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Conservation of running waters: beyond riparian vegetation and species richness

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INTRODUCTION

In this paper, I describe a hierarchical framework for the conservation of running waters over broad geographical areas. My objective is to describe a scheme for the conservation of drainage basins (catchments) within a landscape hierarchy and to advocate the use of non-taxonomic biological measures for the assessment of rivers.

HIERARCHICAL FRAMEWORK

The concept of scale is fundamental in addressing ecological problems. A framework for rivers may be based on how they are organized in hierarchical space and how they change through time (Frissell *et al.*, 1986). Riverine systems have several hierarchical or nested levels, including drainage basin or catchment, valley segment, stream reach and channel unit (Conquest *et al.*, 1994). Hynes (1975) emphasized that streams are heterotrophic and 'that in every respect the valley rules the stream'. Accordingly, anthropogenic changes (even subtle ones) in the valley often have important effects on receiving waters (Hynes, 1975).

At large scales, rivers also depend on the particular biome through which they flow. Biomes are defined by climate (temperature and precipitation), but are characterized by climax vegetation types. Both the climax vegetation of a biome and its evolutionary history are important determinants of species diversity within biomes (Milchunas *et al.*, 1988). In streams, diversity and habitat characteristics depend on temperature, quantity and velocity of water, which in turn relate to rainfall and air temperature (the main determinants of terrestrial vegetation). Therefore, the effect of a biome on streams should be more apparent in a region with a ratio of large land area to river area (Ross, 1963). Ross suggested that the link between Trichoptera (aquatic caddisflies) and biomes was stronger in small rivers than large ones. Corkum (1990, 1992) expanded this idea and proposed the Biome Dependency Hypothesis, which predicts that assemblages of macroinvertebrates are most likely to be similar at sites along rivers if drainage basins occupy the same biome.

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In hierarchy theory, large-scale patterns are thought to be constrained by higher levels in the system (Allen and Starr, 1982). In nested systems, the upper level or the whole (i.e. a continental landmass) turns over more slowly than its parts (biomes and, in turn, drainage basins or valleys within biomes). Rivers within biomes across Canada show this pattern, with community composition and density of invertebrates in drainage basins nested within biomes structured by the biome level of organization (Corkum, 1992) (Figure 1).

Longitudinal variables are frequently cited as the most important influences on stream community structure, but few studies have looked at streams at the biome scale. In a study of 100 river sites in north-western North America, Corkum (1989) showed that a model incorporating only landscape features correctly classified river sites with distinct invertebrate assemblages more often than one that used only hydrological features. Thus, patterns in landscape, imposed by geology or land use and vegetation type, can account for variations in invertebrate community patterns at large spatial scales. Further evidence for the relevance of large-scale approaches stems from the concept of ecoregions (Omernik, 1987; Bailey, 1996), which has also emerged as a unifying theme in aquatic classification and in the conservation of biota (Harding *et al.*, 1997).

RIVER–LAND LINKAGES

Recent research on river processes has focused on the immediate riparian zone (shoreline communities) or land-use pattern and type adjacent to the river. Riparian zones often regulate aquatic–terrestrial linkages; and their manipulation is a common watershed management tool in disturbed ecosystems (Naiman and Décamps, 1997; National Resources Conservation Service, 1999). The apparent significance of riparian vegetation or land use on receiving waters will depend on the scale or scope of the study (Frissell *et al.*, 1986), the similarity between the riparian zone to land cover in the drainage basin (Johnson *et al.*, 1997), and other interacting processes.

The riparian zone is thought to have a disproportionate influence (relative to its land area) on running waters because of its immediate effects on the transport of water, nutrients and sediments (Peterjohn and Correll, 1984). Yet, there are conflicting reports on whether small-scale (riparian) vegetation or large-scale (basin-wide) factors are more important in affecting the biological integrity of streams. For example, Omernik *et al.* (1981) showed that nutrient levels in rivers were related more strongly to the total amount of agriculture and forested land in a drainage basin than to the vegetation type in the riparian zone. Further, Barton (1996) demonstrated that both channelization and subsurface tile drainage eliminated the benefits of riparian buffer strips and magnified the effects of farming practices on stream macroinvertebrates.

At local scales, biotic responses to changes in either riparian zones or land use are linked to factors that affect the sources of energy in rivers. These ultimately influence the density and diversity of lotic invertebrates that depend on a detrital food base (Dobrin and Giberson, 1999). Energy factors, however, are also important at broader scales, where invertebrate density patterns at sites along rivers are associated with land use within catchments (Corkum, 1992). Allan *et al.* (1997) showed that regional climate, geology and vegetation away from the river channel affected channel form as well as nutrient and sediment influx. Typically, more nutrients are released into receiving waters from farmland than from forested areas and from low gradient than high gradient landforms.

The relationship between river biota and the biome in which they reside has important implications for monitoring land-use change, which is currently occurring on a global scale. Biotic responses to altered land use have been well documented, but the implications are rarely if ever considered at broad scales. Riverine communities in one biome (e.g. the Eastern Deciduous Forest, EDF) could take on characteristics of another biome (e.g. Grasslands) if land-use patterns alter the natural vegetation type in

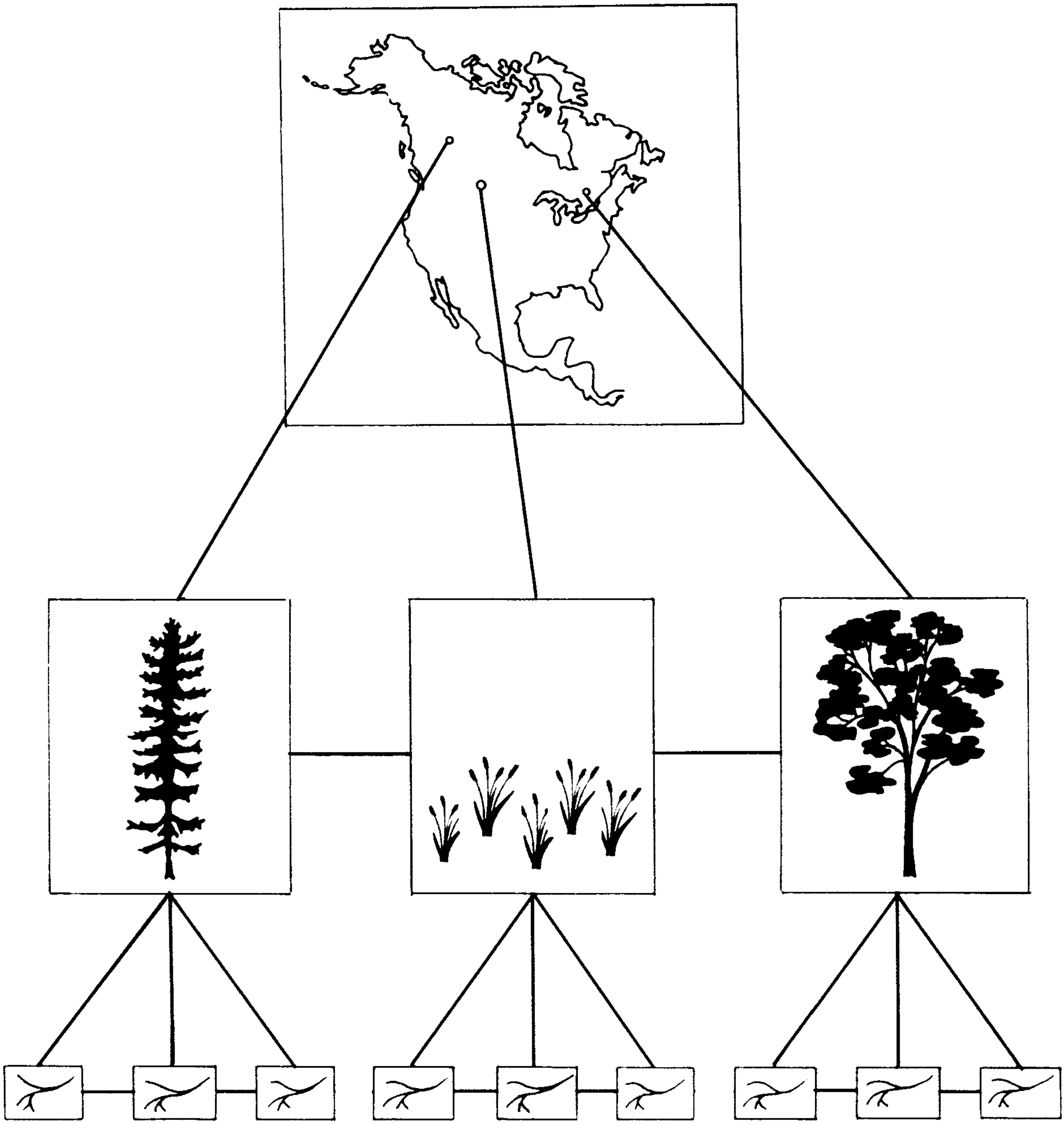

Figure 1. A hierarchical scheme is illustrated in which assemblages of macroinvertebrates in drainage basins are nested within biomes of a continental landmass. Three biomes are represented by the climax vegetation of the Western Montane Coniferous Forest, the Grasslands, and the Eastern Deciduous Forest (EDF). Horizontal lines joining biomes and drainage basins represent the potential influence of land use changes on rivers. For example, land use that changes forests in the EDF to cropland will drive changes in the invertebrate community so that dominant life forms will become similar in rivers of those biomes (EDF and Grasslands) where land use is comparable (Corkum, 1992, 1996). Treed areas in Grasslands drive the lotic community to forested-like fauna (Wiley *et al.*, 1990).

a region. In the hierarchical scheme pictured in Figure 1, horizontal lines joining the biome panels (and panels between drainage basins) represent the potential influence of land use on riverine invertebrate communities. At the biome level, land-use changes in the EDF, from forests to cropland, drive changes in the density and community composition of the dominant macroinvertebrates (Corkum, 1996). Similarly, forestation of the Grassland biome should result in a corresponding change in the riverine community to resemble the fauna in rivers of forested biomes. Wiley *at al.* (1990) demonstrated such changes in fauna in the downstream regions of prairie rivers that are characterized by riparian canopies. With time, the relative abundance of dominant macroinvertebrates will become similar in rivers of both EDF and Grassland biomes if land use in each region is comparable.

ALTERNATIVE BIOTIC CLASSIFICATIONS

Another long-standing debate on river restoration and conservation is the level of taxonomic resolution needed to characterize communities. Species-specific taxonomic groupings provide useful information for life history and zoogeographic studies, but time, money and systematic expertise are simply not available to allow focus on species-level identification at either local or worldwide scales. For example, Allan and Flecker (1993) cite the almost two-decade effort by Professor P. Zwick in identifying 1044 species of invertebrates in a 4.5 km stretch of a German stream. However, organisms identified to species are seldom pandemic, and results are not easily generalized to other systems. Hawkes (1975) summarized attempts to apply taxonomic designations developed from single-river zonation studies to other catchments. The predictive power of the relationships declined with increasing distance from the home stream.

An alternative to taxonomic designation is to use non-taxonomic groupings of biota in environmental assessment (Corkum and Ciborowski, 1988; Richards *et al.*, 1997). One non-taxonomic criterion for grouping is the concept of 'life form' (Thorup, 1966), which considers body shape and size. Similarities in morphological adaptations of benthic macroinvertebrates throughout the world have been linked to changes in current velocity and substrate type (Hynes, 1970). These patterns of form and function led to a study of alternative classifications of Ephemeroptera by Corkum and Ciborowski (1988), who showed that the most significant types of groupings with respect to abiotic factors were related to body type. The relative abundance of sprawling mayflies was positively associated with conductivity and negatively associated with latitude. Importantly, no taxonomic knowledge was required to classify the life forms of these mayflies. Direct observation of the living specimens or the morphological examination of preserved specimens permitted the identification of the behavioural group.

Life history and behavioural characteristics also may show stronger patterns than species groupings. In a study of 58 catchments in a mixed land-use basin in Michigan, USA, Richards *et al.* (1997) concluded that life history and behavioural traits of macroinvertebrates were useful in enabling researchers to explain the mechanisms responsible for assemblage structure in rivers. Because life history and behavioural attributes are not constrained by biogeographical distributions, these biological groupings can be applied 'across ecoregions' (Richards *et al.*, 1997) and at different levels in the hierarchical scheme.

CONSERVATION APPLICATIONS

Conservation action plans need to be integrated across broad geographical scales to preserve the waters that run through the land. Management of riparian zones and river restoration techniques cannot be expected to offset the dramatic changes in broad-scale land use over the last century that have altered major biomes (Ojima *et al.*, 1994). We should stop directing 'almost all resources to restoring the most degraded or worst looking river reaches, single (usually game) species, or to improving water quality with little awareness of the needs of the overall ecosystem' (Doppelt *et al.*, 1993).

Conservation of rivers should be linked to conservation efforts on land. Changes in land cover resulting from human activity represent a major loss of biodiversity and a major source of global environmental change (Hannah *et al*., 1995). Appropriate farm and forestry practices, necessary sewage treatment, and commitment by industry to the zero discharge of persistent toxic substances are all required to conserve rivers.

Conservation strategies focused on biotic assemblages are more ecologically sound than keeping score of imperiled or vulnerable species (Orians, 1993; Angermeier and Schlosser, 1995). Conservationists should focus on protecting and preserving the land that rivers flow through. One check or measure of conservation success on land may be to examine the variety of life-forms of invertebrates that dwell in rivers. The expected characteristics of invertebrate assemblages can be predicted from landscape features obtained from maps (Corkum, 1989).

The hierarchical classification scheme can be used in conservation. Specific forest practices can be modified for designated valley segments. For example, unconstrained channels with a wide valley floor and open canopies require different management techniques than constrained channels (Naiman *et al*., 1992). However, actions for conservation of rivers should be integrated at different geographical scales. As the geographical scale increases, the need for multi-jurisdictional coordination increases (Salwasser, 1990).

Successful conservation of large lands (and concurrently, rivers) will occur only if partnerships are developed among government agencies, farmers, industries, environmental groups, and researchers to achieve shared objectives. The piecemeal application of conservation tools (land acquisition, riparian restoration, and reforestation) will not work if efforts are not coordinated across both geographical and political boundaries because the scale of remediation is simply too small to have more than a local effect. Federal governments should take the lead in the development of Conservation Acts that demonstrate the solid link between economic development and ecological integrity. All lands (public and private) should be integrated into a successful International Conservation Strategy.

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