EPA/600/A-92/204

USE OF ECOREGIONS IN BIOLOGICAL MONITORING

Robert M. Hughes. ManTech Environmental Technology, Incorporated. U.S. EPA Environmental Research Laboratory. 200 SW 35th Street. Corvallis, OR. 97333.

Steven A. Heiskary. Nonpoint Source Section. Minnesota Pollution Control Agency. 520 Lafayette Road. Saint Paul, MN. 55155-3898.

William J. Matthews. Biological Station. University of Oklahoma. Star Route B. Kingston, OK. 73439.

Chris O. Yoder. Ecological Assessment Section. Ohio Environmental Protection Agency. 1800 WaterMark Drive. Columbus, OH. 43266-0149.

In S.L. Loeb (ed.) Biological Monitoring of Freshwater Ecosystems. Lewis Publishers. Chelsea, MI.

INTRODUCTION

In order to better manage populations of lakes and streams it is useful to have some form of lake and stream classification. Such classifications may be based on site-specific data or on some form of regionalization generated from those or other data. The goal of any classification is to stratify variance, and the greater the variance that a classification accounts for, the more useful it is. The process of classification is iterative; as we learn more about aquatic ecosystems through site-specific monitoring and theoretical advances, we can use that knowledge to improve our classification and thereby the quality of our science and management.

In biological monitoring programs, particularly at the state, regional, or national level, an appropriate geographic framework is useful for developing estimates of organisms likely to be collected and conditions likely to be encountered. Such a framework is also useful for setting biological criteria, for interpreting the relative health of the site, and for extrapolating the results of collections or samples to a population of water bodies. State agencies, in particular, need a method to break a large complex set of systems into rational units for management and for predicting the results of management actions. Traditionally, aquatic biologists have used river basins to determine these frameworks.

As assemblage and water quality data bases and statistical software have become available, they have been used to frame regions. When mapped, the ordination results often are interpreted from some preconceived landscape level pattern, such as river basins (Hocutt and Wiley 1986), catchments (Matthews and Robison 1988), or physiography (Pflieger 1971).

Others have compared aquatic ecosystem patterns with various environmental variables. Ross (1963) showed a strong association between North American caddisfly species in small streams and terrestrial biomes. Legendre and Legendre (1984) found climatic, geomorphic, and vegetation patterns more useful than river basins for explaining fish distribution patterns in Quebec. Minshall et al. (1985) concluded that regional patterns in climate, geology, and land use were necessary for appropriately applying the river continuum concept across regional scales. Jackson and Harvey (1989), in a study of available data from 286 lakes in the northern Great Lakes area of Ontario, found that fish faunas were significantly correlated with geographical proximity, but not with lake area, maximum depth, or pH. They proposed that the faunal patterns were a function of differing post-glacial dispersal routes and climatic regimes. Corkum (1989), examining benthic invertebrate data from 100 river sites in northwestern North America, determined that drainage basin, physiographic region, and bedrock geology were more useful for classifying the fauna than were environmental variables measured at the sites. In a study of five sites along each of three rivers in eastern Ontario, she concluded that macroinvertebrate assemblages corresponded more with land use than with season, site location along the rivers, or drainage (Corkum 1990).

Recently, aquatic ecoregions, developed from a combination of landscape characteristics, have been proposed as a framework for assisting water body managers (Omernik 1987, Hughes and Larsen 1988). Ecoregions are defined as mapped regions of relative homogeneity in land surface form, soil, potential natural vegetation, and general land use. Ecoregions group water bodies that would be naturally similar in the absence of permanent human settlements and thereby they stratify variability; such regions are substantially less diverse than an entire nation or state. They have been shown to correspond to statewide differences in fish and water quality in Ohio streams (Larsen et al. 1986, 1988); fish, water quality, and physical habitat in Arkansas streams (Rohm et al. 1987); fish, macroinvertebrates, physical habitat, and water quality in Oregon streams (Hughes et al. 1987, Whittier et al. 1988); water quality in Minnesota lakes (Heiskary et al. 1987); and fish in Wisconsin streams (Lyons 1989).

The purpose of this paper is to (1) compare fish faunal regions and ecoregions, (2) summarize the experiences of two states that use ecoregions as management units, and (3) summarize the concerns of workshop participants about the use of ecoregions.

CORRESPONDENCE BETWEEN FISH FAUNAL REGIONS AND ECOREGIONS

Pflieger (1971) and Pflieger et al. (1981), using fish assemblage data from over 1600 localities, described three fish faunal regions and a large river fauna for Missouri. Except for northwest Missouri, their regions and Omernik's show considerable correspondence (Figure 1), possibly because both frameworks are partly based on physiographic patterns.

Analyzing data from 410 stream sites, Hawkes et al. (1986) distinguished six major fish regions delineated mostly by drainage in Kansas. These bear no resemblance to the six regions Omernik mapped for the state (Figure 2). Hawkes et al. observe, however, that the Walnut Creek drainage (which is split by an Omernik ecoregion) divides into two fish regions.

Using discriminant analysis of fish data from 350 stream sites, Bazata (1991) found that five fish faunal regions were more appropriate than the seven ecoregions of Omernik. However, the reduced number of faunal regions were obtained by combining two small portions of Omernik ecoregions with two larger ecoregions (Figure 3).

Hughes et al. (1987) used available data from 9100 collections in 85 catchments to evaluate the ability of ecoregions, drainage basins, and physiographic regions to form ichthyogeographic regions. They found that 2 of 10 physiographic provinces, 5 of 18 river basins, and 4 of 8 aquatic ecoregions could serve as fish faunal regions in Oregon (Figure 4). This indicated that, statewide, ecoregions offer the single most suitable system to classify fish assemblages, but that they alone are insufficient.

Rohm et al. (1987) and Matthews and Robison (1988) analyzed the fish fauna of Arkansas through use of an ecoregion and a data base/drainage units approach, respectively. Rohm et al. used collections from 22 streams in the 6 ecoregions of Omernik, whereas Matthews and Robison described 5 discontinuous fish faunal regions from over 2000 collections, but mapped the regions as individual drainage units. In order to make comparisons at a similar scale for this paper, their 101 drainages were coded and plotted by the 5 major river basins and 6 ecoregions of Arkansas (Figure 5). Both Rohm et al. and Matthews and Robison distinguished two lowland regions and an Ozark region. However, Matthews and Robison's Ouachita-Ozark border region included Omernik's Ouachita and Boston Mountains regions, and part of his Ozark region. Matthews and Robison did not delineate a separate Arkansas River Valley region. The actual ordinations in both papers showed considerable differences between lowland and Ozark regions, but a gradual transition among the other regions.

These examples illustrate two inadequacies with river basins and Omernik's ecoregions as frameworks for fish monitoring. (1) Pflieger and Matthews and Robison described a large river fauna that ecoregions and basins may miss. (2) Available fish data offer more detailed information about fish presence and absence than ecoregions, and, consequently, should be examined while developing regional expectations for fish assemblages.

On the other hand, a focus on available data (fish or other assemblages) presents different problems. Single assemblage analyses are appropriate only for that assemblage or data base. It is unrealistic to expect state and federal agencies to develop individual regions for algae, benthos, fish, water quality, and physical habitat. Agencies must manage lakes and streams as aquatic ecosystems. It is theoretically possible to simultaneously ordinate a number of assemblages and physical and chemical habitat variables, but to our knowledge this has not been demonstrated.

Regardless of whether available water body data are used to draw ecological regions or whether Omernik's ecoregion map is used, there is a need for a hierarchical set of regions. Many state and federal monitoring agencies lack the resources to monitor and interpret data at a site-specific level, except at a small number of sites. Consequently, agencies tend to make screening assessments at a regional level. Regions at the scale of Omernik's ecoregions or Pflieger's fish faunal regions are appropriate for such purposes. Scientists concerned with cause and effect and compliance monitoring require less heterogeneous regions, perhaps at the habitat type scale. We are a long way from delineating such classifications at the state or national level. Intermediate regions at the scale of drainage units (Matthews and Robison 1988) or subregions (Clarke et al. 1991, Gallant et. al. 1989) offer greater precision than regions at far less expense than habitat classification, but their usefulness is untested.

The research described above also reveals the wisdom of considering both drainages and landscape characteristics when delineating regions, regardless of scale. Clearly, the distributions of fishes and nonflying macroinvertebrates are restricted to historical and present water bodies. Additionally, it is clear that considerable heterogeneity exists within drainages. For example, Hughes and Gammon (1987) found distinctly different fish assemblages in four reaches of the mainstem Willamette River, Oregon. Omernik and Griffith (1991) were better able to stratify the heterogeneity of dissolved oxygen in Arkansas streams and the fish assemblages in the Calapooia River, Oregon, through the use of ecoregions than through drainages (Figure 6). Hawkes et al. (1986) indicated a substantial difference in Walnut Creek, Kansas, which is divided into two ecoregions (Figure 1). Finally, Smith et al. (1981) observed that fishes of the Raisin River, Michigan, were distributed in a nonrandom pattern; distributions of some species change near ecoregion boundaries (Figure 7).

Despite being classified by drainage unit, the results of Matthews and Robison reveal that ecoregions may better classify fish regions than do river basins, at least among lowlands. All the big rivers of Arkansas share a similar fauna. Within basins, there are regional differences as one moves across ecoregions; however, there are no obvious basin differences within ecoregions. Although neither basins nor ecoregions classified fish assemblages accurately, ecoregions were consistently more accurate than basins (Figure 5, Table 1). It seems wise, then, to consider both ecoregions and drainage units in delineating fish faunal regions, regardless of the scale of interest.

MANAGEMENT APPLICATIONS OF ECOREGIONS

Although ecoregions and some other forms of water body classification are useful to researchers interested in large scale patterns, their greatest proponents are agency scientists charged with monitoring and assessing many waters across a large area. Two states, Minnesota and Ohio, have made extensive use of ecoregions, as well as of existing data.

In Minnesota, Moyle (1956) recognized regional patterns in lake productivity as a result of differences in geology, hydrology, vegetation, and land use. More recently, the Minnesota Pollution Control Agency (MPCA) has used Omernik's map to assess patterns in lake trophic state and morphometry and apply the results to lake management. Heiskary and his colleagues (Heiskary et al. 1987, Heiskary 1989, Heiskary and Wilson 1989) used trophic state variables from a 1400-lake MPCA data base, existing fish data, and a data base from 90 minimally disturbed reference lakes to evaluate four lake-rich ecoregions. Marked ecoregional differences occurred for total phosphorus (Figure 8) and fish assemblages (Table 2). Heiskary and Wilson also found ecoregional differences in user perceptions about conditions suitable for swimming and for what constitutes a nuisance algal bloom. Persons in regions where lakes are typically clearer required lakes to be twice as clear as did people in regions characterized by more turbid lakes (Figure 9). Information such as this has been very useful for a staff of 2 to 3 limnologists in planning, goal setting, and communicating with citizens about the 12,000 lakes in the state. Ecoregions facilitated quantitative regional estimates of reasonable trophic state values and variability, and improved model predictions of trophic state variables and data interpretation among neighboring states.

Ohio, like Minnesota, was graced by early regional analyses conducted by an ichthyologist. Trautman (1957) found physiographic regions useful frameworks for fish faunas and he reviewed Omernik's draft Ohio ecoregion map. The Ohio Environmental Protection Agency (OEPA) used Omernik's ecoregions and a fish and macroinvertebrate data base from over 300 minimally disturbed reference sites to develop biological criteria for the 45,000 miles of streams and rivers in Ohio (OEPA 1987, 1988, 1989a,b, Yoder 1989). The reference site data base was used to calibrate the index of well-being (Gammon et al. 1981), index of biotic integrity (Karr 1981, Karr et al. 1986), and an invertebrate community index (OEPA 1987). Index values determined from the regional reference sites were used to set regional criteria for ambient biological assemblages. Values for each index were plotted by ecoregion and warmwater criteria were set at the 25th percentile for streams of three size ranges (headwater, wading, boat) in each region (Yoder 1989, Figure 10). Criteria for exceptional and physically modified sites were also developed. The ecoregional reference sites are systematically remonitored to adjust calibration curves and biological criteria and to evaluate background changes in biological integrity. Biological criteria are used by OEPA to demonstrate temporal and spatial trends (Yoder 1989, Figure 11), detect impairment of aquatic life uses (Yoder 1991), provide biennial water resource summaries (OEPA 1990), and diagnose types of stressors. Quantitative biocriteria are not only a major improvement over chemical criteria, they also provide a more accurate measure of water resource quality than the more commonly used narrative criteria. In a study of over 400 sites, OEPA found 61% of the sites attaining and 9% not attaining narrative biological criteria based on professional judgement. When numerical biological criteria based on macroinvertebrate assemblage scores at regional reference sites were applied to the same sites, 34% attained and 44% did not attain the criteria (Yoder 1991).

Use of regional reference lakes or stream reaches (Hughes et al. 1986) to develop water resource criteria is hindered by ecoregion heterogeneity. Regional reference sites are inappropriate benchmarks for sites that naturally differ from them, to a considerable degree. For example, sites with substantial natural difference in gradient, substrate, or water quality in the same ecoregion should not have the same set of reference sites. If such sites occur in a distinct geographic pattern, the ecoregion should be subregionalized (Gallant et al. 1989). If there is no pattern to the differences, reference sites for each type of natural gradient, substrate, or water quality should be selected.

Reference sites in extensively disturbed regions may be extremely difficult to locate and may represent unacceptable levels of degradation. But use of least degraded or desirable sites in such areas offers a realistic goal for improvement. Lake sediment cores may offer alternative references for assemblages preserved therein (Charles et al. this volume); however, criteria based on presettlement conditions are unrealistic without major changes in land use. Minimally disturbed catchments or sites can serve as references of the best we can expect, given current land use patterns, and they are certainly in better than average condition. Reference site selection involves both objective and subjective standards (Table 3) and many sites are necessary where regions are heterogeneous or where numerous water body types occur in a region. Many of these issues will require additional federal and multi-state research and analysis to resolve.

CONCERNS ABOUT THE USE OF ECOREGIONS

<u>Is ecosystem health a value concept and consequently not determinable scientifically?</u> Ecosystem health certainly involves values; however, Karr (this volume) and Karr and Dudley (1981) offered a solution. They defined ecosystem health, or biological integrity as "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." Ecoregions offer a regional framework for classifying natural habitat and for stratifying entire communities, as opposed to an individual assemblage such as fish or macroinvertebrates. Ecoregional reference sites represent comparable natural habitat against which the integrity of other sites in the ecoregion can be compared. Moyle (this volume) emphasized that there is not one healthy community, but several. The set of ecoregional reference sites used by Ohio EPA and Minnesota PCA provide examples of such communities. Contrary to the implications of Conquest et al. (this volume), we should not require only pristine systems as references. Doing so usually restricts us to no benchmarks for evaluating restoration results or deterioration. Also, many of our most pristine arctic and mountain waters are impacted by atmospheric deposition. Even if they were not, they would be inappropriate references for waters in other regions. Regional reference sites would certainly offer Stewart and Loar (this volume) and others benchmarks for evaluating assemblages in streams with highly perturbed headwaters. Of course, such sites must be monitored regularly to evaluate the degree to which they change as a result of natural and anthropogenic modifications.

Is any geographic framework ready for immediate adoption by state and federal management agencies? Additional tests of ecoregions, basins, and other frameworks are needed in areas other than those already studied. Such tests should involve multiple variables to examine ecosystem or community, as well as assemblage, differences, and similarities, because we cannot afford to develop many issue- or variable-specific regions for large areas. Even if we could develop many variable-specific regional maps, state and federal management agencies would find them difficult to use. The research would be even more useful if done at more than one scale. Existing lake chemistry and fish and macroinvertebrate data bases are promising sources of information for such analyses, particularly the fish data bases residing in many museums.

Can we base ecoregions on geology or individual chemical, hydrological, and topographic variables? Omernik's ecoregion map actually integrates these variables by using maps of landform, soil, and vegetation, in addition to other mapped information. These maps, in turn, were drawn from considerable site specific chemical and physical data.

Do the 76 ecoregions of the U.S. incorporate too much heterogeneity? The answer to this question depends on their use. They are too detailed for some uses and users and not detailed enough for others. This is why a hierarchical set of regions would be appropriate. Omernik is now working with individual states, focusing on ecoregions that are particularly troublesome or important to managers. The Science Advisory Board of the U.S. Environmental Protection Agency (1991) recommended that the Agency fund subregionalization, along with further tests of ecoregions, but this has not occurred.

Must we deal with individual lakes or stream reaches? If our research is limited only to the system that we study, that leaves an enormous number of unstudied systems about which we are ignorant. It is very useful to study individual water bodies and be able to extrapolate the results to others. Ecoregions provide a useful framework for bounding our extrapolations. It is unwise to assume that structures and functions characteristic of a small northern mountain lake or stream typify all lakes and streams, or even all mountain waters. Water resource managers do not have the luxury of such research. Whether they take action or accept the status quo, they must extrapolate their knowledge of a relatively small proportion of waters. If we ever hope to understand and manage all lakes or streams, we must begin to assess and regulate them as populations, as well as individuals. Then we can use population-based information to help us make decisions about individual water bodies. Ecoregions simply are a way to classify landscapes and their watersheds so that we can generalize, much in the same manner that we use taxonomic classifications to generalize in biology.

Might we be just as well, or better, off with a coarse classification of vegetation (say agriculture, grassland, deciduous forest, and coniferous forest) if we are interested in process or function rather than composition? This is an interesting point because most of our examples involve species composition. Minshall et al. (1985) stated that climate, geology, and land use may explain a great deal of the process differences found across the northern U.S. However, ecoregions can be easily aggregated by color on Omernik's map, which will offer a biome level classification, and the map of Omernik and Gallant (1990) is at the biome scale of resolution. Note also that many ecoregions, such as those in Minnesota, subsume these major vegetation breaks and provide a useful framework for stratifying lake processes. As we learn more about stream processes and monitoring data become more available from more places, we may want greater detail than that provided by biomes. Presumably, we will also continue to be interested in species and guilds, for which greater regional detail is useful.

Can we use river basins as the classification tool as is done in Britain? We do use basins in this way in the U.S., but they are problematic. Basins frequently cross ecoregions that are drastically different (mountains, plains). Therefore, river basins and hydrologic units frequently do not correspond with patterns in aquatic variables, as this paper, Omernik and Griffith (1991), Hughes and Gammon (1987), and Smith et al. (1981) demonstrate. It is appropriate to evaluate both basins and ecoregions, especially for fishes.

Is it possible to regionalize by stressor (such as acid rain) and lake or watershed size? This is an effective approach where there is a single very important issue. Omernik and his colleagues developed alkalinity maps (Omernik and Griffith 1986, Omernik and Powers 1983) that were used to frame regions of sensitivity to acidification for EPA's National Surface Water Survey and produced nutrient maps for evaluating patterns in eutrophication (Omernik 1977, Omernik et al. 1988). However, where agencies are concerned with multiple problems and multiple indicators, a general ecoregion map is more appropriate. The map need not and cannot be optimal for all purposes and users; it should be adequate, useful, logical, and able to explain much of the observed variance.

When will the mapping of ecoregions be complete? It is important to realize that there are two national ecoregion maps developed by EPA to date (Omernik 1987, Omernik and Gallant 1990). Work is continuing at the subregion scale through cooperative work with a handful of states, but it receives no research funds from EPA at present. The entire ecoregion project has been an evolving process leapfrogging among monitoring, research, and regulation. The lack of a national ecoregion research and mapping program to assist states in developing biological criteria means that some states will be inadequately mapped and that inconsistent maps may be produced by the states.

What are the dangers of using ecoregions blindly? As with any new idea, especially one that has an entire country as its subject, it is likely that ecoregions will be misused. They are presently being applied to develop biocriteria. We would be concerned if states ignore basin differences where they exist, overlook subregion differences where they are great, disregard different stream or lake types and sizes in the same region, assess too few reference sites to obtain a meaningful estimate of variability, or use ecoregions where they are obviously inadequate or for purposes for which they were not intended. On the other hand, we would be concerned if academic researchers fail to use ecoregions to bound their lake or stream study areas or to examine regional patterns in other lakes or streams of that type.

Given the resource shortages of state agencies and university researchers, why not involve more academics in ecological monitoring? This is something that Societas Internationalis Limnologiae and other professional associations focusing on water issues could try to foster. It would be possible only for academics that have the time to conduct considerable monitoring for months at a time and through the use of standard, quality controlled methods. Agencies need funding mechanisms that allow easy transfer of research funds, as opposed to hiring staff. Both parties would require equal access to the data and it should be in easily accessible data bases, along with historical data. As the Environmental Monitoring and Assessment Program (EMAP, Paulsen, this volume) is implemented, there is likely to be considerable demand for academic biologists to conduct much of the field work and taxonomic identifications. EMAP and ecoregion researchers must also continue to seek and evaluate existing data bases and consult with state and local experts.

CONCLUSIONS

Study and management of anything as complex as lake and stream ecosystems requires recognition of local, regional, and historical factors or filters (Ricklefs 1987, Tonn 1990). An ecoregion focus can be damaging if we ignore the local scale, but more frequently we tend to focus on the local factors and fail to see the broader picture.

We can also be misled by available museum data. Although greater use of such data is warranted, that use must be tempered by knowledge of how thoroughly the data were collected at the site, the quality of the proportionate abundance estimates, and the spatial intensity of the collections, both regionally and by water body type and size. Nonetheless, museum data, especially if compiled nationally or across a multi-state region, could be valuable for estimating species pools, for calibrating indices such as the index of biotic integrity (Karr 1981, Karr et al. 1986), and for determining locations where sub-ecoregions require delineating.

Fish faunal regions generated from museum data, together with ecoregions, should facilitate federal and interstate cooperation in biological monitoring by providing common biogeographic frameworks. Of course, this will still require much more federal leadership than currently exists to avoid generating inadequate, redundant, and conflicting state and federal biological monitoring programs.

We should be encouraged by renewed interest in biological monitoring and criteria evidenced by this workshop and others (McKenzie In Press, USEPA 1987, Yount and Niemi 1990), by the EPA's requirement for states to develop biological criteria (USEPA 1990), by large national biological monitoring programs (Gurtz this volume, Paulsen this volume), and by the growing number of states that are increasing their biological monitoring. However, much remains to be done. A very small part of state and federal budgets are spent on monitoring the biological resources that citizens assume we are protecting and little of that monitoring information is used in making management decisions. This is particularly discouraging as the resources we love and study disappear to human overpopulation and overconsumption before we even get to know them very well (Hughes and Noss 1992).

ACKNOWLEDGMENTS

This paper was, in part, derived from a panel discussion held at a workshop, Biological Monitoring of Freshwater Ecosystems, held at Purdue University, West Lafayette, Indiana, December 1990. We thank Stan Loeb for inviting us to participate and the Environmental Monitoring and Assessment Program-Surface Waters Group of the U.S. EPA for travel expenses. An earlier draft of this manuscript was improved through reviews by Susan Christie, Deborah Coffey, John Giese, Phil Larsen, Stan Loeb, Terry Maret, Jim Omernik, and Bill Platts. The research was partially funded by the U.S. Environmental Protection Agency through contract 68-C8-0006 to ManTech Environmental Technology, Incorporated. This chapter was partially prepared at the EPA Environmental Research Laboratory in Corvallis, Oregon, and subjected to Agency peer and administrative review and approved for publication.

REFERENCES

Bazata, K. 1991. Nebraska stream classification study. Nebraska Department of Environmental Control. Lincoln, NB.

Borchert, J.R., G.W. Orning, J. Stinchfield, and L. Maki. 1970. Minnesota's lakeshore: resources, development, policy needs. II. University of Minnesota Geography Department. Minneapolis, MN.

Charles, D.F., et al. This Volume.

Clarke, S.E., D. White, and A.L. Schaedel. 1991. Oregon, USA, ecological regions and subregions for water quality management. Environmental Management 15:847-856.

Conquest, L.L., S.C. Ralph, and R.J. Naiman. This Volume.

Corkum, L.D. 1989. Patterns of benthic invertebrate assemblages in rivers of northwestern North America. Freshwater Biology 21:191-205.

Corkum, L.D. 1990. Intrabiome distributional patterns of lotic macroinvertebrate assemblages. Canadian Journal of Fisheries and Aquatic Sciences 47:2147-2157.

Gallant, A.L., T.R. Whittier, D.P. Larsen, J.M. Omernik, and R.M. Hughes. 1989. Regionalization as a tool for managing environmental resources. EPA/600/3-89/060. U.S. Environmental Protection Agency. Corvallis, OR.

Gammon, J.R., A. Spacie, J.L. Hamelink, and R.L. Kaesler. 1981. Role of electrofishing in assessing environmental quality of the Wabash River. pp.307-324 in J.M. Bates and C.I. Weber (eds.) Ecological assessments of effluent impacts on communities of indigenous aquatic organisms. American Society of Testing and Materials. STP 703. Philadelphia, PA.

Gurtz, M. This Volume.

Hawkes, C.L, D.L. Miller, and W.G. Layher. 1986. Fish ecoregions of Kansas: stream fish assemblage patterns and associated environmental correlates. Environmental Biology of Fishes 17:267-279.

Heiskary, S.A. 1989. Lake assessment program: a cooperative lake study program. Lake and Reservoir Management 5:85-94.

Heiskary, S.A. and C.B. Wilson. 1989. The regional nature of lake water quality across Minnesota: an analysis for improving resource management. Journal of the Minnesota Academy of Science 55:71-77.

Heiskary, S.A., C.B. Wilson, and D.P. Larsen. 1987. Analysis of regional patterns in lake water quality: using ecoregions for lake management in Minnesota. Lake and Reservoir Management 3:337-344.

Hocutt, C.H. and E.O. Wiley. 1986. The zoogeography of North American freshwater fishes. John Wiley & Sons. New York.

Hughes, R.M. and J.R. Gammon. 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Transactions of the American Fisheries Society 116:196-209.

Hughes, R.M. and D.P. Larsen. 1988. Ecoregions: an approach to surface water protection. Journal of the Water Pollution Control Federation 60:486-493.

Hughes, R.M. and R.F. Noss. 1992. Biological diversity and biological integrity: current concerns for lakes and streams. Fisheries 17:00-00.

Hughes, R.M., D.P. Larsen, and J.M. Omernik. 1986. Regional reference sites: a method for assessing stream potentials. Environmental Management 10:629-635.

Hughes, R.M., E. Rexstad, and C.E. Bond. 1987. The relationship of aquatic ecoregions, river basins, and physiographic provinces to the ichthyogeographic regions of Oregon. Copeia 1987:423-432.

Jackson, D.A. and H.H. Harvey. 1989. Biogeographic associations in fish assemblages: local vs. regional processes. Ecology 70:1472-1484.

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

Karr, J.R. and D.R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55-68.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5.

Larsen, D.P., J.M. Omernik, R.M. Hughes, C.M. Rohm, T.R. Whittier, A.J. Kinney, A.L. Gallant, and D.R. Dudley. 1986. Correspondence between spatial patterns in fish assemblages in Ohio streams and aquatic ecoregions. Environmental Management 10:815-828.

Larsen, D.P., D.R. Dudley, and R.M. Hughes. 1988. A regional approach for assessing attainable surface water quality: Ohio as a case study. Journal of Soil and Water Conservation 43:171-176.

Legendre, P. and V. Legendre. 1984. Postglacial dispersal of freshwater fishes in the Quebec peninsula. Canadian Journal of Fisheries and Aquatic Sciences 41:1781-1802.

Lyons, J. 1989. Correspondence between the distribution of fish assemblages in Wisconsin streams and Omernik's ecoregions. American Midland Naturalist 122:163-182.

Matthews, W.J. and H.W. Robison. 1988. The distribution of the fishes of Arkansas: a multivariate analysis. Copeia 1988:358-374.

McKenzie, D. (ed) In Press. Ecological indicators. Elsevier. Essex. England

Minshall, G.W., K.W. Cummins, R.C. Petersen, C.E. Cushing, D.A. Bruns, J.R. Sedell, and R.L. Vannote. 1985. Developments in stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Sciences 42:1045-1055.

Moyle, J.B. 1956. Relationships between the chemistry of Minnesota surface waters and wildlife management. Journal of Wildlife Management 20:303-320.

Moyle, P.B. This Volume.

OEPA. 1987. Biological criteria for the protection of aquatic life: Vol II: user's manual for biological field assessment of Ohio surface waters. Ohio Environmental Protection Agency. Columbus, OH.

______. 1988. Biological criteria for the protection of aquatic life: Vol. I: the role of biological data in water quality assessment. Ohio Environmental Protection Agency. Columbus, OH.

______. 1989a. Addendum to biological criteria for the protection of aquatic life: vol II: user's manual for biological field assessment of Ohio surface waters. Ohio Environmental Protection Agency. Columbus, OH.

______. 1989b. Biological criteria for the protection of aquatic life: Vol. III. Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities. Ohio Environmental Protection Agency. Columbus, OH.

______. 1990. Ohio water resource inventory. Ohio Environmental Protection Agency. Columbus, OH.

Omernik, J.M. 1977. Nonpoint source-stream nutrient level relationships: a nationwide study. EPA-600/3-77-105. U.S. Environmental Protection Agency. Corvallis, OR.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118-125.

Omernik, J.M. and A.L. Gallant. 1990. Defining regions for evaluating environmental resources. pp. 936-947 in Global Natural Resource Monitoring and Assessments: Preparing for the 21st Century. Vol. 2. American Society of Photogrammetry and Remote Sensing. Bethesda, MD.

Omernik, J.M. and G.E. Griffith. 1986. Total alkalinity of surface waters: a map of the western region. Journal of Soil and Water Conservation 41:374-378.

Omernik, J.M. and G.E. Griffith. 1991. Ecological regions versus hydrologic units: frameworks for managing water quality. Journal of Soil and Water Conservation 46:334-340.

Omernik, J.M. and C.F. Powers. 1983. Total alkalinity of surface waters-a national map. Annals of the Association of American Geographers 73:133-136.

Omernik, J.M., D.P. Larsen, C.M. Rohm, and S.E. Clarke. 1988. Summer total phosphorus in lakes: a map of Minnesota, Wisconsin, and Michigan, USA. Environmental Management 12:815-825.

Paulsen, S.G. This Volume.

Pflieger, W.L. 1971. A distributional study of Missouri fishes. University of Kansas Publications Museum of Natural History 20:225-570.

Pflieger, W.L., M.A. Schene, and P.S. Haverland. 1981. Techniques for the classification of stream habitats, with examples of their application in defining the stream habitats of Missouri. pp. 362-368 in N.B. Armantrout (ed.) Acquisition and Utilization of Aquatic Habitat Inventory Information. American Fisheries Society. Bethesda, MD.

Ricklefs, R.E. 1987. Community diversity: relative roles of local and regional processes. Science 235:167-171.

Rohm, C.M., J.W. Giese, and C.C. Bennett. 1987. Evaluation of an aquatic ecoregion classification of streams in Arkansas. Journal of Freshwater Ecology 4:127-140.

Ross, H.H. 1963. Stream communities and terrestrial biomes. Archives fur Hydrobiologie 59:253-242.

Science Advisory Board. 1991. Evaluation of the ecoregion concept. U.S. Environmental Protection Agency. EPA-SAB-EPEC-91-003. Washington, DC.

Smith, G.R., J.N. Taylor, and T.W. Grimshaw. 1981. Ecological survey of fishes in the Raisin River drainage, Michigan. Michigan Academician. 13:275-305.

Stewart, A.J. and J.M. Loar. This Volume.

Tonn, W.M. 1990. Climate change and fish communities: a conceptual framework. Transactions of the American Fisheries Society 119:337-352.

Trautman, M.B. 1957. The fishes of Ohio. Ohio State University Press. Columbus, OH.

U.S. Environmental Protection Agency. 1990. Biological criteria: national program guidance for surface waters. Office of Water. EPA-440/5-90-004. Washington, DC.

U.S. Environmental Protection Agency. 1987. Report of the national workshop on instream biological monitoring and criteria. Office of Water. Washington, DC.

Whittier, T.R., R.M. Hughes, and D.P. Larsen. 1988. The correspondence between ecoregions and spatial patterns in stream ecosystems in Oregon. Canadian Journal of Fisheries and Aquatic Sciences 45:1264-1278.

Yoder, C.O. 1991. Answering some concerns about biological criteria based on experiences in Ohio. pp. 95-104 in Water Quality Standards for the 21st Century. U.S. Environmental Protection Agency. Office of Water. Washington, DC.

______. 1989. The development and use of biological criteria for Ohio surface waters. pp. 139-146 in Water Quality Standards for the 21st Century. U.S. Environmental Protection Agency. Office of Water. Washington, DC.

Yount, D.J. and G.J. Niemi (eds). 1990. Recovery of lotic communities and ecosystems following disturbance: theory and application. Environmental Management 14(5).

Table 1. Percent misclassifications* of Arkansas fish faunal regions by ecoregion and river basin.

	% Misclassifications	
Faunal Region	Ecoregion	River Basin
1	34	64
2	61	74
3	67	71
4	46	83

*Misclassification is defined as a fish assemblage other than that predominating in that ecoregion or basin.

Table 2. Ecological classification of all lakes greater than 60 hectares (approximately 1800 lakes) within 4 Minnesota ecoregions (from Borchert et al. 1970 and Heiskary et al. 1987).

	Ecoregion (%)			
Lake Class	NLF	CHF	WCP	NGP
Lake trout	2	-	-	-
Walleye	20	5	-	-
Bass-panfish-walleye	48	37	13	7
Bullhead-panfish	4	6	14	4
Winterkill-roughfish	13	34	65	66
No data/other	13	18	8	23

NLF (northern lakes and forests), CHF (central hardwoods forest), WCP (western cornbelt plains), NGP (northern great plains).

Table 3. Steps in ecoregional reference site selection.

1. Define area(s) of interest on maps
    - Delineate ecoregions and subregions on 1:250,000 scale maps
    - Delineate river basins and subbasins supporting different faunas
    - Combine regions and basins to produce potential natural regions

2. Define water body types, sizes, and classes of interest
    - Evaluate their number and importance in the region

3. Delineate candidate reference watersheds through use of maps, available data, air photos, and local experts
    - Eliminate disturbed areas
        - Point sources (atmospheric, aquatic)
        - Hazardous waste sites, landfills
        - Mines, oil fields
        - Feedlots, poultry farms, hatcheries
        - Urban, industrial, commercial, residential
        - Channelization, dams
        - Transportation and utility corridors
        - Logged or burned forests
        - Intensively grazed or cropped lands
    - Seek minimally disturbed, typical areas or potential natural landscapes
        - Agricultural or range oases
        - Old growth forests, woodlots
        - Roadless areas
        - Preserves, refuges, exclosures

4. Conduct field reconnaissance to locate potential natural sites
    - Aerial observation, remote sensing
    - Site inspection
        - Extensive, old riparian vegetation
        - Complex channel morphology
        - Variable substrate, with large resistant objects and minimal sedimentation
        - Considerable cover (overhanging vegetation, undercut banks, large woody debris, deep pools, large turbulent riffles, macrophytes)

High water quality (clear, odorless)

Vertebrates and macroinvertebrates present

Minimal evidence of humans, livestock, and human activity

5. Determine number of ecoregional reference sites needed

    Balance regional variability, resources, and study duration

6. Monitor sites and evaluate their chemical, physical, and biological integrity. At least two assemblages should be evaluated.

LIST OF FIGURES

Figure 10. Box plots of Ohio reference sites for wading streams by ecoregion--Huron Erie lake plain (HELP), interior plateau (IP), Erie Ontario lake plain (EOLP), western Allegheny plateau (WAP), eastern corn belt plain (ECBP) (from Yoder 1989). Box notch represents 95% confidence interval of the median; the number above the acronym is the number of reference sites per region.

Figure 11. Longitudinal trend in the index of biotic integrity (IBI) between 1979 and 1987 for the Scioto River near Columbus, Ohio. Flow is from left to right, vertical arrows indicate major pollution sources, IBI of 40 equals biological criterion for warmwater habitat, 50 is the criterion for exceptional warmwater habitat (from Yoder 1989).

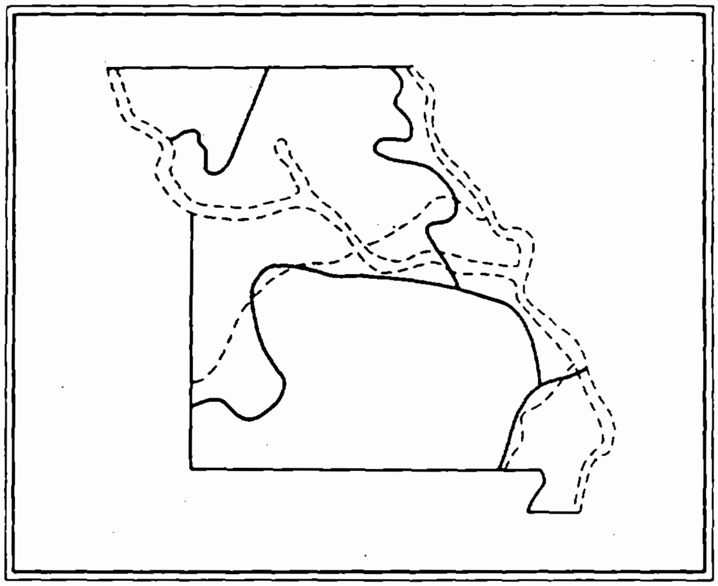


FIG. 1

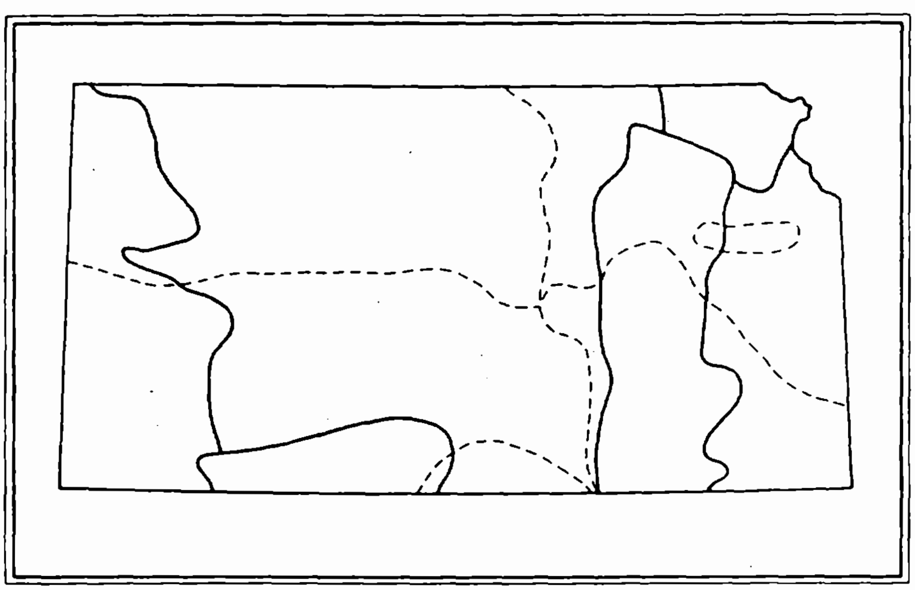


FIG. 2

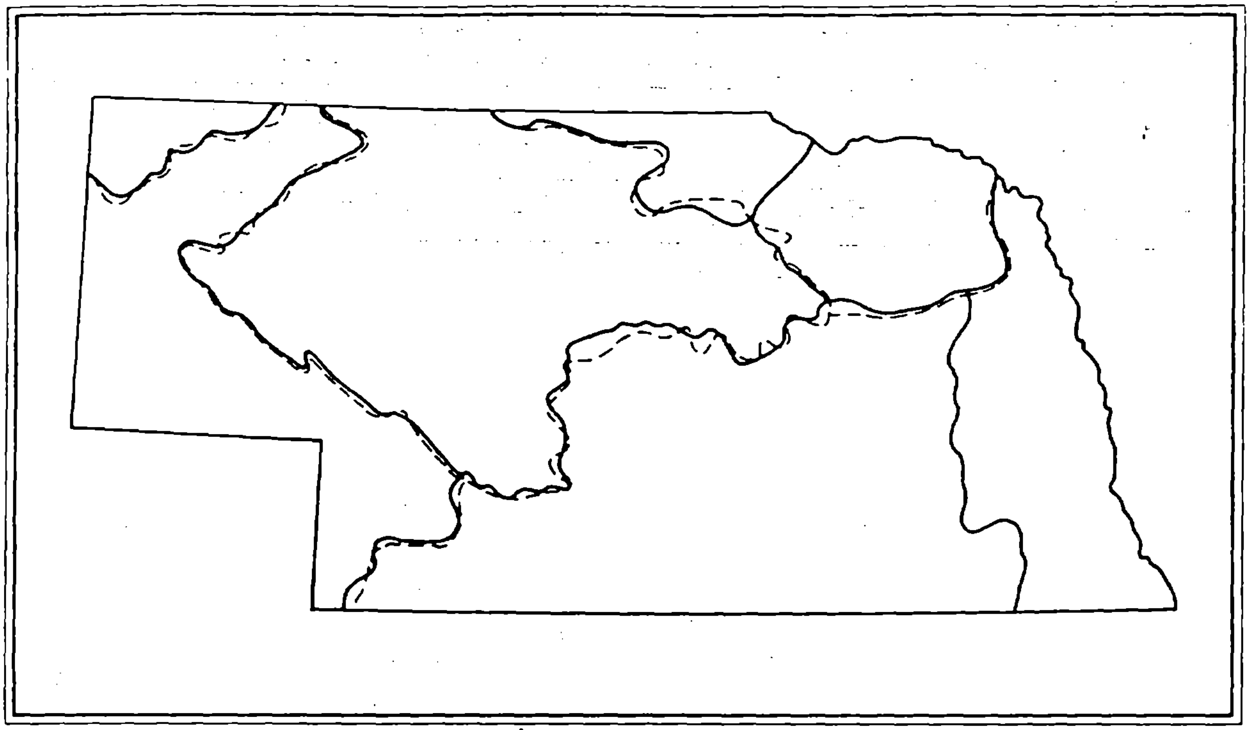


FIG 3

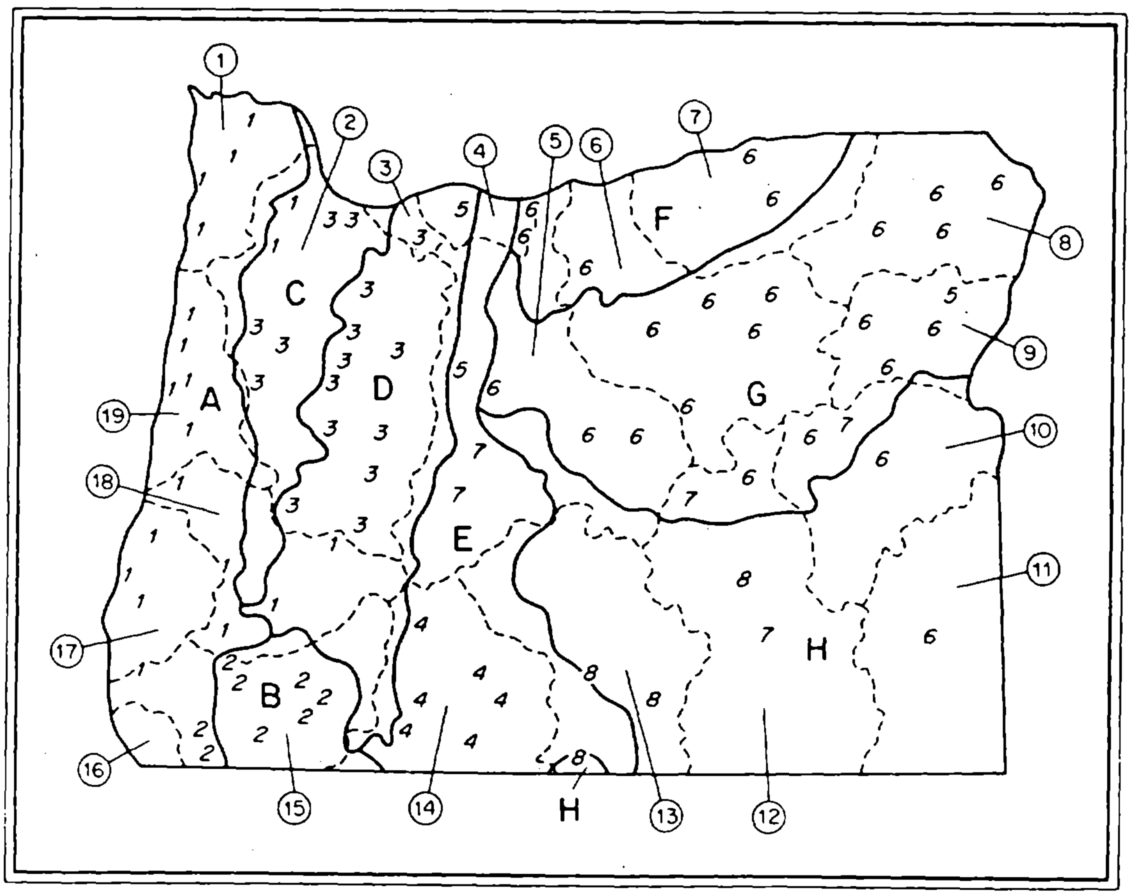


Fig 4

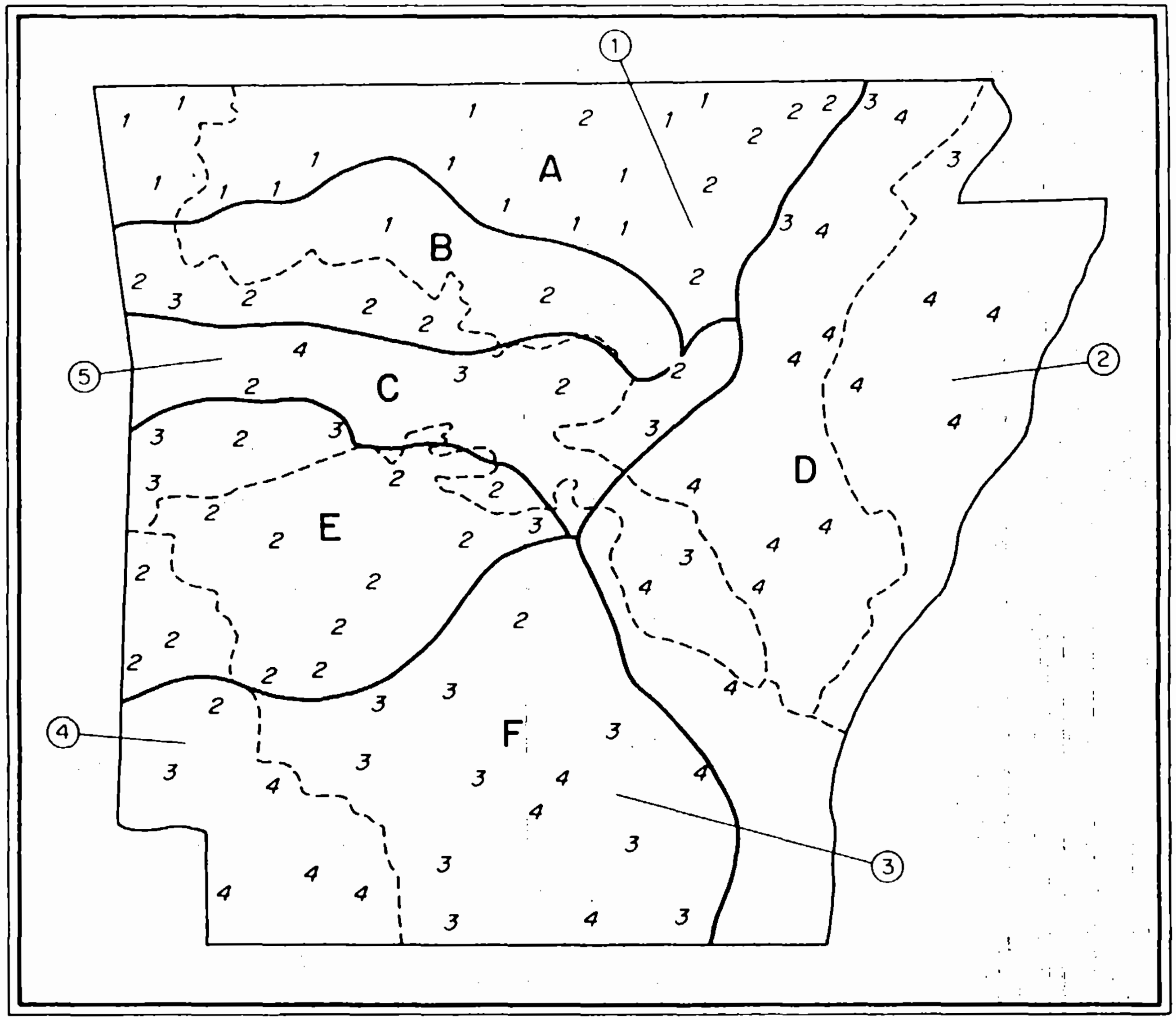


Fig 5

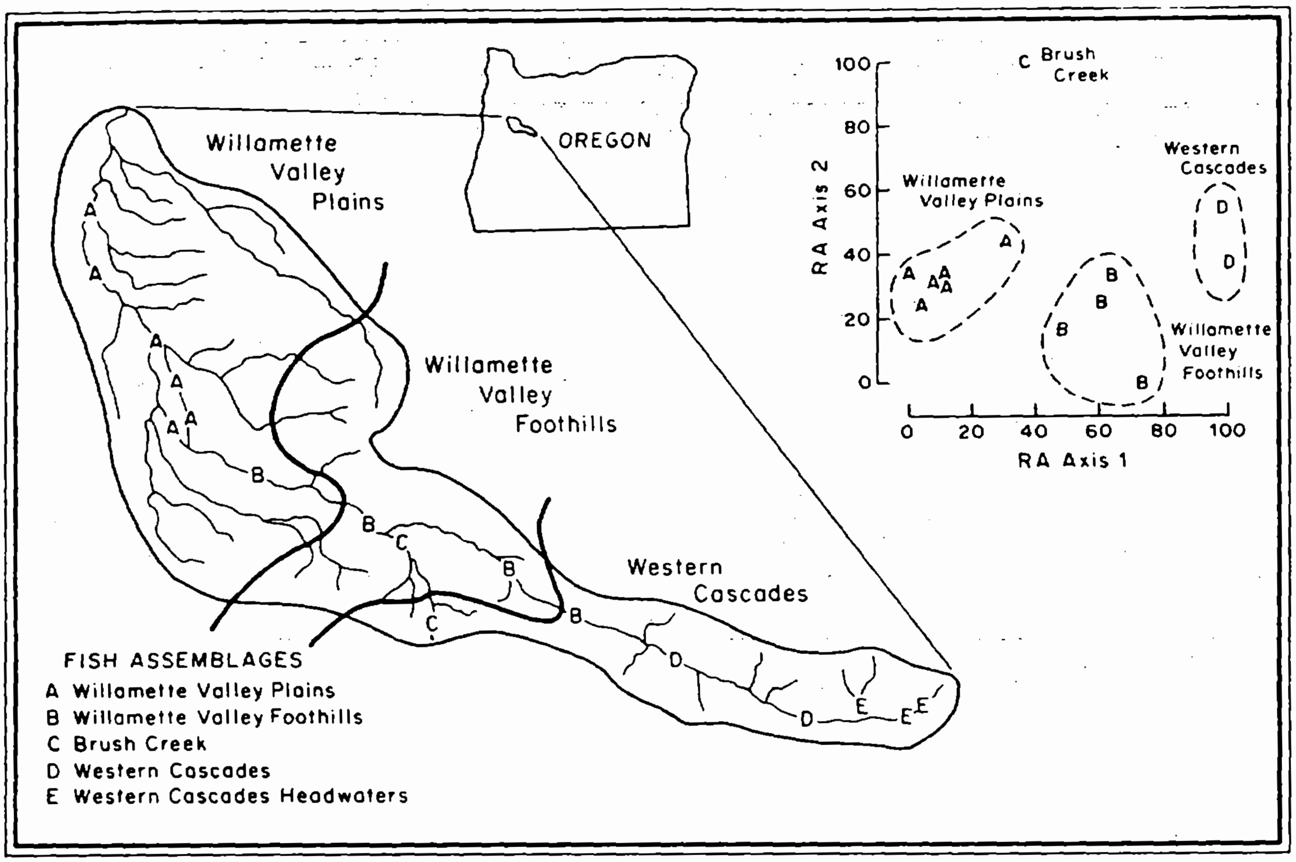
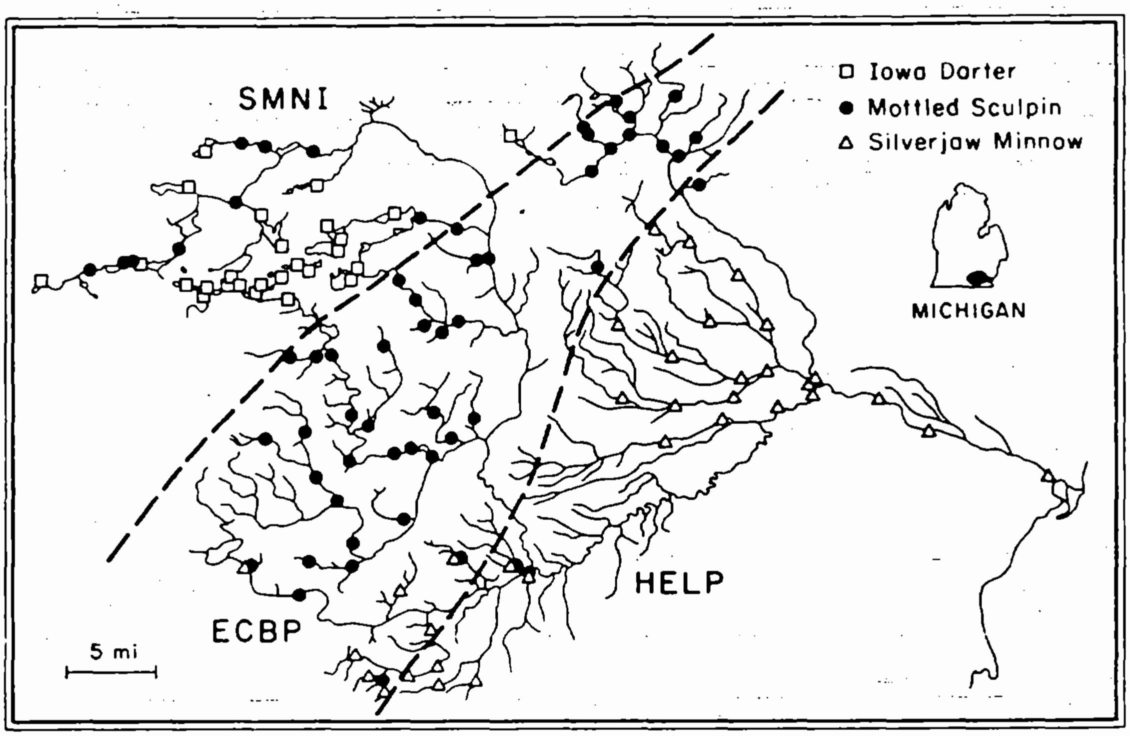
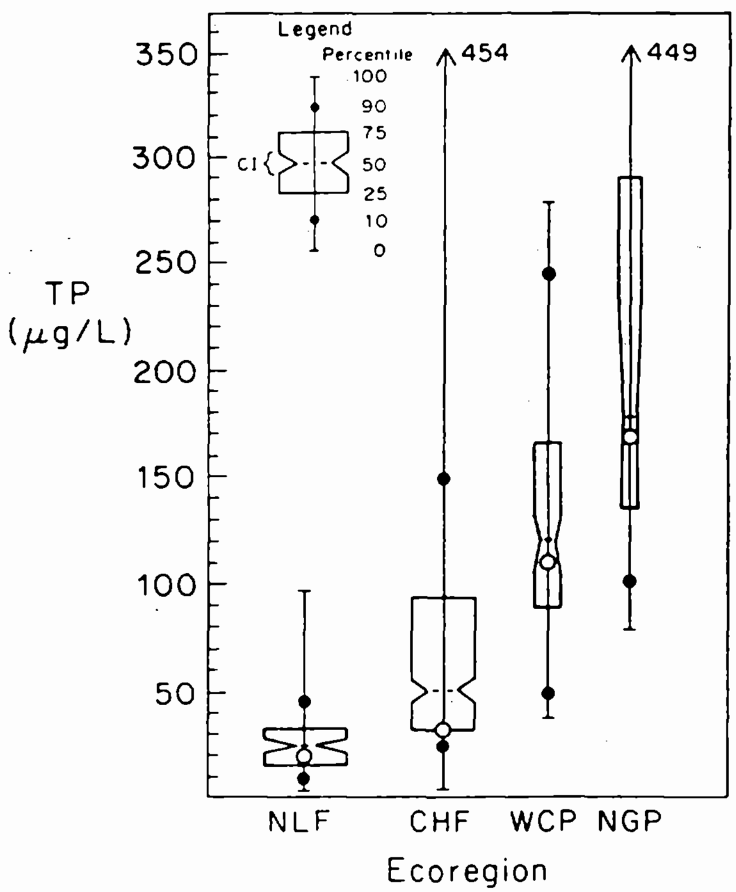

Willamette
Valley
Plains
OREGON
Willamette
Valley
Foothills
Western
Cascades
FISH ASSEMBLAGES
A Willamette Valley Plains
B Willamette Valley Foothills
C Brush Creek
D Western Cascades
E Western Cascades Headwaters
C Brush Creek
Willamette Valley Plains
Western Cascades
Willamette Valley Foothills
RA Axis 2
RA Axis 1
0
20
40
60
80
100

Fig 6



SMNI
Iowa Darter
Mottled Sculpin
Silverjaw Minnow
MICHIGAN
HELP
ECBP
5 mi

Fig 7



Legend
Percentile
100
90
75
CI
50
25
10
0
454
449
350
300
250
200
150
100
50
TP
(μg/L)
NLF
CHF
WCP
NGP
Ecoregion

Fig 8

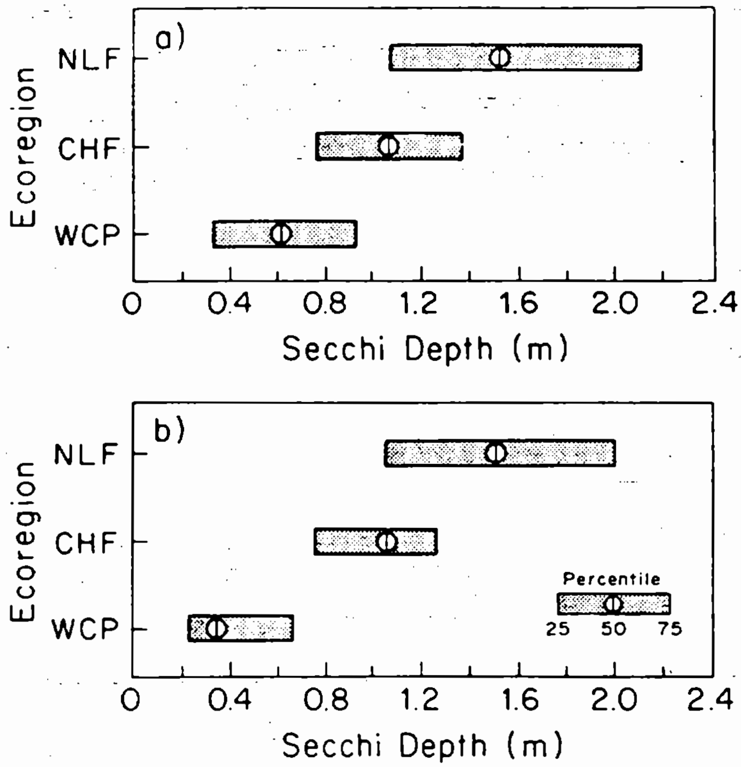

a)
NLF
CHF
WCP
Ecoregion
0
0.4
0.8
1.2
1.6
2.0
2.4
Secchi Depth (m)
b)
NLF
CHF
WCP
Ecoregion
Percentile
25
50
75
0
0.4
0.8
1.2
1.6
2.0
2.4
Secchi Depth (m)

Fig 9

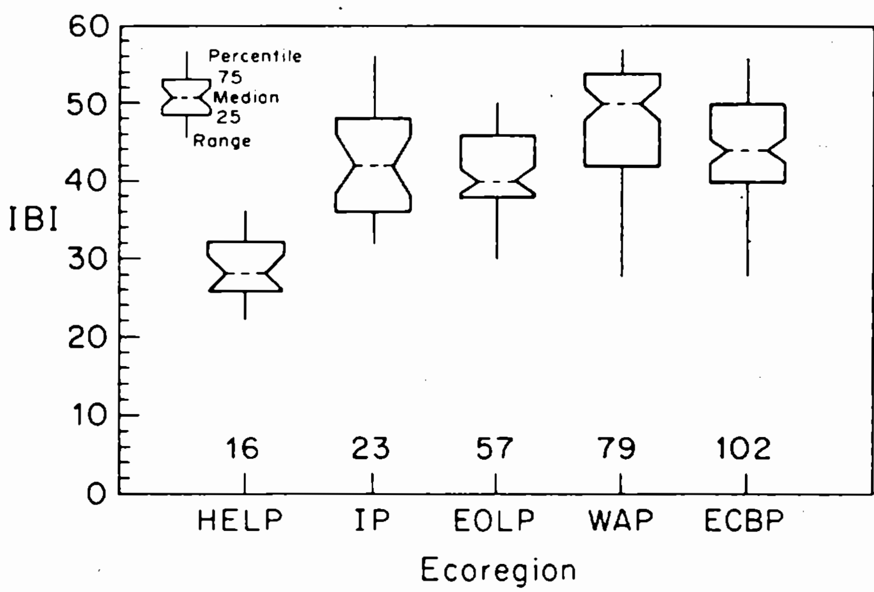
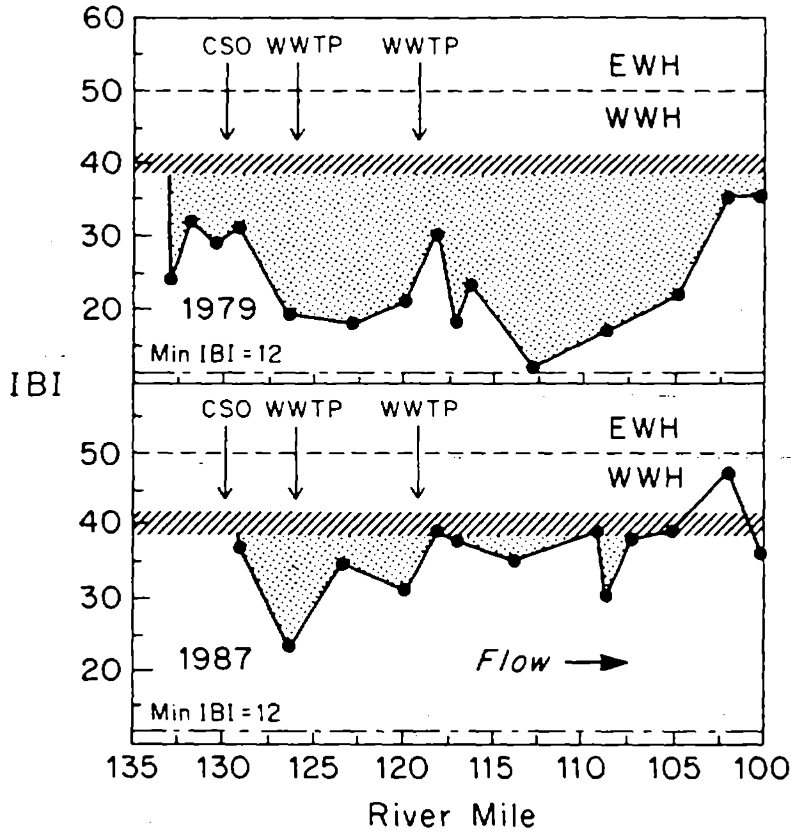

60
50
40
30
20
10
0
IBI
Percentile
75
Median
25
Range
16
23
57
79
102
HELP
IP
EOLP
WAP
ECBP
Ecoregion

Fig 10



CSO
WWTP
WWTP
EWH
WWH
1979
Min IBI = 12
IBI
CSO
WWTP
WWTP
EWH
WWH
1987
Flow
Min IBI = 12
60
50
40
30
20
135
130
125
120
115
110
105
100
River Mile

Fig 11

ERL-COR- 1475D

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before complet

1. REPORT NO. EPA/600/A-92/204	2.	3. PB93-106730
4. TITLE AND SUBTITLE Use of Ecoregions in Biological Monitoring		5. REPORT DATE
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.M. Hughes, S. A. Heiskary, W.J. Matthews, C.O. Yoder		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS METI, Corvallis, OR MN Pollu. Contr. Agy., St. Paul, MN U. of O, Kingston, OK Ohio EPA, Columbus, OH		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS US Environmental Protection Agency Environmental Research Laboratory 200 SW 35th Street Corvallis, OR 97333		13. TYPE OF REPORT AND PERIOD COVERED Symposium Paper
		14. SPONSORING AGENCY CODE EPA/600/02

15. SUPPLEMENTARY NOTES
1991. In: Symposium on: Biological Monitoring of Freshwater Ecosystems, Purdue Univ., West Lafayette, IN Nov. 29 - Dec. 1, 1990

16. ABSTRACT

In order to better manage populations of lakes and streams it is useful to have some form of lake and stream classification. In biological monitoring programs, an appropriate geographic framework is useful for developing estimates of organisms likely to be collected and conditions likely to be encountered. As assemblage and water quality data bases and statistical software have become available, they have been used to frame regions. Others have compared aquatic ecosystem patterns with various environmental variables. The purpose of this paper is to compare fish faunal regions and ecoregions, summarize the experience of two states that use ecoregions as management units, and summarize the concerns of workshop participants about the use of ecoregions.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Ecoregions, river basins, fish faunal regions, biomonitoring, biocriteria		

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 30
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)