A Regional Framework for Establishing Recovery Criteria

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ABSTRACT / Effective assessments of aquatic ecosystem recovery require ecologically sound endpoints against which progress can be measured. Site-by-site assessments of end points and potential recovery trajectories are impractical for water resource agencies. Because of the natural variation among ecosystems, applying a single set of criteria nationwide is not appropriate either. This article demonstrates the use of a regional framework for stratifying natural variation and for determining realistic biological criteria. A map of ecoregions, drawn from landscape characteristics, formed the framework for three statewide case studies and three separate studies at the river basin scale. Statewide studies of Arkansas, Ohio, and Oregon, USA, streams demonstrated patterns in fish assemblages corresponding to ecoregions. The river basin study in Oregon revealed a distinct change at the ecoregion boundary; those in Ohio and Montana demonstrated the value of regional reference sites for assessing recovery. Ecoregions can be used to facilitate the application of ecological theory and to set recovery criteria for various regions of states or of the country. Such a framework provides an important alternative between site-specific and national approaches for assessing recovery rates and conditions.

Progressive management of water resources requires realistic biological goals and objective biological criteria to measure the attainment of those goals (Hughes and Larsen 1988). Without such goals and criteria, we can know neither the direction we are heading nor what we have achieved. An ecoregion approach and biological criteria provide a scientific basis for establishing quantitative, feasible recovery expectations for aquatic ecosystems (Ohio EPA 1987). This article demonstrates the use of an ecoregional framework to determine biological criteria for assessing recovery on a regional scale. First the need for ecoregions and biocriteria is discussed; next the ecoregional framework is described; then patterns in biological conditions are related to ecoregional patterns; and finally the approach is applied to the evaluation of recovery trajectories. The article is a summary of recent research and publications cited herein; it is not an explicit description of the methods proposed.

Most state water pollution control agencies rely on a technology-based process for regulating water quality that includes: (1) setting broad goals (such as protection of aquatic life), (2) establishing numerical or narrative chemical and microbiological criteria, and chemical discharge permit limitations to meet the goals, (3) designing waste treatment works to meet National Pollutant Discharge Elimination System (NPDES) permit requirements, and (4) monitoring the permitted chemicals and microbes to measure compliance. Usually, attainment of the goals of the Federal Water Pollution Control Act and its amendments is assessed by comparing those criteria with chemical and microbial attributes of permitted discharges to receiving waters. This process has produced major improvements in water quality and has greatly reduced the incidence of waterborne diseases. For example, the number of fish species and their abundances have increased in the Willamette and Wabash rivers since installation of point source controls (Hughes and Gammon 1987, Gammon 1989).

Although the above process has been largely successful, damage to aquatic communities continues. For example, ten fish taxa have become extinct since 1979 and 217 others are endangered or threatened (Williams and others 1989), and nonpoint source pollution and physical habitat alteration remain serious and unregulated problems (Judy and others 1984, Miller and others 1989, US EPA 1989). Assessment and control

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of this damage through traditional physical and chemical measurements remains unsatisfactory because control programs often have negligible effects (Ohio EPA 1987, Karr and others 1985). Approaches that are more responsive to the US Environmental Protection Agency's charge of restoring, maintaining, and protecting aquatic communities are more difficult and require a more comprehensive approach than traditional methods (especially in the case of nonpoint source pollution), for four reasons:

1. National chemical and microbial criteria and permits may be over- or underprotective of aquatic life. This results partly from natural variation among aquatic ecosystems and partly because of factors not included in the permit process, e.g., erosion-caused sedimentation may be limiting to aquatic organisms (Karr and others 1986). Overprotective criteria are needlessly expensive and misuse limited restoration dollars. Criteria based on acute or chronic toxicity tests may not protect aquatic life from the long-term effects of bioconcentration or from indirect effects of changes in competition and predation.
2. Criteria for essentially nontoxic pollutants, such as dissolved oxygen, sediments, and nutrients are difficult to establish. For such pollutants, the traditional toxicological criterion approach is not feasible. These naturally occurring constituents vary greatly through time and among various regions of the country. Criteria levels that are protective in one region of a state may be impractical or precluded by naturally high levels in a neighboring region. For example, Arkansas DPCE (1988) found that summer median 72-h dissolved oxygen concentrations in unperturbed streams of the Mississippi Alluvial Plain region were 3 mg/liter, while those in the Boston Mountains region were 7 mg/liter.
3. Physical habitat varies regionally and remains essentially unregulated despite its frequency as a limiting factor. Substantial changes in the aquatic fauna occurred soon after land settlement as a result of physical changes in water bodies (e.g., Trautman 1981, Smith 1971, Miller 1961). Physical habitat alteration was the primary factor contributing to the extinctions of the 40 fish taxa that have disappeared from North America this century (Miller and others 1989). Although physical habitat (flow, channel morphology, substrate, and cover) impairs aquatic life in more streams than toxic chemicals (Judy and others 1984), few physical habitat criteria, such as Idaho's embeddedness criterion, exist. Most physical habitat models, such as the instream flow incremental methodology (Bovee and Milhous 1978) are species specific and inapplicable to multispecies fish assemblages. Physical habitat restoration receives a few thousand dollars in the form of demonstration projects, while chemical habitat restoration receives millions in the form of point source controls and treatment plants. Thus the US EPA and the states are not mitigating several key physical stressors.
4. Quantitative biological criteria are difficult to develop. Only a few states (Florida, Maine, Ohio, Vermont) have explicit biological criteria and the US EPA is just beginning to consider them. Without quantitative biological criteria, such as biological index or species richness values, it is impossible to determine whether aquatic life uses are fully met or whether biotic communities are recovering, deteriorating, or remaining the same as a result of regulatory actions. One reason that states have not developed and used biological criteria is the large spatial (statewide and nationwide) variability in species composition and abundance compared with chemical criteria (Pflieger 1975, Hocutt and Wiley 1986). Another is that there is little agreement on what constitutes a substantial or significant change in biological variables. This has made biological criteria much more difficult to apply in a regulatory context.

Natural variation is a complication common to all four issues. Site-specific criteria may resolve this complication, but they are expensive to develop and their potentially infinite number would create an enormous regulatory burden for states. No state has the staff to develop and enforce separate criteria for each stream reach within its boundaries. Another option, based on the concept of natural regional patterns of ecosystems (ecoregions) and regional biological criteria, offers considerable promise for resolving these four issues.

Ecoregions are areas containing naturally similar ecosystems, hence they stratify and reduce the apparent variability in physical, chemical, and biological measures that exist in large political and hydrological units. Ecoregions are far less diverse than the entire nation, a large state, or a major river basin. This is because sites classified by ecoregions occur in ecologically similar landscapes, which restrict present and potential discharge, substrate, chemistry, and biota. Rather than establish recovery criteria from laboratory conditions or from conditions at a few pristine sites, recovery criteria can be based on biological community conditions at a series of relatively undisturbed sites that represent regional potentials. To avoid unrealistic expectations, such reference sites must be selected very carefully, following a prescribed protocol (e.g., Hughes and others 1986). The sites should resemble conditions believed to exist before massive human disturbance of the watershed, yet be typical of the region in which they exist. In other words, their water quality, physical habitat, flow, food base, and biota should be comparable to pristine streams of a similar size. Some scientists prefer a more objective, random selection of reference sites. However, the extensive disturbance of surface waters by nonpoint sources and the rarity of minimally disturbed sites means that random selection is unlikely to produce sites of sufficiently high quality. Also, selection of a cutoff level of statistical significance or power is a subjective decision. Although imperfect, the ecoregion approach provides a useful compromise between national or statewide and site-specific methods for developing biological criteria.

An Ecoregional Framework

Natural regional patterns in physical, chemical, and biological attributes have been recognized for some time (Herbertson 1905, Clements 1916). Regional differences are indicated by names like the Great Basin, the Tall Grass Prairie, and the Piedmont. Recognition and application of these natural regional differences are appropriate for water resource management because waterbodies, especially streams, reflect the landscapes they drain. This characteristic of rivers that drain both mountains and plains makes river basins too heterogeneous for establishing regional expectations or for reporting regional condition.

Omernik (1987) developed a map of natural ecological regions (Figure 1) by analyzing and synthesizing existing maps of regional patterns in land-surface form, soil, potential natural vegetation, and general land use. We evaluated his map in statewide case studies in Arkansas, Ohio, and Oregon and in three separate basin studies in Montana, Ohio, and Oregon. Our evaluation criteria in these studies were: (1) if an ecoregion map is to stratify natural variation in lotic ecosystems, stream attributes should demonstrate ecoregional patterns, (2) ecoregions with greatly different landscape characteristics should support greatly different stream habitats and communities, (3) similar ecoregions should support similar habitats and communities, and (4) within-region variation should be less than among-region variation.

In the three statewide studies (Larsen and others 1986, Rohm and others 1987, Whittier and others 1987), we used data collected from 23 to 107 regional reference sites to evaluate Omernik's map. We selected regional reference sites in watersheds that typified the regions, yet were relatively undisturbed (Hughes and others 1986). Reference sites lacked point and major nonpoint sources in their watersheds and had extensive riparian vegetation, relatively clear water, heterogeneous habitats, and considerable cover. Values for the biological, physical, and chemical variables at reference sites indicated the range of conditions that could reasonably be expected in the ecoregion, given natural limits and present land use practices. These regionally attainable values represented the range of realistic recovery potentials for the more perturbed sites in the same ecoregion.

We also applied the ecoregion approach in the basin studies. In an unpublished study of the Calapooia River, Oregon, we were concerned with discerning changes in the river as it passed from one ecoregion to another. In research on Prickly Pear Creek, Montana (Hughes 1985), we assessed recovery of sites from mine pollution by comparing those sites with appropriate regional reference sites. We evaluated recovery of Yellow Creek, Ohio (Ohio EPA 1987), from point and nonpoint source pollution by relating conditions there to conditions at comparable regional reference sites.

We applied two widely available analytical techniques to evaluate the data. We used detrended correspondence analysis (DCA) for displaying site similarity based on biological variables, for revealing relationships among ecoregions, and for developing coarse biological criteria. DCA is an ordination technique developed to show correspondences among samples (Gauch 1982). It is especially useful for nonlinear variables, such as species data that tend to form overlapping curves, and indistinct ordination patterns along environmental gradients. DCA allows presentation of species abundance data on a single figure that would otherwise require several histograms. If there is no ecoregion effect, sites will occur randomly scattered on the DCA plot; if there are distinct ecoregional differences, the sites occur as discrete, widely separated groups; if a transitional region occurs between two regions, the sites should show the same pattern.

We also used the index of biotic integrity (IBI) (Karr and others 1986) and species profiles as criteria for evaluating potential recovery. The IBI incorporates information about species richness and composition [total number of species, number of sunfish (water column) species, number of darter (benthic) species, number of sucker (long-lived) species, number of intolerant species, percent green sunfish (dominance by a common tolerant species), trophic guilds

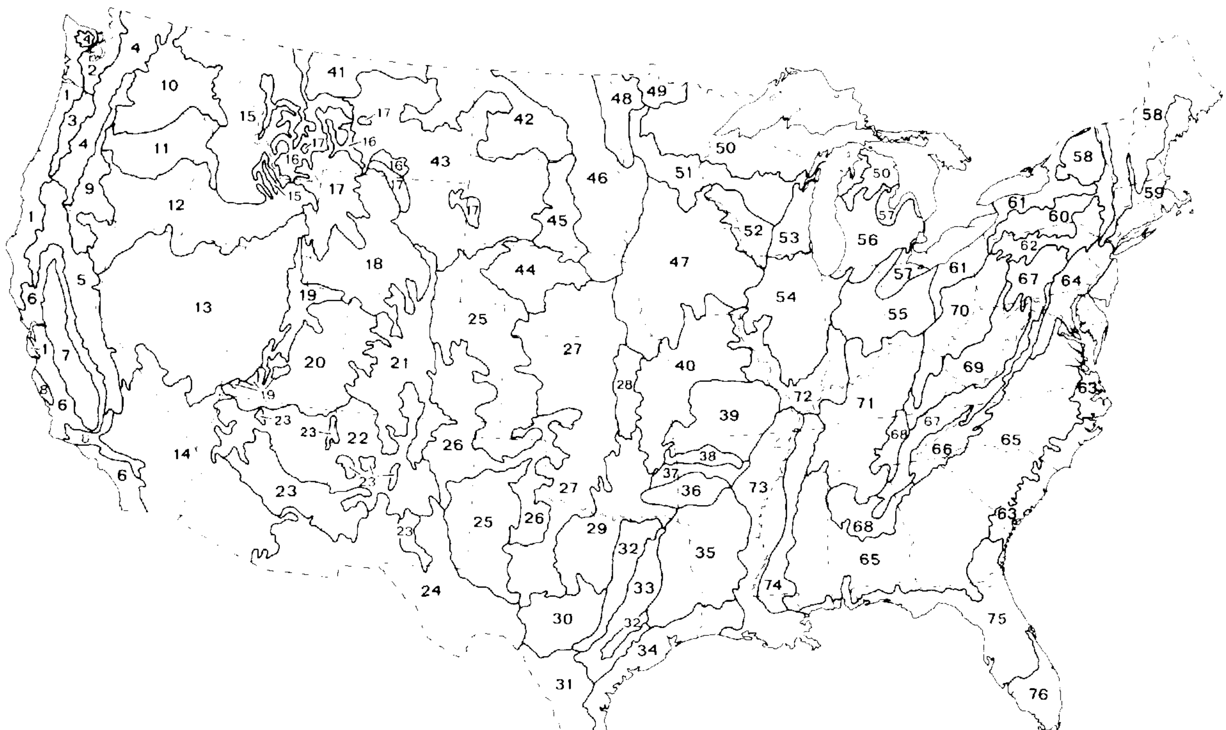

Figure 1. Ecoregions of the conterminous United States (from Omernik 1987). 1 Coast Range, 2 Puget Lowland, 3 Willamette Valley, 4 Cascades, 5 Sierra Nevada, 6 Southern and Central California Plains and Hills, 7 Central California Valley, 8 Southern California Mountains, 9 Eastern Cascades Slopes and Foothills, 10 Columbia Basin, 11 Blue Mountains, 12 Snake River Basin/High Desert, 13 Northern Basin and Range, 14 Southern Basin and Range, 15 Northern Rockies, 16 Montana Valley and Foothill Prairies, 17 Middle Rockies, 18 Wyoming Basin, 19 Wasatch and Uinta Mountains, 20 Colorado Plateaus, 21 Southern Rockies, 22 Arizona/New Mexico Plateau, 23 Arizona/New Mexico Mountains, 24 Southern Deserts, 25 Western High Plains, 26 Southwestern Tablelands, 27 Central Great Plains, 28 Flint Hills, 29 Central Oklahoma/Texas Plains, 30 Central Texas Plateau, 31 Southern Texas Plains, 32 Texas Blackland Prairies, 33 East Central Texas Plains, 34 Western Gulf Coastal Plain, 35 South Central Plains, 36 Ouachita Mountains, 37 Arkansas Valley, 38 Boston Mountains, 39 Ozark Highlands, 40 Central Irregular Plains, 41 Northern Montana Glaciated Plains, 42 Northwestern Glaciated Plains, 43 Northwestern Great Plains, 44 Nebraska Sand Hills, 45 Northeastern Great Plains, 46 Northern Glaciated Plains, 47 Western Corn Belt Plains, 48 Red River Valley, 49 Northern Minnesota Wetlands, 50 Northern Lakes and Forests, 51 North Central Hardwood Forests, 52 Driftless Area, 53 Southeastern Wisconsin Till Plains, 54 Central Corn Belt Plains, 55 Eastern Corn Belt Plains, 56 Southern Michigan/Northern Indiana Till Plains, 57 Huron/Erie Lake Plain, 58 Northeastern Highlands, 59 Northeastern Coastal Zone, 60 Northern Appalachian Plateau and Uplands, 61 Erie/Ontario Lake Plain, 62 North Central Appalachians, 63 Middle Atlantic Coastal Plain, 64 Northern Piedmont, 65 Southeastern Plains, 66 Blue Ridge Mountains, 67 Central Appalachian Ridges and Valleys, 68 Southwestern Appalachians, 69 Central Appalachians, 70 Western Allegheny Plateau, 71 Interior Plateau, 72 Interior River Lowland, 73 Mississippi Alluvial Plain, 74 Mississippi Valley Loess Plains, 75 Southern Coastal Plain, 76 Southern Florida Coastal Plain.

(percent omnivores, percent insectivores, percent top carnivores), and assemblage abundance and condition (number of individuals, percent hybrids, percent diseased)]. The IBI estimates the relative health and complexity of a fish assemblage by comparing scores of the 12 metrics against previously determined regional standards; higher scores represent greater biological integrity. Results from the studies demonstrate the relationships between stream characteristics and Omernik's ecoregions. The studies are fully documented in the references cited below and are described only briefly here.

Ecoregional Patterns in Biological Assemblages

Arkansas. During 1983–1985, the Arkansas Department of Pollution Control and Ecology sampled two to five relatively undisturbed regional reference sites in each of the state's six ecoregions. Streams were sampled during spring and late summer. Physical, chemical, and biological (fish, macroinvertebrates) data were collected, including continuous 72-h dissolved oxygen monitoring performed at each site. Fish were sampled by use of rotenone and electrofishers. Arkansas fish assemblage data revealed expected regional patterns. Fish assemblages from the mountainous (D, E, F) and lowland (A, B) ecoregions differed distinctly; assemblages from the Arkansas River Valley ecoregion (C) were transitional (Rohm and others 1987) (Figure 2).

Ohio. Regional reference sites were sampled to determine water character and biological integrity in Ohio. Fish assemblages were sampled during the summers of 1983 and 1984, by electrofishing two or three times at 107 stream sites in five Ohio ecoregions. Macroinvertebrates were collected by multiplate samplers once at the same sites and conventional chemicals (nutrients, major ions, heavy metals) were monitored monthly for 16 months. IBI values were calculated from the fish data; these are presented as box plots (Larsen and others 1986, Whittier and others 1987) (Figure 3). Substantial differences occurred between values in the Huron/Erie Lake Plain and the western Allegheny Plateau; values for the other ecoregions were intermediate between these two.

Oregon. During summer 1984, fish in 49 regional reference streams were sampled by backpack electrofishing (Whittier and others 1988). The same sites also were sampled once at three stations for algal and macroinvertebrate communities and a variety of chemical and physical habitat variables. Site similarity was evaluated by DCA of fish species presence/absence data (Figure 4). Fish assemblages differed among regions, especially between ecoregions characterized by high- versus low-gradient streams (DCA axis I scores > 300 represent low-gradient streams). Regional differences within the high- and low-gradient groups of ecoregions could be distinguished but were less apparent.

Calapooia River. During summer 1983, fish from 17 sites along the Calapooia River, Oregon, were sampled by backpack or boat electrofishers (Giattina unpublished data). Ancillary physical–chemical habitat and macroinvertebrate data were taken at the same sites. Sites were ordinated based on the fishes present and formed four groups, each characterized by a distinct type of fish assemblage. Assemblages in first- and second-order streams differed from the mainstem sites, and mainstem sites of the same order differed between ecoregions (Figure 5).

Prickly Pear Creek. Prickly Pear Creek, Montana, contained metal concentrations that were in violation of US EPA acute and chronic criteria for aquatic life. Earlier toxicological studies showed considerable recovery (i.e., presence of trout and insignificant results with toxicity tests on resident fish). In an attempt to assess the recovery more fully, fish were sampled in summer 1981 by backpack electrofishing at eight sites; macroinvertebrates, physical habitat, and metals were sampled at the same sites. Fish assemblages of the chemically impacted site (Prickly Pear at Jefferson City, PPJ) and the chemically "recovered" site (Prickly Pear at Montana City, PPM) were similar but differed substantially from the six regional reference sites (Hughes 1985) (Figure 6).

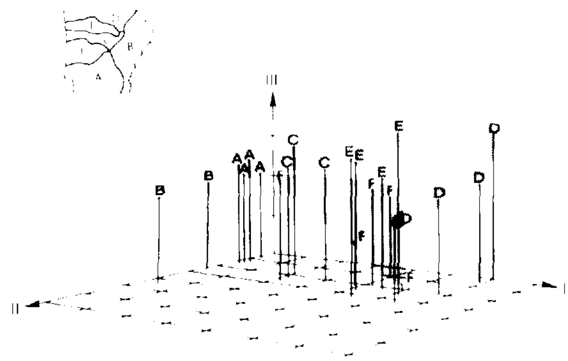

Figure 2. Ecoregional patterns of fish assemblages of Arkansas as depicted by detrended correspondence analysis (from Rohm and others 1987). Shading circumscribes sites within each ecoregion. **A,** South Central Plains, **B,** Mississippi Alluvial Plain, **C,** Arkansas Valley, **D,** Ozark Highlands, **E,** Boston Mountains, **F,** Ouachita Mountains. Differences in fish assemblages are associated with geographic trends in topographic relief and water quality.

Yellow Creek. Yellow Creek, in the Erie/Ontario Lake Plain of Ohio, was impacted by a point source and demonstrated a downstream recovery curve characteristic of municipal wastewater pollution. In 1984, fish were sampled at nine sites by towed electrofisher. IBI values were calculated from the data and compared with the 75th percentile of regional reference site values (exceptional warm water habitat, IBI = 49) (Ohio EPA 1987) (Figure 7). Although eventual downstream recovery from the effluent was apparent, diffuse pollution and physical habitat degradation prevented the creek from attaining its potential integrity at the upstream "control" and downstream "recovery" sites. If the criterion was lowered to the 25th percentile of regional reference site values (warm water habitat, IBI = 42), then the upstream controls would be considered unimpaired, but the downstream sites would remain impaired.

Use of Ecoregions and Biological Criteria for Evaluating Recovery

The relationships between ecoregions and patterns in fish assemblages demonstrate the value of ecoregions for assessing aquatic ecosystem potential and recovery. Distinct regional patterns occur within individual states and river basins. These patterns are func-

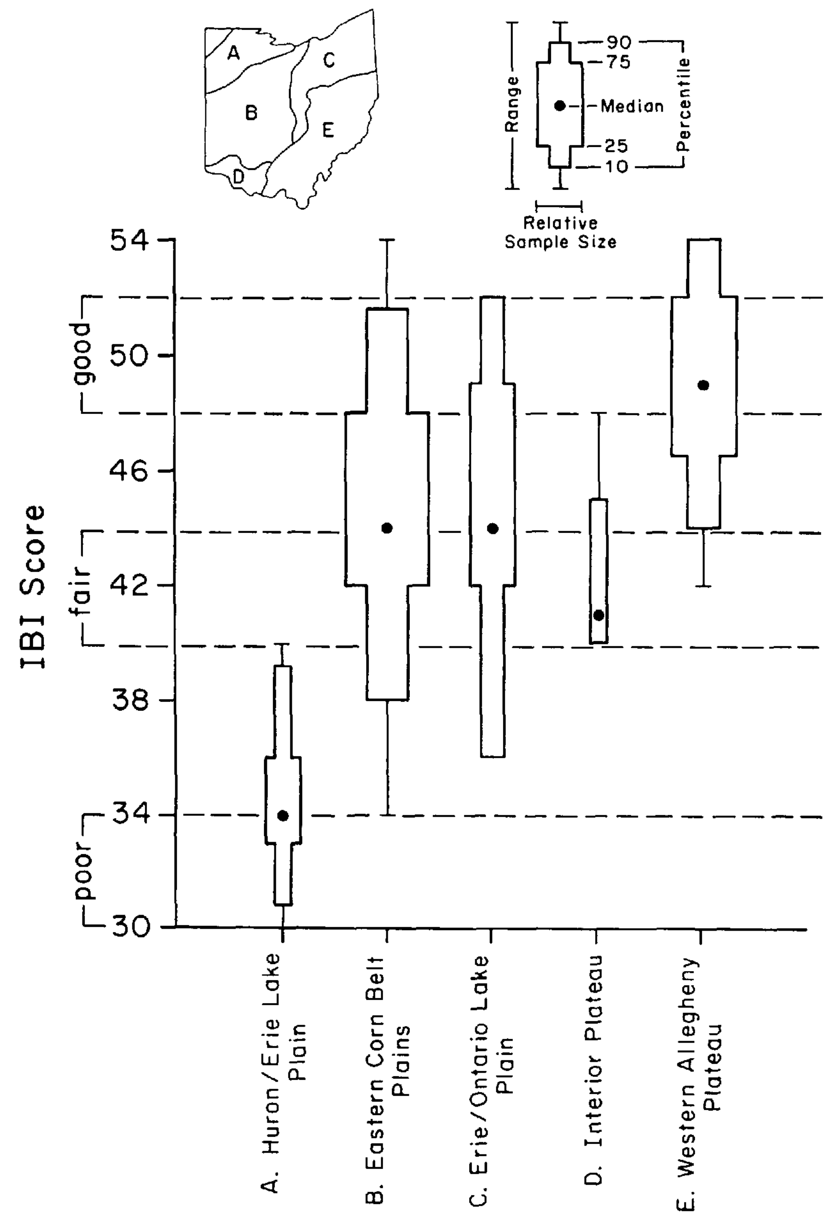

Figure 3. Ecoregional patterns in the index of biotic integrity (IBI) for fish assemblages of Ohio streams (from Whittier and others 1987). See upper right inset for description of box plots. **A,** Huron/Erie Lake Plain, **B,** Eastern Corn Belt Plains, **C,** Erie/Ontario Lake Plain, **D,** Interior Plateau, **E,** Western Allegheny Plateau. Greater index values represent greater complexity and health of fish assemblages.

tions of natural differences and prevailing land management practices. Ecoregions offer a useful geographic framework for establishing quantitative, attainable biological criteria, given present best management practices, such as no-till agriculture and 100-ft riparian buffer strips.

Ecoregions and biological criteria are beginning to be used as a basis for resource management. Ohio and Arkansas have developed ecoregion-based biological criteria (Ohio EPA 1987, Arkansas DPCE 1988), and the US EPA is developing policy and guidance documents that encourage other states to develop in-stream biological criteria (US EPA 1988, 1990). Ecoregions and a set of regional reference wetlands also have been proposed for assessing wetland creation and restoration projects (Brooks and Hughes 1988, Henderson and others 1988).

Biological criteria. Biological criteria for assessing

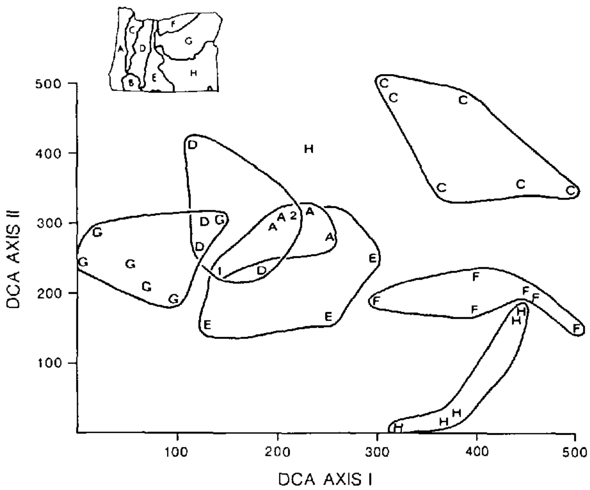

Figure 4. Ecoregional patterns in fish assemblages of Oregon streams (from Whittier and others 1988). **A,** Coast Range, **B,** Sierra Nevada, **C,** Willamette Valley, **D,** Cascades, **E,** Eastern Cascades Slopes and Foothills, **F,** Columbia Basin, **G,** Blue Mountains, **H,** Snake River Basin/High Desert. **1** = sites with rainbow trout only; **2** = sites with rainbow trout and reticulate sculpin only. Different distribution patterns of fish assemblages correspond to trends in humidity, topographic relief, and water quality.

impairment and recovery can be developed from data collected at a series of subjectively selected regional reference sites. Fish assemblage criteria can be described by indices, such as Karr's IBI, that reflect an overall assessment of a stream's condition. For example, unimpaired small streams in the western Allegheny Plateau ecoregion of Ohio are expected to have IBI values greater than 46 (25th percentile of regional reference site values) and 25% of these streams should have IBI's exceeding 52 (75th percentile). Such values are highly unlikely in the Huron/Erie Lake Plain, where the regional IBI criterion might be 33 (25th percentile) and "recovery" would be indicated by values exceeding 36 (75th percentile). These regional biological differences result from natural differences in landform, soil, and vegetation, which are reflected in differences in land use. The biological criteria should not reflect recovery to a pristine state, which generally remains undefined and unlikely, given the intense agricultural use of the land.

The IBI, because of its firm foundation in community ecology, seems particularly well-suited for assessing the recovery of aquatic ecosystems. It has been modified recently (Miller and others 1988, Steedman 1988, Oberdorff and Hughes 1990) for use in regions outside the Midwest, where it was originally developed. Similar broad-based indices have been proposed for macroinvertebrates by Ohio EPA (1987) and Plafkin and others (1989).

It may be possible to use multivariate patterns in the biological data from regional reference sites to evaluate recovery or impairment. Using the fish assemblages as an example, the initial ordination of reference site data would be compared with an ordination of the same sites plus a few sites suspected of impairment. In the second ordination, the reference sites for each region could be circumscribed subjectively (by eye) to delineate a hypothetical unimpaired area of "species space" for the regions. Or, more objectively, confidence ellipses could be calculated for each region's reference sites (Sokal and Rohlf 1981). In either case, the sites suspected of impairment that occur within the regional reference site ellipse would be considered satisfactory or recovered. Those falling just outside the ellipse, but towards a lower quality assemblage, would be considered as nearly recovered or slightly perturbed. Sites in the same ecoregion that occur well outside the ellipse and near the lower quality ecoregion would be considered highly perturbed. For example, an impaired site in the Cascades ecoregion of Oregon, where healthy streams normally are dominated by salmonids and sculpins, might contain a number of minnow species more typical of the Willamette Valley ecoregion. This site would ordinate in the Willamette Valley group of Figure 4, indicating a perturbation, even if an occasional salmonid or sculpin were present. If the site or watershed were managed more appropriately, its recovery could be tracked as it moved toward the Cascades group.

Precautions. Some precautions should be considered when an ecoregional approach to assessing impairment and recovery is used, relating primarily to selection of regional reference sites and their comparison with other sites (Hughes and others 1986). The search for least impacted watersheds should not totally override the criterion of regional representativeness. Sites that are pristine because of conditions atypical of the region (e.g., areas of steep rocky woodlands in an otherwise agricultural region) are not appropriate reference sites for that region. Such atypical sites would lead to unrealistic expectations for most sites in the region.

A considerable amount of map evaluation, aerial photography, and stream walking is essential before reference sites are selected. It is best to select a series (20–50) of candidate sites per region from maps. This number is reduced after field reconnaissance to 6–15 sites per region to select the least disturbed sites and to compensate for inadvertently selecting anomalous sites from maps, yet it ensures that the variability inherent

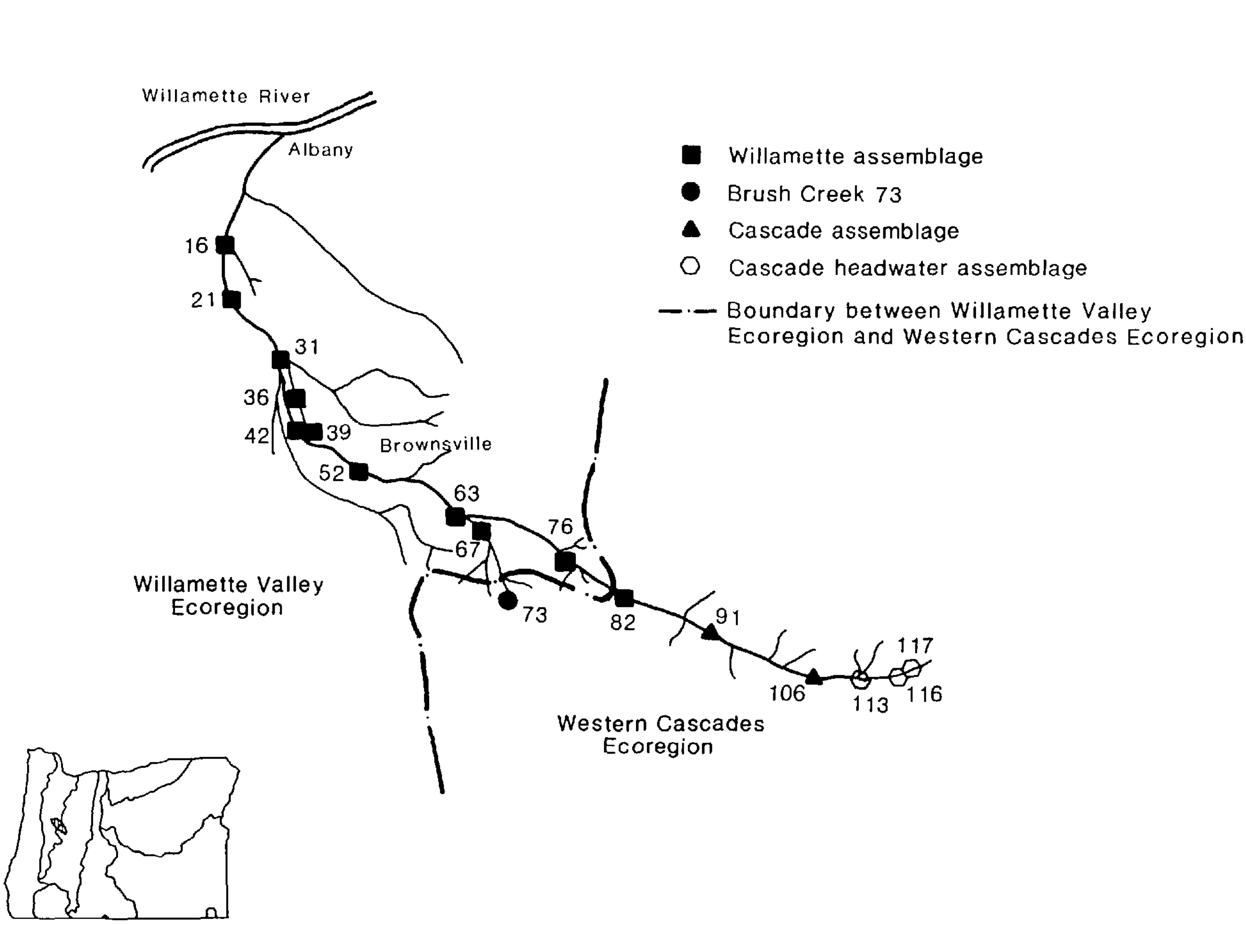

Figure 5. Correspondence between fish assemblages of the Calapooia River and ecoregions (from Giattina, personal communication, US EPA, Chicago). Note that headwater sites differ between ecoregions and that assemblages change independently of stream order.

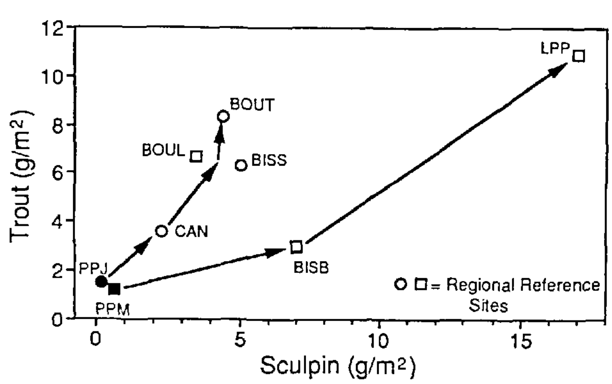

Figure 6. Recovery trajectories of western Montana trout streams (from Hughes 1985). PPJ, upstream site impacted by metals; PPM, downstream "recovery" site impacted by sediments; CAN, BOUT, and BISS are reference sites for PPJ; BOUL, BISB, and LPP are reference sites for PPM. Increases in fish biomass were associated with increases in habitat quality at the reference sites. Although having twice the discharge, BOUL is in the same ecological subregion and in the same area on the figure as the PPJ reference sites, suggesting characteristics of this subregion have a greater influence on the fish assemblages than does stream size.

in the region is represented. The process is necessarily subjective, but it is tempered by evaluation of the landscape and a large number of sites. It should not be attempted by persons unfamiliar with the ecoregions and biota of concern.

The stream size and origin and site-specific characteristics of sites also must be examined. Comparisons should be made only among similar sized streams because of the changes in the biological assemblages that occur as stream size increases. Sites on rivers and streams that drain major parts of two or more ecoregions should not serve as references for sites on streams draining only one ecoregion. For example, fish assemblages in large rivers originating in the forested mountainous Cascades ecoregion of Oregon resemble those in the Cascades for some distance after the streams enter the Willamette Valley ecoregion, an agricultural plain (Hughes and others 1987, Hughes and Gammon 1987). Sites on such mountain dominated rivers would be unsuitable references for rivers lying entirely on the plain, even though both types flow across the plain. Sites near ecoregion boundaries should be evaluated from the perspective of the con-

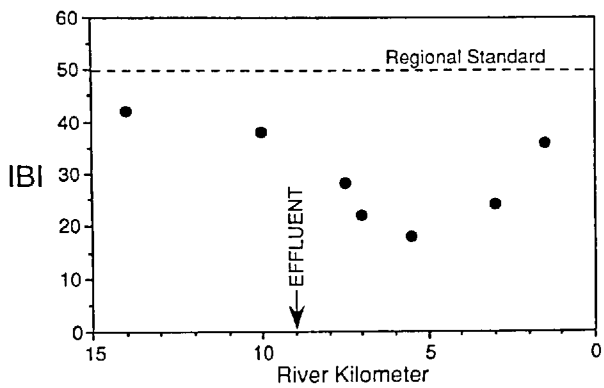

Figure 7. Recovery of Yellow Creek, a stream in Ohio's Erie/Ontario Lake Plain ecoregion (from Ohio EPA 1987). A regional standard was developed from data collected at reference sites in that ecoregion. Note that because of nonpoint source pollution and suboptimal physical habitat, neither the upstream "control" sites nor the "recovery" site at river kilometer 2 attains the integrity of the regional reference sites.

tiguous ecoregions. Fish assemblages also are affected by river basins, species introductions, unusual substrate, springs, migration barriers, and confluence with large waterbodies (Gorman and Karr 1978, Gilbert 1980, Matthews 1986). These must be evaluated in the map analysis or field reconnaissance phases.

In highly heterogeneous ecoregions, within-region variability might prevent assessment of the recovery of all but the most disturbed sites. In such ecoregions, it is best to map ecological subregions (Clarke and others 1990, Gallant and others 1989) or to further classify sites by stream valley type (e.g., Rosgen 1985). High- and low-gradient streams in some ecoregions of Oregon have slightly different fish assemblages (Whittier and others 1988). For example, the mountainous ecoregions all support salmonids and sculpins, but the species and their relative occurrences and abundances differ. In other words, expectations of recovery rate and characteristics for particular sites must be tempered by ecological and biogeographical knowledge and field experience.

Conclusions

Ecoregions provide a geographic framework for assessing data from many sites, for extrapolating data from a few sites to a region, or for predicting conditions at sites of interest. Ecoregions provide a biogeographic framework for setting biological criteria, for assessing recovery potential, and for evaluating and tracking actual recovery of lotic ecosystems. In statewide case studies to date, distinctly different ecoregions support distinctly different fish assemblages or levels of biological integrity or condition. Transitional regions support fish assemblages with intermediate characteristics and integrity.

It can be argued that values measured at reference sites that are less than pristine do not represent real recovery or biological integrity, which Karr and Dudley (1981) define 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." Although this is true in most cases, we are exceedingly naive if we think that our society will return landscapes to their Precolumbian state. This would require massive depopulation and a return to a hunting and gathering economy. However, it does seem reasonable to expect that most riparian lands can be managed at least as well as the best managed (least disturbed) riparian areas of the ecoregion, that channel modifications can be strongly curtailed, that silvicultural rotations can be lengthened, and that grazing and farming intensity can be reduced. If these objectives were accomplished, we should expect considerable recovery because of the immediate local effects or improvements and their cumulative effects down- and upstream.

By stratifying spatial variability, an ecoregion map offers a simple, but generally useful tool for helping resource managers implement feasible regional management practices, for developing objective biological goals for restoration, and for determining measurable biological criteria to assess the attainment of those goals. Ecoregions make the problem of natural variability more manageable and facilitate development of biological criteria that are regionally appropriate and more protective of aquatic life than chemical criteria. Ecoregional biological criteria can improve our ability to detect and predict trends in recovery or degradation. In summary, an ecoregion map provides geographic classes that are more ecologically based than are hydrologic units or political boundaries. Thus, the map enables us to monitor the results of management actions more effectively, and the biological criteria provide direct and meaningful measures of ecological integrity.

Research Needed

As is common in many newly developed assessment areas, additional research is needed to evaluate fully ecoregional reference sites and assessments of community integrity. It is also necessary to evaluate the long-term biological results of continued restoration of reference site watersheds. The degree of difference among ecoregions needs assessing to determine whether reference sites in a neighboring and similar ecoregion may serve for an ecoregion that is extensively perturbed. On the other hand, many ecoregions are likely to require subregionalization to provide useful reference sites. Considerably more research is needed to evaluate the degree to which rivers change as they cross ecoregion boundaries. Finally, the concept has been assessed in only three states. Ecoregional reference sites elsewhere in the United States, particularly the Southeast and Southwest, await rigorous evaluation as was done in Ohio, Oregon, and Arkansas.

More research also is required on the preferred assemblages to be evaluated. Although fish assemblages were shown to be more appropriate in the three statewide studies, macroinvertebrate and algal assemblages may prove more useful for subregional reference sites because these assemblages are more responsive to local habitat conditions. Whatever the degree of regionalization, questions remain about natural variability in time and space, in the degree of uncertainty of the measurements, and in the statistical tests and biological indices used to make the assessments. These issues are pertinent to a number of papers in this volume. Research is needed to refine habitat, trophic, and tolerance guilds of fish and macroinvertebrate species. These data are required for developing IBI-like indices for macroinvertebrates and for modifying the IBI in the southeast and southwest United States. This information, in turn, is useful for evaluating the response of the indices to various physical and chemical stressors, which might allow their use as stressor screens and early warning tools.

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