. The authors would like to thank Jim McHugh, Project Officer, for his encouragement over the course of the study. A number of people/Institutions were instrumental in helping to develop the databases. We are particularly indebted to Malcolm Pierson and others (APC), Carrie Strait and Bud Freeman (Georgia Natural History Museum), Jon Armbruster and Dave Werneke (Auburn University Museum), Rick Mayden and Bernie Kuyhada (University of Alabama Ichthyological Collection), personnel from Georgia Department of Natural Resources stream team, and anyone who ever wetted a seine in the ACT Basin. We appreciate the contributions of all of these colleagues.

LITERATURE CITED

Alabama Department of Conservation and Natural Resources, Division of Wildlife and Freshwater Fisheries. 2005. Alabama's Comprehensive Wildlife Conservation Strategy. ADCNR. Available: http://alapark.com/research-mgmt/cwcs/outline.cfm. (April 2007).

Albertson, P. N. and L. J. Torak. 2002. Simulated effects of pumpage on stream-aquifer flow in the vicinity of federally protected species of freshwater mussels in the lower Apalachicola-Chattahoochee-Flint River Basin (subarea 4), Southeastern Alabama, Northwestern Florida, and Southwestern Georgia. Water-resources investigations report 02-4016. U.S. Geological Survey, Atlanta, Georgia.

Bailey, L. L., T. R. Simons, and K. H. Pollock. 2004. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. Ecological Applications 14:692-702.

Bayley, P.B. and L. L. Osborne 1993. Natural rehabilitation of stream fish populations in a Illinois catchment. Freshwater Biology 29: 295-300.

Bayley, P.B. and J.T. Peterson. 2001. Species presence for zero observations: an approach and an application to estimate probability of occurrence of fish species and species richness. Transactions of the American Fisheries Society 130:620-633.

Bogan, A. E., J. M. Pierson and P. Hartfield. 1995. Decline in the freshwater gastropod fauna in the Mobile Bay basin. *Pages* 249-252 *In* E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran and M.J. Mac, *editors*. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service, Washington D.C.

Boschung, H. T. and R. L. Mayden. 2004. Fishes of Alabama. Smithsonian Books, Washington, D.C.

Burkhead, N. M., S. J. Walsh, B. J. Freeman and J. D. Williams. 1997. Status and restoration of the Etowah River, an imperiled southern Appalachian ecosystem. *Pages* 375-444 *in* G. W. Benz 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.

Chambers, J. M. and T. J. Hastie. 1992. Statistical Models in *S*. Chapman and Hall, Pacific Grove, CA.

Clark, W. Z., Jr. and A. C. Zisa. 1976. Physiographic map of Georgia. Georgia Geologic Survey Map SM-4. Atlanta, GA.

Clemen, R. T. 1996. Making hard decisions: An introduction to decision analysis. Duxbury Press, Belmont, CA.

Conroy M.J. and B.R. Noon. 1996. Mapping of species richness for conservation of biological diversity: conceptual and methodological issues. Ecological Applications 6:763-773.

Costley, K. M. 1998. Diel shifts in habitat use by small fishes in the Tallapoosa River, Alabama. M.S. Thesis, Auburn University, Alabama.

Di Luzio, M., R. Srinivasan, J.G. Arnold , and S.L. Neitsch. 2002. Soil and Water Assessment Tool. ArcView GIS Interface Manual: Version 2000. GSWRL Report 02-03, BRC Report 02-07, Published by Texas Water Resources Institute TR-193, College Station, TX. 346p.

Dunham, J. B. and B. E. Rieman. 1999. Metapopulation structure of bull trout: influences of habitat size, isolation, and human disturbance. Ecological Applications 9:642-655.

Efron, B. 1983. Estimating the error rate of a prediction rule: improvement on cross-validation. Journal of the American Statistical Association 78:316-331.

Freeman, M. C., E. R. Irwin, N. M. Burkhead, B. J. Freeman, and H. L. Bart, Jr. 2005. Status and conservation of the fish fauna of the Alabama River system. *Pages* 557-585 *in* J. N. Rinne, R. M. Hughes, and R. Calamusso, *editors*. Historical changes in large river fish assemblages of the Americas. American Fisheries Society Symposium 45, Bethesda, Maryland.

Freeman, M. C., J. T. Peterson, E. R. Irwin, and B. J. Freeman. 2003. Distribution and status of at-risk aquatic taxa in the upper Tallapoosa River System, Georgia and Alabama. Final Report to U.S. Fish and Wildlife Service, Ecological Services, Athens, Georgia.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199-214.

Haas, T. C., J. T. Peterson, D. C Lee. 1999. An evaluation of parametric and nonparametric models of fish population response. BPA Report DOE/BP-25866-8. Bonneville Power Administration, Portland, OR.

Hand, D. J. 1982. Kernel discriminant analysis. Research Studies Press, New York.

Hjorth, J.S.U. 1994. Computer intensive statistical methods validation, model selection, and bootstrap. Chapman and Hall, London.

Irwin, E. R. and M. C. Freeman. 2002. A proposal for adaptive management to conserve biotic integrity in a regulated segment of the Tallapoosa River, Alabama (U.S.A.). Conservation Biology 16:1212-1222.

Irwin, E. R., J. T. Peterson, B. J. Freeman, E. Kramer, M. C. Freeman, G. Turner, D. Moosman, K. Mickett, P. Sakaris, C.-A. Hayer, T. Piper, and C. Straight. 2004. Aquatic GAP: Regional Analysis of Biodiversity in the ACT/ACF Basins: Tallapoosa River Basin. Final Report to U.S. Geological Service, GAP Analysis Program, Moscow, Idaho.

Jackson, H. H. III. 1995. Rivers of history: Life on the Coosa, Tallapoosa, Cahaba and Alabama. The University of Alabama Press, Tuscaloosa, Alabama.

Lindley, D. V. 1985. Making decisions. Wiley, New York.

Mirarchi, R.E, J.T. Garner, M.F. Mettee, and P.E. O’Neil. 2004. Alabama wildlife: Imperiled aquatic mollusks and fishes. The University of Alabama Press, Tuscaloosa, Alabama.

Morgan, M. G., and M. Henrion. 1990 Uncertainty: a guide to dealing with uncertainty in quantitative risk and policy analysis. Cambridge University Press, Cambridge.

Mount, R.H., ed. 1986. Vertebrate animals of Alabama in need of special attention. Alabama Agricultural Experiment Station, Auburn University, Alabama.

Neves, R. J., A. E. Bogan, J. D. Williams, S. A. Ahlstedt and P. W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of diversity. *Pages* 43-85 *in* G. W. Benz 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.

Olden, J.D. and D.A. Jackson. 2002. A comparison of statistical approaches for modelling fish species distributions Freshwater Biology 48:1976-1995.

Osborne, L.L. and M.J. Wiley. 1992. Influence of tributary spatial position on the structure of warm water fish communities. Canadian Journal of Fisheries and Aquatic Sciences 49:671-681.

Peterson, J.T. 2003. Toward the development of a common framework for assessing the distribution and potential threats to bull trout. Final Report to U.S. Fish and Wildlife Service, Aquatic Resources Division, Lacey, WA.

Peterson, J. T., and P. B. Bayley. 1993. Colonization rates of fishes in experimentally defaunated warmwater streams. Transactions of the American Fisheries Society 122: 199-207.

Peterson, J. T. and J. Dunham. 2003. Combining inferences from models of sampling efficiency, detectability, and suitable habitat to classify landscapes for conservation of threatened bull trout, Salvelinus confluentus. Conservation Biology 17:1070-1077.

Peterson, J. T., B. J. Freeman, E. Kramer, E. Irwin, M. C. Freeman, C. Straight, A. Wimberley, and J. C. Ruiz. 2003a. Aquatic GAP: Regional analysis of biodiversity in the ACT/ACF basins. Final Report to U.S. Geological Survey, Gap Analysis Program, Moscow, Idaho.

Peterson, J. T., C. R. Jackson, G. Li, J. McCargo, and R. McPherson. 2003b. The development and evaluation of tools for evaluating flow requirements in streams in the Lower Flint River Basin, Georgia. Annual Report to the Georgia Department of Natural Resources, Social Circle, GA.

Peterson, J. T., J.W. McCargo, and J.C. Ruiz. 2002. An evaluation of drought impacts on fish communities in the lower Flint River Basin, Georgia. Final Report to U.S. Fish and Wildlife Service, Ecological Services, Panama City, FL.

Peyton, J. S. and E. R. Irwin. 1997. Temporal dynamics of a shallow water fish assemblage in a shoals reach of the Coosa River. Final report submitted to Alabama Power Company. Birmingham, Alabama.

Rieman, B.E., J.T. Peterson, J. Clayton, W. Thompson, R.F. Thurow, P. Howell, and D.C. Lee. 2001 Evaluation of the potential effects of federal land management alternatives on the trends of salmonids and their habitats in the Interior Columbia River Basin. Journal of Forest Ecology and Management. 153:43-62.

Santhi, C., J. Arnold, J. Williams, W. Dugas, R. Srinivasan, and L. Hauck. 2001. Validation of the SWAT model on a large river basin with point and nonpoint sources. Journal of the American Water Resources Association 37:1169-1188.

SAS Institute. 2001. SAS Software for Version 8.1. SAS Institute, Inc. Cary, North Carolina.

Shreve, R. L. 1966. Statistical law of stream numbers. Journal of Geology 74:1737.

Shao, J. 1997. An asymptotic theory for linear model selection. Statistica Sinica 7:221-264.

Southwood, T. R. E. 1977. Habitat the templet for ecological strategies. Journal of Animal Ecology 46:337-365.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. American Geophysical Union Transactions 38:913-920.

Turner, G., E. Irwin, J. Peterson, B. Freeman, M. Freeman, E. Kramer, C. Straight, A. Wimberly, D. Moosman, C. Hayer, and J. Ruiz. 2004. Aquatic GAP: A GIS and modeling approach for analysis of biodiversity in the Tallapoosa River basin, Alabama and Georgia, S. Ramroop, editor. 2004. Proceedings of the Troy State University GIS Symposium, Troy State University, Troy, Alabama.

U.S. Department of Agriculture, Agricultural Research Service. 2005. ArcView Soil and Water Assessment Tool (AVSWAT).

U.S. Geological Survey. 1992. 1992 National Land Cover Dataset (NLCD). United States Department of the Interior, U.S. Geological Survey, Reston, Virginia.

U.S. Geological Survey. 1999. National Elevation Dataset (NED). United States Department of the Interior, U.S. Geological Survey, Reston, Virginia.

U.S. Geological Survey. 2001. National Hydrography Dataset (NHD). United States Department of the Interior, U.S. Geological Survey, Reston, Virginia.

U.S. Geological Survey. 2001. 2001 National Land Cover Dataset (NLCD). United States Department of the Interior, U.S. Geological Survey, Reston, Virginia.

Warren, M. L. and 11 co-authors. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. Fisheries 25(10):7-29.

Wharton, C. H. 1978. The natural environments of Georgia. Geologic and Water Resources Division and Resource Planning Section, Office of Planning and Research, Georgia Department of Natural Resources, Atlanta, GA.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from population of marked animals. Bird Study 46(supplement):120–139.

Williams, B.K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and Management of Animal Populations. Academic Press, New York.

Table 1.-Data sources for species locales in the ACT basin.

Source	Time period	Number of collections (State)
M. Pierson, unpublished[1]	Pre-1990	269[2] (AL, GA)
Freeman 1990	1989-1990	40 (GA)
Irwin et al. 1998	1997-1998	43 (AL, GA)
Irwin and Peyton 1997	1997	19 (AL)
Pierson 1999	1999	20 (AL, GA)
Costley 1997	1996	4 (AL)
GA DNR	2001	15 (GA)
AU and UAIC Fish collection databases	AU 1970-2006 UAIC 1970-2004	956[3]
SAR/CN	2001-2002	118 (AL, GA)

[1] Malcolm Pierson provided mapped localities for all Tallapoosa fishes, based pre-1990 records from diverse databases. These distribution maps were published, in whole or part, by Mettee et al. 1996.

[2] Number of sites, many with multiple collections.

[3] Total collections from the two databases for Alabama and Coosa basins; Tallapoosa basin collections number > 700.

Table 2. Source, location, and scale of landscape and stream reach data used for species distribution modeling and prediction.

Data Type	Source	Location	Scale
12-digit hydrologic units (subwatersheds)	USGS 1999 and NRCS 2003	http://water.usgs.gov/GIS/huc.html	1:24,000
Geology	USGS Digital Data Series 11, Release 2	http://pubs.usgs.gov/dds/dds11	1:2,500,000
Hydrography	USGS 1999	http://nhd.usgs.gov/	1:100,000
Land use and land-type	USGS 2001	http://landcover.usgs.gov/natllandcover.html	30 meter resolution
National Elevation Dataset	USGS 1999	http://gisdata.usgs.net/NED/default.asp	1:24,000
Physiography	Alabama Agricultural Experiment Station	---	1:2,000,000
Roads	US Census Bureau	http://www.census.gov/geo/www/tiger	1:100,000
Sample site locations	Compiled by: Alabama Cooperative Fish and Wildlife Research Unit	---	---

Table 3. The mean, standard deviation (SD), and range of sample reach (N= 1,211) and subwatershed (N= 372) characteristics used to fit species-specific models of presence in the ACT Basin. Data are from the 2001 NLCD; see methods and the summary data include the Tallapoosa Basin.

Characteristic	Abbreviation	Mean	SD	Range
Sample reach				
Site elevation (m)	ELEV	157.39	91.22	0 – 391.54
Stream gradient (%)	SLOPE	5.31	7.12	0 – 58.01
Stream aspect (degrees)	ASPECT	165.73	99.06	-1 – 359.79
Stream link magnitude	LINK_MAG	919.20	4067.91	1 - 33001
Link magnitude of nearest downstream reach	D_LINK	1227.39	4495.80	2 - 33002
Stream Order	STREAM_ORD	3.3	1.56	1 - 7
Isolation (% of sampled stream reaches)	ISOLATION	1.08	0.27	1 - 2
Subwatershed				
Drainage density (km/km^2)	STR_DEN	0.86	0.09	0.67 – 1.33
Road density (km/km^2)	RD_DEN	1.76	0.68207	0.6 - 4.74
Percent of adjacent subwatersheds occupied (varied among species)	PCTADJ			
Road Length (km)	RD_LEN	193.96	107.836	29.35 - 830.01
Stream Length (km)	STR_LEN	98.38	44.85	23.66 – 254.27
Area (km^2)	AREA	114.69	52.01	26.82 – 271.97
Perimeter (km)	PERI	65	19.12	26.02 – 130.26
Acres	ACRES	28339.77	12851.37	6626– 67206
Number of Impoundments	IMP	6.83	8.12	0 - 60
Located above or below fall line (%)	FALL_LINE**	67%		
Located within the Little Tallapoosa River Basin (%)	LITTLE_TAL**	6%		
Watershed	WATERSHED	2.15	0.96	1 - 4

Table 3. (continued)

Characteristic	Abbreviation	Mean	SD	Range
Parent geology composition (% of subwatershed)				
Holocene	HOL_1	0.01	0.06	0 - 1
Pliocene continental	PIL_2	0.01	0.07	0 – 0.86
Miocene	MIO_3	0.02	0.09	0 – 0.77
Oligocene	OLI_4	0.01	0.06	0 – 0.64
Eocene Jackson Group	EOC_5	0	0.04	0 – 0.55
Eocene Claiborne Group	EOC_6	0.02	0.11	0 – 1
Eocene Wilcox Group	EOC_7	0.04	0.17	0 – 1
Paleocene	PAL_8	0.03	0.15	0 – 1
Navarro Group	NAV_9	0.03	0.12	0 – 0.94
Taylor Group	TAY_10	0.14	0.31	0 – 1
Austin and Eagle Ford Groups	AUS_11	0.09	0.24	0 – 1
Woodbine and Tuscaloosa groups	WOO_12	0.10	0.25	0 – 1
Ultramafic rocks	ULT_13	0	0.04	0 – 0.47
Catacalastic rocks	CAT_14	0.01	0.04	0 – 0.53
Atokan and Morrowan Series	ATO_15	0.02	0.09	0 – 0.89
felsic paragneiss and schist	FEL_16	0.01	0.05	0 – 0.44
mafic paragneiss	MAF_17	0.02	0.10	0 – 0.77
Paleozoic mafic intrusives	PAL_18	0.01	0.06	0 – 0.51
felsic orthogneiss	FEL_19	0	0.05	0 – 0.03
Mississippian	MIS_20	0.05	0.17	0 – 1
Middle Paleozoic granitic rocks	MID_21	0	0.04	0 – 0.4
Devonian and Silurian	DEV_22	0.02	0.08	0 – 0.55
Lower Paleozoic	LOW_23	0.18	0.06	0 – 1

Table 3. (continued)

Characteristic	Abbreviation	Mean	SD	Range
Parent geology composition (% of subwatershed)				
Ordovician	ORD_24	0.07	0.19	0 – 1
Lower Paleozoic granitic rocks	LOW_25	0.05	0.15	0 – 0.89
Cambrian	CAM_26	0.03	0.12	0 – 0.93
Basal Lower Cambrian clastic rocks	BAS_27	0.01	0.04	0 – 0.41
Z sedimentary rocks	SED_28	0.03	0.13	0 – 1
Orthogneiss	ORT_29	0.01	0.06	0 – 0.94
Land use/ land type composition (% of subwatershed)				
Water	WATER	0.02	0.05	0 – 0.53
Urban	URBAN	0.06	0.06	0 – 0.45
Barren	BARREN	0	0.01	0 – 0.04
Mixed Forest	MIXED	0.08	0.08	0 – 0.37
Evergreen Forest	EVER	0.21	0.10	0 – 0.66
Deciduous Forest	DEC	0.25	0.15	0 – 0.64
Rangeland	RANGE	0.11	0.05	0 – 0.32
Agriculture	AG	0.17	0.12	0 – 0.51
Wetland	WET	0.09	0.11	0 – 0.86
Physiographic providence composition (% of subwatershed)				
Appalachian Plateau	APPALACH	0.02	0.14	0 - 1
Ridge and Valley	RIDGE_VALLEY	0.15	0.34	0 - 1
Piedmont	PIEDMONT	0.33	0.46	0 - 1
Fall Line Hills	FALL_HILLS	0.19	0.36	0 - 1
Black Belt	BLK_BLT	0.14	0.32	0 - 1
Chunnenuggee Hills	CHUN_HILLS	0.05	0.16	0 - 1
Red Hills	RED_HILLS	0.04	0.19	0 - 1
Lower Coastal Plain	LWR_COAST			

*Values represent entire ACT basin, not subwatershed

**Percentage above and below fall line and proportion of Tallapoosa Basin within the Little Tallapoosa Basin

Table 4. The mean, standard deviation (SD), and range of sample reach (N= 293) and subwatershed (N= 123) characteristics used to fit species-specific models of presence in the Tallapoosa River Basin. Data are from the 1992 NLCD (see methods).

Characteristic	Abbreviation	Mean	SD	Range
Sample reach				
Site elevation (m)	ELEV	225.84	98.00	39-384
Stream gradient (%)	SLOPE	2.33	2.62	0-16
Stream aspect (degrees)	ASPECT	203.27	87.10	-1-360
Stream link magnitude	LINK_MAG	188.75	455.69	1-2127
Link magnitude of nearest downstream reach	D_LINK	243.10	477.50	0-2125
Stream Order	STR_ODR	3.71	2.81	1-12
Isolation (% of sampled stream reaches)	ISOLATION	19.11	-	-
Subwatershed				
Drainage density (km/km^2)	DRN_DENS	0.94	0.19	0-1.45
Road density (km/km^2)	RDDENS	1.88	0.58	1-4
Percent of adjacent subwatersheds occupied (varied among species)	PCTADJ	0.32	0.20	0-1
Road Length (km)	RD_LEN	173.09	87.96	45-506
Stream Length (km)	STR_LEN	94.16	58.50	8-329
Area (km^2)	AREA	98.40	52.60	27-261
Perimeter (km)	PERI	57.74	19.51	28-121
Acres	ACRES	24313	12995	6626-64520
Number of Impoundments	IMP	48.31	39.62	0-208
Located above or below fall line (%)	FALL_LINE	26*	41*	-
Located within the Little Tallapoosa River Basin (%)	LIT_TAL	25*	40*	-

Table 4. (continued)

Characteristic	Abbreviation	Mean	SD	Range
Parent geology composition (% of subwatershed)				
Austin and Eagle Ford Groups	AUS_1	5.89	18.33	0-92
Cataclastic Rocks	CAT_2	1.71	6.76	0-53
Devonian and Silurian	DEV_3	0.13	0.76	0-6.43
Felsic Orthogneiss (=orthogneiss)	FEL_4	0.09	1.00	0-11
Felsic Paragneiss and schist	FEL_5	2.14	7.99	0-44
Lower Paleozoic	LOW_6	41.93	40.82	0-100
Lower Paleozoic Granitic Rocks	LOW_7	11.81	21.06	0-89
Mafic Paragneiss and Schist	MAF_8	6.86	16.00	0-77
Middle Paleozoic Granitic Rocks	MID_9	0.30	3.01	0-33
Navarro Group	NAV_10	0.58	4.39	0-35
Orthogneiss	ORT_11	1.84	9.74	0-94
Paleozoic Mafic Intrusives	PAL_12	3.02	8.63	0-51
Taylor Group	TAY_13	6.15	20.44	0-99
Ultramafic Rocks	ULT_14	1.34	6.52	0-47
Woodbine and Tuscaloosa Groups	WOO_15	8.07	22.40	0-98
Z Sedimentary Rocks	ZSE_16	8.20	19.29	0-100
Land use/ land type composition (% of subwatershed)				
Agricultural	AGRI	16.42	11.34	1-50
Barrenland	BARREN	1.2	1.39	0-8
Forestland	FOREST	75.24	14.00	38-95
Wetland	WET	3.51	5.26	0-27
Water	WATER	2.41	6.89	0-50
Commercial/Industrial/Urban	URBAN	1.22	2.37	0-20

Table 4. (continued)

Characteristic	Abbreviation	Mean	SD	Range
Land use/ land type composition (% of subwatershed)				
Mixed Forest	MIXED	24.35	5.14	13-37
Deciduous	DEC	32.96	9.53	12-54
Evergreen	EVER	17.87	6.36	3-37
High Intensity Urban	HIGH_INT	0.11	0.32	0-2
Low Intensity Urban (residential)	LOW_INT	0.58	1.19	0-9
Commercial and Industrial	COMM_IND	0.51	0.92	0-7
Physiographic providence composition (% of subwatershed)				
Chunnenugee Hills	CHUN_HILLS	4.15	14.62	0-68
Black Black	BLACK_BELT	6.17	19.95	0-94
Fall Hills	FALL_HILLS	12.44	28.98	0-100
Piedmont	PIEDMONT	77.25	40.82	0-100

*Values represent entire Tallapoosa River basin, not subwatershed

Table 5.-Individual species modeled and detection probabilities used for model weights.

Species Name	Common Name	Detection Probability
Ambloplites ariommus	shadow bass	0.544
Ameiurus natalis	yellow bullhead	0.266
Ameiurus nebulosus	brown bullhead	0.013
Campostoma oligolepis	largescale stoneroller	0.754
Carpiodes velifer	highfin carpsucker	0.348
Cottus carolinae	banded sculpin	0.515
Cottus sp. cf. *C. bairdii*	Tallapoosa sculpin	0.333
Cyprinella callistia	Alabama shiner	0.799
Cyprinella gibbsi	Tallapoosa shiner	0.056
Cyprinella trichroistia	tricolor shiner	0.056
Cyprinella venusta	blacktail shiner	0.994
Cyprinus carpio	common carp	0.013
Dorosoma cepedianum	American gizzard shad	0.147
Esox americanus	redfin pickerel	0.019
Esox niger	chain pickerel	0.006
Etheostoma artesiae	redspot darter	0.243
Etheostoma chuckwachatte	lipstick darter	0.733
Etheostoma coosae	Coosa darter	0.600
Etheostoma ditrema	coldwater darter	0.050
Etheostoma jordani	greenbreast darter	0.694
Etheostoma ramseyi	Alabama darter	0.266
Etheostoma stigmaeum	speckled darter	0.660
Etheostoma swaini	gulf darter	0.120
Etheostoma tallapoosae	Tallapoosa darter	0.300
Fundulus bifax	stippled studfish	0.567
Fundulus olivaceus	blackspotted topminnow	0.378
Fundulus stellifer	southern studfish	0.378
Gambusia affinis	western mosquitofish	0.697
Hybopsis lineapunctata	lined chub	0.167
Hypentelium etowanum	Alabama hog sucker	0.611
Ichthyomyzon gagei	southern brook lamprey	0.166
Ictalurus punctatus	channel catfish	0.504
Lepomis auritus	redbreast sunfish	0.456
Lepomis cyanellus	green sunfish	0.611
Lepomis gulosus	warmouth	0.631
Lepomis macrochirus	bluegill	0.703
Lepomis megalotis	longear sunfish	0.773
Lepomis microlophus	redear sunfish	0.367
Luxilus chrysocephalus	striped shiner	0.423
Luxilus zonistius	bandfin shiner	0.430
Lythrurus bellus	pretty shiner	0.578
Lythrurus lirus	mountain shiner	0.067

Table 5.-continued

Macrhybopsis aestivalis	speckled chub	0.735
Macrhybopsis storeriana	silver chub	0.441
Micropterus coosae	redeye bass	0.344
Micropterus punctulatus	spotted bass	0.443
Micropterus salmoides	largemouth bass	0.383
Minytrema melanops	spotted sucker	0.456
Moxostoma duquesnei	black redhorse	0.493
Moxostoma poecilurum	blacktail redhorse	0.519
Nocomis leptocephalus	bluehead chub	0.456
Notemigonus crysoleucas	golden shiner	0.013
Notropis ammophilus	orangefin shiner	0.912
Notropis asperifrons	burrhead shiner	0.460
Notropis atherinoides	emerald shiner	0.309
Notropis baileyi	rough shiner	0.629
Notropis buccatus	silverjaw minnow	0.560
Notropis chrosomus	rainbow shiner	0.460
Notropis stilbius	sliverstripe shiner	0.266
Notropis texanus	weed shiner	0.669
Notropis uranoscopus	skygazer shiner	0.803
Notropis volucellus	mimic shiner	0.817
Notropis xaenocephalus	Coosa shiner	0.560
Noturus funebris	black madtom	0.013
Noturus leptacanthus	speckled madtom	0.456
Opsopoeodus emiliae	pugnose minnow	0.407
Percina kathae	Mobile logperch	0.266
Percina nigrofasciata	blackbanded darter	0.839
Percina palmaris	bronze darter	0.767
Percina smithvanizi	muscadine darter	0.850
Phenacobius catostomus	riffle minnow	0.750
Pimephales notatus	bluntnose minnow	0.500
Pimephales vigilax	bullhead minnow	0.800
Pomoxis nigromaculatus	black crappie	0.407
Pylodictis olivaris	flathead catfish	0.088
Semotilus atromaculatus	creek chub	0.100
Semotilus thoreauianus	dixie chub	0.100

Table 5.-List of species of Greatest Conservation Need (GCN) in the study area.

Species name	Common name	Remarks
Alosa alabamae	Alabama shad	One UAIC record in the Cahaba River prior to 1970
Acipenser fulvescens	lake sturgeon	No records in our database
Acipenser oxyrinchus desotoi	gulf sturgeon	One UAIC record from Perdido Bay 1971
Scaphirhynchus suttkusi	Alabama sturgeon	9 records in database
Polyodon spatula	paddlefish	11 records in database
Atracosteus spatula	alligator gar	One record from the Alabama River
Hemitremia flammea	flame chub	Few records from small Coosa River tributaries, recent record (1986) from Hatchet Creek at Hwy 231
Hybopsis lineapunctata	lined chub	1987 records from Hatchet creek; predictive distribution models completed
Macrhybopsis aestivalis	"fall line chub" and "Pine hills chub"	Cryptic species complex; predictive distribution models completed
Notropis cahabae	Cahaba shiner	Records from only 10 sites in Cahaba River
Notropis chalybaeus	ironcolor shiner	1967 was last record in database
Pteronotropis welaka	bluenose shiner	Few records (4 sites); last record in 2000
Cycleptus meridionalis	southeastern blue sucker	Recent records known, but few (13) in database
Noturus munitus	frecklebelly madtom	Records from only 10 sites in Cahaba River
Typhlichthys subterraneus		GAP models not suitable for this species
Fundulus bifax	stippled studfish	predictive distribution models completed
Cottus paulus	pygmy sculpin	Very limited range
Crystallaria asperella	crystal darter	Records from only 19 sites in the Tallapoosa River; 12 sites in the Cahaba River; 4 sites in the Alabama River; 1 site in the Coosa River
Etheostoma brevirostrum	coal darter	Extant in Coosa (complex of cryptic species-4 others in Upper Coosa)
Etheostoma chuckwachatte	lipstick darter	State listed, populations stable in Alabama; predictive distribution models completed
Etheostoma ditrema	coldwater darter	predictive distribution models completed
Etheostoma sp. cf ditrema	coldwater darter	Middle Coosa and cold water spring cryptic fauna
Percina brevicauda	coal darter	Records from only 10 sites in Cahaba River; one in Coosa River (Hatchet Creek)
Percina lenticula	freckled darter	Records from only 16 sites in the Tallapoosa River; 5 in the Cahaba River
Percina smithvanizi	muscadine darter	predictive distribution models completed

Table 7.-Category-wise and overall classification error rates and optimal number of neighbors (K) of best predicting K nearest neighbor models of species presence in sample reaches in the Alabama River Basin. Error rates are expressed as a percentage and variable names and abbreviations can found in Table 3.

Species	Model	K	Absent	Present	Overall
Cyprinidae					
Campostoma oligolepis	ELEV RANGE CHUN_HILLS EVER	5	23.2	3.7	19.2
Luxilus chrysocephalus	BARREN STR_DEN AUS_11 IMP	2	25.3	10.4	20.0
Lythrurus bellus	A_LYTHBE LINK_MAG RD_DEN	18	19.3	25.5	21.4
Macrhybopsis storeriana	FALL_HILLS EVER D_LINK A_MACRST RD_DEN PIL_2	3	12.8	9.5	11.8
Nocomis leptocephalus	CHUN_HILLS TAY_10 LWR_COAST URBAN D_LINK	5	24.5	9.0	20.7
Notropis ammophilus	RED_HILLS STR_DEN D_LINK RD_DEN TAY_10 A_NOTRAM	2	35.6	10.9	25.2
Notropis atherinoides	RED_HILLS STR_DEN D_LINK RD_DEN STREAM_ORD EOC_5	7	20.9	5.0	18.5
Notropis baileyi	ELEV RANGE RD_LEN CHUN_HILLS EVER STREAM_ORD	12	29.1	7.1	20.0
Notropis buccatus	RANGE STREAM_ORD SLOPE	11	32.7	21.6	29.6
Notropis stilbius	DEC URBAN STR_DEN STREAM_ORD SLOPE	7	19.1	.	16.3
Notropis texanus	EVER D_LINK RD_DEN STREAM_ORD SLOPE	7	28.6	12.1	21.5
Opsopoeodus emiliae	TAY_10 LINK_MAG MIO_3 CHUN_HILLS	2	14.0	19.0	14.8
Pimephales notatus	ELEV RANGE BLK_BLT LOW_23 AUS_11	13	24.0	3.2	19.3
Semotilus atromaculatus	D_LINK LWR_COAST LOW_23	6	25.9	.	21.5
Catostomidae					
Carpiodes velifer	RED_HILLS D_LINK STREAM_ORD IMP	11	26.2	.	23.7
Hypentelium etowanum	IMP STR_DEN CAT_14 MIO_3 LOW_23	9	27.6	3.3	22.2
Moxostoma poecilurum	STR_DEN STREAM_ORD	21	42.7	20.5	36.3
Ictaluridae					
Noturus leptacanthus	EVER STR_DEN D_LINK RD_DEN EOC_6	5	14.2	6.9	12.6
Esocidae					
Esox americanus	LINK_MAG DEC MIO_3	11	25.5	8.0	22.2
Fundulidae					
Fundulus olivaceus	WATER OLI_4	3	13.2	38.4	22.9
Poeciliidae					
Gambusia affinis	BLK_BLT CAT_14 AUS_11 ISOLATION LINK_MAG	11	29.1	21.8	27.4
Cottidae					
Cottus carolinae	MIXED STR_DEN AUS_11 A_COTTCA	6	11.6	4.3	10.4
Centrarchidae					
Lepomis cyanellus	CAT_14 WATER ISOLATION PIL_2	12	40.4	6.5	32.5

Table 7. (continued)

Lepomis macrochirus	BLK_BLT WOO_12 MIO_3	7	32.6	23.3	29.6
Lepomis megalotis	A_LEPOME RED_HILLS D_LINK STR_DEN	10	33.3	27.3	30.4
Micropterus punctulatus	A_MICRPU D_LINK	11	18.3	19.2	18.5
Micropterus salmoides	STREAM_ORD AUS_11 D_LINK	23	27.0	37.1	29.6
Percidae					
Etheostoma artesiae	ELEV RANGE PIL_2 BLK_BLT	4	29.2	9.1	25.9
Etheostoma ramseyi	ELEV A_ETHERA MIS_20 BARREN BLK_BLT	9	30.4	13.3	26.6
Etheostoma stigmaeum	RED_HILLS URBAN STR_LEN AUS_11	3	15.6	15.1	15.5
Percina nigrofasciata	D_LINK EVER STR_DEN STREAM_ORD	7	35.9	8.8	24.4

Table 8.-Category-wise and overall classification error rates and optimal number of neighbors (K) of best predicting K nearest neighbor models of species presence in sample reaches in the Coosa River Basin. Error rates are expressed as a percentage and variable names and abbreviations can found in Table 3.

Species	Model	K	Absent	Present	Overall
Cyprinidae					
Campostoma oligolepis	STREAM_ORD CAT_14 WATER	20	40.7	29.3	35.4
Cyprinella callistia	D_LINK URBAN BARREN	2	20.2	17.6	19.6
Cyprinella trichroistia	STR_DEN DEC D_LINK IMP	4	20.6	24.1	21.9
Cyprinella venusta	RIDGE_VALL ELEV RD_LEN BARREN CAM_26	21	35.4	19.1	32.3
Hybopsis lineapunctata	MIXED RD_DEN STREAM_ORD CAT_14	23	15.6	6.3	15.2
Luxilus chrysocephalus	FALL_HILLS WET AG SLOPE	9	18.9	7.5	17.7
Lythrurus lirus	RIDGE_VALL ELEV STREAM_ORD CAT_14	15	29.8	14.5	27.8
Nocomis leptocephalus	MIXED RIDGE_VALL RANGE STREAM_ORD DEV_22	6	13.7	5.0	13.2
Notemigonus crysoleucas	RIDGE_VALL ELEV SLOPE FALL_LINE APPALACH	18	30.7	15.0	29.8
Notropis asperifrons	APPALACH STR_DEN D_LINK IMP	8	21.5	11.1	20.2
Notropis baileyi	FALL_HILLS FALL_LINE SLOPE LOW_25	4	5.7	.	5.3
" "	FALL_HILLS WET SLOPE BARREN	5	6.0	.	5.6
Notropis chrosomus	RD_DEN DEV_22 SLOPE WET RIDGE_VALL	13	32.9	18.2	30.6
Notropis stilbius	PIEDMONT LINK_MAG APPALACH	6	21.3	15.0	20.2
Notropis xaenocephalus	RIDGE_VALL ELEV RD_LEN BARREN EVER ISOLATION	3	32.7	13.3	27.0
Phenacobius catostomus	D_LINK IMP A_PHENCA RIDGE_VALL	10	27.8	6.9	26.1
Semotilus atromaculatus	LINK_MAG RANGE ATO_15 CAM_26	6	39.9	18.2	34.6
Catostomidae					
Hypentelium etowanum	APPALACH A_HYPEET LINK_MAG	15	47.4	21.9	37.3
Moxostoma duquesnei	SED_28 RIDGE_VALL SLOPE URBAN	6	45.0	13.8	39.9
Moxostoma poecilurum	ELEV APPALACH WATER URBAN	14	29.1	7.7	27.5
Ictaluridae					
Ameiurus natalis	LINK_MAG RANGE ORT_29 ATO_15 BAS_27	16	21	12.5	20.2
Noturus leptacanthus	WOO_12 AG WET SLOPE	9	21.5	15.0	21.0
Esocidae					
Esox niger	ELEV WET	14	24.2	23.0	24.1
Fundulidae					
Fundulus olivaceus	ELEV CAM_26 ATO_15	11	26.8	7.4	23.8
Fundulus stellifer	FALL_LINE MID_21 ELEV RD_LEN	10	30.9	5.5	28.3
Poeciliidae					

Table 8. (continued)

Gambusia affinis	RD_DEN STREAM_ORD CAT_14	19	36.9	22.2	33.9
Cottidae					
Cottus carolinae	D_LINK MID_21 WATER ORD_24	2	31.3	14.5	24.4
Centrarchidae					
Ambloplites ariommus	PIEDMONT LINK_MAG CAT_14 MID_21	15	25.3	15.6	24.4
Lepomis auritus	RIDGE_VALL BARREN URBAN ELEV	5	21.3	5.7	19.1
Lepomis cyanellus	RIDGE_VALL MIXED WET ORT_29	12	36.3	31.1	34.5
Lepomis gulosus	RIDGE_VALL ELEV DEV_22 WATER WET	19	32.4	22.8	30.9
Lepomis macrochirus	RIDGE_VALL D_LINK WATER PAL_18	19	28.7	43.9	33.7
Lepomis megalotis	ELEV RD_LEN EVER	22	34.7	28.7	32.3
Lepomis microlophus	RIDGE_VALL D_LINK STR_LEN SLOPE	5	31.7	17.0	30.0
Micropterus coosae	FALL_LINE RD_DEN	16	33.6	33.0	33.4
Micropterus punctulatus	LINK_MAG CAT_14	23	33.0	22.7	31.7
Micropterus salmoides	STR_LEN D_LINK WATER ATO_15 BAS_27	14	38.9	28.7	37.0
Percidae					
Etheostoma artesiae	D_LINK WET AG LOW_23	14	8.5	3.7	8.1
Etheostoma coosae	D_LINK URBAN BAS_27	15	36.2	22.4	30.9
Etheostoma ditrema	APPALACH STR_DEN DEC LOW_25	8	18.5	8.1	17.1
" "	STR_DEN DEC MID_21	8	20.8	8.1	19.1
Etheostoma jordani	APPALACH RD_DEN D_LINK ISOLATION CAT_14	2	17.6	15.0	17.1
Etheostoma stigmaeum	MIXED RD_DEN ISOLATION STREAM_ORD SLOPE	7	31.1	18.6	27.5
Percina kathae	LINK_MAG WATER A_PERCKA PAL_18	8	36.8	19.0	32.6
Percina nigrofasciata	MIXED RD_DEN ISOLATION STREAM_ORD CAT_14	8	32.6	28.1	30.9
Percina palmaris	PIEDMONT RANGE	3	11.7	4.3	10.7

Table 9.-Category-wise and overall classification error rates and optimal number of neighbors (K) of best predicting K nearest neighbor models of species presence in sample reaches in the Tallapoosa River Basin. Error rates are expressed as a percentage and variable names and abbreviations can found in Table 4.

Species	Model	K	Absent	Present	Overall
Petromyzontidae					
Ichthyomyzon gagei	IMP STR_ODR MIXED CAT_2	22	27.6	31.3	28.7
Clupeidae					
Dorosoma cepedianum	ORT_11 PAL_12 LINK_MAG ISOLATION LIT_TAL A_DOROCE	14	16.2	4.8	15.4
Cyprinidae					
Campostoma oligolepis	ORT_11 ELEV IMP HIGH_INT BARREN	10	26.1	24.4	24.9
Cyprinella callistia	AGRI STR_ODR LOW_INT WATER	13	12.8	28.9	17.8
Cyprinella gibbsi	MID_9 DEC RD_DEN ISOLATION	13	28.8	17.1	21.8
Cyprinella venusta	MID_9 FALL_LINE LINK_MAG	2	15.3	22.8	18.8
Cyprinus carpio	WATER FEL_5 MAF_8 FALL_LINE STR_ODR MIXED	14	21.7	4.8	20.5
Hybopsis lineapunctata	FEL_5 LOW_7 ZSE_16 LINK_MAG FEL_4 MIXED FALL_LINE COMM_IND	9	34.8	13.2	25.3
Luxilus chrysocephalus	STR_DEN EVER SLOPE AUS_1 CAT_2 ELEV FOREST	13	26.7	28.6	28.0
Luxilus zonistius	AUS_1 FEL_5 STR_LEN WET BLACK_BELT	3	8.4	12.5	8.9
Lythrurus bellus	STR_ODR ULT_14 URBAN WOO_15 ELEV FOREST IMP BARREN	3	18.5	19.4	18.7
Macrhybopsis aestivalis	WATER CAT_2 DEV_3 PAL_12 FALL_LINE STR_ODR	12	12.4	17.6	13.0
Macrhybopsis storeriana	ORT_11 FALL_HILLS FOREST LINK_MAG ISOLATION	6	7.0	.	6.5
Nocomis leptocephalus	FALL_LINE LOW_7 FEL_4 URBAN MID_9 ISOLATION LINK_MAG	14	30.4	22.5	25.6
Notemigonus crysoleucas	FALL_HILLS ISOLATION LIT_TAL WET URBAN TAY_13 FEL_4	9	29.4	22.0	28.3
Notropis ammophilus	RD_LEN ISOLATION SLOPE MID_9 ELEV HIGH_INT BARREN CHUN_HILLS	8	7.4	2.7	6.8
Notropis atherinoides	ULT_14 FALL_HILLS FOREST LINK_MAG COMM_IND	15	11.0	10.0	10.9
Notropis baileyi	MIXED COMM_IND D_LINK DEC ZSE_16 WATER CHUN_HILLS AUS_1	8	18.7	5.1	15.0
Notropis buccatus	ELEV STR_ODR AGRI	7	12.7	7.1	12.0
Notropis stilbius	LINK_MAG WOO_15 AUS_1	9	17.9	14.1	17.1
Notropis texanus	URBAN RD_DEN WET DEV_3	5	18.5	2.9	16.7
Notropis uranoscopus	PIEDMONT CAT_2 STR_ODR	4	6.4	3.7	6.1
Notropis volucellus	ELEV HIGH_INT ISOLATION ORT_11	13	11.2	8.3	10.9
Phenacobius catostomus	FALL_HILLS LINK_MAG	18	16.5	17.5	16.7
" "	PIEDMONT LINK_MAG	18	16.5	17.5	16.7
Pimephales vigilax	STR_ODR WET	4	21.6	18.1	20.5
Semotilus atromaculatus	CAT_2 FEL_4 FEL_5 STR_ODR ELEV RD_LEN COMM_IND	25	39.7	24.5	34.8
Semotilus thoreauianus	ZSE_16 LOW_INT ELEV	15	16.5	5.0	15.7

Table 9. (continued)

Catostomidae					
Carpiodes velifer	TAY_13 FALL_LINE AGRI MIXED WATER ISOLATION	2	5.5	.	5.1
Hypentelium etowanum	CHUN_HILLS FALL_LINE STR_ODR MIXED LOW_INT WATER	17	22.0	27.0	25.6
Minytrema melanops	STR_ODR DEC ELEV RD_LEN STR_LEN WET	12	30.2	8.0	28.3
Moxostoma duquesnei	MAF_8 ORT_11 PAL_12 STR_ODR MIXED	11	23.5	25.0	23.9
Moxostoma poecilurum	IMP FEL_5 LOW_6 STR_ODR MIXED WATER	7	27.7	31.7	29.4
Ictaluridae					
Ameiurus natalis	FEL_4 LOW_7 RD_DEN WATER A_AMEINA	11	46.9	16.7	42.0
Ameiurus nebulosus	LOW_INT FOREST SLOPE LINK_MAG WATER	13	25.2	21.7	24.9
Ictalurus punctatus	CAT_2 A_ICTAPU LINK_MAG LIT_TAL DEV_3	14	20.9	17.5	20.1
Noturus funebris	LIT_TAL ELEV SLOPE FOREST TAY_13	9	30.7	22.3	27.0
Noturus leptacanthus	LINK_MAG WATER ZSE_16 WOO_15	7	17.4	25.9	19.1
Pylodictis olivaris	WOO_15 STR_ODR ELEV	25	19.0	4.2	17.8
Esocidae					
Esox americanus	TAY_13 STR_DEN D_LINK	6	12.5	9.5	12.3
Fundulidae					
Fundulus bifax	LOW_7 WATER WET LIT_TAL IMP WOO_15 LINK_MAG AGRI STR_DEN	11	14.7	3.7	13.7
Fundulus olivaceus	A_FUNDOL ELEV FOREST COMM_IND ORT_11 WATER	2	17.3	11.9	16.0
Poeciliidae					
Gambusia affinis	ELEV LOW_7 MID_9 ORT_11 LINK_MAG ISOLATION LIT_TAL	10	22.7	28.4	24.6
Cottidae					
Cottus carolinae	DEV_3 ELEV ISOLATION WATER	21	31.6	8.9	27.3
Cottus sp. cf. *C. bairdii*	DEV_3 A_COSPCF STR_ODR STR_DEN MIXED EVER	10	31.1	14.8	23.2
Centrarchidae					
Ambloplites ariommus	LIT_TAL A_AMBLAR TAY_13 STR_ODR MIXED WATER	7	18.4	9.3	16.7
Lepomis auritus	MAF_8 MID_9 LINK_MAG ISOLATION LIT_TAL ELEV STR_DEN DEV_3	11	18.7	25.3	22.9
Lepomis cyanellus	FEL_5 ELEV IMP HIGH_INT DEV_3	25	25.0	43.4	34.8
Lepomis gulosus	ULT_14 PIEDMONT STR_DEN D_LINK RD_DEN SLOPE	9	25.0	26.2	25.3
Lepomis macrochirus	ORT_11 D_LINK LIT_TAL	17	29.7	35.6	33.8
Lepomis megalotis	ELEV HIGH_INT SLOPE MID_9 ORT_11 TAY_13	5	9.8	3.4	8.5
Lepomis microlophus	LINK_MAG ISOLATION LIT_TAL	7	31.9	11.1	29.4
Micropterus coosae	FALL_LINE AGRI STR_ODR	14	35.8	22.1	29.7
Micropterus punctulatus	CHUN_HILLS DEV_3 LINK_MAG URBAN LIT_TAL	11	16.4	23.8	18.4
Micropterus salmoides	STR_ODR MID_9 WET FEL_5 FALL_HILLS LINK_MAG COMM_IND LIT_TAL	8	23.5	30.0	25.9

Table 9. (continued).

Pomoxis nigromaculatus	ULT_14 CAT_2 D_LINK URBAN	14	31.6	21.4	29.7
Percidae					
Etheostoma chuckwachatte	LIT_TAL MAF_8 FALL_LINE STR_ODR AGRI WATER	4	19.5	4.2	15.7
Etheostoma stigmaeum	STR_ODR HIGH_INT LIT_TAL EVER	6	31.1	23.5	27.7
Etheostoma swaini	FALL_LINE A_ETHESW	2	10.3	.	9.6
Etheostoma tallapoosae	A_ETHETA PIEDMONT STR_DEN D_LINK ISOLATION LIT_TAL HIGH_INT	3	33.6	24.4	28.3
Percina kathae	LINK_MAG ISOLATION WOO_15	4	24.3	17.4	23.2
Percina nigrofasciata	BARREN WET ORT_11 FALL_HILLS LOW_INT LIT_TAL	2	9.4	3.4	8.2
Percina palmaris	FALL_LINE STR_ODR LOW_INT	11	23.9	16.8	21.2
Percina smithvanezi	ISOLATION LIT_TAL FALL_LINE STR_ODR MIXED LOW_INT	4	26.6	12.9	20.1

Table 10- Land Use/Land Cover distribution within the model area.

Class	NLCD 1992 Hectares	NLCD 1992 Share	NLCD 2001 Hectares	NLCD 2001 Share	Unweighted Change Acres	Unweighted Change Share
Developed Land	1481	10.8%	3302	24.2%	1820	13.3%
Forested Land	10076	73.7%	7526	55.0%	-2550	18.7%
Range/Brush	69	0.5%	824	6.0%	754	5.5%
Pasture	927	6.8%	1391	10.2%	464	3.4%
Agricultural	726	5.3%	20	0.1%	-706	-5.2%
Wetlands	188	1.4%	227	1.7%	39	0.3%
Other(water/barren)	204	1.5%	382	2.8%	179	1.3%
Total	13672	100%	13672	100%		

Table 11.- Results of the two SWAT models constructed for the urbanized area of Saugahatchee Creek watershed, Alabama. Area (137.051 km²)

Parameter	NLCD 1992		NLCD 2001		Change	
	5-yrs	17-yrs	5-yrs	17-yrs	5-yrs	17-yrs
Nitrogen runoff (kg/ha)	1.14	1.19	1.48	1.55	30.0%	29.9%
Total Nitrogen runoff (kg)	15624	16374	20311	21267	30.0%	29.9%
Phosphorus runoff (kg/ha)	0.08	0.08	0.10	0.12	21..4%	45.8%
Total Phosphourus runoff (kg)	1151	1145	1398	1669	21.4%	45.8%
Sedimentation (ton/ha)	1.20	1.86	3.75	3.58	212.5%	92.7%
Total Sedimentation (tons)	16501	25435	54711	49024	212.5%	92.7%
Total Water Yield (mm)	645	668	681	709	5.5%	6.2%
Surface Water Runoff (mm)	163	181	231	225	41.6	24.3%

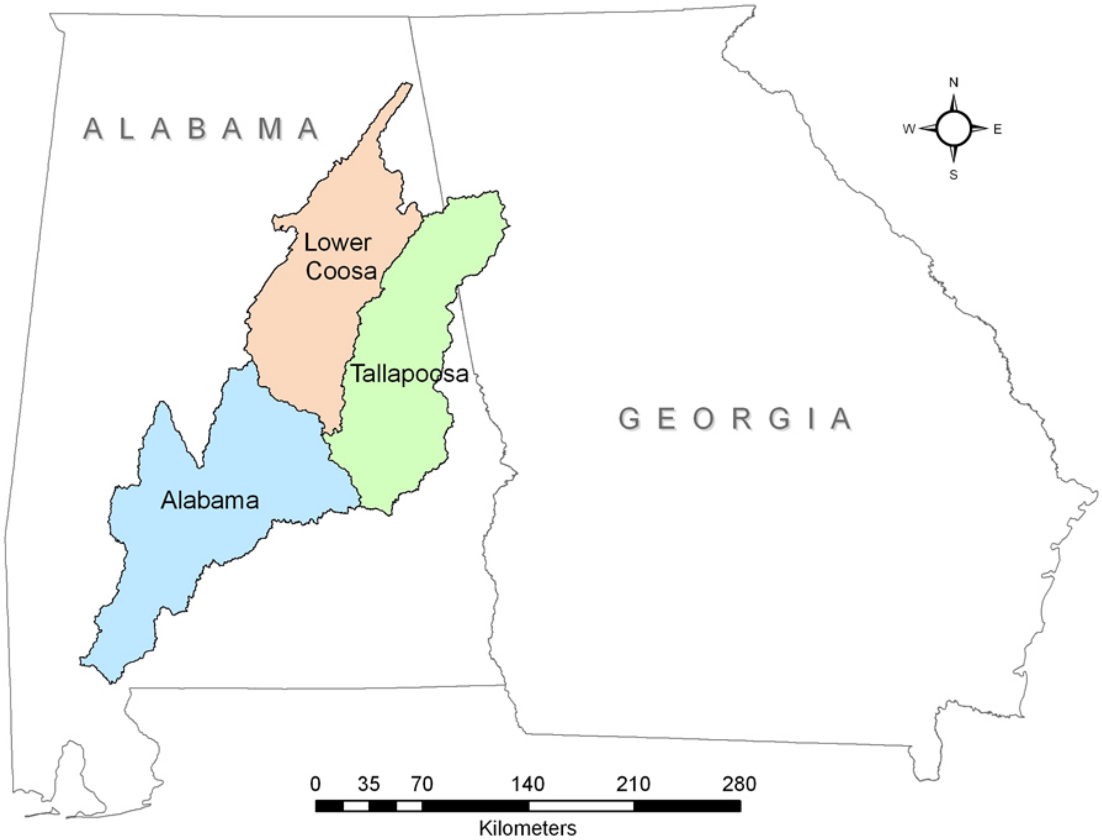

Figure 1. Location of the ACT system in Alabama and Georgia. The Upper Coosa GAP models were completed by Peterson et al. (2004).

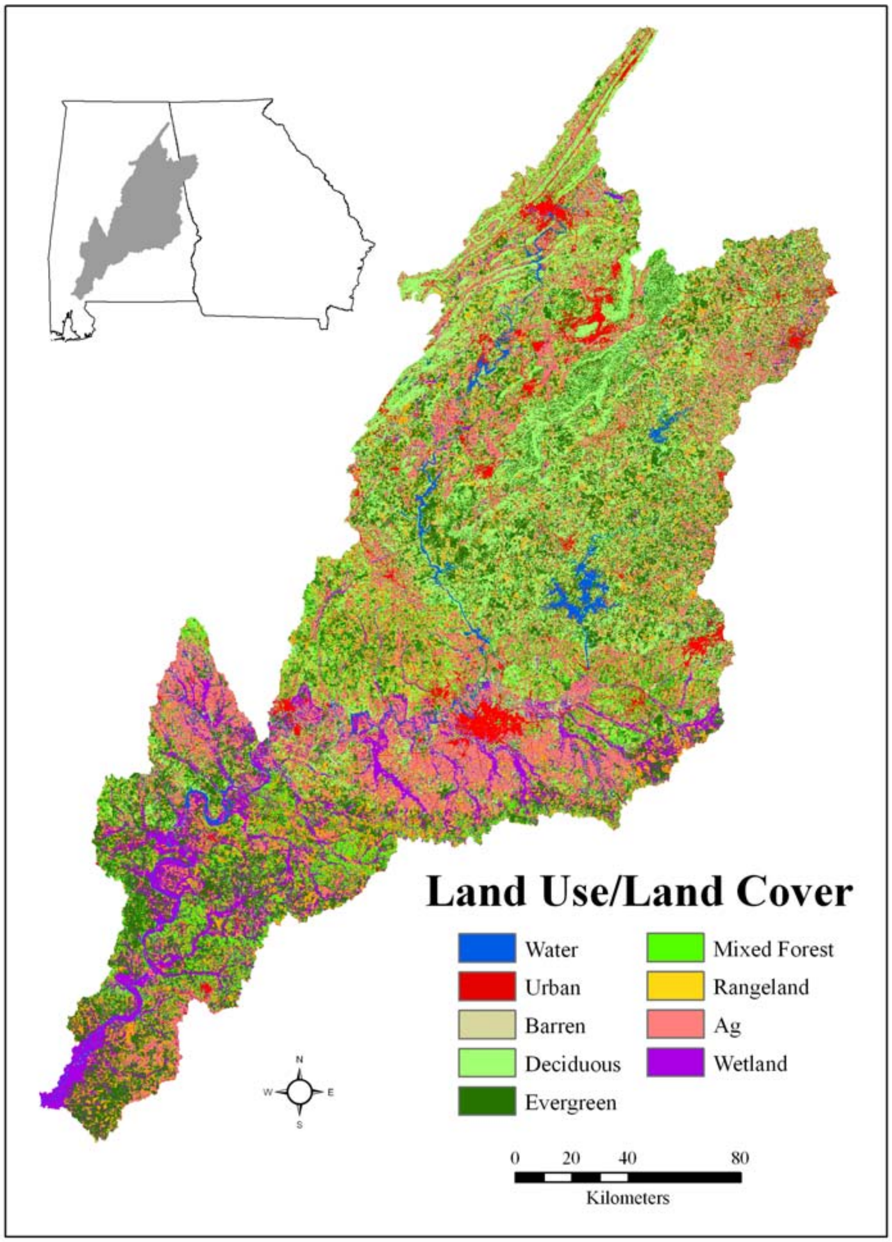

Figure 2.-Land Use/Land Cover for the study area in the ACT basin in Alabama and Georgia. Nine classifications were included in faunal models. Data were derived from the 2001 National Land Cover Dataset.

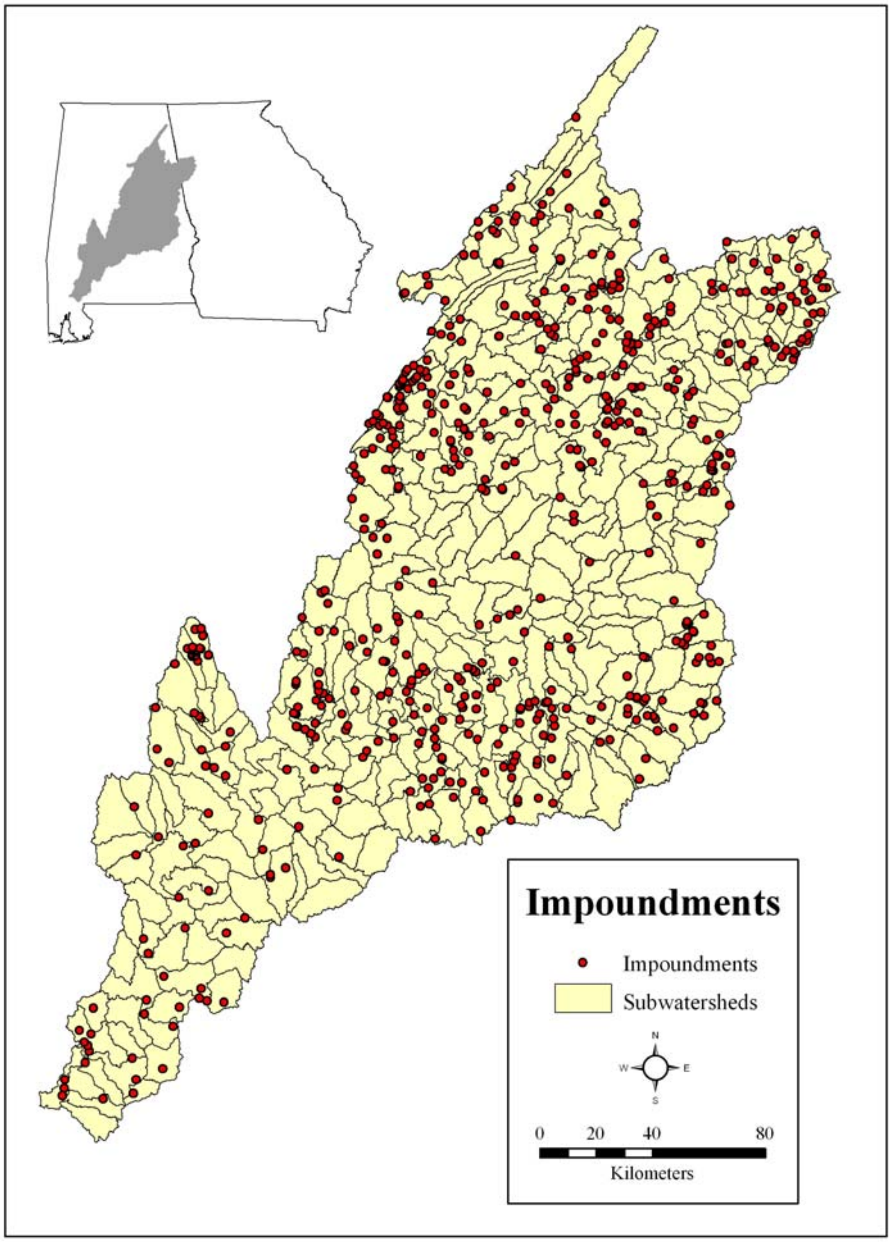

Figure 3.-Impoundments located in the ACT Basin. These were derived from digital elevation models (DEMs).

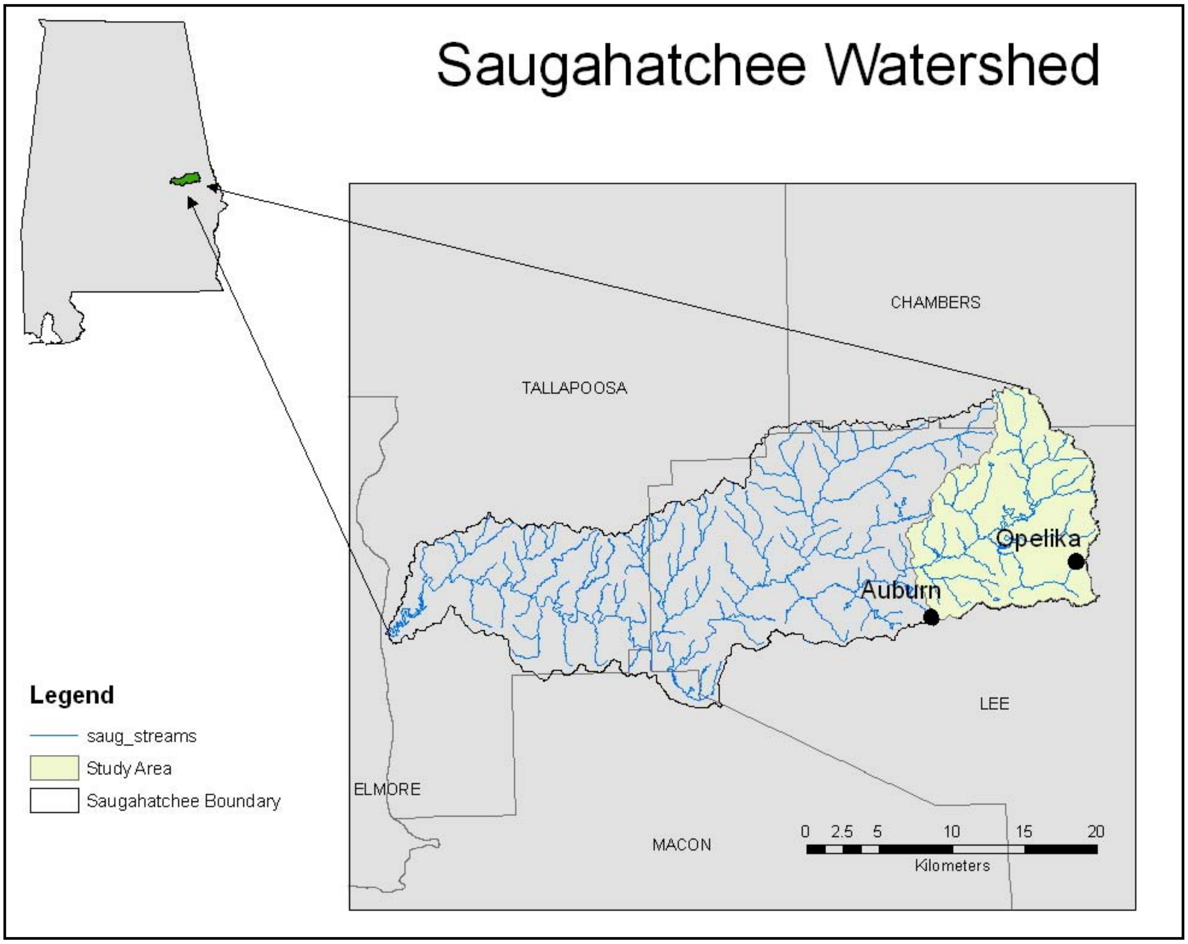

Figure 4.-Location of Saugahatchee Creek watershed in Alabama (Tallapoosa River basin). A Soil and Water Assessment Tools models were run on the yellow area in the watershed.

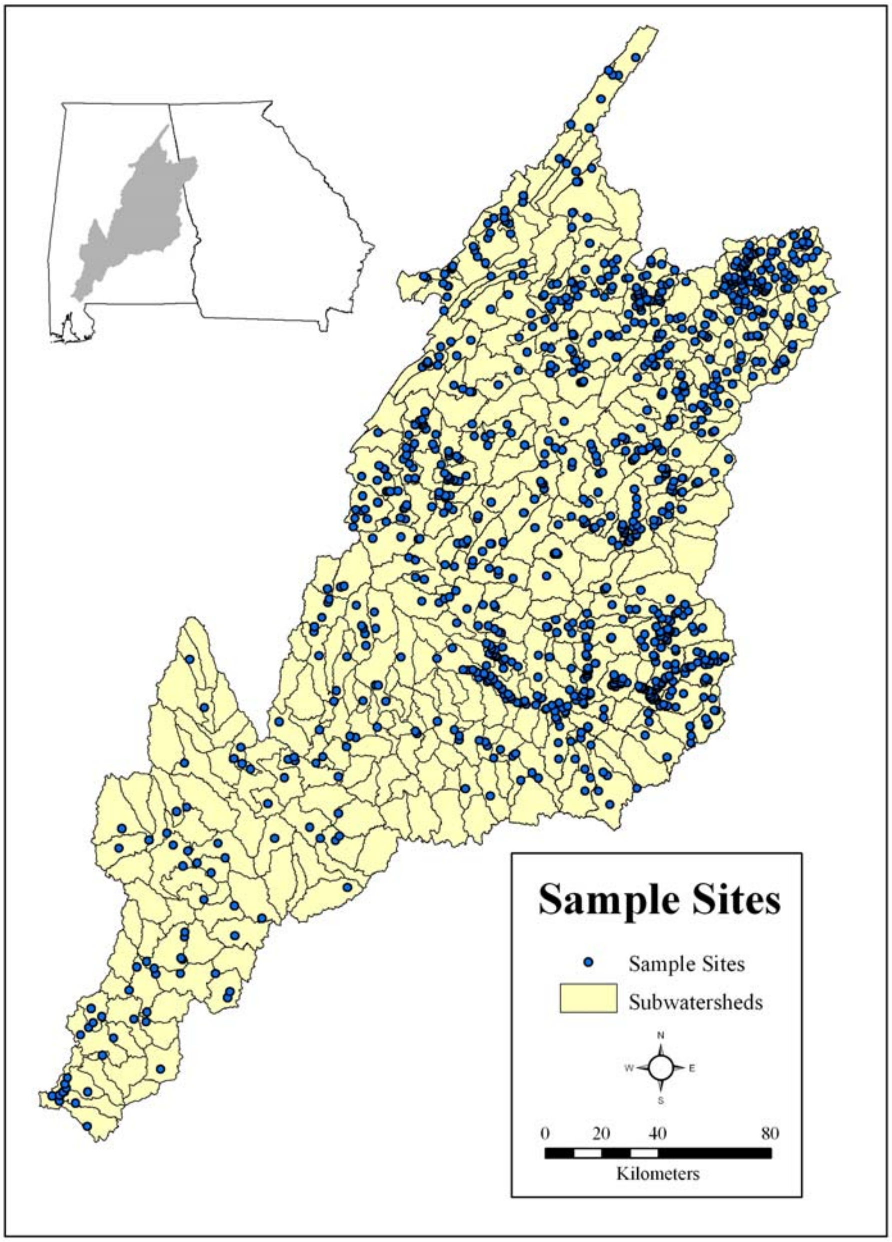

Figure 5.-Locations of fish sample sites in the Alabama-Coosa-Tallapoosa Basin. Sample sites were compiled from multiple collection databases (Table 1) and are from post 1970 collections.

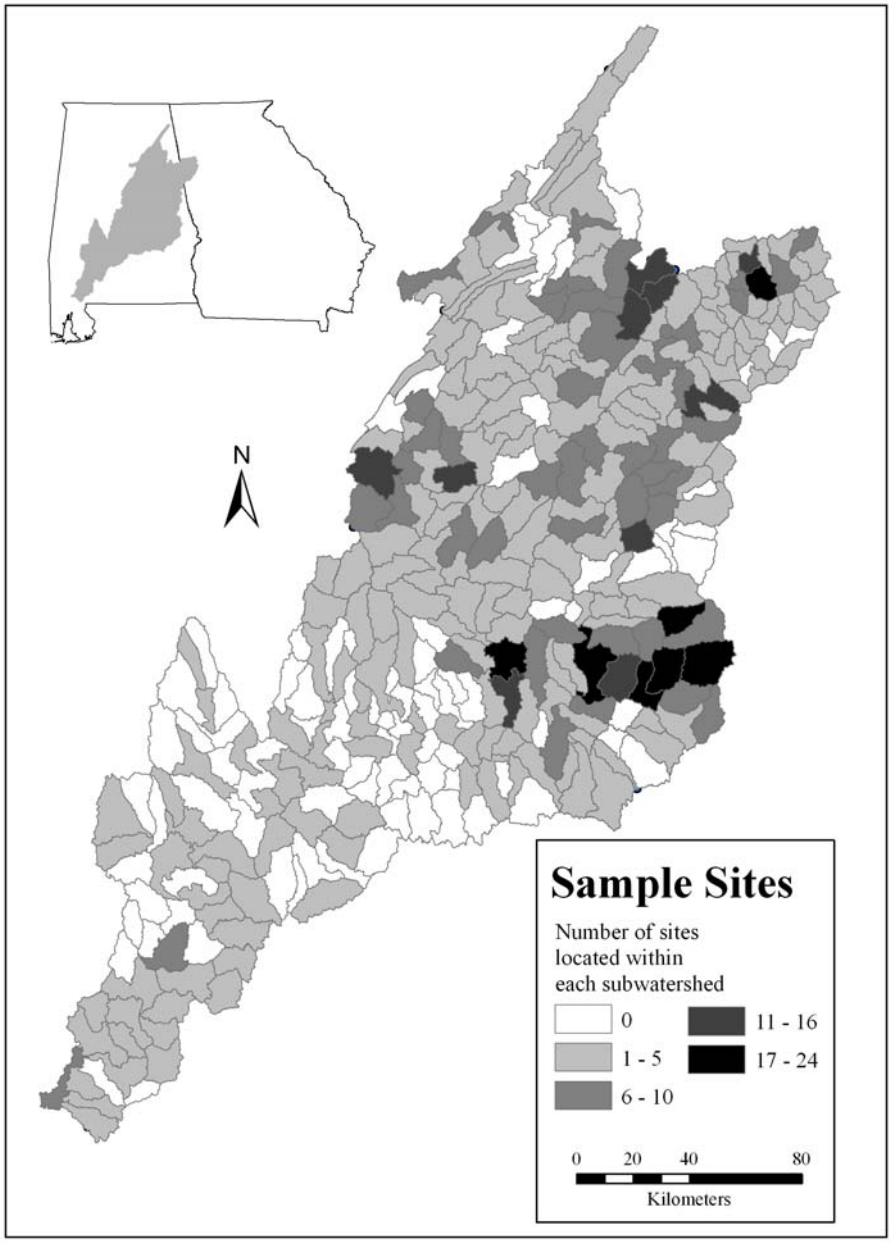

Figure 6.-Number of sites per 12-digit HUC in the ACT basin. Note the absence of sampling efforts in many HUCs, especially in the Alabama River basin.

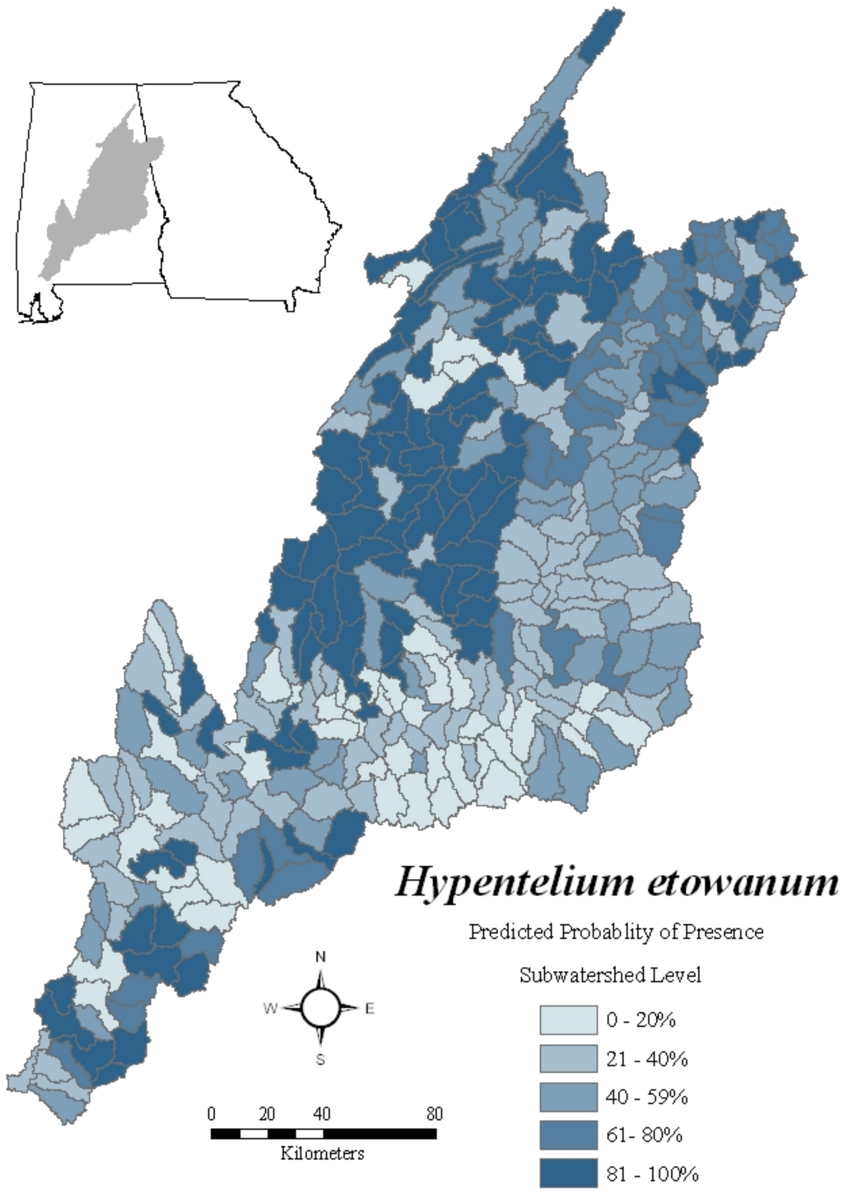

Figure 7. Predicted probability of presence for *Hypentelium etowanum.*

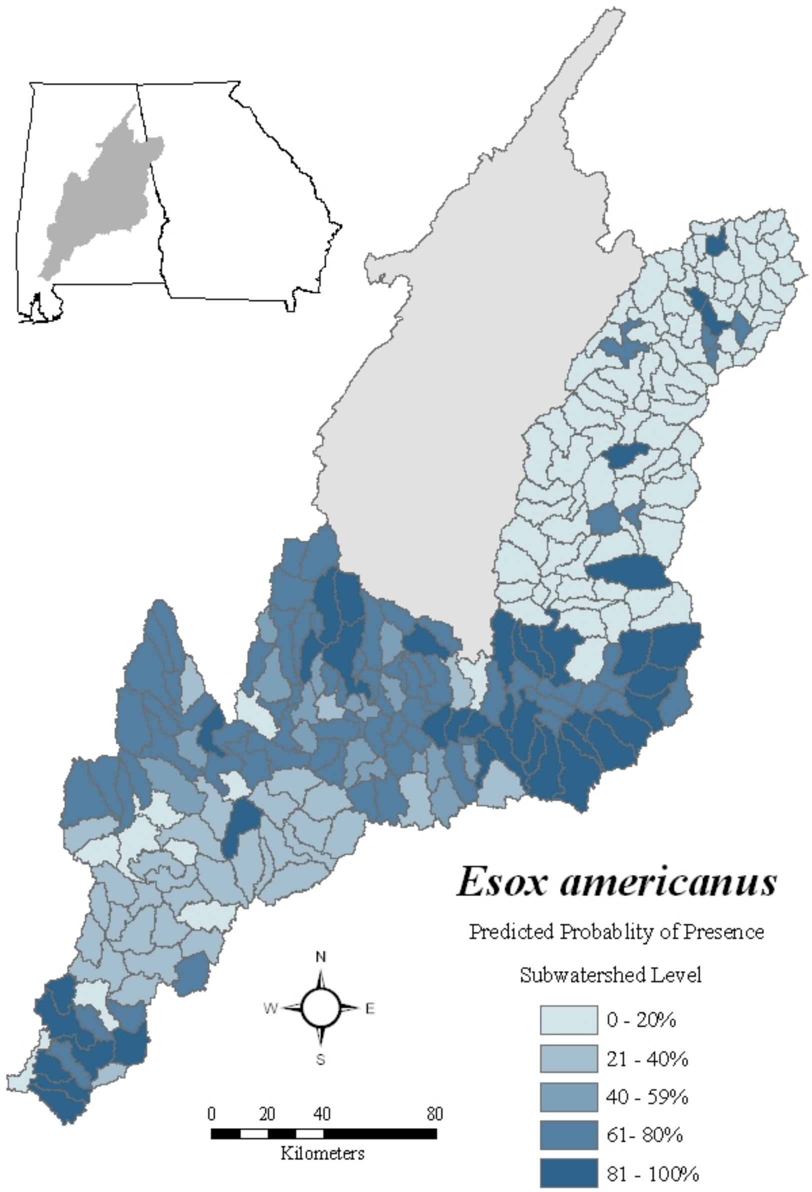

Figure 8.-Predicted probability of presence of *Esox americanus.* We did not construct a model in the Coosa basin.

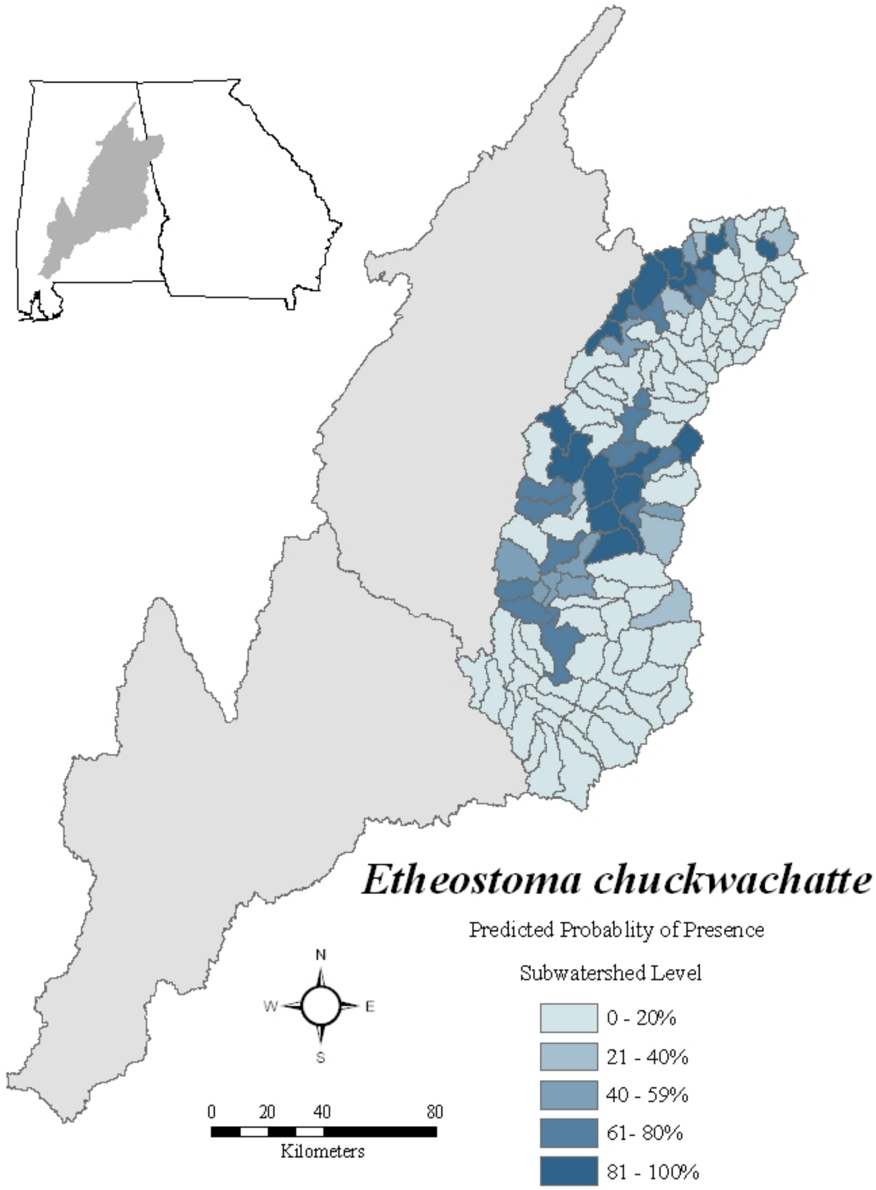

Figure 9. Predicted distribution for *Etheostoma chuckwachatte*. This species is a Tallapoosa River endemic and GCN species.

APPENDIX I

CORRELATION TABLES FOR PREDICTIVE VARIABLES

AG	BLK_BLT
AG	CAT_14
AG	DEC
AG	ELEV
AG	EVER
AG	IMP
AG	LWR_COAST
AG	RD_DEN
AG	RED_HILLS
AG	SED_28
AG	TAY_10
AG	WET
AUS_11	FALL_HILLS
BARREN	D_LINK
BARREN	HOL_1
BARREN	LINK_MAG
BARREN	WATER
BARREN	WET
BLK_BLT	AG
BLK_BLT	EVER
BLK_BLT	MIXED
BLK_BLT	RD_DEN
BLK_BLT	STR_LEN
BLK_BLT	TAY_10
BLK_BLT	URBAN
CAT_14	AG
CAT_14	SED_28
CHUN_HILLS	NAV_9
CHUN_HILLS	PAL_8
D_LINK	BARREN
D_LINK	ELEV
D_LINK	HOL_1
D_LINK	LINK_MAG
D_LINK	RANGE
D_LINK	WATER
D_LINK	WET
DEC	AG
DEC	ELEV
DEC	FALL_HILLS
DEC	LWR_COAST
DEC	RED_HILLS
DEC	WET
DEC	WOO_12

ELEV	AG
ELEV	D_LINK
ELEV	DEC
ELEV	FALL_HILLS
ELEV	HOL_1
ELEV	LINK_MAG
ELEV	LWR_COAST
ELEV	WATER
ELEV	WET
ELEV	WOO_12
EOC_5	OLI_4
EOC_6	RED_HILLS
EOC_7	RED_HILLS
EVER	AG
EVER	BLK_BLT
EVER	IMP
EVER	MIO_3
EVER	MIXED
EVER	RANGE
EVER	TAY_10
EVER	URBAN
EVER	WATER
FALL_HILLS	AUS_11
FALL_HILLS	DEC
FALL_HILLS	ELEV
FALL_HILLS	ISOLATIO_1
FALL_HILLS	WET
FALL_HILLS	WOO_12
HOL_1	BARREN
HOL_1	D_LINK
HOL_1	ELEV
HOL_1	LINK_MAG
HOL_1	LWR_COAST
HOL_1	MIXED
HOL_1	RANGE
HOL_1	WATER
HOL_1	WET
IMP	AG
IMP	EVER
IMP	MIXED
ISOLATIO_1	FALL_HILLS
ISOLATIO_1	WOO_12
LINK_MAG	BARREN
LINK_MAG	D_LINK
LINK_MAG	ELEV
LINK_MAG	HOL_1
LINK_MAG	RANGE

LINK_MAG	WATER
LINK_MAG	WET
LWR_COAST	AG
LWR_COAST	DEC
LWR_COAST	ELEV
LWR_COAST	HOL_1
LWR_COAST	MIO_3
LWR_COAST	OLI_4
LWR_COAST	PIL_2
LWR_COAST	WET
MIO_3	EVER
MIO_3	LWR_COAST
MIO_3	OLI_4
MIO_3	PIL_2
MIO_3	RANGE
MIXED	BLK_BLT
MIXED	EVER
MIXED	HOL_1
MIXED	IMP
MIXED	RANGE
MIXED	TAY_10
MIXED	WATER
NAV_9	CHUN_HILLS
OLI_4	EOC_5
OLI_4	LWR_COAST
OLI_4	MIO_3
PAL_8	CHUN_HILLS
PIL_2	LWR_COAST
PIL_2	MIO_3
RANGE	D_LINK
RANGE	EVER
RANGE	HOL_1
RANGE	LINK_MAG
RANGE	MIO_3
RANGE	MIXED
RANGE	WATER
RANGE	WET
RD_DEN	AG
RD_DEN	BLK_BLT
RD_DEN	RD_LEN
RD_DEN	URBAN
RD_DEN	WET
RD_LEN	RD_DEN
RD_LEN	STR_LEN
RD_LEN	URBAN
RD_LEN	WET

RED_HILLS	AG
RED_HILLS	DEC
RED_HILLS	EOC_6
RED_HILLS	EOC_7
SED_28	AG
SED_28	CAT_14
STR_DEN	WATER
STR_LEN	BLK_BLT
STR_LEN	RD_LEN
TAY_10	AG
TAY_10	BLK_BLT
TAY_10	EVER
TAY_10	MIXED
URBAN	BLK_BLT
URBAN	EVER
URBAN	RD_DEN
URBAN	RD_LEN
WATER	BARREN
WATER	D_LINK
WATER	ELEV
WATER	EVER
WATER	HOL_1
WATER	LINK_MAG
WATER	MIXED
WATER	RANGE
WATER	STR_DEN
WATER	WET
WET	AG
WET	BARREN
WET	D_LINK
WET	DEC
WET	ELEV
WET	FALL_HILLS
WET	HOL_1
WET	LINK_MAG
WET	LWR_COAST
WET	RANGE
WET	RD_DEN
WET	RD_LEN
WET	WATER
WET	WOO_12
WOO_12	DEC
WOO_12	ELEV
WOO_12	FALL_HILLS
WOO_12	ISOLATIO_1
WOO_12	WET

Correlations among predictive variables for the Alabama River basin ($r^2 > 0.36$ or <-0.36).

A_spname	ELEV
A_spname	BARREN
A_spname	RANGE
AG	DEC
AG	EVER
AG	LOW_23
AG	MIXED
AG	ORD_24
AG	PIEDMONT
AG	RIDGE_VALL
APPALACH	ISOLATION
BARREN	A_spname
BARREN	RANGE
CAM_26	RD_DEN
CAM_26	URBAN
CAT_14	LOW_25
D_LINK	ELEV
D_LINK	FALL_HILLS
D_LINK	FALL_LINE
D_LINK	LINK_MAG
D_LINK	MIXED
D_LINK	SED_28
D_LINK	STREAM_ORD
D_LINK	WOO_12
DEC	AG
DEC	ELEV
DEC	LOW_23
DEC	MIXED
DEC	ORD_24
DEC	PIEDMONT
DEC	RANGE
DEC	RD_DEN
DEC	URBAN
DEC	WET
ELEV	A_spname
ELEV	D_LINK
ELEV	DEC
ELEV	FALL_HILLS
ELEV	IMP
ELEV	LINK_MAG
ELEV	LOW_23
ELEV	MIXED
ELEV	RANGE
ELEV	SED_28
ELEV	STREAM_ORD
ELEV	WOO_12
EVER	AG
EVER	IMP
EVER	LOW_23
EVER	MIXED
EVER	PIEDMONT
EVER	RD_DEN
EVER	URBAN
FALL_HILLS	D_LINK
FALL_HILLS	ELEV
FALL_HILLS	IMP
FALL_HILLS	LINK_MAG
FALL_HILLS	MIXED
FALL_HILLS	ORT_29
FALL_HILLS	RIDGE_VALL
FALL_HILLS	SED_28
FALL_HILLS	STREAM_ORD
FALL_HILLS	WOO_12
FALL_LINE	D_LINK
FALL_LINE	LINK_MAG
FALL_LINE	MIXED
FALL_LINE	SED_28
IMP	ACRES
IMP	AREA
IMP	ELEV
IMP	EVER
IMP	FALL_HILLS
IMP	LINK_MAG
IMP	LOW_23
IMP	MIXED
IMP	ORT_29
IMP	PIEDMONT
IMP	RD_LEN
IMP	SED_28
IMP	STR_LEN
IMP	WOO_12
ISOLATION	APPALACH
LINK_MAG	D_LINK
LINK_MAG	ELEV
LINK_MAG	FALL_HILLS
LINK_MAG	FALL_LINE
LINK_MAG	IMP
LINK_MAG	MIXED
LINK_MAG	SED_28
LINK_MAG	STREAM_ORD
LINK_MAG	WOO_12
LOW_23	AG
LOW_23	DEC
LOW_23	ELEV
LOW_23	EVER
LOW_23	IMP
LOW_23	MIS_20
LOW_23	MIXED
LOW_23	ORD_24
LOW_23	PIEDMONT
LOW_23	RANGE
LOW_23	RD_DEN
LOW_23	RIDGE_VALL
LOW_23	WET
LOW_25	CAT_14
MIS_20	LOW_23
MIS_20	PIEDMONT
MIS_20	RIDGE_VALL
MIS_20	STR_DEN
MIXED	AG
MIXED	D_LINK
MIXED	DEC
MIXED	ELEV
MIXED	EVER
MIXED	FALL_HILLS
MIXED	FALL_LINE
MIXED	IMP
MIXED	LINK_MAG
MIXED	LOW_23
MIXED	PIEDMONT
MIXED	SED_28
MIXED	WOO_12
ORD_24	AG
ORD_24	DEC
ORD_24	LOW_23
ORD_24	PIEDMONT
ORD_24	RIDGE_VALL
ORT_29	FALL_HILLS
ORT_29	IMP
ORT_29	SED_28
ORT_29	WOO_12
PAL_18	PIEDMONT
PIEDMONT	AG
PIEDMONT	DEC
PIEDMONT	EVER
PIEDMONT	IMP
PIEDMONT	LOW_23
PIEDMONT	MIS_20
PIEDMONT	MIXED
PIEDMONT	ORD_24
PIEDMONT	PAL_18
PIEDMONT	RD_DEN
PIEDMONT	RIDGE_VALL
PIEDMONT	WET
RANGE	A_spname
RANGE	BARREN
RANGE	DEC
RANGE	ELEV
RANGE	LOW_23
RANGE	WET
RD_DEN	CAM_26
RD_DEN	DEC
RD_DEN	EVER
RD_DEN	LOW_23
RD_DEN	PIEDMONT
RD_DEN	RD_LEN
RD_DEN	URBAN
RD_LEN	IMP
RD_LEN	PERI
RD_LEN	RD_DEN
RD_LEN	STR_LEN
RD_LEN	URBAN
RIDGE_VALL	AG
RIDGE_VALL	FALL_HILLS
RIDGE_VALL	LOW_23
RIDGE_VALL	MIS_20
RIDGE_VALL	ORD_24
RIDGE_VALL	PIEDMONT
RIDGE_VALL	WOO_12
SED_28	D_LINK
SED_28	ELEV
SED_28	FALL_HILLS
SED_28	FALL_LINE
SED_28	IMP
SED_28	LINK_MAG
SED_28	MIXED
SED_28	ORT_29
SED_28	STREAM_ORD
SED_28	WOO_12
STR_DEN	MIS_20
STREAM_ORD	D_LINK
STREAM_ORD	ELEV
STREAM_ORD	FALL_HILLS
STREAM_ORD	LINK_MAG
STREAM_ORD	SED_28
STR_LEN	IMP
STR_LEN	RD_LEN
URBAN	CAM_26
URBAN	DEC
URBAN	EVER
URBAN	RD_DEN
URBAN	RD_LEN
WET	DEC
WET	LOW_23
WET	PIEDMONT
WET	RANGE
WOO_12	D_LINK
WOO_12	ELEV
WOO_12	FALL_HILLS
WOO_12	IMP
WOO_12	LINK_MAG
WOO_12	MIXED
WOO_12	ORT_29
WOO_12	RIDGE_VALL
WOO_12	SED_28

Correlations among predictive variables for the Coosa River basin ($r^2 > 0.36$ or <-0.36)

agri	BLACK_BELT
agri	Dec
agri	Ever
agri	FALL_HILLS
agri	fall_line
agri	forest
agri	imp
agri	Mixed
agri	PIEDMONT
agri	wet
AUS_1	BLACK_BELT
AUS_1	CHUN_HILLS
AUS_1	Elev
AUS_1	Ever
AUS_1	fall_line
AUS_1	forest
AUS_1	PIEDMONT
AUS_1	str_den
AUS_1	TAY_13
AUS_1	wet
BLACK_BELT	agri
BLACK_BELT	AUS_1
BLACK_BELT	d_link
BLACK_BELT	Ever
BLACK_BELT	fall_line
BLACK_BELT	forest
BLACK_BELT	link_mag
BLACK_BELT	PIEDMONT
BLACK_BELT	TAY_13
BLACK_BELT	wet
CHUN_HILLS	AUS_1
comm_ind	High_int
comm_ind	Low_int
comm_ind	rd_den
comm_ind	urban
Dec	agri
Dec	Elev
Dec	FALL_HILLS
Dec	fall_line
Dec	forest
Dec	imp
Dec	LOW_6
Dec	PIEDMONT
Dec	wet
Dec	WOO_15
d_link	BLACK_BELT
d_link	Elev
d_link	Ever
d_link	FALL_HILLS
d_link	fall_line
d_link	forest
d_link	link_mag
d_link	PIEDMONT
d_link	str_odr
d_link	wet
d_link	WOO_15
Elev	AUS_1
Elev	d_link
Elev	Dec
Elev	FALL_HILLS
Elev	fall_line
Elev	imp
Elev	link_mag
Elev	LOW_6
Elev	Mixed
Elev	PAL_12
Elev	PIEDMONT
Elev	rd_len
Elev	str_den
Elev	str_len
Elev	str_odr
Elev	wet
Elev	WOO_15
Ever	agri
Ever	AUS_1
Ever	BLACK_BELT
Ever	d_link
Ever	fall_line
Ever	forest
Ever	link_mag
Ever	PIEDMONT
Ever	wet
FALL_HILLS	agri
FALL_HILLS	d_link
FALL_HILLS	Dec
FALL_HILLS	Elev
FALL_HILLS	fall_line
FALL_HILLS	forest
FALL_HILLS	imp
FALL_HILLS	LOW_6
FALL_HILLS	PIEDMONT
FALL_HILLS	rd_len
FALL_HILLS	str_den
FALL_HILLS	str_len
FALL_HILLS	wet
FALL_HILLS	WOO_15
fall_line	agri
fall_line	AUS_1
fall_line	BLACK_BELT
fall_line	d_link
fall_line	Dec
fall_line	Elev
fall_line	Ever
fall_line	FALL_HILLS
fall_line	forest
fall_line	imp
fall_line	link_mag
fall_line	LOW_6
fall_line	PIEDMONT
fall_line	rd_len
fall_line	str_den
fall_line	str_len
fall_line	wet
fall_line	WOO_15
FEL_5	MAF_8
FEL_5	MID_9
forest	agri
forest	AUS_1
forest	BLACK_BELT
forest	d_link
forest	Dec
forest	Ever
forest	FALL_HILLS
forest	fall_line
forest	imp
forest	link_mag
forest	Mixed
forest	PIEDMONT
forest	urban
forest	wet
forest	WOO_15
High_int	comm_ind
High_int	Low_int
High_int	rd_den
High_int	urban
imp	agri
imp	Dec
imp	Elev
imp	FALL_HILLS
imp	fall_line
imp	forest
imp	LOW_6
imp	PIEDMONT
imp	rd_len
imp	str_len
imp	WOO_15
link_mag	BLACK_BELT
link_mag	d_link
link_mag	Elev
link_mag	Ever
link_mag	fall_line
link_mag	forest
link_mag	PIEDMONT
link_mag	str_ord
link_mag	WOO_15
LOW_6	Dec
LOW_6	Elev
LOW_6	FALL_HILLS
LOW_6	fall_line
LOW_6	imp
LOW_6	MAF_8
LOW_6	Mixed
LOW_6	PIEDMONT
LOW_6	str_len
LOW_6	wet
LOW_6	WOO_15
Low_int	comm_ind
Low_int	High_int
Low_int	rd_den
Low_int	urban
MAF_8	FEL_5
MAF_8	LOW_6
MAF_8	ORT_11
MID_9	FEL_5
Mixed	agri
Mixed	Elev
Mixed	forest
Mixed	LOW_6
Mixed	ORT_11
Mixed	rd_den
ORT_11	MAF_8
ORT_11	Mixed
PAL_12	Elev
PIEDMONT	agri
PIEDMONT	AUS_1
PIEDMONT	BLACK_BELT
PIEDMONT	d_link
PIEDMONT	Dec
PIEDMONT	Elev
PIEDMONT	Ever
PIEDMONT	FALL_HILLS
PIEDMONT	fall_line
PIEDMONT	forest
PIEDMONT	imp
PIEDMONT	link_mag
PIEDMONT	LOW_6
PIEDMONT	rd_den
PIEDMONT	str_den
PIEDMONT	str_len
PIEDMONT	wet
PIEDMONT	WOO_15
rd_den	comm_ind
rd_den	High_int
rd_den	Low_int
rd_den	Mixed
rd_den	urban
rd_len	Elev
rd_len	FALL_HILLS
rd_len	fall_line
rd_len	imp
rd_len	PIEDMONT
rd_len	str_len
rd_len	WOO_15
str_den	AUS_1
str_den	Elev
str_den	FALL_HILLS
str_den	fall_line
str_den	PIEDMONT
str_den	str_len
str_den	wet
str_den	WOO_15
str_len	Elev
str_len	FALL_HILLS
str_len	fall_line
str_len	imp
str_len	LOW_6
str_len	PIEDMONT
str_len	rd_len
str_len	str_den
str_len	WOO_15
str_odr	d_link
str_odr	Elev
str_odr	link_mag
TAY_13	AUS_1
TAY_13	BLACK_BELT
TAY_13	link_mag
urban	comm_ind
urban	forest
urban	High_int
urban	Low_int
urban	rd_den
wet	agri
wet	AUS_1
wet	BLACK_BELt
wet	d_link
wet	Dec
wet	Elev
wet	Ever
wet	FALL_HILLS
wet	fall_line
wet	forest
wet	LOW_6
wet	PIEDMONT
wet	str_den
wet	WOO_15
WOO_15	d_link
WOO_15	Dec
WOO_15	Elev
WOO_15	FALL_HILLS
WOO_15	fall_line
WOO_15	forest
WOO_15	imp
WOO_15	link_mag
WOO_15	LOW_6
WOO_15	PIEDMONT
WOO_15	rd_len
WOO_15	str_den
WOO_15	str_len
WOO_15	wet

Correlations among predictive variables for the Tallapoosa River basin (r^2 > 0.36 or <-0.36)