Ohio Journal of Science (Ohio Academy of Science) Ohio Journal of Science: Volume 93, Issue 4 (September, 1993)

1993-09

Decline in the Index of Biotic Integrity of Delaware Run, Ohio, over 50 Years

Gatz, A. John; Harig, Amy L.

The Ohio Journal of Science. v93, n4 (September, 1993), 95-100
http://hdl.handle.net/1811/23572

Decline in the Index of Biotic Integrity of Delaware Run, Ohio, over 50 Years[1]

A. John Gatz, Jr. and Amy L. Harig[2], Department of Zoology, Ohio Wesleyan University, Delaware, OH 43015

Abstract. The purpose of this study was to compare the present biotic integrity of a central Ohio headwater stream with the conditions in 1940. Major changes in fish faunal composition occurred in Delaware Run over this time period. Only 33% (11 of 33) of the total species collected were present in both years. Indices of biotic integrity (IBI) estimated for the 1940 data indicated that the stream was in good condition then, whereas it is in fair to poor condition now. The primary differences are as follows: 1) an increase in abundance of tolerant species suggesting an increase in general pollution, 2) a decrease in percentage of insectivores together with an increase in percentage of generalists suggesting a reduction of the insect food base, 3) a decrease in the number of simple lithophilic spawners suggesting degradation of reproductive habitat through siltation, and 4) an increase in percentage of pioneering fishes suggesting increased temporal stresses in the stream. Although the stream was not in pristine condition in 1940, it has been degraded further in the past half century.

OHIO J. SCI. 93 (4): 95–100, 1993

INTRODUCTION

The Federal Water Pollution Control Act of 1972 started the nation on a policy to "... restore and maintain the chemical, physical and biological integrity of the Nation's water" (Hocutt 1981). Because fishes are dependent throughout their lives on suitable water conditions, it should be possible to assess both present and recent past conditions in a watershed by examining the fish fauna. In recognition of this, Karr (1981) proposed an initial version of the index of biotic integrity (IBI) calculated by totaling the scores on each of 12 metrics (Table 1). The score on each metric is set at one of three values: five for conditions showing minimal human impact, three for evidence of moderate impact, or one for severe impact. Modifications of the index have been developed for various parts of the United States (e.g., Fausch et al. 1984, Leonard and Orth 1986, Miller et al. 1988, Bramblett and Fausch 1991), including Ohio (Ohio EPA 1988; Table 1), as well as for Ontario (Steedman 1988) and France (Oberdorff and Hughes 1992). Karr et al. (1987) and Fausch et al. (1990) report that the IBI is superior to any current alternative in assessing stream degradation, and Karr (1991) both summarizes the rationale used in the development of the index and presents the presumed ranges of sensitivity for each metric. In the present paper, the IBI is used to compare the ichthyofauna in Delaware Run in 1940 with that present in 1992 as a means of determining if there has been environmental degradation over the 50-year span.

MATERIALS AND METHODS

Delaware Run is a low gradient (2.4 m·km^{-1}), 10-km tributary of the Olentangy River in central Ohio with a watershed of about 25 km^2. At normal water levels, most of the stream consists of glides with occasional pools and riffles. Substrates vary from limestone bedrock to silt, with a mixture of sand and cobble being most common. Much of the upper half of the stream is still bordered by crop and pastureland as it was in 1940, but the lower half is increasingly bordered by residential development although trees remain common in the riparian zone. The last 2 km is highly channelized and spanned by ten bridges as it flows through downtown Delaware, OH, a town of some 20,000.

Between 2 March and 18 May 1940, an Ohio Wesleyan University undergraduate, Robert C. Bailey, and an employee of the Ohio State Department of Conservation, Lloyd E. Volk, used minnow seines to make eight collections of fishes at five different sites spaced along the entire stream. Bailey (1940) indicated sampling distances of 200 m and 400 m for two of the sites, but gave no distances for

Table 1

Karr's (1981) original IBI metrics compared to those used by the Ohio EPA (1988) to assess headwater sites.

Karr (1981)	Ohio EPA (1988)
Number of:	Number of:
1. fish species	1. native fish species
2. darter species	2. darter and sculpin species
3. sunfish species	3. headwater species
4. sucker species	4. minnow species
5. intolerant species	5. sensitive species
6. individuals	6. individuals excluding tolerant species
	7. simple lithophilic spawning species
Percentage of individuals that are:	Percentage of individuals that are:
7. hybrids	
8. green sunfish	8. tolerant species
9. omnivores	9. omnivores
10. insectivorous cyprinids	10. insectivores
11. top carnivores	11. pioneering species
12. diseased	12. diseased or have anomalies

[1]Manuscript received 26 January 1993 and in revised form 22 June 1993 (#92-23).

[2]Present Address: New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, Cornell University, Ithaca, NY 14853

the others. They kept representative specimens of the species collected in proportion to their verbal descriptions of abundance (Bailey 1940).

Between 26 February and 8 May 1992, we made collections of fishes at sites that included three of those used by Bailey and Volk in 1940; the other two sites were dry. Given that Bailey's (1940) site descriptions were sometimes ambiguous, care was taken to sample regions that extended at least as far as what he described. Starting at the mouth, our sites were creek kilometers 0.00-0.53, 1.28-1.91, and 2.55-2.85. We collected fishes once at each site with a backpack DC electrofisher and dipnet, identified and counted every individual collected, and then released all fishes into the stream. However, because the ambiguous historical records undoubtedly led to a lack of precise correspondence between our sampling sites and those used in 1940, IBIs were calculated for the entire stream, not individual sites.

To calculate an initial IBI, we used the 12 metrics defined by the Ohio EPA (1988; Table 1) as appropriate for headwater sites (drainage area <50 km^2). We also used their categorizations of headwater sites as "exceptional" (IBI 50-60), "good" (IBI 40-48), "fair" (IBI 26-38), "poor" (IBI 16-24), or "very poor" (IBI <16). Additionally, we calculated a modified IBI using alternative metrics or altered versions of the Ohio EPA metrics. The modifications were to exclude tolerant species of darters from the number of darter species, to include all cyprinids except tolerant species in the number of minnow species, to use references other than Ohio EPA (1988) to define sensitive species, to use percentage rather than number of simple lithophilic spawning species, to substitute percentage generalists for percentage tolerant species, and to use percentage insectivorous cyprinids for percentage insectivores.

RESULTS

Nearly the same number of species (22 vs. 21) was collected each year, but only 11 of the 33 total species were present both years (Table 2). The most conspicuous changes from 1940 to 1992 were the appearance of carp in the stream, the loss of most species of shiners concomitant with an overwhelming increase in the abundance of creek chubs, a tremendous increase in abundance of white suckers, and a large increase in abundance of sunfishes, especially green sunfish. Creek chubs, white suckers, and green sunfish have been classified as generalists, and their abundance increased from 9% of the total fish population in 1940 to 70% in 1992 (Fig. 1).

Considering the Ohio EPA metrics individually, the greatest differences between years were a decrease in number of simple lithophilic species, an increase in percentage of tolerant fishes, a decrease in insectivores, and an increase in pioneering fishes (Fig. 2). Converted to scores, eight of the 12 Ohio EPA metrics decreased between 1940 and 1992, two increased, and two remained constant (Table 3).

Using Ohio EPA methodology, the overall IBI of the stream fell from 42 in 1940 to 30 in 1992. This 12-point decrease in IBI was significant by Ohio EPA standards, and reduced the biotic integrity of Delaware Run from "good"

TABLE 2

Species and numbers of fishes collected in Delaware Run in 1940 and 1992.

Family Species	1940[a]	1992[b]
Herrings		
Dorosoma cepedianum, gizzard shad[9]	–	1
Minnows		
Campostoma anomalum, stoneroller[4]	39	150
Cyprinella spiloptera, spotfin shiner[10]	–	6
Cyprinus carpio, carp[8,9]	–	41
*Luxilus chrysocephalus**, striped shiner[7,10]	60	–
Lythrurus umbratilis, redfin shiner[10]	17	–
Notemigonus crysoleucas, golden shiner[8,10]	7	4
Notropis buccatus, silverjaw minnow[4,10,11]	3	–
Notropis photogenis, silver shiner[5a,7,10]	20	–
Notropis rubellus, rosyface shiner[5a,7,10]	17	–
Notropis stramineus, sand shiner[5b,10]	1	–
Pimephales notatus, bluntnose minnow[4,8,9,11]	75	189
Pimephales promelas, fathead minnow[4,8,9,11]	13	–
Semotilus atromaculatus, creek chub[4,8,11]	8	1,373
Suckers		
Catostomus commersoni, white sucker[7,8,9]	21	378
Hypentelium nigricans, northern hog sucker[5b,7,10]	2	12
Moxostoma erythrurum, golden redhorse[5b,7,10]	1	–
Catfishes		
Ameiurus melas, black bullhead[10]	2	–
Ameiurus natalis, yellow bullhead[8,10]	–	6
Pikes		
Esox americanus, grass pickerel	1	–
Killifishes		
Fundulus notatus, blackstripe topminnow[10]	1	2
Silversides		
Labidesthes sicculus, brook silverside[5b,10]	–	2
Sunfishes		
Lepomis cyanellus, green sunfish[8,10,11]	1	359
Lepomis macrochirus, bluegill[10]	–	218
L. cyanellus x *L. macrochirus* hybrid	–	7
Micropterus dolomieu, smallmouth bass[5b]	–	31
Micropterus salmoides, largemouth bass	3	66
Pomoxis annularis, white crappie	–	3
Perches		
Etheostoma blennioides, greenside darter[5b,7,10]	–	9
Etheostoma caeruleum, rainbow darter[5b,7,10]	5	–
Etheostoma flabellare, fantail darter[3,10]	–	67
Etheostoma nigrum, johnny darter[10,11]	21	76
Etheostoma spectabile, orangethroat darter[7,10,11]	1	3
Total number of individuals	319	3,003

[a]For the 1940 data, the numbers are the number of individuals retained by the collectors.
[b]For the 1992 data, the numbers are the total number of individuals caught.
±Superscripts indicate categories into which species are placed by the Ohio EPA in their metrics (numbers correspond to Table 1): 3 = headwater species, 4 = minnows, 5a = intolerant species, 5b = sensitive species, 7 = simple lithophilic species, 8 = highly tolerant species, 9 = omnivores, 10 = insectivores, and 11 = pioneering species.
*Bailey (1940) lists *Notropis cornutus*, but given the change in taxonomy (prior to 1964, the striped shiner was classified as a subspecies of *Notropis cornutus*) and Trautman's (1981) range maps, the fish were most likely *Luxilus chrysocephalus* as listed here.

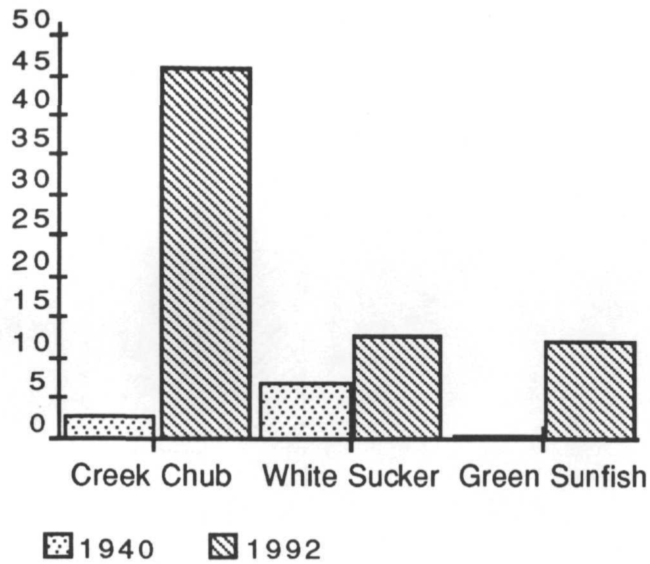


FIGURE 1. Increase in percentage of three species of generalist fishes in Delaware Run, OH, from 1940 to 1992.

in 1940 to "fair" in 1992. Most of the modified metrics yielded even lower scores for 1992 than did the Ohio EPA metrics; as a consequence, the IBI dropped from the same "good" 42 in 1940 to a "poor" 20 in 1992 (Table 3: values in parentheses).

DISCUSSION

Modification of IBI Metrics

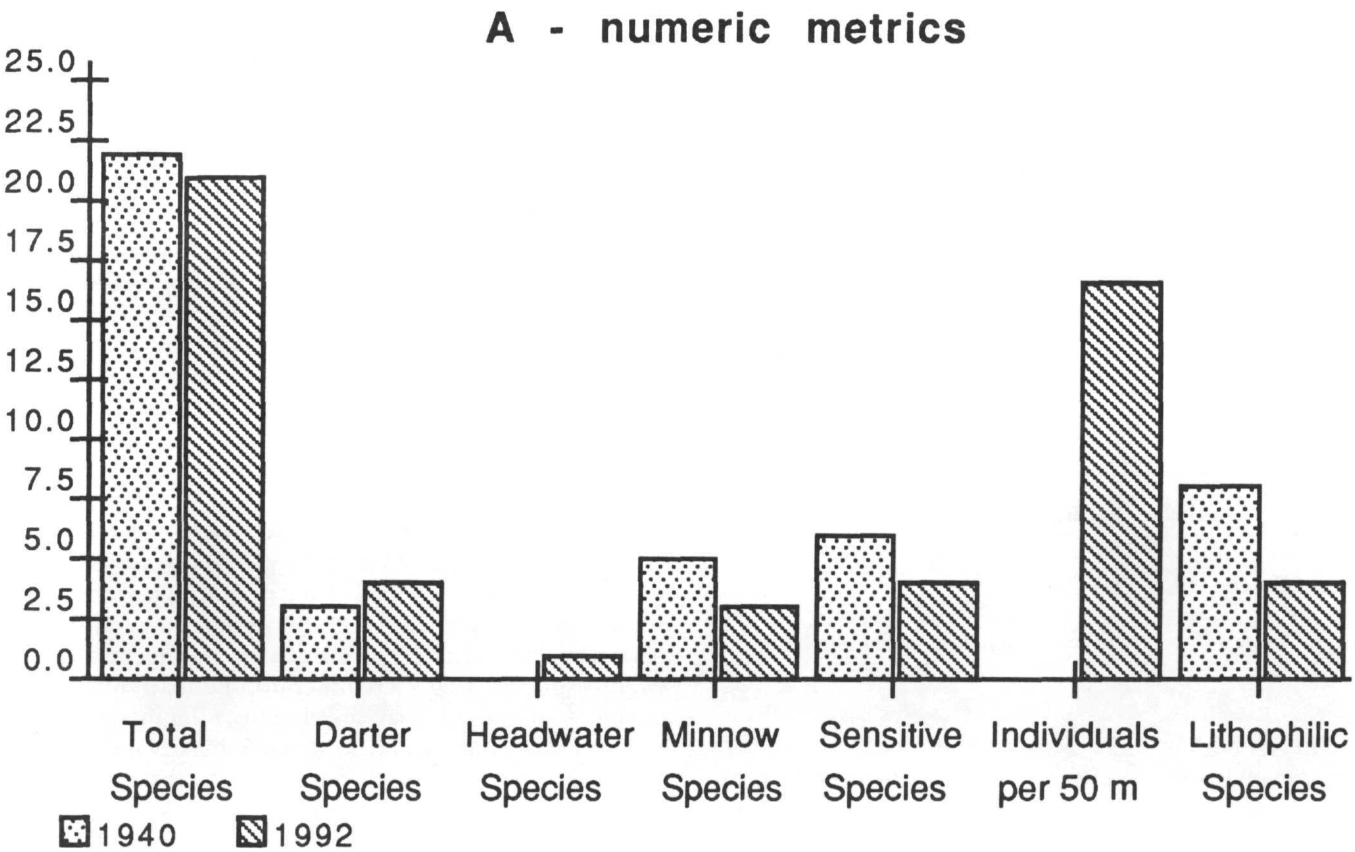
Karr (1991) warned against modification of the IBI without sufficient knowledge and offered one analysis showing that multiple modifications may not greatly change the performance of the IBI. Indeed, the six modifications of the Ohio EPA version of the IBI included above altered neither the 1940 IBI nor the overall conclusion that stream degradation had occurred during the last 50 years. Still, because so many workers have suggested modifications of metrics (e.g., Leonard and Orth 1986, Angermeier and Schlosser 1987, Hughes and Gammon 1987, Miller et al. 1988, Steedman 1988) and because the modifications used in the present study resulted in a substantial reduction in the 1992 IBI, comments are given on the attempted modifications as a way of emphasizing what appear to be problem areas in calculating IBIs. Most problems involve species' tolerances and the appropriateness of the inclusion of particular species in given metrics. Seemingly, what are needed are hard data on species' tolerances to various individual types of habitat degradation so that metrics specific to particular perturbations can be devised. As it is now, some metrics produce ambiguous information because the tolerances of individual species are either ignored or categorized irregularly. Further problems exist due to uncertainty about which alternative metrics are best used in any given situation. Consider how these points apply to the modifications we tried.

The number of darter species metric was designed to indicate high water quality and the absence of chemical disturbances based on the assumption that most species of darters are sensitive habitat specialists. While this characterization may be true of darters in general and is true of the one species of darter lost, the rainbow darter (Trautman 1981, Angermeier and Karr 1986, Ohio EPA 1988, Karr et al. 1986), it is not true of most of the species of darters currently present in Delaware Run. Trautman (1981) called the johnny darter very tolerant "for a darter" of both organic and inorganic pollutants and tolerant of silt, and Karr (1981) noted that the presence of only johnny darters indicates degraded habitat. Similarly, Trautman (1981) considered the fantail darter to be rather tolerant "for a darter" of pollutants and silty clay, and he ranked the orangethroat darter more tolerant of turbidity and siltation than the rainbow darter. Modifying this metric to exclude all tolerant species of darters leaves only a single species in each of the two years.

The number of minnow species metric provides a similar example. The Ohio EPA (1988) designed this metric to indicate general habitat and water quality degradation just like Karr's (1981) original metric using sucker species (Table 1). However, the inclusion of several species (e.g., creek chub, fathead minnow, bluntnose minnow) that are highly tolerant of both chemical degradation and low water makes the metric ambiguous. We agree with the Ohio EPA that it is more appropriate to consider minnows than suckers in small headwater streams, but question the limited group of cyprinids included. A metric excluding tolerant species but including laterally compressed cyprinids such as shiners seems reasonable.

The number of sensitive species metric obviously will vary according to how one classifies intolerant and sensitive species. The Ohio EPA (1988) used analysis of their own data as well as references such as Pflieger (1975) and Trautman (1981) to categorize species. Their conclusions sometimes differ dramatically from Trautman's (1981) work alone or from other sources. Tolerance varies across the range of a species and is often higher in the center than the periphery of the range (Angermeier and Karr 1986, Fausch et al. 1990). Ohio EPA's (1988) list of sensitive species includes three species currently present in Delaware Run that others who worked nearer the periphery of their ranges did not list as sensitive: brook silverside (Angermeier and Karr 1986), smallmouth bass (Hughes and Gammon 1987), and greenside darter (Trautman 1981, Angermeier and Karr 1986). Karr (1991) suggested that 5-10% of the species in any given area should be classified as intolerant, but just which species these should be is a problem.

For two of the metrics we substituted, percentage of simple lithophilic spawners and percentage of insectivorous cyprinids, we recognize no compelling argument for using the Ohio EPA metric or the alternate. However, for the third substitute metric we used, there is such a reason as Leonard and Orth (1986) showed that percentage of generalists was strongly correlated with an independent index of cultural pollution. Thus, their substitute metric has been more strongly verified than either Karr's original percentage of green sunfish or Ohio EPA's percentage of tolerant species, and it retains the original purpose of the metric of identifying tolerant species that often take over a degraded drainage.



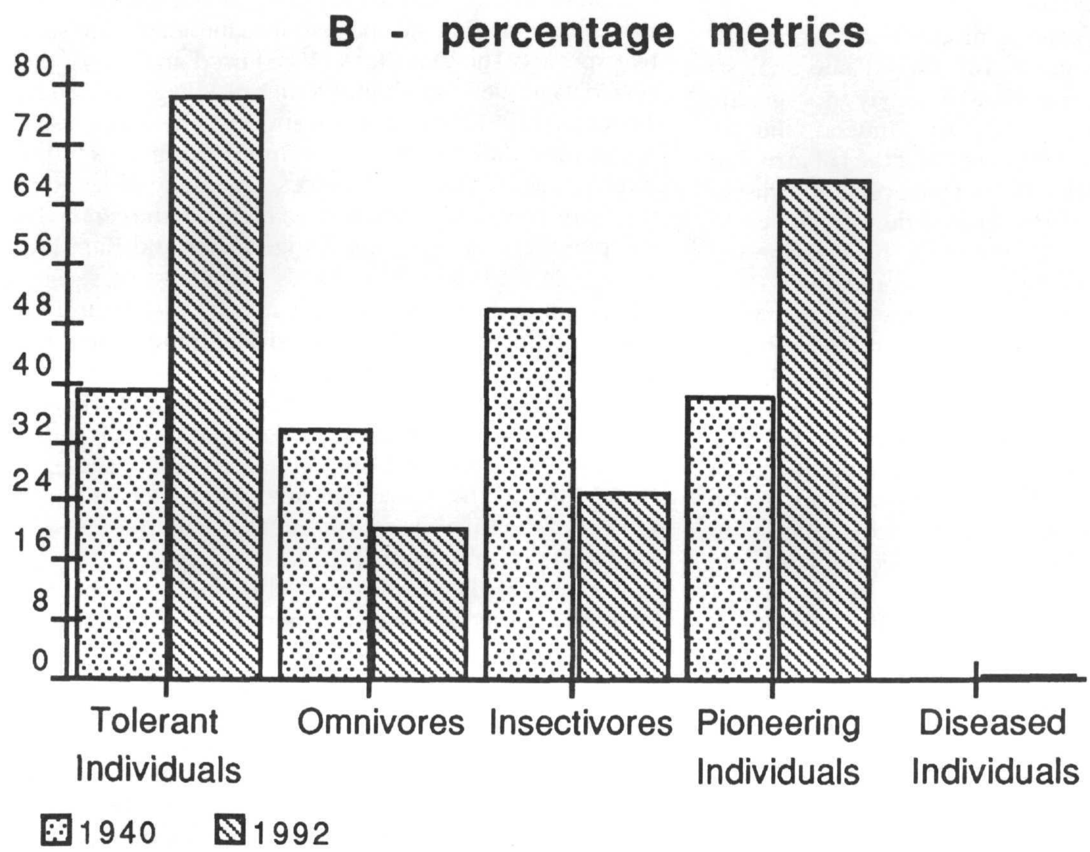


FIGURE 2. Data used for: A) numeric and B) percentage metrics to calculate indices of biotic integrity (IBIs) for 1940 and 1992 according to Ohio EPA methodology (see Table 1).
*No estimate of number of individuals per 50 m is possible for the 1940 data.

TABLE 3

Scores on IBI metrics for Delaware Run, OH, in 1940 and 1992.

Metric[a]	1940 scores Ohio EPA[b]	(modified)[c]	1992 scores Ohio EPA	(modified)
1	5		5	
2	3	(1)	5	(1)
3	1		1	
4	3	(5)	1	(1)
5	5	(5)	3	(1)
6[d]	3		1	
7	5	(5)	3	(1)
8	3	(5)	1	(1)
9	1		3	
10	5	(3)	3	(1)
11	3		1	
12[e]	5		3	
Sum = IBI	42	(42)	30	(20)

[a]Metrics are numbered as in Table 1.
[b]Score based on using Ohio EPA's (1988) metrics and scoring.
[c]Score based on modified metrics discussed in the text.
[d]In the absence of data, we assigned the intermediate score of 3; if a higher score was appropriate, the historical drop in IBI would be even greater.
[e]Bailey (1940) noted no such fishes; we followed the example of Karr et al. (1987) and assigned a score of 5 for this metric historically.

Reliability of the IBI Estimates

Using either the Ohio EPA standards or modified metrics, a basic question that remains is whether the difference in IBI between years represents a true difference in biological integrity or merely a sampling artifact. Four main possible sampling difficulties are: 1) short-term stochastic changes in species composition, 2) adequacy of lengths of sites, 3) differences in collection technique including selectivity of gear, and 4) validity of the historical relative abundance data. These are considered seriatim below.

It is well known that stream fish communities vary naturally over time (e.g., Grossman et al. 1982); in fact, the nature and cause of these variations is the central issue in an ongoing debate (Jackson et al. 1992). Such changes, however, do not seem to have a great effect on IBI values based on the work of Karr et al. (1987) and Steedman (1988). Furthermore, our collections in fall 1991, at the same sites reported here, yielded the same Ohio EPA IBI as the spring collections despite some differences in the rare species present in the collections (unpublished data). However, only the spring results are reported here to make the between year comparisons the most meaningful; lumping both recent seasons of collections into a single IBI would inflate it.

Angermeier and Karr (1986) investigated the length of sampling site needed to obtain consistent IBI estimates. They found that IBI goes up with length of sampling reach up to the longest reach tested (700 m), but found the rate of increase to be minimal after 300 m. Steedman (1988) recommended using two to three pool-riffle sequences or about 100 to 150 m. Thus, combining data from all sites so that a total of over 700 m were sampled in both years should be adequate to give reliable IBIs. Sampling somewhat longer distances in 1992 than in 1940 should, if anything, increase the IBI value, i.e., the opposite of what occurred.

Using the same type of sampling gear for all collections intuitively would seem likely to minimize sampling artifacts, so switching from seines to electrofisher seems potentially risky. However, little has been published on sampling biases, and personal experience comparing samples taken over the past twelve years in another nearby stream provides no dichotomy between samples collected by these two methods (unpublished data). Another aspect to the sampling problem is that different species of fishes are not equally catchable (e.g., Mahon 1980, Gatz and Loar 1988). Thus, there remains the problem that the samples taken may not represent the true natural abundances. However, the IBI should be robust to this problem because it was developed based on data from samples.

Bias in the relative abundances in the sample retained by Bailey and Volk obviously could affect the five percentage metrics, although not the seven numerical metrics. It would seem that the most likely bias would have been for rare species to be overrepresented in the sample (i.e., the "it's rare, keep it" syndrome) and for abundant species to be underrepresented. Bailey (1940) wrote of taking "great numbers" of both bluntnose minnows and stonerollers and "very large quantities" of striped shiners. Tripling the number of individuals for each of these three species and leaving the number of the other rarer species unchanged does not alter the IBI for 1940. A different variation, doubling the number of common shiners while tripling the number of the other two species, only reduces the IBI by two points. Considering this robustness of the IBI to major changes in relative abundance, it can be concluded that the profound differences between the ichthyofauna in 1940 and 1992 (Table 2) leading to the 12- to 22-point drop in IBI indicate a major change in stream conditions over the past half century.

Overall Assessment of Degradation

For Ohio EPA (1988) sites in 19 headwater reference streams (i.e., streams chosen as being the least affected by humans) in the same ecoregion as Delaware Run, the Eastern Corn Belt Plains, IBIs ranged from 34 to 57 with a mean of 45.2 (SD = 6.1). Because combining sites to give a single IBI increases the index, it is clear that Delaware Run was already somewhat degraded in 1940, and is now considerably more degraded. IBIs previously have been shown to respond to degradation stemming from such diverse causes as bridge and highway construction, removal of woody debris, mine drainage, siltation, and the influx of substances as diverse as domestic sewage, agricultural chemicals, chlorine, and ammonia (Angermeier and Schlosser 1987, Fausch et al. 1990, Crumby et al. 1990). The perturbations likely in the Delaware Run watershed as the city grew from under 9,000 in 1940 to over 20,000 in 1992 (U.S. census data) include agricultural runoff and siltation, loss of riparian vegetation, urban runoff including petroleum products, and habitat loss through channelization including the consequential sudden changes in flow with heavy rains. In addition, a dam was built on the Olentangy River upstream from the mouth of Delaware Run.

The few metrics that can be associated with a particular type of perturbation are worth mentioning as they pinpoint aspects of the habitat degradation in Delaware Run over the past 50 years. The metric based on simple lithophilic spawning species is one such metric as these species decrease in response to siltation (Berkman and Rabeni 1987). These species were reduced dramatically between 1940 and 1992; the number of species dropped from eight to four, and the percentage of individuals dropped from 40% to 13%. These drops together with the loss of species that Trautman (1981) listed as intolerant of siltation (e.g., silverjaw minnow, rosyface shiner, sand shiner) and an increase in abundance of species that Trautman (1981) considered tolerant of siltation (e.g., spotfin shiner, creek chub, white sucker, green sunfish, johnny darter) clearly indicate siltation to be one aspect of the inferred habitat degradation.

The percentage of pioneering species (i.e., those species first to reinvade formerly unavailable stream reaches) also has a clear-cut interpretation; it is an index of habitat instability caused by drying or pollution or both. The dramatic increase in pioneering species (Fig. 2) shows that the habitat in Delaware Run has become more unstable and unsuitable for continuous habitation by fishes over the last half century. The upper two sites were dry in fall 1991, and water at the downstream sites had films of petroleum products presumably from surface runoff from streets and parking lots. The incidence of problems like these seems to have increased over the last 50 years.

A final metric with a reasonably clear-cut interpretation is the percentage of fishes with deformities, eroded fins, lesions, and tumors. This metric increases with stresses caused by crowding, various infectious agents, and chemical pollutants (Ohio EPA 1988). The Ohio EPA (1988) reported the highest percentage of such anomalies in areas affected by waste water discharges, sewers, and urban runoff. These factors, including leaking septic fields (J. Sanger, Ohio Wesleyan University, pers. comm.), are likely causes of at least some of the tumors we noted.

ACKNOWLEDGEMENTS. We thank Drs. Wendell K. Patton and Dennis C. Radabaugh and two anonymous reviewers for their helpful comments on the manuscript.

LITERATURE CITED

Angermeier, P. L. and J. R. Karr 1986 Applying an index of biotic integrity based on stream-fish communities: Considerations in sampling and interpretation. N. Am. J. Fish. Manag. 6: 418-429.

___ and I. J. Schlosser 1987 Assessing biotic integrity of the fish community in a small Illinois stream. N. Am. J. Fish. Manag. 7: 331-338.

Bailey, R. C. 1940 An investigation of the distribution of fish life in Delaware Run, including research data on the effect of pollution on fish life. Honors Thesis, Ohio Wesleyan University, Delaware, OH, USA.

Berkman, H. E. and C. F. Rabeni 1987 Effect of siltation on stream fish communities. Environ. Biol. Fishes 18: 285-294.

Bramblett, R. G. and K. D. Fausch 1991 Variable fish communities and the index of biotic integrity in a western Great Plains river. Trans. Am. Fish. Soc. 120: 752-769.

Crumby, W.D., M. A. Webb, F. J. Bulow, and H. J. Cathey 1990 Changes in biotic integrity of a river in North-Central Tennessee. Trans. Am. Fish. Soc. 119: 885-893.

Fausch, K. D., J. R. Karr, and P. R. Yant 1984 Regional application of an index of biotic integrity based on stream fish communities. Trans. Am. Fish. Soc. 113: 39-55.

___ J. Lyons, J. R. Karr, and P. L. Angermeier 1990 Fish communities as indicators of environmental degradation. Am. Fish. Soc. Symp. 8: 123-144.

Gatz, A. J., Jr. and J. M. Loar 1988 Petersen and removal population size estimates: Combining methods to adjust and interpret results when assumptions are violated. Environ. Biol. Fishes 21: 293-307.

Grossman, G. D., P. B. Moyle, and J. O. Whitaker, Jr. 1982 Stochasticity in structural and functional characteristics of an Indiana stream fish assemblage: A test of community theory. Am. Nat. 120: 423-454.

Hocutt, C. H. 1981 Fish as indicators of biological integrity. Fisheries 6: 28-31.

Hughes, R. M. and J. R. Gammon 1987 Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Trans. Am. Fish. Soc. 116: 196-209.

Jackson, D. A., K. M. Somers, and H. H. Harvey 1992 Null models and fish communities: Evidence of nonrandom patterns. Am. Nat. 139: 930-951.

Karr, J. R. 1981 Assessment of biotic integrity using fish communities. Fisheries 6: 21-27.

___ 1991 Biological integrity: a long-neglected aspect of water resource management. Ecol. Applications 1: 66-84.

___, K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser 1986 Assessing biological integrity in running waters: A method and its rationale. Ill. Nat. Hist. Surv. Spec. Publ. 5.

___, P. R. Yant, K. D. Fausch, and I. J. Schlosser 1987 Spatial and temporal variability of the index of biotic integrity in three midwestern streams. Trans. Am. Fish. Soc. 116: 1-11.

Leonard, P. M. and D. J. Orth 1986 Application and testing of an index of biotic integrity in small, coolwater streams. Trans. Am. Fish. Soc. 115: 401-414.

Mahon, R. 1980 Accuracy of catch-effort methods for estimating fish density and biomass in streams. Environ. Biol. Fishes 5: 343-360.

Miller, D. L., P. M. Leonard, R. M. Hughes, J. R. Karr, P. B. Moyle, L. H. Schrader, B. A. Thompson, R. A. Daniels, K. D. Fausch, G. A. Fitshugh, J. R. Gammon, D. B. Haliwell, P. L. Angermeier, and D. J. Orth 1988 Regional applications of an index of biotic integrity for use in water resource management. Fisheries 13: 12-20.

Oberdorff, T. and R. M. Hughes 1992 Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin. Hydrobiologia 228: 117-130.

Ohio Environmental Protection Agency 1988 Biological criteria for the protection of aquatic life. Volumes 1-3. Ohio EPA, Division of Water Quality Monitoring and Assessment, Columbus, OH.

Pflieger, W. L. 1975 The Fishes of Missouri. Missouri Department of Conservation.

Steedman, R. J. 1988 Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. Can. J. Fish. Aquat. Sci. 45: 492-501.

Trautman, M. B. 1981 The Fishes of Ohio. Revised Ed. The Ohio State University Press, Columbus, OH.