Protocol for Evaluating Water-Supply Reservoir Options for Effects on Imperiled Stream Fishes

July 13, 2006

ETOWAH
aquatic habitat conservation plan

The Etowah Aquatic Habitat Conservation Plan Water Supply Evaluation Protocol was developed by a Technical Committee of water supply, use and conservation professionals, as well as local government staff, from the Etowah watershed. The Steering Committee approved the Technical Committee's recommendations for inclusion in the Etowah Aquatic Habitat Conservation Plan on June 9, 2006, with the understanding that the Water Supply Evaluation Protocol, once implemented, will help minimize and mitigate take of imperiled aquatic species in the Etowah watershed, and that the Protocol will be adopted by each jurisdiction prior to the jurisdiction receiving an Incidental Take Permit from the U.S. Fish and Wildlife Service.

Technical Committee Members

The following individuals served on the Water Supply Evaluation Protocol Technical Committee. Members of the committee discussed, reviewed and offered suggestions on the model protocol via a series of meetings and/or in comments to the Technical Committee staff throughout 2005 and 2006.

Marcus Beavers, *Cherokee Citizens for Responsible Growth*
Bob Bourne, *Cobb County Water and Sewer Authority*
Rodney Buckingham, *Pickens County Planning*
Mauro Chiaverini, *Temple Inland Forestry*
Doris Cook, *Etowah Water and Sewer Authority*
Mary Davis, *The Nature Conservancy*
Robin Goodloe, *U.S. Fish and Wildlife Service*
Tyler Hewitt, *Infratec*
Jim King, *Dawson County Board of Commissioners*
Dave Kubala, *Cherokee County Water and Sewer Authority*
Tim Perkins, *Forsyth County Water and Sewer Authority*
Norman Pope, *Pickens County*
Candace Stoughton, *The Nature Conservancy*
Hugh Stowers, *Dawson County Stakeholder*
Roy Taylor, *Cherokee County Stakeholder*
Sandy Tucker, *U.S. Fish and Wildlife Service*
Lynn Tully, *Dawson County*
Shana Udvardy, *The Georgia Conservancy*

Technical Committee Staff

Laurie Fowler, University of Georgia
Bud Freeman University of Georgia
Mary Freeman, U.S. Geological Survey
Curt Gervich Etowah Aquatic HCP Outreach Coordinator, University of Georgia
Seth Wenger, University of Georgia

Technical Assistance

Emily Franzen, University of Georgia
Brenda Rashleigh, US Environmental Protection Agency
Carrie Straight, University of Georgia

Report authored by: Mary Freeman, Curt Gervich, Carrie Straight, and Seth Wenger. July 2006. Revised April 30, 2007 based on comments from the USFWS and to ensure consistency in terminology across documents.

Table of Contents

Committee Process

The Water Supply Evaluation Protocol (WSEP) Technical Committee met several times during 2005 and 2006 to develop a decision-making process for the placement of water supply reservoirs in the Etowah as part of the Etowah Aquatic Habitat Conservation Plan (HCP). The committee included technical staff from local governments, water authorities and utilities, and water conservation experts from throughout the Etowah watershed.

The Technical Committee began its work by discussing city and county future water needs and limitations, especially in the Upper Etowah. Some Upper Etowah jurisdictions have had water shortages in the past and representatives of these local governments and water authorities voiced concern that the HCP may limit their abilities to develop future water resources. From the onset HCP staff confirmed that these concerns were valid and that the intent of the HCP was not to limit future water supply development.

Through several presentations of current research and thinking regarding ecological impacts from and limitations to water supply reservoir development, HCP staff proposed various approaches to developing the water supply component of the HCP. Staff proposals were intended to develop a water supply framework that would minimize habitat loss and fragmentation. The Technical Committee agreed to conduct a pilot study of the most agreeable approach: identifying potential reservoir sites that would have the least ecological impacts on imperiled fish species by using predictive models.

The first step of the pilot study was for the Technical Committee to identify potential reservoir sites. Many local governments and water authorities had researched potential sites prior to the HCP process and were able to quickly locate favorable sites on a map. Once identified, HCP staff began developing a protocol for estimating the impacts to imperiled fishes from reservoirs built at these locations. Upon reviewing the draft protocol, with example evaluations for three hypothetical but potential reservoir locations, the Committee recommended including the protocol as a component of the HCP, rather than including an evaluation of specific reservoir locations themselves. The decision reflected current uncertainty regarding future water needs and reservoir locations, as well as future status of the imperiled fishes, which could render analyses completed now obsolete. The resulting protocol is described herein and was recommended for adoption as a component of the HCP. The HCP Steering Committee approved adoption of the WSEP as an HCP component on June 9, 2006.

Executive Summary

Water-storage reservoirs commonly form a key component of water supply systems in regions that depend on streams to meet domestic and industrial water needs. The jurisdictions participating in the Etowah Aquatic Habitat Conservation Plan, a regional HCP designed to minimize and mitigate impacts of urban and suburban development on imperiled stream fishes in the Etowah River basin, GA, face the need for additional water supply over the next 30 to 50 years, and numerous reservoir options have been proposed. This report describes a protocol for evaluating the relative effects of alternative reservoir placements on the likelihood of persistence of stream-dependent fish species covered by the Etowah Aquatic HCP.

The protocol is based on our best-available understanding of the biology of the HCP-covered fish species ("covered species"), and of the effects of reservoirs on stream fishes. The covered species all live exclusively in streams and rivers; none are known to maintain populations in ponds, lakes or reservoirs. A reservoir may directly affect the covered species by (1) eliminating suitable habitat in the impounded stream reach, (2) altering habitat suitability downstream from the reservoir, and (3) fragmenting upstream and downstream populations that would have been connected by fish movements prior to reservoir construction. The covered species primarily occur in relatively shallow habitats with moderate to swift currents and coarse bed sediments, and are thought to occupy patches of suitable habitats, and to move occasionally among these habitats. With this conceptual framework, species persistence generally can be maximized by maintaining: (1) as many patches as possible, (2) the highest habitat quality possible, (3) connectivity to allow dispersal among patches, and (4) a diversity of patch types (to reduce synchrony in population dynamics among patches).

Available data are insufficient to support construction of population viability models for the covered species under alternative reservoir scenarios. We can, however, use the conceptual framework to evaluate effects of proposed reservoir placements on species persistence *relative to* alternative placements, and in relation to baseline conditions and to effects of land use change. Specifically, the protocol would evaluate the *"persistence value"* for covered species under alternative scenarios by: (1) summing the number of extant patches; (2) summing the amount of available habitat weighted by patch quality; (3) estimating connectivity among patches; and (4) describing changes in patch diversity. Procedures for evaluating persistence value are outlined using an example for effects of three hypothetical reservoirs on one of the covered species.

Implementation of this protocol as a component of the HCP will allow for evaluation of effects of potential reservoirs on the covered species in the context of effects of land use changes or other factors (including, e.g., mitigation) affecting species persistence. The intent is that this protocol will be adopted as a component of the Etowah HCP, and will be revised over the duration of the HCP as additional information on biology of the covered species and improved models are developed.

This protocol is intended to provide a tool for using the best biological understanding to evaluate potential effects of alternative reservoir locations. The protocol examines reservoir placement only and does not address reservoir management, including instream flow requirements or water withdrawal levels. The protocol also does not address any of the other multiple factors that must be considered when locating reservoirs, including need, yield, costs, watershed condition and availability. Thus, the protocol should serve as a screening tool for initial evaluation of proposed reservoir locations with respect to effects on imperiled fishes.

Introduction

The Need for Reservoirs and Issues for Stream Biota

Water-storage reservoirs commonly form a key component of water supply systems in regions that depend on streams to meet domestic and industrial water needs. Typically, a reservoir is created by damming a perennial stream. In some cases, new reservoirs are formed by increasing the height of an existing dam on a stream in order to increase storage capacity. Hundreds of thousands of streams have been dammed to form reservoirs in the U.S. for a variety of purposes including water supply, aquaculture, controlling runoff and erosion, providing water for livestock, and as amenities to developments such as golf courses, parks and residences.

Although reservoirs provide multiple beneficial uses, reservoirs constructed by impounding streams also have environmental costs. These costs are broadly associated with three facets of impoundments: the conversion of flowing-water habitat to slowly-moving or standing water; alteration of stream habitats downstream from the reservoir as a result of changes to hydrology, sediment and material (particulate and dissolved) transport, and water temperature and dissolved oxygen levels; and fragmentation of streams by dams and reservoirs that impede organism movements. For organisms that require stream habitats, building reservoirs on streams can thus be detrimental by eliminating suitable habitat upstream from the dam, altering habitat quality downstream from the dam, and by fragmenting populations above and below the reservoir or by blocking migratory movements. Extensive research has been directed to effects of large hydropower and navigation dams on river biota (Rosenberg et al. 1997, Dudgeon 2000, Pringle et al. 2000). However, studies also have documented harmful effects of non-hydropower dams or reservoirs on fishes and invertebrates, including species losses above (Winston et al. 1991, Watters 1996, Katano et al. 2006) and below (Spence and Hynes 1971, Edwards 1978, Vaughn and Taylor 1999, Freeman and Marcinek 2006) dams.

Water supply reservoirs are permitted under Section 404 of the Clean Water Act, usually administered by the U.S. Army Corps of Engineers (COE). Where reservoirs could affect species protected under the Endangered Species Act (ESA), reservoir permitting is also subject to evaluation for effects on listed species. Generally, under Section 7 of the ESA, the permitting agency (i.e., COE) is required to consult with the U.S. Fish and Wildlife Service (USFWS) to determine the scope of effects of the proposed reservoir on the listed species and, if effects are expected, whether the reservoir is likely to jeopardize the survival and recovery of the species. Information generally included in a Section 7 evaluation includes how many individuals would be affected or how much habitat for the species would be lost or modified. This information must be evaluated in the context of the species' total range – either total population size or total amount of available habitat.

Purpose

Our purpose is to develop a protocol for quantifying the relative effects of alternative reservoir placements on the likelihood of persistence of stream-dependent fish species. The protocol is developed as a component of the Etowah Aquatic Habitat Conservation Plan (HCP), a multi-species, multi-jurisdictional HCP designed to minimize and mitigate impacts of urban and suburban development on imperiled stream fishes in the Etowah River basin, GA. Species covered by the Etowah Aquatic HCP include three stream-dwelling fishes that are listed under the ESA, and six other stream fishes considered imperiled. Under the ESA, it is illegal to engage in activities that result in take of a listed species (broadly defined as harm to an individual or its habitat). However, Section 10 of the ESA provides for HCPs, which are voluntary agreements between entities and the USFWS to minimize effects of otherwise lawful activities that might result in take of a listed species and for which there is no other federal nexus (e.g., no federal permit is required). Completion and approval of an HCP results in the applicant receiving a permit for take of listed species as long as that take is incidental to the HCP-covered activities. Because reservoir construction requires a federal permit, and because take of listed species potentially exceeds that covered by the HCP, the activity of reservoir construction cannot be included under an HCP.

The reasons for including a protocol for evaluating reservoir placements as part of the HCP are two-fold. First, developing additional water supply is an unavoidable consequence of population growth and development. The counties participating in the Etowah Aquatic HCP, situated adjacent to metropolitan Atlanta, have been listed among the fastest-growing populations in the US over the past two decades. Each county faces the need for additional water supply over the next 30 to 50 years, and numerous reservoir options have been proposed. The Etowah Aquatic HCP is addressing activities directly associated with commercial and residential growth (e.g., stormwater runoff, erosion and sedimentation control, fish passage at new road crossings on streams), and in the process is providing estimates of where in the Etowah basin the covered stream fishes are expected to maintain strong populations. This provides the assurance required by the ESA that the listed species will not be jeopardized by activities covered under the HCP. Because the need for new reservoirs at some future point is anticipated, and because the locations of those reservoirs cannot be determined at this time, it is beneficial to the HCP to include a protocol by which future reservoir placements will be evaluated to ensure that those reservoirs do not jeopardize the covered species. Secondly, including this protocol in the Etowah Aquatic HCP helps clarify that the HCP is not intended to stop growth or new reservoirs. Rather, the HCP is intended to ensure the long-term survival of the covered species by providing and implementing means of development that minimize and mitigate harmful effects on streams and stream biota.

This protocol is intended to provide a tool for using the best biological understanding to evaluate potential effects of alternative reservoir locations. The protocol examines reservoir placement only and does not address reservoir management, including instream flow requirements or water withdrawal levels. The protocol also does not address any of the other multiple factors that must be considered when locating reservoirs, including need, yield, costs, watershed condition and availability. Thus, the protocol should serve as a screening tool for initial evaluation of proposed reservoir locations with respect to effects on imperiled fishes.

Approach

Development of a protocol for evaluating reservoir placements with respect to the fishes covered by the Etowah Aquatic HCP has proceeded from the best-available information on the habitat requirements of the species and the effects of reservoirs on stream habitat. We then developed a conceptual framework for quantifying habitat losses and habitat fragmentation, and an application for estimating effects of these habitat changes on persistence of stream fishes.

Habitat Requirements of the Etowah Aquatic HCP Species

The nine fishes covered by the Etowah Aquatic HCP (Table 1) are all obligate stream-dwelling species; none are known to maintain populations in reservoirs, ponds or lakes. Three of the species, the Cherokee darter and the two forms of holiday darter, occur most commonly in small or medium size streams draining about 100 - 250 km^2 or less. The other six species occur in the mainstem of the Etowah River; some of these species also occur in larger tributaries of the Etowah. Distributional maps for all species are provided in Appendix 1. Three of the covered species are presently protected under the ESA; the Cherokee darter (listed as Threatened) occupies small and medium sized tributaries, and the Etowah darter and amber darter (both listed as Endangered) occupy the mainstem and portions of larger tributaries.

Table 1. Imperiled Fish Species Covered by the Etowah Aquatic Habitat Conservation Plan

Scientific Name	Common Name	Status
Percina antesella	amber darter	Fed. E
Etheostoma etowahae	Etowah darter	Fed. E
Etheostoma scotti	Cherokee darter	Fed. T
Noturus sp. cf. *N. munitus*	Coosa madtom	GA E/ Likely candidate
Etheostoma sp. cf. *E. brevirostrum* A	holiday darter	GA T/ Likely candidate
Etheostoma sp. cf. *E. brevirostrum* B	holiday darter	GA T/ Likely candidate
Percina sp. cf. *P. macrocephala*	bridled darter	GA Rare/Likely candidate
Percina lenticula	freckled darter	GA E/ Likely candidate
Macrhybopsis sp. cf. *M. aestivalis*	Coosa chub	Likely candidate

All of the covered fishes occupy areas within the mainstem or tributaries characterized by coarse bed sediments (i.e., cobble, gravel, bedrock and boulder), relatively shallow depths (during baseflow conditions) and moderate to swiftly flowing water. In the smaller streams, appropriate habitat for the Cherokee and holiday darters may occur in pools, runs and riffles; for example, Cherokee darters occur in riffles and runs with moderate to swift velocities, and commonly spawn in flowing pools (Storey 2003). In larger tributaries and in the Etowah mainstem, appropriate habitat occurs in distinct patches – shoals (topographic high points in a river channel) separated by reaches of deeper water with slower current. All of the large-stream species covered by the HCP are only commonly collected in shoal habitats. Several of the species (e.g., amber darter, Coosa madtom and Coosa chub) occur frequently enough in samples to allow estimation of how local habitat features affect their probability of occurrence. These species consistently show strong affinities for shallow areas with fast current and riverweed (*Podostemum ceratophyllum*, a swift-water plant), features not typically found in slow-flowing habitats (Hagler 2006).

Effects of Reservoirs on Stream Habitats

Placement of a dam on a stream to form a reservoir converts the impounded stream reach from a flowing-water habitat to an area of deep water in which flow is minimal, resulting in multiple changes in ecological processes and the plants and animals that populate the impounded reach (Baxter 1977). Slow flows in the reservoir result in the deposition of fine sediments that typically are colonized by a different suite of invertebrates than those that occupied the flowing stream. The riffle or shoal stream community that is lost includes a food-web dominated by insects such as mayflies, stoneflies, and caddisflies feeding on organic matter filtered from the flowing water or trapped between rocks and within riverweed, or on algae scraped from cobbles; these invertebrates are fed upon by fishes such as minnows, darters and small catfishes adapted to foraging among rocks in the swift flow. In contrast, reservoir communities are dominated by animals tolerant of slow flow such as sunfishes feeding on zooplankton, midges and oligochaetes, feeding in turn on phytoplankton (suspended algae) or deposited organic matter. Greater water depths in reservoirs compared to stream riffles create habitat for larger-bodied fish species, including predators on smaller fish. Although some stream fishes, such as sunfishes and channel catfish, can maintain populations in reservoirs, the majority of stream-adapted darters, minnows and madtom catfishes cannot.

Reservoir effects on downstream communities vary depending on how much the reservoir alters stream hydrology, water quality and material transport. Reservoirs can strongly alter stream flow patterns if evaporation or water use from the reservoir is substantial. By trapping and storing water during periods of naturally high runoff, reservoirs can reduce what would have been seasonally moderate or high streamflows to lower flow rates – essentially dampening natural flow variability downstream. Depending on water quality in the reservoir, the downstream reach may also experience altered thermal conditions (warmer, if water flows from the reservoir surface, or cooler if water is released from deep within the reservoir) and lower dissolved oxygen levels. If flows from the reservoir are substantially reduced below natural flow levels, then downstream habitat will have lower water velocities and riffles may become desiccated. Thus, whereas the loss of stream-adapted species in the impounded stream reach is reasonably certain, it is more difficult to predict whether, and which, stream species will persist downstream from a reservoir because of variation in physical effects. A three-year study of stream fish assemblages below water-supply reservoirs and below water withdrawals made directly from unimpounded streams in the Georgia Piedmont has found that sites below reservoirs support fewer stream-dependent fish species ("fluvial specialists", such as darters, minnows and madtoms) than expected, but that habitat-generalist species (such as sunfishes) do not appear affected (Freeman and Marcinek 2006). Predictions of how many stream-dependent species are lost downstream from reservoirs in this study are imprecise (i.e., include wide confidence intervals) reflecting substantial unexplained variation. The state of current understanding is that some stream-dependent fish species are expected to be eliminated downstream from water-supply reservoirs, but how many and which species will disappear cannot be predicted with certainty.

Finally, reservoirs are expected to form nearly impassable barriers to natural movements by stream-dependent fishes. Fish moving upstream will be stopped at the dam unless the dam is small enough to be completely inundated during floods. If the dam is submerged during floods (as may occur, for example, at low-head dams or weirs), stream fishes conceivably could move upstream, as well as downstream, past the dam during these high flow conditions. Downstream movements by stream-dependent fishes should typically be blocked when migrating or dispersing fish encounter the unsuitable habitat created by the impoundment, although during floods adults or larvae could be swept downstream through the reservoir and past the dam. Thus, except for active movements or passive displacement during floods, reservoirs are expected to block fish movements and thereby fragment upstream and downstream populations that would have been connected by movements prior to reservoir construction.

Effects of Habitat Loss and Fragmentation on Persistence of Stream Fishes

Conceptual framework

We conceive of the stream fishes covered by the Etowah Aquatic HCP ("covered species") as inhabiting patches of suitable habitat. For the small-stream species, patches comprise suitably-sized streams in an interconnected network and/or separated by large stream or mainstem reaches. For shoal-dwelling species in the mainstem and larger tributaries, patches comprise shoals separated by reaches of unsuitable (or less suitable) habitat. In this framework, adding reservoirs to the stream network can reduce or eliminate patches (upstream effect), lower patch suitability (downstream effect), and prevent fish from moving between patches separated by reservoirs (fragmentation effect).

The direct effects of a new reservoir on the covered species can be estimated by quantifying the proportion of available habitat for the species that would be (1) eliminated by the reservoir, (2) altered by having a new reservoir upstream, and (3) isolated by the reservoir from other patches. The consequences of these effects on *persistence* of the covered species (meaning survival of the species in the Etowah system over some long time period), depends on the value of the impounded, altered, or isolated patches to species persistence.

We propose that it is also appropriate to conceptualize the covered fish species as existing in metapopulations: groups of populations inhabiting patches (tributaries or shoals) connected by migration. The concept is appropriate when a species inhabits patches that support distinct local breeding populations, and when local populations do not fluctuate in perfect synchrony and are influenced by dispersal of individuals among patches (Rieman and Dunham 2000). Given the distances across which most of the covered species are distributed, we believe individuals in different portions of the species ranges form independent breeding populations. Indeed, genetic analysis of the Cherokee darter supports the existence of three geographically- and genetically-separated groups, or evolutionarily significant units (ESUs, Storey 2003, B. J Freeman and B. A. Porter, unpublished data). Available data on movements by stream fishes, discussed below, indicate that small-bodied species in perennial streams are likely to move tens to hundreds of meters during a lifetime, but typically not the distances spanning the species' ranges (which are in the tens of kilometers).

The importance of metapopulation structure is that species persistence is increased by the potential for patch colonization from other patches. How long a population in a given patch naturally persists is a function of the balance between local reproduction and mortality, and the rates at which individuals move into the patch (from other patches) or out of the patch. If rates of mortality together with emigration (movements out) are greater than rates of reproduction together with immigration (movements in), then the population of the patch will go locally extinct. Conversely, local reproduction and/or immigration rates that exceed population losses will result in local persistence. A final, important point is that population dynamics of stream fishes may vary substantially from year to year. Variation in reproductive success and survival occurs in response to temporal variation in climatic conditions, e.g., flow conditions during spawning periods (Starrett 1951, Schlosser 1985, Mion et al. 1998, Hagler 2006), because of catastrophic events that cause mortality, and because of random variation in reproduction and survival among individuals. The latter effect becomes more severe at small population sizes – i.e., there is greater chance of reproductive failure with fewer reproducing individuals (Morris and Doak 2002). Also, the more population dynamics vary through time, the greater the chance of the population going extinct in any given time period (Bascompte et al. 2002, Morris and Doak 2002).

In summary, the best available understanding of the biology of the covered fishes suggests that: (1) individuals occupy patches of suitable habitat and form local breeding populations; (2) populations are separated by distance and reaches of unsuitable habitat; (3) local population dynamics vary from year to year; and (4) there is a possibility for individuals to move among patches and populations.

Application

Given adequate data to describe 1) local population sizes, 2) local population dynamics (i.e., means and variances of population growth rates), and (3) frequency of dispersal among populations, it would be possible to model population viability (Hanski 1997, Morris and Doak 2002, Beissinger et al. 2006) for the covered fishes under current and alternative scenarios of reservoir placement. Alternatively, if data were available to estimate patterns of patch occupancy and colonization and extinction dynamics for local populations of the covered fishes, occupancy models could be used to estimate expected probability that each species would survive for a specified time period, and these persistence probabilities could be evaluated and compared for alternative reservoir placement scenarios (Hanski 1997). However, sufficient data are not presently available to estimate population sizes or population dynamics (including colonization and extinction frequencies) for the covered fishes in the Etowah, and dispersal is known only approximately. This is true for virtually all small-bodied stream fishes, for which populations may vary widely in time and space, and individual movements are difficult to track. Estimating population sizes and dynamics of the covered fishes is a long-term monitoring problem for which better information is expected in the future. Obtaining a better understanding of dispersal in stream fishes, and ultimately, the data to support quantitative metapopulation models is potentially a long-term management goal for the Etowah imperiled fishes. In the interim, however, decisions must be made using best available data and biological understanding.

Data are available to evaluate proposed reservoir placements in terms of the *relative effects on persistence* of the covered fishes. At a minimum, geographic ranges are reasonably well known for each of the covered species. Additionally, we have *occurrence models* for the listed fishes. These models (developed by S. Wenger, UGA, and described in the Runoff Limits component of the HCP) predict the frequency of species occurrence in suitable habitat for stream reaches within the range of each species, and can be used to estimate changes in species occurrence in response to urban and suburban development.

Information on species ranges and occurrence models (where available) can be used to estimate relative effects of reservoirs on persistence by considering factors that generally affect persistence of species that occur in patches. Specifically, persistence should be *maximized* by maintaining:

1) As many patches as possible;
2) The highest quality in patches as possible;
3) Connections that allow dispersal among patches; and
4) A diversity of patch types and locations across the species range.

Maintaining as many patches as possible reduces the negative effects of random variation in population growth rates on species persistence, reducing the probability of extinction

(Bascompte et al. 2002). Higher quality patches, by definition, support higher population growth rates; given dispersal among patches, increasing patch quality should also increase frequency of occupied patches and reduce probability of extinction. Connections that allow dispersal among patches allow for re-colonization following local extirpation, again increasing frequency of occupied patches and reducing extinction probability. Maintaining patch diversity, either in terms of population growth rates under different climatic conditions or in terms of distribution across the species range, helps reduce synchrony among patches so that subpopulations do not vary together. Asynchrony among patches buffers the species against "bad years" (when mortality exceeds reproduction) and local catastrophes.

Protocol

Using the four principles derived from the conceptual framework and application described above, reservoir placements can be evaluated in terms of effects on:

1) number of patches;
2) habitat quality in patches;
3) connectivity among patches; and
4) diversity of patch types;

for each covered species. Specifically, we propose to evaluate the *"persistence value"* for covered species, under a baseline scenario and a scenario for each proposed reservoir placement. For each scenario we would (1) sum the number of extant patches; (2) sum the amount of available habitat weighted by patch quality; (3) estimate connectivity among patches; and (4) describe changes in patch diversity.

Assumptions and Definitions

(1) Patch size. Ideally, the units used to evaluate patch number, quality, connectedness and diversity in a metapopulation model would represent locally breeding populations. However, defining the scale of a population involves an arbitrary decision concerning the degree of interaction among spatially-defined groups of individuals at which groups should be considered a single population (Waples and Gaggiotti 2006). For this application we propose defining patches either as individual watershed subbasins (for species in tributary streams) or as reaches defined by major tributary junctions and corresponding to divisions used in species occurrence models. Patches should be redefined if and when additional information on fish movements becomes available. However, this arbitrary definition of patches should adequately represent the spatial distribution of covered species in relation to changes in habitat quality and potential for re-colonization.

We advise including in analyses patches that have a high predicted or expected probability of species occurrence, regardless of known occupancy. This equates to the possibility of including "unoccupied" but suitable patches, the existence of which increases metapopulation persistence by providing areas for species to colonize (Hess 1996, Rieman and Dunham 2000).

(2) Habitat quality. For species with occurrence models, habitat quality for each reach representing a patch should be represented by predicted probability of occurrence. This value incorporates the influences of natural factors, historic land use, and/or current land cover on the probability that the species is present in suitable habitat within the reach (S. Wenger, UGA, in preparation), and thus inherently reflects the value of the reach to species persistence. For species lacking occurrence models, empirical estimates of relative population sizes, if available, could be used to represent relative patch quality. Similarly, other factors known to influence

probability of occurrence, such as elevation, could be used to weight patch value if relative effects of those factors can be estimated. Lacking any other information, patch size (i.e., stream reach length within the patch) may be used as a surrogate for habitat quality, under the assumption that larger patches are likely to support more individuals (Hanski 1997).

(3) Connectivity. We propose to use the nearest points between patches, measured along stream channels, to estimate the distances between patches. This implies that adjacent patches are separated by zero distance. However, portions of a patch that are isolated upstream from a reservoir (or other known barrier) are not counted as available to other patches. Large and small reservoirs (e.g. farm ponds) are the most likely barriers to fish dispersal.

Connectivity also depends on the probability of fish dispersing between patches. Movement of stream fishes varies among species and settings (Albanese et al. 2004), but studies of fish moving past a point in a stream, as estimated by catching dispersing fish in weirs, have documented upstream and downstream movements by a wide variety of species (Hall 1972, Albanese et al. 2004). Studies of stream fish dispersal, generally accomplished by marking and recapturing individual fish, characteristically show a tendency for many individuals to remain in a local area, with some individuals moving farther (Smithson and Johnston 1999, Skalski and Gilliam 2000, Rodriguez 2002). Thus, although mean distance moved by marked and recaptured fish is often low, individual small-bodied stream fishes have been observed to move 100 m or more over relatively short periods. For example, minnow species have been observed to move > 100 m in one month (Skalski and Gilliam 2000), and >1000 m in three months (Albanese et al. 2004); blackbanded darters (*Percina nigrofasciata*) have been observed to move >400 m during an 18 month period (Freeman 1995). In addition to movements upstream and downstream by juveniles and adults, many stream fishes may also disperse downstream as larvae that drift with water currents. Although early life-history information is scant for most stream fishes, the possibility of downstream larval dispersal is high for at least some of the HCP-covered fishes. For example, the Etowah darter has a pelagic (swimming) larval stage (Pat Rakes and J.R. Shute, Conservation Fisheries Inc, personal communication), and larval drift has been observed for a related species, *Etheostoma rubrum*, the bayou darter (Slack et al. 2004).

Although little information is available on movement for the covered HCP fishes, we can bracket the possibilities for the purposes of representing effects of reservoirs on population connectivity. Modeling dispersal as an exponentially decreasing function of distance is a common approach (Hanski 1997, Rodriguez 2002), so that probability of movement = $e^{-\alpha \times \text{distance}}$. Reservoir effects on connectivity can then be evaluated using model exponents for “high”, “moderate”, and “low” movement rates (Figure 1). For example, Figure 1 shows probability of an individual fish moving a given distance (in meters) in some unit of time, defined here as a year, assuming restricted movement (α = 0.005), moderate movement (α = 0.001), and high movement rate (α = 0.0005). These correspond to mean distances moved of 200, 1000 and 2000 m, respectively, or probabilities of about 0.7%, 37%, and 61%, respectively, that an individual will move 1 km (about 0.6 mi) in a year. These values are simplistic representations of movement, for at least three reasons. First, individual fish likely differ in their likelihood of movement, and we lack any data on what proportion of a population may be relatively “mobile”. Note, however, that even if most (e.g., 90%) individuals move on average only 100 m, if the remaining “mobile” individuals move on average 1000 m, the mean displacement would equal 190 m (Rodriguez 2002), similar to our “restricted movement” rate. Secondly, movements are likely to differ depending on patch characteristics and in relation to variables such as flow and season (Freeman 1995, Albanese et al. 2004). Finally, these rates ignore differences in movements upstream versus downstream, and between larval and post-larval life stages. In addition, the time-frame of one year is chosen because it represents a large portion of a 3 to 4 year life-span, the likely maximum for most or all of the covered fishes. Because the dispersal rate values are arbitrarily chosen to reflect *relative* movement rates, the unit of time only becomes important for estimating probabilities of fish moving between particular tributaries in a specified time period. *For the purpose of comparing reservoir scenarios to baseline conditions, and until better dispersal data are available, the three movement levels are best thought of as indices of the probability that patches could exchange individuals over some relevant time period.*

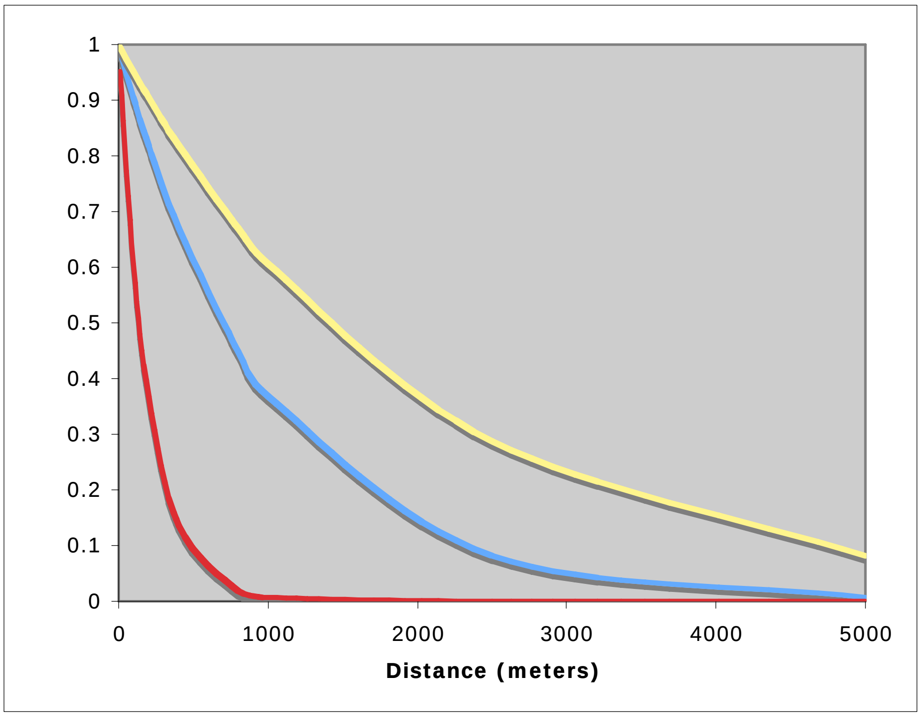

Figure 1. Three Hypothetical Dispersal Rrates for StreamFishes, Showing the Probability of Movement Versus Distance in Meters. *The three curves reflect restricted (lower curve), moderate (middle curve) and high (upper curve) movement rates. Each is used to evaluate reservoir effects on connectivity in the example presented below.*

(4) Patch diversity. Identifying changes in the diversity of patch types will be, in part, qualitative until information becomes available to relating patch characteristics to differences in population responses to, e.g., variation in flow conditions. Lacking this information, loss in patch diversity can be quantified by a decrease in the total geographic range of a covered species.

Procedure

Effects of a proposed reservoir placement would be evaluated relative to a baseline condition. Current conditions as of 2006 would provide a reasonable baseline, allowing estimation of effects of a proposed reservoir on habitat availability and connectivity for the covered species relative to conditions at the inception of the HCP. Evaluation of a proposed reservoir would entail the following steps:

1) Estimate the baseline condition:

a) Delineate and count the known occupied and known suitable patches for the target species.
b) Estimate quality for each patch.
c) Estimate baseline habitat availability as the sum over all patches of available stream length weighted by patch quality:

Habitat availability = $\sum \text{length}_i \times \text{quality}_i$,
where length_i = available stream length in patch i,
quality_i = quality of patch i
and the sum is over all patches, i = 1 to n.

d) Estimate total connectivity among patches. Connectivity is assumed 0 between any lengths of stream separated by a reservoir. For unimpeded paths between two patches, the connectivity from patch i to y, $C_{y(i)}$ is:

$$C_{y(i)} = \text{length}_{ci} \times \text{quality}_{ci} \times e^{-\alpha \times \text{distance}_{yi}}$$

where length_{ci} = available stream length in patch i *excluding any reaches within i that are isolated above reservoirs or other barriers, i.e. "connected length"*

quality_{ci} = quality of connected length in patch i

α = exponent describing effect of distance on migration rate
distance_{yi} = stream distance between nearest points in patches y and i

Connectivity of all patches to y is:

$C_{y(.)} = \sum \text{length}_{ci} \times \text{quality}_{ci} \times e^{-\alpha \times \text{distance}_{yi}}$, (summed over all patches, i=1 to n)

Total connectivity is the sum of connectivity for all patches that are not isolated:

$C = \sum C_{y(.)}$,(summed over all patches, y=1 to n)

2) Repeat steps a-d for each of the following types of scenarios:

- *Current land use*. If there have been changes in land use or existing reservoirs (i.e., reservoirs have been added or removed) since 2006 that affect habitat quality or connectivity for the covered species, these values should be recalculated to provide an estimate of habitat changes that have already occurred.

- *Current land use and proposed reservoir*. This will provide an estimate of additional effects of the proposed reservoir on habitat for covered species given current land use conditions.

- *Projected land use.* Under the runoff limits program of the HCP, participating jurisdictions may estimate locations for future high-density development, constraining these areas to avoid exceeding a specified limit on take of the listed species. If development "nodes" have been specified, steps 1-4 should be repeated using current land use modified by projected development (or other actions, such as land acquisition for conservation) to provide an estimate of habitat availability changes expected to occur as a result of land use changes alone.

- *Projected land use and proposed reservoir.* Repeat steps 1-4 using projected land use conditions with the proposed reservoir in place, to estimate additional effects of the proposed reservoir on habitat for covered species given projected land use conditions.

For each scenario, estimate the change in number of patches, habitat availability (patch size weighted by quality), and patch connectivity relative to the baseline condition. Additionally, one would assess changes in the total geographic range of the covered species.

Together, these scenarios would allow for a comparison of habitat availability, patch connectivity and patch diversity among: baseline (2006) conditions; current conditions; current conditions with proposed reservoir(s); projected land use conditions; and projected conditions with proposed reservoir(s).

Example

To illustrate the protocol, we evaluated effects of three *hypothetical* reservoirs on the upper ESU of the Cherokee darter, one of the species covered by the Etowah Aquatic HCP. The Cherokee darter occurs almost exclusively in tributary streams draining between 0.5 and 100 km^2. The upper ESU of the Cherokee darter occurs in Dawson and Lumpkin counties, and a small area in Forsyth County, in the upper portion of the Etowah basin.

To estimate number and sizes of patches available for Cherokee darters in the upper ESU range, we plotted all known occurrences of the species as of 2005 and overlaid watershed boundaries on the occurrence points. Watersheds were subdivided from Hydrologic Unit Code Level 12 (HUC-12) watersheds. Stream lengths draining between 0.5 and 100 km^2 were calculated for each occupied watershed, and for four additional watersheds without recent or nearby samples but suspected to either be occupied or to have suitable habitat for the Cherokee darter (i.e., U1-U4 in Figure 2). Using ArcView 3.3 and ArcMap 9.1 Geographic Information Systems (GIS), we used a 30m-cell digital elevation model (DEM) to calculate approximate drainage area using flow accumulation modeling. We used 1:24,000 National Hydrography Dataset (NHD) stream coverages to calculate stream lengths draining 0.5 and 100 km^2 and distances between tributary patches, and 1:100,000 NHDs to calculate mainstem distances.

For three hypothetical reservoirs (on watersheds 4, 5 and 18, Figure 3), we used the 1:24,000 digital raster graphs (DRGs) to estimate reservoir size based on a 30.5 m (100 ft) pool above the stream elevation at the proposed crossing. Reservoir locations and sizes were chosen to be realistic and are at locations noted as possible reservoir sites, but are strictly hypothetical for this example. It should be noted that the arbitrary choice of 100 ft reservoir elevation resulted in a pool on watershed 18 that extended to the lower portions of several upstream watersheds.

Baseline conditions: For this example, the upper ESU of Cherokee darters has 18 "occupied" and 4 "unoccupied" watersheds (Figure 2).

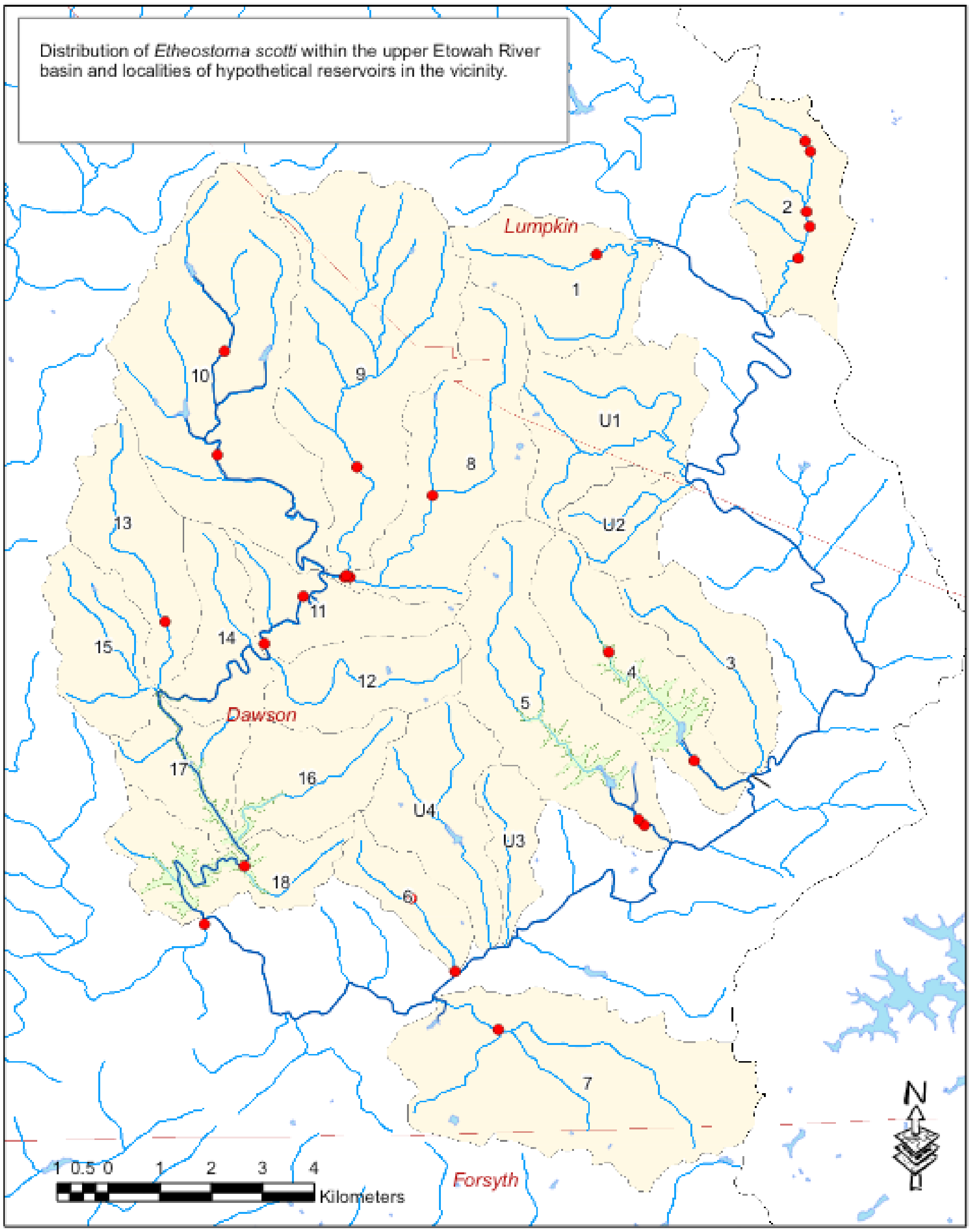

Figure 2. Example: Effects of Three Hypothetical Reservoir Placements within the Range of the Upper ESU of the Cherokee Darter. *Watersheds used to represent population patches are numbered 1-18 for known occurrences of the Cherokee darter, or U1-U4 for sub-basins hypothesized as occupied. Some occurrences are marked by red circles.*

There is not currently a model to predict occurrence rates within patches for the Cherokee darter; therefore, for this analysis patch quality was set to 1 for all patches. Patch stream lengths (draining between 0.5 and 100 km^2) varied from 2.8 km (watershed U3) to 21.5 km (watershed 10). Summed baseline habitat availability was 179 km. For estimating connectivity, we re-estimated connected stream lengths for each patch by subtracting lengths of stream segments that are isolated above reservoirs. For example, three small existing reservoirs in watershed 10 reduced the connected stream length from 21.5 to 14.2 km (with 7.3 km isolated above the reservoirs). The total connectivity for the baseline depended on the value of the coefficient (α) representing the effect of distance on movement rates, and we used three levels representing restricted, moderate and high movement rates (Figure 2).

Effects of the three hypothetical reservoirs were estimated by assuming that (1) Cherokee darters did not persist in the stream segment downstream from the new reservoir, and (2) Cherokee darters would persist in a segment above the new reservoir if the segment was at least as long as the shortest isolated segment known to contain the species. The first condition of no persistence in the reach downstream from the reservoir was considered a "worst-case" scenario. Under the second assumption, Cherokee darters were not predicted to persist upstream of reservoirs on watershed 4 or in the un-impounded portion of watershed 17.

Table 2. Example: Effects of Three Hypothetical Reservoir Placements on Patch Number, Habitat Availability, and Patch Connectivity for the Upper ESU of the Cherokee Darter. *Values in parentheses are change from baseline (for number of patches) or percent of baseline condition.*

			Reservoir location:	
	Baseline	**Watershed 4**	**Watershed 5**	**Watershed 18**
# Patches[1]	22	21 (lose 1)	22 (no change)	21 (lose 1)
Habitat availability, km	179	172 (96%)	173 (97%)	166 (93%)
Connectivity, if movement rates are:				
Low	261679	258792 (99%)	261679 (100%)	177327 (68%)
Moderate	325343	319086 (98%)	324604 (99%)	237091 (73%)
High	404235	396240 (98%)	399872 (99%)	288759 (71%)

[1]*The number of patches with a length of suitable stream as long or longer than the minimum length estimated as necessary to sustain a local Cherokee darter population.*

The comparison (Table 2) projects the greatest effects on habitat availability (7% lost, and loss of 1 patch) and connectivity (decreased about 30%) from the reservoir on watershed 18. Reservoirs on watersheds 4 and 5 have relatively low effects on connectivity. The connectivity results were relatively unaffected by level of movement rate used for evaluation. Effects of the reservoir on watershed 18 could be reduced by projecting a small reservoir that did not extend upstream to the mouths of watersheds 13, 14, and 15 (Figure 2). None of the scenarios reduced the geographic range (i.e., patch diversity) of the upper ESU of the Cherokee darter.

Applications to Other Covered Species

The protocol would be applied to all covered species potentially affected by a proposed reservoir location. Evaluating effects on all covered species will allow decisions regarding reservoir placement to consider relative effects across species. For species in the mainstem Etowah River and larger tributaries, patches would be defined by segments used in the occurrence models applied in the runoff limits components of the Etowah Aquatic HCP. Occurrence models for the Etowah darter and amber darter would be used to estimate patch quality for those species.

Applications to Mitigation

Although not a requirement under the HCP, the protocol could also be used to evaluate the relative persistence value to the covered species of alternative mitigation proposals (i.e., to mitigate for habitat impounded by the reservoir). Specifically, alternative proposals for stream protection (e.g., through acquisition and conservation easements) could be compared in terms of amount and quality of habitat that would be protected, and in terms of connectedness and diversity relative to other populations. Importantly, persistence value could be evaluated in the context of current and projected land use so that, for example, one could explicitly assess the value to covered species of protecting a particular stream that would otherwise be affected by increased development.

Refinements to the Protocol

This protocol should evolve as part of the process of adaptive implementation of the Etowah Aquatic HCP, and with the input of future scientific findings and review. Although the protocol is based on our best current understanding of the covered Etowah fishes, this protocol is limited to comparing *relative* effects of alternative reservoir placements (i.e., rather than actual effects on population viability). Further, the protocol as implemented at present is based on numerous simplifications, made necessary by lack of data. Specific components that should be revised and refined as information becomes available include: patch delineations; estimates of habitat quality; dispersal rates and characteristics; and balance between protecting habitat extent, connectedness and diversity.

Patch delineations should reflect the best available information on what drainage areas, or lengths of stream reaches, contain local breeding populations. Information on how far individuals typically move in a lifetime (including larval and post-larval stages) will help better define patches, as may studies of gene flow between putative populations of the covered species. Estimates of patch-specific habitat quality will improve as monitoring data (collected after HCP implementation) allow refinements to species occurrence models. Habitat quality estimates could also be improved by including a term for how much *appropriate* habitat (e.g., shoals for the mainstem segments) is available in each patch. Improving our understanding of fish movements among patches is essential to clarifying the importance of metapopulation dynamics to species persistence (and the relative importance of protecting many large populations and protecting connectivity between populations).

The protocol for evaluating proposed reservoir locations is based on best-available data and should be periodically reviewed and revised along with other components of the HCP. Revision should include updating estimates of patch occupancy and models used to predict habitat quality and connectivity. The revised protocol should be evaluated by the HCP Scientific Review team to ensure that the protocol remains based on best available science.

Literature Cited

Albanese, B., P. L. Angermeier, and S. Dorai-Raj. 2004. Ecological correlates of fish movement in a network of Virginia streams. Canadian Journal of Fisheries and Aquatic Sciences **61**:857-869.

Bascompte, J., H. Possingham, and J. Roughgarden. 2002. Patchy populations in stochastic environments: critical number of patches for persistence. American Naturalist **159**:128-137.

Baxter, R. M. 1977. Environmental effects of dams and impoundments. Annual Review of Ecology and Systematics **8**:255-283.

Beissinger, S. T., J. R. Walters, D. G. Catanzaro, K. G. Smith, J. B. Dunning, S. M. Haig, B. R. Noon, and B. M. Smith. 2006. Modeling approaches in avian conservation and the role of field biologists. Ornithological Monographs **59**:1-56.

Dudgeon, D. 2000. Large-scale hydrological changes in tropical Asia: prospects for riverine biodiversity. Bioscience **50**:793-806.

Edwards, R. J. 1978. The effect of hypolimnion reservoir releases on fish distribution and species diversity. Transactions of the American Fisheries Society **107**:71-77.

Freeman, M. C. 1995. Movements by two small fishes in a large stream. Copeia **1995**:361-367.

Freeman, M. C., and P. A. Marcinek. 2006. Fish assemblage responses to water withdrawals and water supply reservoirs in Piedmont streams. Environmental Management **in press.**

Hagler, M. M. 2006. Effects of natural flow variability over seven years on the occurrence of shoal-dependent fishes in the Etowah River. M. S. thesis, University of Georgia, Athens, GA.

Hall, C. A. S. 1972. Migration and metabolism in a temperate stream ecosystem. Ecology **53**:585-604.

Hanski, I. 1997. Metapopulation dynamics: from concepts and observations to predictive models. Pages 69-91 *in* I. Hanski and M. E. Gilpin, editors. Metapopulation biology: ecology, genetics, and evolution. Academic Press, San Diego, CA.

Hess, G. R. 1996. Linking extinction to connectivity and habitat destruction in metapopulation models. American Naturalist **148**:226-236.

Katano, O., T. Nakamura, S. Abe, S. Yamamoto, and Y. Baba. 2006. Comparison of fish communities between above- and below-dam sections of small streams; barrier effect to diadromous fishes. Journal of Fish Biology **68**:767-782.

Mion, J. B., R. A. Stein, and E. A. Marschall. 1998. River discharge drives survival of larval walleye. Ecological Applications **8**:88-103.

Morris, W. F., and D. F. Doak. 2002. Quantitative conservation biology: theory and practice of population viability analysis. Sinauer Associates, Inc., Sunderalnd, MA.

Pringle, C. P., M. C. Freeman, and B. J. Freeman. 2000. Regional effects of hydrologic alterations on riverine macrobiota in the New World: tropical-temperate comparisons. BioScience **50**:807-823.

Rieman, B. E., and J. B. Dunham. 2000. Metapopulations and salmonids: a sythesis of life history patterns and empirical observations. Ecology of Freshwater Fish **9**:51-64.

Rodriguez, M. A. 2002. Restricted movement in stream fish: the paradigm is incomplete, not lost. Ecology **83**:1-13.

Rosenberg, D. M., F. Berkes, R. A. Bodaly, R. E. Hecky, C. A. Kelly, and J. W. M. Rudd. 1997. Large-scale impacts of hydroelectric development. Environmental Reviews **5**:27-54.

Schlosser, I. J. 1985. Flow regime, juvenile abundance, and the assemblae structure of stream fishes. Ecology **66**:1484-1490.

Skalski, G. T., and J. E. Gilliam. 2000. Modeling diffusive spread in a heterogeneous population: a movement study with stream fish. Ecology **81**:1685-1700.

Slack, W. T., S. T. Ross, and J. A. Ewing III. 2004. Ecology and population structure of the bayou darter, Etheostoma rubrum: disjunct riffle habitats and downstream transport of larvae. Environmental Biology of Fishes **71**:151-164.

Smithson, E. B., and C. E. Johnston. 1999. Movement patterns of stream fishes in a Ouachita Highlands stream: an examination of the restricted movement paradigm. Transactions of the American Fisheries Society **128**:847-853.

Spence, J. A., and H. B. N. Hynes. 1971. Differences in fish populations upstream and downstream of a mainstream impoundment. Journal of the Fisheries Research Board of Canada **28**:45-46.

Starrett, W. C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. Ecology **32**:13-27.

Storey, C. M. 2003. Genetic population structure and life history aspects of the federally threatened Cherokee darter, Etheostoma scotti. M. S. Thesis, University of Georgia, Athens, GA.

Vaughn, C. C., and C. M. Taylor. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conservation Biology **13**:912-920.

Waples, R. S., and O. Gaggiotti. 2006. What is a population? An empirical evaluation of some genetic methods for identifying the number of gene pools and their degree of connectivity. Molecular Ecology **15**:1419-1439.

Watters, G. T. 1996. Small dams as barriers to freshwater mussels (Bivalvia, Unionoida) and their hosts. Biological Conservation **75**:79-85.

Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society **120**:98-105.