EPA/600/A-96/029

Regional Lake Quality Patterns: Their Relationship to Lake Conservation and Management Decisions

S.A. Peterson[1], R.M. Hughes[2], D.P. Larsen[1], S. G. Paulsen[1], J.M. Omernik[1]
[1]US EPA, NHEERL/WED, 200 SW 35th Street, Corvallis, OR 97333, (541) 754-4457
FAX (541) 754-4716, EMAIL: peterson@mail.cor.epa.gov
[2]ManTech Environmental Research Services Corp., c/o US EPA, NHEERL/WED
200 SW 35th Street ,Corvallis, OR 97333

Abstract

Understanding regional lake quality patterns is important to lake restoration. It puts specific lake conditions into perspective, provides a basis for establishing lake quality goals, identifies lakes most likely to benefit from restoration and forms a framework for assessing restoration success. We describe two techniques used to characterize regional lake quality patterns. Combining the two approaches provides an effective means to describe lake regions, management goals and restoration success. Case examples illustrate the significance of regional lake quality to specific lake restoration projects.

Key words

Lake restoration, Survey Sampling, Ecoregions, Phosphorus

INTRODUCTION

Scientific and public interest in lake restoration owe much to several key events including Dillon and Rigler's (1974) phosphorus/chlorophyll a relationship and Vollenweider's (1975) phosphorus loading and residence time relationships. The passage of the Clean Water

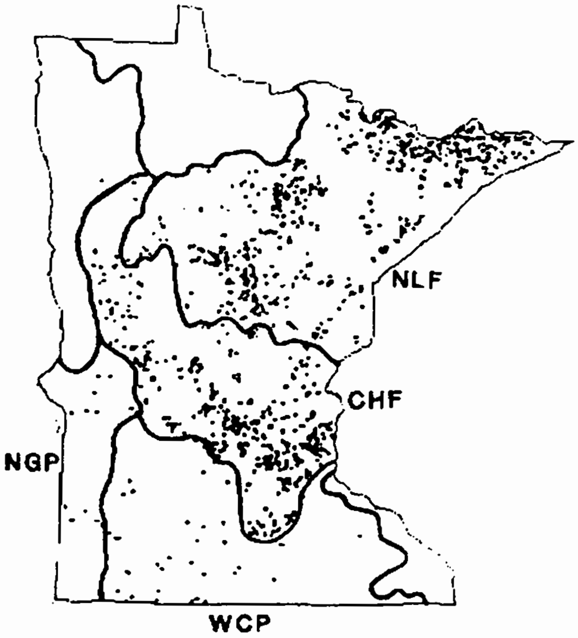
Act of 1972 with the so called "Clean Lakes" section, ultimately was responsible for launching the first formal and orchestrated movement to protect and improve lake quality in the U.S. The Clean Lakes Program provided federal funds to lake associations for diagnosis and "restoration" efforts. Restoration is a misleading term frequently envisioned to mean pristine. In practice, a more accurate definition is that coined by Sven Bjork in 1968, to reflect a recreation of conditions in such a way that acceptable environmental conditions are reestablished. As a rule this recreation of acceptable or suitable conditions reflects a local or regional perspective relative to uses for which the lake was once suitable before its degradation (Bjork 1994).

Based on the phosphorus limitation phenomenon in most freshwater lakes, restoration focused primarily on reducing this nutrient in the lake to a level that produced more acceptable phytoplankton species composition and biomass. Many techniques were employed for this purpose with little consideration for regional lake water quality relative to that of the "special interest lake". It has become apparent that prediction of the effectiveness of lake restoration improves if regional lake quality is considered in the evaluation of potential success. Thus, in this paper we describe two approaches for developing regional lake quality patterns and explain, through the use of case examples, why they are significant to conservation and management ("restoration") decisions.

ECOREGIONS

One approach for characterizing regional lake quality patterns is to integrate existing surrogate landscape level information pertaining to surface water quality in a fashion such as Omernik's ecoregions (1987, 1995). The concept of regional variability, while not new to limnologists, was formally recognized on a national scale by Omernik's (1987) description of 76 ecoregions of the conterminous United States. Omernik's original ecoregions are based on regional similarities in a combination of spatial characteristics that influence aquatic resource condition, including soils, geology, land surface form, climate, potential natural vegetation, and land use. These ecoregions, coupled with data on lake characteristics, provide a basis for delimiting current conditions and expectations for lake quality, assessing deviations from the expected, establishing reasonably attainable conditions, and estimating the success of restoration treatments. Many states are adopting an ecoregional approach to manage water quality (Hughes *et al.* 1994).

Figure 1. Location of 1400 state-wide total phosphorus lake sample sites within the four primary ecoregions [Northern Lakes and Forests (NLF); North Central Hardwood Forests (CHF); Western Corn Belt Plains (WCP); and Northern Glaciated Plains (NGP)] of Minnesota, USA. See Figure 3 for locator map. (Heiskary *et al.* 1987).

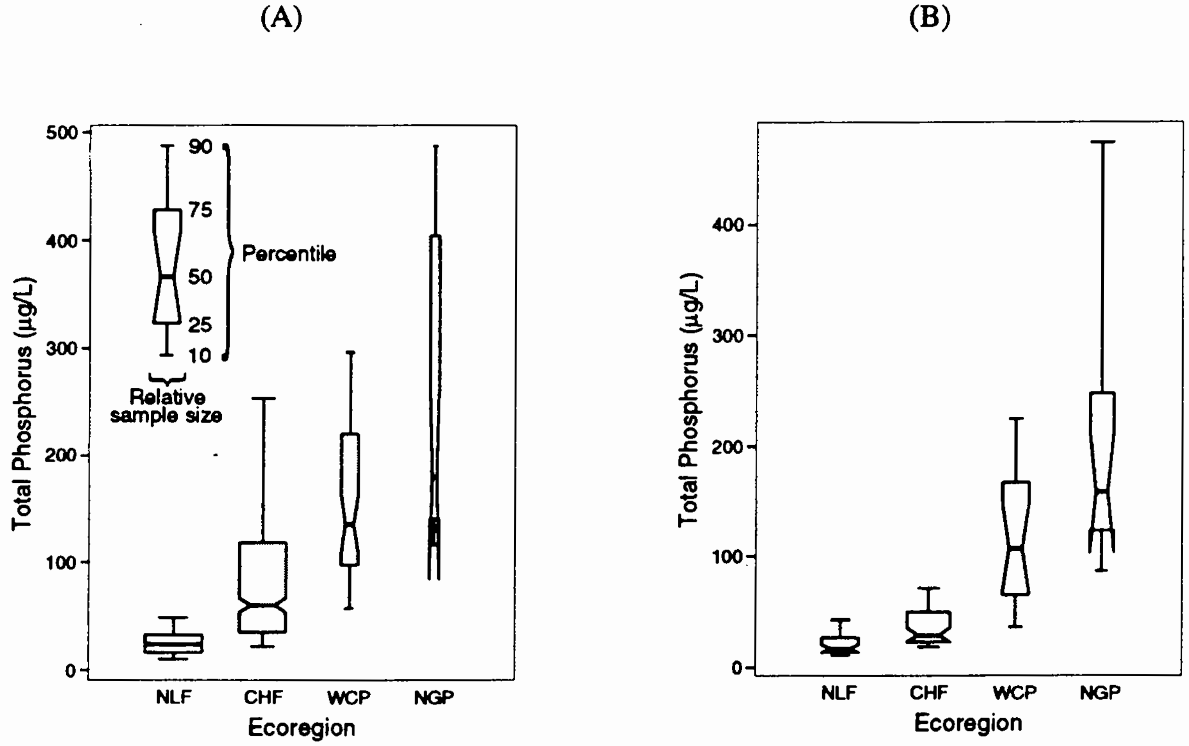


Heiskary and Wilson (1989) used Omernik ecoregions (Figure 1) to define Minnesota lake management goals based on differences in regional lake quality. They characterized total phosphorus by ecoregion from 1,400 lakes sampled state-wide by various investigators between 1970 and 1985 (Figure 2A). The State itself, monitored 90 reference lakes between 1985 and 1989 (Figure 2B), defined as those lakes minimally affected by point and nonpoint sources of pollution and in watersheds with regionally predominant landscapes. It is clear from these box-plots that lake total phosphorus concentrations differ considerably from ecoregion to ecoregion. The Minnesota Pollution Control Agency uses data from the regional reference lake patterns of water quality to define reasonable goals expressed in terms of average summer total phosphorus, likelihood of nuisance conditions (e.g., estimates of algal bloom frequency), and

Figure 2. Total phosphorus (µg/L) box-plots for 1400 lakes in Minnesota sampled state-wide between 1970 and 1985 (A), and 90 reference lakes sampled between 1985 and 1989 (B) by ecoregions. Ninety-five percent confidence interval (Cs_I) of the median is calculated as:

$Cs_I = \pm 1.7(1.25I/1.35\sqrt{n})$ where I = interquartile range and n = number of observations

(redrawn from Heiskary and Wilson 1988, 1989).



likelihood of Secchi disc transparency range exceedances relative to both lake protection and restoration goals. Deviation of non-reference lake conditions from the interquartile range (25th to 75th percentiles) of conditions for reference lakes connotes reasonable cause for concern and possible remediation.

SAMPLE SURVEYS

The ecoregional lake patterns also can be characterized with data collected specifically for that purpose through a well designed sample survey. Sample surveys that incorporate randomization in the selection of lakes to be monitored have the advantage of avoiding unknown biases that can arise if lakes are selected non-randomly. This design based approach to selecting lakes for monitoring is more efficient (requires fewer lakes) than use of less focused historical data and has the added advantage of providing estimates of the statistical confidence with which the regions are characterized (Larsen *et al.* 1994).

This approach has been used by the Environmental Monitoring and Assessment Program (EMAP) throughout the Northeastern United States from 1991through 1994 (Figure 3). For example, there are about 11,089 lakes > 1 ha in the NE U.S. Of these, a stratified random sample of approximately 86 lakes were selected for monitoring each year for four years (Table 1) with results summarized by ecoregion (Figure 4). Paulsen *et al.* (1995) demonstrated that pattern assessment of lakes via a probability design differs markedly from results obtained from a much larger hand-picked data base for the same region. Also, they found that the hand picked data bases underestimate the proportion of lakes that are eutrophic or hypereutrophic. In addition, estimates of trophic condition from yearly probability based sample surveys are much less variable than those from annual hand picked samples. The combination of ecoregional delineations with well designed sample surveys is an effective way to characterize the regional setting within which to evaluate lake protection or restoration.

CASE EXAMPLES

The importance of regional lake quality patterns, relative to restoration efforts, is illustrated by two examples from Minnesota. Shagawa Lake is located in the northern lakes and forests ecoregion (Figure 1). Between 1971 and 1973, average summer total phosphorus in the lake ranged between 50.8

Figure 3. Map of the United States showing Minnesota (Figure 1) and ecoregions of the Northeastern United States with the location of lakes sampled from 1991 through 1994 (EMAP 1991 through 1994 Northeastern Lakes Data Base).

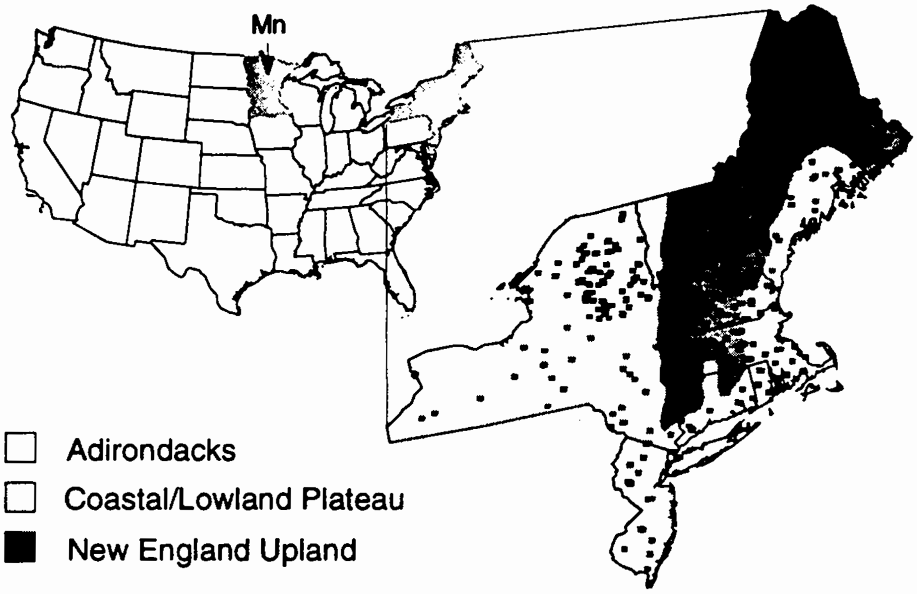
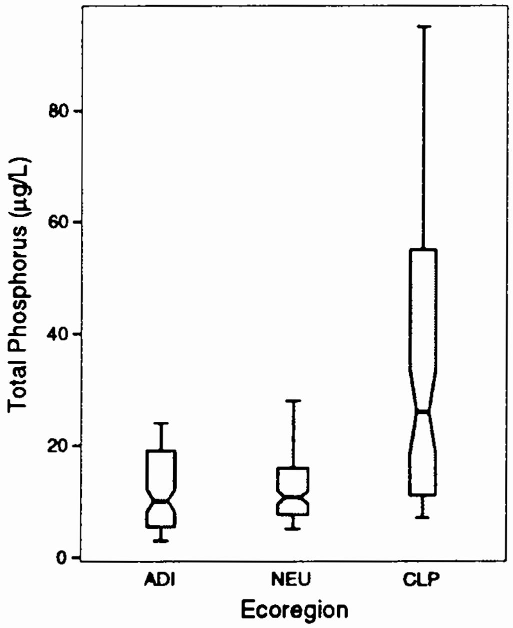


Table 1. Lake size classes, target population (number of lakes) by size class and number of lakes sampled by EMAP in the Northeastern United States from 1991 through 1994. Sample lakes were selected using a stratified random design (EMAP 1991 through 1994 Northeast Lakes Data Base).

Size Class (ha)	Target Lake Population	Sample Size
1 - ≤5	4160	30
>5 - ≤20	2135	69
>10 - ≤50	3287	121
>50 - ≤500	1294	85
>500 - ≤5000	208	39
>5000	5	1
Total	11089	345

Figure 4. Total phosphorus (µg/L) for lakes in ecoregions of the Northeastern United States [Adirondacks (ADI); New England Uplands (NEU) and the Coastal Lowlands and Plateau (CLP).] The legend in figure 2 applies here. (EMAP 1991 through 1994 Northeast Lakes Data Base)



and 60.9 ug/L, clearly an anomaly for the region. Extensive use of nutrient budget and lake loading models identified waste treatment discharge to the lake as exceeding by nearly four times that of natural inflows (Larsen *et al.* 1979). Therefore, given the information at hand and our understanding of phosphorus dynamics in lakes at the time, Shagawa seemed to be an excellent candidate to benefit from nutrient diversion; actually advanced waste treatment. The advanced waste treatment began in 1973 and immediately reduced the total external phosphorus inflow from 6,200 - 7,200 kg/yr to between 900 - 1,500 kg/yr, an amount sufficient to reduce the average inflow phosphorus concentration from 60 - 100 ug/L to less than 20 ug/L (Larsen 1979). In the absence of internal phosphorus supplies, Shagawa Lake should achieve lake total phosphorus levels typical of the region. However, in-lake total phosphorus remained high (34.6 - 35.7 ug/L) from 1974 through 1976. Mass balance analyses identified a large seasonal internal pulse of phosphorus from the sediments that prevented Shagawa Lake from achieving a regionally expected condition.

The Fairmont Lakes are located in the Western Corn Belt Plains (Figure 1). Stefan and Hanson (1981) report total phosphorus in surface waters of these lakes to be 30 to 150 ug/L while that in the hypolimnion ranges from 30 to 1,500 ug/L. Spring snow melt runoff to the lakes typically is 10 to 50 ug/L. By late

8July total phosphorus runoff rises to 150 to 200 ug/L, but occasionally reaches 500 ug/L. Clearly, these lakes are among the most eutrophic in all of Minnesota. Stefan and Hanson concluded that the Fairmont Lakes, like Shagawa, have significant amounts of internal nutrient recycling from the sediments.

A major difference between Shagawa and the Fairmont Lakes is the pattern of lake quality in the surrounding region. The phosphorus concentration in Shagawa Lake is a clear outlier in a region of otherwise high quality lakes. The phosphorus concentration in the Fairmont Lakes is among the highest in a region of high phosphorus concentrations. Consequently, the Fairmont Lakes, are unlikely to ever achieve the quality of lakes in the Northern Lakes and Forest ecoregion. Despite this, the Fairmont Lakes have been subjected to over 60 years of well intentioned "restoration efforts", including copper sulfate and partial dredging (Hanson and Stefan 1984). The result has produced little if any lasting improvement and a host of adverse side effects including oxygen depletion, fish kills, copper accumulation in sediments, algal resistance to copper and shifts from green to blue-green species, disappearance of macrophytes, shifts from game fish to nongame fish and reductions in macroinvertebrates.

CONCLUSIONS

At the time of the Shagawa and Fairmont Lake projects, the extensive Minnesota data bases did not exist. Retrospectively, the Shagawa project was of the right kind, for the right reasons given regional lake quality patterns, but produced less than expected results. While modeling had predicted significant internal nutrient cycling, there was no way of knowing what time would be required for recovery. The Shagawa example, along with others, alerted the limnological and lake management communities to the importance of internal phosphorus supplies, even in regions of high quality lakes.

The Fairmont Lakes projects resulted in frustrations and unrealized expectations, many of which could have been avoided had regional lake quality data bases been available and considered. For example, the location of the Fairmont Lakes among a population of lakes with very high trophic levels should have alerted lake managers and government officials to the low potential for substantial recovery. Among more recent lake restoration efforts, two treatment techniques stand out for their success. These are phosphorus inactivation and dredging (Cooke *et al.* 1993). However, even these highly successful techniques are not failsafe. They cannot be implemented without regard for, and an understanding of regional lake quality patterns relative to the condition of specific lakes destined for restoration.

ACKNOWLEDGEMENTS

The authors are most grateful to Danny Kugler, Sue Pierson and Patti Haggerty for statistical analyses and development of the graphics for this paper and to Steve Heiskary who provided us with the Minnesota Lakes data. We thank Marge Hails who word processed, reformatted and generally cleaned-up the manuscript. Drs. G.D. Cooke, Eugene Welch and Dixon Landers provided helpful comments on a draft version of the manuscript. Data collection and analysis for the Northeastern lakes and preparation of this manuscript was funded by the U.S. Environmental Protection Agency, National Health and Ecological Effects Research Laboratory at Corvallis, OR, USA. The manuscript has been subjected to the Agency's peer and administrative review and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation of use.

REFERENCES

Bjork S. (1994). Overview. In: M. Eiseltova (ed.). *Restoration of Lake Ecosystems: A Holistic Approach.* IWRB Pub. No. 32. IWRB, Slimbridge, Glocester, GL2 7BX UK. 182 pp.

Cooke D.G., Welch E.B., Peterson S.A., & Newroth P. R. (1993) Restoration and Management of Lakes and Reservoirs: 2nd Ed. Lewis Publishers, Boca Raton, FL. 548pp.

Dillon P.J., & Rigler F.H. (1974) The Phosphorus-Chlorophyll Relationship in Lakes. *Limnol. Oceanog.* **19**(5)767-773.

Hanson M.J., & Stefan H.G. (1984) Side Effects of 58 Years of Copper Sulfate Treatment of the Fairmont Lakes, Minnesota. *Water Res. Bull..* **20**(6),889-900.

Heiskary S.A., & Wilson C.B. (1988) Minnesota Lake Water Quality Assessment Report. Minnesota Pollution Control Agency. St. Paul, MI. 148pp.

Heiskary S.A., & Wilson C.B. (1989) The Regional Nature of Lake Water Quality Across Minnesota: An Analysis for Improving Resource Management. *J. Minn. Acad. Sci..* **55**(1),71-77.

Heiskary S.A., Wilson C.B., & Larsen D.P. (1987) Analysis of Regional Patterns in Lake Water Quality: Using ecoregions for Lake Management in Minnestoa. Lake Reserv. Manage, **3**,337-344.

Hughes R.M., & Larsen D.P. (1988) Ecoregions: An Approach to Surface Water Protection. *J. Water Pollut. Control Fed.*, **60**(4),486-493.

Hughes R.M., Heiskary S.A., Matthews W.J., & Yoder C.O. (1994) Use of Ecoregions in Biological Monitoring. pp 125-151. In: S.L. Loeb and A. Specie (eds.) *Biological Monitoring of Aquatic Systems.* Lewis Publishers, Baca Raton, FL. 381pp.

Larsen D.P., Thornton K.W., Urquhart N.S., & Paulsen S. G. (1994) The Role of Sample Surveys for Monitoring the Condition of The Nation's Lakes. *Environ. Monitor. and Assess.* **32**,101-134.

Larsen D.P., VanSickle J., Malueg K.W., & Smith P.D. (1979) The Effect of Wastewater Phosphorus Removal on Shagawa Lake, Minnesota: Phosphorus Supplies, Lake Phosphorus and Chlorophyll A. *Water Research* **13**,1259-1272.

Omernik J.M. (1995) Ecoregions: A Spatial Framework for Environmental Management. In: W.S Davis and T.P. Simon (eds) *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis Publishers. Boca Raton, FL. 415pp.

Omernik J.M. (1987) Ecoregions of the Conterminous United States. *Annals Associ. Ameri. Geog.* **77**,118-125.

Paulsen S.G., Larsen D.P., & Hughes R.M. (1995) A Perspective on the Role of Probability Surveys for Assessing the Condition of Aquatic Systems. (In preparation.) EPA, 200 SW 35th Street, Corvallis, OR 97333.

Stefan H.G., & Hanson M.J. (1981) Phosphorus Recycling in Five Shallow Lakes. *J. Environ.Engin. Division, ASCE,* **107** (EE4),713-730.

Vollenweider R.A. (1975) Input-Output Models with Special Reference to the Phosphorus Loading Concept in Limnology, *Schweiz. Z. Hydrol.* **37**,53-84.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/A-96/029	2.	3. REC
4. TITLE AND SUBTITLE Regional lake quality patterns: Their relationship to lake conservation and management decisions		5. REPORT DATE
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) [1]S.A. Peterson, [2]R.M. Hughes, [1]D.P. Larsen, [1]S.G. Paulsen, [1]J.M. Omernik		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS [1]U.S. EPA, NHEERL, Corvallis, OR, [2]MERSC, U.S. EPA, NHEERL, Corvallis, OR		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS **US EPA ENVIRONMENTAL RESEARCH LABORATORY** **200 SW 35th Street** **Corvallis, OR 97333**		13. TYPE OF REPORT AND PERIOD COVERED Symposium Paper
		14. SPONSORING AGENCY CODE EPA/600/02

15. SUPPLEMENTARY NOTES

1996. International Lake Environment Committee (ILEC) Journal, Lakes and Reservoirs: Research and Management, Special Edition.

16. ABSTRACT

Understanding regional lake quality patterns is important to lake restoration. It puts specific lake conditions into perspective, provides a basis for establishing lake quality goals, identifies lakes most likely to benefit from restoration and forms a framework for assessing restoration success. Two techniques used to characterize regional lake quality patterns are discussed. Combining the two approaches provides an effective means to describe lake regions management goals and restoration success. Case examples illustrate the significance of regional lake quality to specific lake restoration projects.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Lake restoration, survey sampling, ecoregions, phosphorus, dredging		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES 11
	20. SECURITY CLASS *(This page)*	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE