USING STREAM DISCHARGE AS A PREDICTOR OF BIOTIC HEALTH IN THE UPPER OCONEE WATERSHED

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Abstract. Drought is viewed typically as an issue of water quantity, but drought also likely has strong effects on water quality in streams. These effects may occur via increased pollutant and nutrient concentrations and stream water temperature, as well as reductions in in-stream habitat. Many aquatic macroinvertebrate taxa are sensitive to changes in water chemistry, and streams with degraded water quality are often characterized by low macroinvertebrate diversity. A previous study by the Upper Oconee Watershed Network related the Georgia Adopt-A-Stream biotic index for macroinvertebrates to water chemistry (Kominoski et al. 2007), but did not consider the effects of stream discharge, which also potentially influences index scores. We used long-term datasets on biotic indices of water quality in the upper Oconee River watershed to determine whether variation in biotic indices is associated with periods of extreme low flow. We used multiple measures of flow (including seasonal means, minima, maxima, and variability in discharge) from USGS gauge data to examine patterns in the Georgia Adopt-A-Stream macroinvertebrate index for seven tributaries of the North and Middle Oconee Rivers in Clarke County, Georgia. We found that the inclusion of flow variables improved the prediction of macroinvertebrate index scores, compared to a model including only chemical variables, and that a positive response occurred to mean flow in the preceding season. We infer from our results that site-specific flow variability may be structuring benthic macroinvertebrate communities in urban streams in the upper Oconee River basin, and may be important to consider when using indices for bioassessment throughout the state of Georgia.

INTRODUCTION

Stream flows may play an important role in long-term structuring of in-stream habitat and macroinvertebrate communities (Poff et al. 1997). The natural flow regime in rivers and streams consists of a range of flow levels, some of which are considered major disturbances that aid in structuring benthic communities (Lake 2000). Periods of both flood and drought can negatively influence stream macroinvertebrate communities through inputs of chemicals, changes in stream temperature and habitat, and streambed alteration. During floods, increased discharge and velocity can disturb bed sediments, dislodge algae and macrophytes, promote bank scour, and result in high inputs of chemicals and suspended sediment. During severe low-flow periods, streams typically show a dramatic reduction in aquatic habitat availability due to a reduction in wetted width and depth. Increases in stream temperature, lowered dissolved oxygen, and changes in nutrient concentrations may all occur and have a dramatic impact on the diversity of benthic life (Lake 2000).

The effects of floods and droughts may be particularly exacerbated in urban streams. For example, during large rain events, runoff from impervious cover increases the magnitude of high flows, which often deliver chemicals and sediments to streams (Paul and Meyer 2001, Walsh et al. 2005). In addition, riparian buffers are reduced in many urban streams, causing an increase in temperature and a associated decrease in dissolved oxygen, which may intensify during drought.

Drought may have a major impact on benthic macroinvertebrates because many taxa need adequate water velocities to disperse and acquire necessary resources; drought may also affect macroinvertebrates by increasing predation pressure and competition for habitat and food resources (Hart and Finelli 1999). Macroinvertebrates are commonly used as bioindicators in stream studies because they are relatively long-lived and stationary, and therefore they integrate the effects of local disturbance and pollution. Macroinvertebrates are also easy to collect and identify, and their use in biological indices is a cost-effective way to measure water quality (Rosenberg and Resh 1993). Many standard methods of assessing macroinvertebrate diversity and abundance are limited by time and taxonomic knowledge, but it has been shown that rapid assessment protocols performed by volunteers can be accurately used to make regulatory decisions (Engel and Voshell 2002).

The Upper Oconee Watershed Network (UOWN) is a community-based non-profit group based in Athens, Georgia that collects biological and chemical samples from tributaries of the North and Middle Oconee rivers in Clarke County, Georgia, USA. UOWN has been collecting biological and chemical samples four times per year (seasonally) for seven tributaries since 2000 in order to assess long-term trends in water and habitat quality. However, the scope of UOWN's monitoring has not included streamflow. The goal of this study was to understand how patterns of streamflow disturbance events (i.e., periods of flood and drought) are related to the Georgia Adopt-A-Stream macroinvertebrate scores in urban streams of the upper Oconee River basin. We specifically addressed: (1) whether the flow was related to the biotic index (bioscore) at a site, and (2) which measures of flow (means or variation) were the best predictor of bioscore. We hypothesized that macroinvertebrate index scores would increase with increasing discharge and would decrease with increasing variability in discharge.

METHODS

Sampling Sites

Seven sites in the upper Oconee River watershed were sampled quarterly from 2000-2008 (Figure 1). Three sites are located in the North Oconee River watershed: Carr Creek, Trail Creek and Sandy Creek. Four sites drain into the Middle Oconee River: Bear Creek, Brooklyn Creek, Hunnicutt Creek and McNutt Creek. Sites range in impervious surface cover (ISC) from 2% to 32%. Shoal, Sandy and Bear creeks all have the lowest cover, with less than 5% ISC. Brooklyn and Carr have the highest cover with greater than 20% ISC.

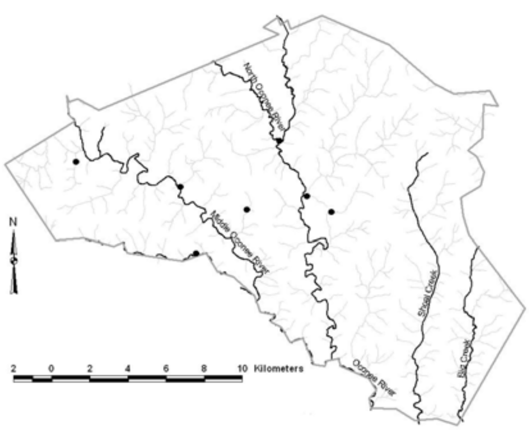

Figure 1. Map of seven sampling sites within the upper Oconee River watershed, Clarke County, Georgia, USA.

Sampling procedures

Macroinvertebrate samples were collected from our study streams quarterly following the Georgia Adopt-A-Stream protocol for rocky-bottom and muddy-bottom streams (GA AAS 2004). In streams with rocky-bottom habitat, riffles were sampled using a kick seine and leaf packs were sampled using a D-net; in muddy-bottom streams, streambed, woody debris, and vegetative margins were sampled using a D-net. Macroinvertebrates were picked from samples in the field, elutriated when necessary, then sorted, counted and identified to taxonomic order using identification keys provided by the Georgia Adopt-A-Stream program. Streams were then scored using the Save Our Streams (SOS) Program of the Izaak Walton League of America, which is based on the presence or absence of "sensitive," "somewhat sensitive," and "tolerant" invertebrate taxa. Numerical biotic scores were used to indicate water quality (excellent > 22, good = 17-21, fair = 11-16, poor < 11) (Georgia AAS 2004).

Discharge

We estimated discharge across the watershed by using long-term flow data from the USGS gauge on the Middle Oconee River near Arcade, Georgia, USA (# 02217475). The gauge is located in neighboring Jackson County, not in Clarke County, but was chosen because there are minimal withdrawals from the river above this gauge and data have been collected at this site since 1988. We downloaded the average daily flow in cubic feet per second (cfs) from the USGS website (www.usgs.gov). We then developed five original flow variables to use in our analyses: mean flow, minimum flow, maximum flow, number of extreme low flow days, and flow coefficient of variation (CV). These five variables were calculated for each sampling event using the daily averages for each day since the last sampling event. We defined drought for the purpose of this study as an unpredictable low flow period that is unusual in its duration, extent, severity or intensity (Humphries and Baldwin, 2003). Extreme low flow days were those in which the gauge discharge was in the lowest 10% of all the daily flow averages in the period of record (less than 85 cfs). Average daily flow over the 22-period of record is 432 cfs (Figure 2). We determined a drought to be a period with a sustained number of days with discharge at or below 85 cfs. These periods occurred in 2000–2002 and 2006–2008.

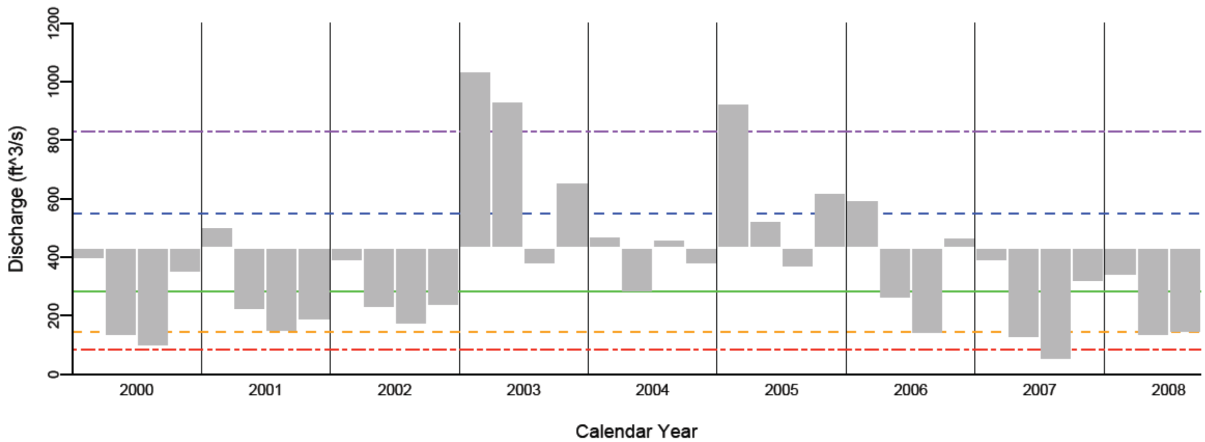

Figure 2. Discharge at the Arcade Gauge (USGS 02217475) on the Middle Oconee River. Shown are mean daily flows for quarters of the calendar years included in the analysis, displayed as deviation from the overall mean daily flow for the gauge's period of record (1988-2008). Horizontal lines indicate percentiles of daily flows for the period of record: solid line, median flow; single-dashed lines, 20th and 80th percentiles; dot-dash lines, 10th and 90th percentiles.

Statistical Analysis

Our initial dataset consisted of specific conductance and the five flow variables. Specific conductance was included because a previous study in this basin (Kominoski et al., 2007) demonstrated that specific conductance (SC) was the best predictor of bioscore. Univariate analysis of the flow data indicated that some of these data were highly skewed, so these data were log(n+1)-transformed to meet assumptions of homoscedasticity. Using spearman correlation analysis for our initial dataset, high positive correlations (≥0.9) were identified among some sets of variables. In order to limit the inclusion of highly correlated variables, we reduced our variable set to a subset of less-correlated (<0.7) variables: SC, mean flow, and low flow days. We defined a new variable, flow coefficient of variation (CV), which is the flow variability divided by the mean flow for the period prior to sampling, to represent variability.

We related our final set of predictors to the response variable of biological score, using multiple linear regression models. These analyses were conducted with PROC MIXED in SAS 9.2 (www.sas.com). We used site as a hierarchical variable because a previous study by UOWN concluded that that there were significant differences in macroinvertebrate index scores among our study sites (Kominoski et al. 2007). We compared alternative one-, two-, and three-variable models that included SC and flow variables, using Akaike's Information Criterion corrected for small sample size (AICc; Burnham and Anderson 2002). We also included squared flow terms, to allow for the possibility of nonlinear responses to these terms. The most parsimonious model was chosen as the model with the lowest AICc.

RESULTS

The mean macroinvertebrate index score over the entire data set was 13.8 (s.d. = 7.7) with a range from 0 to 31 (n = 192). The most parsimonious model for predicting bioscore contained two flow variables, mean flow (Figure 3) and flow CV, with an AICc of 1101. The null model likelihood ratio test indicates a significant improvement over the null model consisting of no random effects and a homogeneous residual error (chi square = 56.63, $p < 0.0001$). For comparison, the AICc for the model including SC alone was 1125. The coefficients and confidence intervals (CIs) for the most parsimonious model are shown in Table 1. The confidence intervals for SC and mean flow do not contain zero, but the confidence intervals for flow CV and flow CV squared do include zero.

Table 1. The coefficients and confidence intervals (CIs) for each variable in the most parsimonious model.

Variable	*Coefficient*	*SE*	*Lower CI*	*Upper CI*
SC	-3.76	1.28	-6.28	-1.24
Mean Flow	10.08	2.26	5.61	14.55
Mean Flow^2	-0.88	0.22	-1.31	-0.45
CV	6.24	5.78	-5.17	17.65
CV^2	-3.43	2.83	-9.03	2.16

DISCUSSION

We found that the inclusion of flow variables improved the overall fit of the model compared to the previously identified effects of conductivity. The most parsimonious model showed a strong negative relationship with SC, so SC is a significant predictor of macroinvertebrate scores. This finding is consistent with the findings of Kominoski et al. (2007) for these streams, and with Roy et al. (2003) for streams in the Etowah River basin in Georgia. Streams in the Georgia Piedmont acquire most dissolved ions from groundwater, so surface waters in the region have relatively low natural concentrations of dissolved ions. High levels of SC in this system are likely indicative of pollution (Wenner et al. 2003). The inclusion of flow parameters improved model fit, although this improvement was not large.

The positive response of macroinvertebrate index scores to flow CV and negative response to flow CV squared may suggest that seasons with less variable flow regimes support more sensitive invertebrate taxa, However, the CIs for flow CV and flow CV squared included zero, so we have very little confidence in these predictions. This response is consistent with our hypothesis that the occurrence of both extremely high and extremely low flows in a season would have an impact on more sensitive macroinvertebrates. Seasons with both high and low flows would be expected to exacerbate the problems associated with flood and drought, thus minimizing potential recovery time after disturbance (Lake 2000). Because of the low confidence in our results, this pattern needs further study.

Several factors could account for our relatively weak response to flow in this system. First, the weak trends found in our results could be attributed to our broad approach in measuring flow. Using discharge measurements from a river gauge was a surrogate for not being able to measure discharge in individual streams. However, if available, site-specific stream discharge would provide a more accurate estimate of flow. Rainfall patterns are not uniform over the entire watershed and differences in underlying geology, watershed size, and quantity of pervious cover may contribute to variations of flow among streams. Individual discharge measurements for each stream might show a better relationship to our macroinvertebrate index scores. We suggest that using finer scale hydrology data (per stream) may decrease our confident intervals.

Second, macroinvertebrates and biotic index scores may respond differently to flows in different streams, thus predicting scores may be more difficult. For example, scores of highly degraded streams may continue to be low despite high or low flow events, and healthy streams may have low scores after the same events due to a decline in sensitive taxa. In a study by Dewson et al. (2007) streams with reduced flow and decreased water quality were less impacted by periods of drought due to the initial presence of less sensitive macroinvertebrate taxa.

Because of certain characteristic attributes of urban streams, such streams could show a different response to flow mean and variability as compared to streams in forested watersheds. Streambed composition may affect the density of certain macroinvertebrates. Often, urbanization increases sedimentation loads, which may limit potential habitat for some more sensitive macroinvertebrate species (Roy et al. 2003). Reduced connection with riparian influences may also exacerbate these extreme flow fluctuations, as some species of macroinvertebrates require particular allochthonous inputs (Wallace et al. 1997, 1999). Given the variation of impervious cover and water quality among the streams in this study, another study might be able to find differing responses to flow reduction and variation among these streams.

Finally, it is also possible that the coarse approach used by the Georgia Adopt-A-Stream protocol is not sensitive enough to detect the types of community shifts that occur due to flow alteration. Further study with more detailed methods could be used to explore this possibility.

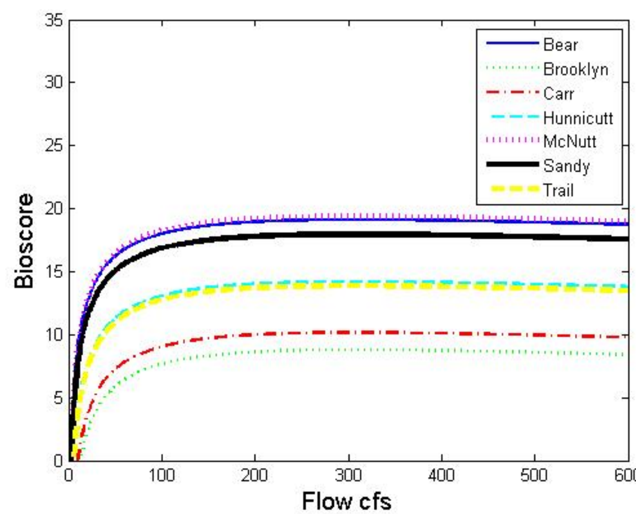

Figure 3. The predicted response of biotic index scores to mean flow at the seven sampling sites. Other parameters are fixed at their mean values.

CONCLUSIONS

Using long-term data sets from watershed monitoring groups can be a valuable tool in assessing impacts to urban streams. Stream-specific measurements of flow in our study streams is needed in order to better understand the relationship between flow variables and macroinvertebrate index scores, and consequently UOWN may incorporate the measurement of flow into its quarterly monitoring program in the near future. The positive trend of flow mean and negative trend of flow CV with macroinvertebrate index scores, while not significant, suggest that flow, if measured for each stream, may help us better predict macroinvertebrate index scores. Further analyses are also needed to examine the effects of urbanization, decreased water quality, and altered flow on macroinvertebrate index scores. As a historic drought in Northeast Georgia persists, understanding the response of stream biota to reduced flow will remain important for monitoring efforts and management decisions.

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