Fish Community Response in a Rapidly Suburbanizing Landscape

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Abstract

Stream biotic integrity in Ohio shows measurable declines when the amount of urban land use, measured as impervious surfaces, first exceeds 5.3%, and declines below basic Clean Water Act goals when urban land use exceeds 25%. Declining biological integrity was noted in Rocky Fork of Big Walnut, a stream with a rapidly urbanizing watershed in the Columbus metropolitan area, at levels of total urban land use as low as 4%, suggesting that poorly regulated construction practices constitute the first step toward declining stream health in suburbanizing landscapes. The pervasiveness of this finding was evaluated in several streams in the periphery of the Columbus metropolitan area by comparing measures of stream health sampled in 1996 and again in 2002. No declines in biological integrity or numbers of sensitive species were noted between time periods. The rate of urbanization in the surrounding watersheds was less in these streams than in Rocky Fork, and construction site environmental practices were more noticeable than in Rocky Fork. This paper discusses the implications of these findings with respect to current storm water and construction best management practices.

Introduction

Biological integrity in Ohio streams declines along a gradient of urban land use, measured as impervious cover (Yoder et al. 2000, Miltner et al. in review). This finding is from IBI scores for streams draining urban and suburban landscapes in the major metropolitan areas of Ohio paired with an estimate of the percent impervious land cover in the watershed upstream from a sampling point. Yoder et al. (2000) observed in these data that both the number of sensitive species and IBI scores declined with increasing amounts of impervious surfaces; however, declines in the number of sensitive fish species were detectable at lower levels of impervious cover than IBI scores.

Initial declines in the number of sensitive fish species were detectible when the amount of impervious cover exceeded 5.3%, and overall biotic integrity declined below Clean Water Act goals when impervious cover exceeded 27.1%. Overall loss of biological integrity, as measured by the Index of Biotic Integrity (IBI, Karr 1981), is characterized by shifts in community structure relative to the fish community expected for a given stream size and location.

The results for Ohio are similar to other studies from around North America. The typical result being that the quality of any given stream is negatively correlated with the amount of urbanization in its surrounding watershed (Steedman 1988; Schuler 1994; Wang et al. 1997; Karr and Chu 2000; Wang 2001). Urban runoff carries toxic contaminants (metals, polynuclear aromatic hydrocarbons [Yaun et al. 2001]), nutrients and sediment (Young et al. 1996), pathogens and debris. Impervious surfaces also result in hydrologic and geomorphic alterations to low order streams: increased variance in stream flow, increased stream temperatures, and destabilization of the channel (Bledsoe 2002). Collectively these stressors act to grossly impair biological communities when the range of impervious cover within a watershed reaches 8 to 20 percent (Karr and Chu 2000, Schuler 1994), and become irreparably damaged in the range of 25 to 60 percent (Karr and Chu 2000). Here “grossly impaired” and “irreparably damaged” are in reference to minimum water quality standards (*e.g.*, state narrative or numeric standards for warm-water habitat), and do not necessarily capture the more subtle, but highly consequential, effects evident at low levels of anthropogenic disturbance (Scott and Helfman 2001, Jones et al. 1999). The reason these ranges vary exponentially is that the severity of impairment in urban areas is dependant on the number and type of allied stressors (*e.g.*, combined sewer overflows [CSOs], wastewater discharges, landfills, accidental spills, intentional dumping, and stream channel dredging and filling) associated with urbanization beyond the retinue of hydrological and water quality consequences effected by imperviousness alone (Yoder and Rankin 1996).

Recently, declining biotic integrity was noted in Rocky Fork of Big Walnut (Miltner et al. in review), a stream located in the rapidly suburbanizing Columbus, Ohio metropolitan area. The IBI scores for Rocky Fork fish communities over time are provided in Figure 1. The declining biotic integrity observed in Rocky Fork mirrored what was observed in the static state-wide urban gradient data set as describe above. These declines were attributed to new home and allied infrastructure construction, and likely hastened by the rapid pace of development. Portions of the watershed that were rural in 1990 had been decidedly urbanized by 2000. Conditions were also aggravated due to a lack of meaningful environmental controls on construction sites, and suggest that land disturbance is the initial cause of declining biotic integrity in a suburbanizing landscape.

We wanted to test for declining biotic integrity in several streams on the periphery of the Columbus Metropolitan area that have suburbanizing watersheds to examine whether conditions observed in Rocky Fork could be generalized among similar sized area streams. The streams chosen had all been sampled between 1996 and 1997, and so offered the opportunity to observe whether measurable differences could be detected within five years, and at rates of development modest compared to that observed in the Rocky Fork watershed. This paper discusses our current findings in light of previous findings for urban streams (Yoder et al. 2000, Miltner et al. in review) and potential directions for land-use policies.

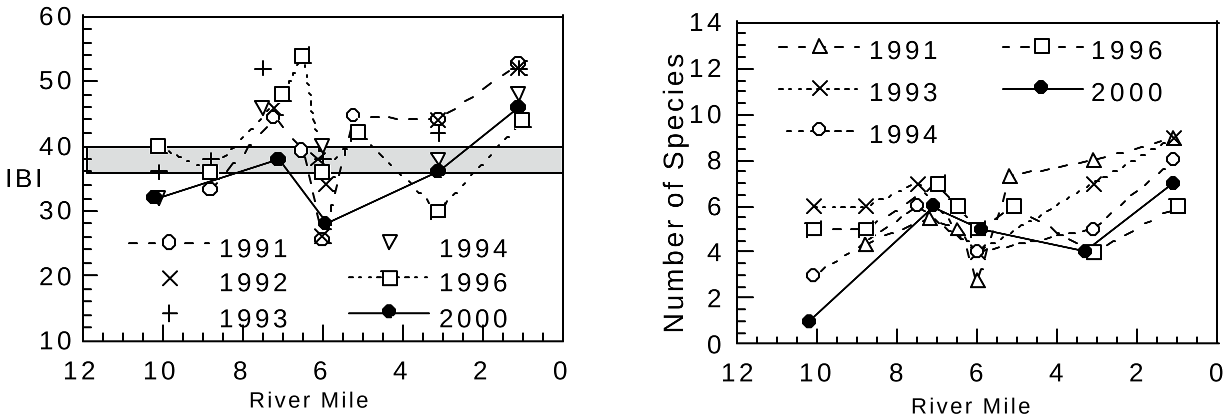

Figure 1. Trends in IBI scores (left panel) and the number of sensitive fish species sampled in Rocky Fork, 1991-2000. The shaded bar in the left plot shows the minimum range for acceptable IBI scores for small warm-water Ohio streams.

Methods

Fish communities were sampled at eight locations in seven streams (Figure 2; Table 1) using generator-powered, pulsed D.C. electrofishing units and a standardized methodology (Yoder and Smith 1999). Fish community attributes were quantified with the Index of Biotic Integrity (IBI; Karr 1981; Karr et al. 1985), as modified for Ohio streams and rivers (Ohio EPA 1987,Yoder and Rankin 1995). Habitat was assessed at all fish sampling locations using the Qualitative Habitat Evaluation Index (QHEI; Rankin1995). The QHEI is a qualitative, visual assessment of the functional aspects of stream macrohabitats, and includes rankings for such things as amount and type of cover, substrate quality and condition, riparian quality and width, siltation, and channel morphology.

An estimate of urbanization between 1990 and 2000 was made for each sampling location by comparing data from census blocks immediately surrounding and upstream from a sampling location and using housing density as a surrogate for urban land-use. The number of sensitive species and IBI scores sampled at the same locations and for each time period were compared using a two sample t-test. Sample distributions were checked for normality using a normal probability plot. Sample variances between time periods for both IBI scores and number of sensitive fish species were compared using a two-tailed variance ratio test (Zar 1999) and found equal ($F_{1-\alpha/2, 9, 9}$ = 4.03, > ratio of variances for IBI scores and number of sensitive fish species was 52.778/42.000 and 4.528/2.444, respectively).

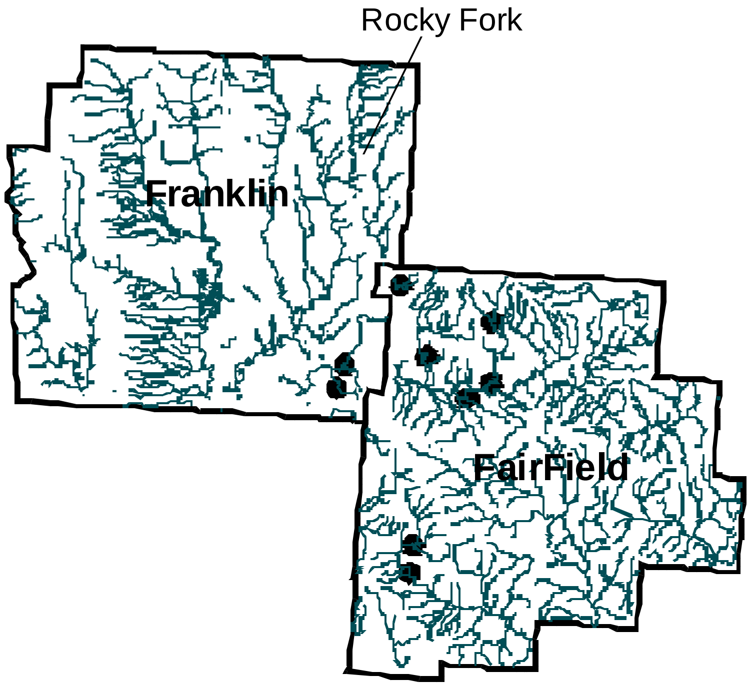

Figure 2. Study area and locations sampled in 2002. Rocky Fork is located for reference.

Table 1. Change in housing density (units•mi^{-2}) in census blocks surrounding and upstream from stream sampling locations.

Stream Name	Location	Drain Area (mi^2)	Housing Density 1990	Housing Density 2000	Percent Change	IBI 1996	IBI 2002	QHEI
Clear Creek	Dst US 22, Amanda Twp.	19.7	25.80	29.61	15	50	38	58.5
Poplar Creek 2	Poplar Cr. Rd., Liberty Twp.	8.1	48.32	55.73	15	58	56	76.0
Poplar Creek 1	Bish Rd., Liberty Twp.	17.5	48.32	55.73	15	42	48	79.5
Muddy Prairie Creek	Amanda-Northern Rd., Amanda Twp.	3.8	25.80	29.61	15	52	42	41.5
Sycamore Creek	Busey Rd., Violet Twp.	21.6	176.67	301.40	71	44	44	78.5
Big Run	Hayes Rd., Madison Twp.	6.3	95.78	172.38	80	46	38	56.0
George Creek	Groveport Rd., Madison Twp.	15.4	95.78	172.38	80	40	44	61.0
Blacklick trib 10.36	SR 256, Violet Twp.	2.9	153.19	281.76	84	44	50	71.0
Rocky Fork 3.1*	Clark Rd., Jefferson Twp.	22.4	57.10	202.50	254	30	NA	66.0

* Rocky Fork was not sampled in 2002.

Results and Discussion

In contrast to what was observed in Rocky Fork (Figure 1), no differences (P > 0.05) were found in either the number of sensitive species at a given site, nor for IBI scores at the eight study sites (Figure 2; Table 1), most notably at the two sites that had the greatest rate of increase in housing density between 1990 and 2000, Blacklick trib 10.36 and Sycamore Creek. One explanation for this observation is that the level of urban land use in each of the eight study sites is estimated at less than 5%, except for Blacklick trib 10.36 where the level of urban land-use from the 1994 Landsat Thematic Mapper Data was 7%. Also, the rate of change in housing density in all cases is less than that observed in Rocky Fork (Table 1). Another difference, though not directly quantified, is that proper construction site environmental practices were observed in Fairfield County where six of the eight samples were collected (Figure 2). Fairfield County has storm water and construction site regulations requiring environmental measures, and performs regular inspections for compliance through the local Soil and Water Conservation District (Fairfield County SWCD, personal communication, Chad Lucht). Environmental measures to mitigate construction site impacts were rarely observed in the Rocky Fork watershed (Figure 3).

Water resources can be impacted by land development. Whether that is because existing regulations are under-enforced or are under-protective is an open question. Regulations vary widely between political jurisdictions. In Ohio, a general storm water construction permit that is applicable state-wide requires best management practices (BMPs) to minimize sediment loads. Temporary stabilization is one such BMP wherein disturbed areas that will lie dormant for at least 45 days must be stabilized with fast growing grasses and straw mulch within seven days, or within two days if within 50 feet of a stream. Other required BMPs include sediment ponds, silt fences, construction entrances, inlet protection, and permanent stabilization. This basic level of protection is augmented by stricter regulations and enforcement in some Ohio counties, such as Fairfield County.

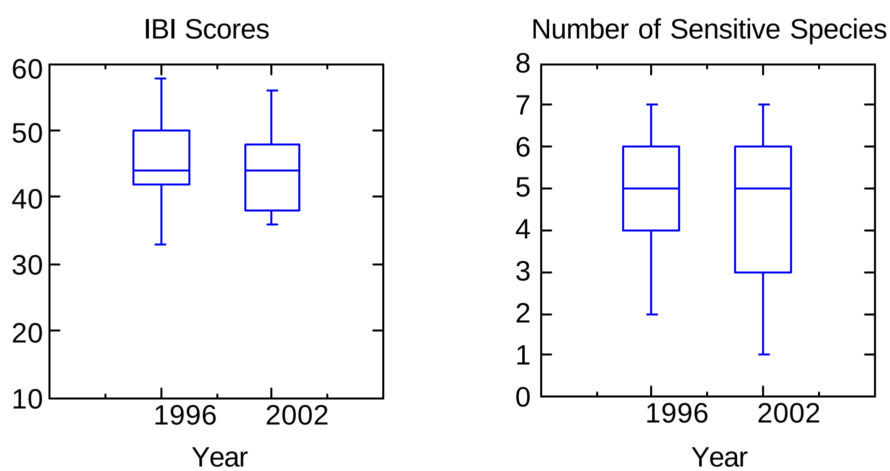

Figure 3.. Distributions of IBI scores (left panel) and number of sensitive fish species (right panel) sampled at the same location in 1996 and 2002 in seven streams located in the periphery of the Columbus, Ohio metropolitan area.

Other states have been more aggressive in regulating nonpoint pollution. Storm water protection in the State of Maryland is administered is through local governance with state oversight. For example, Baltimore County has a stream protection ordinance that calls for a forested buffer to extend on both sides of a stream and to include the adjacent floodplain, slopes, and wetlands. And wherever development may adversely affect water quality, the buffer can be extended to protect steep slopes, erodible soils and other sensitive areas. This is in addition to the fourteen general performance standards for storm water management applicable throughout Maryland (Maryland Department of the Environment 2000, and available at http://www.mde.state.md.us/programs/waterprograms/sedimentandstormwater/stormwater_design/index.asp). These performance standards go beyond simply minimizing the amount of sediment from construction sites by striving to maintain the pre-disturbance hydrology of the watershed including groundwater recharge, stream channel stability, and peak discharge volume. Compliance with local storm water regulations is encouraged through performance bonds. A performance bond is bond issued to a contractor or other responsible party conducting land development, forfeiture of which is risked if the party does not comply with the terms of the bond (*i.e.*, performance standards) Wisconsin has recently enacted sweeping state-wide regulations governing both urban and agricultural nonpoint pollution.

The realization of environmental consequences from land development has brought environmental considerations to the fore as evidenced by model "smart growth" legislation proposed by the American Planning Association (2002), and as enacted in Maryland and Wisconsin. Aggressive regulation and follow-up enforcement is needed to address water quality impacts associated with land development, but finite limits on development must also be an integral component of any future land use planning and regulatory framework. Significant numbers of sensitive species are lost at relatively low levels of impervious cover, suggesting that the upper limit of urban land use for the highest quality watersheds is about 5%. This argues strongly for no net gains in impervious cover in some watersheds. However, for less sensitive waterbodies, aggressive regulations that protect riparian buffers and preserve much of the pre-development hydrology may be effective at maintaining aquatic life uses consistent with basic Clean Water Act goals at comparatively high levels of urban land use. Such regulations should include performance standards analogous to those for Maryland. More specifically, they should minimize the loss of pervious cover, manage and treat stormwater runoff to remove pollutants, retain stormwater and promote infiltration to maintain groundwater recharge and stream base-flow, and pre- and post development peak discharge should remain similar to protect stream channels. The level of urban land-use that can be reached and stream biotic integrity maintained under a regimen of aggressive protection is currently unknown, but may go as high 50%. For example, from our previous study of state-wide urban gradient sites (Yoder et al. 2000), sites that maintain good IBI scores at impervious cover greater than 30% have either intact riparian zones and undeveloped floodplains, or have high sustained base-flows relative to their drainage area. Also, Steedman (1988) found that an intact riparian zone of 20 m width was important in mitigating effects of urban land use on aquatic life in Toronto area streams.

In summary, the cause and effect relationship between increasing land development and decreasing stream quality is clear and abundantly demonstrated. For future land development to be sustainable, finite, watershed-specific limits to development must be defined, land use planning must consider the ecological aspects of the landscape and allocate development accordingly, and state and local governments must adopt rigorously protective environmental regulations governing land development.

Figure 4. Construction sites observed in the rapidly suburbanizing Columbus, Ohio metropolitan area. Upper left, a construction site in the Rocky Fork watershed; the exposed soil is supposed to be stabilized with straw and seeded with grass. Upper right, another tributary bulldozed for new construction. Lower picture, a construction site in Fairfield County instituting proper environmental controls including silt fencing and a settling pond.

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