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Landscape urbanization and associated increases in impervious surface cover have resulted in widespread hydrologic alteration of streams. Fishes may be impacted by increased erosional stormflows and reduced baseflows in urbanized streams either directly (e.g., via physical washout) or indirectly (e.g., via reduced habitat quality, water quality, or habitat availability). We investigated what aspects of the hydrograph are particularly important in driving fish assemblage structure and what fishes are most affected by these hydrologic alterations in small streams. We measured hydrologic patterns and sampled fish assemblages in 30 small streams (basin area 8-20 km^2) in the Etowah River basin (Georgia, USA) that were stratified by percent impervious cover (<10%, 10-20%, >20%) and the estimated degree of hydrologic alteration (based on synoptic measurements of baseflow yield). Continuous stream stage monitoring at each study site for 1 y (January 2003-2004) was used to used to derive hydrologic variables. Relations between hydrology and fishes were tested at the times of year when fishes are expected to be most vulnerable to hydrologic alteration: in late spring and summer (May-August) during spawning, and in autumn (August-November) during low flow periods.

Increased % impervious cover was positively correlated with the frequency of storm events and rates of the rising and falling limb of the hydrograph (i.e., storm "flashiness") during most seasons. Increased duration of low flows associated with impervious cover only occurred during the autumn low-flow period, and this measure of low-flow conditions corresponded to increased richness of habitat generalist species (i.e., tolerant of lentic conditions). The lack of hydrologic relations with other fishes, however, suggests that reduced baseflows during the study year (a year with higher than average precipitation) was not a dominant mechanism of fish assemblage alteration. Altered stormflows in summer and autumn were related to decreased richness of endemic (locally distributed), cosmopolitan (widespread), and sensitive fish species, and decreased abundance of lentic tolerant species. Species predicted to be sensitive to urbanization based on life history and other attributes were also related to stormflow variables and % fine bed sediment in riffles. Overall, hydrologic variables explained 22 to 66% of the variation in fish assemblage richness and abundance.

The linkages between hydrologic alteration and stream fishes were potentially complicated by contrasting effects of elevated flows on sediment delivery and scour, and mediating effects of stream gradient. Nonetheless, % variance in fish assemblages explained by hydrologic variables was 2-36% higher than that explained by impervious surface cover alone. Stormwater management practices that promote natural hydrologic patterns are likely to reduce the negative effects of impervious cover on stream fish assemblages.

FISH ASSEMBLAGE RESPONSES TO WATER WITHDRAWALS AND WATER SUPPLY RESERVOIRS IN THE GEORGIA PIEDMONT

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Understanding effects of flow alteration on stream biota is essential to developing ecologically sustainable water supply strategies. To improve our understanding of the biological effects of water withdrawals, I collaborated with the Georgia Department of Natural Resources (GDNR) in a State Partnership Program study of relations between fish assemblage characteristics and water extraction in wadeable streams in the Piedmont region of Georgia. The Piedmont is an area of rapid growth in human populations and water demand. We sampled fishes downstream from water supply withdrawals, where withdrawals were either taken directly from the stream ("stream-intake sites", total n=14) or from an instream impoundment ("reservoir sites", total n=14) with the sampled reach occurring immediately downstream of the intake or dam. Permitted average monthly withdrawal amounts ranged from < 0.05 to > 13 times the stream's 7Q10 flow, providing a broad gradient of potential flow alteration. Sites varied in drainage area from about 14 to 1010 km^2; reservoir sites tended to occur on smaller streams and have larger relative withdrawals. We sampled during two years (2000 and 2001) of regional drought and a third year (2003) with above-average rainfall and stream flow.

Sample ordination (using non-metric multidimensional scaling of fish catch data) and evaluation of alternative linear regression models predicting estimated species richness provided evidence that increasing permitted withdrawal amount and use of an instream reservoir altered downstream fish assemblages. Samples of fish assemblages downstream from reservoirs had lower abundances of a variety of fluvial specialist species compared to sites downstream from stream-intakes. Stream intake sites displayed greater assemblage similarity to samples from regional reference sites (sampled in 2000 and 2001 by the GDNR). Additionally, among alternative regression models predicting species richness of fluvial specialists as functions of drainage area, percent urban land use upstream from the withdrawal, average bed sediment size, and water withdrawal variables, the most strongly supported models consistently included drainage area and either withdrawal type (2001) or an index of permitted withdrawal size (in 2000 and 2003). Species loss was estimated to be about three to five fish species at sites downstream from reservoirs compared to stream-intakes, and about six species as permitted water withdrawal amount increased from 0 to 12 times 7Q10. Wide confidence intervals indicated substantial variability in responses, especially during the above-average flow year (2003) when 90% confidence intervals for both effects included 0. I expect that predictions of biological responses to water withdrawal and flow alteration will always entail considerable uncertainty given the additional, unmeasured effects of other influences (such as stream fragmentation and pollutant input) as well as sampling variability. However, estimates of species loss such as those provided by this study could be used in landscape models to support adaptive water supply planning intended to meet societal needs while conserving biological resources.

THE EFFECTS OF EXTENDED LOW-FLOWS ON FRESHWATER MUSSELS IN THE LOWER FLINT RIVER BASIN, GEORGIA: A CASE STUDY

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Freshwater mussel assemblages in the Flint River Basin (FRB) of southwestern Georgia are among the most diverse in the southeastern Coastal Plain of North America. Historically, 29 species, including 7, endemics occurred in the FRB. A drought during the summer of 2000 caused extended low flows and many perennial streams dried or became intermittent. Pre-drought surveys conducted in 1999 allowed an assessment of the impact of the drought on mussel assemblages. During extreme drought conditions (June-October 2000), mussel survivorship and habitat conditions (water depth, water temperature, dissolved oxygen and flow velocity) were monitored weekly at nine locations representing a gradient in stream size. Cumulative unionid mortality ranged from 13 - 93% per site, and was associated with low flow velocity (below 0.01 m/s) and dissolved oxygen concentrations below 5 mg/L. During 2001, 21 stream reaches that had abundant or diverse mussel assemblages in 1999 were resurveyed. Study sites were classified as flowing or non-flowing during the drought based on data from stream gauging stations or visual observation of study reaches. Mussels were classified by conservation status, either stable, special concern, or federally endangered. Greater than 90% of the mussels observed in the lower FRB were species with stable conservation status. Special-concern species represented 5 to 6% and endangered species represented 1% of mussel abundance. Sites that ceased flowing during the drought had significant declines in the abundance of stable

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