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INDEX TO EVALUATE LAKE RESTORATION[a]

Discussion by G. Fred Lee,* M. ASCE, R. A. Jones,* A. M. ASCE, and W. Rast[6]

The authors of the paper propose an LEI (Lake Evaluation Index) which is based on Secchi depth, total phosphorus, total nitrogen, chlorophyll *a*, dissolved oxygen, and the areal extent to which macrophytes cover a water body, as a means of evaluating the efficacy of lake restoration techniques. The approach used by the authors in developing their LEI is similar to those which have been used in the past by various individuals, most of which seem to have originated with the work of Lueschow, et al. (34). It consists of combining a variety of load (driving force) and water quality and other response parameters to derive a numerical ranking to characterize a lake or impoundment's eutrophication-related water quality. This basic approach was also used in the U.S. EPA's National Eutrophication Survey (37) and has been used in various forms by others, usually in attempting to classify the trophic status of water bodies. As discussed by Piwoni and Lee (35) however, the approach originally developed by Lueschow, et al. (34), which incorporates many of the same parameters as the LEI proposed by the authors, has a number of significant technical problems which can lead to inappropriate classifications of a water body's trophic status or in the case of the LEI, an inappropriate assessment of the degree of improvement in the beneficial uses of a water body resulting from a lake restoration technique. Piwoni and Lee (35) and Rast and Lee (36) have specifically pointed out that load (driving force) parameters should not be mixed with response parameters in a trophic state evaluation. For example, nitrogen or phosphorus loads or concentrations within a water body should not be given ranks with planktonic algal chlorophyll, macrophyte biomass, Secchi depth, etc. The major problems associated with such an approach are discussed in detail by Rast and Lee (39) and are summarized in the following section.

Any trophic state or lake evaluation index designed to assist the public or its representatives, or both, in assessing the cost-effectiveness and technical validity-water quality benefit of a particular activity must focus on those parameters which the public can recognize as affecting their beneficial uses of the water. Trophic state indices (TSI) and LEIs should only contain response terms relating to the beneficial use(s) of concern if their purpose is related to water quality management. The inclusion of such load (driving force) parameters as total phosphorus and total nitrogen in a trophic state index or LEI can readily lead to erroneous conclusions concerning the eutrophication-related water

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quality of a water body. This is largely due to the fact that the public does not care about, nor is their use of a particular water influenced by the nutrient loads or concentrations or some parts thereof per se. They are concerned about the greenness of the water (which can be measured by planktonic algal chlorophyll), water clarity-Secchi depth (i.e., the depth at which the bottom still can be seen), and the hypolimnetic oxygen depletion which affects the possibility of developing a cold water fishery in a water body that has summer surface water temperatures greater than about 20° C. Further, as indicated in the foregoing, only those response parameters related to designated, desired beneficial uses of the water body should be included in a trophic state index for water quality management. For example, hypolimnetic oxygen depletion may not be an appropriate response parameter to consider for a water body used for aesthetic enjoyment or a warm water fishery, as it may have no impact on these uses.

As discussed by Piwoni and Lee (35) and Rast and Lee (36), if the trophic state index is to focus on load (driving force) terms such as nutrient concentrations (which effect a eutrophication-related response), only the algal growth limiting nutrient at the time of water quality concern should be included in the index. It is generally agreed that in many parts of the U.S. and for that matter the world over, phosphorus is the chemical element most likely to limit maximum algal biomass production during the summer growing season in lakes and reservoirs. This does not mean, however, as is frequently assumed, that phosphorus is limiting algal growth at all times during the year. Further, as discussed by Rast and Lee (36), Jones and Lee, and Lee and Jones, nutrient limitation during one season of the year cannot be determined by nitrogen to phosphorus ratios determined at other times of the year. It is also important to recognize that the N to P ratio, for which the value of approx 16 to 1 on an atomic basis (7.5 to 1 on a mass basis) is often used as the demarcation between N and P limitation, does not necessarily indicate what is actually limiting algal growth. It only indicates which nutrient will likely be used up first and, therefore, be limiting if, among other things, the supply of nutrients is steady and growth is not inhibited by some other factor such as light intensity or photoperiod. Actual nutrient limitation *only* occurs when the concentration of the nutrient is at growth rate limiting values, which in the case of phosphorus is on the order of a few μg/L of available P. The growth of algae in general is not phosphorus limited if there are more than about 5 μg/L of available phosphorus (soluble orthophosphate) in the sample at the time that the measurements are made, independent of the N to P ratio. Further information on the appropriate approach for determination of nutrient limitation for a phytoplankton population is presented in the American Water Works Association Quality Control in Reservoirs Committee manual (36).

Another criticism of the authors' approach is that by incorporating a nonlimiting element (such as nitrogen) in the TSI or LEI, the index can readily be skewed in such a way as to cause it to have little or no relationship to those eutrophication-related beneficial uses of a water about which the public is concerned. For example, some water bodies have nitrate concentrations on the order of several mg N/L, far in excess of growth-limiting concentrations. To include nitrate in the TSI when its concentration can change by orders of magnitude without affecting the planktonic algal chlorophyll (greenness) i.e., when algal growth is phosphorus limited, is technically invalid. This is the most significant

deficiency with the authors' LEI, the trophic state indices of the National Eutrophication Survey and others as noted above. While TSIs or LEIs of the type normally proposed may have some validity as limnological research tools, they have considerable problems when used as quality management tools. Lee, et al. have studied in detail the major problems with various TSI classification systems and propose a system which eliminates the problems inherent in the authors' LEI and other similar trophic state systems which have been proposed. They point out that a lake evaluation index designed to help evaluate the efficacy of a lake restoration technique should include not only the trophic response of a water body, but also the length of time that significantly improved water quality is to persist and the cost of achieving the improved water quality for this period of time.

Due to space limitations, it was not possible to address all the problems on the paper by Porcella, et al. Further discussion is provided by Lee, et al. (38)

Appendix.—References

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