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Relationships between air temperature, depth, nutrients and chlorophyll in 103 Argentinian lakes

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With 2 figures and 6 tables in the text

Introduction

There are very few comparative studies of lakes and reservoirs in South America (Tundisi 1981). Most of them were produced in the last few years (Löffler 1959, Bonetto et al. 1976, Matsumura et al. 1981, Tundisi 1981, Tundisi & Matsumura 1981, Campos 1984, Miller et al. 1984, Montecino & Cabrera 1984, Quiros & Drago 1985).

In Argentina there are more than 400 lakes and reservoirs with surface area over 5 km^2. Only about twenty of them have been studied. Our approach to study the Argentinian lakes and reservoirs is an extensive one. Our main objective was to obtain a first typology of lakes and reservoirs and to relate it to the potential fish yield on a regional basis.

The importance of predictive ability of empirical models for management purposes in lakes has been stressed elsewhere (Ryder 1965, Brylinsky & Mann 1973, Dillon & Rigler 1974, Carlson 1977, among others). Primary productivity and chlorophyll are, in general, good predictors of fish yield (Melack 1976, Oglesby 1977). Chlorophyll has been suggested as related to the morphometric, climatic, edaphic and hydrologic characteristics of lakes and reservoirs (Rawson 1955, Sakamoto 1966, Brylinsky & Mann 1973, Schindler 1978, Brylinsky 1980) and can be predicted from nutrient levels in lakes and reservoirs (Dillon & Rigler 1974, Jones & Bachmann 1976).

The present paper refers to the mid-summer relationships between chlorophyll-a and nutrient levels, morphometry and climatic characteristics in 103 Argentinian lakes and reservoirs. Surface waters were sampled for nutrients and chlorophyll-a.

Material and methods

103 lakes and reservoirs of Argentina were sampled during the summers of 1984, 85 and 86. Each lake was sampled only once, except six of them which were studied during two years. We excluded reservoirs with hydraulic residence time of less than about one month (Quiros & Cuch 1983). The sampling was performed by the National Institute of Fisheries and the Chubut Province. The total set of lakes and reservoirs is extremely heterogeneous in its climatic, morphometric, edaphic and hydrologic characteristics. It includes lakes and reservoirs on the Patagonian Plateau and Patagonian Andes Mountains, ponds and very shallow lakes on the Pampa Plain and reservoirs and ponds in the Central-West and North-West arid regions of Argentina. It also includes a high-mountain lake, an acidic lake and some saline lakes (Fig. 1).

The sampling stations were located in the deepest part of each basin for lakes and 500 m to 2 km from dam for reservoirs. For each lake vertical profiles were obtained for temperature, dissolved oxygen, electrical conductivity, pH and alkalinity. Lake surface area, latitude and elevation were determined from 1 to 50,000 and 1 to 100,000 topographic maps. Bathymetric surveys with a SIMRAD Skipper 411 model echosounder and line and lead (Welch 1948) were conducted on 40 lakes. We claim for a 10% error in the mean depth. Morphometric data for the other lakes were obtained from the literature (Quiros et al. 1983). For seven lakes mean depth was estimated from the area-mean depth relationships for other lakes on each region and the maximum depth obtained at sampling. Mean annual air temperature (TEMP) and frost free period (FFP) were obtained from Quiros et al. (1983). We considered this last information of low quality specially in the Patagonian Andes Region (Quiros & Drago 1985).

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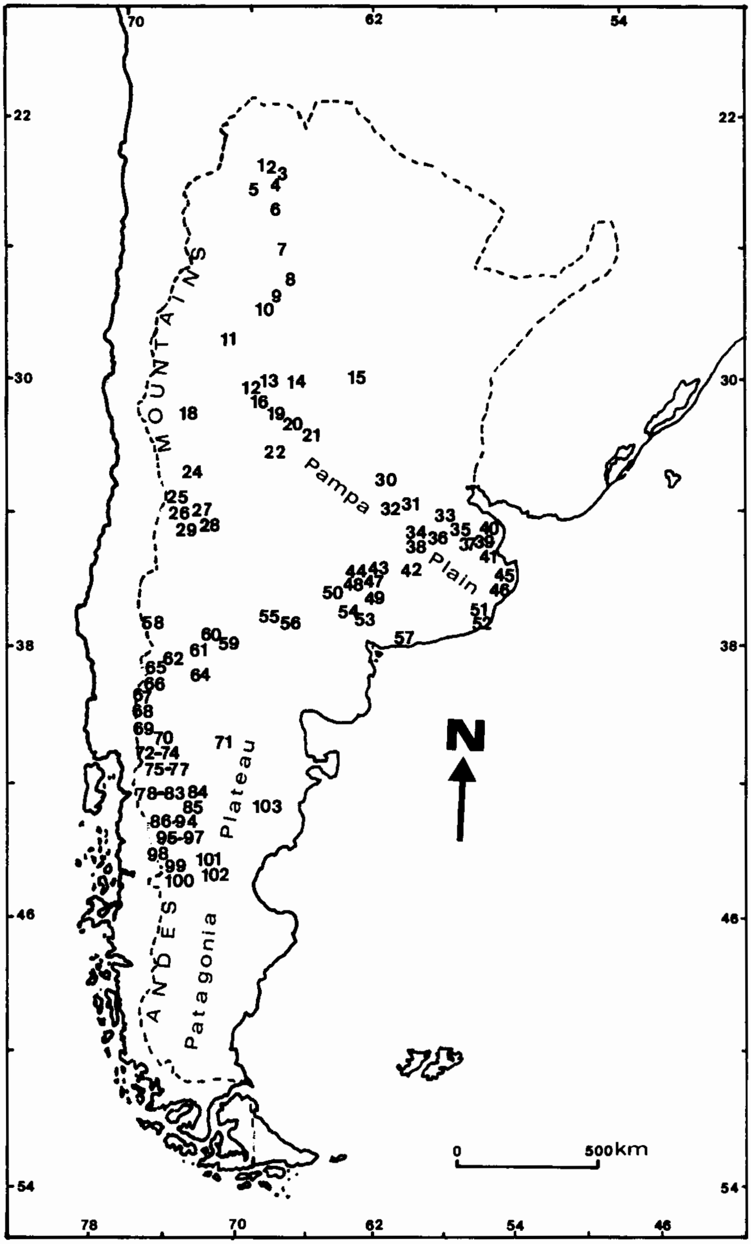

Fig. 1. Argentina showing the location of the 103 lakes and reservoirs.

The transparency measures were obtained with a 25 cm black and white SECCHI disk. Color was determined visually on a HAZEN platinum-cobalt scale on water filtered through Millipore membrane filters (0.45 μm pores) with a MERCK aqua tester model Aquaquant 14421. Chlorophyll-a (CHL-a), total phosphorus (TP), total organic nitrogen (TON), total organic carbon (TOC), nitrate, nitrite, major ions and total dissolved solids (TDS) were determined from samples collected at

0.5 m depth. Total nutrients were determined on samples which had been placed in 1 liter acid cleaned plastic bottles with 0.8 ml concentrated sulfuric acid and preserved at 4 °C. Total phosphorus was analyzed by the ascorbic acid method corrected for turbidity (APHA et al. 1975). Total organic nitrogen was determined by the KJELDAHL method and the ammonia in the digested samples was determined by the phenolhypochloride method (Central-West and North-West lakes and reservoirs) and with an ORION ammonia specific electrode (Patagonia and Pampa regions lakes and reservoirs). Total organic carbon was determined by wet oxidation with dichromate (GOLTERMAN et al. 1978). Chlorophyll determinations, without pheopigments corrections, were done according to STAUFFER et al. (1979) after filtration through a Whatman GF/C filter, which had been rinsed with 0.2 ml of a saturated $MgCO_3$ solution. The filters were protected with aluminium foil and placed in dark at 4 °C. Analysis was completed within three weeks of collection and results are expressed as total chlorophyll-a. All nutrients and chlorophyll-a determinations were done in duplicate.

Nitrate was determined with an ORION D7 93 – 07 electrode for the Patagonia and arid regions lakes. For the Pampa Region ponds we estimate nitrate as 20 % of total organic nitrogen concentration. Nitrite was determined by the diazotation method (APHA et al. 1975). We only use nitrate and nitrite results in order to estimate the TN : TP ratios.

Before statistical analyses, data were transformed to base *e* logarithms in order to stabilize the variance (WEISBERG 1980).

Results

The total data base is highly heterogeneous and the climatic, edaphic and morphometric variables are highly related. Surface lake area ranged from 0.09 to 1984 km^2, mean depth from 0.7 to 166 m and annual mean air temperature from 3.0 to 20.4 °C (Table 1). The deepest lakes are located on the Patagonian Andes Region. Their CHL-a levels were below 1.0 $mg \cdot m^{-3}$. Patagonian Plateau lakes are shallower and their TDS levels are higher than those on the Patagonian Andes Mountains. CHL-a levels ranged from 1.0 to 80 $mg \cdot m^{-3}$. All the lakes on the Pampa Plain are ponds or very shallow lakes with CHL-a levels as high as 400 $mg \cdot m^{-3}$. On the Central-West Region, near the Andes Mountains, CHL-a ranged from 1.0 to 13 $mg \cdot m^{-3}$ and on the North-West Region CHL-a levels were between 1.0 and 218 $mg \cdot m^{-3}$. Most of the Patagonian Andes lakes had TN : TP ratios above 80 and most of the Pampa lakes had TN : TP ranging between 10 and 100. The CHL-a : TP ratio ranged from 0.001 to 1.8 for the total data set. For 103 lakes and reservoirs ZMEAN, TEMP, TP and TON explained 59, 49, 61 and 73 % of CHL-a variance, respectively. There were 13 lakes with TN : TP lower than 22 (molar basis) in the total set. When data for these lakes were screened, ZMEAN, TEMP, TP and TON explained 58, 55, 79 and 73 % of the CHL-a variance respectively. There were also significant relationships between CHL-a and mid-summer surface total alkalinity ($r^2 = 0.62$, $P < 0.001$) and TDS ($r^2 = 0.49$, $P < 0.001$). There was no relationship between lake surface area and CHL-a.

The regression coefficient for TP in the regression equation for N = 103 is 0.84 and it goes up to 1.17 for N = 90 (Table 2). For this last set there was no improvement for the variance explained when TON was regressed with TP against CHL-a. For a set with TN : TP < 22 (N = 12), TON explained 85 % of CHL-a variance (Table 2) and there was no improvement when TP was included in the regression. For the total set and for the set with TN : TP > 22, ZMEAN and TEMP accounted for more variance in CHL-a than TP did alone. For N = 103, ZMEAN and TEMP explained 7 and 9 % more than TP alone, respectively. The regression equation for CHL-a against SECCHI disk transparency (SDT) was:

Table 1. Argentinian lakes (L) and reservoirs (R). Area (A, km^2), mean depth (ZMEAN, m), elevation (ALT, m), latitude (LAT, °S), annual mean air temperature (TEMP, °C), Secchi disk transparency (SDT, m), total phosphorus (TP, $mg \cdot m^{-3}$), total organic nitrogen (TON, μM) and total chlorophyll-a (CHL-a, $mg \cdot m^{-3}$).

	A	ZMEAN	ALT	LAT	TEMP	SDT	TP	TON	CHL-a
1. Rodeo (L)	0.09	3.6	1446	24.12	16	0.85	15	63	15.4
2. Comedero (L)	0.12	4.0	1446	24.12	16	1.20	18	36	22.5
3. La Cienaga (R)	2.8	9.3	1212	24.47	17.5	1.00	25	45	7.4
4. Las Maderas (R)	9.6	31.3	1185	24.45	18	1.40	23	35	13.3
5. Campo Alegre (R)	3.2	14.4	1200	24.63	19	1.20	58	62	23.7
6. Cabra Corral (R)	115	27.0	1037	25.30	17	2.10	16	37	7.1
7. El Cadillal (R)	13.5	22.2	611	26.62	18	0.45	59	35	3.8
8. Rio Hondo (R)	330	5.3	275	27.50	20	0.40	322	61	10.4
9. Sumampa (R)	2.2	10.0	516	27.95	20	0.90	54	61	24.6
10. Las Pirquitas (R)	2.8	26.8	759	28.33	20	0.78	44	49	15.4
11. Los Sauces (R)	1.5	8.1	847	29.42	20.4	0.70	86	59	37.4
12. Anzulon (R)	5.5	4.9	575	30.88	19	0.28	477	75	4.0
13. Portezuelo (R)	2.5	3.3	750	30.67	18	0.80	79	125	25.1
14. Cruz del Eje (R)	13.5	9.5	500	30.77	19.3	1.10	22	27	5.6
15. Mar Chiquita (L)	1984	7.3	69	30.70	18.5	1.10	86	204	38.5
16. Saladillo (R)	4.8	3.0	600	31.00	19	0.30	320	352	218.1
17. San Roque (R)	24.8	14.1	640	31.42	17	2.40	28	45	9.0
18. Ullum (R)	32.0	14.0	768	31.53	17.3	1.27	17	20	0.93
19. La Viña (R)	10.5	23.0	846	31.85	16.9	2.20	25	37	6.7
20. Los Molinos (R)	24.5	16.3	770	31.83	16	2.30	26	29	14.1
21. Rio Tercero (R)	54.3	13.5	661	32.22	16.7	2.50	24	36	18.5
22. San Felipe (R)	15.4	7.1	843	32.78	16.5	0.90	41	76	50.8
23. La Florida (R)	7.0	15.0	1032	33.18	16	3.2	15	23	3.8
24. El Carrizal (R)	32.0	12.2	790	33.33	15	1.90	13	22	4.8
25. El Diamante (L)	13.4	38.6	3250	34.17	3	4.9	11	22	0.67
26. Agua del Toro (R)	10.5	36.2	1339	34.62	12	4.9	5	13	1.11
27. Los Reyunos (R)	7.5	33.3	991	34.65	13	4.0	9	21	1.45
28. Valle Grande (R)	5.1	33.0	814	34.80	13	4.9	9	14	1.16
29. El Nihuil (R)	96	4.0	1325	35.70	11	5.8	18	29	1.30
30. Melincue (L)	48.2	3.2	97	33.72	16.5	0.15	7912	240	5.7
31. El Carpincho (L)	4.4	1.2	70	34.58	15.8	0.60	1288	299	82.4
32. De Gomez (L)	36.6	1.1	75	34.63	15.8	0.18	1250	762	405.3
33. Navarro (L)	2.1	0.7	30	35.05	16.3	0.17	350	434	112.7
34. Las Mulitas (L)	1.4	1.5	40	35.43	15.5	0.65	102	283	24.1
35. De Lobos (L)	7.5	1.2	20	35.27	16	0.25	285	359	166.2
36. Indio Muerto (L)	6.3	1.6	35	35.45	16	1.00	119	192	12.6
37. De Monte (L)	6.4	1.4	20	35.45	16	0.70	245	165	40.6
38. La Chilca (L)	10.0	1.5	55	35.78	15.5	1.05	81	220	13.5
39. Chascomus (L)	28.7	1.5	7	35.60	16.5	0.15	230	168	57.3
40. La Limpia (L)	5.6	1.9	10	35.62	16.5	0.15	1137	173	8.6
41. La Tablilla (L)	12.9	1.1	9	35.80	16	2.10	23	92	2.0
42. Blanca Grande (L)	4.1	1.5	100	36.47	15	0.20	250	185	67.4
43. Alsina (L)	25.7	1.1	105	36.88	15	0.30	207	292	120.8
44. Cochico (L)	36.6	1.9	103	36.92	15	0.45	181	281	98.2
45. Salada Grande (L)	48.1	2.0	2	36.92	14.5	4.6	53	161	1.6
46. Los Horcones (L)	2.0	1.3	5	37.00	14.5	0.65	264	233	15.7
47. Del Monte (L)	80.1	5.2	100	37.00	15	0.50	157	300	89.0
48. Dulce (L)	2.5	2.7	98	37.06	15	0.25	398	363	115.1
49. Del Venado (L)	25.3	3.8	97	37.08	15	0.28	456	339	153.4
50. Epecuen (L)	45.0	4.0	95	37.13	15	0.20	1608	316	55.4

Table 1. continued.

	A	ZMEAN	ALT	LAT	TEMP	SDT	TP	TON	CHL-a
51. La Brava (L)	4.3	3.4	70	37.88	14	1.40	188	79	7.9
52. De Los Padres (L)	2.9	2.7	50	37.87	13.8	2.9	124	73	3.3
53. De Pigue (L)	6.4	2.5	250	38.05	14	0.33	127	278	46.7
54. De Saavedra (L)	4.5	2.7	253	38.03	14	0.52	72	117	23.8
55. La Dulce (L)	49.0	3.8	230	38.05	15	1.10	25	78	12.8
56. Urre Lauquen	62.9	1.6	230	38.08	15	0.83	38	58	7.6
57. Sauce Grande (L)	18.2	2.1	11	38.95	14.5	0.35	246	136	37.9
58. Agrio (L)	9.7	50.8	1650	37.88	6	9.0	238	21	0.61
59. Pellegrini (L)	100.7	9.4	270	38.41	14.5	2.0	24	45	14.1
60. Mari Menuco (R)	174	79.4	421	38.58	13	8.5	4	6	0.66
61. Los Barreales (R)	411	68.3	422	38.53	13	2.1	9	12	1.73
62. Blanca (L)	17.0	8.4	1230	39.05	10	5.5	102	115	1.43
63. Alumine (L)	57.0	69.4	1125	38.92	4	13.3	3	14	0.31
64. Ramos Mexia (R)	816	24.7	381	39.42	12	4.0	9	15	2.16
65. Norquinco (L)	5.4	41.9	1025	39.15	3	7.8	5	17	0.43
66. Quillen (L)	23.0	59.0	975	39.42	4	16.5	3	6	0.29
67. Huechulafquen (L)	78.2	142	875	39.77	5	7.5	14	14	0.74
68. Lacar (L)	49.0	166	625	40.17	5	14.5	4	21	0.37
69. Nahuel Huapi (L)	557	157	764	40.88	5	12.5	4	15	0.41
70. Gutierrez (L)	16.4	79.7	750	41.20	5	10.5	2	14	0.39
71. Ne Luan (L)	0.6	6.4	1000	40.88	9.6	0.60	68	48	23.8
72. Mascardi (L)	39.2	111	750	41.30	5	9.5	3	9	0.22
73. Guillelmo (L)	5.4	61.3	826	41.38	5	11.0	4	14	0.55
74. Steffen (L)	6.3	46.7	525	41.52	6	13.0	3	13	0.21
75. Las Chultas (L)	0.6	11.4	585	42.17	7	9.0	9	29	0.69
76. Epuyen (L)	17.4	92.4	250	42.17	5	19.0	1	9	0.16
77. Puelo (L)	44.0	111	150	42.17	5	7.0	3	9	0.23
78. Cholila (L)	17.5	(48.5)	540	42.47	5	11.5	9	17	0.33
79. Lezama (L)	7.5	36.0	750	42.45	6	16.0	4	20	0.74
80. Los Mosquitos (L)	4.6	(6.1)	500	42.50	7	0.90	30	61	54.1
81. Rivadavia (L)	21.7	104	527	42.57	5	11.5	3	17	0.35
82. Esquel (L)	2.8	2.1	650	42.88	8	2.8	74	72	4.1
83. Brecham (L)	0.3	3.3	480	42.90	8	1.50	43	45	12.0
84. Verde (L)	1.4	18.3	520	42.72	5	11.0	4	23	0.68
85. Willimanco (L)	0.6	(6.4)	700	42.88	8	4.0	25	38	7.2
86. Zeta (L)	0.8	5.9	850	42.88	8	3.6	92	63	6.6
87. Largo (L)	2.8	19.5	800	42.90	5	13.5	7	21	0.49
88. Terraplen (L)	2.7	3.5	750	42.98	6	1.10	30	69	20.1
89. Amutui Quimei (R)	86.7	64.7	502	42.88	5	10.5	3	22	0.68
90. Futalaufquen (L)	44.6	101	518	42.83	5	14.0	2	13	0.50
91. Rosario (L)	14.5	24.9	650	43.25	8	5.9	20	33	1.69
92. Quichaura (L)	2.5	3.4	900	43.55	7.5	5.0	38	83	1.10
93. Cronometro (L)	5.8	4.4	850	43.25	8	1.2	294	120	9.6
94. Los Niños (L)	0.7	4.3	900	44.87	7	12.0	6	22	0.47
95. Pico 4 (L)	5.3	6.8	550	44.27	5	12.0	9	24	1.81
96. Pico 3 (L)	4.5	3.8	550	44.20	5	3.2	33	41	2.8
97. Pico 1 (L)	12.0	41.0	550	44.25	5	12.9	9	28	0.92
98. La Plata (L)	76.0	(97.0)	940	44.87	5	12.6	6	20	0.26
99. Fontana (L)	81.5	(79.0)	930	44.93	5	14.5	6	20	0.28
100. Blanco (L)	31.7	(0.7)	550	45.90	5	0.03	1550	411	77.8
101. Muster (L)	414	20.0	275	45.37	10.9	1.2	30	52	7.1
102. Colhue Huapi (L)	810	2.0	265	45.50	10.9	0.07	608	127	17.0
103. Ameghino (R)	65.0	24.6	169	44.10	11	2.2	43	41	2.17

Table 2. Regression equations relating chlorophyll-a (CHL-a, mg · m^{-3}) to total phosphorus (TP, mg · m^{-3}) and total organic nitrogen (TON, μM) for different levels of data screening.

N	Equation	r^2	F
103	$\log_e$CHL*a* = −1.37 + 0.84 $\log_e$TP	0.61	158.1*
103	$\log_e$CHL-a = −4.24 + 1.48 $\log_e$TON	0.73	271.8*
90	$\log_e$CHL-a = −2.21 + 1.17 $\log_e$TP	0.80	350.0*
12	$\log_e$CHL-a = −5.18 + 1.61 $\log_e$TON	0.85	58.0*
80	$\log_e$CHL-a = −2.18 + 1.22 $\log_e$TP	0.86	485.0*
67	$\log_e$CHL-a = −2.47 + 1.37 $\log_e$TP	0.88	472.6*
47	$\log_e$CHL-a = −2.68 + 1.47 $\log_e$TP	0.80	180.5*

* P<0.001

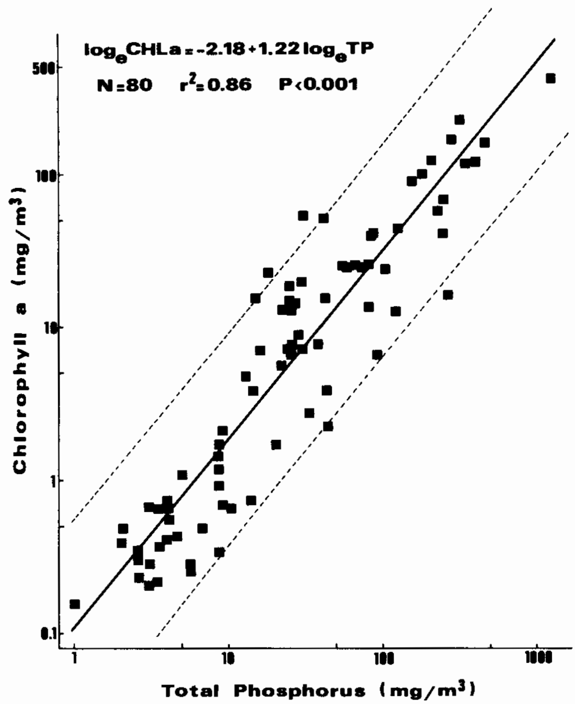

Fig. 2. Relation between mid-summer chlorophyll-a and total phosphorus concentration for 80 Argentinian lakes and reservoirs with TN : TP > 22 (molar basis). Broken line is the 95 % predictive confidence interval.

$$\log_e \text{CHL-a} = 2.36 - 1.17 \log_e \text{SDT}$$
$$N = 103, r^2 = 0.77 \; (P < 0.001)$$

Submersed aquatic macrophytes (Canfield et al. 1984) and non algal turbidity (Hoyer & Jones 1983) can inhibit or limit the development of phytoplankton. When the screening of the data was made for lakes and reservoirs with important development of submersed macrophytes or with evident nonalgal turbidity, the TN : TP > 22 set was reduced to N = 80 (Fig. 2). Most of the lakes with important development of submersed macrophytes (more than 85 % of the lake bottom) showed SDT > ZMEAN. Twenty five percent of the lakes and reservoirs were outside the 95% predictive limit of JONES & BACHMANN (1976) equation for natural lakes. TP explained 86% of the CHL-a variance and the slope coefficient was 1.22 (Table 2). This regression equation is similar to that derived by SCHINDLER (1978) for worldwide lakes and by WHITE (1983) for New Zealand lakes. ZMEAN and TEMP explained 1 and 4% more than TP alone, respectively. The regression equation for SDT was

$$\log_e \text{CHL-a} = 2.79 - 1.46 \log_e \text{SDT}$$
$$N = 80,\ r^2 = 0.91\ (P < 0.001)$$

SAKAMOTO (1966) and FORSBERG et al. (1978) suggested that P is generally the controlling factor in algal growth in waters having TN : TP > 37.6, and SMITH (1979) suggested that P is the primary controlling factor for photosynthesis when TN : TP > 46.5. When screening of the data was made for lakes and reservoirs with TN : TP < 35 and for two lakes with color higher than 100 Hazen, TP explained 88% of the CHL-a variance. The set was reduced to N = 67 and the regression coefficient for TP was 1.37; ZMEAN and TEMP explained 74 and 62% of the CHL-a variance, respectively. When they were included in the regression they improved the explained CHL-a variance in 1 and 3% respectively (Table 3). Similar results had been obtained when the screening was made with TN : TP < 47 (N = 57). In this last set there are still lakes and reservoirs of different water chemistry type. When we screened the data for lakes with anionic (carbonate plus bicarbonate to chloride plus sulfate) or cationic (calcium plus magnesium to sodium plus potassium) ratios below one (equivalent basis), the set was reduced to N = 47 lakes and reservoirs. In this case TP explained 80% of the CHL-a variance and the slope coefficient was 1.47 (Table 2). This regression equation is similar to that derived by DILLON & RIGLER (1974) for the relationship between spring TP and summer CHL-a and to those derived by CARLSON (1977) and by JONES & BACHMANN (1976) for mean summer concentrations in natural lakes. In this set all the lakes located on the Patagonian Andes Region, the reservoirs on the Patagonia Plateau and some of the reservoirs and lakes on the North-West arid region were included. By incorporating ZMEAN and TEMP terms in the regression, an additional 9% on the CHL-a variance was accounted for (Table 3). In all the sets we have analyzed, the additional variance explained by incorporating ZMEAN and TEMP in the CHL-a-TP regression ranged from 4 to 13%. Latitude and elevation terms generally explained the same percentage of CHL-a variance as TEMP.

To study the effect of ZMEAN on the CHL-a—TP regression, the N = 67 set was divided into three subsets, the first with TEMP < 10 (N = 30), the second with 10 < TEMP < 16 (N = 22) and the third with TEMP > 16 (N = 15). TP explained 70, 89 and 83% of the CHL-a variance, respectively (Table 4). For TEMP < 10, ZMEAN was

Table 3. Regression equations relating chlorophyll-a (CHL-a, $mg \cdot m^{-3}$) to total phosphorus (TP, $mg \cdot m^{-3}$), mean annual air temperature (TEMP, °C) and mean depth (ZMEAN, m) for different levels of data screening.

N	Equation	r^2	F
103	$\log_e$CHL-a = −1.47 − 0.43 $\log_e$ZMEAN + 1.18 $\log_e$TEMP + 0.84 $\log_e$TP	0.74	94.0
80	$\log_e$CHL-a = −2.41 − 0.25 $\log_e$ZMEAN + 0.98 $\log_e$TEMP + 0.77 $\log_e$TP	0.91	248.2
67	$\log_e$CHL-a = −2.19 − 0.30 $\log_e$ZMEAN + 0.88 $\log_e$TEMP + 0.85 $\log_e$TP	0.92	247.4
47	$\log_e$CHL-a = −1.83 − 0.41 $\log_e$ZMEAN + 1.06 $\log_e$TEMP + 0.71 $\log_e$TP	0.89	112.7

P < 0.001

Table 4. Regression equations relating chlorophyll-a (CHL-a, $mg \cdot m^{-3}$) to total phosphorus (TP, $mg \cdot m^{-3}$) for subsets of N = 67.

N	Limits	Equation	r^2	F
30	TEMP < 10	$\log_e$CHL-a = −2.47 + 1.22 $\log_e$TP	0.70	64.8*
22	10 < TEMP < 16	$\log_e$CHL-a = −1.70 + 1.20 $\log_e$TP	0.89	166.1*
15	TEMP > 16	$\log_e$CHL-a = −0.99 + 1.04 $\log_e$TP	0.83	62.7*
26	ZMEAN > 32	$\log_e$CHL-a = −1.67 + 0.66 $\log_e$TP	0.40	16.1*
16	10 < ZMEAN < 32	$\log_e$CHL-a = −2.91 + 1.55 $\log_e$TP	0.77	45.9*
25	ZMEAN < 10	$\log_e$CHL-a = −0.61 + 0.96 $\log_e$TP	0.66	45.1*

* $P < 0.001$

Table 5. Regression equations relating chlorophyll-a (CHL-a, $mg \cdot m^{-3}$) to total phosphorus (TP, $mg \cdot m^{-3}$) for a stratified and an unstratified group, and for lakes and ponds and reservoirs. For N = 67.

N	Conditions	Equation	r^2	F
33	stratified	$\log_e$CHL-a = −2.50 + 1.38 $\log_e$TP	0.84	163.6*
34	unstratified	$\log_e$CHL-a = −2.45 + 1.36 $\log_e$TP	0.83	155.3*
44	lakes and ponds	$\log_e$CHL-a = −2.60 + 1.36 $\log_e$TP	0.88	299.6*
23	reservoirs	$\log_e$CHL-a = −2.04 + 1.32 $\log_e$TP	0.92	247.5*

* $P < 0.001$

Table 6. Regression equations relating chlorophyll-a (CHL-a, $mg \cdot m^{-3}$) to total phosphorus (TP, $mg \cdot m^{-3}$) for Patagonia, Central-West and North-West and Pampa Plain regions. For N = 67.

N	Region	Equation	r^2	F
34	Patagonia	$\log_e$CHL-a = −2.50 + 1.29 $\log_e$TP	0.74	90.9*
25	Central-West and North-West	$\log_e$CHL-a = −1.97 + 1.30 $\log_e$TP	0.76	74.6*
8	Pampa Plain	$\log_e$CHL-a = −2.40 + 1.30 $\log_e$TP	0.83	28.6**

* $P < 0.001$, ** $P < 0.01$

the second most important variable in the multiple regression, for 10 < TEMP < 16, TEMP was the second variable in importance and for TEMP > 16, ZMEAN and TEMP were direct and inversely related to CHL-a respectively. They improved the explained variance in only 2% (Table 4). Then, the set with N = 67 was divided into three subsets, with ZMEAN > 32, 10 < ZMEAN < 32 and ZMEAN < 10, respectively. In all the three cases the variance explained by TP was lower than that for the whole set and TEMP was the second most important variable in the multiple regression. The regression equations differ significantly among them, both in their slopes and their intercepts.

When we considered the whole set with N = 67 into two subsets according to whether they were stratified or not by mid-summer (Table 5), no significant differences between them were detected in the relation CHL-a against TP. TP explained 84 and 83% of the CHL-a variance. TEMP increases the explained variance in 2 and 7% in unstratified and stratified lakes respectively and ZMEAN was not important to explain the residual variance in the unstratified group.

When we considered lakes and ponds on one hand and reservoirs on the other (Table 5), TP explained 88 and 92% of the CHL-a variance respectively. The slopes did not differ significantly for N = 67. For lakes and ponds ZMEAN and TEMP improved the explained variance in 2 and 3 % respectively. For reservoirs neither ZMEAN nor TEMP increased the explained variance of CHL-a.

When we performed the analysis by geographic region, beginning with n = 67, the regression equations of CHL-a against TP did not show significantly different slopes (Table 6). The difference in intercepts might be related to the different ranges of the variables involved in each subset. For 34 lakes and reservoirs in Patagonia, TP explains 74 % of the CHL-a variance (Table 6) and by incorporating ZMEAN and TEMP terms an additional 8 % of the variance is accounted for. For 25 lakes and reservoirs in the Central-West and North-West arid regions, TP explained 76 % of CHL-a variance and incorporating ZMEAN and TEMP the explained variance was 85 %. For eight ponds in the Pampa Plain, TP explained 83 % in CHL-a variance and incorporating ZMEAN and TEMP terms an additional 9 % is accounted for. In this last case the regression coefficient for ZMEAN was positive and that for TEMP negative. This last result with respect to ZMEAN was identical to that obtained for the subsets with ZMEAN < 10 or TEMP > 16. This might be related to a negative effect of non algal suspended solids on algal yield in very shallow lakes and ponds.

Discussion

As in other regional studies in the Northern and Southern hemispheres (FERRIS & TYLER 1985) and for worldwide models (SCHINDLER 1978), P represented the most important variable analyzed to explain chlorophyll variation in the Argentinian set of lakes and reservoirs when a screening for TN : TP < 22 was made. Thirty percent of the studied lakes were limited or could be limited by N by mid-summer. When screening for TN : TP > 37 was made, total organic nitrogen was the most important variable analyzed to explain chlorophyll variance. These results are in general agreement with those of SAKAMOTO (1966) and SMITH (1979). For lakes with TN : TP ratio between 22 and 37 photosynthesis might be controlled by either N or P.

As in SCHINDLER's (1978) set, the difference between CHL-a – TP regressions for a stratified and an unstratified group was not significant. In all the sets we have analyzed, the predicted chlorophyll was lower for lakes and ponds than for reservoirs. This might be related to the composition of the data base, without main-channel type reservoirs of very low hydraulic residence time and high inorganic turbidity.

Among the factors which have been suggested to explain the residual variance, in CHL-a – TP relations are: methodology (NICHOLLS & DILLON 1978), the portion of the annual cycle represented by the data (NICHOLLS & DILLON), TN : TP ratios (SAKAMOTO 1966, SMITH 1979), flushing rate (DILLON 1975), zooplankton abundance (SHAPIRO 1980), zooplankton community structure (PACE 1984), non algal suspended solids (CANFIELD & BACHMANN 1981, JONES & NOVAK 1981, HOYER & JONES 1983) and aquatic macrophytes (CANFIELD et al. 1984). BRYLINSKY & MANN showed through IBP data, that latitude (related to daylength) is directly related to the level of productivity in lakes. RAWSON (1955) and SAKAMOTO (1966) showed that algal biomass is inversely related to mean depth. Our results suggest that morphometry and climate are related to CHL-a levels in lakes and reservoirs. Mean annual air temperature and mean depth might explain some of the residual variance in CHL-a – TP relationship in very heterogeneous data bases or in worldwide models. Similar results with respect to mean depth were obtained when we had analysed SAKAMOTO's (1966, Table 1) and AIZAKI et al. (1981, Tables 1 and 2) data.

When CHL-a was regressed on TP, TEMP and ZMEAN, the regression coefficient for TP was generally lower than one. This indicates that for fixed values of TEMP and ZMEAN a doubling in TP will produce an increase smaller than twice for CHL-a. This result might be important for the management of lakes and reservoirs on a worldwide basis.

Although our sampling was limited, a wide range of limnological characteristics were sampled. Further sampling and testing are needed to ascertain our results.

Our results also indicate the key role played by data screening (ORTIZ CASAS & PEÑA MARTINEZ 1984). We have not used any statistical approach for screening our data. None of our regressions accounts for chlorophyll concentration for two lakes and one reservoir with an error smaller than three times. From our analysis we cannot reject the effect of the zooplankton community on our CHL-a–TP relationships. There are at least two zooplanktophagous and microbentophagous fish species of the Atherinidae family described for Argentine freshwaters. These fish species are in general of high abundance in very shallow natural eutrophic lakes and ponds (QUIROS & BAIGUN 1986). The catch per unit effort of Atherinidae was over 64 % of the total in the two lakes and the reservoir (QUIROS & BAIGUN unpublished data) in which the CHL-a predicted was only one third or less of the measured one.

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