Testing Models of Chlorophyll and Transparency for Midwest Lakes and Reservoirs

Matthew F. Knowlton and John R. Jones

School of Natural Resources, University of Missouri, Columbia, MO 65211

ABSTRACT

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Seasonal means of chlorophyll (Chl), total phosphorus (TP), total and non-volatile suspended solids (TSS, NVSS), and Secchi depth from 28 reservoirs and natural lakes in Iowa, Kansas, and Oklahoma were used to test predictions of log-log regression models developed from Missouri reservoirs by Jones and Knowlton (1993). Waterbodies in Iowa, Kansas, and Oklahoma exhibited a curvilinear relation between log-Chl and log-TP similar to that for Missouri reservoirs. These data fit the Missouri regressions for Chl-TP and Chl-(TP NVSS) fairly well; although the Missouri models usually underpredicted Chl for Iowa waterbodies. Missouri models provided an excellent fit to outstate transparency data.

Key Words: chlorophyll, phosphorus, suspended solids, lakes, reservoirs, transparency, regional limnology.

Recently several authors have presented empirical chlorophyll-total phosphorus models showing significant departures from the log-linearity of earlier relations (e.g. non-linear models: Canfield 1983, McCauley et al. 1989, Prairie et al. 1989, versus linear models: Sakamoto 1966, Dillon and Rigler 1974, Jones and Bachmann 1976). One model, presented by Jones and Knowlton (1993), showed an asymptotic relation between seasonal means of $\log_{10}$ chlorophyll (LChl) and $\log_{10}$ total phosphorus (LTP) for reservoirs in Missouri. The curvilinearity of this relation was statistically related to $\log_{10}$ - transformed concentrations of non-volatile suspended solids (LNVSS). A previous study of some of the same lakes (Hoyer and Jones 1983) also showed a depressing effect of suspended solids on chlorophyll. Jones and Knowlton speculated that high concentrations of suspended clays and other minerals common to many lentic systems in the region dampen algal growth relative to total phosphorus concentration. High concentrations of suspended solids are also common in lakes and reservoirs in other states in the midwest. This note presents data from waterbodies in Iowa, Oklahoma, and Kansas which exhibit relations among LChl, LTP, and LNVSS and among Secchi depth, LChl, LNVSS, and total suspended solids (LTSS), similar to those described by Jones and Knowlton for Missouri reservoirs. These results may be useful in regional assessments of lake water quality.

Data Base

Measurements of Chl, TP, NVSS, TSS, and Secchi depth were collected from 28 waterbodies in summer 1983 (Table 1). Included were five natural lakes and seven reservoirs in Iowa, 12 reservoirs in Oklahoma and four reservoirs in Kansas. Waterbodies were sampled two (Iowa) or three (Oklahoma and Kansas) times during June-September. Data are from samples collected at the surface. Methods of analysis are described in Knowlton and Jones (1989). Data were averaged for individual sampling sites and transformed to base 10 logarithms prior to analysis to correct for non-normality and non-constant variance in the raw data. In statistical analyses the 28 lakes were treated as a group or split into broad regional categories: Iowa versus Kansas-Oklahoma.

Results

Figure 1 shows mean values of LChl and LTP from this data set superimposed on the regression line and 95% confidence interval of the quadratic LChl-LTP model for Missouri reservoirs of Jones and Knowlton (1993). The trends shown by the Iowa and Kansas-Oklahoma data are similar, in aggregate or by region, to the Missouri model; although waterbodies in Iowa tended to have higher Chl per unit TP than lakes in Missouri or Kansas-Oklahoma. A quadratic regression fitted to the data (Table 2) nearly overlaps the Missouri regression for the lowest range of TP but predicts much higher Chl in the upper range of TP (Fig. 1). In a multiple regression with LTP, the slope parameter for LNVSS was significant ($p < 0.05$) and negative with respect to LChl (Table 2).

Table 1. Lake name (county), surface area (ha), mean depth (m), total phosphorus (TP - μg/L), non-volatile suspended solids (NVSS - mg/L), and Secchi depth (SD - m). Water quality data are seasonal means from a single mid-lake sampling site visited 2-3 times in summer 1983.

	SURFACE AREA	MEAN DEPTH	TP	CHl	TSS	NVSS	SD
IOWA							
Anita (Cass)	74	3.7	55	45	6.8	2.6	1.1
Big Creek (Polk)	367	5.3	27	41	5.1	2.1	1.6
Black Hawk (Sac)[a]	295	1.7	203	50	62.8	51.4	0.3
Clear (Cerro Gordo)[a]	1491	2.9	90	89	30.1	15.2	0.3
Cold Springs (Cass)	6	2.1	74	99	11.4	3.2	0.6
East Okoboji (Dickinson)[a]	743	3.2	70	53	7.4	3.0	1.6
Green Valley (Union)	173	3.0	381	69	10.3	4.6	1.1
Hawthorne (Mahaska)	72	3.8	49	58	6.5	1.7	1.0
Prairie Rose (Shelby)	83	3.1	46	70	7.4	2.9	1.0
Spirit (Dickinson)[a]	1688	5.3	49	40	8.8	3.5	1.2
Viking (Montgomery)	55	4.6	33	11	3.8	2.4	1.7
West Okoboji (Dickinson)[a]	550	11.5	16	9	2.5	1.3	3.6
Mean	550	4.2	91	53	13.6	7.8	1.3
OKLAHOMA							
Carl Blackwell (Payne)	1357	4.8	22	7	5.0	4.1	1.1
Eucha (Delaware)	1172	8.4	31	20	4.2	2.2	2.0
Eufala (McIntosh)	33863	7.0	72	16	9.8	7.7	0.8
Ft. Gibson (Cherokee)	7904	5.7	64	31	7.3	5.0	1.1
Grand Lake (Delaware)	18990	10.8	27	14	3.2	1.9	2.2
Hefner (Oklahoma)	1012	8.8	62	25	7.5	5.4	1.1
Hudson (Mayes)	4412	5.6	58	31	7.3	4.9	1.0
Kaw (Kay)	7201	7.8	173	13	4.7	3.7	1.3
Overholser (Canadian)	607	3.0	313	26	18.3	15.2	0.6
Spavinaw (Mayes)	663	5.9	19	12	2.3	1.0	2.2
Stanley Draper (Cleveland)	1186	10.4	16	3	4.2	3.2	1.2
Tenkiller Ferry (Sequoyah)	5061	15.4	13	11	2.2	0.8	2.7
Mean	6952	7.8	73	17	6.3	4.6	1.4
KANSAS							
Cheney (Reno)	3927	5.2	90	9	11.7	10.3	0.6
Melvern (Osage)	1619	5.4	34	10	6.6	5.3	1.1
Pomona (Osage)	1134	2.4	56	14	10.7	8.5	0.7
Toronto (Woodson)	2805	6.8	69	13	22.2	19.2	0.4
Mean	2371	5.0	62	12	12.8	10.8	0.7

[a] Natural lakes.

Jones and Knowlton presented regression models relating variation in seasonal mean LChl to LTP and LNVSS for their statewide data set (Table 6 in Jones and Knowlton 1993). Residuals derived from those equations using our Iowa, Kansas, and Oklahoma data show regional variation in the fit. The quadratic LTP model and the LTP-LNVSS model both tend to under-predict mean Chl in Iowa waterbodies and slightly overpredict mean Chl in Kansas-Oklahoma (Table 3). The LTP-LNVSS model gave better predictions of mean Chl for Iowa lakes than the quadratic LTP model (Table 3) both in terms of mean bias (distance of the mean residual above or below zero) and overall "goodness of fit" (mean difference between predicted and observed disregarding sign). Back-transforming from the log units, the Iowa Chl observations averaged 240% of values predicted by the quadratic LTP model for Missouri lakes and 150% of values predicted by the LTP-LNVSS model. Mean Chl for Kansas-Oklahoma waterbodies averaged 87 and 70%, respectively, of

Table 2. Simple and multiple regression models of variation among $\log_{10}$ -transformed seasonal means of Chl. Independent variables are abbreviated as: LTP = Log_{10}TP, LTP^2 = $(\text{Log}_{10}\text{TP})^2$, LNVSS = Log_{10}NVSS.

Independent Variables	Slope(s)	Intercept	r^2
LTP	0.521	0.454	0.26
LTP LTP^2	1.775 –0.618	–1.515	0.34
LTP LNVSS	0.756 –0.315	0.244	0.32

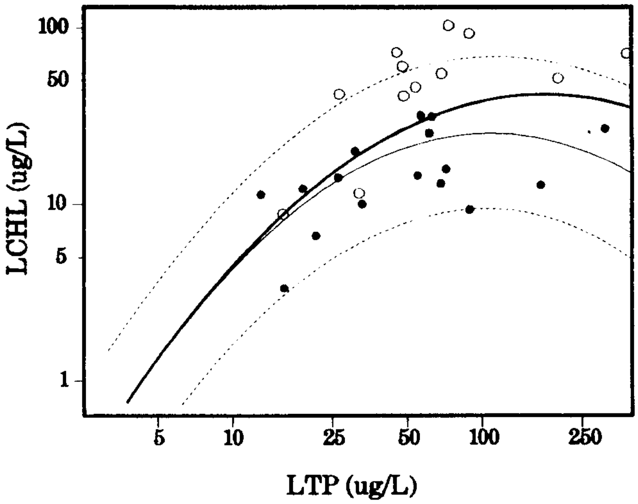

Figure 1. Plot of $\log_{10}$Chl (LChl) versus $\log_{10}$TP (LTP) for 28 waterbodies in Iowa (open circles), and Kansas-Oklahoma (solid circles). A heavy line depicts the regression line of a quadratic LChl-LTP model fitted to the combined data of both regions (Table 2). Lighter lines show the regression lines and 95% predictive confidence intervals of the quadratic LChl-LTP model of Jones and Knowlton (1993—see Table 3 in the text).

values predicted by the two Missouri models. Goodness of fit for the Kansas-Oklahoma data was only slightly less than that obtained with the original Missouri data set.

Regional biases affecting the performance of chlorophyll regression models were less evident in the relations of transparency to chlorophyll and to total and non-volatile suspended solids. Once again, the Kansas-Oklahoma data fit the models better than those from Iowa (Table 3). Iowa lakes were slightly less transparent than predicted from non-volatile suspended solids (mean bias ≈ -11%) and more transparent than predicted from total suspended solids (mean bias ≈ + 23%) or from NVSS and Chl (mean bias ≈ +10%). But in terms of the average difference between predicted and observed values, the Iowa data fit the model nearly as well as the original Missouri observations. For the Kansas-Oklahoma data, mean goodness of fit was actually better than for the original data (Table 3).

Discussion

Evidence continues to mount that simple log-linear models are not adequate for describing algal-

Table 3. Analysis of residuals from selected regressions based on data from Missouri reservoirs (from Tables 5 and 6 in Jones and Knowlton 1993). Residuals were calculated as percentages (residual = 100 * antilog (observed - predicted)) from the original log-transformed data. The mean of the residuals for a given region is given below as the "mean residual," the mean of the absolute value of the residuals for a region is given as "mean goodness of fit." Abbreviations follow those in Table 2 except LSD = $\log_{10}$ (Secchi depth) and LTSS = $\log_{10}$ (TSS).

MISSOURI REGRESSION	REGION	MEAN RESIDUAL	MEAN "GOODNESS OF FIT"
CHLOROPHYLL			
LChl = 2.905*LTP - 0.715*LTP^2 -1.564	IOWA	240%	257%
	KANSAS-OKLAHOMA	87%	155%
	MISSOURI[a]	100%	148%
LChl = 1.193*LTP - 0.414*LNVSS -0.447	IOWA	155%	200%
	KANSAS-OKLAHOMA	71%	158%
	MISSOURI	100%	145%
SECCHI DEPTH			
LSD = -0.71*LNVSS + 0.48	IOWA	89%	135%
	KANSAS-OKLAHOMA	105%	115%
	MISSOURI	100%	129%
LSD = -0.86*LTSS + 0.75	IOWA	123%	129%
	KANSAS-OKLAHOMA	98%	112%
	MISSOURI	100%	120%
LSD = -0.64*LNVSS -0.17*LChl + 0.63	IOWA	110%	132%
	KANSAS-OKLAHOMA	105%	120%
	MISSOURI	100%	126%

[a] Same Missouri statewide data set used to derive regression models (Jones and Knowlton 1993).

nutrient relations among lakes in some regions. The data presented here corroborate the results of Jones and Knowlton in showing a curvilinear relation between log-transformed values of mean chlorophyll and total phosphorus. Taken together or separated by regions, data from Iowa, Kansas, and Oklahoma show a nearly flat response of Chl to TP, especially at TP >50 ug/L — a range that includes a large percentage of the lakes surveyed in these states. The effect of non-volatile suspended solids in explaining some of the variation in chlorophyll points to non-algal turbidity, or conditions associated with turbidity, as one cause of the weak response of Chl to TP. The suspended solids comprising the non-volatile fraction of TSS include clay minerals and precipitated carbonates that absorb and scatter light and may adsorb phosphorus. Thus high NVSS may be correlated with conditions of light limitation or low biological availability of phosphorus. These or related conditions may be important in individual lakes or in whole suites of lakes in a given region. For such waterbodies, phosphorus control may not be of primary importance for management of lake water quality.

A consistent pattern in this data set is the high average ratio of Chl:TP in Iowa lakes compared with those in Kansas, Oklahoma, and Missouri. Regional differences in suspended solids seem to explain only part of this difference which averages >50%, relative to the Missouri data set, even if NVSS are taken into account (Table 3). We cannot, on the basis of this small sample, draw strong conclusions about this possible regional difference. The individual lake means used in this analysis are based on minimal sampling and are subject to a large measure of statistical uncertainty (e.g. Knowlton et al. 1984). The Iowa lakes in this data set, however, were generally smaller and shallower than those in Kansas and Oklahoma (Table 1) and may be less susceptible to the light limiting effect of suspended solids. Also, some of the Iowa lakes were dominated by large cyanobacteria (University of Missouri unpublished data) which may be associated with high Chl:TP ratios (Lijklema et al. 1989).

Much remains to be done in verifying the existence of true regional differences in algal-nutrient relations among midwest lakes and reservoirs and in consolidating this information into a form directly applicable to lake management. The specific causal role of non-algal suspended solids needs to be elucidated as does the role of possible regional differences in algal community composition, nitrogen regimes, morphology, mixing, and other contributing factors. It seems well established, however, that relations between Chl and TP over a broad range of lakes should be assumed curvilinear unless shown otherwise (Forsburg and Ryding 1980, Canfield 1983, McCauley et al. 1989, Prairie et al. 1989, Jones and Knowlton 1993). In management of nutrient-rich lakes, simple extrapolations along a linear continuum may soon be anachronistic.

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Literature Cited

Canfield, D. E. Jr. 1983. Prediction of chlorophyll a concentrations in Florida lakes: the importance of phosphorus and nitrogen. Wat. Resour. Bull. 19: 255-262.

Dillon, P. J. and F. H. Rigler. 1974. The phosphorus-chlorophyll relationship in lakes. Limnol. Oceanogr. 19: 767-773.

Forsberg, C. and S. Ryding. 1980. Eutrophication parameters and trophic state indicies in 30 Swedish waste-receiving lakes. Arch. Hydrobiol. 89: 189-207.

Hoyer, M. V. and J. R. Jones. 1983. Factors affecting the relation between phosphorus and chlorophyll a in midwestern reservoirs. Can. J. Fish. Aquat. Sci. 40: 192-199.

Jones, J. R. and R. W. Bachmann. 1976. Prediction of phosphorus and chlorophyll levels in lakes. J. Water Pollut. Control Fed. 48: 2176-2182.

Jones, J. R. and M. F. Knowlton. (1993). Limnology of Missouri reservoirs: an analysis of regional patterns. Lake Res. Manage. 8(1): 19-30.

Knowlton, M. F., M. V. Hoyer and J. R. Jones. 1984. Sources of variability in phosphorus and chlorophyll and their effects on use of lake survey data. Water Res. Bull. 20: 397-407.

Knowlton, M. F. and J. R. Jones. 1989. Comparison of surface and depth-integrated composite samples for estimating algal biomass and phosphorus values and notes on the vertical distribution of algae and photosynthetic bacteria in midwestern lakes. Arch. Hydrobiol./Suppl. 83: 175-196.

Lijklema, L., J. H. Jansen and R. M. M. Roijackers. 1989. Eutrophication in the Netherlands. Sci. Tech. 21: 1899-1902.

McCauley, E., J. A. Downing and S. Watson. 1989. Sigmoid relationships between nutrients and chlorophyll among lakes. Can. J. Fish. Aquat. Sci. 46: 1171-1175.

Prairie, Y. T., C. M. Durante, and J. Kalff. 1988. Unifying nutrient-chlorophyll relationships in lakes. Can. J. Fish. Aquat. Sci. 46: 1176-1182.

Sakamoto, M. 1966. Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth. Arch. Hydrobiol. 62: 1-28.