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Unlocking the relationship of biotic integrity of impaired waters to anthropogenic stresses

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Abstract

The Clean Water Act expressed its goals in terms of restoring and preserving the physical, chemical and biological integrity of the Nation's waters. Integrity has been defined as the ability of the water body's ecological system to support and maintain a balanced integrated, adaptive community of organisms comparable to that of a natural biota of the region. Several indices of biotic integrity (IBIs) have been developed to measure quantitatively the biotic composition and, hence, the integrity. Integrity can be impaired by discharges of pollutants from point and nonpoint sources and by other pollution-related to watershed/landscape and channel stresses, including channel and riparian zone modifications and habitat impairment. Various models that link the stressors to the biotic assessment endpoints, i.e., the IBIs, have been presented and discussed. Simple models that link IBIs directly to single or multiple surrogate stressors such as percent imperviousness are inadequate because they may not represent a true cause–effect proximate relationship. Furthermore, some surrogate landscape parameters are irreversible and the relationships cannot be used for development of plans for restoration of the water body integrity.

A concept of a layered hierarchical model that will link the watershed, landscape and stream morphology pollution stressors to the biotic assessment endpoints (IBIs) is described. The key groups of structural components of the model are: IBIs and their metrics in the top layer, chemical water and sediment risks and a habitat quality index in the layer below, in-stream concentrations in water and sediments and channel/habitat impairment parameters in the third layer, and watershed/landscaper pollution generating stressors, land use change rates, and hydrology in the lowest layer of stressors. A modified and expanded Maximum Species Richness concept is developed and used to reveal quantitatively the functional relationships between the top two layers of the structural components and parameters of the model.

Keywords: Ecological risk; Water body integrity; Hierarchical ecologic models; Biotic assessment endpoints; Index of biotic integrity; Maximum species richness

1. Introduction

The US Clean Water Act (CWA) has a goal of *restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters.* The Act also

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defined *pollution* as anything that downgrades the integrity of the water body and is caused by humans or human activities. Such downgrades can be caused by discharges of pollutants from various (point and diffuse) sources, by habitat degradation due to a change in hydrology, unnatural invasion of foreign species and other actions by humans. Similarly, The European Union (EU) Water Framework Directive (WFD) requires that surface waters should achieve "good" status that is based on "ecological quality", taking into account biology, chemistry and physical status (habitat) (Chave, 2001). The EU approach calls for integration of natural and anthropogenic factors affecting the waters.

"Integrity" has been defined as the ability of the water body ecological system to support and maintain "a balanced integrated, adaptive community of organisms having a species composition, diversity and functional organisms comparable to that of a natural biota of the region" (Karr et al., 1986). Recently, the term "integrity" has been applied to water bodies that are minimally impacted by human activities while the term "health" is reserved for conditions desired by humans but not necessarily natural (Karr, 1996). "Good ecological quality" as used in the WFD, may have the same meaning. In many areas, human activities have radically altered the landscape and the aquatic ecosystem, such that an attainment of the predisturbance ecologic condition of the watershed and the water body is impossible (National Research Council (NRC), 2001). Therefore, establishing the ecological potential of the water body, while considering irreversible and reversible changes in the watershed, is the goal of both the European WFD and the US watershed management programs required by the CWA.

During most of the last century, water pollution remediation efforts focused on the water body itself and clean-up involved focused on point sources by building wastewater collection and treatment systems. The objective of abatement was improvement of water quality expressed by a few chemical parameters such as dissolved oxygen (DO), BOD, ammonium, nutrients, or suspended solids. During the last quarter of the 20th century, abatement of nonpoint sources of pollution became a part of the picture and by the end of the last century it was realized that nonpoint pollution was responsible for more than half of the remaining water quality problems.

Today, the focus of pollution abatement and water body restoration has shifted to a more holistic view. Following Leopold's (2001) paradigm, a water body and its watershed are parts of the same system and streams and rivers reflect the landscape they drain (Hynes, 1975; Poff and Ward, 1990). The spatial relationships of any lotic ecosystem are lateral (channel–riparian zone–floodplain), longitudinal (a lower-order stream to a higher-order stream, upstream to downstream), and vertical (atmospheric–surface–ground water interactions), the relative importance of which vary both spatially and temporally. Finding the causes of the impairment of integrity and development and implementation of a remedy are now the key components of watershed management.

Until recently, interest in the implementation of biotic integrity concepts has been in the domain of aquatic biologists. Environmental engineers and planners remained locked in the tradition of chemically based approaches, relying on established chemical water quality standards and models. This led to problems with full implementation of the total maximum daily load (TMDL) program and plans required by the CWA (NRC, 2001). In Europe, many states also classified water quality in water quality classes ranging from "excellent" to "very poor" using mostly chemical parameters. There is now a strong effort in the US and EU to include biotic criteria and to relate pollution abatement to the ecologic (integrity). The goal of these efforts is to link qualitatively the impairment of integrity to the causative stressors and to development of watershed vulnerability evaluations that would allow prioritization of watersheds requiring remediation and development of better pollution abatement programs. This represents a new challenge not only to aquatic biologists and chemists but also to environmental engineers and planners

2. Expressing integrity of aquatic ecosystems—endpoints

Environmental indicators are categorized as *stressors, exposure, and response indicators* (Yoder and Rankin, 1999; Yoder et al., 2000). Stressors include point and nonpoint loadings (including atmospheric deposition), land use changes, stream modification, and other large scale influences that generally result from anthropogenic activities. A disruptive stressor that can cause damage or an adverse change of integrity is called a *hazard* (Hunsaker et al., 1990). An external pollutant load stress becomes a hazard if the loads exceed the loading capacity of the receiving water body (US Environmental Protection Agency (US EPA), 1991; National Research Council (NRC), 2001) or when the stress causes a damage to and/or disappearance of the indigenous biota. This is the basic concept of the TMDL process. *Exposure indicators* include chemical parameters, whole effluent toxicity, tissue residues, sediment contamination, habitat degradation and other parameter values that result in a risk to the resident biota. A *risk* is a numeric value assigned to an exposure stressor that expresses a probability that the numbers and diversity of the resident organisms will be degraded and some organisms will be lost from the system, either due toxic or chronic effects or due to habitat degradation.