Bull. N.J. Acad. Sci., 45(1), pp. 1–12.

Evaluating Temporal Changes in Stream Condition in Three New Jersey River Basins by Using an Index of Biotic Integrity

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Abstract. *An index of biotic integrity (IBI) modified for New Jersey streams was used to compare changes in stream condition from the 1970s to the 1990s in the Delaware, Passaic, and Raritan River Basins. Stream condition was assessed at 88 sampling locations. Mean IBI score for all basins increased from the 1970s to the 1990s, but the stream-condition category improved (from fair to good) only for the Delaware River Basin. The number of benthic insectivores and the proportion of insectivorous cyprinids increased in all three basins; however, the number of white suckers decreased significantly only in the Delaware River Basin. Results of linear-regression analysis indicate a significant correlation between the percentage of altered land in the basin and change in IBI score (1970s to 1990s) for Delaware River sites.*

Results of analysis of variance of the rank-transformed IBI scores for the 1970s and 1990s indicate that the stream condition among the three basins was equal in the 1970s. Results of a multiple-comparison test demonstrated that the 1990s IBI values for the Delaware River Basin differed significantly from those for the Passaic and Raritan River Basins.

Many factors, such as the imposition of more stringent standards on wastewater and industrial discharges during the 1980s and changes in land-use practices, likely contributed to the change in the Delaware River Basin. A general increase in IBI values for the Passaic, Raritan, and Delaware River Basins over the past 25 years appears to reflect overall improvements in water quality.

Key Words: Index of Biotic Integrity, IBI, Fish communities, Stream condition

INTRODUCTION

The Water Pollution Control Act of 1966, the Federal Water Pollution Control Act Amendments of 1972, and the Clean Water Act of 1977 require states to restore and maintain the quality and biotic integrity of surface-water bodies (Karr et al., 1986). This requirement, which is administered by the U.S. Environmental Protection Agency (USEPA), has provided state water-resource managers with the incentive to include biological community assessments in water-quality-monitoring efforts. Karr et al. (1986) devised the Index of Biotic Integrity (IBI) to provide federal, state, and local agencies with a reliable and cost-effective framework for assessing water-resource quality.

The IBI is an indicator of fish community characteristics derived from measures of species composition and ecological structure that can be used to evaluate changes in stream condition (Karr, 1981). Fish are ideal indicators of changes in watersheds because they are (1) sensitive to a wide variety of stresses (Fausch et al., 1990), (2) dependent on suitable water-quality conditions throughout their lives (Gatz and Harig, 1993), (3) subject to adverse effects associated with modifications in habitat and prey base (Karr, 1981), (4) long-lived, and therefore can integrate cumulative changes in the environment through changes in reproduction and life history (Karr et al., 1986; Harris, 1995), and (5) widely recognized for their important economic and aesthetic value (Fausch et al., 1990).

The IBI was developed as an assessment tool to identify changes in biotic integrity resulting from anthropogenic factors (Karr et al., 1987; Fausch et al., 1990). In New Jersey, these factors include changes in land use (e.g., reductions in areas of forest and agricultural land, and urban development) and extensive population growth. Urbanization has been defined as an increase in human habitation, combined with increased per capita energy consumption and extensive modification of the landscape (McDonnell and Pickett, 1990). Changes in the landscape, especially urbanization, are known to affect aquatic communities (e.g., Wang et al., 1997; Scott et al., 1986; Klein, 1979). Influences of land-use activities on stream ecosystems is typically concentrated at the terrestrial-aquatic interface (Schlosser, 1991). Any alterations at this interface can result in a change in fish diversity, a shift in fish trophic structure, and an increase in temporal variability of fish abundance in stream ecosystems. Consequently, the proportion of tolerant fish species increases as landscapes are modified; these changed fish communities are highly vulnerable to other threats, such as population fragmentation and invasion by exotic species (Allan and Flecker, 1993).

Because fish communities respond to environmental changes, it is possible to assess both past and present conditions in a watershed by examining the fish fauna. The IBI has been found to detect effects of many types of anthropogenic processes, including wastewater discharges, channelization, and agricultural runoff (Fausch et al., 1990). The IBI consistently ranks sites relative to level of environmental degradation and can be a more sensitive ecological measure of stream condition than those derived by using other methods (Karr et al., 1987). Few studies to-date have assessed temporal changes in stream condition by using an IBI (see Bramblett and Fausch, 1991; Gatz and Harig, 1993). This paper compares changes in stream condition from the 1970s (1968–80) to the 1990s (1990–95) in three basins in New Jersey by using a modified IBI. The results of this analysis will aid in the design of future biomonitoring efforts and help identify areas of New Jersey where stream condition has changed significantly.

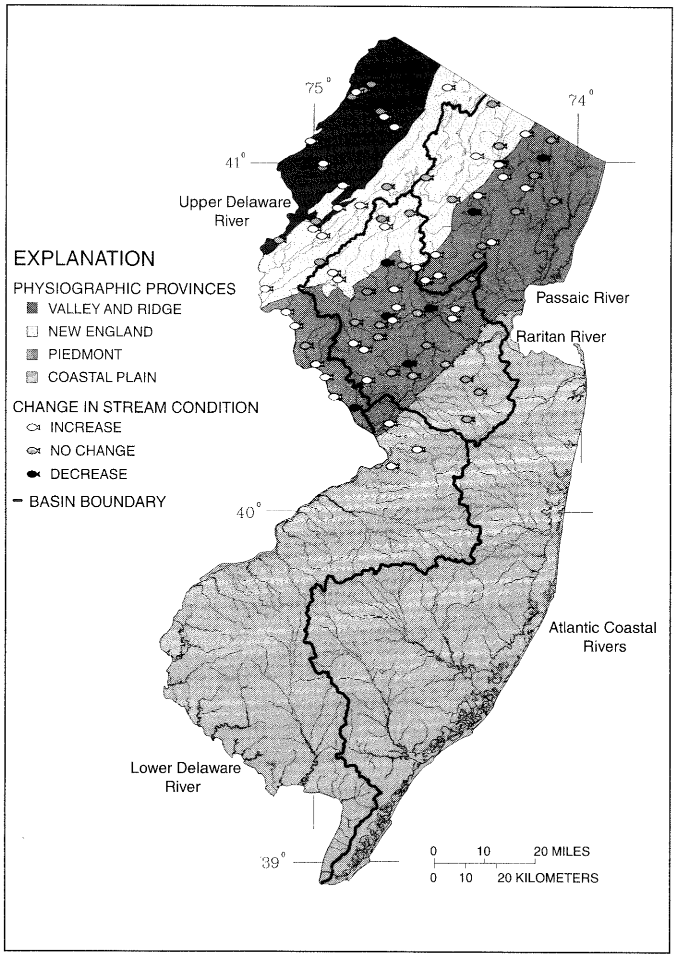

Fig. 1. Change in stream condition from the 1970s to the 1990s at fish-sampling sites in major New Jersey drainage basins. (Sites are labeled as "increase" if condition category improved, "no change" if condition category remained the same, and "decrease" if condition category worsened.)

Study Area

The principal basins assessed in this study are the Raritan and those parts of the Delaware and Passaic River Basins that lie in New Jersey (Fig. 1). These three systems are biologically diverse and differ with respect to geologic characteristics, water resources, and land use, population, and other anthropogenic modifications.

Delaware River Basin

The Delaware River is the largest of the three major basins in New Jersey. It drains an area of 12,765 mi^2, with approximately 2,345 mi^2 within New Jersey's boundaries (Anderson and Faust, 1973). In New Jersey, the Delaware River flows through four physiographic provinces; from north to south, they are the Valley and Ridge, New England, Piedmont, and Coastal Plain (Fig. 1). This river is used as a source of potable and industrial water supply and also supports extensive recreational use (Delaware River Basin Commission, 1992). Land use in the Delaware River Basin is largely agriculture and forest, with moderate residential and commercial development (New Jersey Department of Environmental Protection, 1993; Kennen, 1998).

Historically, the Delaware River Basin and some of its tributaries were used to dispose of sewage and industrial discharge. In 1967, stricter water-quality standards were imposed that required a minimum of secondary treatment of all wastes before discharge into the Delaware River (Patrick et al., 1992). In the 1970s, water quality in the Delaware River Basin was generally "good," with most of the river meeting the federal fishable, but not swimmable, standards (U.S. Environmental Protection Agency and New Jersey Department of Environmental Protection, 1979). Sewage-treatment-facility upgrades in New Jersey and Pennsylvania in the early 1980s led to improved compliance with the new standards.

With the increased access to more remote areas provided by interstate highways, human population in the upper part of the Delaware River Basin is continuing to grow rapidly. The effects of population growth, land development, and recreational use on water quality are a major concern (Delaware River Basin Commission, 1996).

Passaic River Basin

The drainage area of the Passaic River Basin is 935 mi^2, with 787 mi^2 in northeastern New Jersey and the remaining 148 mi^2 in southern New York State. The basin drains two physiographic provinces, the New England and the Piedmont (Fig. 1). The New England physiographic province is largely forested, except for some scattered farmland and urban areas. The Piedmont contains many densely populated and industrialized areas (New Jersey Department of Environmental Protection, 1987a).

Water quality in the Passaic River deteriorated from 1945 to 1970 mainly as a result of human activity (New Jersey Department of Environmental Protection, 1987a). This basin is one of the most urbanized basins in New Jersey and its waters are used more extensively than those of any other basin (Anderson and Faust, 1973). The Passaic River Basin serves not only as a major supply of potable water but also as a channel for wastewater discharge. From the 1960s to the 1970s, the Passaic River was described as one of the most contaminated streams in the United States (Anderson and Faust, 1973). Even with improvements in wastewater treatment beginning in the early 1970s, excessive demands are still being placed on the assimilation capacity of the river (New Jersey Department of Environmental Protection, 1987a). In the early 1990s, water quality in the Passaic River Basin generally was fair to good (New Jersey Department of Environmental Protection, 1995).

Raritan River Basin

The Raritan River Basin (1,100 mi^2) is the largest basin entirely within New Jersey (Fig. 1). It contains five major subbasins whose tributaries feed into the main stem before discharging into the Raritan Bay (New Jersey Department of Environmental Protection, 1976). Land use is primarily agricultural in the southern part of the basin; rural, forested, agricultural, and scattered commercial/residential in the northern part; and mostly urban/suburban with scattered industrial and commercial centers along the main stem of the Raritan River (New Jersey Department of Environmental Protection, 1993).

In the 1970s, the Raritan River was used mainly for public and industrial supply and the disposal of municipal and industrial wastewater (Anderson and Faust, 1975). Water quality in the 1970s was reported to be good, primarily as a consequence of dilution by upstream reservoir releases during low flow (Anderson and Faust, 1975). In the late 1980s, a large part of the basin was still affected by point-source discharges from water-treatment facilities (New Jersey Department of Environmental Protection, 1987a). From 1920 to 1970, dissolved-oxygen concentrations and biochemical oxygen demand in the lower Raritan River Basin generally reflected a deterioration of water quality through time (Anderson and Faust, 1975). In the early 1990s, water quality in the Raritan Basin was fair to good (New Jersey Department of Environmental Protection, 1995).

MATERIALS AND METHODS

Index of Biotic Integrity

A modified IBI for assessing regional differences in fish communities was developed for use in New Jersey streams (Kurtenbach, 1993). The IBI is an improvement over former bioassessment tools, because it incorporates several different community characteristics to reflect stream conditions. It is a quantitative measure that can be used to distinguish among a range of conditions (poor through excellent), preserves the integrity of the data, and incorporates professional judgment (Miller et al., 1988). Although Karr's (1981) original IBI was designed for use in warmwater systems in the Midwest, many regional applications have been presented (e.g., Fausch et al., 1984; Miller et al., 1988; Halliwell et al., 1999).

Like most biomonitoring tools, the IBI is based on the premise that pristine systems have biological characteristics that can be accurately measured and that departure from these characteristics is directly related to the severity of degradation (Fausch et al., 1990; Bramblett and Fausch, 1991). The IBI used to assess New Jersey streams consists of 10 metrics that retained many of Karr's standard components, including species richness and composition, trophic composition, and fish abundance and condition (Table 1). Metrics are compared for each site and assigned a value, based on scoring criteria, that ranges from 1 to 5, with 5 representing little or no deviation expected from an unimpaired reference site. Scores assigned to each metric are summed to produce an IBI value that ranges from 10 to 50. For New Jersey streams, the IBI value is assigned a condition category according to the following qualitative scale: excellent (44–50), good (37–43), fair (29–36), or poor (10–28). Additional information on the development of the New Jersey IBI can be found in Kurtenbach (1993).

Data-Base Development and Site Comparison

A data base was compiled from results of analyses of fish samples collected at 155 sites by the USEPA (1990–95) and 566 sites by the NJDEP (1969–80). All 566 NJDEP fish-collection sites were located on USGS 1:24,000-scale topographic maps and digitally referenced with a geographic information system (GIS) to create an ARC/INFO[1]-based point coverage (Environmental Systems Research Institute, 1992). A digital point coverage also was created for all USEPA sites, which were located by using global positioning system (GPS) units. The goal of this GIS approach was to locate historical NJDEP fish-collection sites that directly overlap recent USEPA fish-collection sites. The term "mirror site" refers to a USEPA sampling site (1990s data) on the same stream reach or at the same location as an NJDEP site (1970s data). This assessment resulted in an overlap of 88 sampling sites—24 in the Passaic River Basin and 32 each in the Raritan and Delaware River Basins. IBI scores for the 1970s and the 1990s were compared at mirror sites. A New Jersey IBI based on 10 metrics outlined by the USEPA was calculated for all mirror sites (Kurtenbach, 1993) and mean IBI scores were calculated for each basin.

Because the incidence of disease and anomalies was not recorded as part of the 1970s assessments, the highest possible IBI score for these sites was 45 rather than 50. Karr et al. (1986) suggested a conservative method of assigning a score of 5 for these sites. This approach, however, may inflate site quality at degraded locations. Instead, the method proposed by Bramblett and Fausch (1991), which uses a multiplicative factor to adjust the IBI score in situations where anomaly information is unavailable, was applied. Therefore, all 1970s IBI scores were multiplied by a factor of 1.11 to adjust for the difference in number of integrity classes. This enabled us to use the 50-point IBI scale devised by Kurtenbach (1993) to directly compare 1970s and 1990s assessments.

To improve the sensitivity of the New Jersey IBI, certain fish species are excluded from metric criteria (Table 1). Trout are excluded from the total number of fish species metric because their presence or absence in many streams may not accurately represent true population status due to stocking and angling practices. However, because many trout species are extremely sensitive to habitat degradation, native and naturally-produced fish (non-stocked) are a preferred indicator and are used in calculation of the number of trout or sunfish metric. Sunfish are substituted in the absence of trout because in some aquatic systems, both share a similar ecological niche. American eels *(Angullia rostrata)* were excluded from the percent composition metrics because they are ubiquitous throughout various water quality and habitat conditions in New Jersey, therefore limiting their use as an aquatic indicator (Kurtenbach, 1993).

Determination of Land Use and Population

Total areas of urban, forested, and agricultural land and total population upstream from each sampling site in the 1970s and the 1990s were obtained by using a spatial GIS model. This model was based on an infrastructure of more than 7,200 stream reaches in New Jersey developed by using 1:250,000-scale digital-elevation models (White et al., 1992). The 1970s land-use categories for the model were acquired from digitized high-altitude aerial photographs taken in the 1970s (Fegeas et al., 1983). Population estimates were obtained from the 1980 Census of Population and Housing (Lanfear, 1993). The 1990s land-use information was acquired through an integration of Landsat Thematic Mapper data for August 1985 (computerized data file available at the U.S. Geological Survey, West Trenton, N.J.) and level I Anderson classifications of 1:250,000-scale land-use data (Fegeas et al., 1983). Current population estimates were derived from data from the U.S. Bureau of the Census (1991). The minimum mapping unit for these assessments ranged from 4 to 16 hectares depending on land-use category (Anderson et al., 1976).

Fish-Community Assessment

Fish samples were collected by the NJDEP, Bureau of Freshwater Fisheries, from 1968 to 1980, and by the USEPA from 1990 to 1995. Samples typically were collected from June to October throughout

[1]The use of trade names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

stable, low-flow periods. Stream-reach lengths averaged 180 m and 150 m for the NJDEP and USEPA fish samples, respectively. Each stream reach was electrofished in an upstream direction by using pulsed direct current (DC) output. Electrofishing equipment used during sampling depended on stream size. Small streams (first and second order) were electrofished by using a pulsed DC backpack unit; medium-sized streams (third and fourth order) were sampled by using a longline streambank generator and pulsator (USEPA) or a towed barge (NJDEP). In large (non-wadeable) streams (fifth order or greater), fish were sampled by using a boat-mounted electrofishing unit (Kurtenbach, 1993). Stream order, a measure of the position of a stream in a hierarchy of tributaries (Strahler, 1957), was determined from USGS 1:24,000-scale topographic maps.

Stunned fish were netted immediately and placed in holding tanks along the stream reach. Sampling effort was measured as a function of total power applied to the electrodes and typically ranged from 1,400 to 3,800 shocking seconds, depending on stream size and reach length (Reynolds, 1996). Fish were identified to the species level, counted, and released. The USEPA also examined all fish externally for disease and anomalies (except black spot disease). Reference specimens of unknown or difficult-to-identify species (e.g., *Notropis* spp.) were retained for laboratory identification using regional taxonomic keys (Stiles, 1978; Smith, 1985). Chemical, physical, and habitat assessments also were made in conjunction with fish collection at all USEPA sampling sites. These assessments were used later to develop an independent measure of water quality and habitat condition that assisted in IBI calibration (Kurtenbach, 1993).

Statistical Analysis

A standard two-tailed t-test (Zar, 1984) was used to determine whether differences exist between 1970s and 1990s mean IBI scores. In addition, all individual metrics that comprise the New Jersey IBI except metric 10 (proportion of individuals with disease and anomalies) were statistically compared (Table 1). Linear-regression analysis was used to examine relations between land-use variables, population variables, and biotic integrity for 1970s and 1990s data (relations observed included percentage of land use to change in IBI score, population density to IBI score, and percentage of altered land to change in IBI score). To further examine the effect of land use on biotic integrity, total altered land (the percentage of urban and agricultural land combined) was regressed against change in biotic integrity from 1970s to 1990s data. Statistical analyses were considered significant if $p<0.05$.

One-way non-parametric analysis of variance (ANOVA) on the 1970s and 1990s rank- transformed IBI scores was used to determine whether the mean ranked scores differed among the three major basins for each assessment. The null hypothesis (H_0) states that the mean ranked IBI scores are the same among all three basins. The alternative hypothesis (H_1) states that at least one inequality exists among the mean ranked IBI scores. If the null hypothesis proved false, then Tukey's honestly significant difference test (Tukey's test) was used to determine which mean IBI rank differed. Tukey groups are represented by letters A and B. The letter A represents the basin with the highest mean ranked condition score and the letter B represents a basin with a lower ranked score. Basins with the same letters did not differ significantly from one another (Helsel and Hirsch, 1992). All null-hypothesis testing was performed at the 95-percent confidence level ($\alpha = 0.05$).

Limitations

The comparison of IBI values for the 1970s and 1990s is associated with some uncertainty. The results of these comparisons could reflect other factors in addition to changes in biotic integrity. Comparability of fish assessments in this study could be affected by sampling period, reach length, sampling procedure and gear, and the accuracy of historical fish-species identification (Gatz and Harig, 1993). Despite these limitations, which are examined further below, the IBI comparisons are considered to be a reasonable method of

Table 1. Statistical summary of mean metric values for 1970s and 1990s fish collections in the Delaware, Passaic, and Raritan River Basins (1968–95) [*p*-value is derived from a standard two-tailed t-test; n, number of sites; NS, not significant; —, insufficient data to calculate test statistics]

Metrics	Delaware River Basin (n=32)			Passaic River Basin (n=24)			Raritan River Basin (n=32)		
	1970s	1990s	*p* value[1]	1970s	1990s	*p* value[1]	1970s	1990s	*p* value[1]
Abundance Metrics									
Total number of fish species[2]	9.53	12.09	0.002	9.46	10.75	NS	9.75	11.97	0.036
Number of benthic insectivorous species	3.47	4.56	0.007	2.88	3.71	0.041	2.56	3.69	0.001
Number of trout (non-stocked)	1.00	0.66	NS	0.42	0.75	NS	0.47	0.34	NS
or Number of sunfish species[3]	2.19	2.72	NS	2.71	3.20	NS	2.84	3.19	NS
Number of intolerant species	1.50	1.63	NS	0.67	1.21	NS	0.59	0.50	NS
Number of individuals in the sample	195.25	226.69	NS	140.08	193.96	NS	162.16	200.53	NS
Percent Composition Metrics									
Proportion of individuals as omnivores	5.26	4.69	NS	9.25	9.56	NS	6.81	5.87	NS
Proportion of individuals as white suckers	16.14	10.76	0.017	23.92	15.93	NS	14.95	10.98	NS
Proportion of individuals as insectivorous cyprinids	32.50	42.54	NS	19.61	33.76	0.047	29.42	32.50	NS
Proportion of individuals as piscivores[4]	7.42	7.92	NS	7.32	12.73	NS	10.14	6.57	NS
Proportion of individuals with disease and anomalies	0.00	0.03	—	0.00	0.69	—	0.00	0.02	—
Mean Index of Biotic Integrity Score	34	40	0.000	30	35	0.003	33	36	0.005

[1] Significance level was set at p<0.05 [2] Excludes trout [3] In the absence of trout, the sunfish metric is used [4] Excludes American eel

Table 2. Index of biotic integrity scores and condition category for mirror sites in the Delaware River Basin, New Jersey, 1970s and 1990s.
[ID is the site identification reference used in the New Jersey Department of Environmental Protection (1970s) and the U.S. Environmental Protection Agency (1990s) data bases; sites at which condition category increased are in **bold**]

Sampling Site	1970s				1990s			
	ID	Year	IBI Score	Condition Category	ID	Year	IBI Score	Condition Category
Big Flatbrook at Stokes South Forest	F0271	1968	39	Good	D09A	1990	40	Good
Big Flatbrook at Camp Olympia	F0273	1968	39	Good	D09B	1990	38	Good
Big Flatbrook at Sandyston	F0275	1970	37	Good	D09C	1990	42	Good
Pohatcong Creek at Washington	**F0407**	**1970**	**34**	**Fair**	**D73A**	**1993**	**42**	**Good**
Dry Brook at Branchville	F0352	1970	39	Good	D27	1994	34	Fair
Blair Creek at Blairstown	**F0348**	**1970**	**39**	**Good**	**D13**	**1991**	**44**	**Excellent**
Hakikokake Creek at Alexandria	**F0237**	**1970**	**21**	**Poor**	**D34A**	**1992**	**44**	**Excellent**
Blacks Bacon Creek at Bordentown	**F0459**	**1975**	**32**	**Fair**	**D12**	**1995**	**40**	**Good**
Bear Creek at Allamuchy	**F0375**	**1970**	**32**	**Fair**	**D06B**	**1991**	**38**	**Good**
Moore Creek at Hopewell	**F0254**	**1970**	**34**	**Fair**	**D54**	**1995**	**38**	**Good**
Alexauken Creek at West Amwell	**F0236**	**1970**	**37**	**Good**	**D01**	**1993**	**44**	**Excellent**
Nishisakawick Creek at Alexandria	**F0243**	**1970**	**39**	**Good**	**D58**	**1992**	**48**	**Excellent**
Wickecheoke Creek at Delaware	**F0248**	**1970**	**32**	**Fair**	**D96**	**1991**	**40**	**Good**
Buckhorn Creek at Harmony	F0261	1970	37	Good	D15	1994	38	Good
Furnace Brook at Oxford	F0380	1970	28	Poor	D31B	1990	24	Poor
Pequest River at Independence	**F0389**	**1970**	**23**	**Poor**	**D69A**	**1991**	**30**	**Fair**
Paulinskill River at Blairstown	F0359	1970	37	Good	D65B	1993	42	Good
Furnace Brook at Oxford (Site 2)	**F0381**	**1971**	**30**	**Fair**	**D31A**	**1990**	**40**	**Good**
Culvers Brook at Frankford	F0351	1968	39	Good	D22	1995	38	Good
Pauliuskill River at Frankford	**F0358**	**1968**	**34**	**Fair**	**D65A**	**1993**	**40**	**Good**
Lockatong Creek at Alexandria	F0242	1970	43	Good	D42	1991	40	Good
Doctors Creek at Upper Freehold	**F0232**	**1971**	**28**	**Poor**	**D25A**	**1991**	**36**	**Fair**
Pauliuskill River at Lafayette	**F0360**	**1970**	**34**	**Fair**	**D65C**	**1995**	**44**	**Excellent**
Van Campens Brook at Pahaquarry	**F0269**	**1968**	**39**	**Good**	**D90A**	**1991**	**48**	**Excellent**
Jacobs Creek at Hopewell	F0253	1972	37	Good	D39	1994	34	Fair
Musconetcong River at Lebanon	F0328	1970	39	Good	D55B	1995	38	Good
Musconetcong River at Mount Olive	**F0327**	**1970**	**28**	**Poor**	**D55A**	**1991**	**38**	**Good**
Lubbers Run at Byram	F0322	1970	37	Good	D44	1995	40	Good
Black Creek at Vernon	**F0395**	**1970**	**23**	**Poor**	**D10**	**1993**	**34**	**Fair**
Little Flatbrook at Layton	**F0276**	**1968**	**41**	**Good**	**D41B**	**1995**	**46**	**Excellent**
Miry Run at Hamilton	**F0220**	**1971**	**23**	**Poor**	**D52**	**1995**	**38**	**Good**
Pohatcong Creek at Pohatcong	**F0409**	**1970**	**26**	**Poor**	**D73B**	**1995**	**44**	**Excellent**
AVERAGE		**1970**	**34**	**Fair**		**1993**	**40**	**Good**

exploring temporal changes in stream condition.

Differences in sampling period between 1970s and 1990s assessments may affect the relative abundances of certain fish species. Karr et al. (1987) state that samples collected during summer can produce higher IBI values than those collected during late spring or early summer. In New Jersey streams, spawning season for resident fishes normally is early spring. Similarly, movement and spawning of migratory fishes (e.g., white suckers) typically is complete by late spring. The resulting young-of-the-year (YOY) would not affect any of the species-composition metrics; however, the relative abundance of some species could change during these periods (Karr et al., 1987), and samples collected during these periods could be biased if YOY individuals are overrepresented in the sample. To reduce the possibility of bias associated with high abundances of YOY individuals, only fish longer than 20 mm were included in the IBI calculations. Thus, it is unlikely that the number of YOY individuals could have significantly altered the calculated IBI scores. In addition, no sampling periods compared differed by more than 3 months and most sampling occurred within the summer-fall season (June-October). All samples were collected during normal and low flow periods, never during conditions of high turbidity or atypical flow.

Sampling protocols designed for IBI assessments indicate that stream size should determine sampling distance (Kurtenbach, 1993). For wadeable streams (first through fourth order), a sampling distance of 150 to 200 m was used to obtain the most representative sample. Stream reaches sampled by the USEPA were required to have a minimum of one riffle, run, and pool sequence. Although the average length of a sampling reach for the NJDEP was 180 m as compared to 150 m for the USEPA, this difference is unlikely to significantly affect IBI score. Both agencies collected samples from the minimum number of geomorphic channel units in a reach and, thus, collected a representative fish sample.

Sampling gear and fish behavior can affect the accuracy of IBI data (Karr et al., 1986). Gear should be able to collect all species in proportion to their relative abundance (Karr et al., 1986). Certain species are difficult to catch with standard electrofishing gear. In addition, some species are sampled more easily at night or by disturbance of the substrate (Karr et al., 1987). Because electrofishing gear and protocol used by both agencies were comparable, the samples are unlikely to be biased. Thus, the proportion of fish collected for the 1970s and 1990s assessments are considered to be equally representative of the proportions present in the stream during sampling.

The accuracy of historical data commonly is tenuous because the purpose for which the data originally were collected may dictate their applicability (Karr et al., 1986). Unrecorded anomaly information and misidentification of fish species may account for some minor differences found between 1970s and 1990s assessments. Differences in assessments associated with anomaly data were addressed previously. In addition, any apparent discrepancies in species identification in the 1970s data were reevaluated by examining distribution records and updated to current taxonomic status by using Robins et al. (1991).

RESULTS

Changes in Biotic Integrity

IBI scores in all basins generally increased from the 1970s to the 1990s. Scores increased at least one condition category (e.g., from poor to fair, or from fair to good) for 20, 10, and 11 sites in the Delaware, Passaic, and Raritan River Basins, respectively (Tables 2, 3, and 4). No change in level of condition was found at 10 sites in the Delaware, 11 sites in the Passaic, and 15 sites in the Raritan River Basin. Scores at two sites in the Delaware, three sites in the Passaic, and six sites in the Raritan River Basin decreased at least one condition category (Tables 2, 3, and 4).

Mean IBI score in the Passaic River Basin increased from 30 (fair) to 35 (fair) (Table 1). Although the condition category did not change, the difference in mean IBI score is statistically significant (Table 1; $p<0.003$). Mean score in the Raritan River Basin increased from 33 (fair) to 36 (fair); this was not a category improvement, but was within one point of a condition-category increase. This difference in mean condition score also is statistically significant (Table 1; $p<0.005$). The Delaware River Basin showed the greatest improvement in mean score, increasing across one category boundary from 34 (fair) to 40 (good) (Table 1; $p<0.0001$). Mean IBI scores provide evidence that stream conditions in the Delaware, Passaic, and Raritan Rivers improved from the 1970s to the 1990s.

Results of ANOVA indicate that the mean level of stream condition in the three drainage areas in the 1990s was not equal ($p<0.001$). Results of the Tukey's test demonstrated that the level of stream condition in the Delaware River Basin differed significantly from that in the Passaic and Raritan River Basins (Fig. 2). Stream condition did not differ significantly between the Passaic and Raritan Basins, and these two basins had a higher probability of reflecting an impaired stream condition than the Delaware River Basin. No difference in mean level of stream condition was found among the basins for the 1970s data.

A significant positive correlation was found between the percentage of altered land and the change in IBI score (1970s to 1990s) for the Delaware River Basin ($p<0.031$). In the Raritan River Basin, a significant negative correlation between population density and IBI score was found for both the 1970s and 1990s data ($p<0.012$ and $p<0.046$ respectively). No significant correlations were found between basin characteristics and IBI score in the Passaic River Basin.

Differences in Fish Community

In the 1970s, white suckers comprised the greatest percentage of the fish community in the Delaware, Passaic, and Raritan River Basins (18, 23, and 14 percent, respectively; Table 5), and blacknose dace *(Rhinichthys atratulus)* was the second most abundant species in the three river basins (16, 9, and 12 percent, respectively; Table 5). In contrast, during the 1990s, blacknose dace was the most abundant species in the Delaware, Passaic, and Raritan River Basins, comprising 27, 19, and 13 percent of the fish community, respectively (Table 5). White sucker was the second most abundant species in the Passaic and Raritan River Basins (17 and 13 percent, respectively); however, the American eel *(Angullia rostrata)* was the second most abundant species in the Delaware River Basin (12 percent) (Table 5).

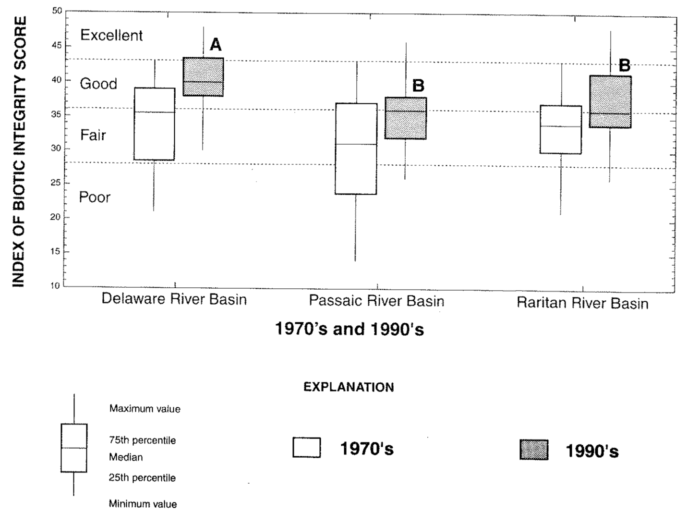

Fig. 2. Statistical distributions of index of biotic integrity scores for drainage basins in New Jersey and results of Tukey's test. (Results of Tukey's test are reported as letters A and B; drainage basins that have letters in common do not differ significantly; dotted lines indicate approximate divisions between condition categories, which range from poor to excellent)

The mean number of individuals and species captured increased from the 1970s to the 1990s (Table 1). The number of benthic insectivores increased significantly and the proportion of white suckers and omnivores generally decreased (Table 1). The Delaware River Basin was the only basin in which the proportion of white suckers decreased significantly ($p<0.017$). The proportion of piscivores increased in the Passaic and Delaware River Basins, but decreased in the Raritan River Basin (Table 1). The proportion of insectivorous cyprinids increased in all three basins; however, only the Passaic River Basin showed a significant increase ($p<0.05$; Table 1). The mean number of intolerant species was constant from the 1970s to the 1990s (Table 1). The mean number of trout species decreased in the Delaware, increased in the Passaic, and decreased in the Raritan River Basin (Table 1). The mean number of sunfish species increased in all three basins (Table 1).

DISCUSSION

Land-use activities result in alterations in the population and community dynamics of stream fishes (Schlosser, 1991). Urbanization, channelization, wastewater effluents, and other anthropogenic disturbances are known to cause a deterioration of habitat and water quality, and can also simultaneously affect fish-species composition and abundance (Karr et al., 1987; Kemp and Spotila, 1996). Because the IBI was designed to evaluate stream condition, it can be a useful tool for monitoring long-term changes in the environment (Karr et al., 1987). The mean IBI scores for the Delaware, Passaic, and Raritan basins did increase from the 1970s to the 1990s. Many factors such as more stringent standards on wastewater and industrial discharge

Table 3. Index of biotic integrity scores and condition category for mirror sites in the Passaic River Basin, New Jersey, 1970s and 1990s
[ID is the site identification reference used in the New Jersey Department of Environmental Protection (1970s) and the U.S. Environmental Protection Agency (1990s) data bases; sites at which condition category increased are in **bold**]

Sampling Site	1970s				1990s			
	ID	Year	IBI Score	Condition Category	ID	Year	IBI Score	Condition Category
Ramapo River at Mahwah	**F0581**	**1980**	**26**	**Poor**	**P78A**	**1992**	**30**	**Fair**
Pequannock River at Kinnelon	**F0057**	**1968**	**30**	**Fair**	**P68B**	**1990**	**38**	**Good**
Pequannock River at Riverdale	**F0054**	**1968**	**23**	**Poor**	**P68A**	**1990**	**34**	**Fair**
Wanaque River at Wanaque	F0082	1968	32	Fair	P92B	1992	32	Fair
Wanaque River at Riverdale	F0603	1980	39	Good	P92C	1995	34	Fair
Wanaque River at West Milford	F0084	1968	37	Good	P92A	1991	40	Good
Passaic River at Harding	**F0050**	**1969**	**40**	**Good**	**P64F**	**1994**	**46**	**Excellent**
Rockaway River at Jefferson	F0592A	1980	43	Good	P79A	1990	40	Good
Pompton River at Pompton Plains	**F0578**	**1980**	**19**	**Poor**	**P74B**	**1993**	**32**	**Fair**
Dead River at Bernards	F0024	1969	37	Good	P23	1991	38	Good
Rockaway River at Parsippany-Troy Hills	**F0011A**	**1974**	**22**	**Poor**	**P79C**	**1992**	**36**	**Fair**
Rockaway River at Denville	F0591A	1980	34	Fair	P79D	1995	36	Fair
Harrisons Brook at Bernards	**F0033**	**1969**	**34**	**Fair**	**P36**	**1991**	**38**	**Good**
Passaic River at Passaic	**F0048**	**1969**	**19**	**Poor**	**P64E**	**1993**	**38**	**Good**
Passaic River at Chatham	F0001	1974	30	Fair	P64C	1991	36	Fair
Passaic River at Florham Park	F0002	1974	14	Poor	P64G	1995	20	Poor
Troy Brook at Troy Hills	F0081	1969	37	Good	P89	1992	36	Fair
Molly Ann Brook at Patterson	**F0567**	**1980**	**26**	**Poor**	**P53**	**1993**	**34**	**Fair**
Canoe Brook at Livingston	**F0019**	**1969**	**19**	**Poor**	**P16**	**1992**	**34**	**Fair**
Hohokus Brook at Waldwick	F0037	1968	37	Good	P37	1990	32	Fair
Saddle River at Rochelle Park	F0070	1968	32	Fair	P81C	1995	36	Fair
Peckman River at Verona	F0051	1969	26	Poor	P67	1992	26	Poor
Saddle River at Upper Saddle River	F0072	1971	43	Good	P81A	1990	38	Good
Goffle Brook at Hawthorne	F0027	1968	26	Poor	P32	1993	26	Poor
AVERAGE		**1972**	**30**	**Fair**		**1992**	**35**	**Fair**

Table 4. Index of biotic integrity scores and condition category for mirror sites in the Raritan River Basin, New Jersey, 1970s and 1990s
[ID is the site identification reference used in the New Jersey Department of Environmental Protection (1970s) and the U.S. Environmental Protection Agency (1990's) data bases; sites at which condition category increased in **bold**]

Sampling Site	1970s				1990s			
	ID	Year	IBI Score	Condition Category	ID	Year	IBI Score	Condition Category
Spruce Run Creek at Lebanon	**F0203**	**1971**	**28**	**Poor**	**R86**	**1991**	**42**	**Good**
Stony Brook at Hopewell	**F0204**	**1969**	**33**	**Fair**	**R87A**	**1992**	**40**	**Good**
Pleasant Run at Readington	F0178	1969	43	Good	R72	1994	36	Fair
Neshanic River at Hillsborough	F0097	1974	30	Fair	R57A	1993	36	Fair
Neshanic River at Raritan	**F0171**	**1969**	**34**	**Fair**	**R57B**	**1993**	**38**	**Good**
Bedens Brook at Montgomery	F0112	1969	37	Good	R08C	1995	36	Fair
Bedens Brook at Skilman	F0113	1969	37	Good	R08A	1991	42	Good
Millstone River at Manalapan	F0167	1969	34	Fair	R50C	1993	30	Fair
South Branch Raritan River at Branchburg	F0105	1974	37	Good	R84E	1995	32	Fair
South Branch Raritan River at Raritan	F0186	1970	37	Good	R84F	1995	42	Good
Manalapan Brook at Monroe	F0158	1969	14	Poor	R45	1995	26	Poor
Holland Brook at Readington	F0144	1969	43	Good	R38	1991	36	Fair
Back Brook at Vanliews Corners	**F0109**	**1969**	**30**	**Fair**	**R05**	**1995**	**38**	**Good**
S. Branch Rockaway Creek at Readington	F0197	1969	32	Fair	R85	1991	36	Fair
Oakeys Brook at South Brunswick	F0173	1969	32	Fair	R61	1994	30	Fair
Lamington River at Branchburg	**F0092**	**1973**	**34**	**Fair**	**R40A**	**1992**	**42**	**Good**
Millstone River at Princeton	F0096A	1973	34	Fair	R50A	1992	34	Fair
South Branch Raritan River at Lebanon	**F0185**	**1969**	**32**	**Fair**	**R84D**	**1993**	**42**	**Good**
Six Mile Run at Raritan	F0200	1969	34	Fair	R83	1994	34	Fair
North Branch Raritan River Bridgewater	**F0099**	**1974**	**28**	**Poor**	**R59C**	**1995**	**42**	**Good**
Lamington River at Tewksbury	F0152	1969	37	Good	R40B	1993	34	Fair
Peapack Brook at Peapach	F0174	1969	43	Good	R66	1990	42	Good
South Branch Raritan River at Washington	F0184	1969	39	Good	R84G	1990	38	Good
Mine Brook at Bernardsville	**F0168**	**1969**	**34**	**Fair**	**R51**	**1995**	**40**	**Good**
Drakes Brook at Chester	**F0128**	**1969**	**37**	**Good**	**R26A**	**1990**	**48**	**Excellent**
Matchaponix Brook at Monroe	F0159	1969	23	Poor	R46	1995	22	Poor
Green Brook at Watchung	F0140	1969	32	Fair	R33A	1991	36	Fair
Middle Brook at Bridgewater	F0162	1969	39	Good	R48	1993	36	Fair
Black River at Succasuna	F0116	1969	30	Fair	R11	1993	36	Fair
Bound Brook at Dunellen	**F0119**	**1969**	**21**	**Poor**	**R14B**	**1992**	**30**	**Fair**
Ambrose Brook at Piscataway	**F0107**	**1969**	**26**	**Poor**	**R02**	**1990**	**34**	**Fair**
Peters Brook at Bridgewater	F0176A	1969	32	Fair	R70A	1993	30	Fair
AVERAGE		1972	33	**Fair**		1992	36	**Fair**

Table 5. Ecological characteristics and abundances of fish species collected in the Delaware, Passaic, and Raritan River Basins, New Jersey, 1970s and 1990s [*, none captured; BH, benthic herbivore; BI, benthic insectivore; E, exotic; F, filter feeder; I, insectivore; IS, intolerant species; N, native; NN, non native (introduced); O, omnivore; P, piscivore; PL, planktivore; T, tolerant species (Haliwell et al., 1999; Kurtenbach, 1993)]

ORDER Family Genus & species	Common Name	Trophic Guild	Tolerance Class	Historical Presence	Delaware River Basin		Passaic River Basin		Raritan River Basin	
					1970s	1990s	1970s	1990s	1970s	1990s
PETROMYZONTIFORMES										
Petromyzontidae										
Lampetra appendix	American brook lamprey	F	IS	N	26	8	*	4	*	*
Petromyzon marinus	Sea lamprey	P	T	N	*	18	*	*	*	*
ANGUILLIFORMES										
Anguillidae										
Anguilla rostrata	American eel	P	T	N	584	854	73	68	202	774
CLUPEIFORMES										
Clupeidae										
Alosa aestivalis	Blueback herring	I	T	N	6	*	*	*	*	*
Alosa pseudoharengus	Alewife	PL	T	N			2	*	*	*
Brevoortia tyrannus	Atlantic menhaden	F	T	N	16	*	*	*	12	*
CYPRINIFORMES										
Cyprinidae										
Carassius auratus	Goldfish	O	T	E	4	*	133	*	4	*
Cyprinella analostana	Satinfin shiner	I	T	N	40	43	26	64	321	108
Cyprinella spiloptera	Spotfin shiner	I	T	N	*	*	*	*	*	29
Cyprinus carpio	Common carp	O	T	E	18	*	30	5	14	20
Exoglossum maxillingua	Cutlips minnow	BI	IS	N	164	263	73	114	39	21
Hybognathus regius	Eastern silvery minnow	BH	T	N	62	37	25	24	6	*
Luxilus cornutus	Common shiner	I	T	N	422	294	276	164	408	305
Notemigonus crysoleucas	Golden shiner	O	T	N	89	11	158	3	218	8
Notropis amoenus	Comely shiner	O	T	N	*	*	*	*	*	64
Notropis bifrenatus	Bridle shiner	I	T	N	83	*	*	*	178	*
Notropis hudsonius	Spottail shiner	I	T	N	23	54	230	331	195	345
Notropis procne	Swallowtail shiner	I	T	N	*	23	*	19	*	107
Pimephales promelas	Fathead minnow	O	T	NN	50	*	20	*	74	*
Rhinichthys atratulus	Blacknose dace	BI	T	N	1028	1949	318	863	598	849
Rhinichthys cataractae	Longnose dace	BI	T	N	414	544	132	73	97	628
Semotilus atromaculatus	Creek chub	O	T	N	208	235	110	271	161	34
Semotilus corporalis	Fallfish	O	T	N	80	186	80	53	185	167
Catostomidae										
Catostomus commersoni	White sucker	O	T	N	1107	676	830	775	741	843
Erimyzon oblongus	Creek chubsucker	O	IS	N	72	2	30	7	93	26
SILURIFORMES										
Ictaluridae										
Ameiurus catus	White catfish	P	T	N	2	*	8	*	*	*
Ameiurus natalis	Yellow bullhead	O	T	N	*	2	4	35	*	10
Ameiurus nebulosus	Brown bullhead	O	T	N	35	10	23	13	36	37
Noturus gyrinus	Tadpole madtom	BI	T	N	1	*	*	*	*	*
Noturus insignis	Margined madtom	BI	IS	N	53	34	10	8	21	7
Noturus spp.	Unidentified madtom	BI	T	N	8	2	*	*	1	*
SALMONIFORMES										
Esocidae										
Esox niger	Chain pickerel	P	T	N	4	7	11	2	8	8
Esox americanus americanus	Redfin pickerel	P	T	N	41	57	56	33	25	46
Umbridae										
Umbra pygmaea	Eastern mudminnow	O	T	N	6	372	4	6	16	7
Salmonidae										
Salvelinus fontinalis	Brook trout	P	IS	N	22	24	1	2	6	31
Salmo trutta	Brown trout	P	IS	E	113	126	50	108	91	43
Oncorhynchus mykiss	Rainbow trout	P	IS	NN	23	14	9	16	7	4
PERCOPSIFORMES										
Aphredoderidae										
Aphredoderus sayanus	Pirate perch	I	T	N	*	3	*	*	*	*
ATHERINIFORMES										
Cyprinodontidae										
Fundulus diaphanus	Banded killifish	I	T	N	14	35	38	47	121	231
Fundulus heteroclitus	Mummichog	O	T	N	*	*	64	*	6	*
SCORPAENIFORMES										
Cottidae										
Cottus cognatus	Slimy sculpin	BI	IS	N	10	22	*	*	10	31
PERCIFORMES										
Percicthyidae										
Morone americana	White perch	P	T	N	*	*	*	17	3	4
Centrarchidae										
Pomoxis nigromaculatus	Black crappie	P	T	NN	7	21	3	3	*	2
Pomoxis annularis	White crappie	P	T	NN	3	*	*	*	*	*
Lepomis macrochirus	Bluegill sunfish	O	T	NN	44	61	70	34	38	101
Lepomis cyanellus	Green sunfish	O	T	NN	*	11	*	138	*	25
Lepomis gibbosus	Pumpkinseed sunfish	O	T	N	148	111	170	128	260	143
Lepomis auritus	Redbreast sunfish	O	T	N	348	177	221	339	366	466
Lepomis spp.	Unidentified sunfish	O	T		33	*	*	*	21	*
Enneacanthus gloriosus	Bluespotted sunfish	I	T	N	2	4	22	4	*	*
Ambloplites rupestris	Rock bass	P	T	NN	128	91	40	66	156	173
Micropterus salmoides	Largemouth bass	P	T	NN	29	58	24	28	52	39
Micropterus dolomieu	Smallmouth bass	P	T	NN	53	64	2	61	87	35
Percidae										
Percina peltata	Shield darter	BI	IS	N	32	2	*	*	*	5
Etheostoma olmstedi	Tesselated darter	BI	T	N	592	710	164	723	296	641
Stizostedion vitreum	Walleye	P	T	NN	*	3	*	*	*	*
Perca flavescens	Yellow perch	P	T	N	1	4	14	6	16	*
TOTAL NUMBER OF SPECIES					**46**	**42**	**39**	**38**	**40**	**38**
TOTAL NUMBER OF FISH					**6248**	**7222**	**3554**	**4655**	**5189**	**6417**

beginning in the 1980s, and changes in land-use practices have likely contributed to this increase.

Delaware River Basin

Land use in parts of the Delaware River Basin has changed over the last 20 years from predominantly agriculture in the 1970s to largely urban in the 1990s (Fig. 3). During the 1970s, however, wastewater facilities contributed as much as 95 percent of the nutrient loading in Delaware River tributaries (New Jersey Department of Environmental Protection, 1993). Most of these facilities have since been upgraded and are now in compliance with federal and state regulations. Water quality has improved substantially as a result of water-contaminant-control efforts extending back 40 years (Delaware River Basin Commission, 1992). Currently, secondary wastewater treatment is considered sufficient to meet water-quality standards in most of the upper Delaware River Basin (Delaware River Basin Commission, 1996).

The Delaware River Basin Commission (1996) reports that the water quality in the upper Delaware River Basin is good to high. A significant increase in stream condition from 34 (fair) to 40 (good) supports this finding (Table 2). IBI scores for individual sites increased at 25 of the 32 sites assessed and, of these, 20 increased at least one condition category (Table 2). Results of Tukey's test indicate that the 1990s mean IBI score for the Delaware River Basin was significantly higher than those for the Raritan and Passaic River Basins (Fig. 2). Study sites downstream from wastewater-treatment facilities that are now in compliance may be largely responsible for this difference.

The implementation of stricter regulations on the discharge of industrial contaminants in the Delaware River Basin has resulted in a great reduction in the input of organic compounds and toxic materials. Currently, the primary contaminants in the Delaware River Basin are derived from nonpoint sources (Patrick et al., 1992). The improvement in Delaware River Basin IBI scores may indicate, however, that current levels of nonpoint-source contamination are less significant in terms of water quality than point sources in determining stream condition. In addition, the Delaware River Basin contains more undeveloped land and has a lower population density than the Passaic and Raritan River Basins (Fig. 3); these were likely the mitigating factors in averting additional environmental degradation in many Delaware River tributaries. Thus, formerly uninhabitable areas may have been recolonized by immigration of fish from localized habitat refuges. This hypothesis is supported by the significant increase in the number of benthic insectivore species from the 1970s to 1990s ($p<0.007$; Table 1), which typically decreases with increasing habitat degradation. In addition, the mean IBI score in the 1990s for the Delaware River Basin was significantly higher than those for the Raritan and Passaic River Basins (Tukey's test; Fig. 2), indicating a more rapid increase in stream condition, which may also result from recolonization of indigenous fauna. The Delaware River Basin was the only basin that showed a significant decrease ($p<0.017$) in the proportion of white suckers; however, the proportion of omnivores did not change significantly (Table 1).

Passaic River Basin

Historically, most of the degradation in the Passaic River Basin resulted primarily from point- source contamination (New Jersey Department of Environmental Protection, 1987a). In the 1970s, 10 water-supply purveyors used the basin's streams as a source of potable water and 160 municipal and wastewater-treatment plants used the streams for disposal of treated effluent (Anderson and Faust, 1973). The NJDEP predicted that at current growth rates and without the implementation of a strategy for water-resource management, concentrations of dissolved oxygen in parts of the Passaic River would fall to zero by the year 2000 (New Jersey Department of Environmental Protection, 1987a). Today, the Passaic River Basin is one of the most densely populated and urbanized basins in New Jersey (Fig. 3). Nevertheless, the IBI score increased significantly from 30 (fair) to 35 (fair) ($p<0.003$; Table 1), even though no condition-category improvement occurred (Table 3). IBI scores increased at 16 of the 24 sites assessed and, of these sites, scores at 10 increased by at least one condition category (Fig. 1; Table 3). This change may be directly attributable to improvements in many wastewater-treatment plants, which are now in compliance with Federal and State regulations (New Jersey Department of Environmental Protection, 1993).

The Passaic River Basin contains the highest percentage of urban land of the three basins assessed (Fig. 3). Urban land use can affect water quality and the health of aquatic communities (Wang et al., 1997). Lenat and Crawford (1994) found that fish communities at urban sites were distinguished by low species richness, low biomass, and the absence of intolerant species. In the Passaic River Basin, few intolerant species were present in either the 1970s or the 1990s (Table 1). In addition, the proportion of omnivores increased, which commonly is a direct indication of water-quality degradation (Table 1). Although this change was not significant, the high percentage of omnivores, absence of intolerant species, and low mean condition rating (fair) indicate that water quality in the Passaic River Basin is still highly impaired. In addition, the percentage of anomalies, which can indicate severe water-quality degradation (Karr et al., 1986), was highest in the Passaic River Basin in the 1990s (0.7 percent; Table 1).

Raritan River Basin

Despite the presence of a large number of wastewater-treatment facilities and hazardous- waste sites (point sources) in the Raritan River Basin, water quality typically has been reported as good (New Jersey Department of Environmental Protection, 1987b; 1993). Significant improvements in the quality of water in the Raritan River have been observed since the early 1980s; these improvements can be attributed to the elimination of major sources of industrial discharge (New Jersey Department of Environmental Protection, 1993). The mean IBI score for the Raritan River Basin increased significantly ($p<0.005$), from 33 (fair) to 36 (fair). Although the condition category remained the same, the mean IBI score in the 1990s came within one point of the next higher condition category (good) (Table 1). Individual IBI scores increased at 18 out of 32 sites and, of these, scores at 11 sites increased by one or more condition categories (Fig. 1; Table 4). The shift in land use in much of the Raritan River Basin from agricultural to suburban and urban has led to a decline in the amount of cropland runoff, which was a major contributor of nonpoint-source contamination (Fig. 3; New Jersey Department of Environmental Protection, 1993). This may be one of the factors that has contributed to the overall increase in water quality in this basin.

Other measures, however, appear to indicate that increasing urbanization in the Raritan River Basin continues to promote water-quality degradation. The proportions of omnivores and white suck-

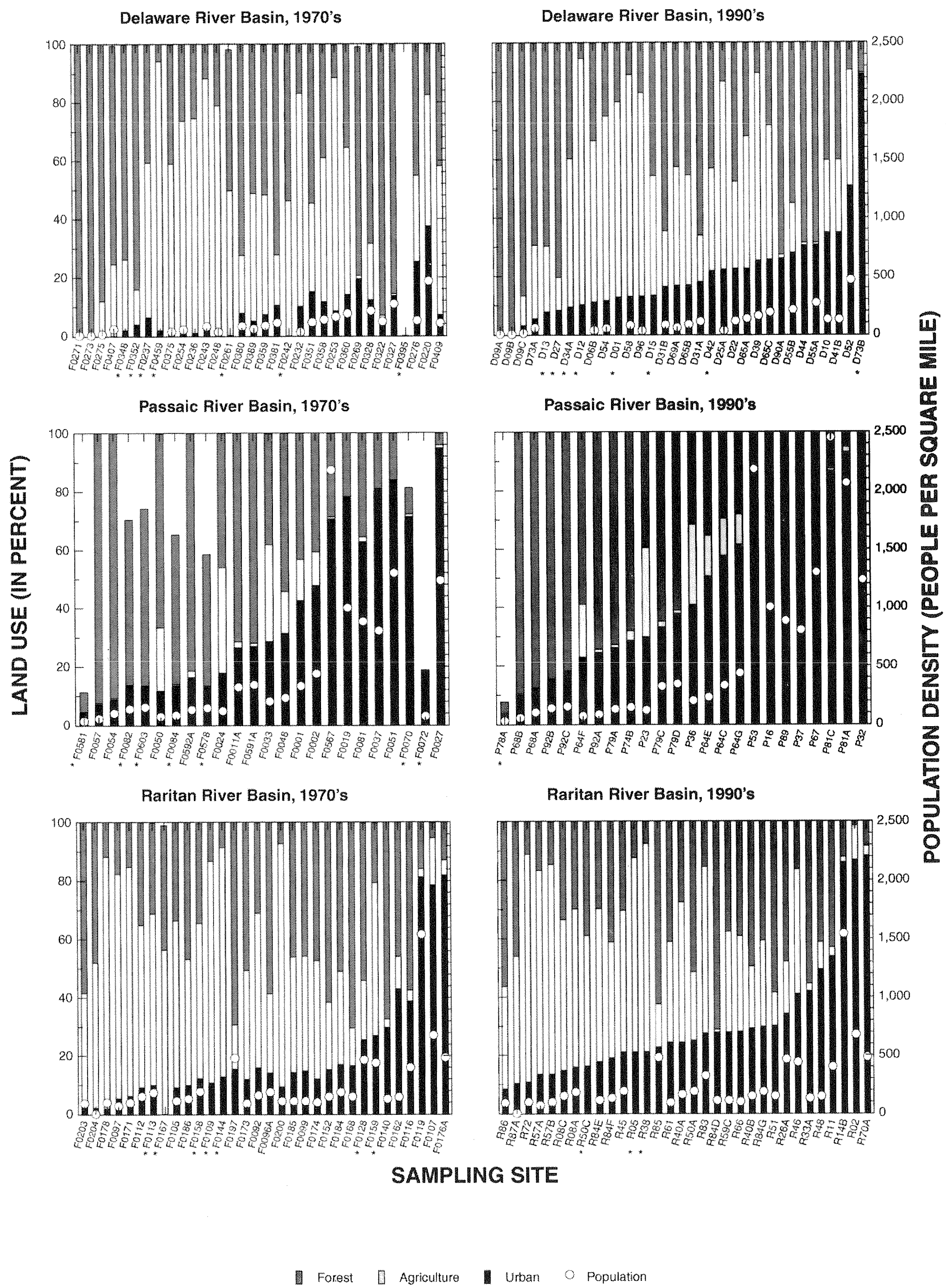

Fig. 3. Land use and population density for fish-sampling sites in the Passaic, Raritan, and Delaware River Basins, New Jersey, 1970s and 1990s. (Complete land use and/or population density information was not available for some sites (*)). Barren and water and wetlands land use information was not available for most 1970s sites; therefore, total land use was reported as the sum of forest, agriculture, and urban. Sites are arranged in order of the proportion of urban land use in the 1990s. Site names are provided in Tables 2, 3, and 4)

ers did not change significantly from the 1970s to the 1990s. Thus, despite changes in wastewater treatment and a decline in cropland runoff, water quality in the Raritan River remains impaired. This is especially apparent in main-stem reaches, where many sites still are severely impaired primarily as a result of municipal/industrial and stormwater discharges (U.S. Environmental Protection Agency and New Jersey Department of Environmental Protection, 1979; New Jersey Department of Environmental Protection, 1993).

Although IBI score at some sites did decrease (Tables 2, 3, and 4), relatively few sites reflected a change in condition category, and of these, only five decreased in score by five or more points. In the Delaware River Basin, Dry Brook at Branchville decreased by one condition category from good to fair. In the Passaic River Basin, two sites, Wanaque at Riverdale and Hohokus Brook at Waldwick decreased by one condition category from good to fair. Two sites in the Raritan River Basin, Pleasant Run at Readington and Holland Brook at Readington, also decreased by one condition category from good to fair. Although no direct statistical relations were established, assessment of current USGS 1:24,000 scale topographic maps indicate that changes in condition category at these sites appear to be the result of recent anthopogenic modifications of the basin landscape (e.g., rapid increase in urban development proximal to the sampling sites).

CONCLUSIONS

In this study, the index of biotic integrity proved to be an effective tool for quantifying differences in water quality in New Jersey streams. Although human population and urbanization have increased, higher IBI scores and improvements in stream condition in the Passaic, Raritan, and Delaware River Basins from the 1970s to the 1990s appear to reflect overall improvements in water quality. This improvement appears to be the result of more stringent guidelines for wastewater-treatment facilities in many New Jersey river basins. For urbanized systems with a history of water-quality degradation, the New Jersey IBI appears to provide resource managers with an effective assessment tool that is sensitive to temporal changes in stream condition at the basin and state scales.

ACKNOWLEDGMENTS

The authors thank James Kurtenbach of the U.S. Environmental Protection Agency and Walter Murawski of the New Jersey Department of Environmental Protection, Bureau of Freshwater Fisheries, for their assistance in data-base compilation. Assistance with historical-site location and validation from Timothy Dunne of the Natural Resource Conservation Service and analytical help from Thomas Barringer of the USGS are greatly appreciated. Thoughtful reviews and comments were provided by Robert Daniels of the New York State Museum and Robin Brightbill and Dale Simmons of the USGS. This project was supported in part by an appointment to the U.S. Geological Survey Earth Sciences Internship Program administered by Oak Ridge Associated Universities and the Environmental Careers Organization.

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