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

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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 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.

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), 10-km tributary of the Olentangy River in central Ohio with a watershed of about 25 km². 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

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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 Voll 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 km²). 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**

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>1940</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herring</td>
<td><em>Dorosoma cepedianum</em>, gizzard shad</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Minnows</td>
<td><em>Campostoma anomalum</em>, stonercoller</td>
<td>39</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td><em>Cyprinella sphyoptera</em>, spotfin shiner</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Cyprinus carpio</em>, carp</td>
<td></td>
<td>41</td>
</tr>
<tr>
<td></td>
<td><em>Lepomis chryscephalus</em>, striped shiner</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Lepomysis umbratilis</em>, redfin shiner</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Notomisurus crysoleucus</em>, golden shiner</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><em>Notropis hussatus</em>, silverjaw minnow</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><em>Notropis photea</em>, silver shiner</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Notropis rubellus</em>, rosyface shiner</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Notropis stramineus</em>, sand shiner</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Pinephiles notatus</em>, bluntnose minnow</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td></td>
<td><em>Pinephiles promelas</em>, leafhead minnow</td>
<td></td>
<td>189</td>
</tr>
<tr>
<td></td>
<td><em>Semotilus arstraculatus</em>, creek chub</td>
<td>8</td>
<td>1,375</td>
</tr>
<tr>
<td>Suckers</td>
<td><em>Catostomus commersonii</em>, white sucker</td>
<td>21</td>
<td>378</td>
</tr>
<tr>
<td></td>
<td><em>Hypentelium nigricum</em>, northern hog sucker</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td><em>Moxostoma erythraum</em>, golden redhorse</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Catfishes</td>
<td><em>Ameurus melas</em>, black bullhead</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Ameurus natalis</em>, yellow bullhead</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Pikes</td>
<td><em>Esox americanus</em>, grass pickerel</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Killifishes</td>
<td><em>Fundulus notatus</em>, blackstripe topminnow</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Silversides</td>
<td><em>Lepidesthes sicculus</em>, brook silverside</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Sunfishes</td>
<td><em>Lepomis cyanellus</em>, green sunfish</td>
<td></td>
<td>359</td>
</tr>
<tr>
<td></td>
<td><em>Lepomis macrochirius</em>, bluegill</td>
<td></td>
<td>218</td>
</tr>
<tr>
<td></td>
<td><em>L. cyanellus x L. macrochirius</em> hybrid</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td><em>Micropterus dolomieu</em>, smallmouth bass</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Micropterus salmoides</em>, largemouth bass</td>
<td>3</td>
<td>66</td>
</tr>
<tr>
<td>Perches</td>
<td><em>Etheostoma blennioides</em>, greenside darter</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td><em>Etheostoma caeruleum</em>, rainbow darter</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Etheostoma fishiellare</em>, fantail darter</td>
<td></td>
<td>67</td>
</tr>
<tr>
<td></td>
<td><em>Etheostoma nigra</em>, johnny darter</td>
<td>21</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td><em>Etheostoma spectabile</em>, orangenthroat darter</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total number of individuals</td>
<td>319</td>
<td>3,003</td>
<td></td>
</tr>
</tbody>
</table>

²For the 1940 data, the numbers are the number of individuals retained by the collectors.
³For the 1992 data, the numbers are the total number of individuals caught.
⁴Species represent categories into which species are placed by the Ohio EPA in their metrics (numbers correspond to Table 1): 5 = 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.
⁵Bailey (1940) lists *Notropis cornutus*, but given the change in taxonomy (prior to 1984, the striped shiner was classified as a subspecies of *Notropis cornutus*) and Trauman's (1981) range maps, the fish were most likely *Lepomis chryscephalus* as listed here.
disturbances based on the assumption that most species of 
indicators high water quality and the absence of chemical 
modifications we tried. 
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approach alternative metrics are best used in any given 
what appear to be problem areas in calculating IBIs. Most 
Angermeier and Schlosser 1987, Hughes and Gammon 
years. Still, because so many workers have suggested 
irregularly. Further problems exist due to uncertainty 
produce ambiguous information because the tolerances of 
perturbations can be devised. As it is now, some metrics 
habitat degradation so that metrics specific to particular 
Modification of IBI 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).

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 
cyprinid species 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 Dela-
ware 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 
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.
**A - numeric metrics**

<table>
<thead>
<tr>
<th>Species</th>
<th>1940</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Species</td>
<td>25.0</td>
<td>22.5</td>
</tr>
<tr>
<td>Darter Species</td>
<td>20.0</td>
<td>17.5</td>
</tr>
<tr>
<td>Headwater Minnow Species</td>
<td>15.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Sensitive Species</td>
<td>10.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Lithophilic Species</td>
<td>5.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**B - percentage metrics**

<table>
<thead>
<tr>
<th>Category</th>
<th>1940</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tolerant Individuals</td>
<td>80.0</td>
<td>72.0</td>
</tr>
<tr>
<td>Omnivores</td>
<td>72.0</td>
<td>64.0</td>
</tr>
<tr>
<td>Insectivores</td>
<td>56.0</td>
<td>48.0</td>
</tr>
<tr>
<td>Pioneering Individuals</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Diseased Individuals</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

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.*
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 Lox 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.

**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

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**Table 3**


<table>
<thead>
<tr>
<th>Metric</th>
<th>1940 scores</th>
<th>1992 scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ohio EPA 5 (modified)</td>
<td>Ohio EPA (modified)</td>
</tr>
<tr>
<td>1</td>
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<td>2</td>
</tr>
<tr>
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<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6^a</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
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<td>1</td>
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<td>10</td>
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<td>3</td>
</tr>
<tr>
<td>11</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>12^a</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

^aMetrics are numbered as in Table 1.
^bScore based on using Ohio EPA's (1988) metrics and scoring.
^cScore based on modified metrics discussed in the text.
^dIn 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.
^eBailey (1940) noted no such fishes; we followed the example of Karr et al. (1987) and assigned a score of 5 for this metric historically.

**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 Oleniagany 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 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.

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