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The biotic integrity of streams in urban and suburbanizing landscapes

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Abstract

The biological health of lotic communities is negatively correlated with the amount of urban land use in the surrounding watershed. This association is due, in part, to a historic lack of regard for the ecological consequences of development. Environmental considerations are increasingly being brought to the fore in land use planning, and to bear on development in the form of stormwater regulations and best management practices. The effectiveness of these practices in maintaining the biological integrity of receiving waters is assumed, though largely untested. We examined the relationship between urban land use and the biological health of streams in historically urbanized areas of Ohio, USA, and tracked the health of three streams over a decade in the rapidly suburbanizing Columbus, Ohio metropolitan area. The health of streams, as measured by the Index of Biotic Integrity, declined significantly when the amount of urban land use measured as impervious cover exceeded 13.8%, and fell below expectations consistent with Clean Water Act goals when impervious cover exceeded 27.1%. Declining biological integrity was noted in two of the three streams with suburbanizing watersheds at levels of total urban land use as low as 4%, demonstrating that poorly regulated construction practices are the first step toward declining stream health in urbanizing landscapes, and also demonstrate that the current regulatory structure is wanting. The few sites in our data set where biological integrity was maintained despite high levels of urban land use occurred in streams where the floodplain and riparian buffer was relatively undeveloped. An aggressive stream protection policy that prescribes mandatory riparian buffer widths, preserves sensitive areas and minimizes hydrologic alteration needs to be part of the larger planning and regulatory framework.

Keywords: Biological integrity; Fish; Land use; Streams; Rivers; Urbanization

1. Introduction

Urbanization and land use planning has historically occurred apart from a watershed context and without regard for ecological consequences (Arnold and Gibbons, 1996). 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) (Yuan et al., 2001), nutrients and sediment (Jones et al., 1999), pathogens and debris. Impervious surfaces also result in hydrologic and geomorphic alterations to low order streams: increased variance in stream flow, increased

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stream temperatures, and destabilization of the channel (Bledsoe, 2001). Collectively these stressors act to grossly impair biological communities when the range of impervious cover within a watershed reaches 8–20% (Karr and Chu, 2000; Schuler, 1994), and become irreparably damaged in the range of 25–60% (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 warmwater 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 hydrologic and water quality consequences effected by imperviousness alone (Yoder and Rankin, 1996). Apportioning the magnitude of impairment among all the various stressors has been wanting, but streams lacking allied urban stressors generally fare better than otherwise, as one might expect (Yoder et al., 2000; see Fig. 3). 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 by aggressive stormwater regulations typified by those for Maryland (Maryland Department of the Environment, 2000). Understanding the potential magnitude of consequences for all stressors, from initial disturbance to complete urban infrastructure, can help managers direct remediation of damaged watersheds, better plan future development, and most importantly, recognize that finite limits to development exist if Clean Water Act goals are to be met. From a regulatory standpoint, the first step to developing realistic aquatic life use expectations for urban streams is knowing what range of urbanization, in the absence of manageable allied stressors, is likely to preclude attainment of basic Clean Water Act goals.

From a practical standpoint, all Ohio streams have experienced initial disturbance through deforestation and wetland draining for farming. Most streams have suffered further disturbance through ditching and dredging, deliberate introductions and redistributions through stocking, accidental redistribution via canals, and sundry other forms of pollution. Consequently, the one true endemic fish, the Scioto madtom (Noturus trautmani) is probably extinct. And of the other 21 fish species considered the least tolerant of pollution or habitat destruction for Ohio (Table 1), four are extinct or extirpated from Ohio, and the remainder have very limited and fragmentary distributions. Placed in the context of Scott and Helfman's (2001) time course of homogenization, disturbance has had its effect on reducing or extirpating highly specialized species or those on the edge of their range such that now, a further increase in disturbance for a given stream reach is likely to result in a loss of overall diversity. Because the historical account of fish species abundance and distribution is so well documented for Ohio (Trautman, 1981, Ohio EPA data), assigning disturbance or pollution tolerances to Ohio fishes has been made possible by reviewing patterns in abundance and distribution through time, and by examining distributions of relative abundance against an environmental gradient in conjunction with published life histories and ecologies of individual species (Ohio EPA, 1987). Species with markedly reduced state-wide distributions, and species sampled frequently at the least disturbed sites and rarely or never at disturbed sites, are considered the least tolerant of disturbance or pollution. Pollution tolerances for Ohio fishes are listed in Table 1, and together with

Table 1
Fish species native to Ohio rivers and streams that are highly sensitive to either habitat degradation, pollution, or both

Common name	Latin	Susceptibility
Northern brook lamprey	*Ichthyomyzon fossor*	R
Ohio lamprey	*Ichthyomyzon bdellium*	R
Mountain brook lamprey	*Ichthyomyzon greeleyi*	R
American brook lamprey	*Lampetra appendix*	R
Lake sturgeon[a]	*Acipenser fulvescens*	H

Table 1 (*Continued*)

Common name	Latin	Susceptibility
Shovelnose sturgeon[b]	*Scaphirhynchus platorynchus*	H
Paddlefish[b]	*Polyodon spathula*	H
Goldeye	*Hiodon alosoides*	I
Mooneye	*Hiodon tergisus*	S
Brook trout[a]	*Salvelinus fontinalis*	T, S, H
Muskellunge[a]	*Esox masquenongy*	H
Blue sucker	*Cycleptus elongatus*	P
Black redhorse	*Moxostoma duquesnei*	S
Greater redhorse	*Moxostoma valenciennesi*	S, H
River redhorse	*Moxostoma carinatum*	S, I
Harelip sucker[b]	*Lagochila lacera*	S
Hornyhead chub	*Nocomis biguttatus*	S
River chub	*Nocomis micropogon*	P
Bigeye chub	*Notropis amblops*	S
Streamline chub	*Erimystax dissimilis*	S, P
Speckled chub	*Macrhybopsis aestivalis*	S, P
Longnose dace	*Rhinichthys cataractae*	T
Tonguetied minnow	*Exoglossum laurae*	T, S, H
Redside dace	*Clinostomus elongatus*	T, S, H
Rosyside dace	*Clinostomus funduloides*	R
Pugnose minnow	*Opsopoeodus emiliae*	S
Silver shiner	*Notropis photogenis*	S, P
Rosyface shiner	*Notropis rubellus*	S, P
Blackchin shiner[b]	*Notropis heterodon*	S
Bigeye shiner	*Notropis boops*	S
Mimic shiner	*Notropis volucellus*	S, P
Blacknose shiner	*Notropis heterolepis*	S, H
Pugnose shiner[b]	*Notropis anogenus*	S
Popeye shiner	*Notropis ariommus*	S
Channel shiner	*Notropis wickliffi*	S, P
Stonecat madtom	*Noturus flavus*	I
Mountain madtom	*Noturus eleutherus*	R
Northern madtom	*Noturus stigmosus*	R
Scioto madtom[b]	*Noturus trautmani*	S, P
Brindled madtom	*Noturus miurus*	I
Western banded killifish	*Fundulus diaphanus menona*	R
Walleye[a]	*Stizostedion vitreum*	H
Longhead darter[b]	*Percina macrocephala*	H
Slenderhead darter	*Percina phoxocephala*	P
Channel darter	*Percina copelandi*	S
Gilt darter[b]	*Percina evides*	S, H
Crystal darter[b]	*Ammocrypta asprella*	S, H
Eastern sand darter	*Ammocrypta pellucida*	S, P
Banded darter	*Etheostoma zonale*	S, P
Variegate darter	*Etheostoma variatum*	S, P
Spotted darter	*Etheostoma maculatum*	S, P
Bluebreast darter	*Etheostoma camurum*	S, P
Tippecanoe darter	*Etheostoma tippencanoe*	S, P

The letters under "susceptibility" denote the evidence given by Trautman (1981) and Ohio EPA (1988) for declining abundance or local extirpation as follows: H: habitat or hydrologic alteration, especially dams; I: industrial pollution; P: pollution, chiefly organic; R: limited zoogeographic distribution in Ohio; S: sedimentation; T: temperature.

[a] The last population of native brook trout in Ohio exists in only one very small stream. Lake sturgeon have been extirpated from the Ohio River drainage in Ohio. Self-sustaining populations of muskellunge exist in only three rivers in Ohio, and walleye in the Ohio River drainage of Ohio are maintained through artificial propagation.

[b] Extinct or extirpated from Ohio.

the Index of Biotic Integrity (IBI; Karr, 1981) modified for Ohio (Yoder and Rankin, 1995; Ohio EPA, 1987) provide a framework for judging the effects of increasing suburban development.

This paper summarizes the status of urban streams in Ohio preliminarily reported in Yoder et al. (2000), and reports on recent findings for three streams in the Columbus Metropolitan Area (i.e. Franklin County, Ohio), two with rapidly suburbanizing drainages (Rocky Fork and Hellbranch Run), and one poised for development (the headwater portion of Blacklick Creek in northeastern Franklin County). The results are interpreted in light of basic Clean Water Act goals as defined by designated aquatic life uses. Ohio EPA employs a tiered system for designating aquatic life uses for waters of the state. The three basic tiers are Modified Warmwater Habitat for waters with significant, irretrievable anthropogenic modifications, Warmwater Habitat for natural streams with aquatic assemblages typical for the stream size and ecoregion, and Exceptional Warmwater Habitat for streams whose aquatic assemblages approximate the best that can be expected for the ecoregion and stream size. Ohio EPA assigns aquatic life uses empirically, and has defined numeric biological criteria to assess whether a given stream is meeting its assigned use.

2. Study area

The three Franklin County streams and their location in Ohio and Franklin County are shown in Fig. 1. All streams are located in the Eastern Corn Belt Plains (ECBP) ecoregion of Ohio. The gently rolling glacial till plain comprising the ECBP ecoregion is broken by moraines, kames, and outwash plains. Local relief is generally less than 50 feet. Soils within the Hellbranch basin contain substantial amounts of clay, and so drainage has been facilitated by channelization of its headwaters. Land use within the Rocky Fork drainage is now largely a mixture of rural residential lots (1–5 acres) and suburban housing developments. Agricultural lands remain present in the south and western portions of the Hellbranch drainage, and the northeastern portion of Blacklick, but are being rapidly lost to residential development. Residential development, where it occurs in the Hellbranch drainage, is dense. Residential developments tend toward large lot sizes in the northern half of the Blacklick drainage, and are dense in the southern half. Construction site erosion and streambank modifications are the major sources of nonpoint pollution in the study area.

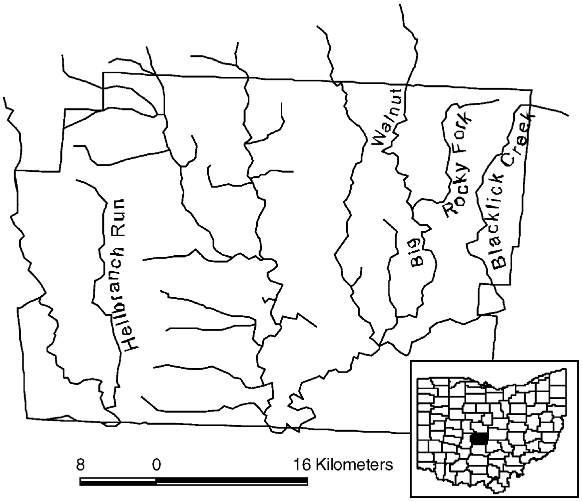

Fig. 1. Location of Rocky Fork, Blacklick Creek and Hellbranch Run in Franklin County, Ohio.

3. Methods

Fish community information from 267 sampling locations from the six major metropolitan areas of Ohio were selected from the Ohio EPA statewide biological and habitat database. Most of these sites were sampled between 1990 and 1998 and contained watershed areas less than 130 km^2, with most draining less than 50 km^2. Urban land use effects are more apparent in these smaller watersheds as evidenced by the higher proportion of impaired stream length compared to larger streams and rivers in Ohio (Yoder and Rankin, 1995; Yoder and Rankin, 1996).

Fish communities were sampled using generator-powered, pulsed dc electrofishing units and a standardized methodology (Ohio EPA, 1987a,b, 1989a,b; Yoder and Smith, 1999). Fish community attributes were collectively expressed by the IBI (Karr, 1981; Karr et al., 1986), as modified for Ohio streams and rivers (Yoder and Smith, 1999; Ohio EPA, 1987). Habitat was assessed at all fish sampling locations using the Qualitative Habitat Evaluation Index (QHEI;

Rankin, 1989; Rankin, 1995). The QHEI is a qualitative, visual assessment of the functional aspects of stream macrohabitats (e.g. amount and type of cover, substrate quality and condition, riparian quality and width, siltation, channel morphology, etc.).

Urban land use for all major metropolitan areas in Ohio was derived from Landsat Thematic Mapper satellite imagery (September 1994) of land cover classification provided by the Ohio Department of Natural Resources. The percentage of land use in the urban classification was calculated for the subwatershed upstream from each fish sampling location to the boundary of the watershed. Because many of the sites included in the statewide data set are subjected to a variety of stressors, each site was qualitatively classified by predominant impact type. Impact types included least impacted, estate for subwatersheds with large lot sizes or green space provided by parks, habitat impaired, sites impacted directly by discharges from combined or sanitary sewer overflows (CSO/SSOs), sites receiving wastewater treatment plant (WWTP) discharges, sites impacted by instream sewer line placement and construction (Cincinnati area only), legacy pollutants, and sites with no identified impact other than being urbanized.

The relationship between IBI scores and urban land use was initially characterized by regressing IBI scores against percent urban land use (log 10 transformed) and QHEI scores for all 267 sites in the six major metropolitan areas of Ohio. Diagnostic plots (e.g. residuals on predicted) were used to evaluate model assumptions (Neter et al., 1990). A strong relationship existed with QHEI scores; therefore, an analysis of covariance (ANCOVA) model was used to further explore the relationship where IBI scores were assigned to quartile levels of percent urban land use, and QHEI scores served as a continuous, linear covariate.

Fish communities and habitat quality were surveyed as described above in Rocky Fork, Blacklick Creek and Hellbranch Run. Four common sites were sampled each year in Rocky Fork in 1991, 1992, 1993, 1994, 1996 and 2000. Five common sites were sampled in Blacklick Creek in 1991, 1996 and 2000. In Hellbranch Run, five common sites were sample in 1992 and 2001, two of which were also sampled in 1997 (see Fig. 4).

A crude estimate of the relative change in urban land use between 1990 and 2000 was made for the Hellbranch Run, and Rocky Fork-Blacklick Creek drainages by comparing census data from the two time periods using population density as a surrogate for urban land use (Stankowski, 1972) for the census blocks in or straddling the respective watersheds. Rocky Fork and Blacklick Creek were not differentiated because they share common block groups. The relationship between population density and percent urban land use for Franklin County was estimated by regressing the percent urban land use ($\log_{10} Y + 1$ transformation) estimated from the 1994 Landsat imagery on the $\log_{10}$ of population density (from the 1990 Census) for subwatersheds upstream from sampling points ($N = 79$) in Franklin County (a subset of the Statewide data set). The number of highly sensitive species sampled at the same locations at the beginning and end of the decade in each stream were compared using a two sample *t*-test.

4. Results

4.1. Overview of Ohio urban streams

The relationship between the IBI and urban land use was initially characterized by regressing IBI scores against percent urban land use ($\log_{10}$ transformed) and QHEI scores using a database of 267 sites for all of the six major metropolitan areas of Ohio. Diagnostic plots (e.g. residuals on fitted values) indicated nonconstancy of error variance. Inspection of the data set showed that legacy, CSO/SSO, habitat, and WWTP impacts were stressors largely independent of the urban gradient (Fig. 1, right panel; Table 2). Although these impacts are common to urban areas, they were removed from the remaining statistical analyses reducing the sample size to 123 “gradient” sites. This resulted in a better regression model fit (Fig. 1, left panel; Table 2), and diagnostics consistent with regression model assumptions (Neter et al., 1990). Results from the ANCOVA model illustrate the threshold relationship between the amount of urbanization and stream biotic integrity as the mean IBI response in the highest quartile level urban land use (>27.1%) was significantly lower than that of the other three quartiles (Table 3). The relationship between mean IBI response to urbanization was more continuous between the first through third quartiles. The mean IBI response in the first quartile

Table 2
Results for the regression of IBI on percent urban land use and QHEI for sites having no identified impacts beyond urbanization, and those sites having identified impacts

Effect	Coefficient	S.E.	*t*-test	*P* (two-tail)
Gradient sites only[a]				
Constant	32.4069	4.2184	7.6882	0.0000
QHEI	0.2390	0.0605	3.9493	0.0001
Urban	−11.1496	1.3102	−8.5096	0.0000
Stressed sites only[b]				
Constant	19.5328	3.5037	5.5749	0.0000
QHEI	0.1668	0.0499	3.3405	0.0011
Urban	−2.5991	1.4887	−1.7459	0.0830

[a] Dep Var: IBI, $N = 123$, adjusted $R^2 = 0.4190$.
[b] Dep Var: IBI, $N = 144$, adjusted $R^2 = 0.0859$.

level of urbanization (<4.4%) was significantly higher than that in the third quartile (13.8–27.1%), but not from that in the second. And the mean IBI of the second quartile did not significantly differ from the third. Sites with allied stressors had lower IBI scores across the gradient of urban land use (Fig. 1). When plotted by impact type (Fig. 2), CSO/SSO, legacy and habitat impacts had the strongest negative effects on the IBI, and combinations of those three impacts affect all sites in the Toledo and Youngstown metropolitan areas.

4.2. Rocky Fork, Blacklick Creek and Hellbranch Run

Between the 1990 and 2000 Censuses, the population per area more than doubled in Census blocks comprising the Hellbranch basin (151–370 people km^{-2}) and Rocky Fork and Blacklick Creek (88–184 people km^{-2}). The total amount of urban land estimated from the 1994 Landsat imagery was 2.1% for Rocky Fork (exclusive of Blacklick Creek) and 3.3% for Hellbranch. Based simply on the population increase between 1990 and 2000 in each basin, and given the regression equation of urban land use on population density having a slope approximating 1 (Fig. 7), the amount of urban land in each basin is likely to have at least doubled. However, the actual increase in the Rocky Fork drainage is likely higher as suburban development within the census blocks comprising Rocky Fork and Blacklick Creek occurred mostly in the Rocky Fork drainage.

Fish communities in Rocky Fork have become significantly degraded as a result of suburbanization. IBI scores from samples collected in 2000 were clearly lower compared to samples collected in 1996, 1994, 1993, 1992 and 1991 (Fig. 4, middle panel). Most telling of all was the local extirpation of pollution intolerant silver shiners (*Notropis photogenis*) and hornyhead chubs (*Nocomis biguttatus*) in a reach where historically they were abundant (Fig. 4, middle panel). Based on the Ohio EPA statewide database, the probability of not collecting a highly sensitive species at a location where at least one highly sensitive species was present in any prior year is about 10%, but the probability falls to 2.5% when a highly sensitive species was collected in any two prior years (Fig. 7). This suggests that the loss of silver shiner and hornyhead chub was not a coincidence of inter-annual variation. The average number of highly sensitive species sampled at common sites between the beginning and end of the decade was similar (two

Table 3
Analysis of covariance results for IBI scores by quartile level of percent urban land use and habitat quality as measured by the QHEI

Source	Sum-of-squares	d.f.	Mean-square	*F*-ratio	*P*
Quartile	4020.66	3	1340.22	28.81	0.0000
QHEI	640.71	1	640.71	13.78	0.0003
Error	5488.39	118	46.51		
Quartile range	<4.4%	4.4–13.8%	13.8–27.1%	>27.1%	
Multiple comparisons: matrix of pairwise probabilities					
<4.4%	1.0000				
4.4−13.8%	0.2615	1.0000			
13.8−27.1%	0.0018	0.2587	1.0000		
>27.1%	0.0000	0.0000	0.0000	1.0000	

Multiple comparisons were made using Tukey’s method (Neter et al., 1990).

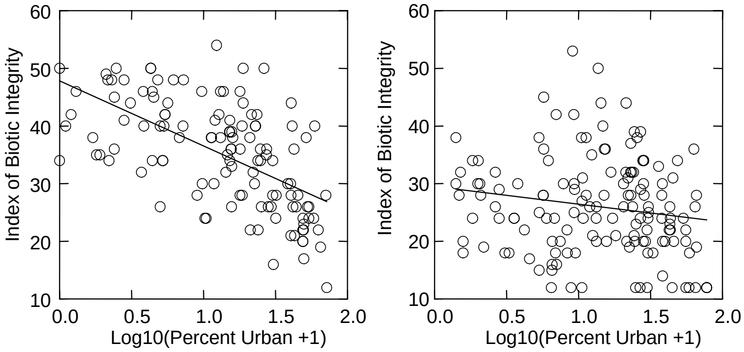

Fig. 2. Scatter plots of Index of Biotic Integrity (IBI) scores for stream fish communities on the percent of land classified as urban in the upstream watershed. The left panel is for sampling locations where allied stressors (see text) were not apparent. The right panel shows sites associated with allied stressors. The regression parameters for these scatter plots are given in Table 2.

sample t-test, $P > 0.05$) as impacts from development were already occurring in 1991 as evidenced by the longitudinal plots shown in Fig. 4. However, the relative abundance of all pollution sensitive species obviously declined throughout Rocky Fork over the last decade (Fig. 5). This overall decline has resulted in a reduction in aquatic life use from EWH to less than WWH in the span of a decade.

Similarly, IBI scores for Hellbranch Run were generally lower in 2001 compared to 1997 and 1992 (Fig. 3, lower panel). Pollution sensitive species showed a significant overall decline between 1992

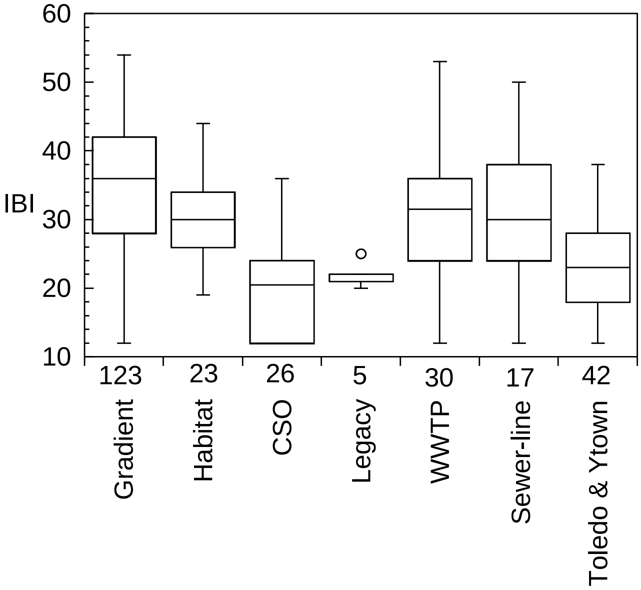

Fig. 3. Distributions of IBI scores for urban “gradient” sites and for allied stressors. Gradient sites are those that have no identified impact (i.e. allied stressor) beyond urban land use. Allied stressors are defined as follows: habitat, streams with significant direct anthropogenic modifications; CSO, combined or sanitary sewer overflows; legacy, residual contamination from heavy industry; WWTP, sites downstream from wastewater treatment plants; sewerline, sites in the Cincinnati metro area where sewer lines were buried beneath the stream bed. All sites sampled in the Toledo and Youngstown metropolitan areas were impacted by one or more of the allied stressors. Sample sizes are indicated along the x-axis.

and 2001 for sites sampled in common (two sample *t*-test, $P < 0.01$), as well a general decline in terms of relative abundance (Fig. 5). A loss of the most highly sensitive species was also noted from a reach where they were historically present (Fig. 3, upper panel).

In Blacklick Creek, fish communities fared as well or better in 2000 compared to 1996, 1991 or 1986 (Fig. 3), especially in the lower 24 kilometers of creek due to improved sewage treatment. However, the fish community is showing signs of stress from suburbanization. IBI scores in the upper half of the watershed were slightly lower in 2000 than those from previous years, and though the difference in IBI scores falls within the range of variation expected between years, the highly sensitive silver shiner was lost at RM 20.4 where it had been present in two prior years (Fig. 3, upper panel), suggesting that a more general decline, like that seen in Rocky Fork and Hellbranch, is impending.

5. Discussion

Urban stressors act to grossly impair biological communities when the range of impervious cover within a watershed reaches 8–20% (Karr and Chu, 2000; Schuler, 1994), and become irreparably damaged in the range of 25–60% (Karr and Chu, 2000). The results presented here show a similar range for our urban gradient sites with significant declines in biological integrity detectable when the amount of impervious cover exceedes 13.8%, and a complete loss of aquatic life use consistent with Clean Water Act goals when impervious cover exceeds 27.1%. For sites having allied stressors, percent impervious surface was marginally important in explaining variation among sites. The strong negative effect allied stressors have on biotic integrity, independent of percent imperviousness, argues that control and remediation strategies should not be ignored. At relatively low levels of urbanization (i.e. <10%), restoration of aquatic life uses to basic Clean Water Act goals should be expected for most waters. However, the threshold response in biotic integrity to urbanization observed here suggests that for highly urbanized areas (>27.1% impervious), aquatic life uses consistent with basic Clean Water Act goals are not likely to be achieved under most scenarios. Restoration goals for streams in highly urbanized areas should be directed first toward control of allied stressors for public health and recreational uses, at least in the near-term, and toward protecting aquatic life by mitigating events causing acute toxicity (e.g. first-flush stormwater). This latter goal then becomes the minimum standard for an aquatic life use for streams in highly urbanized areas. Restoration goals for intermediate levels of urbanization will likely fall along a continuum between full aquatic life use restoration and the goals previously stated for highly urbanized areas depending on site-specific circumstances. To correct for the historic lack of watershed planning and concern for ecological consequences, more ambitious long-term restoration goals should be part of the urban revitalization process.

Population density in the Rocky Fork and Hellbranch Run watersheds more than doubled between 1990 and 2000. The extent of declining biotic integrity of Rocky Fork, and to a lesser degree, Hellbranch Run demonstrate the impact from suburbanization and the lack of ecologically meaningful controls on land development. Local impacts due to construction were evident in the early 1990s for Rocky Fork (Fig. 4) when the total amount of urban land was less than 3% and demonstrate that poorly regulated construction practices are the first step toward declining biotic integrity in urbanizing landscapes. The cumulative impact over a decade resulted in the loss of aquatic life use for Rocky Fork. Because the Rocky Fork basin experienced a rapid construction boom through the 1990s, some recovery may be possible as vegetation becomes re-established on construction sites and the pace of new construction slows. In any event, the decline in Rocky Fork is particularly alarming because the total area of urbanized land is estimated at less than half the threshold level of 13.8% identified from the statewide data. Hellbranch Run has not declined as dramatically as Rocky Fork despite a doubling of population and an estimated higher level of urbanization. This may be because most of the development in the Hellbranch watershed is concentrated in a tributary subwatershed allowing for some attenuation of impacts. Also, Rocky Fork has a shallow soil layer over sandstone bedrock and consequently has less groundwater influence than Hellbranch Run which has a thick layer of glacial till over limestone bedrock. Although the overall biotic integrity of Hellbranch Run has not declined as sharply as in Rocky Fork, fewer sensitive

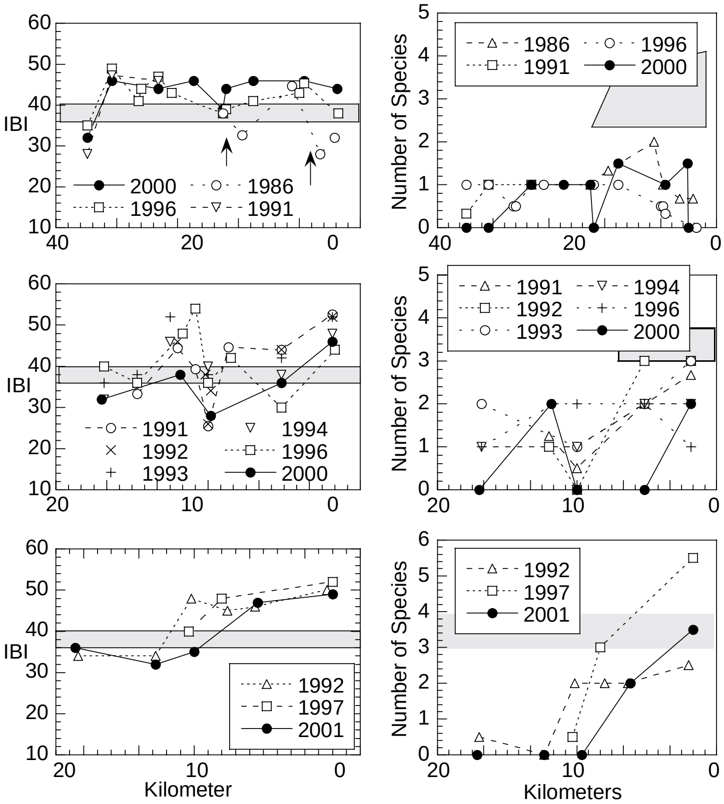

Fig. 4. Longitudinal plots of IBI scores (left column) and the number of highly sensitive species (right column) sampled by year in Blacklick Creek, Rocky Fork and Hellbranch Run. The shaded area of each plot shows the lower range of expected scores or expected number of species based on drainage area. Expectations for the number of highly sensitive species vary by drainage area, and have not been estimated for drainage areas less than 52 km^2. The arrows in the IBI plot for Blacklick denote the location of municipal wastewater sources.

species were sampled at common sites in Hellbranch Run in 2001 compared to 1992 suggesting that further development, without appropriate controls, will result in the loss of aquatic life use (Figs. 5–7).

The loss of several sensitive species from Blacklick Creek from a reach recently pressured by development may herald a more general decline that would negate the aquatic restoration realized by the upgrade of two municipal wastewater plants that discharge to the creek. The capital outlay for the upgrades approached two million dollars. What is happening in Blacklick Creek parallels statewide trends (Ohio EPA 2000) where gains in stream kilometers attaining their aquatic life uses brought about by improved wastewater treatment have leveled off, and will certainly reverse given that nonpoint pollution is increasing and remains under-regulated.

Whether water resources are impacted by land development because existing regulations are under-enforced or are under-protective is an open question. Regulations vary widely between political jurisdictions. In Ohio, a general stormwater 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 7 days, or 2 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. Temporary stabilization, sediment ponds and

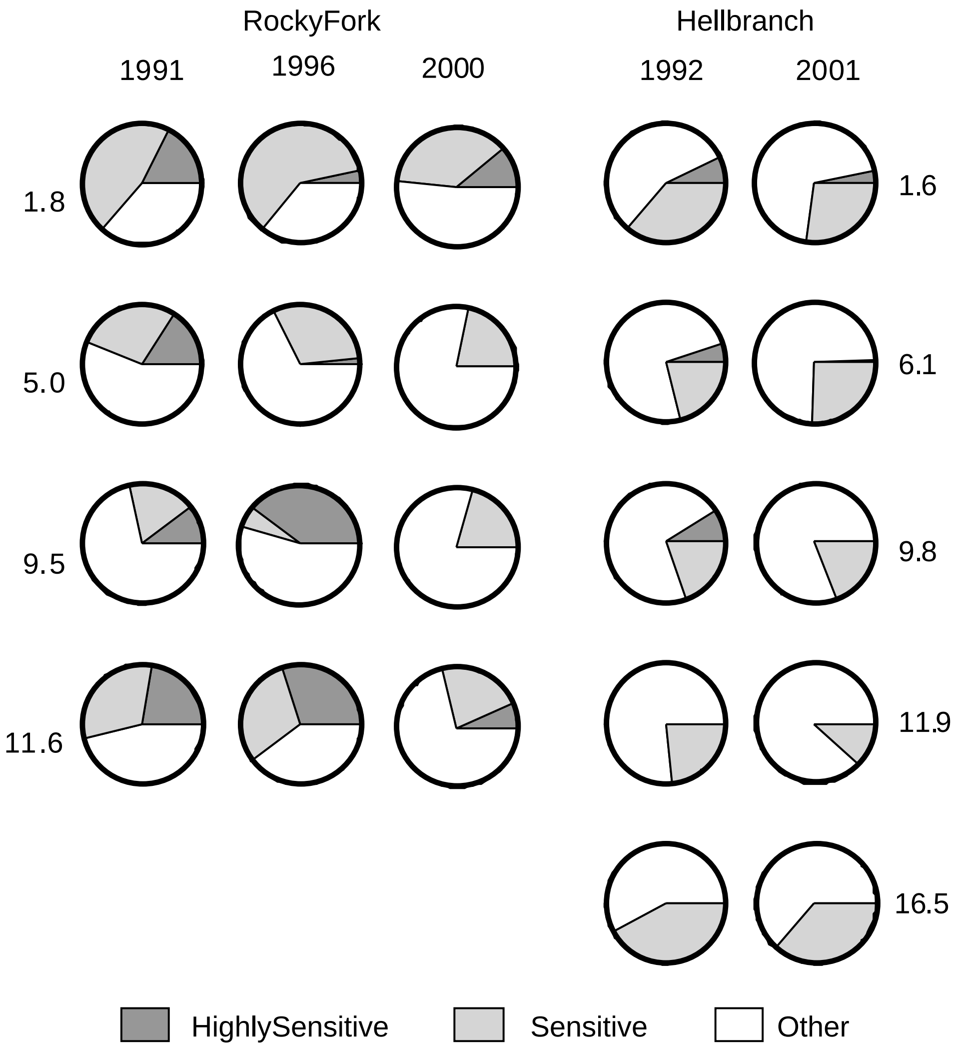

Fig. 5. Relative abundance of fish classified as highly sensitive or sensitive as a fraction of the whole catch at sites sampled in common in Rocky Fork and Hellbranch Run. Sample year is indicated at the top of each column; sampling location (as distance in kilometers from the downstream terminus) is indicated at the left of each row for Rocky Fork, and at the right each row for Hellbranch Run.

silt fences were rarely observed at construction sites throughout the Big Walnut basin to which Rocky Fork and Blacklick Creek are tributaries (Fig. 8). Enforcement of the general stormwater permit for a 10 county area in Central Ohio falls to one person.

Contrasting sharply with Ohio is stormwater protection in the State of Maryland were stormwater administration 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 contiguous sensitive areas. This is in addition to the 14 general performance standards for stormwater management applicable throughout Maryland (Maryland Department of the Environment, 2000). These performance standards go beyond simply minimizing the amount of

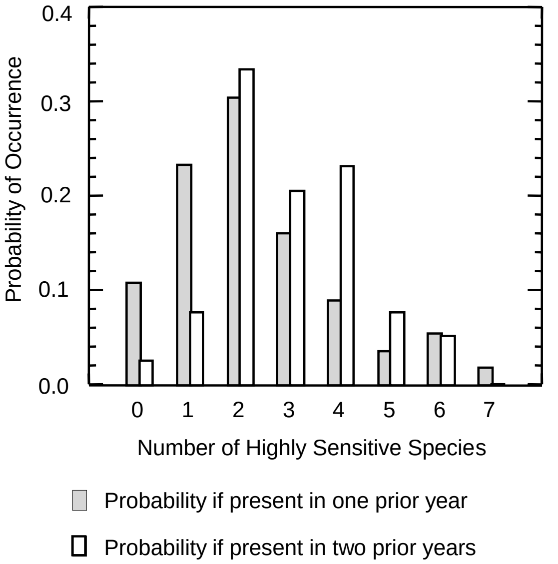

Fig. 6. Probability distributions of the number of highly sensitive fish species sampled at a given location if at least one highly sensitive fish species was sampled in any prior year (shaded bars), or in 2 prior years (open bars).

sediment from construction sites by striving to maintain the predisturbance hydrology of the watershed including groundwater recharge, stream channel stability, and peak discharge volume. Compliance with local stormwater regulations is encouraged through performance bonds required prior to issuance of construction permits. These more stringent regulations have not been in place long enough to test whether they will minimize loss of aquatic life uses during development. However, rehabilitation of the urbanized and highly degraded Sligo Creek watershed in Maryland using multiple stormwater BMPs and treatments demonstrated some success in recovering previously extirpated fish species (Stribling et al., 2002). It seems reasonable to assume that a suite of active and passive (e.g. preserving riparian buffers) BMPs would be more successful applied pro-actively rather than retroactively.

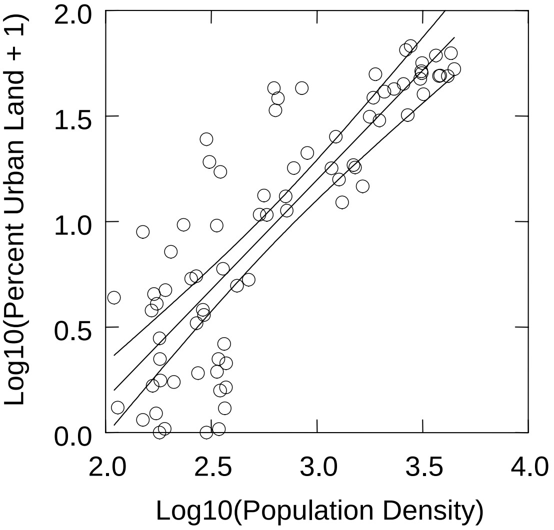

Fig. 7. The relationship between the percent of land classified as urban from the 1994 Landsat imagery and the 1990 population density in 79 subwatersheds of Franklin County, Ohio ($Y = -1.7702 + 0.9915\times$, $R = 0.8536$, $P < 0.0001$).

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. Our own data show habitat quality as an important explanatory variable across the urban gradient. Also an examination of sites where good IBI scores were maintained despite levels of urban land use greater than 30% revealed that those sites either have intact riparian zones and undeveloped floodplains, or receive significant amounts of groundwater. Together these results suggest that aggressive regulations that protect riparian buffers and preserve much of the predisturbance hydrology may be effective at maintaining aquatic life uses consistent with basic Clean Water Act goals in suburbanizing watersheds, at least up to a point. That point currently appears in the range of 10–30%, but may go as high as 50–60% under a regimen of aggressive watershed protection (Steedman, 1988). Obviously finite limits to development must be an integral component of any future land use planning. Such limits may range from no net development for sensitive watersheds with unique, highly diverse or recreationally important ecosystems to focused development in less sensitive watersheds paired with aggressive stormwater management and treatment to minimize downstream impacts.

The impetus for the Clean Water Act was the catastrophic failure of our water resources to provide goods and services following a century of neglect, examples of which included Lake Erie and the burning Cuyahoga River. The realization that point source controls alone are not enough to affect restoration is evidenced by Maryland's response to the Chesapeake Bay.

Fig. 8. Construction sites observed during the year 2000 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, a properly constructed silt fence retaining sediment on a tributary to Rocky Fork. Lower right, a construction site lacking required soil stabilizing measures and silt fencing is located adjacent to a Big Walnut tributary (the tree line is the stream bank). Lower left, another Big Walnut tributary bulldozed for new construction.

Apparently, even where highly valuable resources are at stake, society is vulnerable to the shifting baseline syndrome postulated by Pauly (1995) and observed empirically by Post et al. (2002). Suburbanization is insidious because the effects on the landscape are cumulative and generally slow such that the loss of ecological goods and services goes unnoticed and becomes culturally normative. It is the responsibility of those charged with the public trust to prevent this slow erosion of ecological integrity.

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