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Conservation planning for imperiled aquatic species in an urbanizing environment

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ABSTRACT

As the global area devoted to urban uses grows, an increasing number of freshwater species will face imperilment due to urbanization effects. Management of these impacts on both private and public lands is necessary to ensure species persistence. Such management entails several hallenges: (1) development of a management policy appropriate to the stressors; (2) linking stressor levels to species population attributes; (3) forecasting the effects of alternative management policy decisions on the species, and (4) using adaptive management to adjust the policy in the future. We illustrate how these challenges were addressed under the Etowah Habitat Conservation Plan (Etowah HCP), a management plan for three federally protected fish species in Georgia, USA. The plan involved the creation of a management policy to address the impacts of the greatest stressor, stormwater runoff, as well as other stressors. Models were constructed to link population indices of the three species with a key indicator of stormwater runoff, effective impervious area (EIA). Then, models were applied to projected levels of EIA under full watershed buildout to fine-tune the parameters of the management policy. Forecasting indicated that the most sensitive species, the Etowah darter, was likely to decline by 84% in the absence of the Etowah HCP, but only 23% if the Etowah HCP were implemented. Although there was substantial uncertainty in model predictions, an adaptive management plan was established to incorporate new data and to adjust management policies as necessary.

1. Introduction

The world's land area devoted to urban, suburban, and exurban uses is rapidly increasing (UNFPA, 2008; note: in the rest of the article we use the term "urban" to refer to all development densities of 1 dwelling per 10 acres or higher). This has important implications for freshwater biodiversity, as even low intensities of urban land use can contribute to extirpations of sensitive freshwater fauna (e.g., Ourso and Frenzel, 2003; Walsh et al., 2001). Narrowly distributed species are particularly vulnerable, because continued urban growth implies that the entire ranges of some endemic aquatic species eventually will be subsumed within predominantly urban watersheds. Extinctions of some of these species are likely without deliberate management intervention.

Many conservation biologists consider land preservation in managed reserves to be the backbone of biodiversity protection (Margules and Pressey, 2000). For freshwater ecosystems, however, reserves have traditionally received little attention, both in the scientific literature and in conservation programs (Abell et al., 2007). One reason for this may be the financial cost of preserving sufficient land to maintain healthy aquatic habitat; this is especially challenging in urbanizing watersheds where land values are high. For that reason, we assert that a management program relying solely on preservation is unlikely to be sufficient for protecting an imperiled aquatic species confined to urbanizing watersheds, unless the species has an exceedingly small natural range or exceedingly large sums of money are dedicated to the purpose. Otherwise, successful aquatic species management plans must incorporate provisions to reduce the impacts of private urban land use on the aquatic environment.

Policies that affect actions on private lands frequently engender landowner opposition (Beatley, 1994; Langpap and Wu, 2004; Peterson et al., 2004), and the potential for conflict may explain why few aquatic species management plans have been developed to manage urban impacts. Any such proposed plan must have a solid scientific basis that will withstand the scrutiny of landowners, government officials, and other stakeholders. In addition, the coordination of all of the disparate groups – scientists, policy analysts,

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government officials, landowners, developers, and other stakeholders – is no small task. These difficulties manifest themselves in several particular challenges:

(1) A science-based management policy is required, but the science of urban streams is new. Urban impacts to aquatic systems are complex phenomena, and it is only recently that the scientific community studying these streams has reached a degree of consensus on the principle stressors (Walsh et al., 2005), allowing for creation of targeted management policies. Urban land use management policies must also be practical to implement and acceptable to the regulated community.
(2) Stressors must be quantitatively linked to population attributes of the species of management concern to establish response thresholds. For species faced with threats or stressors that are expected to increase, this can be viewed as a general three-step process: (1) develop models of species response to increasing stressor levels, (2) determine minimal viable population sizes for the species, and (3) combine these to determine response thresholds—i.e., maximum stressor levels that do not threaten species persistence. This approach is consistent with commonly used species management frameworks, such as The Nature Conservancy's Conservation Action Planning protocol (The Nature Conservancy, 2007) and the Fish and Wildlife Services' Strategic Habitat Conservation approach (http://training.fws.gov/EC/Resources/SHC/shc.htm), but we emphasize quantification of stressor-response relationships that are often only qualitatively described.
(3) Using these relationships, forecasting must be conducted to evaluate the effects of alternative management scenarios and to compare them to response thresholds. The need for better forecasting has been identified as a general ecological imperative (Clark et al., 2001), but predicting future land use changes is particularly challenging (Lohse et al., 2008). In addition, iterative forecasting and adjustment of management scenarios requires close interaction between biologists, modelers, policy makers and stakeholders.
(4) Adaptive management must be used to adjust the policy over time in response to improved understanding of ecological system dynamics. This requires ongoing funding and continued involvement of scientists and policy makers.

In this article we present a case study in which these challenges were addressed (although the success of meeting challenge four cannot yet be evaluated). The case study involves the creation of the Etowah Aquatic Habitat Conservation Plan (Etowah HCP; Etowah HCP Advisory Committee, 2007), a management plan for three imperiled fishes threatened by increasing urbanization in the southeastern United States. To our knowledge, this is the first plan that incorporates concrete policies for limiting the impacts of urbanization on private lands to imperiled aquatic species and uses population forecasts to tune those policies for the long-term persistence of the species. The approach we employed is flexible and adaptable to other conservation planning efforts for aquatic species in urbanizing regions. This article is organized as follows: first we present the study area and background, then we describe how the four challenges were met, and finally we conclude with a discussion. Because the methodologies for forecasting (challenge 3) are complex, we divide this section into subsections detailing methods and results.

2. Study area, species and the Etowah Aquatic Habitat Conservation Plan

The Etowah River is a major tributary of the Coosa River system in the Mobile River Basin (Fig. 1), draining 4871 km^2 of land. A portion of the Etowah lies within the Southern Appalachian highlands, a global hotspot of fish endemism (Warren et al., 2000). The Etowah supports four endemic fish species and another eight species endemic to the larger Mobile River Basin (Burkhead et al.,

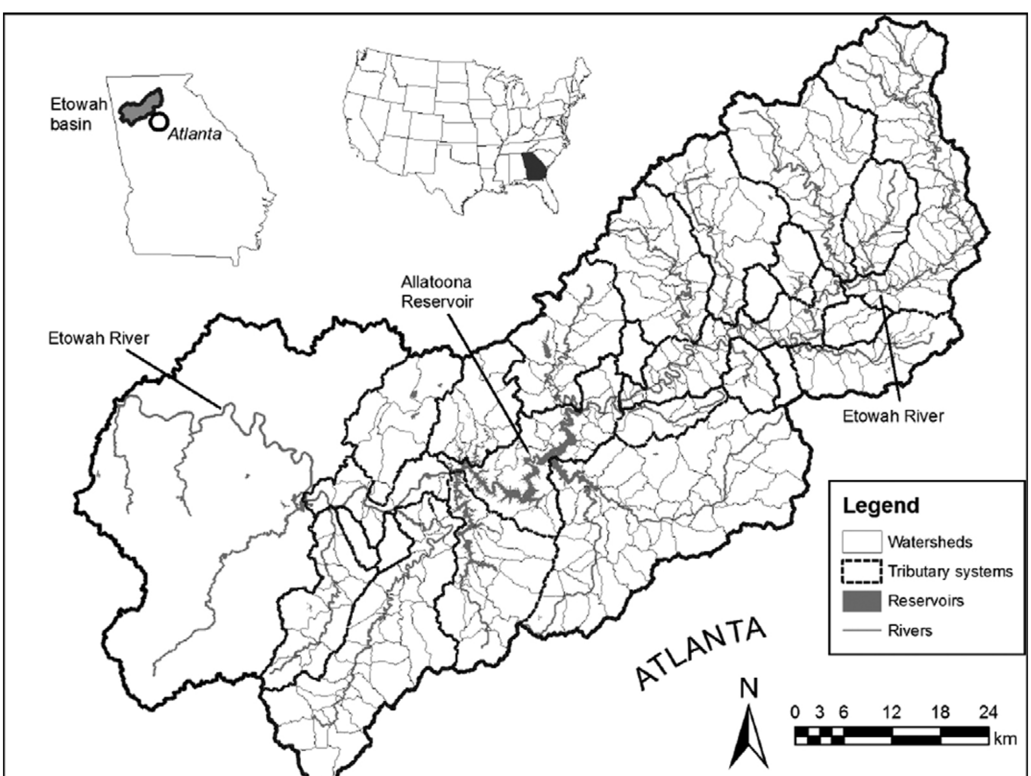

Fig. 1. The Etowah Basin, showing tributary systems and watersheds.

1997). Three of these fishes, the Etowah darter (*Etheostoma etowahae*), Cherokee darter (*Etheostoma scotti*) and amber darter (*Percina antesella*) of the family Percidae, are federally listed under the US Endangered Species Act (ESA) and are the subjects of this study. All are small (total length ≤ 80 mm) benthic fishes commonly found in shallow riffles. The Etowah darter and amber darter are listed as endangered and occur in the Etowah River mainstem and either mid-sized tributaries (Etowah darter) or the lower reaches of large tributaries (amber darter). The Etowah darter is endemic to the Etowah, while the amber darter occurs only in the Etowah and the nearby Conasauga basins. The Cherokee darter is listed as threatened and is endemic to small streams of the Etowah River basin. There are three genetically distinct evolutionarily significant units (ESUs) of the Cherokee darter, roughly corresponding to populations in the upper, middle, and lower parts of the basin (Storey, 2003).

Development of a Habitat Conservation Plan for these three species began in 2002 in response to local government concerns that enforcement of the ESA for declining listed species could constrain future economic growth unless a proactive plan was implemented. Under the ESA, a Habitat Conservation Plan is a voluntary agreement between the federal government and a permittee (who may be an individual, organization or other entity) that calls for the permittee to implement a set of species protection measures; in exchange, the permittee receives an "incidental take permit" that shields him from prosecution for any incidental harm to protected species or their habitat. Under the proposed Etowah HCP, the permittees are county and municipal governments who will implement land use and regulatory policies to manage urban impacts to the three listed species. Developers and landowners who adhere to these policies are covered by incidental take permits by extension. If implemented, compliance with the terms of the HCP can be expected to be high, as the HCP and the incidental take permits are binding legal agreements that are enforceable by the US Fish and Wildlife Service under the ESA. Development of the Etowah HCP began in 2002 and was overseen by a steering committee, whose voting members were representatives of participating local governments. Representatives of the development industry and other stakeholders participated extensively in the creation of Etowah HCP policies by serving on technical committees and by providing comments to the researchers and staff who drafted provisions for their consideration.

3. Challenge 1: development of a science-based management policy for urban streams

We based management policies for urban-related stressors in the Etowah on a scientific literature review that identified specific mechanisms and sources of urban stressors and potential management strategies to minimize those impacts (Wenger and Freeman, 2007). Management strategies were reviewed by technical advisory committees (TACs) who selected policies that reduced stressors to "acceptable" levels (see below) while minimizing the regulatory burden. The selected policies included controls on erosion and sedimentation from construction, road crossing design requirements to maximize fish passage, policies to minimize utility line impacts, riparian buffer regulations, recommendations for siting new water supply reservoirs, and a stormwater management policy. Based on this review and past research work in the Etowah basin (Roy et al., 2005), we determined that the stormwater management policy was the most critical. This agrees with findings of a recent consensus document from an international meeting of urban stream ecologists, which identified stormwater runoff from impervious surfaces as the paramount stressor to urban streams (Walsh et al., 2005). Increased stormwater runoff alters stream hydrology and can lead to sustained channel erosion and sedimentation; equally important, runoff carries a mix of contaminants that may be toxic to stream organisms or cause other changes to ecosystem structure and function (Paul and Meyer, 2001; Walsh et al., 2004a). Past researchers have found strong relationships between aquatic organism populations and a key indicator of stormwater runoff, effective impervious area or EIA (Hatt et al., 2004; Walsh et al., 2004b). This is typically defined as the amount of impervious cover directly connected to streams via an artificial drainage network.

To manage both the hydrologic and contaminant impacts of stormwater runoff, we proposed applying a recently developed stormwater performance standard called the "Runoff Limits Program" (Runoff Limits, Wenger et al., 2008a). The Runoff Limits program limits the volumes of precipitation from small storms (less than 2-year annual recurrence interval) permitted to leave a site as surface runoff. The focus is on small events because studies have identified these as the main sources of hydrologic alteration and contaminant flux in urban areas (Walsh et al., 2005; Ladson et al., 2006). To meet the policy, developers can employ a flexible combination of (1) low impact development strategies to minimize runoff and (2) stormwater management practices to infiltrate runoff into the soil. Because infiltration practices tend to have very high contaminant removal levels (Barraud et al., 2005; Murakami et al., 2008), when properly implemented this approach should provide a complete solution to stormwater runoff impacts. This performance-based approach was far more acceptable to the regulated community than other alternatives, such as strict limits on development density or impervious cover itself.

The Runoff Limits Program incorporated different performance standards for different geographic areas (Fig. 2). For "Priority 1" watersheds supporting the federally endangered Etowah darters and amber darters, the runoff standard was set equal to that of forest. This means that the volume of runoff from a new development site cannot exceed the volume of runoff that would occur from that site under forested conditions, for small storms, given the soils present. For "Priority 2" watersheds supporting the federally threatened Cherokee darters, the limit was less strict, such that runoff volume cannot exceed the volume that would have come from the site if 5% were impervious and 95% were forested. The decision to apply a less strict standard to Cherokee darter watersheds was based on preliminary analyses (unpublished data) that showed a much lower sensitivity of the species to urbanization than that observed for other species, such as the Etowah darter. The sensitivity of amber darters was unknown, but amber darters mostly occurred within the range of Etowah darters, and out of precaution Priority 1 areas were set to include the full range of both amber darters and Etowah darters (Fig. 2).

Recognizing that it would be a challenge to meet the performance standards in Priority 1 and Priority 2 areas for high-intensity land use classes such as commercial development, the stormwater TAC added a Runoff Limits category for "development nodes," which could be designated within priority areas by local governments. The development node standard was set at 50% of the actual impervious cover for the site. For example, a site with 60% impervious cover would be limited to the volume of runoff expected from the site if it had 30% impervious cover (and the remainder forested). This limit was an arbitrary standard designed to be achievable for developers while still reducing runoff. Of course, the size and locations of development nodes had to be limited to a level that would not threaten the viability of the target fish populations; the methods for doing so are described in the next sections.

4. Challenge 2: linking stressors with species population attributes to establish population thresholds

We linked the occurrence or abundance of the three target fish species to EIA, our indicator of stormwater runoff intensity, using

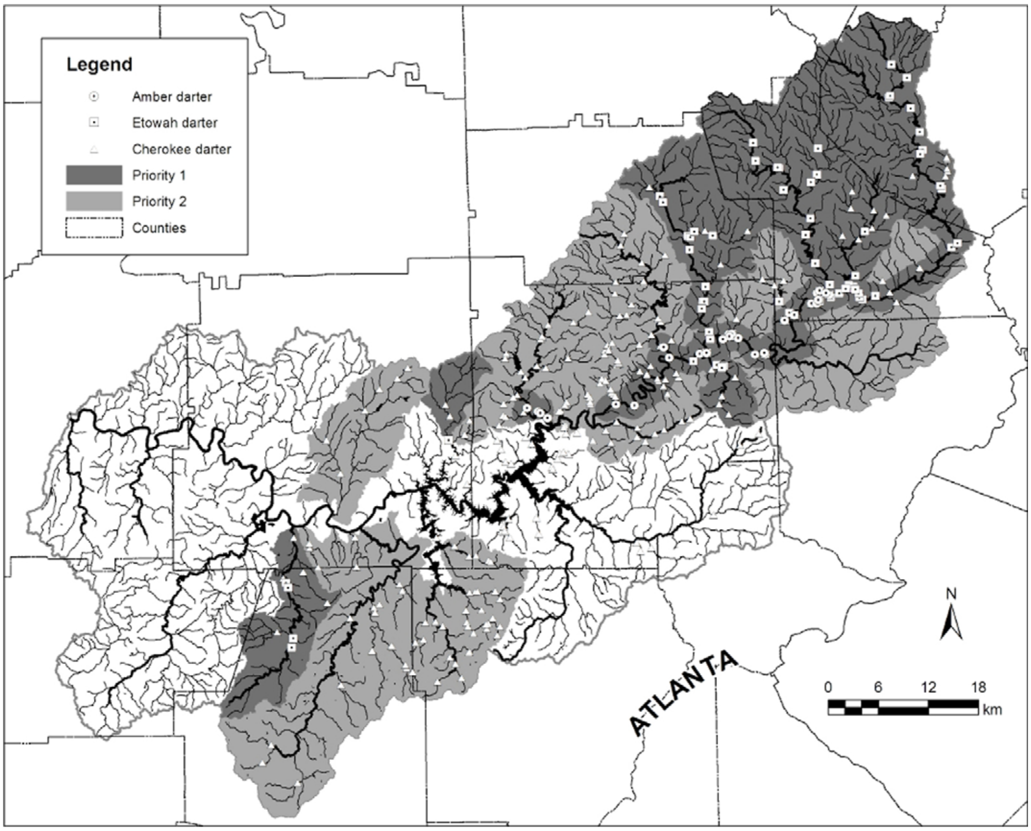

Fig. 2. Priority areas and known occurrences of threatened and endangered fish species in the Etowah basin.

models developed in other studies (Wenger et al., 2008b; Wenger and Freeman, 2008; Wenger, 2008). The Etowah darter model was an occupancy model accounting for incomplete detectability and spatial autocorrelation in a Bayesian framework, with the best-supported model (Table 1) selected from a set of candidate models based on predictive performance (Wenger et al., 2008b). The Cherokee darter model used an approach that simultaneously estimated occurrence, abundance and detection probability, with EIA as a covariate on abundance (Wenger and Freeman, 2008). The best model (Table 1) was selected using Akaike's Information Criterion.

The amber darter is difficult to model because the species occurs in significant numbers at only two localities: the mainstem of the Etowah and the mainstem of the neighboring Conasauga River (small populations also inhabit the lower reaches of three large Etowah tributaries; Fig. 2). Because of this restricted range, it is impossible to infer the sensitivity of the species to impervious cover based on its existing distribution. In such cases, researchers have proposed using a surrogate species to estimate a hypothesized response of the species of interest (Wenger, 2008). Our model for the amber darter was based on a study that used a Bayesian

Table 1
Covariates of the predictive models used for the three species. "Modifying" indicates which model response variable is modified by the covariate. "Direction" indicates whether the covariate is positively (+) or negatively (−) associated with the response variable. Asterisk (*) indicates that the effect is positive or negative, depending on the collector institution (i.e., collectors from different institutions had different probabilities of detecting Cherokee darters when they were present). "In Little River tributary system" means that the site is located within a stream draining into the Little River, a tributary of the Etowah; all such sites had unexpectedly low probabilities of Cherokee darter occurrence. Further details on model covariates are found in Wenger et al. (2008b), Wenger and Freeman (2008), and Wenger (2008) for Etowah darter, Cherokee darter and amber darter, respectively.

Species	Covariate	Modifying	Direction
Etowah darter	Watershed area	Occupancy	+
	Dlink (downstream link magnitude)	Occupancy	+
	$Dlink^2$	Occupancy	−
	Mean slope of tributary system	Occupancy	+
	% of tributary system inundated by impoundments	Occupancy	−
	% EIA within 1.5 km radius	Occupancy	−
Cherokee darter	Micaceous saprolite	Abundance	+
	% EIA within 1 km radius	Abundance	−
	Elevation	Occupancy	−
	Gneiss bedrock	Occupancy	−
	Metagraywacke bedrock	Occupancy	+
	In Little River tributary system	Occupancy	−
	Collector institution	Detection	*
Amber darter	Watershed area	Occupancy	+
	% EIA within 1.5 km radius	Occupancy	−

approach to combine data from a surrogate, the bronze darter (*Percina palmaris*), with the limited available data for the amber darter to create a model of amber darter occupancy in response to EIA (Wenger, 2008). The bronze darter was selected as a surrogate because it was the sympatric congeneric most similar to the amber darter in habits and habitat occupied. The model included only one other variable, watershed area (Table 1).

Modeling results indicated that Etowah darters were sensitive to increasing EIA, with occurrence probability approaching zero as EIA increased beyond 4% EIA, with other parameters held to fixed values. Cherokee darters, in contrast, appeared to be less sensitive, with populations declining from a mean of 80–120 individuals per 150 m stream reach to abundances of 30–40 at 20% EIA. Amber darters were predicted to be intermediate in sensitivity, with occurrence probability approaching zero above 10% EIA.

These modeled relationships described how stormwater, as indicated by EIA, affected the target species' populations at the scale of the individual reach. We assumed a reach corresponded to a population or a portion of a population. The next step was to scale up to determine how declines in reach-scale populations affect the entire populations or metapopulations of these species. We needed to answer the question: how many reaches could be lost or degraded without jeopardizing each species' survival?

Answering these questions required a population viability analysis (PVA) for each species. A full demographic PVA requires data to estimate growth rates and stochasticity, which are used to compute the probability of extinction or quasi-extinction over a specified time period (Morris and Doak, 2002). However, Moilanen et al. (2005) note that "for most species in most landscapes, insufficient ecological data, population parameters or habitat distribution information are available to allow the application of simulation modeling" such as a demographic PVA, and several researchers have cautioned against over-reliance on this tool when data are limited (Beissinger and Westphal, 1998; Ellner et al., 2002). As we lacked adequate data for a formal demographic PVA, we conducted a PVA using expert opinion to estimate the number of putative populations or subpopulations that had to remain minimally impacted to ensure each species' ongoing survival.

To develop this PVA, our Scientific Advisory Committee (members are listed in acknowledgments) used the following assumptions about species population/metapopulation dynamics:

- Stream reaches that currently have high occupancy or abundance are most valuable to the population. This was equivalent to assuming that source/sink dynamics (Pulliam, 1988), if present, do not result in higher occupancy or abundances in population sinks.
- High occupancy/abundance habitat should be maintained in different parts of the species' ranges to support multiple populations. Toward this end, the Etowah darter range was assumed to be composed of five significant "population areas," representing distinct tributary watersheds, albeit with some arbitrarily defined boundaries separating them (Fig. 3). The amber darter range was assumed to comprise four population areas, representing three sections of the mainstem and a disconnected tributary; and the Cherokee darter range was divided to correspond to its three ESUs (Etowah HCP Advisory Committee, 2007).
- Connectivity among patches should be maximized to minimize interruption of dispersal among presently occupied, connected habitat patches. The committee assumed that patches of very low predicted occupancy/abundance might constitute barriers (heavily degraded reaches through which individuals would be unwilling or unable to move), and determined that no patches should be allowed to decline to this level (note: other forms of

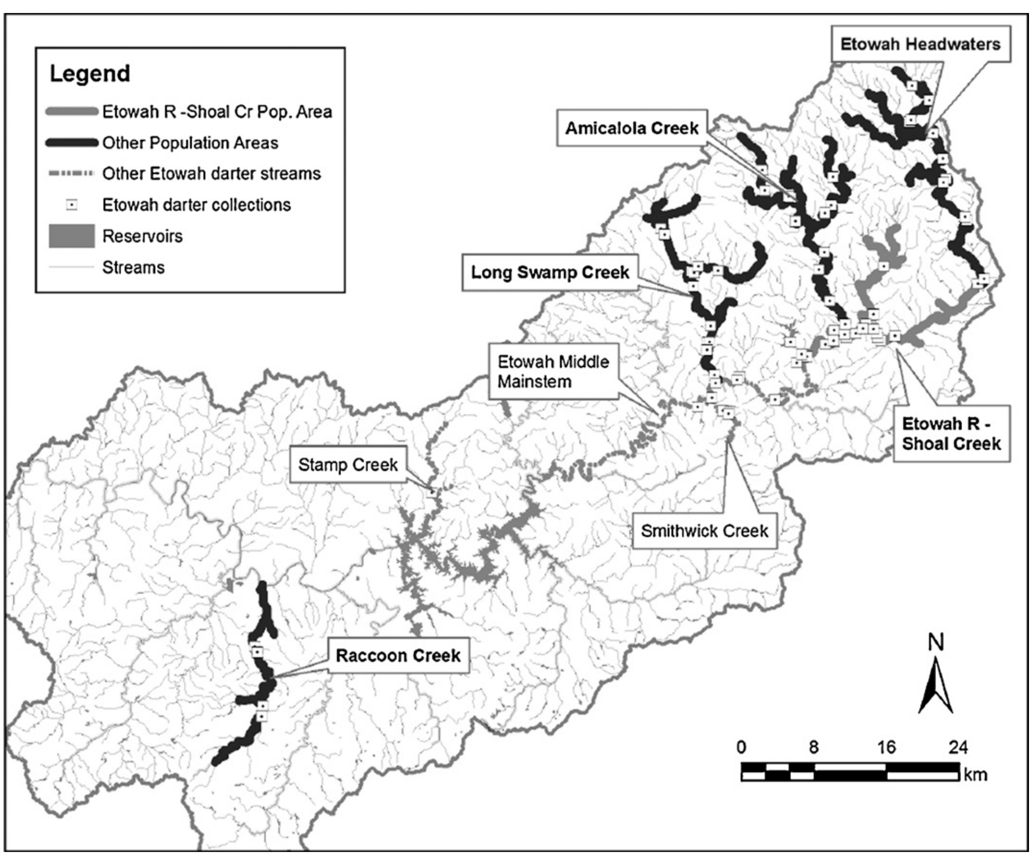

Fig. 3. Population areas for Etowah darters under the population thresholds. Population areas are shown in heavy black or grey, with bold labels. Other streams with Etowah darter collections (not considered major population areas) are labeled in normal font.

barriers, including road crossings and dams, were addressed by other Etowah HCP policies).

Based on these principles and the results of preliminary modeling, the Scientific Advisory Committee established numeric limits for each species in the form of "population thresholds." We provide the population thresholds for the Etowah darter here as an example. The population thresholds for the other species are given in the Etowah HCP draft document.

The Etowah darter population thresholds require that the projected occurrence probability of the Etowah darter meets the following criteria:

1. At least 30% of stream miles in which modeled probability of occurrence is greater than or equal to 80% under 2006 conditions must maintain a predicted probability of occurrence greater than or equal to 80% under the buildout scenario.
2. At least 50% of stream miles in which the 2006 modeled probability of occurrence is greater than or equal to 80% must maintain a predicted probability of occurrence greater than or equal to 50% under the buildout scenario.

   Conditions 1 and 2 apply to five designated population areas that have high probability of occurrence and known occupation under 2006 conditions (see Fig. 3). The Scientific Advisory Committee identified these as major population areas critical for the survival of the species:
   a. Headwaters of the Etowah River mainstem.
   b. Upper Etowah River mainstem and lower reach of Shoal Creek (Dawson County).
   c. Amicalola Creek system.
   d. Long Swamp Creek system.
   e. Raccoon Creek.
3. 100% of streams with a modeled probability of occurrence 25% or greater under 2006 conditions must maintain a probability of occurrence above 5% under the buildout scenario.
4. The total decline in length of occupied Etowah darter reaches across the basin (i.e., total take of the species) under the buildout scenario, relative to 2006 conditions, must not exceed 30%.

5. Challenge 3: forecasting effects of alternative management scenarios

The models and population thresholds described above provided a means to estimate the effects of different levels of stormwater impact on the populations of the three target fish species. The next step was to create spatially explicit forecasts of future levels of stormwater impact using EIA with and without the Runoff Limits, and to fine-tune the policy to ensure viable populations of all three fish species.

5.1. Methods

For each species, we used the selected model (Table 1) to predict occupancy (for Etowah darters and amber darters) or both occupancy and abundance (for Cherokee darters) for stream reaches across the Etowah basin, based on the values of the model covariates. Predictions were made for three scenarios: (1) current (as of 2006) conditions, (2) full watershed buildout with Runoff Limits ("HCP scenario") and (3) full watershed buildout without the Runoff Limits ("no-action alternative"). Multiple versions of scenario 2 were created in the process of fine-tuning the Runoff Limits, as described below. We modeled conditions under full watershed buildout because this represented the greatest degree of stormwater runoff and therefore highest degree of stress to the target fish species. The scenarios differed only in their values for EIA. Note that for model development, EIA was defined as directly connected impervious area. However, the forecasting assumed that future stormwater management policies would reduce the effects of some directly connected impervious area through treatment practices, such that a given level of directly connected impervious area might have less impact to stream ecosystems than under current conditions. Thus, EIA was defined more generally as directly connected impervious area adjusted for stormwater treatment practices above and beyond those that were commonly employed under current conditions.

Data preparation was performed using ESRI ArcMap 9.0 Geographic Information System (GIS). Stream reaches were clipped to a custom watershed coverage, created by subdividing the USGS hydrologic unit code level-12 watersheds at stream confluences (Fig. 1). Watershed-scale covariates were measured as the dominant class (geologic variables), the maximum value (watershed area and downstream link magnitude) or the mean value (elevation). Some covariates were measured at the scale of tributary systems (Table 1), which are larger watersheds shown with heavy outline on Fig. 1.

5.1.1. Estimating EIA under 2006 conditions

The 2001 National Land Cover Database Imperviousness layer (US Geological Survey, 2003), the most recent available imperviousness data set, was used as the baseline for total impervious area (TIA). This was a 30 m resolution raster coverage derived from a supervised classification of LandSat satellite imagery. It was converted to EIA based on an empirical relationship between TIA and EIA (Wenger et al., 2008b). We updated the 2001 EIA coverage to 2006 conditions by analyzing land use maps, parcel maps and recent aerial photography to identify parcels that had developed since 2001, applying appropriate EIA values to each identified location of recent development based on lot density, aerial photography and literature values (Capiella and Brown, 2001).

5.1.2. Estimating EIA under HCP and no-action scenarios

We assumed that currently developed cells (EIA > 0 under 2006 conditions) would not increase or decrease in EIA value at buildout under the HCP and no-action scenarios, but that all undeveloped cells would be developed unless they lay within designated conservation areas. Conservation areas were mapped from a statewide database of protected areas (Natural Resources Spatial Analysis Laboratory, 2003), augmented by additional permanently protected lands identified by local governments and stakeholders. This approach to estimating buildout was equivalent to assuming complete infill with no redevelopment, a necessary simplifying assumption. To calculate EIA values for currently undeveloped cells, we first estimated buildout TIA parcel-by-parcel based on zoning class, future land use category, and whether the parcel lay within a node, conservation area, Priority 1 area or Priority 2 area. We then converted TIA values to EIA based on assumptions about how the stormwater management requirements of the Runoff Limits (for the HCP scenario) or conventional stormwater policy (for the no action scenario) would reduce stormwater runoff impacts (for details see Etowah HCP Advisory Committee, 2007).

5.1.3. Calculating effect on populations

We estimated the decline in modeled occupancy/abundance from 2006 conditions for each species under the HCP and no-action scenarios. We only modeled changes within the range of each species as it was known in 2006. For Etowah and amber darters, we multiplied estimated occupancy values for each reach by the reach length, which produced an estimate of occupied stream habitat for each reach. For Cherokee darters, abundance estimates reflected the number of individuals in a standard sampling length of 150 m. Therefore, for each reach, we extrapolated the abundance by the length of the reach and the occupancy probability of the reach to produce an estimate of total individuals (for example, a 500 m reach with an estimated abundance of 80 and an occupancy probability of 70% has an estimated total abundance of 500 m[80 fish/150 m] × 7 = 187 fish).

The primary goal in forecasting was to identify appropriate levels of stormwater management under the Runoff Limits that would meet the Population Thresholds for all target species. This required iterative runs of the HCP scenario with changes made to the size and locations of the development nodes, which were the main parameters of the Runoff Limits program subject to adjustment. Initially, development nodes were identified by local government officials based on zoning maps and future land use maps. Runs of the predictive model under these initial settings indicated that the Population Thresholds would be exceeded in some regions, so we consulted with relevant local government officials to identify parcels that could be removed from node status. Local officials identified a subset of development nodes that were less appropriate for high-density development than others, and we re-ran the model with some of these removed from node status. After several attempts we were able to identify a set of development node locations acceptable to the local governments and which met the Population Thresholds for all species. This was the final HCP scenario.

5.1.4. Model uncertainty and sensitivity

We tested the contribution of uncertainty in each parameter of the Etowah darter and amber darter models to the overall uncertainty of the prediction by systematically holding all parameters but one to their mean values and observing the change in mean standard error of predicted occupancy. We also examined the variance parameter of the negative binomial abundance distribution of the Cherokee darter model as an indicator of the uncertainty in its predictions. Another source of uncertainty lay in the assumptions used to calculate EIA under the HCP and no action scenarios. To explore the consequences of a systematic bias in the EIA estimates, we analyzed the sensitivity of the Etowah darter modeling results to an increase in EIA values to 110% and 125% of the estimated values and a decrease to 90% and 75% of the estimated values. We analyzed only the Etowah darter model because it showed considerably more sensitivity to EIA than the other two species models and was the determining factor affecting development node size and location.

5.2. Results

We provide results including maps for the Etowah darter here as an example, and summary results for the amber darter and Cherokee darter; further results are available in the Etowah HCP draft document. The HCP scenario described here is the final HCP scenario, after modifications to the development nodes with local government input to meet the Population Thresholds.

5.2.1. Etowah darter

Our modeling predicted that the amount of occupied stream length would decline from 2006 levels by about 23% under the HCP scenario and 84% under the no-action alternative (Table 2). The Population Thresholds were met for each of the five population areas under the HCP scenario, but were violated in all population areas under the no-action alternative. Model results are shown spatially for 2006 conditions (Fig. 4) and under the HCP scenario (Fig. 5); results under the no-action alternative may be found in the Etowah HCP draft document. Much of the decline under the HCP scenario was projected to occur in Pickens County and Dawson County, two jurisdictions that have large areas of Etowah darter habitat and substantial pressure for high-intensity development along road corridors adjacent to that habitat. Three areas that were predicted to experience large percentage reductions in habitat – the Etowah Middle Mainstem (Forsyth and Cherokee Counties), Smithwick Creek and Stamp Creek – were not considered major population areas essential to the survival of the Etowah darter by the Scientific Advisory Committee.

5.2.2. Amber darter and Cherokee darter

Amber darters were predicted to decline by an estimated 11% of occupied habitat under the Etowah HCP policies. Under the no-action alternative, 61% of the habitat was expected to be lost (Table 2). Cherokee darter abundances were estimated to decline by an overall 21% under the HCP scenario, with most of the losses accruing to the middle and lower ESUs. Under the no-action alternative, the decline was estimated at 43% (Table 2). Model results indicated that the population thresholds would be met for both species under the HCP scenario, but for neither species under the no-action alternative.

5.2.3. Model prediction uncertainty and sensitivity

Predictions of occupancy and abundance were characterized by high levels of uncertainty for some reaches. For both the Etowah and amber darters, the probability distributions of occupancy for many stream reaches were broad (Fig. 5, inset), indicating a high level of uncertainty in the probability of species presence or the degree of occupancy. For other reaches, however, the predicted occupancy was zero with low variance, and for a few reaches occupancy was near one with low variance. Thus, some reaches were definitively predicted to be occupied or unoccupied, and others had uncertain predictions of intermediate occupancy. For both the Etowah darter and amber darter, the parameter that contributed the most uncertainty was EIA. The Cherokee darter modeling was also characterized by high uncertainty in the form of unexplained variance in the abundance estimates. The variance parameter of the negative binomial distribution was estimated at 0.78, which means that for a mean abundance of 100, the 90% confidence interval ranges from 2 to 328, indicating much unexplained variance in Cherokee darter abundance in any given stream reach.

We found that if EIA were 10% higher than estimated, there would be an additional 2% decline in occupancy of Etowah darters, although such a scenario still would meet the population thresholds for each of the five population areas. If EIA values were 25% higher than estimated, the decline in occupancy would be 5% greater than estimated in the HCP scenario, and two of the five population areas would not meet the population thresholds. If EIA values were 10% or 25% less than predicted population thresholds would be easily met.

6. Challenge 4: adaptive management

Adaptive management is a required component of habitat conservation plans (Wilhere, 2002). Adaptive management allows policies to be adjusted as additional data are collected and understanding of the relationships between stressors and species improves. The proposed Etowah HCP specifies a passive adaptive management approach (Walters and Hilborn, 1978) that calls for the collection of annual biological monitoring data at fixed sites (monitored every year) and floating sites (each monitored one time only) within the range of target species, including locations where development is occurring. These data will be used to evaluate the relative support for the current models versus alternative models, including ones that do not include EIA as a predictor. Subsequently, these new data will be added to the existing datasets used to run the models. If appropriate, policies will be adjusted to reflect the improved understanding (Etowah HCP Advisory Committee, 2007).

Table 2
Estimated habitat occupied by Etowah darters and amber darters (in km) and abundances of Cherokee darters (in 1000 s) under 2006 conditions, the HCP scenario and the no-action scenario. Proportional losses in habitat from 2006 conditions are shown for the HCP scenario and no action scenario.

Species	2006 Scenario	Etowah HCP Scenario		No Action Scenario	
	Habitat/Pop	Habitat/Pop	Loss fr 2006	Habitat/Pop	Loss fr 2006
Etowah darter	231.9 km	178.9 km	23%	36.9 km	84%
Amber darter	64 km	57 km	11%	25 km	61%
Cherokee darter	678,000	536,000	21%	384,000	43%

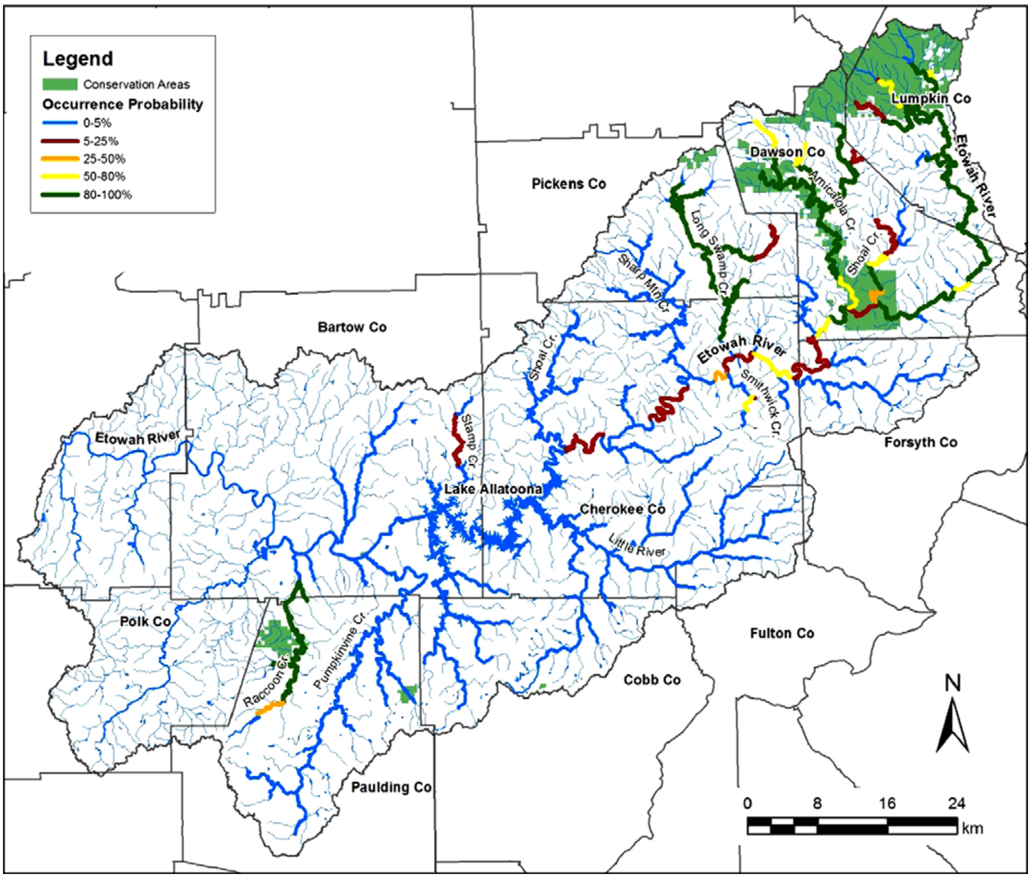

Fig. 4. Modeled Etowah darter occupancy (occurrence probability) under 2006 conditions. Color-coded stream labels indicate mean of the posterior occurrence probability for each reach. Results are only shown for streams with known occupation.

In addition to biological monitoring, the Etowah HCP includes compliance monitoring to assess performance in governments' implementation of Etowah HCP policies and to identify regulatory provisions that require adjustment. Other potential adaptive management actions range from minor corrections of ordinance language to addition of new (but previously identified) policy provisions. At the time of this writing the Etowah HCP is still in federal review (see Section 4), so the adaptive management program has yet to be implemented and its success cannot be evaluated. We foresee three particular challenges in adaptive management implementation. First, maintaining sustained funding for monitoring may be difficult. Second, finding skilled personnel to conduct model updating will be a challenge. And third, if monitoring indicates the need for stricter controls, there will likely be considerable opposition within the development community to any ratcheting-up of regulatory provisions.

7. Discussion

Our forecasts suggest that if the Etowah basin were to develop without the stormwater management provisions of the Etowah HCP, the length of streams occupied by Etowah darters and amber darters eventually would decline by 84% and 61% respectively, putting the persistence of both species into doubt. Cherokee darters would decline in abundance by 43% and would fail to meet the minimum population thresholds set by the Scientific Advisory Committee. The forecasts suggested that all three species also will decline if the Etowah HCP is implemented, but the declines will be much less and all species will have a high probability of long-term persistence. Although these forecasts include a high degree of uncertainty, they are based on the best available information and provide a rational basis for decision making.

The Etowah HCP is somewhat unusual in its emphasis on managing the impacts of private urban land. Most previous HCPs have focused on land preservation, even in urban areas. This makes abundant sense for terrestrial species with habitat needs that are fundamentally incompatible with urban land uses, but less so for aquatic species. For example, one of the first HCPs was the Coachella Valley HCP for the fringe-toed lizard, a species which requires fine wind-blown sand and a large contributing area to generate the appropriate sand habitat (Beatley, 1992). The Coachella Valley HCP set aside nearly 17,000 acres that might otherwise have

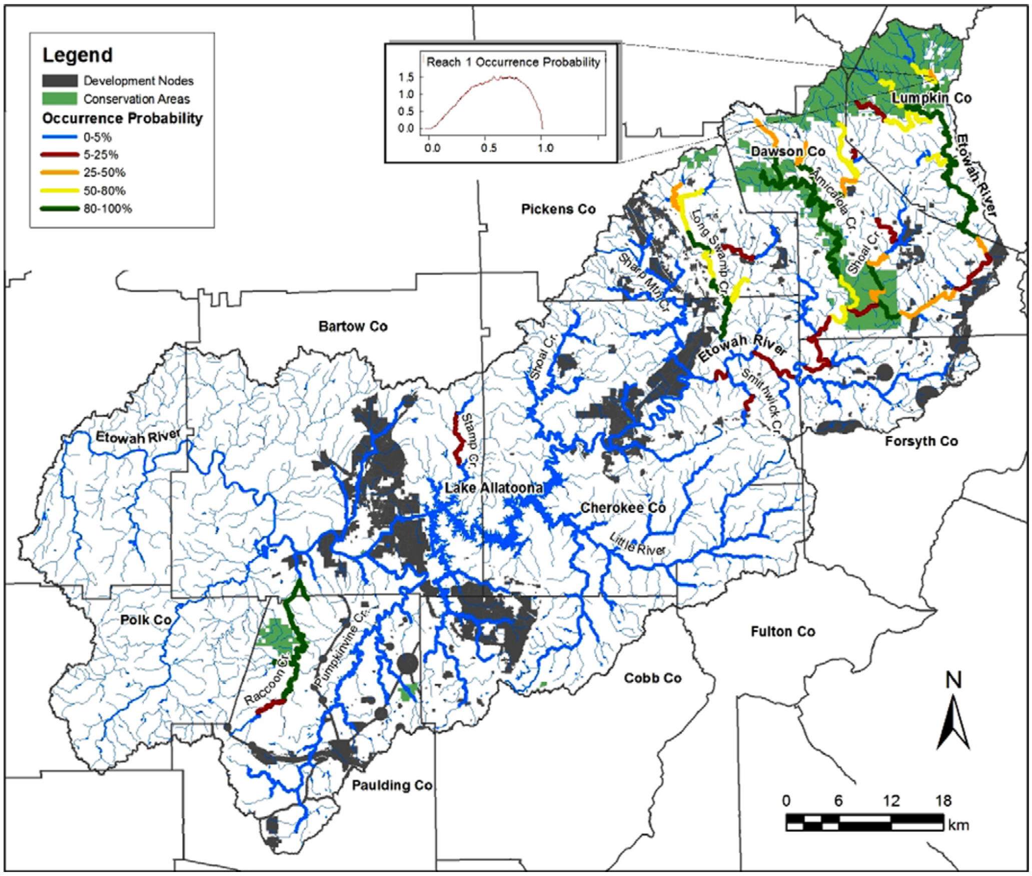

Fig. 5. Modeled Etowah darter occupancy (occurrence probability) under the HCP scenario. Color-coded stream labels indicate mean of the posterior occurrence probability for each reach. Inset shows full posterior distribution of occurrence probability for an individual reach. Results are only shown for streams with known occupation.

undergone urban development as preserves for the species. In contrast to terrestrial species, aquatic species experience many of the effects of urbanization only indirectly, although such impacts may be propagated downstream (and sometimes upstream) for long distances. This has two important implications: (1) reserves *per se* may not be necessary if urban impacts to streams can be managed properly and (2) even reserves that cover most of the landscape may be insufficient if the remaining area includes high-impact urban activities that cause severe aquatic habitat degradation.

As of this writing, the draft Etowah HCP document is undergoing review by the U.S. Fish and Wildlife Service (FWS). When this review is complete, the local governments of the basin will have the opportunity to vote individually on whether they wish to participate by implementing the requisite ordinances and policies, including the Runoff Limits. Participating local governments will be issued incidental take permits. In the meantime, the FWS has adopted many of the Etowah HCP policies as "best available science" and requests that developers in the region voluntarily employ them to avoid the need for formal consultation under the ESA. As a result, the Runoff Limits already enjoys partial implementation among the larger development projects within the basin.

The success of the Etowah HCP will depend in large measure on the success of the implementation of the Runoff Limits. Although we know of no other comprehensive basin-wide program designed to limit runoff volumes, other runoff volume limit policies exist (see Wenger et al., 2008a; Roy et al., 2008), and the infiltration practices and site design practices used to meet the Runoff Limits have been successfully employed under a range of conditions for many years (e.g., US Environmental Protection Agency, 2000). Ladson et al. (2006) argue that these techniques can be used to reach EIA < 2% with TIA as high as 50%. Naturally, the potential economic cost of implementation is a concern to members of the development community in the Etowah region, as is often the case with low-impact designs (e.g., Bowman and Thompson, 2009). However, numerous studies have demonstrated that the cost of employing low impact design and infiltration practices is frequently less than that of conventional site design and stormwater management approaches (US Environmental Protection Agency, 2007).

The sensitivity analysis revealed that a relative minor underestimate in forecasted EIA values (between 10 and 25% error) would cause a failure to meet the population thresholds for Etowah darters. This would appear to be quite risky. However, we believe this risk is mitigated by two factors. First, we assumed complete watershed buildout of all lands except those that were currently in some type of conservation use. Complete buildout is not guaranteed and yields a conservative (high) estimate of EIA, as some future preservation activity is likely. Second, the models were based on impervious cover estimates derived from satellite imagery, which may have a slight negative bias (Wenger et al., 2008b), resulting in lower than expected TIA and EIA values. In contrast, forecasted estimates of EIA were derived from literature values of TIA and so should not suffer from this bias. Thus, we believe that forecasted EIA values are likely biased slightly high relative to those values used to fit the model. We therefore consider it unlikely that forecasted EIA values were significantly underestimated.

In our forecasts, we did not attempt to produce a year-by-year buildout of land cover. Studies have demonstrated that over short time frames few models perform better than a null model (i.e., one that predicts no change at all) at fine scales or a random model at coarse scales (Pontius et al., 2004). As pointed out by Clark et al. (2001), the transition of individual parcels over the short term is determined by the unpredictable decisions of individual humans, but over the long run land use patterns are constrained by overriding variables such as topography. We therefore focused exclusively on the full buildout state of the basin, which we also reasoned would produce the greatest level of stressors to the fish species. Since the future land use maps of the counties and municipalities of the Etowah basin were developed with input from both planning experts and the general public, we concluded that such maps provided a reasonable basis for buildout scenarios. Furthermore, the Runoff Limits provisions of the Etowah HCP reinforce the future land use and zoning maps by placing limits on the size and locations of development nodes, such that it would be difficult to make major land use changes that would jeopardize survival of the target species. Note that there is not a specific time frame associated with reaching full buildout of the basin, even though the terms of Incidental Take Permits to be issued under the Etowah HCP are 25 years. Such permits are indefinitely renewable, and forecasting must consider whether the HCP will allow for long-term persistence of the protected species. We argue that all conservation planning efforts in urbanizing areas should consider the effect of a potential management action (and inaction) under potential full buildout scenarios or other likely high-stress scenarios, even if the immediate management time horizon is much shorter.

Many HCPs have been criticized as having an insufficient scientific basis and inadequate assessment of impacts (Harding et al., 2001; Rahn et al., 2006). We believe these are problems of individual HCPs and not of the HCP program itself, which we contend offers a useful tool which (like any tool) can be applied properly or improperly. Our intent with the Etowah HCP was to avoid past mistakes and make the best use of available scientific data to set appropriate policies, and to forecast the outcomes of those policies. This entailed a number of assumptions and involved considerable uncertainty in the predictions, but we have attempted to thoroughly document both assumptions and uncertainty so that they can be reevaluated in the future when additional data become available.

We argue that the approach exemplified by this case study can be readily generalized to apply to any aquatic species of conservation interest in an urbanizing environment. In fact, this can be viewed as a specific application of more general conservation planning approaches such as The Nature Conservancy's Conservation Action Planning protocol (The Nature Conservancy, 2007). What is often missing from such planning efforts, however, is the quantification of the relationship between key stressor(s) and responses, and the use of this relationship to set appropriate management targets. We have demonstrated that this can be done even in the face of very limited data, through the use of surrogate species. In such cases the relationship is a working hypothesis to be tested and reevaluated as additional data are collected in an adaptive management process. The advantage of quantifying the relationship, even if confidence intervals are very large, is that all interested parties can see the assumptions and data that underlie the management decisions. Of course, these management decisions may still be unpopular if they involve restrictions on activities on private lands, but we argue that a transparent process that makes the best use of available scientific data represents the best opportunity for preventing species extinctions in urbanizing watersheds.

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