Correspondence between Spatial Patterns in Fish Assemblages in Ohio Streams and Aquatic Ecoregions

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ABSTRACT / Land classification systems can be useful for assessing aquatic ecosystems if relationships among them exist. Because the character of an aquatic ecosystem depends to a large extent upon the character of the landscape it drains, spatial patterns in aquatic ecosystems should correspond to patterns in the landscape. To test this hypothesis, the US state of Ohio was divided into four aquatic ecoregions based on an analysis of spatial patterns in the combination of land-surface form, land use, potential natural vegetation, and soil parent material. During the period July–October 1983, fish assemblages were sampled in 46 streams that were representative of the ecoregions, and that had watersheds relatively undisturbed by human activities. Spatial patterns of the fish assemblages were examined relative to the ecoregions; distinct regional differences were identified. The assemblages differed most between the Huron/Erie Lake Plain region and the Western Allegheny Plateau region; assemblages in the Eastern Corn Belt Plains and the Erie/Ontario Lake Plain–Interior Plateau regions were intermediate. This pattern also reflects the gradient in landscape character as one moves from the northwest to the southeast of Ohio.

The US Environmental Protection Agency's revised Water Quality Standards Regulation (Federal Register 1983) reflects a change in the fundamental direction of federal and state water quality programs. For the past decade, these programs had a "water pollution control" focus aimed at reduction of pollution discharges, especially through the national effort to build wastewater treatment plants and to attain a zero discharge of toxic materials. This approach did not assess whether and to what extent receiving systems would benefit. The new direction is toward "attainable water quality" with greater emphasis on assessing the quality of receiving systems and what is realistically attainable.

Although the basic elements of the new approach have an apparently sound scientific basis, the specific scientific knowledge and techniques required for implementation have not been fully developed. One major need is to clarify the regional patterns of attainable quality and uses. We suggest doing this by characterizing minimally disturbed streams that are representative of a region as a measure of what might be attainable in that region. Our approach defines aquatic ecosystem regions (using a land classification system). Then the regions can be characterized with data on the biota, chemistry, and physical habitat from groups of relatively undisturbed streams/watersheds in each region. This approach is appropriate if spatial patterns in stream ecosystems correspond with regions delineated through land classification.

One method of identifying and characterizing regional patterns of aquatic ecosystems is through the spatial analysis of a set of site-specific characteristics and their distribution. Several investigators have produced fish faunal regions using this approach (Hawkes and others 1986, Legendre and Legendre 1984, Pflieger 1971, Pflieger and others 1981). Although realistic patterns are produced, it is a time-consuming data-intensive process. It develops regions specific to the property analyzed, for example, fish faunal regions, as opposed to ecosystem regions. So far, this approach has been applied only on a local scale, and would be prohibitive at the national level.

As an alternative, we suggest that spatial patterns in aquatic ecosystems can be delineated from mapped patterns of terrestrial characteristics of their watersheds. Aquatic ecosystems derive their character primarily from the watersheds they drain (Hynes 1975,

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Karr and Schlosser 1978, Likens and Bormann 1974, Warren 1979). The physical character of a stream is controlled by the physical characteristics of its watershed, for example, land-surface form, geology, soil, and climate. Similarly, the stream's chemical character depends upon the interaction of precipitation falling on its catchment with these same terrestrial characteristics, modified by land use. The distribution and abundance of organisms are determined in part by the physical and chemical habitats created in these watersheds. To some extent their spatial patterns reflect spatial patterns in the physical–chemical character of the streams and watersheds. If streams depend on watersheds for their character, then stream systems can be classified according to mapped patterns of terrestrial characteristics.

Few, to our knowledge, have attempted to determine how well the spatial patterns in aquatic ecosystems correspond with patterns produced by land classification systems. It is certainly logical to expect a correspondence (Jarman 1984, Platts 1979), and Bailey (1983) has advocated that land classification systems be treated as hypotheses that must be tested and validated.

As a result, in several state case studies, we examined how closely patterns of various stream characteristics correspond to regions as a way of verifying and characterizing them. In one case study in Ohio, after delineating the regions, we selected and sampled streams for physical and chemical habitat, and fish and macroinvertebrate assemblages. In this article, we briefly describe how the regions were delineated in Ohio, and in more detail the correspondence between them and spatial patterns in fish assemblages.

Methods

Aquatic Ecoregions in Ohio

National maps have been compiled for a variety of climatic and terrestrial characteristics including land-surface form, soil, surficial and bedrock geology, potential natural vegetation, land use, runoff, precipitation, solar radiation, and temperature. Some of these maps have been integrated to produce national maps delineating regions of similar ecological character. Most notable of these are Bailey's (1976) map of ecoregions of the United States, the US Department of Agriculture's (USDA 1981) map of agricultural potential and Fenneman's (1928 and 1946) Physical Divisions of the United States. Bailey presents an ecoregion classification system that divides the country into Domains, Divisions (both based on climate), Provinces (based on vegetation and soil), and Sections (based on climax vegetation). The USDA map is based primarily on soil characteristics and resultant agricultural potential, and depicts Land Resource Regions and Major Land Resource Areas. Fenneman derives his classification from land-surface form, dividing the country into Major Divisions, Provinces, and Sections. Others have mapped smaller areas of similar ecological character (Shirazi 1984, Rowe and Sheard 1981).

We followed this general approach in delineating spatial patterns in aquatic ecosystems, an approach that Rowe and Sheard (1981) call the landscape method. However, we differ in that we delineated spatial patterns in aquatic ecosystems by examining the pattern produced by the combination of selected terrestrial features instead of using single features at a particular level of resolution as others have done. We did this because the character of aquatic ecosystems reflects the combination of effects of watershed characteristics. It would have been ideal if we had been able to identify several independent characteristics that have a dominant influence. At most temporal and spatial scales, however, most of the characteristics are interdependent. Land-surface form is influenced by geologic processes and climate; soil is influenced by geologic parent materials, land-surface form, vegetation, and climate; and vegetation is influenced by soil, land-surface form, and climate. Consequently, we delineated spatial patterns of relative homogeneity of terrestrial characteristics that should encompass corresponding homogeneous regions of aquatic ecosystems. Crowley (1967) and Bailey (1976) suggest calling these ecosystem regions *ecoregions;* consistent with that suggestion, we call the hypothesized homogeneous regions of aquatic ecosystems *aquatic ecoregions.* We believe that the approach and the map will also be useful for terrestrial analyses and assessments as well.

Our approach for defining aquatic ecoregions consisted of several steps; the first were necessarily qualitative and the latter more quantitative. Initially, we obtained small-scale maps of factors that either cause regional variations in ecosystems (soil, land-surface form, climate, surficial geology) or tend to integrate causal factors [potential natural vegetation and land use (Figure 1)]. Most useful were maps of land use (Anderson 1970), land-surface form (Hammond 1964), potential natural vegetation (Kuchler 1964), and soil (Ohio DNR 1973). Then these maps were analyzed in combination; regions that exhibited a relatively great amount of spatial homogeneity in the combination of characteristics were sketched out and the characteristics that typified each were tabulated (Table 1). Third, ecoregion boundaries and boundaries of most

Table 1. Summary of geographic characteristics descriptive of various aquatic ecoregions in Ohio. Note the transition in characteristics from the Huron/Erie Lake Plain to the Western Allegheny Plateau.

	Huron/Erie Lake Plain	Eastern Corn Belt Plains	Erie/Ontario Lake Plain–Interior Plateau	Western Allegheny Plateau
Land-surface form (Hammond 1964)	Flat plains	Smooth plains	Irregular plains and tableland	Hills
Land use (Anderson 1970)	Cropland	Cropland	Mosaic of cropland, woodland, and forest	Mosaic of woodland and forest with some cropland and pasture
Soil parent material (Ohio DNR 1973)	High lime glacial lake sediments	High lime glacial drift	Low lime glacial drift	Sandstone and shale
Potential natural vegetation (Kuchler 1964)	Elm–ash forest	Beech–maple forest	Beech–maple and oak–hickory forest	Appalachian oak and mixed mesophytic forest

typical areas of ecoregions were delineated using map overlays and a qualitative assessment of the relative accuracy and level of generality of each map. In some areas, one or two particular maps were most useful, and in other areas other maps were more useful. The most typical area of each ecoregion was defined where all four tabulated predominant characteristics occurred in combination (Figure 2). Boundaries distinguishing the aquatic ecoregions were drawn to include areas where most, but not all, of the characteristics typifying a region occurred in combination. Such areas were considered generally typical of their ecoregions.

The delineation of ecoregions began as part of a cooperative project with the Ohio Environmental Protection Agency to determine reasonably attainable water quality and biotic conditions in their streams. At that time, one of the ecoregions in that state was determined to be discontinuous. Later, when ecoregions were delineated for the entire conterminous United States, it became apparent that the region was not discontinuous. Rather, it comprised a portion of the Erie/Ontario Lake Plain that extends well into Pennsylvania and New York, and a portion of the Interior Plateau that occurs primarily in Kentucky and Tennessee. However, because the sampling design had been defined relative to four ecoregions in Ohio, and because the terrestrial characteristics in Ohio of these parts of the two ecoregions were relatively similar, the data have been analyzed as they relate to four ecoregions.

Candidate Watersheds and Study Sites

The initial step in selecting watersheds and sites for data collection was to outline all watersheds that fell completely within the most typical or generally typical areas of each ecoregion on a 1:500,000-scale topographic map. This selected watersheds that represented their respective ecoregions and did not aggregate characteristics from different ecoregions or areas of ecoregions. We selected a range of watershed sizes. The smallest watersheds were those expected to have permanent flow. The largest watersheds were those that could be contained within a generally typical or most typical portion of an ecoregion. After considering mean annual runoff patterns in Ohio, we selected the minimum stream size to be that relative to a watershed of about 25 km^2. The largest streams were relative to watersheds of 250–750 km^2. The number of watersheds chosen in each ecoregion was roughly proportional to each ecoregion's area.

Using information on point and nonpoint sources of pollution, we eliminated those watersheds that appeared to be heavily impacted and retained those with minimal impact. The source materials used for this sorting process included:

1) Maps of human population density and census data from towns and cities.
2) Maps of land use, past and present strip mining, and streams impacted by strip mines.
3) A watershed disturbance ranking compiled from the land use and strip-mining maps. For each watershed, a disturbance ranking was calculated by multiplying the percent area in each land use class by a disturbance value arbitrarily assigned to each class. In the absence of an appropriate precedent, the ranking was based on an estimate of relative probable impact (for example, strip mining was assigned a value of 10; forest, 0; cropland, 4; industrial, 7; and residential, 4).

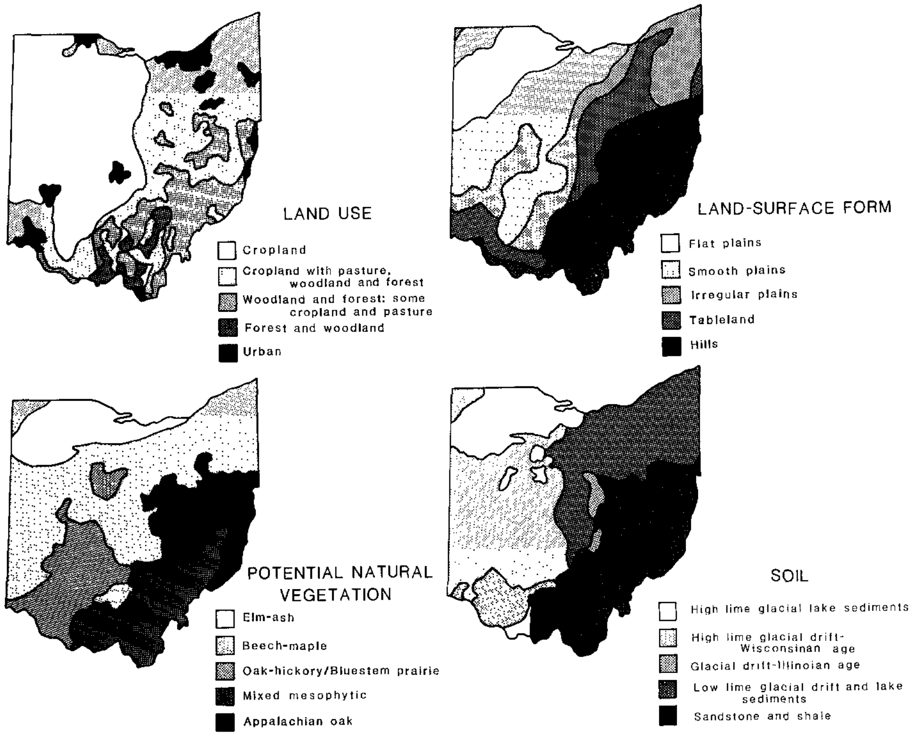

Figure 1. Maps of land use, land-surface form, potential natural vegetation, and soil parent material for Ohio used to delineate aquatic ecoregions in Ohio.

4) A list of point sources occurring in the candidate watersheds compiled from Ohio EPA files of known municipal and industrial point sources.

Using this approach, we selected sets of least-impacted candidate watersheds in the most typical and generally typical areas of each region and in some areas that straddled regional and most typical boundaries. We stress that these watersheds are not pristine, but they represent the least-impacted conditions in an area, and they should therefore have the least-impacted streams from a regional, or macro, viewpoint. The character of these streams should reflect the reasonably attainable quality for streams within that particular region, given current land use practices.

Final Selection of Study Sites

Final selection was based on field examination of each of the candidate watersheds and streams. Each candidate stream site, and the watershed immediately upstream from the site, was photographed from altitudes approximately 600 and 1500 m (2000 and 5000 ft) above ground. Each candidate site and two or three additional locations immediately upstream or downstream were inspected from the ground. Factors examined included the amount and age of stream channelization, amount and size of riparian canopy, channel morphology, water volume, bottom substrate size and heterogeneity, obvious color or odor problems, the amount of large woody debris in the channel, and the representativeness and accessibility of the site. Locations of the sampled watersheds are shown in Figure 2 and the number of candidate sites per region and their average watershed areas are summarized in Table 2.

Field Sampling

A total of 42 sites were sampled three times and four sites were sampled twice during July–October 1983. One river was sampled with a boat-mounted electrofisher, eight creeks were sampled with a backpack electrofisher, and the other streams were sampled with a towed electrofisher. Whenever possible the towed unit was used because of its greater effectiveness. Sites sampled by boat, towboat, or backpack were fished for a distance of approximately 500, 300, or 200 m, respectively, with the availability of microhabitats determining the actual distance fished. All captured fish were identified to species, enumerated, and anomalies noted.

Data Analysis

We analyzed the fish data in several ways to determine relationships between patterns in the fish assemblages and the aquatic ecoregions. *First,* we identified regional differences in the abundance of individual species using a Duncan's multiple range test (Steel and Torrie 1980) and determined characteristics that seemed to typify a particular region. Since we collected 93 species and hybrids, we would expect regional dif-

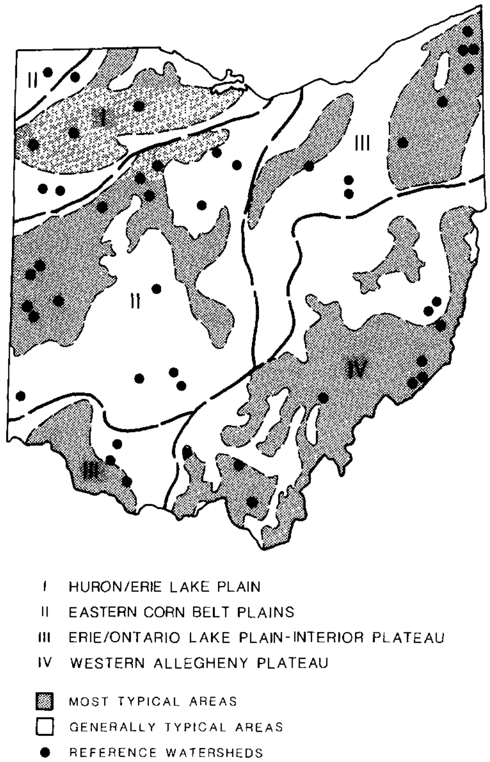

Figure 2. Map of aquatic ecoregions in Ohio derived from component maps in Figure 1. *Dots* indicate watersheds sampled during this study.

ferences to occur some of the time even though those differences were not real. However, if the group of species that was detectably different in one region displayed a common trait, such as generally being tolerant of siltation, then the regional differences would be of some importance. We also examined the group of species in each region that accounted for >10% by numbers in any collection to determine whether certain kinds of fish were typically dominant in one region.

Second, we selected several indices of fish assemblages and examined the within-region and between-region variation in those measures using statistics such as medians, ranges, and interquartile ranges (Reckhow 1980). The indices we used were species richness, Karr's index of biotic integrity (IBI), and the fraction of the community that was intolerant of sedimentation and turbidity. To determine tolerance and trophic level (used in another analysis described later) we consulted a variety of references on fishes and attempted to derive a consensus from them (Becker 1983, Carlander 1969 and 1977, Lee and others 1980, Pflieger 1975, Smith 1979, Trautman 1981). We also looked for trends in these measures: did the values systematically change as we moved from one ecoregion to another, and were there consistent patterns from one index to another?

Karr's IBI (Karr 1981, Fausch and others 1984) combines 12 metrics selected to represent various aspects of fish assemblages. The concept that underlies the IBI is that fish assemblages can be described by the combination of certain metrics of the assemblage and that a reasonably unperturbed assemblage represents what might be attained or expected in an area. The metrics used are numbers of species, darter species, sunfish species, sucker species, intolerant species, and individuals, and proportion of green sunfish, omnivores, insectivorous cyprinids, piscivores, hybrids, and diseased individuals. The various metrics that make up the IBI are assigned a "qualitative" measure of goodness: 1 = poor, 3 = fair, and 5 = excellent. Because larger streams naturally support more species than do smaller streams, several metrics must be calibrated for stream size. The following metrics were examined as a function of stream size: number of species, sunfish species, sucker species, darter species, and intolerant species. Number of individuals was examined as a function of fishing effort. Upper boundaries, or maximum richness lines, were drawn by eye for each of these metrics, and intervals were defined for which numeric values of 5, 3, or 1 could be assigned. All other metrics were assigned values given by Fausch and others (1984). Then, individual indices were calculated for each sample and regional summaries were produced and compared.

Third, we used several multivariate analyses to determine whether the patterns in sites grouped by similarity in their fish assemblages corresponded to ecoregion patterns. The multivariate techniques were detrended correspondence analysis (DECORANA; Gauch 1982) and canonical discriminant analysis (SAS Institute 1982). DECORANA (Hill 1979) is an ordination technique that examines the similarity of sites in species space by determining orthogonal axes that maximize variance of sites in species space. It is analogous to reciprocal averaging, but it eliminates the arch or horseshoe effect seen in reciprocal averaging (Gauch 1982). We examined the location of sites based on presence/absence of species along the first three DECORANA axes to determine whether there was any correspondence between the assignment of sites to ecoregions and their locations in species space. We expected that the clearer the correspondence was between sites grouped by ecoregion and sites located along the DECORANA axes, the stronger would be the association between fish assemblages and aquatic ecoregions. If we saw no similarity, aquatic ecoregions would be of no benefit for explaining patterns in fish assemblages.

Table 2. Summary of sampled watershed characteristics in each of the Ohio aquatic ecoregions.

	Regions			
	Huron/Erie Lake Plain	Eastern Corn Belt Plains	Erie/Ontario Lake Plain–Interior Plateau	Western Allegheny Plateau
Number of sites				
Most typical (MT)	3	9	7	6
Generally typical (GT)	3	8	5	2
Boundary between MT and GT	0	1	0	2
Watershed sizes (km^2)				
Mean	124	192	184	262
Median	111	171	137	249
Range	26–290	47–420	23–603	18–715

We used canonical discriminant analysis to quantify how well aquatic ecoregions classified sites based on fish assemblage similarity. Discriminant analysis limits the number of variables (fish species) that can be used as a function of the number of groups (aquatic ecoregions) and the number of units (sites) per group. Our combination of four aquatic ecoregions and 6–18 sites per ecoregion limited the number of fish species we could use to about 20. Also, as the number of variables approaches the upper limit of 20, the discriminatory power increases—the more variables used, the better the ability to classify. There is no explicit rule that can be used to determine the "best" number of variables to use. As the upper limit is approached, the technique begins to "overfit" similar to the way that linear regression "overfits" as the number of independent variables approaches the number of samples measured. We selected ten as the approximate number of species to use in the discriminant analysis, and conducted the analysis five times using darters, suckers, minnows, sunfish, and a trophic guild–tolerance guild combination. Some species were eliminated from the groupings because they were ubiquitous or rare.

We also assigned all species to tolerance and trophic guilds. Tolerance guilds were described earlier. Species were tolerant, moderately tolerant, or intolerant. Feeding guilds were herbivore, insectivore, piscivore, or omnivore. For the trophic guild–tolerance guild discriminant analysis, we combined groupings to produce 12 possible discriminant variables, for instance, tolerant insectivores or intolerant piscivores. Four of the combinations had very few or no fish, so these were not used in the analysis. The discriminant analysis was run on the $\log_{10}$ transformed number of fish in each of the eight remaining discriminant variables.

Results

Individual Species Distributions

The most ubiquitous and abundant species was the bluntnose minnow (*Pimephales notatus*). It often was the most abundant species at sites in all four ecoregions, it was present at all sites, and it displayed no pattern to its distribution related to our ecoregions. Other common species were preferentially dominant in one region or another or in groups of regions, as indicated by the frequency with which they accounted for >10% of a particular sample by relative abundance (Table 3). Most of these species tend to be widely distributed and are quite tolerant of degraded conditions related to turbidity and sedimentation. The green sunfish (*Lepomis cyanellus*) tended to be dominant often in the Huron/Erie Lake Plain (HELP), and occasionally in the Eastern Corn Belt Plains (ECBP) and Erie/Ontario Lake Plain–Interior Plateau (EOLP-IP); the creek chub (*Semotilus atromaculatus*) tended to be dominant in the HELP and the ECBP, and occasionally in the Western Allegheny Plateau (WAP); and the central stoneroller (*Campostoma anomalum*) tended to be dominant in the WAP and occasionally in the EOLP-IP and the ECBP. The striped shiner (*Notropis chrysocephalus*) was often dominant in the WAP and occasionally in the ECBP. With the exception of the lack of pattern for the bluntnose minnow, the general pattern was that the species dominant in the HELP were most dissimilar from those of the WAP.

Regional differences can also be seen by examining whether mean abundances of individual species differed among the various ecoregions based on a univariate comparison of species across regions. Species that were significantly more abundant in the HELP tend to be tolerant or moderately tolerant of sedimen-

Table 3. Dominant species (>10% by numbers) in each Ohio aquatic ecoregion and the fraction of samples in which that species was dominant. Species tolerance relative to sedimentation and turbidity is indicated by T, tolerant; M, moderately tolerant; and I, intolerant.

Species	Tolerance	Huron/Erie Lake Plain	Eastern Corn Belt Plains	Erie/Ontario Lake Plain–Interior Plateau	Western Allegheny Plateau
Bluntnose Minnow (*Pimephales notatus*)	T	0.67	0.69	0.81	0.59
Green Sunfish (*Lepomis cyanellus*)	T	0.47	0.11	0.19	—
Creek Chub (*Semotilus atromaculatus*)	T	0.33	0.50	—	0.17
Fathead Minnow (*Pimephales promelas*)	T	0.20	—	—	—
Gizzard Shad (*Dorosoma cepedianum*)	T	—	—	—	0.14
Blackstripe Topminnow (*Fundulus notatus*)	M	0.13	—	—	—
Greenside Darter (*Etheostoma blennioides*)	I	0.13	—	—	—
Orangethroat Darter (*Etheostoma spectabile*)	M	0.13	—	—	—
Striped Shiner (*Notropis chrysocephalus*)	M	—	0.15	—	0.34
Central Stoneroller (*Campostoma anomalum*)	M	—	0.13	0.11	0.48
Common Shiner (*Notropis cornutus*)	M	—	—	0.11	—
Emerald Shiner (*Notropis atherinoides*)	M	—	—	—	0.24
Rock Bass (*Ambloplites rupestris*)	I	—	—	0.17	—
Longear Sunfish (*Lepomis megalotis*)	I	—	0.27	0.22	0.24

tation and turbidity whereas species that were significantly more abundant in the WAP tend to be intolerant (Table 4). Species significantly more abundant in the EOLP-IP are moderately tolerant and are all gamefish. Species significantly less abundant in the HELP compared with the other three regions tend to be intolerant species (Table 5). Too few species were significantly less abundant in other regions to suggest any other pattern.

Species Richness

Species richness varied from a low of eight at one site in the HELP to a high of 38 at one site in the ECBP. Species richness is often a function of stream size. Because our watersheds ranged in size from 25 to 750 km^2, we examined species richness as a function of watershed area, then looked for regional patterns in species richness–watershed area relationships. We used watershed area as an estimate of stream size because runoff varies little across Ohio, so similar-sized watersheds should produce similar-sized streams. We chose the maximum species richness value for each site as representative of that site's carrying capacity.

We regressed species richness on $\log_{10}$ watershed area for each region, then determined whether slopes and intercepts differed regionally (Figure 3). Slopes were not detectably different (p = 0.05; Neter and Wasserman 1974, SAS Institute 1982). Intercepts were compared by testing for differences among adjusted means. The adjusted means (species richness corresponding to the mean of $\log_{10}$ watershed area, 137 km^2) were lowest in the HELP and highest in the WAP: HELP, 17.8; ECBP, 23.5; EOLP-IP, 23.3; and WAP, 27.7. The difference between the HELP and the WAP was highly significant (p = 0.0006); there was no difference between the ECBP and EOLP-IP; other pairwise comparisons were significant at differing probability levels (Table 6).

Table 4. Species whose mean abundance is significantly higher in one Ohio aquatic ecoregion than in all others based on Duncan's multiple range test on $\log_{10}$ transformed abundances. Tolerances as in Table 3. No species were significantly higher in the Eastern Corn Belt Plains.

Huron/Erie Lake Plain		Erie/Ontario Lake Plain–Interior Plateau		Western Allegheny Plateau	
Common Carp (*Cyprinus carpio*)	T	Black Crappie (*Pomoxis nigromaculatus*)	M	Shorthead Redhorse (*Moxostoma macrolepidotum*)	M
Fathead Minnow (*Pimephales promelas*)	T	Largemouth Bass (*Micropterus salmoides*)	M	River Chub (*Nocomis micropogon*)	I
Black Bullhead (*Ictalurus melas*)	T	Pumpkinseed (*Lepomis gibbosus*)	I	Emerald Shiner (*Notropis atherinoides*)	M
Orangespotted Sunfish (*Lepomis humilis*)	T			Rosyface Shiner (*Notropis rubellus*)	I
				Spotted Bass (*Micropterus punctulatus*)	M
				Banded Darter (*Etheostoma zonale*)	I
				Freshwater Drum (*Aplodinotus grunniens*)	M

Table 5. Species whose mean abundance is significantly lower in one Ohio aquatic ecoregion than in all others based on Duncan's multiple range test on $\log_{10}$ transformed abundances. Tolerances as in Table 3. No species were significantly lower in the Eastern Corn Belt Plains or the Erie/Ontario Lake Plain–Interior Plateau.

Huron/Erie Lake Plain		Western Allegheny Plateau	
Golden Redhorse (*Moxostoma erythrurum*)	M	Yellow Bullhead (*Ictalurus natalis*)	M
Northern Hogsucker (*Hypentelium nigricans*)	I	Green Sunfish (*Lepomis cyanellus*)	T
Striped Shiner (*Notropis chrysocephalus*)	M		
Rockbass (*Ambloplites rupestris*)	I		
Smallmouth Bass (*Micropterus dolomieui*)	I		
Greenside Darter (*Etheostoma blennioides*)	I		
Rainbow Darter (*Etheostoma caeruleum*)	I		
Fantail Darter (*Etheostoma flabellare*)	M		

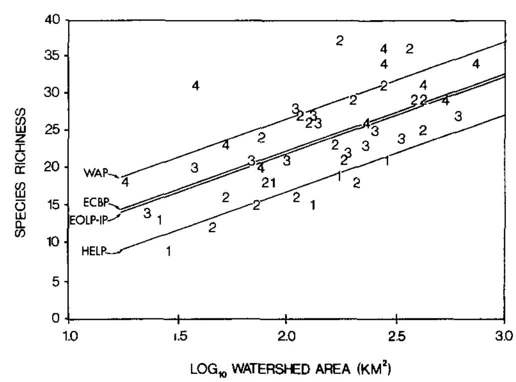

Figure 3. Relationship between maximum species richness and watershed area: *1*, HELP; *2*, ECBP; *3*, EOLP-IP; and *4*, WAP.

Karr Index of Biotic Integrity (IBI)

The IBI ranged from a low of 28 to a high of 50 with a trend for low values in the HELP, high values in the WAP, and intermediate values in the ECBP and EOLP-IP (Figure 4). Examination of individual metrics suggests that a large number of sites had fish with anomalies and had low fractions of insectivorous cyprinids and piscivores. The generally low values for these metrics for most sites tended to result in IBI values that rarely fell into the numeric categories characterized as good or excellent (>48). Most sites would be characterized as fair or poor.

Tolerance/Intolerance Guilds

The fish assemblages in the HELP are characterized by low numbers of both intolerant species and intolerant individuals; the fish assemblages in the WAP have greater numbers of intolerant species (Figure 5a) and greater proportions of intolerant individuals (Figure 5b). There are not great differences among the ECBP, EOLP-IP, and WAP regions. The ECBP has sites that have the highest fractions of intolerant individuals and the greatest numbers of intolerant species.

Detrended Correspondence Analysis (DECORANA)

The spatial pattern suggested by grouping sites by aquatic ecoregion is also reflected in the pattern of sites displayed along the first three DECORANA axes

Table 6. Pairwise differences in adjusted mean species richness between ecoregions. Probability values associated with the Bonferroni *t*-test appear in parentheses below each difference (SAS Institute 1982).

Ecoregion	Huron/Erie Lake Plain	Eastern Corn Belt Plains	Erie/Ontario Lake Plain–Interior Plateau
Eastern Corn Belt Plains	5.7 (0.067)		
Erie/Ontario Lake Plain–Interior Plateau	5.5 (0.108)	0.149 (1.000)	
Western Allegheny Plateau	9.9 (0.0006)	4.21 (0.129)	4.36 (0.167)

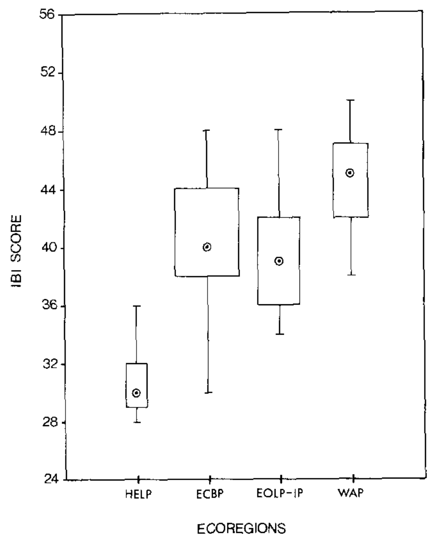

Figure 4. Relationship between Karr's IBI and aquatic ecoregions. The *box plots* include median (⊙), interquartile range (*height of the box*), and range (*length of vertical line*); *width of the box* indicates relative sample size.

based on presence/absence of fish species at the sites. Axis I generally aligns sites along a northwest–southeast gradient with sites grouped in the HELP region distinct from those in the WAP region (Figure 6a). The second and third axes tend to separate ECBP sites from EOLP-IP sites, with a fair amount of interspersion (Figure 6b). A similar pattern is seen if relative abundance data are used.

Note that Figure 6a and b shows separate views of the same three-dimensional graph. For clarity, different perspectives are presented to show the major separation between the HELP and the WAP region along axis I (Figure 6a). ECBP and ELOP-IP sites (not shown) are interspersed in the gap between these two groups in this perspective. The separation of ECBP and EOLP-IP sites is seen best from another perspective (Figure 6b). In this view, HELP sites would have low values along the vertical axis (short lollipops) and WAP sites would have high values along the vertical axis (tall lollipops).

Discriminant Analyses

Regardless of which fish grouping was used, discriminant analyses produced statistically significant separation of ecoregions (Table 7). In general, two or three species were sufficient to produce the separations. The first axes consistently separated the HELP from the WAP with ECBP and EOLP-IP intermediate (Figure 7). The separation of regions along the second axis was not so consistent; the regions most separated from one another were a function of the grouping used. For example, sunfish axis II separated EOLP-IP from WAP while darter axis II separated EOLP-IP from HELP (Figure 7). Species in each grouping that were important in separating the regions are summarized in Table 7. Species with high positive factor loadings along axis I reflect their greater relative abundances in WAP when compared with HELP. Note that these species also tend to be intolerant or moderately tolerant of sedimentation and turbidity. The ecoregions are also fairly consistent in their ability to classify sites regardless of the fish groups used, ranging from 57% to 74% of sites correctly classified.

Discussion

The results of the various analyses of the fish assemblages in Ohio support the notion that there are regional differences related to our delineation of aquatic ecoregions. Clearest are the differences between the HELP and the WAP. The contrast is one in which the HELP supports fewer fish species than the WAP, and one that reflects poorer integrity of those streams as measured by Karr's IBI and the ratio of tolerant to intolerant species. The pattern is also seen in the ordination of the fish assemblages. The HELP sites are distinctly separated from the WAP sites based on presence/absence (Figure 6). Sites in the ECBP and EOLP-IP are intermediate between these extremes. There is not a clear grouping of streams into the ecoregions we have delineated; rather there is a gradient as one moves from streams in the HELP to those in

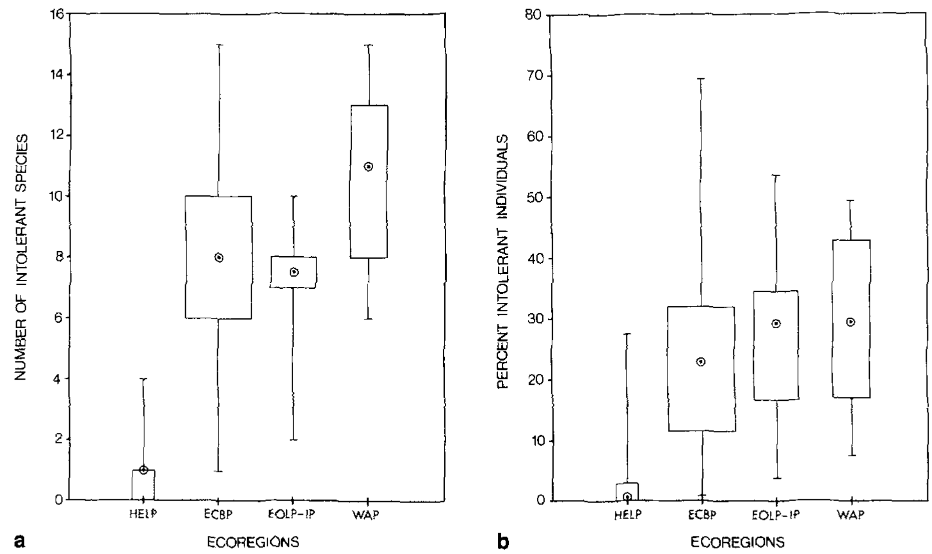

Figure 5. **(a)** Number of intolerant species as a function of aquatic ecoregion. **(b)** Proportion of intolerant individuals as a function of aquatic ecoregion. *Box plots* as in Figure 4.

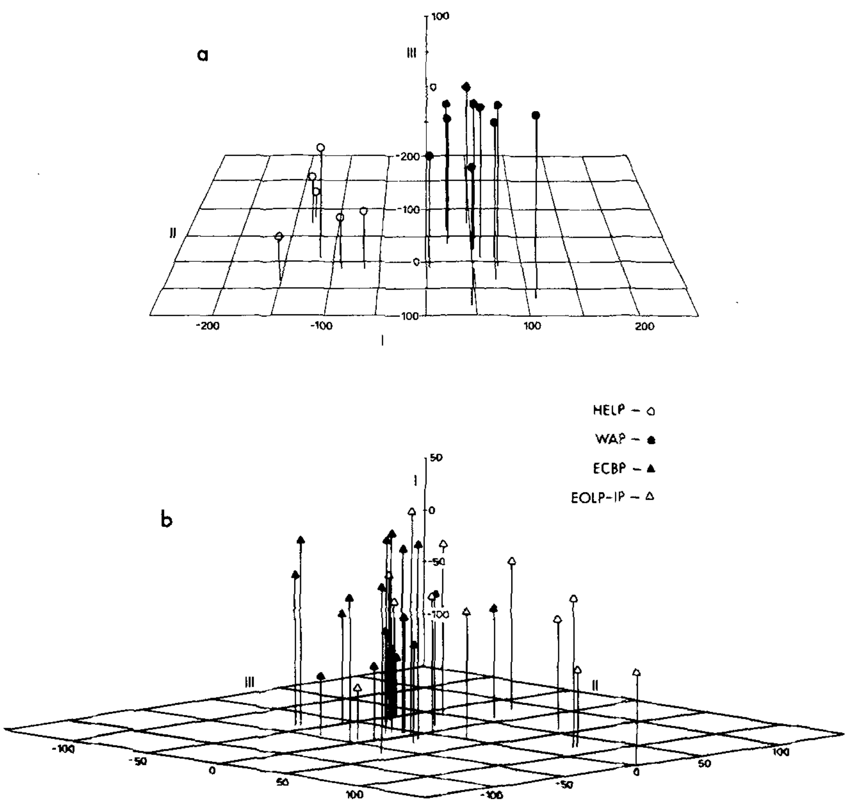

Figure 6. **(a)** Ordination of Huron/Erie Lake Plain and Allegheny Plateau sites along first three DECORANA axes using presence/absence of fish species. **(b)** Ordination of Eastern Corn Belt Plains and Erie/Ontario Lake Plain–Interior Plateau sites along first three DECORANA axes using presence/absence of fish species.

the WAP. This trend reflects the trend in geographic characteristics summarized in Table 1.

The ability for the aquatic ecoregions to classify sites correctly based on fish assemblages is also seen in the results of the discriminant analyses. The limitations of sample size prevented aggregation of all species into one analysis, so the fish assemblage was examined in several ways—first by families, then by trophic classification and tolerance to sedimentation and turbidity. In each of the classifications, statistically significant regional effects were seen and, in general, about 60%–70% of the sites were correctly classified.

Table 7. Summary of results of canonical discriminant analyses. Fish species which account for most of the discrimination along axes I and II are listed along with their factor loadings in parentheses; *p* values indicate the probability that the classification occurred from random association. Tolerances as in Table 3.

Grouping	Axis I		Axis II	*p*	Percent sites correctly classified
Darters	Banded darter (0.69) (*Etheostoma zonale*)	I	Fantail darter (−0.53) (*Etheostoma flabellare*)	0.0003	70
	Dusky darter (0.57) (*Percina sciera*)	I	Greenside darter (−0.52) (*Etheostoma blennioides*)		
	Fantail darter (0.55) (*Etheostoma flabellare*)	M			
Sunfish	Bluegill (0.79) (*Lepomis macrochirus*)	T	Green sunfish (0.68) (*Lepomis cyanellus*)	0.001	67
			Pumpkinseed (0.67) (*Lepomis gibbosus*)		
			Black crappie (0.62) (*Pomoxis nigromaculatus*)		
Minnows	Emerald shiner (0.80) (*Notropis atherinoides*)	M	Rosefin shiner (0.59) (*Notropis ardens*)	0.03	57
	River chub (0.73) (*Nocomis micropogon*)	I	Golden shiner (−0.49) (*Notemigonus crysoleucas*)		
	Rosyface shiner (0.62) (*Notropis rubellus*)	I	Suckermouth minnow (0.48) (*Phenacobius mirabilis*)		
			Silver shiner (0.45) (*Notropis photogenis*)		
Suckers	Northern hogsucker (0.77) (*Hypentelium nigricans*)	I	Black redhorse (0.55) (*Moxostoma duquesnei*)	0.001	63
	Golden redhorse (0.65) (*Moxostoma erythrurum*)	M	Shorthead redhorse (0.43) (*Moxostoma macrolepidotum*)		
	Shorthead redhorse (0.51) (*Moxostoma macrolepidotum*)	M			
Tolerance/ trophic guild	Intolerant piscivores (0.94)		Tolerant insectivores (0.73)	<0.001	74
	Intolerant insectivores (0.56)		Moderately tolerant insectivores (−0.40)		
	Tolerant insectivores (−0.49)				

Those sites that were incorrectly classified tended to fall into neighboring regions rather than into regions that were further removed.

Rowe and Sheard (1981) and Bailey (1983) stated that ecosystem regions such as we have delineated are hypotheses about the spatial patterns in ecosystems. Although numerous land classification systems have been proposed and developed, relatively few have been "tested" or "verified." Jarman (1984) examined the relationship between a land classification system he developed for Oklahoma and fish assemblages in that state. Platts (1979) summarized relationships between fish populations and physical habitat and a land classification system developed for US Forest Service lands in Idaho. Rowe and Sheard (1981) used discriminant analysis to test the ability of their land classification system to group vegetative cover over a 200,000-km^2 area. Bailey (1984) tested his ecoregion classification by comparing runoff per unit area in the dry domain with that in the humid temperate domain. Olson and coworkers (1982) used a variety of data describing terrestrial characteristics of ecosystems to evaluate Bailey's map at the section level. They examined four sections covering states along the northern border of the eastern United States. All of the above methods showed distinct correspondence between the regional classifications and the spatial patterns in the data used to verify the approaches.

Others who defined fish faunal regions using classification techniques attributed these regions to various

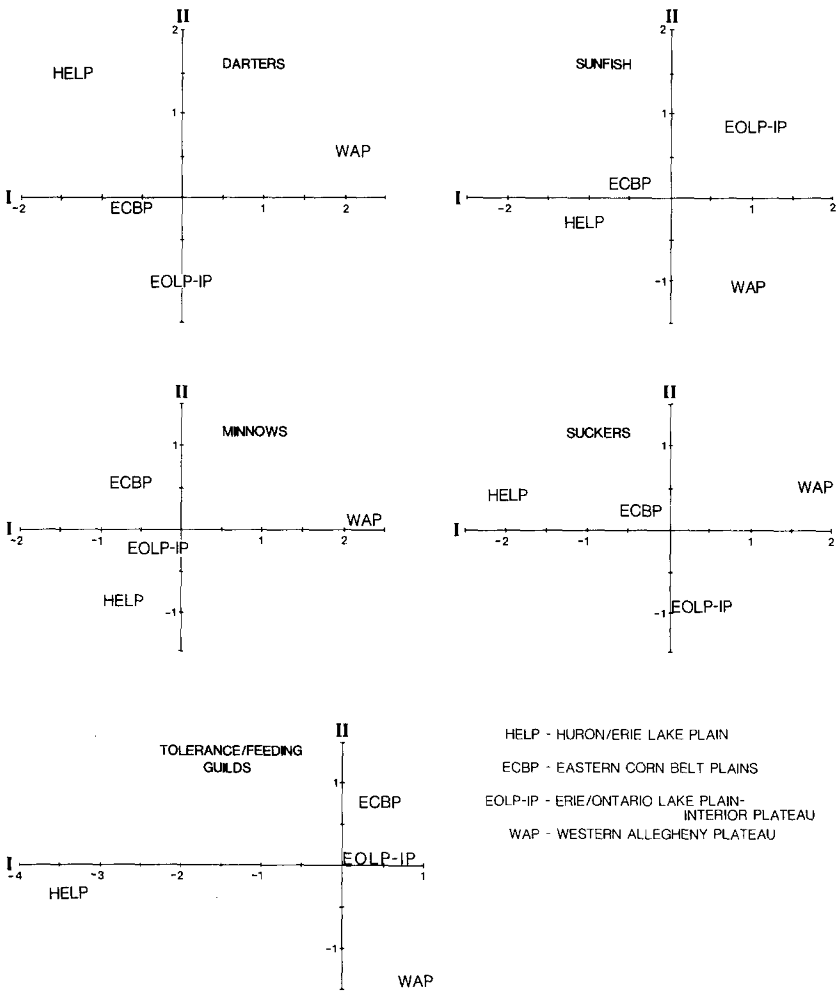

Figure 7. Centroids of the results of canonical discriminant analyses for various groupings of Ohio fish. Centroids are indicated by ecoregion abbreviation.

land characteristics such as drainage boundaries, major physiographic features, geologic formations, soils, or vegetation (Hawkes and others 1986), climatic, vegetational, and geomorphological limits or gradients (Legendre and Legendre 1984), or drainage boundaries and physiographic regions (Pflieger 1971, Pflieger and others 1981).

The basis for our delineation of aquatic ecoregions is the concept that patterns in aquatic ecosystems ought to reflect patterns in terrestrial factors controlling their character. Fish communities are but one component of aquatic ecosystems and, even though their patterns might not correspond exactly to those suggested by aquatic ecoregions, the correspondence we do see is encouraging. Other stream characteristics, such as water chemistry or macroinvertebrate assemblages, might display somewhat different patterns. It is important, however, to consider aquatic ecosystems holistically. If there is also a correspondence between the aquatic ecoregions of Ohio and patterns of such characteristics as water chemistry, physical habitat, and macroinvertebrate assemblages, then use of these regions would be convenient for organizing our knowledge about characteristics of aquatic ecosystems over broad areas.

The correspondence between spatial patterns in stream systems and aquatic ecoregions is particularly relevant for management of aquatic ecosystems. The aquatic ecoregion approach recognizes the linkages between aquatic ecosystems and the ecological character of the land that produces these streams. In the HELP, the land-surface form is typically flat, and the soil originates from high lime glacial lake sediments (Table 1). While, at one time, streams in this area might have been clear and might have been characterized by high proportions of piscivorous fish intolerant of sedimentation and turbidity (Trautman 1981), their present state reflects the use to which land in this area has been put: essentially entire removal of the native forest, extensive tile drainage and ditching, extensive row cropping of corn and soybeans up to the stream banks, little riparian forest as a buffer zone, and extensive channelization of streams. These land characteristics tend to produce warm, turbid, sluggish, nutrient-rich, silt-bottomed streams with little instream cover. Even in the least-impacted streams in this region, these characteristics are apparent. The streams in the HELP support relatively depauperate fish assemblages consisting largely of species tolerant of sedimentation and turbidity.

This description of the landscape and streams in the HELP contrasts with that seen in the WAP. There the land-surface form is typically hills, the soil derives from sandstone and shale, and land use is typically woodland and forest with some cropland and pasture. Channelization is far less common, and riparian forest is more extensive. Streams are typically cooler, clearer, faster flowing, lower in nutrients, and coarser bottomed than those in the HELP. As a result, streams in the WAP support fish assemblages with greater species richness and with greater proportions of species that are intolerant of sedimentation and turbidity.

By recognizing these regional landscape differences, those concerned with stream management can begin to examine: (a) the regional characteristics of streams and their inherent capabilities and potentials, (b) the regional differences in human activities that affect streams over broad areas, and (c) remedial management practices that might be effective in one area but not in others. Characterizing minimally disturbed streams that are representative of a region provides a measure of what might be attainable in that region. Comparing regional disturbances and their consequences with the characteristics of minimally disturbed streams provides a measure of the impact of human activities on streams. Examining the differences among minimally impacted and heavily impacted streams provides us with a guide for the kinds of remedial management practices that might effectively improve streams. An ecoregion perspective, therefore, provides a useful framework for managing entire watershed/stream systems, as well as for assessing patterns in fish assemblages.

Summary and Conclusions

A conceptual approach that integrates management of land and water resources is needed to help reveal the influences that land activities have on aquatic ecosystems. Organization of aquatic ecosystem information within an ecoregional perspective is one way of providing this framework. A regional perspective is useful if spatial patterns in aquatic ecosystems correspond with ecoregions. In this study we describe an overview of an approach for delineating aquatic ecoregions and the correspondence between patterns in fish assemblages in Ohio streams and four ecoregions delineated in Ohio. The ecoregions were defined by analyzing the spatial homogeneity in land-surface form, soil, potential natural vegetation, and land use. Fish assemblages were sampled in 46 streams during the period July–October 1983. Patterns in the data were analyzed using a variety of univariate and multivariate methods.

There were differences among the fish assemblages that corresponded to the ecoregional pattern. In streams of the Huron/Erie Lake Plain, fish assemblages were lowest in species richness and in overall biotic integrity, and were dominated by species that are tolerant of sedimentation and turbidity. At the other extreme, in streams of the Western Allegheny Plateau, the fish assemblages contained significantly more species, significantly higher biotic integrity, and significantly more species intolerant of sedimentation and turbidity. Fish assemblages in the intermediate regions, the Eastern Corn Belt Plains and the Erie/Ontario Lake Plain–Interior Plateau, were intermediate between these extremes. The correspondence between fish assemblage patterns and the ecoregions suggests that an ecoregional framework can be a useful context for integrating land-water systems. Studies that relate other aquatic ecosystem characteristics such as water chemistry and physical habitat to ecoregions are needed, as well as more studies with fish assemblages in other parts of the country.

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