Final Report for LEQI 01-09 – a Lake Erie Quality Index Special Grant

DEVELOPMENT AND EVALUATION OF AN INDEX OF BIOTIC INTEGRITY FOR THE OFFSHORE FISH ASSEMBLAGE OF LAKE ERIE

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Introduction

During the past three decades, environmental quality in the Lake Erie ecosystem has gone through significant changes. As recently as the late-1960s/early-1970s, Lake Erie was referred to as the "Dead Sea of North America" because of the negative effects of cultural eutrophication and excessive phosphorus loading (Sweeney 1993). With eutrophication, hypolimnetic dissolved oxygen levels and water clarity were greatly reduced (Rosa and Burns 1987, Bertram 1993, Ludsin et al. 2001), altering the availability of both food and habitat for fishes. Ultimately, these environmental changes, coupled with commercial exploitation, resulted in major declines of native fish species (Hartman 1972, Regier and Hartman 1973, Leach and Nepszy 1976).

However, with the passage of the Great Lakes Water Quality Agreement in 1972 and removal of phosphates from detergents in the 1980s, phosphorus loading into Lake Erie has declined dramatically (Makarewicz and Bertram 1991, Dolan 1993), possibly resulting in reduced lakewide productivity and system oligotrophication (Ludsin et al. 2001). These changes, coupled with reductions in contaminant loading and commercial fishing pressure, have greatly modified the fish assemblage during the last 30 years (Regier and Hartman 1973, Leach and Nepszy 1976, Ludsin et al. 2001). In fact, there is strong evidence that the Lake Erie fish assemblage is recovering to something closer to its natural condition, with six fish species tolerant of eutrophy declining in the western basin during 1969-1996, and three species intolerant of eutrophy increasing during the same time period (Ludsin et al. 2001).

When the Great Lakes Water Quality Agreement (GLWQA) was renewed in 1978, the United States and Canada set a goal "to restore and maintain chemical, physical, and biological integrity of waters of the Great Lakes Basin Ecosystem." In fact, GLWQA partners are establishing indicators to assess habitat quality in the Great Lakes (Bertram and Stadler-Salt 2000). Similarly, Lake Management Plans (LaMPs) were put in place on the Great Lakes (including Lake Erie) to develop procedures to monitor ecosystem integrity and management strategies to promote system rehabilitation. One approach to monitoring ecosystem integrity or "health" is the use of indices, and in the case of fishes, the index of biotic integrity (IBI) has been used to characterize the ecological integrity of fish assemblages in many systems (Karr 1981, Karr et al. 1986, Minns et al. 1994, Hughes et al. 1998, Thoma 1999, Belpaire et al. 2000). Typically, IBIs seek to provide a more integrative view of fish assemblage structure through metrics that describe assemblage integrity, taxonomic richness, habitat guilds, trophic guilds, and individual health and abundance (Karr et al. 1986). If these metrics are effective, they can communicate information about environmental quality and habitat conditions for fish, possibly helping managers identify when problems are developing. At their best, these indices can reveal significant ecological changes, and capture the most critical dynamics of ecological systems with the most efficient use of resources (NRC 2000).

Clearly, the Lake Erie ecosystem has gone through tremendous changes during the past three decades. As we begin to see significant changes in populations of individual fish species (e.g., Ludsin et al. 2001), it seems appropriate to take a more integrative view of Lake Erie offshore fish assemblages (*sensu* Karr et al. 1986), as has been done for the nearshore and lacustuary regions of Lake Erie by the Ohio EPA (Thoma 1999). To do this, we set the goal of developing an index of biotic integrity (IBI) for Lake Erie's offshore fish assemblage that will allow us to characterize the temporal variability of water quality and habitat availability for different fish species and/or groupings (e.g., habitat guilds).

Most IBIs developed for different systems have used the traditional approach generated by Dr. James R. Karr (e.g., Karr 1981, Karr et al. 1984, Karr et al. 1986, Thoma 1999 as a Lake Erie example). However, a few recent studies (Minns et al. 1994, Hughes et al. 1998) have taken a different approach to IBI development. The major difference between these two approaches is how they standardize the wide diversity of indicator metrics used to estimate the IBI, as Karr (1981) and Karr et al. (1984, 1986) use an integer-based scale; in contrast, Minns et al. (1994) uses a continuous scale. Further detail on this topic will be given in the **Materials and Methods**. We generated IBIs using both of these approaches (i.e., the "Karr approach" and the "Minns approach"). To our knowledge, no one has made a direct comparison of IBIs generated using these two approaches.

We used Ohio Department of Natural Resources (ODNR) bottom trawl data collected during 1969-1999 to construct these IBIa. Given that trawl data were available for both the western and central basins of Lake Erie, we generated IBIs for each basin independently, as well as an IBI that combined data from the two basins. Finally, fish age structure has been shown to have an effect on IBIs (Schlosser 1985, Angermeier and Karr 1986) on IBI development. Fish collected in the bottom trawls were characterized relative to age class. Thus, we will use these data to generate independent IBIs for age-0 fish and age-1+ fish, as well as an IBI based upon all fish in the data set. By generating IBIs that are specific to basins and fish age classes as well as IBIs that use different methods, a broad range of options will be available to those who use these IBIs to track the integrity of Lake Erie's offshore fish assemblage.

Materials and Methods

To construct an index of biotic integrity for the offshore fish assemblage of Lake Erie, we examined data collected during monthly (May-October) fishery assessment surveys conducted by the Ohio Department of Natural Resources during 1969-1999. Data used for index construction were collected using daylight bottom trawl surveys conducted at both fixed and random sites throughout the western and central basins of Lake Erie. In these trawl surveys, sampling was stratified by 3-m depth strata based upon the relative amount of lake surface area per depth stratum.

Trawl surveys deployed a 10-m semi-balloon Biloxi bottom trawl with a 6.4-mm cod-end mesh using a single winch with bridle arrangement. Tow duration ranged from 10-15 min (actual time on bottom), which was then standardized to catch-per-hour-trawling (CPHT). At some trawl tow sites, ODNR personnel recorded water depth (m), Secchi disk transparency (m), surface and bottom water temperatures (^{o}C), and bottom dissolved oxygen (mg/L). Fishes captured in a given tow were identified to species and counted. In addition to biotic and abiotic data, ODNR personnel also recorded the "status" of each tow; for example, if the net became snagged on the bottom or another problem (e.g., torn net) occurred during net deployment or retrieval, this was noted. With trawl status information, we were able to identify trawl tows for which there were no problems and thus, only used data from these trawls.

Choice of data set for IBI development

The data set used for development of the IBI for the Lake Erie offshore fish assemblage was collected from fixed and random sites in the western and central basins that were sampled from late September through early October during 1969-1999. The number of September/October trawls during this time period ranged from 6 in 1983 to 115 in 1999 (Figure 1A). Along with trawl number, trawling effort (measured as time spent on the bottom by the trawl) also varied, ranging from 5-30 minutes. To assess the potential effect of trawling effort on the number of species captured, we examined this relationship across all bottom trawls conducted during 1969-1999 (Figure 1B). Based upon this analysis, we chose to limit trawls included in IBI development to only those with a trawl duration of $\geq$ 10 minutes. Coupling the year-to-year consistency in fixed sampling locations with annual samples provided an excellent representation of both temporal (annual) and spatial variability in offshore fish assemblage structure in Lake Erie. The scope for variability associated with these data proved very useful in constructing the IBI because of the probable broad range of environmental conditions represented by these samples. Another major rationale for using late September/early October data is that most fish species have recruited to the sampling gear by this time of year (i.e., they can be effectively sampled using bottom trawls). Thus, sampling during these late-summer, early-fall periods provide the best and broadest 'snapshot' of the relative abundance of species that constitute Lake Erie's offshore fish assemblage.

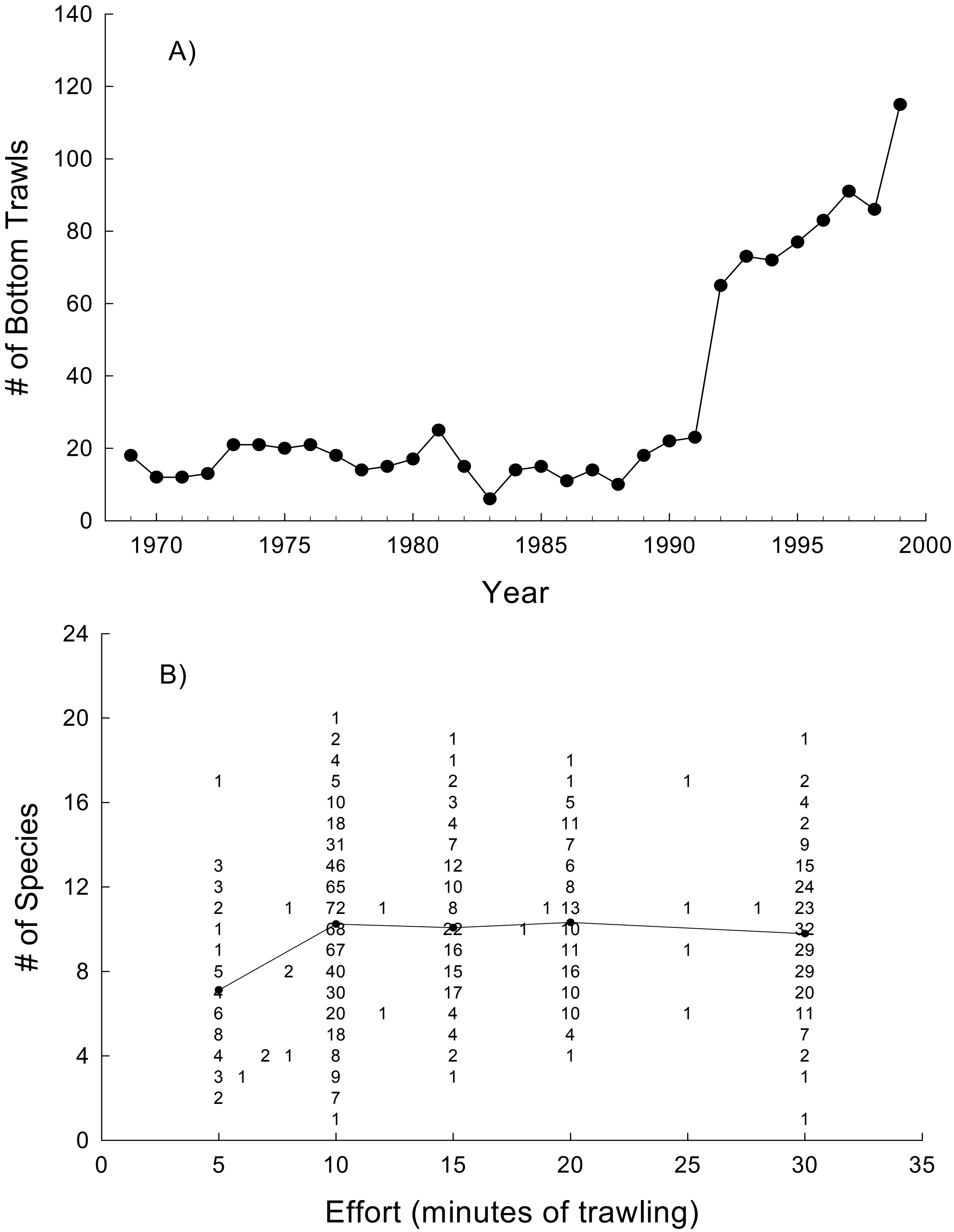

Figure 1. A) Number of September/October bottom trawls conducted by ODNR in Lake Erie during 1969-1999. **B)** The number of species captured by individual bottom trawls relative to effort (i.e., minutes trawling). The numbers representing the data points are the number of trawls at that effort level.

Determination of the Reference Condition for the IBI

Typically, researchers constructing IBIs define their reference (i.e., natural) condition based upon undisturbed sites that have not been degraded or altered by anthropogenic activities (Karr et al. 1986, Hughes et al. 1998). Without a reference condition as a baseline, it becomes difficult to assess 1) the magnitude of degradation, 2) whether the magnitude is important, or 3) if rehabilitation efforts are succeeding (NRC 2000). However, in many ecosystems, defining a reference condition is exceedingly difficult due to the ubiquitous nature of environmental degradation (Minns et al. 1994, Hughes et al. 1998). This is certainly the case for Lake Erie where we have limited information regarding the structure of offshore fish assemblages during pristine, natural time periods. Thus, similar to Minns et al. (1994), we assumed that some of the site/year combinations in the September/October trawl data possess representative healthy fish assemblages (i.e., that show limited signs of impairment). This assumption allowed us to set threshold values in metrics and the IBIs that provide insight into habitat integrity.

Selection/Evaluation of Indicator Metrics for the IBI

To determine appropriate indicator metrics to use in the IBI for Lake Erie's offshore fish assemblage, we considered 1) metrics used in the original derivation/application of the IBI in midwestern streams (Karr 1981, Karr et al. 1984, 1986) and 2) metrics used in other systems documented by the growing body of IBI literature (e.g., Minns et al. 1994, Hughes et al. 1998, Simon 1999, Thoma 1999, Belpaire et al. 2000, Brown 2000, Lyons et al. 2000). Metrics chosen for this IBI characterized the integrity of offshore lentic fish assemblages relative to species richness and composition, habitat guilds, behavior and trophic guilds, and fish community health and abundance. From a list of 29 candidate metrics, 14 were discarded primarily for ecological reasons. From the remaining 15 metrics, the list had to be narrowed down to the final 12 metrics, given that most fish IBIs use 12 metrics for IBI construction (Karr 1981, Minns et al. 1994, Thoma 1999).

To aid in selection of individual indicator metrics from the remaining 15 candidate metrics, we used September/October bottom trawl catch data to prepare a matrix of species captured during 1969-1999. Each species was characterized relative to a wide range of factors including point of origin (native vs. non-indigenous), trophic guild (e.g., carnivore, omnivore, etc...), tolerance of environmental degradation (tolerant vs. intolerant), habitat guild (e.g., pelagic, benthic, etc...), and other life history information relevant to metrics used for IBI construction (Table 1). In order to construct this matrix, we used multiple sources to provide insight into appropriate categorization of each species when possible (e.g., Trautman 1981, Karr 1981, Karr et al. 1984, 1986, Mills et al. 1993, Simon 1999, Thoma 1999, Ludsin et al. 2001). Coupling this matrix of species characteristics with trawl data collected during 1969-1999, we then computed actual metric values for each candidate metric for each individual trawl. For metrics that characterized fish abundance (e.g., total # of fish caught, # native fish caught), we standardized among trawls by calculating fish abundance relative to unit effort, in this case, 'per minute trawling'. Standardization by effort was necessary given that trawls included in the data set ranged from 10-30min duration.

Table 1. Fish species captured in September bottom trawls during 1969-1999, categorized (where possible) relative to metrics regarding origin (N = native, E = exotic/non-indigenous), pollution tolerance (I = intolerant, T = tolerant), trophic guild (C = top carnivore, O = omnivore, I = invertivore), and whether or not they are benthic species, phytophilic species, or native Cyprinidae (X = yes).

Common Name	Scientific Name	Origin	Pollution Tolerance	Trophic Guild	Benthic Species	Phytophilic Species	Native Cyprinidae
Alewife	*Alosa pseudoharengus*	E	–	I	–	–	–
Black crappie	*Pomoxis nigromaculatus*	N	T	C	–	X	–
Blackside darter	*Percina maculata*	N	–	I	X	–	–
Bluegill	*Lepomis macrochirus*	N	T	I	–	–	–
Bowfin	*Amia calva*	N	T	C	–	X	–
Brown bullhead	*Ameiurus nebulosus*	N	T	O	–	–	–
Burbot	*Lota lota*	N	I	C	–	–	–
Channel catfish	*Ictalurus punctatus*	N	T	C	–	–	–
Common carp	*Cyprinus carpio*	E	T	O	–	–	–
Emerald shiner	*Notropis atherinoides*	N	–	I	–	–	X
Freshwater drum	*Aplodinotus grunniens*	N	–	I	X	–	–
Ghost shiner	*Notropis buchanani*	E	–	–	–	–	–
Gizzard shad	*Dorosoma cepedianum*	E	T	O	–	–	–
Goldfish	*Carassius auratus*	E	T	O	–	X	–

Table 1. (continued)

Common Name	Scientific Name	Origin	Pollution Tolerance	Trophic Guild	Benthic Species	Phytophilic Species	Native Cyprinidae
Greenside darter	*Etheostoma blenniodes*	N	–	I	X	–	–
Johnny darter	*Etheostoma nigrum*	N	–	I	X	–	–
Lake whitefish	*Coregonus clupeaformis*	N	I	I	X	–	–
Logperch	*Percina caprodes*	N	–	I	X	–	–
Longnose gar	*Lepisosteus osseus*	N	–	C	–	X	–
Mimic shiner	*Notropis volucellus*	N	I	O	–	–	X
Northern hog sucker	*Hypentelium nigricans*	N	–	O	–	–	–
Pumpkinseed	*Lepomis gibbosus*	N	T	I	–	X	–
Quillback	*Carpiodes cyprinus*	N	T	O	–	–	–
Rainbow smelt	*Osmerus mordax*	E	I	O	–	–	–
Rock bass	*Ambloplites rupestris*	N	I	C	–	–	–
Round goby	*Neogobius melanostomus*	E	–	I	–	–	–
Sand shiner	*Notropis stramineus*	N	I	O	–	–	X
Sauger	*Stizostedion canadense*	N	–	C	–	–	–
Sea lamprey	*Petromyzon marinus*	E	–	–	–	–	–
Shorthead redhorse	*Moxostoma macrolepidotum*	N	–	I	X	–	–

Table 1. (continued)

Common Name	Scientific Name	Origin	Pollution Tolerance	Trophic Guild	Benthic Species	Phytophilic Species	Native Cyprinidae
Silver chub	*Macrhybopsis storeriana*	N	–	I	–	–	X
Smallmouth bass	*Micropterus dolomieui*	N	I	C	–	–	–
Spottail shiner	*Notropis hudsonius*	N	–	I	–	–	X
Stonecat madtom	*Noturus flavus*	N	I	I	X	–	–
Trout-perch	*Percopsis omiscomaycus*	N	–	I	–	–	–
Walleye	*Stizostedion vitreum*	N	–	C	–	–	–
White bass	*Morone chrysops*	N	–	C	–	–	–
White crappie	*Pomoxis annularis*	N	T	C	–	X	–
White perch	*Morone americana*	E	–	C	–	–	–
White sucker	*Catostomus commersoni*	N	T	O	–	–	–
Yellow perch	*Perca flavescens*	N	–	C	–	X	–

Based upon examination of the resulting metric-specific data, we were able to eliminate two candidate metrics from consideration. We did not use the 'number of sunfish species' metric used in many fish IBIs because they were in limited abundance in offshore trawls. Given their likely association with nearshore littoral zones, one would not expect sunfish to be a prominent member of the offshore fish assemblage even in high-quality systems. The '% DELTs' (i.e., externally observable Deformities, Eroded fins, Lesions, and Tumors) metric was excluded because these data are not recorded for fish collected in ODNR's bottom trawl efforts. Finally, correlations were run among candidate metrics to assess potential redundancy among individual metrics. This analysis allowed us to eliminate the 'total # fish species' metric given that it was highly correlated (r=0.94) with the '# native species' metric, which we retained for the IBI. These metric eliminations resulted in the final list of 12 metrics used for IBI development (Table 2).

Table 2. Metrics used in the construction of the IBI for Lake Erie's offshore fish assemblages, categorized relative to metric type.

Metric	Metric Type
# Native species	Species richness and composition
# Intolerant species	Species richness and composition
# Benthic species	Species richness and composition
# Phytophilic species	Species richness and composition
# Exotic species	Species richness and composition
# Native Cyprinid species	Species richness and composition
% Omnivores	Behavior/trophic guild
% Top Carnivores	Behavior/trophic guild
% Tolerant individuals	Behavior/trophic guild
% Non-indigenous individuals	Behavior/trophic guild
# of Individuals	Community health/Fish Abundance
# of Native Individuals	Community health/Fish Abundance

Standardization of IBI Metrics
We used both the Karr and Minns approaches to standardize the diverse array of individual age-class-specific IBI metrics to a common scale. Metric standardization is necessary because of lack of similarity (and thus, comparability) in the distributions of

numbers of species, number of fishes, and proportional metrics. Prior to metric standardization, trawl-specific values for each of the twelve indicator metrics were calculated in the three following ways: 1) using only age-0 fish, 2) using only age-1+ fish, and 3) using all fish regardless of age. These separate data sets allowed for generation of independent IBIs that accounted for potential effects of age structure on these analyses.

First, we used the traditional standardization approach (the Karr approach) of assigning integer scores of “5" (representing sites of high habitat integrity), “3" (representing sites of intermediate habitat integrity), and “1" (representing sites that are likely to be very degraded) to threshold values within the range of each metric (*sensu* Karr et al. 1984, 1986). For scoring according to the Karr system, the first step is to calculate the 95th cumulative percentile value for that metric. The range of values less than the 95th percentile value is then “trisected” equally, with each section corresponding to one of the possible integer metric scores. The score reversal process for negative metrics (those for which the metric’s relationship with the biotic integrity of the system is expected to be negative, e.g., # exotic species) was carried out after the 95th percentile was calculated by simply reversing the integer metric scores relative to the 95th percentile. Along with the possible 5, 3, 1 thresholds and scores, we assigned “zeroes” to metric scores of zero in positive metrics and to metric scores greater than the 95th percentile value in negative metrics (*sensu* Thoma 1999).

Second, we used a standardization approach (the Minns approach) that treats each metric as a continuous variable (*sensu* Minns et al. 1994). Following Minns et al. (1994), we standardized all metric value ranges to a linear function that yields output from “0" (the floor threshold; i.e., no fish caught for that metric) to “10" (the ceiling threshold; represented by values greater than or equal to the 95th cumulative percentile for a given metric) [see Minns et al. (1994) for the scoring algebra]. The score reversal process for negative metrics was carried out after the scores were initially determined by subtracting the positive score from ten, thus reversing the distribution along the continuum from zero to ten.

Construction of the Actual IBI

IBI scores were assigned to each individual bottom trawl that was conducted. For the Karr approach (Karr et al. 1984, 1986), we summed the 12 individual standardized metrics allowing for a range of 0-60 for the actual IBI score of a given trawl. For the Minns approach (Minns et al. 1994), we summed all standardized IBI metrics for a given trawl, multiplied by this value by 10, and divided by the number of metrics (i.e., 12) with the resulting value representing the IBI score for that site. This approach results in a minimum value of zero if no fish are caught in a given trawl sample and a maximum value of 100.

Once total IBI scores were calculated for individual trawls using the Karr and Minns methods, yearly averages were calculated for each basin and the two basins as a whole. IBI ranges for each approach were then be subdivided into qualitative designations of site health/quality. For example, a site with the maximum IBI score of either 60 (using the Karr approach) or 100 (using the Minns approach) would be given a qualitative designation of “Excellent”. To set the thresholds for these qualitative designations, the 95th percentile value of the individual total IBI scores was calculated, and then the range below this value was divided equally into four parts (i.e., quadrisected). Within these ranges, trawls with scores greater than the 95th percentile were characterized as “Excellent”. The quadrisected ranges below this line were then characterized in succession as: “Good”, “Fair”, “Poor”, and “Very Poor”.

Results

Temporal trends of individual IBI metrics

Sensitivity to environmental change is a key characteristic for indicator metrics used in the construction of an IBI. The metrics we chose to characterize Lake Erie’s offshore fish assemblage show a broad range of temporal (annual) and spatial (trawl-to-trawl) variability (Figures 2-13). The average number of pollution-intolerant species present in trawls has increased since the early 1980s regardless of age class, with more recent trawls showing increased frequency of more intolerant species being captured (Figure 2). The number of benthic species captured in trawls has not changed much during 1969-1999, although recent trawls begin to indicate an increased number of benthic species present (Figure 3). It is important to note that we did not include the bullheads (typically pollution-tolerant species) or round goby (an exotic species) in this metric despite their benthic nature because we did not feel that they were representative of increased system integrity. The number of phytophilic species has declined substantively regardless of age class (Figure 4). The number of native species has not changed much during 1969-1999, although there is an indication of a positive trend in average native species richness during the 1990s (Figure 5). The average number of exotic/non-indigenous species has increased, particularly as a result of large catches of white perch and round goby (Figure 6). The number of native cyprinid species has not changed much during 1969-1999, although there is an indication of a positive trend in average native cyprinid species richness during the 1990s (Figure 7). The % carnivores metric values increased dramatically up until the 1990s regardless of age class (Figure 8). Large year classes of walleye are primarily responsible for these trends. However, in recent years, average values for this metric have declined and stabilized (Figure 8). The % omnivores metric values have not changed substantively during 1969-1999 and are highly variable regardless of time period (Figure 9). The % of tolerant fish captured in bottom trawls has declined since the mid-1980s, although there are still many trawls that have higher catches of these species (Figure 10). The % of exotic/non-indigenous fish captured in bottom trawls has increased for age-1+ fish since the early 1980s (Figure 11). Age-0 exotic fish increased in trawl dominance into the early1990s (Figure 11), primarily as a result of large catches of white perch, but have declined since that time. Total catch per unit effort (CPUE; per minute trawling) was quite variable during 1969-1999 with no consistent trend (Figure 12). However, during the 1990s there has been an increase in average CPUE for age-1+ fishes and an increased frequency of trawls with CPUEs > 100 (Figure 12). Finally, native catch per unit effort (per minute trawling) showed with no consistent trend during 1969-1999 (Figure 13). However, during the 1990s, there has been an increase in average native CPUE and an increased frequency of trawls with CPUEs > 50 (Figure 13). Interestingly, there were uniformly low native CPUEs during the 1980s (Figure 13), this is likely a function of large walleye year classes (the dominant carnivore) during that time period.

Standardization of IBI indicator metrics

For the Karr approach, metrics were standardized to a discreet set of integer values (i.e., 5, 3, 1, 0), with this range of values representing metric quality, with “5" representing highest quality and “0" representing the most degraded situation. Age-class-specific scoring ranges for each standardized metric are presented in Table 3. For the Minns approach, metrics are standardized to a common, continuous range of values (0-100).

Generation of IBIs for the Karr and Minns approaches

Age-class-specific IBIs were constructed for the western basin, the central basin, and both basins combined using both the Karr and Minns approach. For both the Karr and Minns IBIs, there were no consistent trends for central basin trawl sites regardless of age class, however, IBI scores for western basin sites showed a positive trend starting in the early 1990s for all age classes (Figures 14-19). When all sites were combined, regardless of basin, only IBI scores for YOY fish did not show an increase in the 1990s. Relative to the qualitative integrity classifications, most sites were classified as either “Good” or “Fair”, with a few sites characterized as “Excellent”, “Poor” and “Very Poor” (regardless of basin or age class; Figures 14-19). Average IBI scores of the two approaches correlate very strongly regardless of basin or age class. For YOY fish, the correlation coefficients are: 0.96 for the western basin, 0.88 for the central basin, and 0.93 for all sites combined. For age-1+ fish, the correlation coefficients are: 0.91 for the western basin, 0.95 for the central basin, and 0.89 for all sites combined. Finally, for all fish combined, the correlation coefficients are: 0.71 for the western basin, 0.39 for the central basin, and 0.59 for all sites combined.

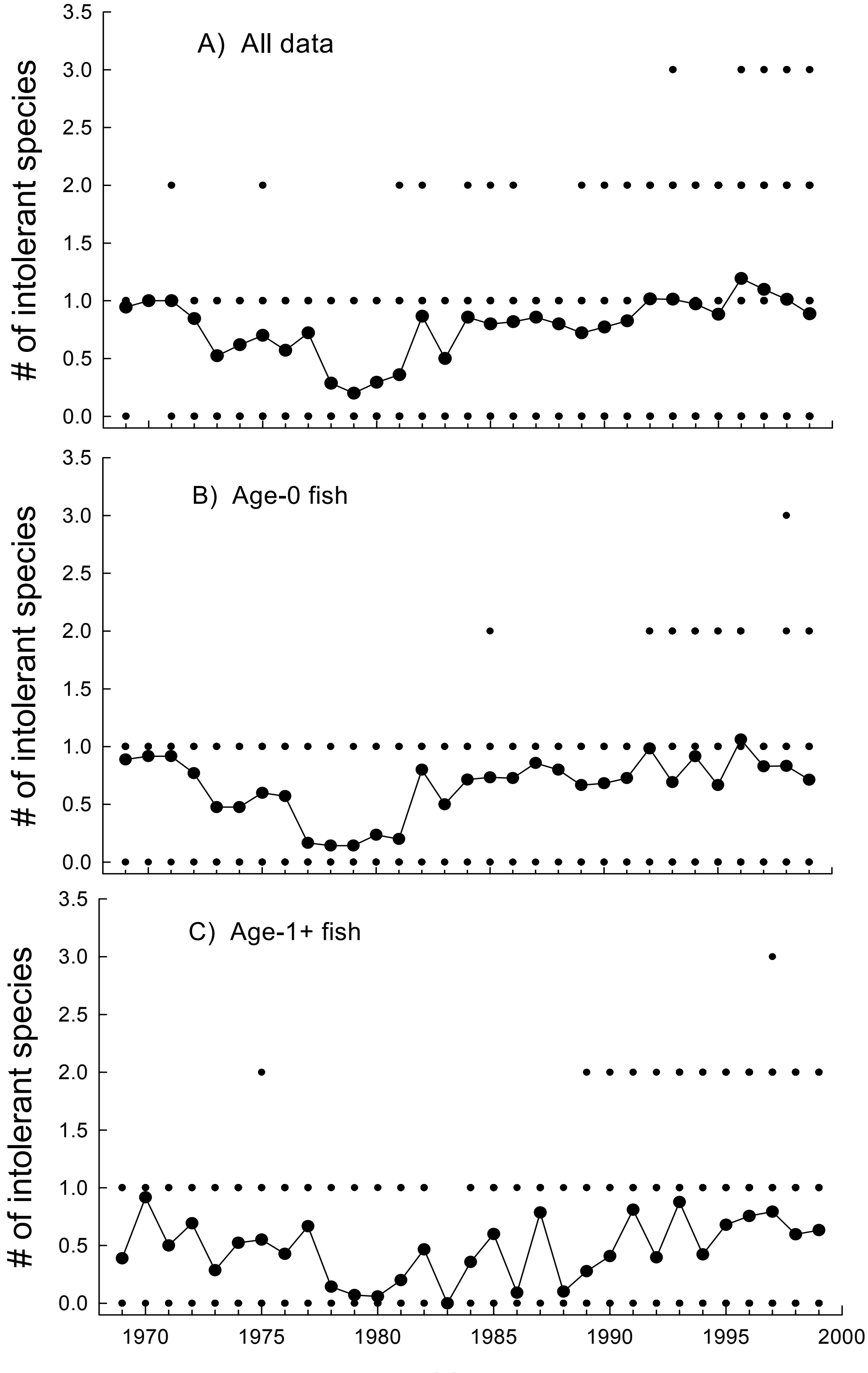

Figure 2. Age-class-specific metric scores for the number of pollution-intolerant species in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

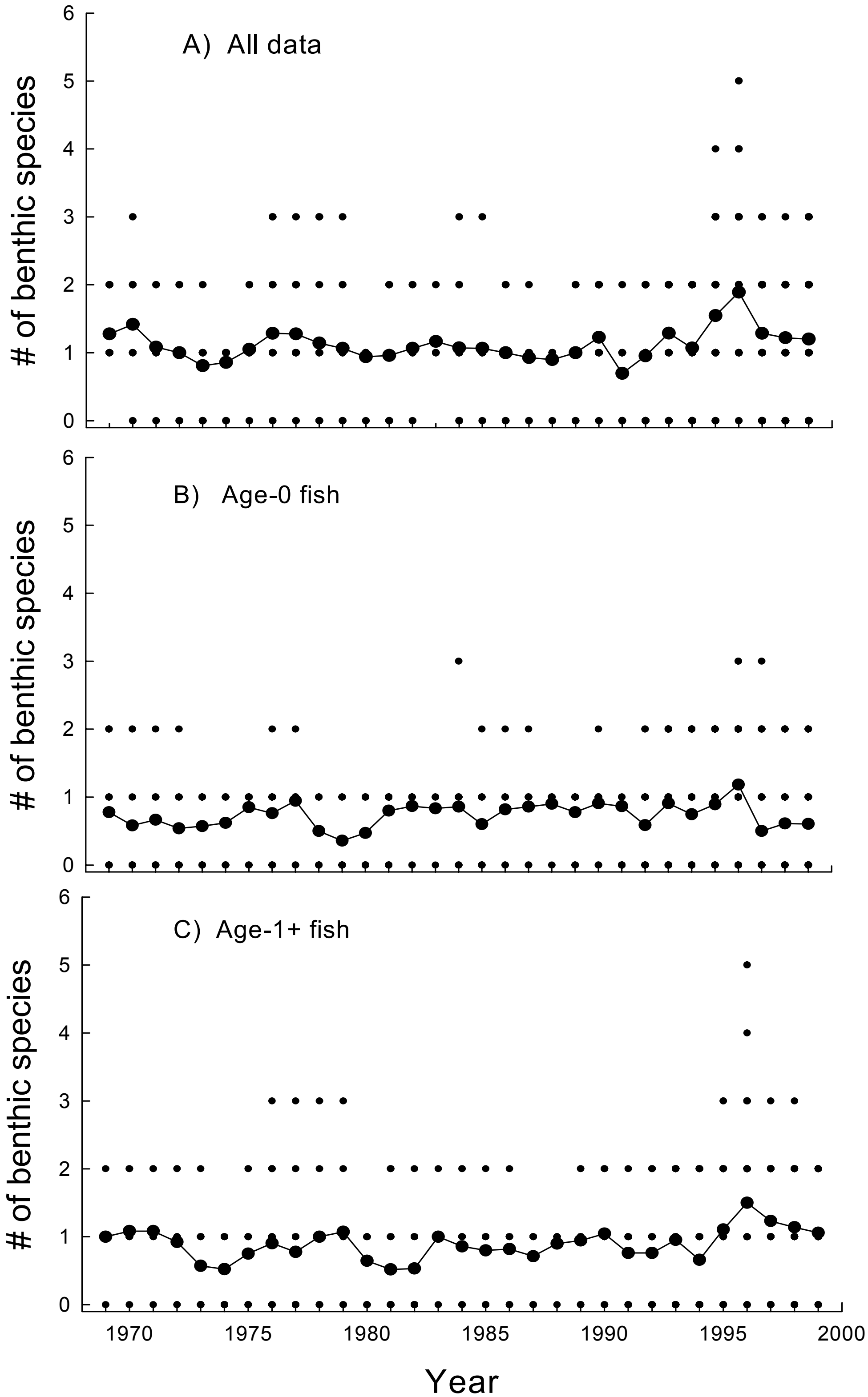

Figure 3. Age-class-specific metric scores for the number of benthic species in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

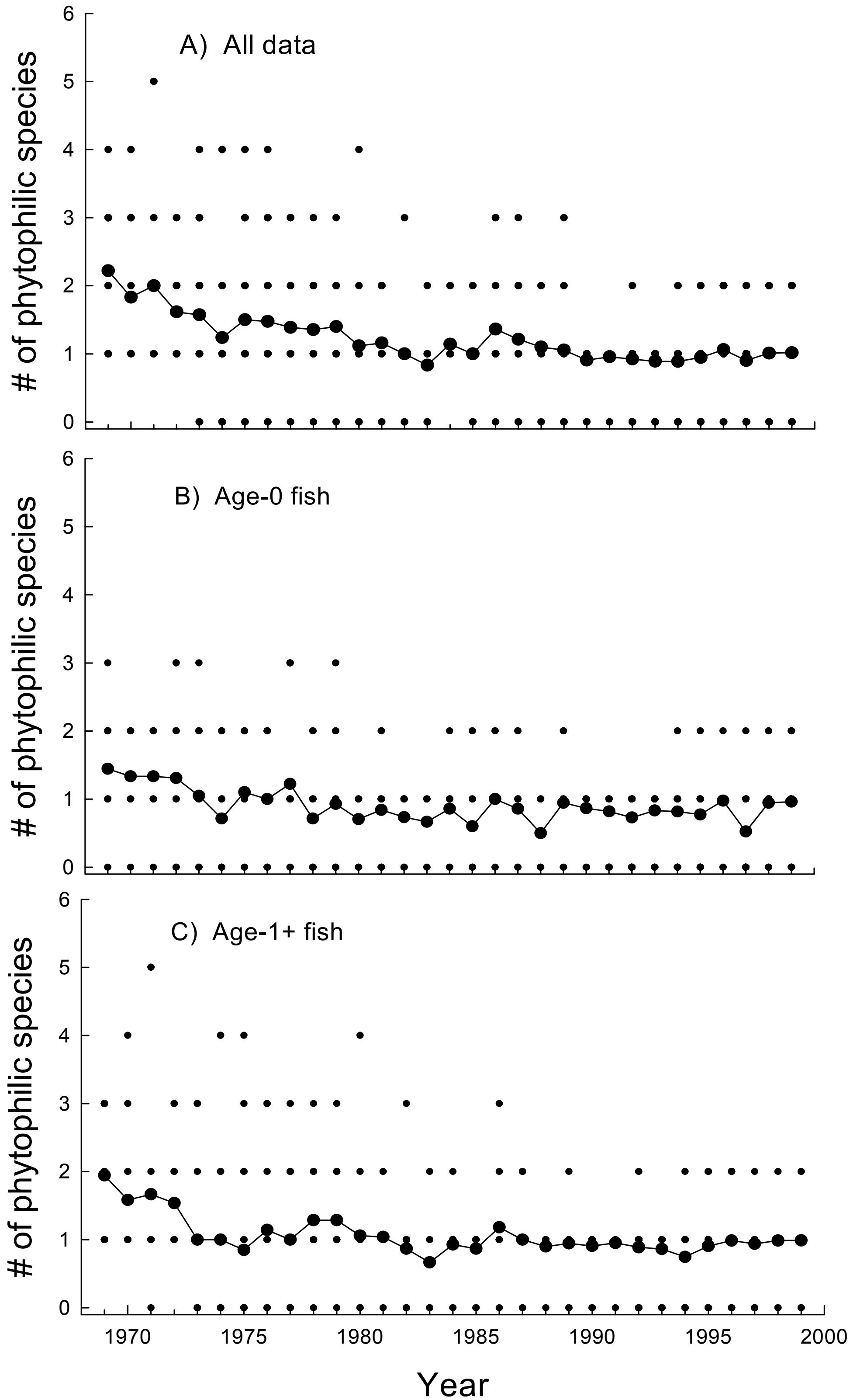

Figure 4. Age-class-specific metric scores for the number of phytophilic species in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

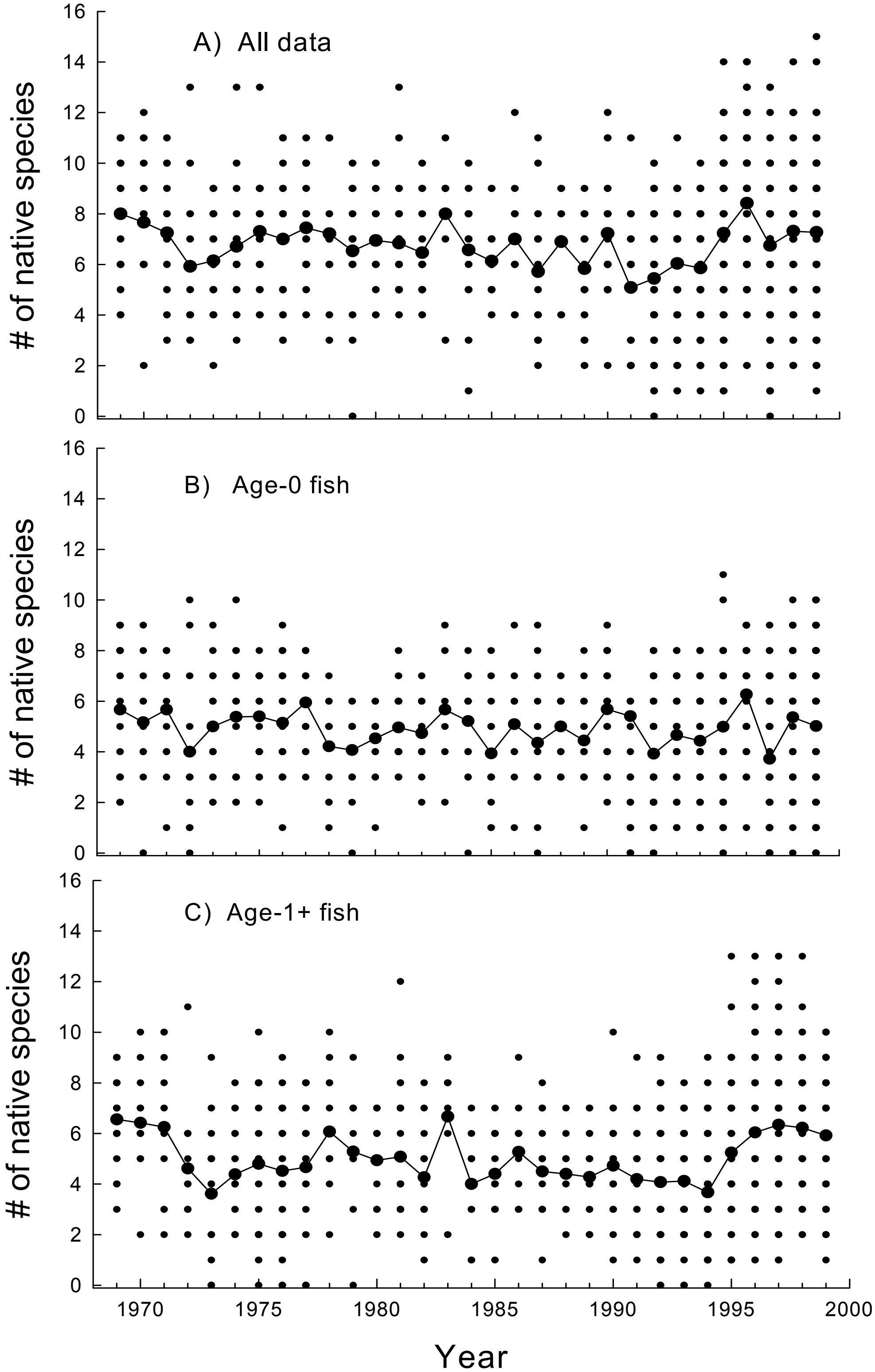

Figure 5. Age-class-specific metric scores for the number of native species in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

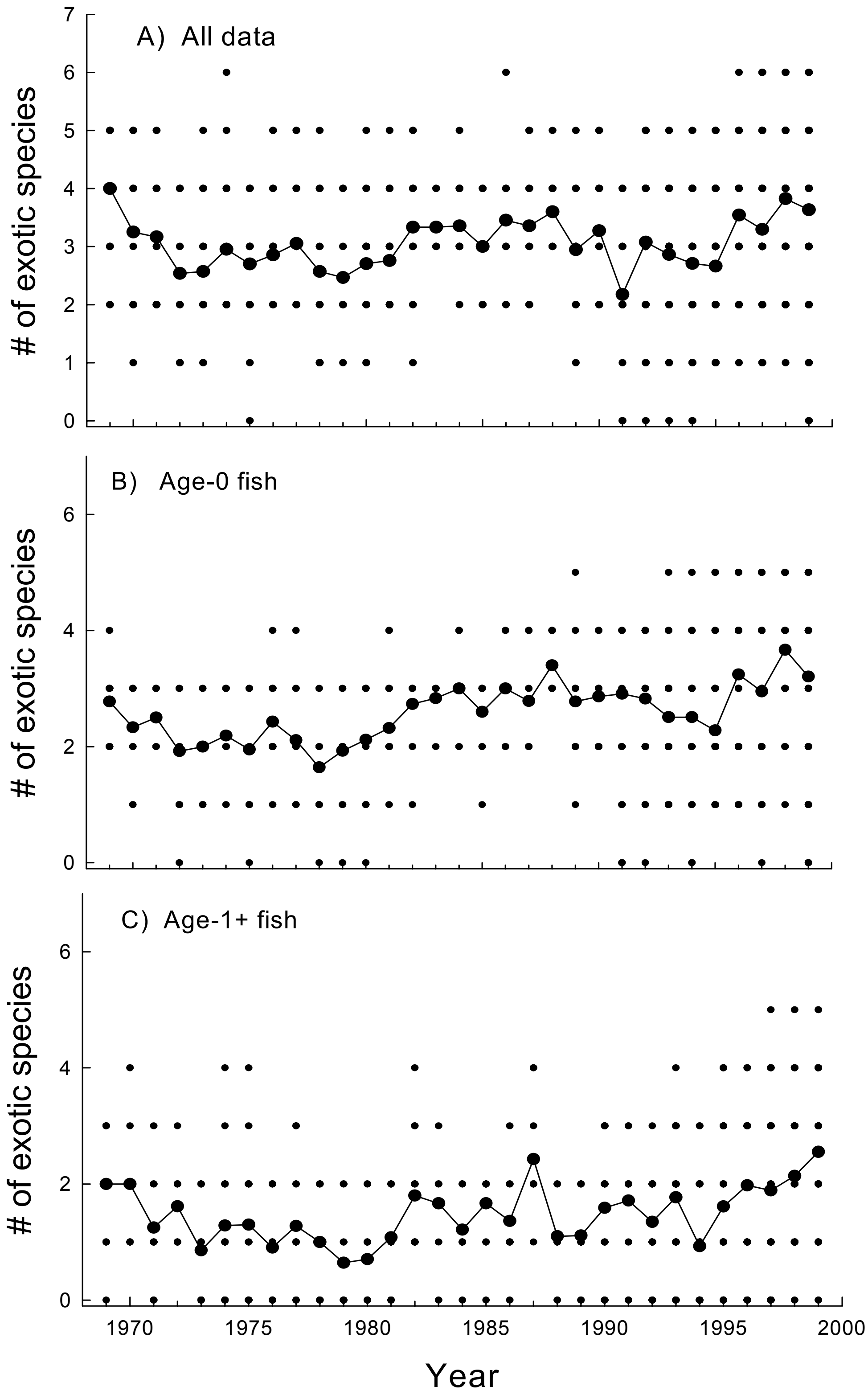

Figure 6. Age-class-specific metric scores for the number of non-indigenous/exotic species in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

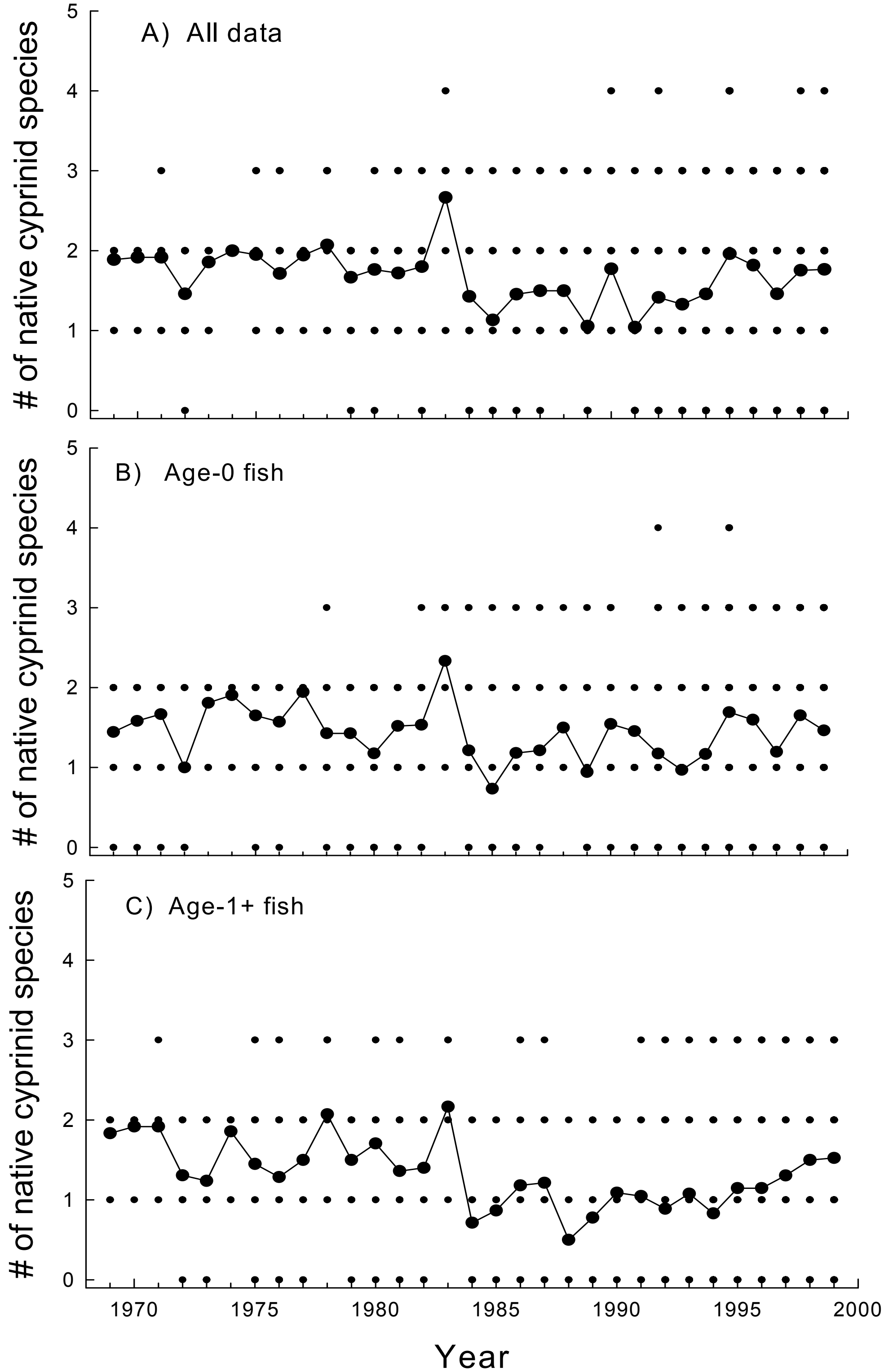

Figure 7. Age-class-specific metric scores for the number of native cyprinid species in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

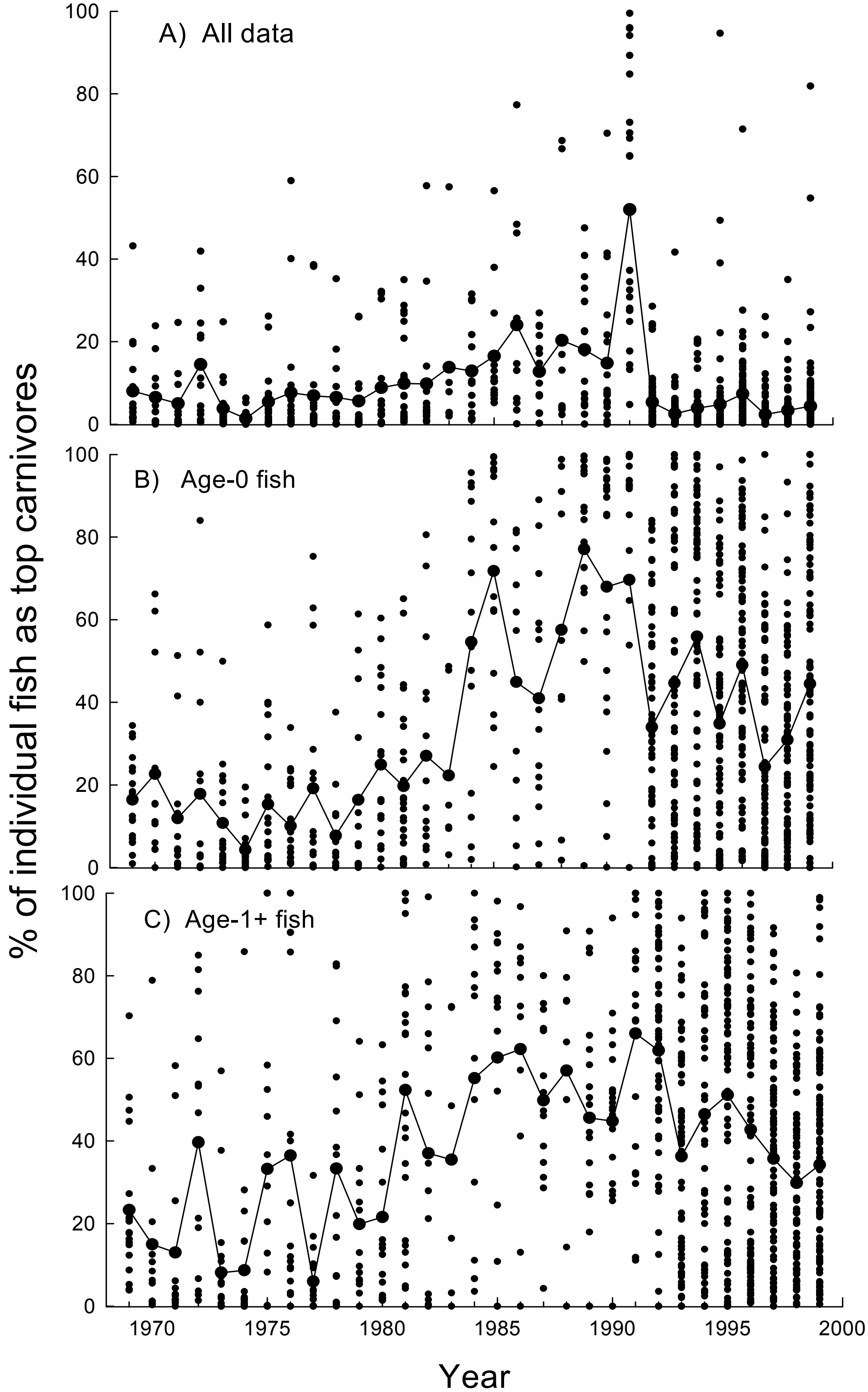

Figure 8. Age-class-specific metric scores for the % of carnivorous individuals in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

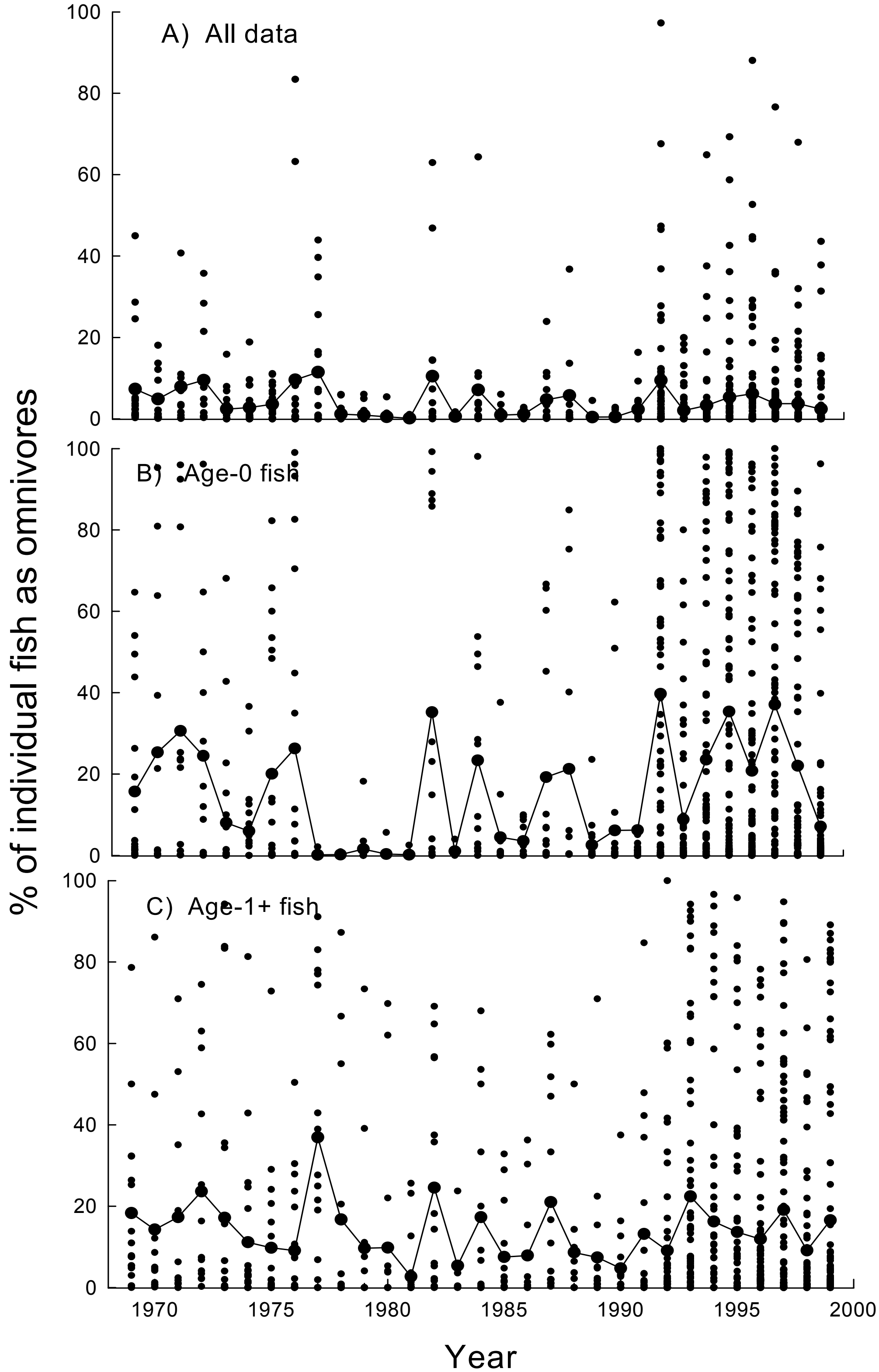

Figure 9. Age-class-specific metric scores for % of omnivorous individuals in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

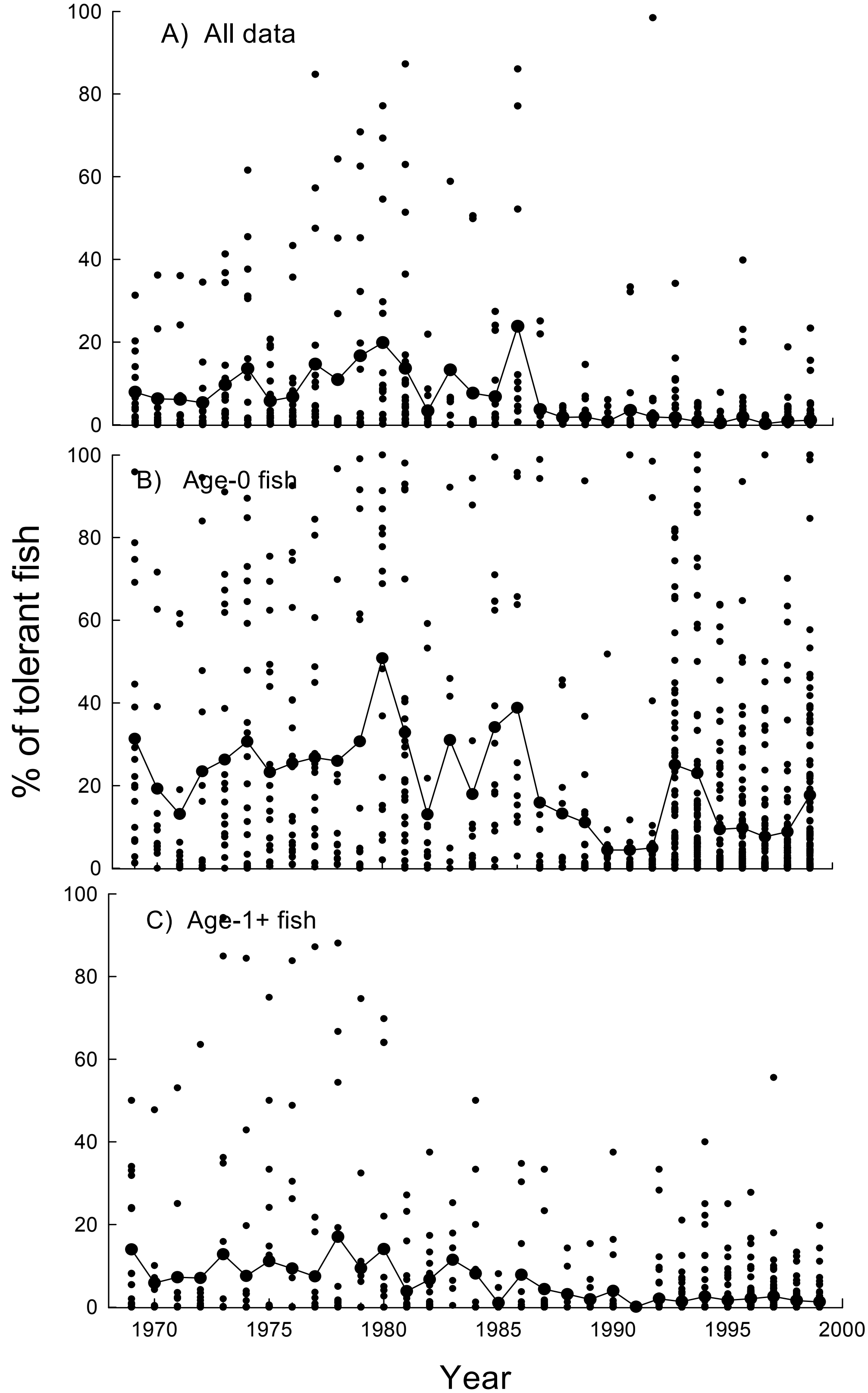

Figure 10. Age-class-specific metric scores for the % of pollution-tolerant individuals in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

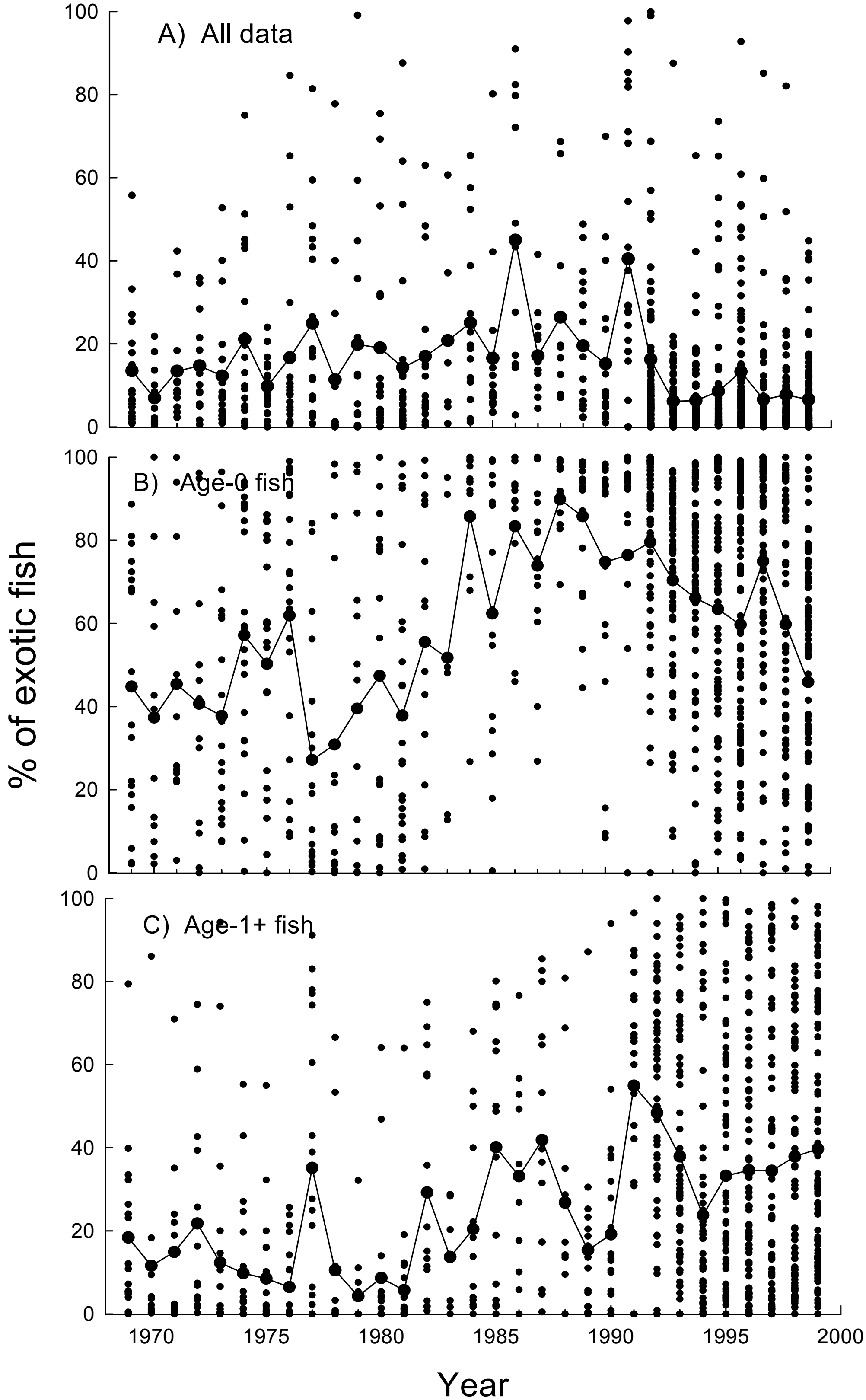

Figure 11. Age-class-specific metric scores for the % of non-indigenous/exotic individuals in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999.

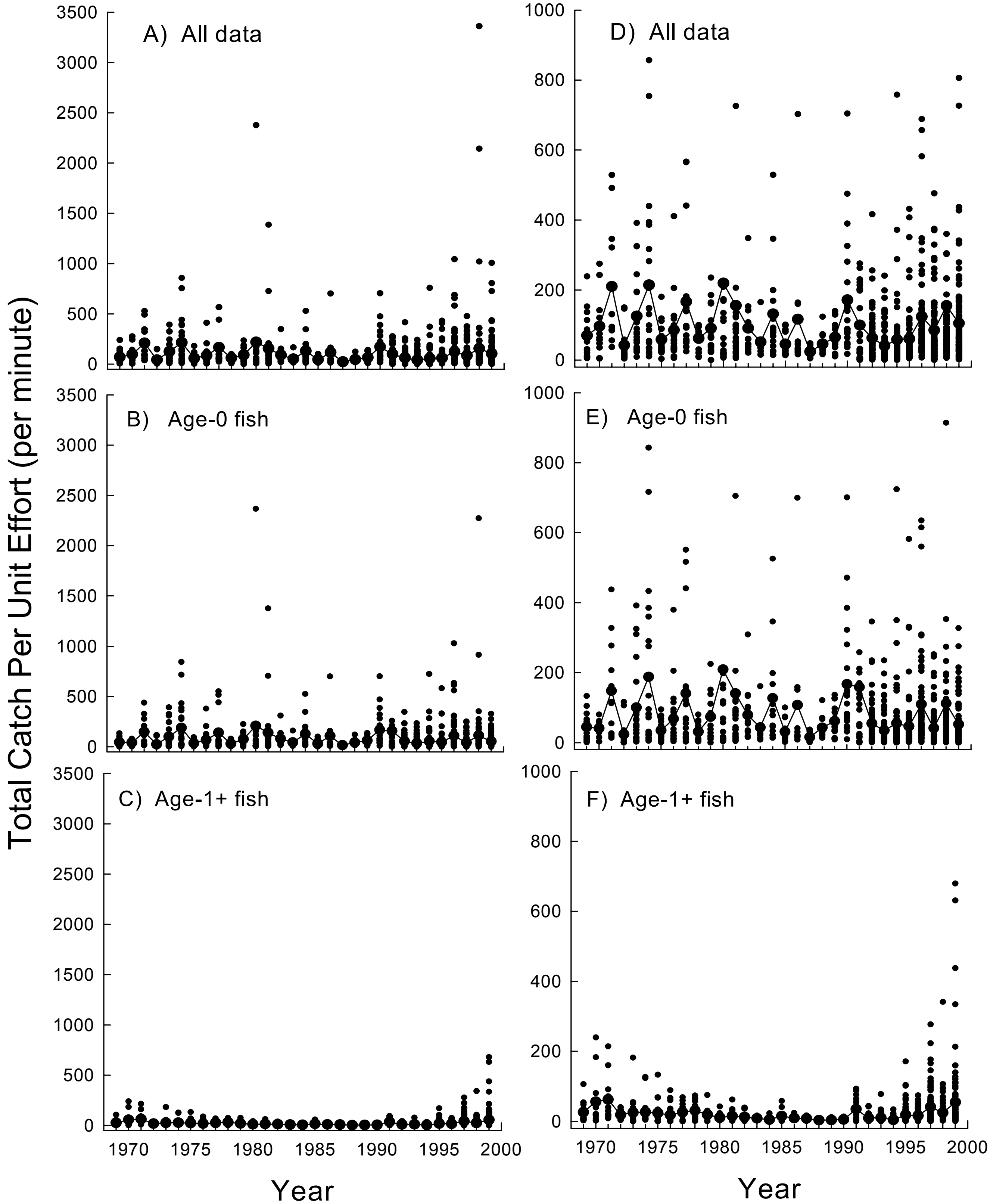

Figure 12. Age-class-specific metric scores for total catch-per-unit-effort in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999. Panels D-F represent lower range of values (i.e., a subset of the data) for panels A-C.

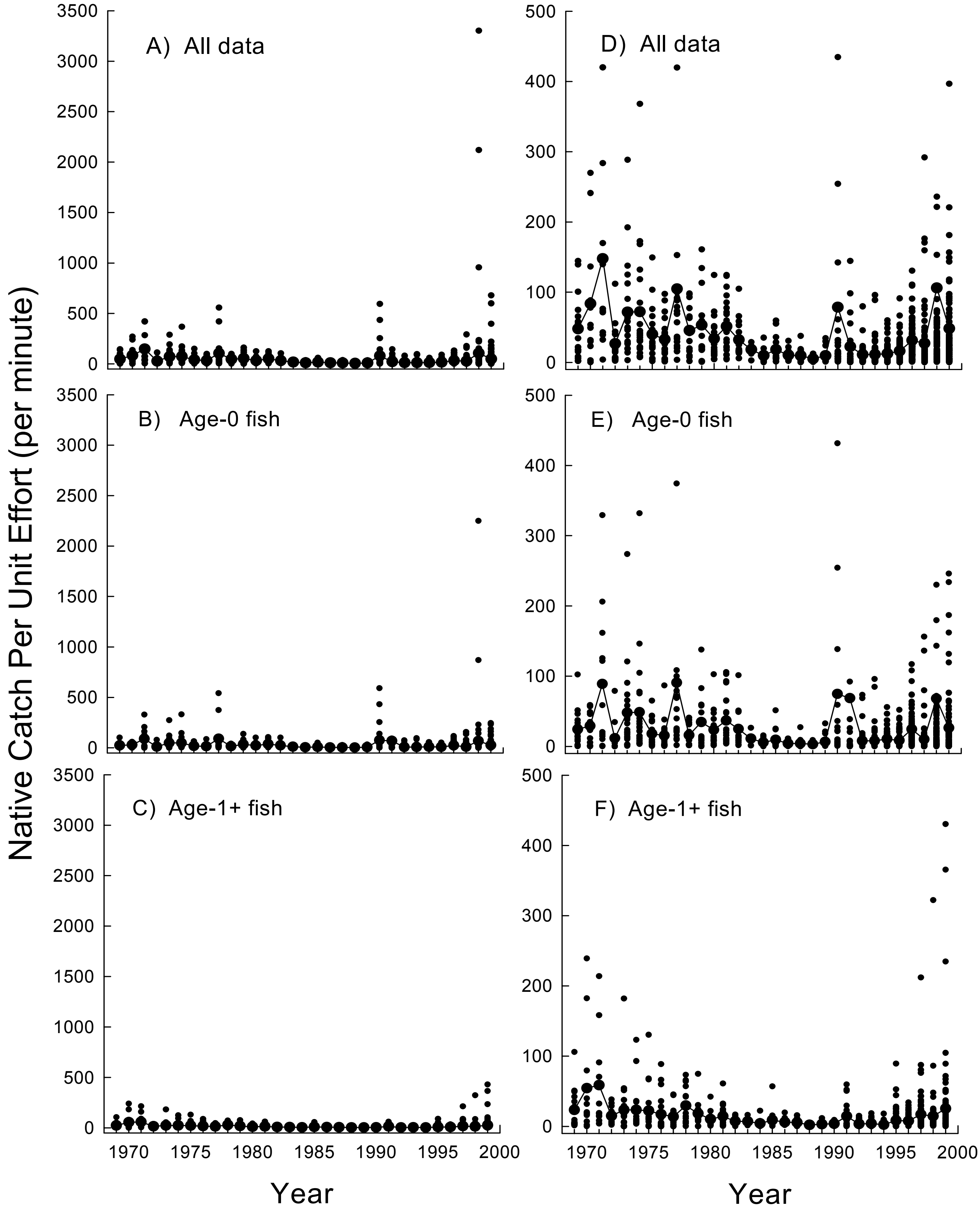

Figure 13. Age-class-specific metric scores for native catch-per-unit-effort in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999. Panels D-F represent lower range of values (i.e., a subset of the data) for panels A-C.

Table 3. Age-class-specific metric ranges/values for the standardized scoring values for the Karr approach. For metric type, "+" = positive metric and "-" = negative metric. When two conditions are given, both must be met.

Metric (type)	Age class	Values for "5"	Values for "3"	Values for "1"	Values for "0"
# intolerant spp. (+)	0	≥ 3	2	1	0
	1+	≥ 3	2	1	0
	All	≥ 3	2	1	0
# benthic spp. (+)	0	≥ 3	2	1	0
	1+	≥ 3	2	1	0
	All	≥ 3	2	1	0
# phytophilic spp. (-)	0	0	1	2	≥ 3
	1+	0	1	2	≥ 3
	All	0	1	2	≥ 3
# native spp. (+)	0	> 6	4-6	1-3	0
	1+	> 6	4-6	1-3	0
	All	> 6	4-6	1-3	0
# non-indigenous spp. (-)	0	0-1	2-3	4-5	≥ 6
	1+	0-1	2-3	4-5	≥ 6
	All	0-1	2-3	4-5	≥ 6
# native cyprinid spp. (+)	0	≥ 3	2	1	0
	1+	≥ 3	2	1	0
	All	≥ 3	2	1	0
% carnivores (+)	0	> 62	> 31, ≤ 62	> 0, ≤ 31	0
	1+	> 62	> 31, ≤ 62	> 0, ≤ 31	0
	All	> 20	> 10, ≤ 20	> 0, ≤ 10	0
% omnivores (-)	0	0-30	> 30, ≤ 60	> 60, ≤ 90	> 90
	1+	0-25	> 25, ≤ 50	> 50, ≤ 75	> 75
	All	0-8	> 8, ≤ 16	> 16, < 24	≥ 24

Table 3. (continued)

% tolerant individuals (-)	0	≤ 27	> 27, < 54	> 54, < 81	≥ 81
	1+	≤ 8	> 8, ≤ 16	> 16, < 24	≥ 24
	All	≤ 8	> 8, ≤ 16	> 16, < 24	≥ 24
% non-indigenous ind. (-)	0	0-33	> 33, ≤ 67	> 67, ≤ 99	> 99
	1+	0-30	> 30, ≤ 60	> 60, ≤ 90	> 90
	All	0-17.7	> 17.7, ≤ 35.3	> 35.3, ≤ 53	>53
Total CPUE (+)	0	≥ 170	≥ 85, < 170	> 0, < 85	0
	1+	≥ 58.7	≥ 29.3, < 58.7	> 0, < 29.3	0
	All	≥ 216	≥ 108, < 216	> 0, < 108	0
Native CPUE (+)	0	≥ 52.7	≥ 26.3, < 52.7	> 0, < 26.3	0
	1+	≥ 33.3	≥ 16.7, < 33.3	> 0, < 16.7	0
	All	≥ 82	≥ 41, < 82	> 0, < 41	0

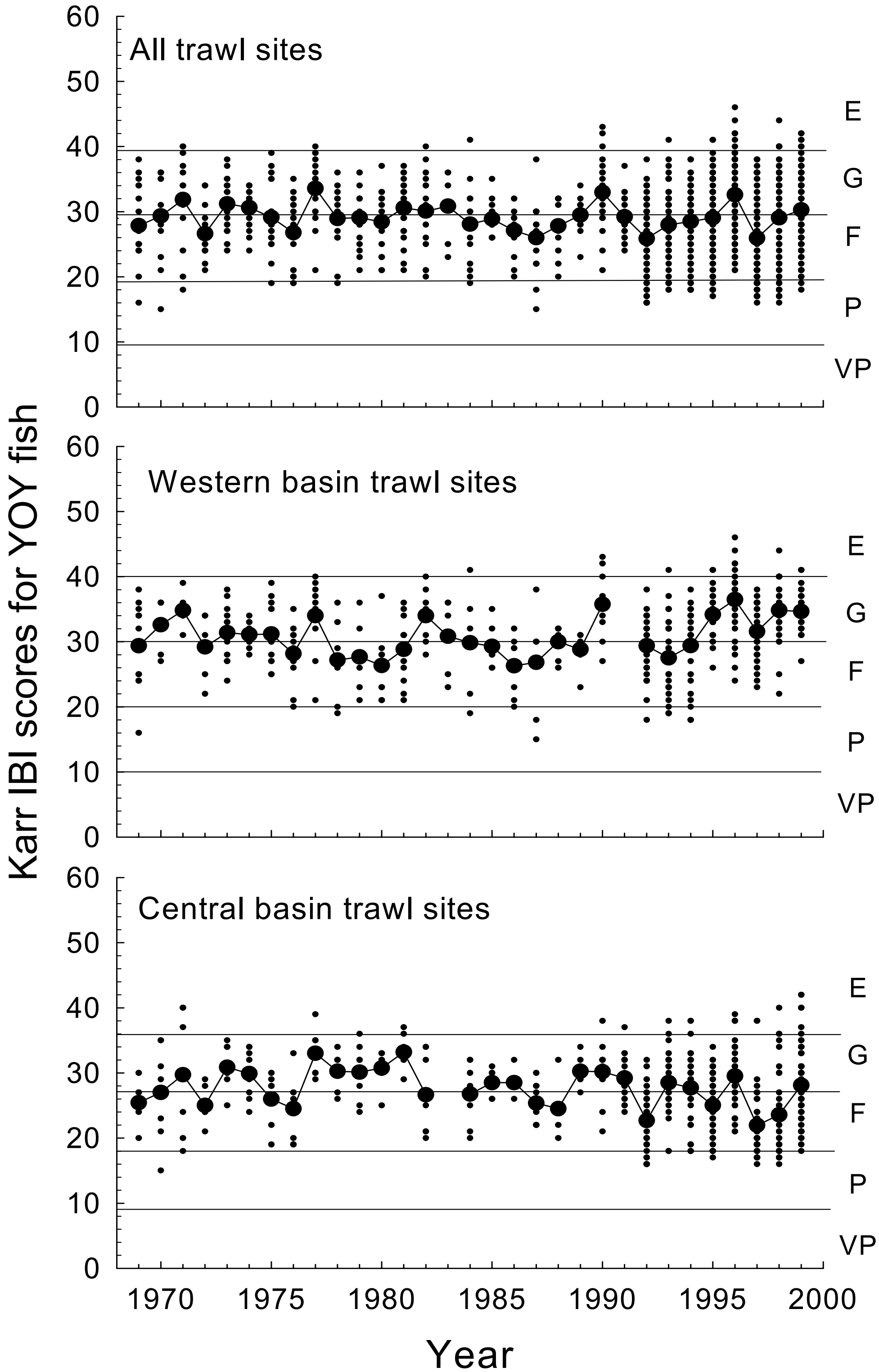

Figure 14. Basin-specific Karr IBI scores for YOY fish in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999. Integrity classifications: “E” = Excellent, “G” = Good, “Fair” = Fair, “P” = Poor, “VP” = Very Poor.

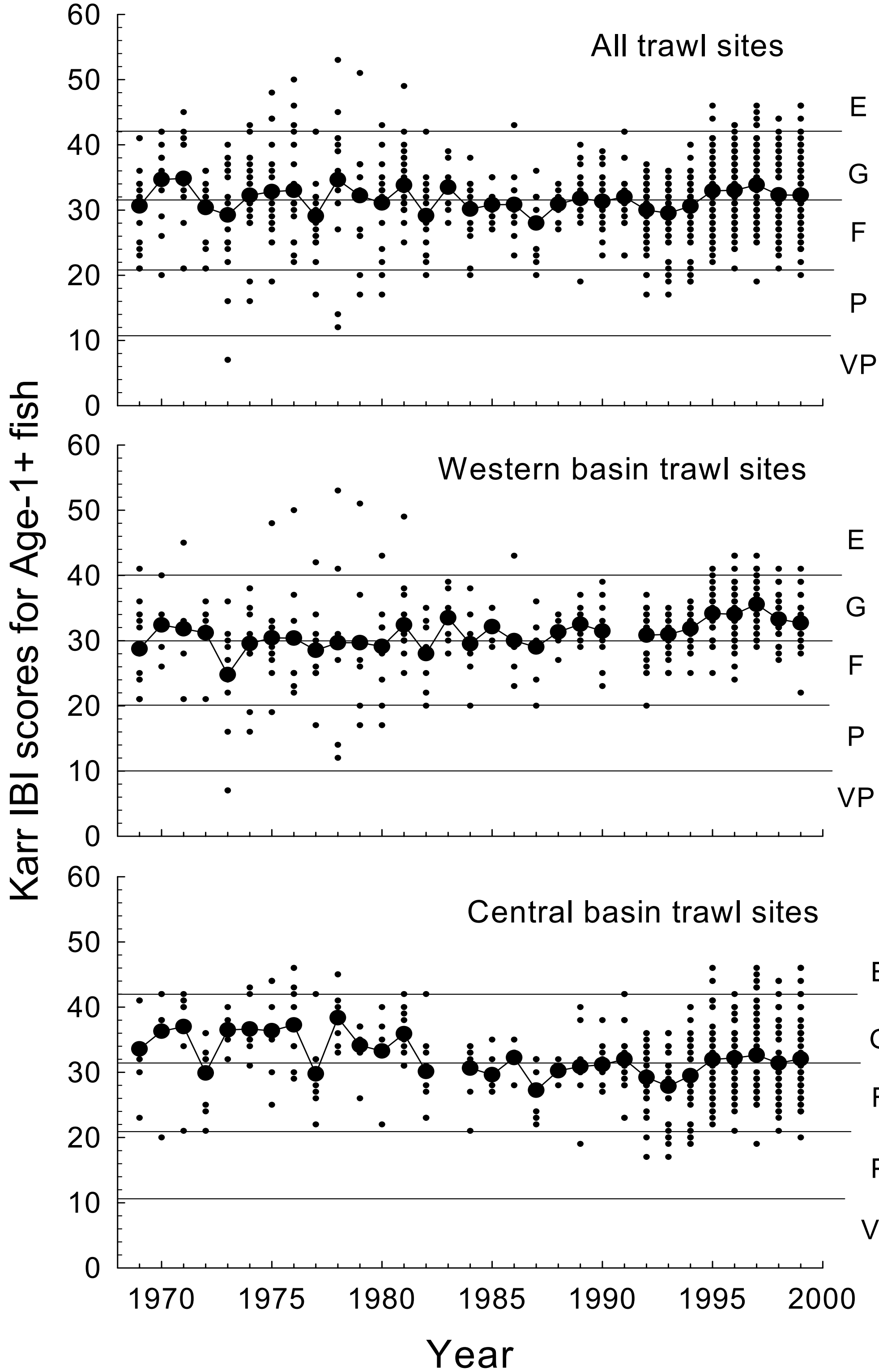

Figure 15. Basin-specific Karr IBI scores for age-1+ fish in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999. Integrity classifications: “E” = Excellent, “G” = Good, “Fair” = Fair, “P” = Poor, “VP” = Very Poor.

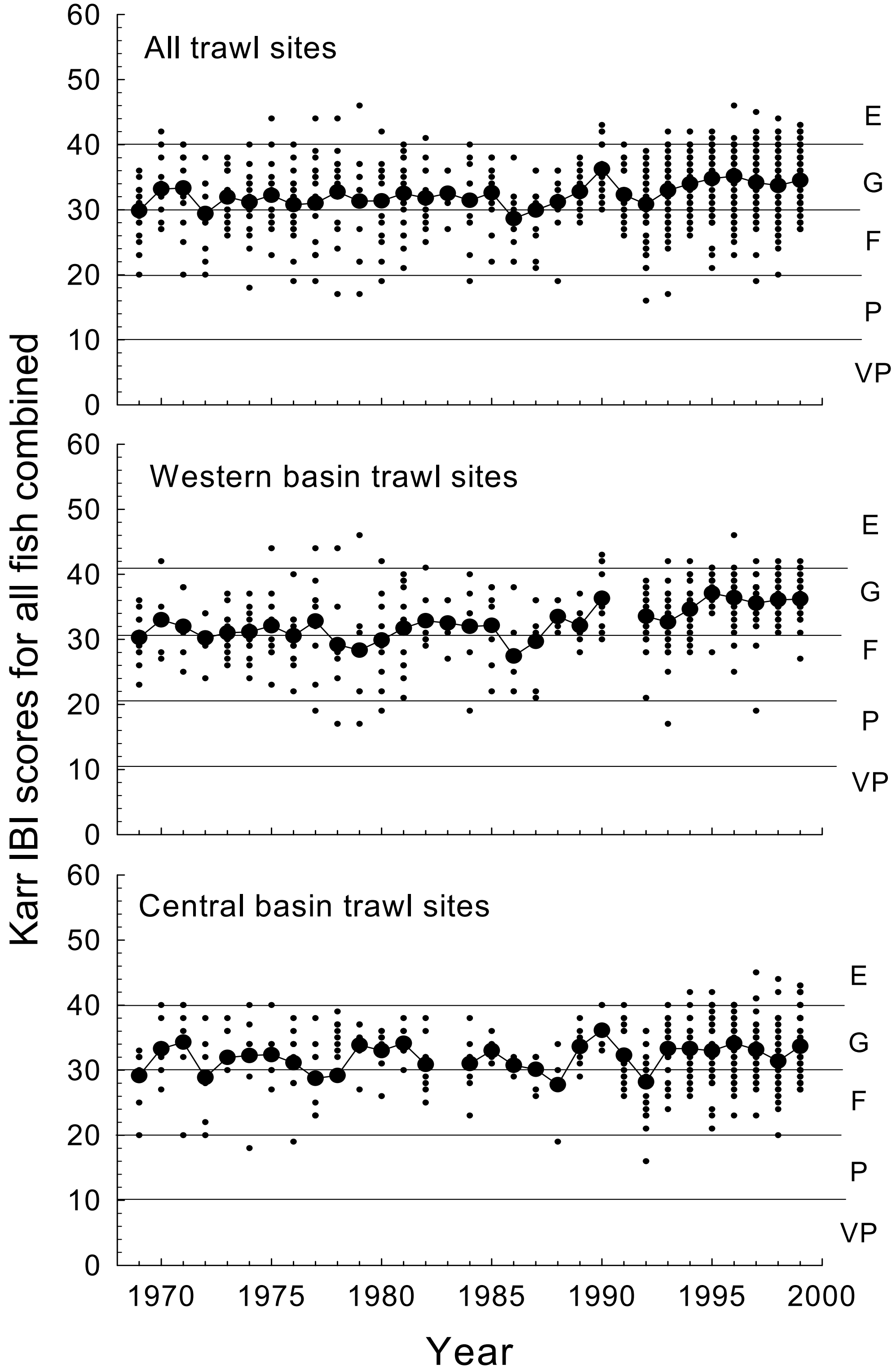

Figure 16. Basin-specific Karr IBI scores for all fish in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999. Integrity classifications: "E" = Excellent, "G" = Good, "Fair" = Fair, "P" = Poor, "VP" = Very Poor.

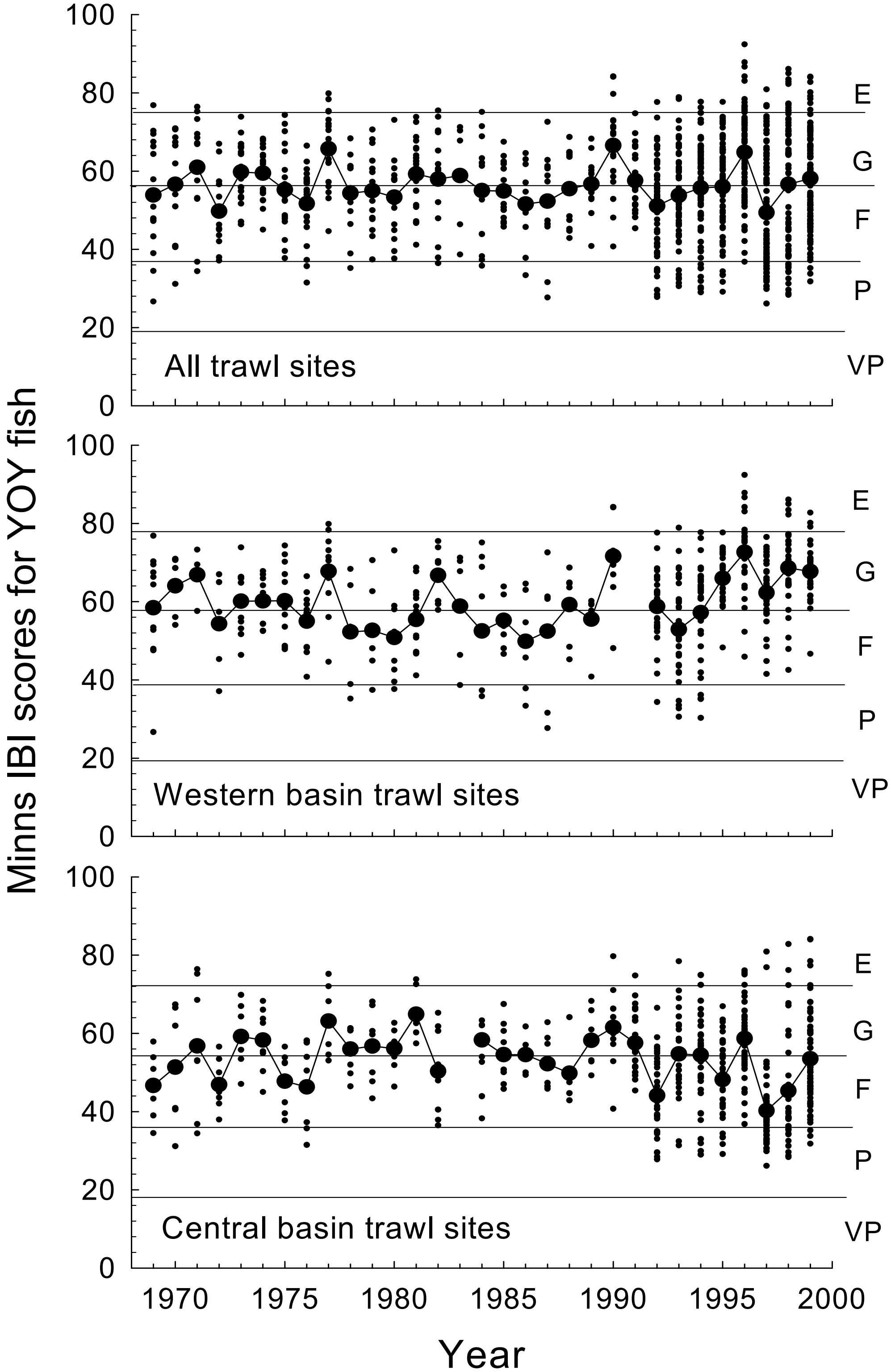

Figure 17. Basin-specific Minns IBI scores for YOY fish in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999. Integrity classifications: "E" = Excellent, "G" = Good, "Fair" = Fair, "P" = Poor, "VP" = Very Poor.

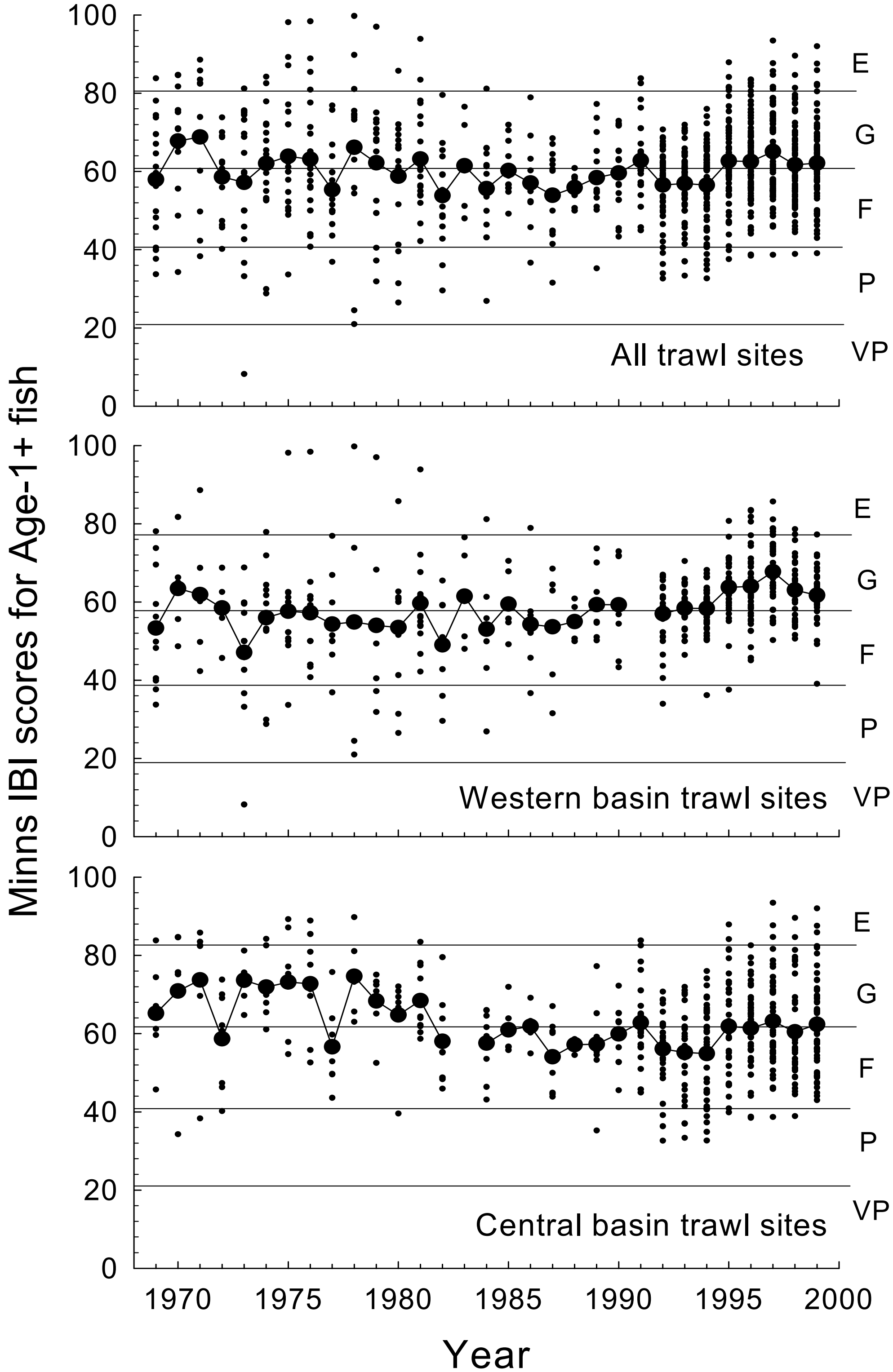

Figure 18. Basin-specific Minns IBI scores for age-1+ fish in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999. Integrity classifications: “E” = Excellent, “G” = Good, “Fair” = Fair, “P” = Poor, “VP” = Very Poor.

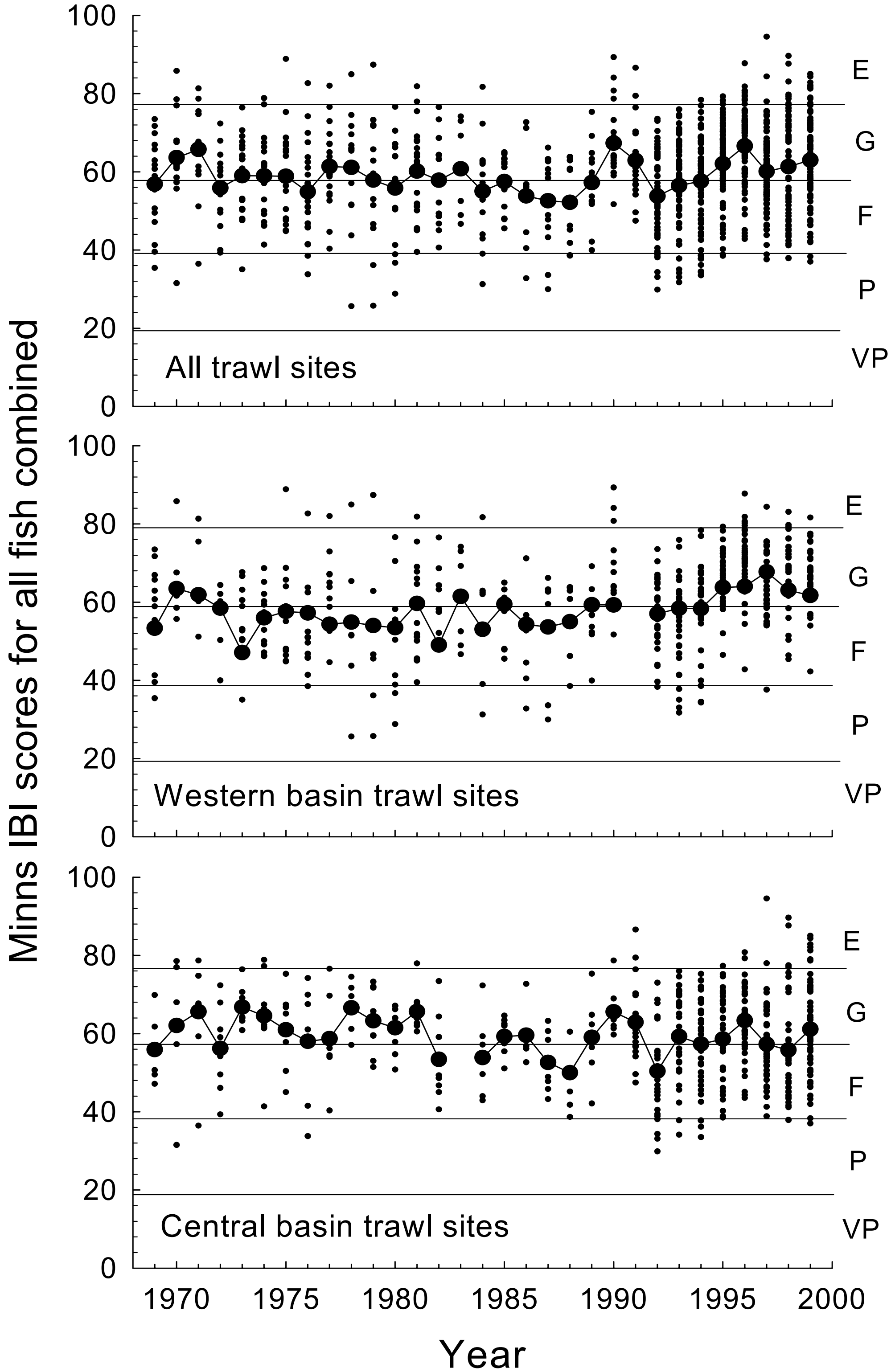

Figure 19. Basin-specific Minns IBI scores for all fish in individual bottom trawls (small filled circles) and yearly averages (large filled circles) for offshore Lake Erie for September/October 1969-1999. Integrity classifications: "E" = Excellent, "G" = Good, "Fair" = Fair, "P" = Poor, "VP" = Very Poor.

Discussion

During the three decades encompassed by this data set (1969-2000), there have been significant changes in the Lake Erie ecosystem. With the passage of the Great Lakes Water Quality Agreement in 1972, phosphorus loading to Lake Erie and possibly lakewide productivity have declined markedly (Dolan 1993). Food web structure has also changed with many successful species invasions during the past few decades (e.g., round goby *Neogobius melanostomus*, zebra mussel *Dreissena polymorpha*, the zooplankter *Bythotrephes cederstroemi*, etc...; Mills et al. 1993). With the magnitude/importance of these major environmental changes in the Lake Erie ecosystem, there is evidence of rehabilitation and recovery of Lake Erie' fish assemblage (Ludsin et al. 2001).

In fact, the results of this effort to construct an IBI for the offshore fish assemblage in Lake Erie provide some support for this. The individual indicator metrics used in this index appear to be fairly sensitive to environmental change. Multiple metrics (i.e., number of intolerant species, number of phytophilic species, % carnivorous individuals, % tolerant individuals) show clear evidence of system recovery. Other metrics (i.e., number of native species, number of native cyprinids, % omnivorous individuals, total CPUE, and native CPUE) show little evidence of improvement until the 1990s, at which point their appears to be positive trends associated with the metrics. However, the three remaining metrics (i.e., number of exotic species, % exotic individuals, % omnivorous individuals) show trends associated with reduction in system integrity (i.e., degradation). The exotic metrics are driven by common exotic species such as white perch and round goby (a very recent invader). Despite these last few metrics, the trend appears to be one rehabilitation and recovery for the offshore fish assemblage. Most importantly, each of these metrics appears to have enough range of variability such that they are sensitive enough to detect major environmental changes, but not so sensitive that important environmental signals are masked by natural variability.

While total IBI scores showed no apparent trend during the first two decades of sampling, there has been a consistent increase in IBI scores for both YOY and age-1+ fishes during the 1990s, particularly in the western basin. Thus, this IBI appears to be somewhat sensitive to environmental changes in the Lake Erie ecosystem. Overall, most IBI scores fell into the Good and Fair ranges for site integrity. This is not that surprising given that the offshore zone of Lake Erie can be thought of as being an integrator of processes, including its own inherent drivers. While it is certainly influenced by nearshore processes and river plumes, it is also less directly influenced by anthropogenic effects than nearshore areas of the lake.

Issues associated with the IBI

As noted earlier, we have no reference condition representative of pristine conditions to compare these results with. Thus, we followed the approach used by other researchers who have faced this problem (Minns et al. 1994, Hughes et al. 1998) and made the assumption that some portion of our trawl site/year combinations were representative of healthy fish assemblages. Despite our lack of knowledge regarding pristine, pre-history conditions in Lake Erie, care must still be taken to maintain the stringency of the IBI relative to its classification of habitat integrity. While Lake Erie is demonstrating resilience from decades of anthropogenic influence (Makarewicz and Bertram 1991, Ludsin et al. 2001), we must be conservative in our classification of habitat integrity (e.g., Thoma 1999). Thus, as new years of data become available, one might consider using them to rescale this metric – with the assumption that environmental conditions have continued to improve.

In general, the central basin showed no consistent trends for the IBI scores. While this is not inconsistent with previous research (Ludsin et al. 2001), one must also consider another potential factor that might limit the effectiveness of an IBI based upon bottom trawls in the central basin. In contrast with the uniformly shallow western basin, the central basin is much deeper, in which case, their may be significant gear biases driving this index. In the future, a combination of midwater and bottom trawls may be a better way of deriving an IBI for the central basin.

As noted earlier, by constructing IBIs based upon both the Karr and Minns approaches, we would be able to directly compare their results. Using the Minns approach may result in a more accurate representation of the data than the traditional integer-based Karr approach due to reductions in metric variance (Hughes et al. 1998), avoidance of range gaps that can result from the use of integer values (Minns et al. 1994). The Minns approach should also more accurately reflect total variation in indicator metrics, given that lumping potentially quite different results into the same broad score category (in the Karr approach) likely buries much of the actual variation. That said, a proponent of the Karr approach might assert that metric scores should only be used to make broad generalizations, such as 'the number of species differs [significantly or slightly or not-at-all] from that found in a similar, pristine habitat'. In other words, by using a continuous scale and scoring small variations differently we may, in effect, be reading more information into the data than their resolution warrants.

Ultimately, both approaches correlate quite well, indicating that either method should provide comparable insight into system integrity. That said, we favor the Minns approach for this IBI because of the lack of good reference sites. Karr worked with small streams, and had good reference sites from which to draw conclusions about his scoring categories. In contrast, the western and central basins of Lake Erie have been heavily impacted. Without good reference sites, the IBI scores have only relative meaning. Thus, it seems appropriate to preserve as much of the actual variation as possible. By preserving the variation, the Minns approach allows for more accurate comparisons between trawl sites, which is desirable when the scores have only relative meaning due to a lack of good reference sites in Lake Erie.

Finally, by using Karr's approach as well as Minns' approach, we can maintain compatibility with the Ohio EPA's nearshore and lacustuary IBIs (Thoma 1999). Ultimately, this will allow for both comparison and synthesis of our understanding of the integrity of the Lake Erie fish assemblage. Also, the protocols for the ODNR trawl surveys are still in place, which provides a significant advantage relative to future application of this IBI. In other words, data that were used in IBI development are collected as part of current ODNR assessment efforts, allowing annual evaluation of Lake Erie's offshore fish assemblage using this IBI.

Benefits

The development and evaluation of an IBI for the offshore fish assemblage of Lake Erie provides the following benefits to the State of Ohio and Lake Erie proper:

– The IBI is useful as an assessment tool relative to water quality and habitat availability for Lake Erie's offshore fish assemblage and appears to be a sensitive indicator of environmental change. Because data required for the IBI are collected within the scope of normal ODNR sampling efforts (ongoing since 1969), annual IBI estimates can be calculated, allowing tracking of the recovery of Lake Erie fish assemblages.

– Due to complementarity in IBI construction, offshore IBI results may well comparable with the Ohio EPA's nearshore and lacustuary IBIs, allowing for a more synthetic understanding of the overall integrity of the Lake Erie fish assemblage.

– The IBI for offshore fish assemblages in Lake Erie will be incorporated into the *2003 Lake Erie Quality Index*, which has been developed by member agencies of the Ohio Lake Erie Commission. With the integration of individual water quality metrics, lake managers will have an unprecedented understanding of the health of this ecosystem.

– This research also benefits the mission of the Lake Erie LaMP 2000, which emphasizes the need to develop procedures to monitor ecosystem integrity and gauge the success of management strategies. Efforts described herein are complementary with these ongoing efforts and may well provide a more complete understanding of what endpoint fish assemblages can be expected/managed for in Lake Erie. Essentially, the IBI provides a tool that can be used to assess 1) the integrity of offshore regions of the Lake Erie ecosystem in all jurisdictional waters and 2) how fish assemblages are responding to management strategies resulting from ecosystem objectives set by the Lake Erie LAMP 2000.

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