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Introduction to the Special Section: Wetlands Health Indicators

Next Generation of Ecological Indicators of Wetland Condition

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The search for indicators of ecological condition of aquatic ecosystems has intensified in recent years. However, the set of ecological and socioeconomic indicators available for assessing and predicting environmental integrity, health, and sustainability is not complete, nor is it formulated for consistent assessments across aquatic ecosystem types or scales. Thus, management activities are not effectively or efficiently applied across the wide array of political divisions, and application of the existing array of indicators for aquatic ecosystems is suboptimal. A common language is needed for managers of terrestrial and aquatic resources, so that their assessments and subsequent management activities can be linked throughout the continuum of aquatic ecosystems, which include headwater wetlands and streams, floodplains and rivers, lakes and reservoirs, and tidal marshes and coastal bays. Only in this way will these critical ecosystems be protected and managed appropriately.

Given limited resources for the assessment and protection of ecosystem health, a suite of ecological and socioeconomic indicators, if properly selected, evaluated, and synthesized, could help scientists, managers, and policy makers document trends, prioritize issues, and target management activities. By providing reliable expressions of environmental stress or change, ecological indicators can integrate impacts that are spatially and temporally disparate. Surveys have demonstrated that resource managers prefer to have a suite of indicators from which they can select ones that meet their particular needs.

For indicators of aquatic ecosystems to be effective, coasts, estuaries, rivers, streams, lakes, and wetlands must be viewed as one integrated system. Then, when combined with the contributing terrestrial areas, a reliable assessment of a true watershed or estuary can be conducted. Only a fully integrated system of inventory, assessment, and restoration can effectively and efficiently protect the nation's waters and the biota dependent upon them. The availability of a defensible and useful suite of environmental indicators is essential for this to happen. Indicators should help managers and communities understand how the health of aquatic ecosystems affects their society, economy, culture, and quality of life. That is, humans are part of, not apart from, coastal and freshwater ecosystems. Based on choices made by individuals and communities, respectively, landscapes

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evolve such that a single reference condition cannot be representative, and there is a distinctive context for each geographic region where an indicator might be applied.

The portfolio of assessment tools for aquatic ecosystems has been expanded substantially in the past several decades with improved levels of detection for chemical pollutants, expanded use of biological indicators, and implementation of citizen monitoring programs. Still, gaps remain in the system of resources that are assessed (e.g., tidal and freshwater wetlands, headwater streams, riparian corridors). The linkages among aquatic ecosystems, terrestrial surroundings, and societal activities are postulated, sometimes confirmed, but rarely integrated.

This Special Section of *EcoHealth* seeks to move us toward that level of integration. As a first step in selecting indicators, **Wardrop et al.** offer an indicator taxonomy. They describe three major impediments to identifying and repairing impaired areas: the scarcity of effective ecological indicators, that existing indicators are not applicable at spatial scales relevant to management and restoration, and a disconnect between existing indicators and the land use contexts to which they apply. The authors use these impediments to frame their taxonomy. Focusing on a specific question or objective necessitates development and selection of effective indicators, and identifying the scales and context of the research objective addresses the two remaining impediments. A fourth *and major* impediment to identifying impaired areas is the paucity of probability sampling to develop and validate ecological indicators. For example, one might select the best possible indicator for a particular question, a particular spatial/temporal scale, and a particular context, but if observations of that indicator are not obtained using a probability-based sample, then any inferences based on that indicator are not at all guaranteed to be representative of the specified spatial/temporal scale or context. There are myriad examples in which inferences based on convenience samples and those based on probability samples are wildly different. While we would not advocate introducing probability-based sampling as part of the taxonomy, it could become part of the *sampling protocol* for any monitoring endeavor that implements the taxonomy.

Several of the articles included in this Special Section are evaluated using this taxonomy. **Hershner et al.**, using the indicator taxonomy to categorize the suite of indicators used by the Chesapeake Bay Program, demonstrated that the predominance of indicators yielded condition assessments, not ones suitable for diagnostic or forecasting purposes. Evaluating other broad-scale monitoring programs using this approach should prove beneficial as managers seek to balance the selection of indicators against multiple objectives and limited resources.

The article by **Hanowski et al.**, working with birds, effectively illustrates the challenges facing integration and comparison of environmental assessments across substantial geographic areas that span the different ecoregions of the Great Lakes. Substantially different physiographic and climatic contexts cannot be directly integrated or compared at all levels of detail. Species with broad geographic ranges typically have considerable tolerance to environmental variation, whereas species with high environmental specificity often have rather restricted ranges. In order to obtain indigenous bioindicators having high sensitivity to the onset and degree of ecological degradation, it becomes necessary to use niche specialist species occurring in local ecozones. Thorough ecological characterization of reference sites and electronic publication of the basic data for easy access by potential users becomes critically important in efforts to extend and integrate bioindicators over larger geographic and ecological scales. This type of integrative work becomes a substantial undertaking using multivariate analysis, and it is important to recognize and characterize the larger framework within which operational ecological indicators are developed.

Similarly, results of a landscape approach based on remote-sensing in Florida by **Reiss and Brown** resonate with other assessments based on some categorization and/or synthesis of land-cover/land-use in terms of the intensity of human influence in modifying or altering the proximate ecosystems. *Emergy* is one among several possible avenues for expressing degree of human influence, and is expedient in this case due to the sophistication of its elaboration for the Florida context. The basic requirement, however, is to have a categorization of land-cover/land-use and a complementary rating of categories with respect to degree of degrading human influence. Universally important in this regard are the extent of artificial impervious surfaces and the degree of hydrologic alteration as urbanization progresses, albeit that concerns for wetland habitats do not always follow a human disturbance gradient. For example, pasturing of livestock in wetlands of the Mid-Atlantic region has proven to have a positive influence for maintaining habitats for the federally threatened bog turtle *(Clemmys muhlenbergii).* Thus, paying attention to the target guilds, functional groups, or in some cases, species, is a necessary prerequisite to applying and interpreting specific indicators.

Florida is representative of a more general coastal context in which the subdued relief makes determination of likely flow paths from digital elevation models quite problematic, in contrast to settings with more pronounced topography. When topographic relief is slight, direct distance weighting is less prone to errors than attempting to determine flowpaths that are critical for predicting hydrologic impacts. The availability of fine-resolution remote-sensing data is critical to the success of this type of indicator. One of the important findings of this type of research is that landscape, rapid, and intensive measures are significantly correlated to each other. **Reiss and Brown**, and studies conducted elsewhere, have concluded that, by correlating the results of assessment techniques from different assessment levels, it is possible to forecast the potential range of score for one assessment level based on the calculated score from the other assessment level. Indicators like the Land Development Index (LDI) are the fastest and least expensive methods to assess wetland conditions, however, their accuracy largely depends on the precision of the existing, and hopefully current, land use maps. Associations among assessment scores at each level of investigation may provide a more comprehensive understanding of the current condition of wetland ecosystems. In addition, when limited resources do not allow an extensive field assessment to obtain detailed biological data, inferences of wetland condition can be made based on the established correlations among assessment methods.

Similar correlations were recognized by **Lane**, also working in Florida. His study of diatoms as an assessment tool for determining wetland condition provides strong evidence that an Index of Biological Integrity (IBI) developed for diatoms identified at the genus level can be equally useful as those developed using diatoms at the species and subspecies level. The results are particularly encouraging when limited resources are available for wetland assessment or diatom identification below the genus level.

Most aquatic monitoring programs include chemical characterization, because water chemistry variables provide meaningful proxies of human disturbance. However, monitoring strategies that rely solely on chemical data may be deficient by providing only snapshot measurements. Using biological indicators in conjunction with chemical and physical parameters can reflect the impact of human activities both in the aquatic habitats and in the surrounding terrestrial portions of a watershed. Many agencies responsible for assessing water resources now rely on measures of resident faunal and floral communities. Algal-based indicators provide some advantages over the commonly used fish and macroinvertebrate measures, because of the species diversity generally present in a single sample, the ease of sampling, and the narrowly defined responses to environmental and human-generated factors in many species. Diatoms respond rapidly to stressors, and they are well preserved in sediment deposits, making them among the preferred algal taxa for use as indicators. That said, diatoms may not be universally applied due to the logistic constraints of cost, time, and the lack of taxonomic expertise. However, if low-resolution taxonomic identification to the genus level proves to be widely applicable, as shown by **Lane**, then some of the obstacles to their adoption as an indicator may be removed.

Realistically, there should be a suite of indicators developed for discrete ecological regions. These should, and probably will, include physical, chemical, and biological elements. One can see from the diversity of approaches reported in this Special Section of *EcoHealth* that biological indicators, such as birds, plants, and diatoms, along with other taxa, can contribute to obtaining the most integrative and diagnostic assessment of aquatic ecosystem condition. Any indicator that can rapidly classify wetlands or other aquatic habitats into discrete classes or bins, such as "optimal," "suboptimal," or "marginal" categories, can prove to be a powerful assessment tool. In all cases, indicator development and application should be an iterative process that continues to explore performance across a series of environmental gradients and a breadth of geographic regions.