A PROBABILISTIC STREAM ASSESSMENT TO SUPPORT FRESHWATER CONSERVATION: PRELIMINARY RESULTS FROM THE COASTAL PLAIN

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Abstract. There is international and national recognition of the need for sustainable development. Specifically, natural resource managers need ways to ensure that human activities proceed in a manner that maintains the integrity of ecosystems for future generations, including the full complement of native species and array of ecosystem functions. Strategies for achieving sustainable development require an understanding of the cause and effect relationships between stressors and affected ecosystems. Sound science can lead decision-making activities down a sustainable path. However, management is particularly challenging for freshwater ecosystems due to the complex terrestrial-aquatic linkages involving delivery and transport of water, sediment, and nutrients, forming environmental regimes under which biological populations sustain themselves and communities interact. The Southeastern U.S. is rich in aquatic biodiversity, and has been suffering long-term declines in native aquatic species, particularly those sensitive to environmental change. In response to concerns over this trend, SC Department of Natural Resources, with Clemson University, began the SC Stream Assessment to evaluate the status of aquatic resources throughout the state. The goals are to understand how aquatic species composition varies across the landscape, evaluate how human activities affect the processes linking terrestrial and aquatic systems, and develop forecasts specific to any given watershed to predict ecosystem response to environmental change. Some preliminary results from the coastal plain indicate that replacement of forest with development increases stream contaminants, alters habitat by reducing the occurrence of woody debris in channels, and simplifies fish communities by reducing diversity and compressing life-history guild structure. Our approach is intended to facilitate proactive aquatic conservation by addressing cumulative effects to watersheds.

Background

Freshwater ecosystems worldwide face well-documented threats to their integrity (Dudgeon et al., 2006). Imperilment and extinction risks to freshwater taxa are elevated relative to most terrestrial taxa (Ricciardi and Rasmussen, 1999; Sala et al., 2000), making conservation of aquatic resources a high priority of government agencies and many environmental NGOs. The southeastern United States is a recognized hotspot of temperate freshwater biodiversity, with high levels of endemism and species turnover across the region among taxa such as aquatic insects, unionid mussels, crayfishes, fishes, amphibians, and reptiles (Herrig and Shute, 2002).

The participation of fourteen states, including South Carolina, in the Southeast Aquatic Resource Partnership (SARP) illustrates the concern over the decline of aquatic resources of the region. The Comprehensive Wildlife Conservation Plan (CWCP; SCDNR, 2006) that SCDNR has developed contains descriptions of priority species of conservation concern. Over 125 species of fish, herpetofauna (i.e., reptiles and amphibians), mussels, crayfish, and snails are included that are directly dependent on aquatic systems for some or all of their life-stages, accounting for approximately 40% of the State's total number of priority species. Common threats appear in the CWCP species accounts, generally associated with pollution from point and nonpoint sources, habitat alteration due to water flow disruption, and population fragmentation due to loss of hydrologic connectivity.

Known distribution in the State of conservation priority fish species alone (Figure 1) depicts the landscape scale over which their management should be considered. The interconnected nature of aquatic systems also renders attempts at conservation in isolated, fragmented reserves problematic (Pringle, 2001). Water coursing through freshwater streams integrates the entire drainage area due to the cumulative nature of hydrologic systems, with the consequences of poor land management (e.g., siltation, excessive nutrients, flow disruption) eventually ending up in the rivers, reservoirs, and coastal systems. The quality of water and aquatic habitat reflects the condition of the uplands drained by the stream. As has been widely noted in conservation literature, successful aquatic conservation must focus on landscapes and watersheds (Allan, 2004). A reversal of the decline of native aquatic species requires an understanding of factors that are critical for maintenance of suitable water quality and habitat capable of supporting

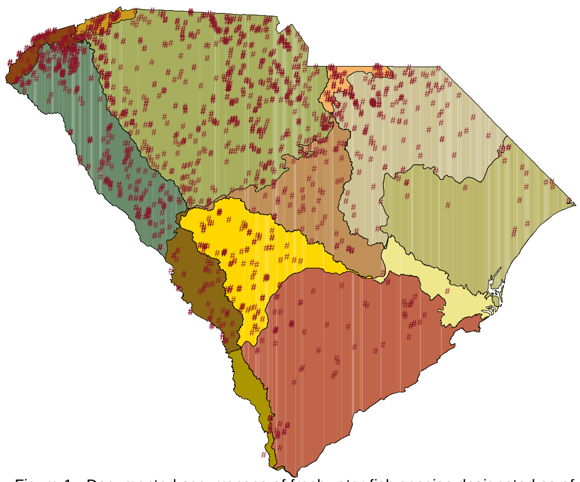

Figure 1. Documented occurrences of freshwater fish species designated as of priority conservation concern in the CWCP. Polygons designate "ecobasins" of SC, defined as unique combinations of river drainage and ecoregion.

sensitive forms. We must identify the threats that degrade water quality and aquatic habitats to the point where they no longer support sensitive species. We do not currently possess this information in sufficient detail to recommend efficient and effective on-the-ground conservation actions. The foundation of such an approach should include a system-led (e.g., watershed) rather than species-led focus; biological integrity goals applied in the context of preventing degradation of high-quality systems and restoring poor-quality systems; recognition of land and water resources as integrated parts of the same system; and commitment to implementing effective land-water management practices (Angermeier, 1995; Warren et al., 1997).

The South Carolina Stream Assessment

The South Carolina Stream Assessment (SCSA) was initiated in 2006 to collect data with standardized procedures necessary to support decision-making with respect to aquatic resources in the state. Watersheds of wadeable size (4 km^2 to 150km^2) are sampling units stratified by unique combinations of ecoregion and major river basin in the state, termed "ecobasins". Two methods of watershed selection are employed. One method established long-term annual monitoring of 85 least-impacted, or reference, watersheds, identified by biologists familiar with the region. This method is intended to provide expected resource conditions for comparative purposes as well as range due to temporal variability. The second method employs random selection of 450 watersheds allocated proportionally among ecobasin strata to allow statistically defensible estimates of statewide resource parameters from the sample data. Data collection is identical in both sampling designs, occurring at two spatial scales:

- *Watershed* – nonpoint sources as measured by appropriate land use/land cover in entire basin and within riparian buffer (detailed below), point sources as measured by NPDES permits, hydrological disruption indicated by impoundment area or dam occurrence;
- *Stream Reach* – Selected measures of channel geomorphology and flow characteristics, water quality, vertebrate and invertebrate species composition and abundance (Table 1).

The project schedule calls for rotating the randomized sampling effort annually among ecobasins of the state to provide complete coverage within five years (scheduled to be complete in 2011).

Random sites are selected with known probability using a multistage design from a list frame of all stream segments in the state, stratified by ecobasin and stream size. This "stream population" was constructed using the ArcGIS Spatial Analyst extension with Flow Direction and Flow Accumulation data, derived from existing Digital Elevation Models comprising a 30 x 30m spatial resolution with a vertical accuracy of 15 meters or less (USGS, 1993). Each 100 m segment of stream length that drains watersheds between 4 km^2 and 150 km^2 in area was assigned a unique site identification number and stored in a database with stream network information. A query was constructed using VisualBasic that selects segments randomly from the ecobasin specified by the user. A novel component of the site selection routine avoids a common pitfall in stream site selection: dependence among sample sites, or spatial autocorrelation. The user can specify how much dependence, defined as shared drainage, will be allowed in the site selection process; the default value is less than 50%. This translates into a set of sample sites that share no more than half of the drainage of any downstream site, which we believe ensures a reasonable level of independence among samples.

Field sampling follows standard operating procedures (SCDNR, 2003). This protocol mainly proscribes fish, water quality, and habitat data collection. Fish collections upslope of the fall line are made in sections of 30X mean wetted stream width in a single backpack electrofishing pass. On the coastal plain the same gear is used to make three-passes within a section 20X wetted width. All fishes encountered are identified and counted. Other sampled taxa include aquatic insects, crayfish, mussels, and herps. Aquatic macroinvertebrates are collected according to SC Department of Health and Environmental Control protocols (SCDHEC, 1997). Freshwater mussels and crayfishes receive particular attention as highly imperiled groups of organisms, and in North America, they are declining more rapidly than any other taxonomic group (Master et al., 2000; Bogan, 2001; Taylor et al., 2007). Of the thirty-eight crayfish species native to South Carolina, at least seven are endemic to the State, and most of these endemic species are of conservation concern (Eversole, 1995; SCDNR, 2006).

Table 1. Suite of measurements corresponding to each stream sample site (n=450) in the SC Stream Assessment.

Variables associated with each stream site (units)	
Stream reach ID	Drainage area of watershed (km^2)
Longitude (decimal degrees)	Elevation (m above mean sea level)
Latitude (decimal degrees)	Channel gradient (percent slope)
Water quality/chemistry	
Dissolved oxygen (mg/L)	Nitrogen (mg/L): nitrate, nitrite, TN
Conductivity (µS/cm)	Phosphorus (mg/L): ORP, TP
pH	Metals (water & sediment; µg/L and mg/kg respectively): Ag, Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Se, Tl, Zn
Hardness	Organic compounds (µg/L): selected polycyclic aromatic hydrocarbons, nonylphenols, estrogens, caffeine, tricolosan, & atrazine
Turbidity (NTU)	
Total suspended solids (mg/L)	
Total dissolved solids (anions, cations; mg/L)	
Physical/Geomorphological	
Water temperature (ºC) continuous hourly logging	Mean wetted width (m)
Channel dimensions: ratios of width to depth, bank height/angle, cross sectional area	Mean and standard deviation (STD) water depth (m)
	Mean and STD water velocity (m/sec)
Channel substrate particle size distribution	Percent occurrence of organic debris and wood in stream channel
Biological	
Biomarkers indicating exposure to pollutants in sunfish individuals: EROD activity, bile fluorescence, and induction of metallothionein and vitellogenin	Biological Community Structure:
	aquatic insects
	crayfishes
Indicators of fish health: hepatosomatic index, gonadosomatic index and splenosomatic index	mussels
	fishes
	reptiles & amphibians (herpetofauna)

Reptiles and amphibians are experiencing anthropogenic declines globally (Stuart et al., 2004). Landscape integrity is particularly important for predicting the composition of herpetofaunal communities, as most amphibians and reptiles found in stream networks use a combination of terrestrial and aquatic habitats at multiple spatial scales (Semlitsch and Bodie, 2003). Data collection for herpetofauna entails reporting on all species (identity and number) encountered during stream assessment activities.

Grab samples of stream water from each site are returned to the SCDNR Analytical Lab for analysis of standard water quality, including nutrients (Table 1). Metals and selected organic components of water and sediment are collected for analysis at Clemson University. A subsample of up to ten sunfish (genus *Lepomis*) are processed at each site for tissue biomarkers and individual health indicators (Table 1). Population data includes distribution and catch per effort of each species, whereas community parameters are derived from species composition and abundance among sites.

Analysis of these data will ultimately aim to develop watershed models describing the impacts of land use/land cover change and cumulative impacts on aquatic habitats and biological assemblages across the river basins and ecoregions of the state. Toward this end, Marion (2008) obtained standardized terrain and land cover data from the U.S. Geological Survey (USGS) in conjunction with Earth Resources Observation and Science (EROS). The USGS site (http://seamless.usgs.gov) hosts digital elevation models and land cover data for 2001 and 1992. USGS seamless digital elevation models and land cover data were utilized in ESRI's ARCGIS v. 9.0 to a) delineate watersheds of 80 stream locations sampled in 2006 and 2007 based on the entire drainage area upstream of sample locations, b) categorize those watersheds for 2001 land use, c) categorize land use for a 100m riparian buffer for 2001, d) categorize watershed land use for 1992, e) categorize land use for a 100m riparian buffer for 1992. In addition, variables indicating land cover change over time for both watersheds and 100m riparian buffers were generated by subtracting 1992 land use categories from 2001 land use categories (% land use change = % 2001 land use minus % 1992 land use).

USGS national land cover data (NLCD) is produced by the Environmental Protection Agency's Multi-Resolution

Land Characteristics Consortium (MRLC) and is derived from NASA's LandSat Thematic Mapper satellite imagery (30 meter pixel resolution). The NLCD are presently available only for 1992 and 2001, and distinguish 16 land cover class definitions for 2001, and 21 land cover class definitions for 1992 (www.epa.gov/mrlc/definitions). For the purpose of this project, land cover classes were combined into 6 land use categories: open water, urban, forest, pasture/scrubland, agriculture (cultivated crops), and wetlands (Marion, 2008).

Preliminary Results and Discussion

Preliminary analyses of SCSA data collected from coastal plain streams in the Pee Dee and Ashepoo-Combahee-Edisto river basins in 2006 and 2007 have thus far revealed several significant relationships between stream condition and watershed land use. Keaton (2007) noted a significant negative relationship between percent urban land use in the watershed and hepatosomatic index values in sunfishes, indicating weakened physiologic condition of fish in urban waters. She also reported that levels of a biomarker, bile fluorescence, was positively related to urban land use, indicating increased exposure to polycyclic aromatic hydrocarbons in urban streams. Dissolved trace metal concentrations (chromium, nickel, and lead) were negatively related to percent forest cover in riparian buffers, and sediment silver concentrations were positively related to urban development (A. Jones, unpublished data). These results demonstrate that stream contaminants increase where human activities have replaced native forest cover, particularly with urban land uses, and that fishes exhibit physiological evidence of stress in these ecosystems.

Marion (2008) used linear regression to examine stream habitats and fish assemblages at the same coastal plain sites. She reported that loss of forest cover and its replacement with urban land uses on the landscape was associated with decreased woody debris in stream channels. This reduction in the habitat represented by woody debris in turn was associated with several aspects of the fish assemblage. Less woody debris correlated with lower fish species richness and diversity, indicating potential sensitivity of some species to the loss of habitat heterogeneity in coastal plain streams. Indeed, Marion (2008) reported lower abundance of fishes endemic to the southern Atlantic coastal plain and reduced breadth of life-history guild structure in the fish assemblages of the less-forested, more urbanized watersheds. This suggests a simplification of the biological community in altered watersheds due to loss of sensitive endemic taxa that may have life-history traits specialized for life in these coastal stream systems.

Although the results from the coastal plain are not necessarily those one would expect from upland streams, the approach will be similar. The SCSA database will allow researchers to empirically identify the functional forms of relationships between stressors and ecosystem responses using data on a suite of physical and chemical characteristics of streams and their watersheds across the state, as well as diverse biological measures at molecular through community levels of organization. Plans are to investigate more powerful modeling techniques, such as generalized linear models using maximum likelihood methods and various link functions evaluated with information theoretic criteria (Burnham and Anderson 1998). Other methods we will explore for building habitat suitability models include classification and regression trees (CART) and its offshoot, random forests (Carlisle et al., 2008).

The goal is to create science-based information tools to be made available to decision-makers that allow a spatially explicit watershed perspective on management of cumulative impacts to water quality and aquatic ecosystems. The decision-support system should reflect causal pathways of threats to aquatic resources, be freely available through the web to communicate status and expected responses of aquatic resources to environmental change, and provide resource conservation guidance that has the potential to effectively mitigate impacts at the planning stages of land management and development activities.

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