COMPARATIVE EUTROPHICATION AND PRODUCTION MEASUREMENTS IN PRAIRIE LAKES [1]

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ABSTRACT

The trophic status of six very different prairie lakes was evaluated from measurements of algal concentrations, water transparency, and chemical parameters taken weekly or bi-weekly over one to four open water seasons. The lakes were ranked quite differently when concentrations of dissolved ions and conductivity were used as indicators of water quality than when algal concentrations and water transparency were used as indicators. The latter parameters gave the more reliable measure of trophic status.

Primary production measurements were made by the oxygen light and dark bottle technique and indicate that specific rates of gross production and respiration of algae were significantly lower at high algal densities (bloom conditions) than at low algal densities. Thus, rates of gross production of organic matter per unit area were as high, or higher in the less eutrophic lakes than in the more eutrophic lakes. Self-shading by the dense algal bloom may also prevent higher gross production rates in the more eutrophic lakes. Initial evaluation of net production measurements indicates that net production may be higher in the more eutrophic lakes. The different trends indicated by net production measurements as opposed to gross production measurements emphasize the importance of measuring net production and respiration as well as gross production in evaluating trophic status.

INTRODUCTION

In recent years, many states have shown extensive interest in classifying lakes to trophic status in order to provide protective legislation. In many cases, classification has been based on a small

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[1]Funding was provided in part by the U.S. Department of the Interior as authorized under the Water Resources Research Act of 1965 through project A-047-SDAK of the South Dakota State University Water Resources Institute, and in part by the South Dakota Agricultural Experiment Station Project SD00590. I thank Shirley Mittan, Lee Tucker and Brian Thoreson for help with chemical analyses, statistical analyses and field collection of data, respectively.

Approved for publication by the Director, Agricultural Experiment Station, South Dakota State University, Brookings, as Journal series No. ———.

number of measurements, and because lakes can vary greatly from date to date, may not be accurate. Extensive studies of several lakes in the prairie lake region include algal and nutrient level data taken at many different dates and these lakes can be adequately classified to trophic level. (Hauber 1971, Nickum 1972; Tipton et al 1972; Haertel 1972, 1976, 1977; Brashier et al 1973; Applegate et al, 1973; Churchill et al 1975; Thoreson et al 1976.) This study examines and compares the data taken from six of those lakes.

An important biological measure which should be included in any evaluation of lake usage is the productivity level of the lake, or the rate at which new organic material is being produced by photosynthesis, relative to the rate at which it is being used up by respiration.

The level of net production (photosynthesis minus respiration) that results is important for two reasons. First, it is this rate, and not the total amount of algae present, which measures the amount of food being made available to higher trophic levels and thus determines the amount of other organisms such as fish the lake can support. Second, if the lake is excessively productive, unutilized net production will accumulate on the bottom of the lake and contribute to filling in the lake. A few measures of photosynthetic rates on prairie lakes have been made (Haertel 1972, Steinberg 1972, Tipton et al 1972), but no data are available on respiration rates. This study compares the results of 16 production and respiration experiments made on four prairie lakes and relates those values to trophic status.

II. Method

A. Field Sampling and Laboratory Analyses.

Sampling was conducted approximately bi-weekly from April through October 1974 in Lakes Enemy Swim and Pickerel and from April through September 1975 in Lakes Enemy Swim, Pickerel, Cochrane and Hendricks. Duplicate surface water samples were taken at four sites in Enemy Swim and two sites in Pickerel in 1974. In 1975 one site was sampled at two depths (just below the surface and just above the bottom), in all four lakes. Again, duplicate samples were taken.

Samples for water chemistry, chlorophyll *a* analysis, and algal cell counts were taken out of the same Van Dorn Bottle cast. Methods for determination of chemical parameters, chlorophyll *a*, and cell counts are given in Haertel (1977).

Zooplankton were sampled with a Clarke-Bumpus sampler, with a #12 mesh net. Duplicate oblique tows were made at one

station in each lake on all dates. Zooplankton were counted using the method described in Haertel and Osterberg (1967).

Temperature was determined at all locations by use of a bucket thermometer, and water transparency was measured with a Secchi disc. The 1% level of light penetration was determined by submarine photometer.

B. Primary Production Experiments

Four primary production experiments were conducted in each lake in 1975. The oxygen light and dark bottle technique was used (Vollenwieder 1969). Incubation times varied from 2 to 7 hours, with the shorter times used in the more eutrophic lakes. Bottles were suspended at four depths in the deeper lakes, three depths in Lake Hendricks. Quadruplicates of each treatment were used, and light and dark bottles were always taken out of the same Van Dorn Bottle cast. Initial bottles were sometimes taken from different bottle casts. Significant differences between light and dark bottle treatments were determined separately at each depth by least squares analysis of variance. Differences between all three treatments (light, dark and initial bottles) were later determined by Dunnett's Test (Steel and Torrie 1960).

All production and respiration values were converted to milligrams of carbon according to the equation (Strickland 1960):

$$mgO_2 \text{ evolved/hr. X .375/photosynthetic quotient.}$$

A value of 1.20 was chosen for the photosynthesis quotient (Ryther 1956).

Photosynthesis or gross primary production values (light bottle-dark bottle) were converted to production per m_2 by plotting the values obtained per m^3 on a graph and planimetering the area under the curve (Figure 1). Non-significant values were included; calling those values "0" would have resulted in more error than including the measured value.

Respiration was assumed to proceed at a similar rate at all depths, and respiration values (initial bottle-dark bottle) were converted to respiration per m^2 by averaging the values obtained at the different depths and multiplying by the mean depth of the lake. On several dates anomalously high, statistically significant O_2 values were obtained in the dark bottle, especially at the shallower depths, a result also observed by other investigators (Dugdale and Wallace 1960, Vollenwieder 1969). The reason for this anomaly is unknown. On those dates only the deeper bottles were used to calculate respiration.

On dates where dark bottles showed anomalously high values at all depths, respiration values were extrapolated from specific

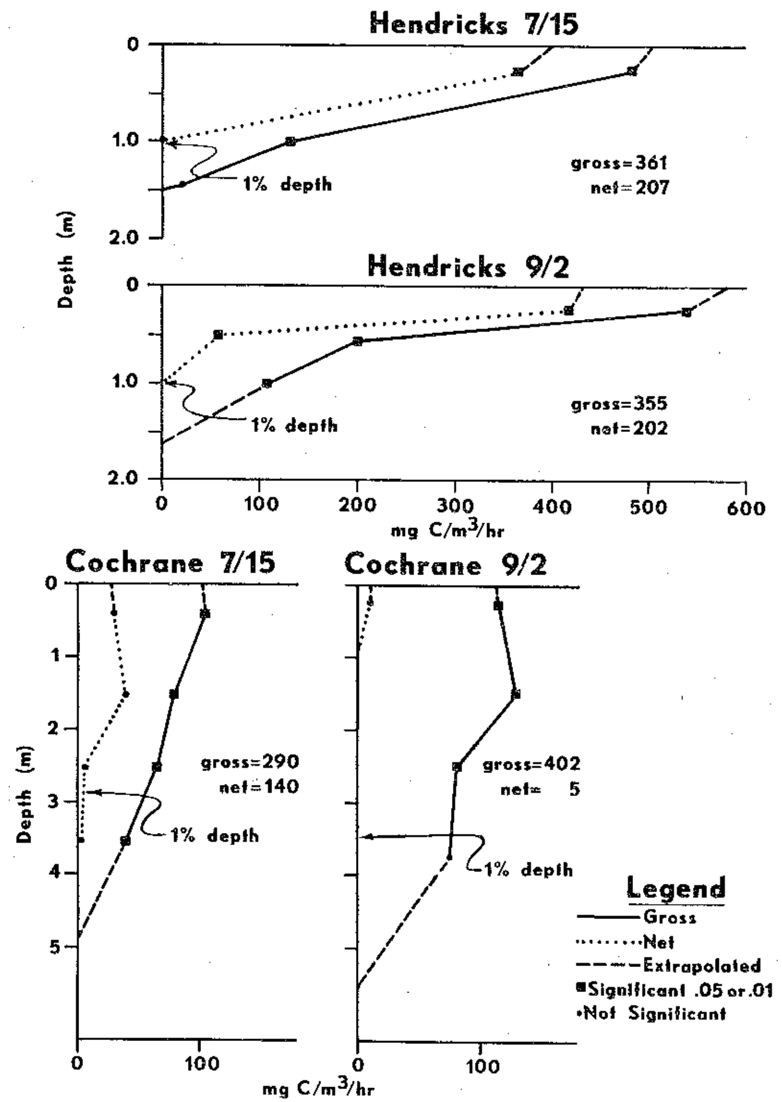

Figure 1. Comparison of planimetered gross and net production values (mg C/m²/hr) in Lakes Cochrane & Hendricks on 2 dates in 1975.

respiration values measured in the same lake at different dates when similar chlorophyll *a* concentrations were measured. Values thus calculated are designated as such in the tables. On dates and at depths where the dark bottle respiration measurement was unreliable, gross production was determined by adding the calculated respiration values to the planimetered net production values in the photic zone. Values thus calculated are designated as such in the tables.

Net production was determined by two methods. The best method involved subtracting respiration per m² from gross production per m². Net production in the photic zone could also be obtained from planimetered values (light bottle-initial bottle, Figure 1). However, as this value did not include respiration below the photic zone, it gave higher values. This measure was useful only for calculation of gross production on dates when anomalous O_2 production in the dark bottle made direct measurement of gross production impossible. As it was impossible to exclude respiration of bacteria and microscopic animals from the bottles, all net production values calculated are best regarded as measures of net "community" production (Odum 1971) and are a less reliable measure of primary production than the gross production values.

All production and respiration values were converted to specific terms by dividing by mg chlorophyll *a*/m². Mg chlorophyll *a*/m² was determined by multiplying mean chlorophyll *a*/m³ by the mean depth of the lake.

Production and respiration measurements were run through linear correlation analysis to determine which biological, chemical, and physical variables were interrelated. Included in the correlation analysis was solar radiation (Langleys), averaged on the day of sampling, measured at Brookings, 120 km away from Lakes Enemy Swim and Pickerel, 89 km from Lake Cochrane and 32 km from Lake Hendricks. After a correlation matrix was determined, multiple regression (Little 1966) was performed on certain variables to evaluate predictive factors.

III. Results and Discussion

A. Trophic status

The lakes selected for this study represent a wide range of degree of eutrophication. Table 1 shows the least eutrophic of the lakes to be Enemy Swim when algal concentration is used as the basis of evaluation of trophic status. Pickerel Lake is very close; it has greater water transparency and also slightly lower concentrations of total N and total P. Pickerel Lake did have buildups of bluegreen algae during this study. Nuisance concentrations of

TABLE 1

Water Quality Ranking of Lakes Based on Mean Algal Concentrations, Water Transparencies and Nutrient Levels

	Most Eutrophic ——→					Least Eutrophic
	Bitter	Hendricks	Bluedog*	Cochrane	Pickeral	Enemy Swim
Secchi (M)	0.1	0.8	0.5	1.6	2.3	1.7
Chlorophyll a (mg/m^3)	136	79	41	13	12	9
Total Algae (10^3/1)	664.6	53.3	5.1	5.3	5.5	4.6
NO_3-N	.17	.09	.06	.02	.02	.015
NH_3-N	.00	.31	.01	.04	.005	.005
PO_4-P	.13	.20	.01	.02	.02	.015
Total N	8.98	2.79	1.41	1.34	.70	.81
Total P	.50	.61	.07	.16	.09	.10
Mean depth (m)		1.7		3.9	4.8	4.8
Maximum Depth (m)	1.5	2.4	2.3	8.2	14.5	9.7
# dates sampled	11	9	11	9	20	20
Years of data included	1974	1975	1974	1975	1974-1975	1974-1975

Chemical concentrations given in mg/1

*From Thoreson et al. 1976.

Gloeotrichia echinulata were present in July 1974, and a combined bloom of *Anacystis, Aphanizomenon* and *Anabaena* was present in September 1975. *Gloeotrichia* is known to cause symptoms similar to swimmer's itch. Beaches had to be closed in Pickerel Lake in late summer 1976 because of swimmer's itch during an intense algal bloom. However, we were no longer sampling Pickerel Lake and do not know if *Gloeotrichia* was present at that time.

Lake Cochrane is also a relatively clean lake; although it had slightly higher average concentration of chlorophyll a and total N and total P than Enemy Swim and Pickerel Lake, it did not have a noticeable bloom during this study. Both lakes Hendricks and Bitter represented extreme eutrophication. Bluedog Lake was intermediate in degree of eutrophication, having low algal concentrations during most of the year but intense blooms of *Aphanizomenon* in late summer.

Other extensively studied prairie lakes include Poinsett and Herman. Lake Poinsett would probably rank intermediate between Bluedog and Cochrane in degree of eutrophication. Published mean values for chlorophyll a in Lake Poinsett were about 32 mg/m^3 (Applegate et al 1973) and NO_3-N, ortho-P and total P were 0.052, .036 and .072 mg/1 respectively (Skille 1971). Lake Herman may rank similarly to Bitter in degree of eutrophication. Extreme high values of NH_3, NO_3, total P and ortho P were 3.0, 1.5, 0.7 and 0.4 (Churchill et al 1975), higher than or similar to the extremes measured in Bitter Lake of 0.36, 0.04, 0.74 and 0.42 in 1974 (Thoreson et al 1976). Algae counts in Lake Herman were also similar in range to Bitter Lake with extremes of 1.5-3,000 X 10^3/1 recorded (Hauber 1971, Nickum 1972).

Degree of water quality is frequently also measured by electircal conductivity or by total dissolved solid concentration. Ranking the lakes on that basis can be misleading. Lake Cochrane is the second poorest of the lakes in terms of conductivity and dissolved solids (Table 2) even though it is one of the cleanest lakes in terms of absence of nuisance blooms of bluegreen algae. Bluedog Lake has very low concentrations of dissolved solids but higher concentrations of total nitrogen, and its usability is greatly degraded by the late summer algae bloom.

Three of the lakes, Cochrane, Hendricks and Enemy Swim, had been extensively studied previously (Hauber 1971, Nickum 1972, Haertel 1972 and 1976). Data from those studies are compared with data taken in this study to check for any trends. Lake Enemy Swim has maintained consistent to improved water quality over the 8 years of study (Table 3). Secchi disc readings showed the same range in 1974-75 as during the 1967-70 period and the conductivity

TABLE 2

Water Quality Ranking of Lakes Based on Concentrations of Dissolved Ions and Conductivity

	Highest Concentrations →				Lowest Concentrations	
	Bitter[1]	Cochrane[2]	Hendricks[2]	Pickerel[1]	Enemy Swim[1]	Bluedog
Ca	24	107	101	47	30	
Mg	5,000	336	35	44	50	
Na	4,200	107	7	8	8	
K	900	51	10	7	9	
SO_4	21,350	1,384	135	77	33	
Cl	931	16	5	4	4	
HCO_3	518	186	157	240	243	236
CO_3	353	47	25	7	22	12
Total	33,276	2,234	575	434	399	
Conductivity (umhos/cm²)	11,904	2,842	695	386	380	378

Chemical Concentrations given in mg/l

[1]Levels of Ca, Mg, Na, K, SO_4, Cl based on samples taken July 31, 1975. Other parameters sampled bi-weekly.
[2]From Haertel, 1976.

TABLE 3

Changes in Selected Water Quality Parameters With Time in Lake Enemy Swim*

		NO_3-N mg/l	NH_3-N mg/l	Org N mg/l	Ortho P mg/l	Total P mg/l	HCO_3 mg/m³	CO_3 mg/m³	Cond. umhos/cm³	Secchi (m)	Chl. a (mg/m³)	Total Algae (10³/ml)
	low	.00	.00	.00	.01	.02	107	0		1.1	0	1.3
1975	mean	.01	.01	.87	.20	.15	160	12		1.7	11	4.2
	high	.10	.43	2.33	.41	.56	239	34		3.0	30	6.8
	low	.00	.00	.68	.00	.02	232	11	299	.8	3	1.8
1974	mean	.02	.00	.71	.00	.04	244	20	380	1.7	10	4.9
	high	.05	.08	.95	.04	.07	257	27	560	2.9	22	8.3
1967-	low		.03			.03	224	0	280	1.2		5.0
1970*	high		.67			.43	227	29	575	3.0		141.9

*From Hauber, 1971 and Nickum, 1972.

TABLE 4

Changes in Selected Water Quality Parameters With Time in Lake Cochrane

		NO_3-N mg/l	NH_3-N mg/l	Org N mg/l	Ortho P mg/l	HCO_3 mg/l	CO_3 mg/l	Secchi m	Chl *a* mg/m³	Total Algae* 10^3/ml
	low	.00	.00	0.00	.00	224	0	1.0	0	30
1975	mean	.02	.04	1.27	.04	253	30	1.6	13	178
	high	.13	.72	3.45	.13	312	46	2.7	23	500
	low	.00	.00	.79	.00	68	34	0.8	3	2
1972	mean	.02	.00	1.35	.01	196	47	1.3	18	1,290
	high	.08	.00	1.70	.13	244	136	2.0	44	2,943
	low	.00	.00	.46	.00	65	0	0.7	3	2
1971	mean	.03	.02	1.55	.02	190	51	1.3	19	831
	high	.39	.12	2.98	.41	288	136	3.1	41	2,078
	low	.00	.00	.00	.00	0	26	1.1	0	0.3
1970	mean	.05	.06	1.12	.01	106	61	2.0	10	38
	high	.31	.27	4.16	.25	280	140	3.6	25	188

*All species (including bluegreens) counted as individual cells for comparison with previous year's data. This accounts for the discrepancy with Table 1 where bluegreen species are counted as colonies.

range is similar. Much greater concentrations of algae were recorded in fall 1967 (high, Table 4) than any time during 1974 or 1975. Peak concentrations of algae in 1968 and 1969 were 51.6 and 105.7 X 10^3/1 respectively, still much higher than encountered in 1974 and 1975. Levels of NH_3-N encountered were also higher in 1967-70 than in 1974-75.

Lake Cochrane shows generally improved water quality (as determined by either Secchi disc, chlorophyll *a* or algal cell concentrations) in 1975 over that measured in 1971 and 1972 (Table 4). However, water quality was still not as high in 1975 as that measured in 1970. Lake Cochrane experienced very high phosphate concentration in June 1971 that were significantly correlated with a buildup in *Anacystis* spp. concentrations not previously measured in Lake Cochrane (Haertel 1976). *Anacystis* populations were lower in 1975 than in 1971 and 1972, but still much higher than in 1970.

Different measures of water quality give different interpretations of changes in Lake Hendricks (Table 5). Mean cell counts were highest in 1970 and 1975 and mean chlorophyll *a* concentrations were highest in 1971 and 1975. Despite the fact that both measures of algal bloom concentrations were high in 1975; Secchi disc water transparency was also highest in 1975. Very eutrophic lakes such as Lake Hendricks are characterized by extreme fluctuations in all parameters. They are also probably self-sufficient in nutrient levels (Harrison et al 1972, Barica 1974, Haertel 1976), and significant changes in water quality as measured by algal bloom concentrations would not be expected to occur.

B. Production Experiments.

Measured values of production and respiration rates per unit of chlorophyll *a* show great variation between experiments (Table 6). Lower specific rates of both gross production (photosynthesis) and respiration are associated with the higher standing crops of algae (Figure 2), and both correlations are significant. The correlation between metabolic rate and concentration of organisms may be related to the different size of the algal species involved. Larger organisms have slower metabolic rates (Odum 1971). Many of the common blue-green bloom species form large colonies, and slower metabolic rates would be expected when they are present. Also, at higher algal densities, the nutrients dissolved in the water have to be shared between more cells, and less is available per individual cell.

TABLE 5

Changes in Selected Water Quality Parameters With Time in Lake Hendricks

	NO_3-N mg/l	NH_3-N mg/l	Org N mg/l	Ortho P mg/l	HCO_3 mg/l	CO_3 mg/l	Secchi m	Chl a mg/m^3	Total Algae* 10^3/ml
low	.01	.00	.75	.01	107	0	0.2	5	36
1975 mean	.09	.31	2.39	.20	160	12	0.8	79	385
high	.32	.77	5.18	.41	239	34	2.0	205	929
low	.00	.00	.84	.00	51	0	.2	9	1
1972 mean	.09	.02	2.16	.13	181	25	0.7	38	198
high	.20	.28	4.06	.40	244	54	1.5	119	702
low	.00	.00	1.27	.03	42	0	0.2	3	2
1971 mean	.13	.05	2.60	.18	154	32	0.5	58	195
high	.53	.48	16.51	.36	216	86	1.7	365	1,764
low	.00	.00	.58	.05	0	0	0.2	4	4
1970 mean	.22	.18	1.77	.13	133	30	0.5	20	383
high	.73	1.10	2.96	.18	230	105	1.4	149	1,894

(*Same as Table 4)

TABLE 6

Specific Gross Production, Respiration and Net Production Rates in Four Lakes, 1975. (All Expressed in Terms of mg C/mg Chl a/hr)

		Specific Gross Production (Planimetered)	Specific Respiration (averaged over depth)	Specific Net Production (by difference)	Chlorophyll a mg/m^3
Hendricks	4/29	1.0†	0.7	0.3	112
	6/6	5.6	6.4	−0.8	9.2
	7/15	1.2†	0.6†	0.6	184
	9/2	1.7†	1.1†	0.6	122
Cochrane	4/29	6.7	16.0*	−9.4	4.5
	6/6	0.9	2.2*	−1.3	19.0
	7/15	5.1†	3.4†	1.7	14.6
	9/2	5.5†	6.9†	−1.4	18.6
Pickerel	5/5	(6.0)[1]*	4.9	(1.1)	12.1
	6/2	6.6	3.7*	−1.8	5.2
	7/19	(10.5)[1]†	(4.3)[2]	(6.2)	11.8
	9/4	0.6*	1.3†	−0.7	26.7
Enemy Swim	5/5	(11.5)[1]	(11.4)[2]	(0.2)	9.0
	6/2	?	?	?	8.2
	7/19	(9.2)[1]	(11.4)[2]	(−2.2)	9.7
	9/4	8.0†	11.4†	−3.3	11.8

*Values significant at .05 level at 1 or more of the depths tested.

†Values significant at .01 level at 1 or more of the depths tested.

( )[1]Values calculated by adding respiration values to planimetered net production at those depths where positive net production was measured. *Indicates significance of net production measures.

( )[2]Values calculated from respiration values measured in the same lake on (a) different date(s).

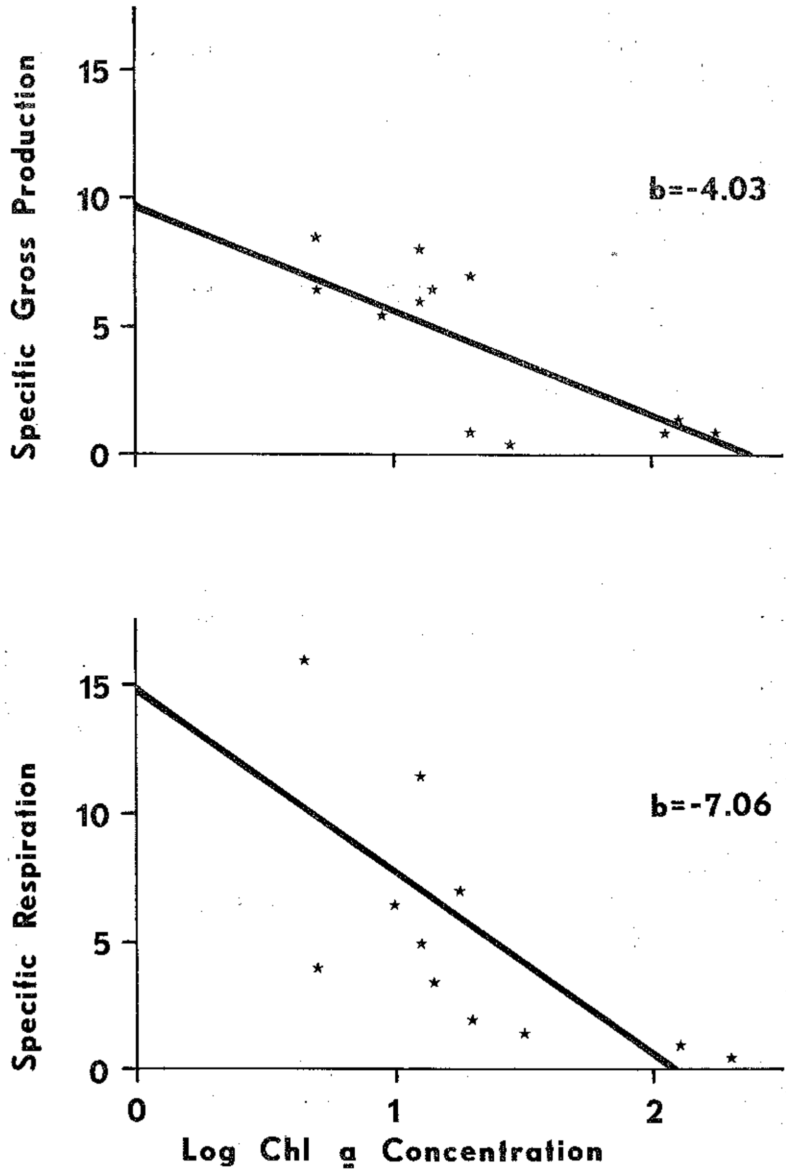

Figure 2. Comparison of the slope of the regression lines between specific gross production and specific respiration (both as mg C/mg chlorophyll a/hr) against chlorophyll a concentration (mg/m^3).

Additional gross production data is available for two of the lakes for 1970-1972 (Haertel 1972, unpublished data; Steinberg 1972). In these data also the standing crop of algae was the factor most highly correlated with specific gross production rates (Table 7). Light levels (as measured by both solar radiation and water transparency) and nutrient concentrations might be expected to also be important influences on production rates. However, correlation coefficients were much lower with those variables than with algal concentrations. Respiration rates and net production rates are also significantly correlated with algal concentrations.

The highly significant relationship between gross production rates and chlorophyll *a* concentrations would be useful for predictive purposes if it is repeatable, as chlorophyll is simpler and less expensive to measure than production rates. Regression analysis gives amazingly similar equations for predicting gross production rates from chlorophyll concentrations from different years and lakes, analyzed separately and together (Table 8). Both the slope and the y-intercept give similar values from different analyses. The y-intercept value is also practically the same whether chlorophyll or cell counts are used as the measure of algal density.

The percent of the variation of the dependent variable that is significantly predicted by the independent variable is given by the value for R^2. In some cases, a higher percentage of the variation in production rates could be significantly predicted when multiple regression was used. Solar radiation, water transparency (secchi depth for 1970-1972 data, and 1% depth for 1975 data) and nutrient concentrations (NO_3, NH_3, PO_4) were added to chlorophyll concentration as independent variables. For Lake Cochrane alone, the R^2 was increased to 77% with the addition of zooplankton filtration and to 89% at the 5% level of significance with the addition of NO_3. For Lake Hendricks alone (1971-1972), R^2 was increased to 70% at the 5% level of significance with the addition of secchi depth as an independent variable. For all lakes combined (1975) none of the additional variables entered significantly into the predictive equations.

The equations are only shown for chlorophyll and cell counts, as the relationship with algal density was the most consistent with different lakes and different dates.

Another way to examine production values is to examine the overall productivity of a lake on a unit area basis ($mg/m^2/hr$), as this is the measure that gives the best estimate of food made available to zooplankton, benthos, and fish populations. Figure 1 compares production per unit area in two lakes that are typical of prairie lake extremes. Even though Lake Hendricks has a much greater algal bloom present than Lake Cochrane, the gross produc-

TABLE 7

Correlation Coefficients Between Measures of Production and Respiration and Other Environmental Variables

Specific Gross Production	Log Chl. *a*	Log Cells	Zoopl. Filtr.	Solar Rad.	Secchi Depth	1% Depth	NO_3	NH_3	PO_4	Resp.	Net Prod.
1970-1975 (n=41)	−.59†	−.58†	.05	−.13	.36*		−.01	−.09	−.13		
1975 (n=12)	−.78†	−.81†	.26	.03	.51	.74†	−.14	−.39	−.05	.84	−.46
Specific Respiration: 1975 (n=12)	−.78†	−.88†	.07	−.37	.55	.83†	−.19	−.32	−.17	1.00	−.87†
Specific Net Production: 1975 (n=12)	.58*	.73†	.06	.61*	−.42	−.68*	.21	.19	.25	−.88†	1.00

*Sign .05

†Sign .01

TABLE 8

Simple Regression Estimates For Prediction Specific Production And Respiration Rates From Algal Density Estimates[1]

Parameter	Regression Equation	R	R^2
Specific Gross Production			
1. All dates, all lakes (N=41)	Y = 9.46 − 4.45 Log Chl *a* (mg/m^3)	−.59†	36%†
2. 1970-1972 Lake Cochrane (N=15)	Y = 8.17 − 4.94 Log Chl *a* (mg/m^3)	−.70†	50%†
3. 1971-1972 Lake Hendricks (N=11)	Y = 10.02 − 4.47 Log Chl *a* (mg/m^3)	−.56*	32%*
4. 1975 - All Lakes (N=12)	Y = 9.46 − 4.03 Log Chl *a* (mg/m^3) Y = 8.87 − .055 Log Cells (#/ml)	−.78† −.81†	61%† 66%†
Specific Respiration			
1. 1975 - All Lakes (N=12)	Y = 14.70 − 7.06 Log Chl *a* (mg/m^3)	−.78†	61%†
Specific Net Production			
1. 1975 - All Lakes (N=12)	Y = −5.45 + 3.11 Log Chl *a* (mg/m^3)	.58*	33%

[1]All rates given as mgC/mg chlorophyll a/hr.