Verh. Internat. Verein. Limnol. | 23 | 558–565 | Stuttgart, Januar 1988

III. Lakes. 3. Asia

Pre- and postmonsoon limnological characteristics of lakes in the Pokhara and Kathmandu Valleys, Nepal[1]

KIRK LOHMAN, JOHN R. JONES, MATTHEW F. KNOWLTON, D. B. SWAR, M. ANNE PAMPERL
and BLAISE J. BRAZOS

With 3 figures and 3 tables in the text

Introduction

Three lakes in the Pokhara Valley (Phewa Tal, Begnas Tal, and Rupa Tal), and two smaller ponds in the Kathmandu Valley (Tau Daha and Nag Daha), Nepal, were sampled in spring and fall 1985 to examine the influence of the monsoon on their limnological conditions. We expected to find differences between seasons, because the spring samples represent conditions at the end of the dry period (October to May) and the fall samples were taken at the end of monsoon rains (June to September).

Materials and methods

Surface samples were collected on 4—8 dates in April—May 1985 and 2—4 dates in September—October 1985 from each lake in the Pokhara Valley. Samples were taken from five stations on Phewa Tal and four stations on both Begnas Tal and Rupa Tal. In addition to surface samples, vertical profiles were collected from the deepest part of Phewa Tal before and after the monsoon. Profile data represents average values from two profiles for each season. In the Kathmandu Valley, Nag Daha was sampled once in April 1985 and Tau Daha twice in April—May. Both ponds were sampled twice in September—October 1985. Characteristics of the lakes and their watersheds were described by HICKEL (1973 a, b) and SWAR (1980).

Chlorophyll-a was measured spectrophotometrically using a Beckman Mini 20 after extraction by ethanol (SARTORY & GROBBELAAR 1984). In fall, an additional set of chlorophyll-a samples were stored at ambient temperature in the dark in dessicant, then transported to the United States and analyzed fluorometrically (KNOWLTON 1984). Results from the two analyses were virtually identical. Total phosphorus was determined using the ascorbic acid method after persulfate oxidation (PREPAS & RIGLER 1982, APHA 1981) and total nitrogen was analyzed by cadmium reduction after persulfate oxidation (D'ELIA et al. 1977). Bacteria and phytoplankton samples were preserved with formalin. Other chemical analyses were conducted according to APHA (1981) or USEPA (1979).

Results and discussion

Premonsoon conditions

Salinity in the Pokhara Valley lakes averaged less than 41 mg/l (Table 1), which is a third of the world average for river waters (WETZEL 1983). Values were among the lowest in a premonsoon survey of 50 lakes and ponds in Nepal (J. R. JONES, unpublished data). Calcium accounted for 66.3 % of the cation concentration in Phewa Tal and about 43 %

---

[1] Contribution from the Missouri Agricultural Experiment Station, Journal Series Number 10255.

0368-0770/88/0023-0558 $ 2.00

Table 1. Pre- and postmonsoon surface values for lakes in the Pokhara and Kathmandu valleys.

	Phewa Tal		Begnas Tal		Rupa Tal		Tau Daha		Nag Daha	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Water Temperature (°C)	26.9	27.3	27.2	28.6	26.5	27.9	–	23.8	–	24.2
SECCHI Transparency (m)	2.5	3.3	1.6	1.7	1.1	1.5	2.6	–	1.4	–
Color (Pt units)	<5	<5	14	10	10	11	10	21	15	28
pH	8.2	7.2	8.2	7.2	7.6	7.1	7.6	7.7	7.5	7.3
Alkalinity (mg/l $CaCO_3$)	22.7	12.6	16.4	12.0	23.0	14.8	88.0	71.7	56.0	24.6
Chlorophyll-*a* (μg/l)	11.2	4.8	21.2	23.3	39.7	34.5	5.6	5.7	7.6	8.5
Total Phosphorus (μg/l)	24	7	48	20	41	33	31	16	22	35
Total Nitrogen (mg/l)	0.14	0.12	0.31	0.33	0.42	0.27	0.45	0.42	0.33	0.48
Silica (mg/l)	0.3	4.8	8.9	7.2	0.6	9.3	5.2	12.8	5.5	6.9
Total Suspended Solids (mg/l)	3.4	1.8	5.2	4.0	7.4	4.0	1.8	2.2	4.1	6.3
Calcium (mg/l)	6.95	2.71	2.99	1.49	4.25	1.40	25.68	22.12	10.52	5.12
Magnesium (mg/l)	1.16	0.57	1.04	0.76	1.57	0.90	6.52	4.29	2.67	1.32
Sodium (mg/l)	1.48	1.32	2.25	2.14	3.17	26.2	3.38	2.68	10.40	5.44
Potassium (mg/l)	0.63	0.45	0.39	0.34	0.77	0.48	1.21	1.75	4.40	1.34
Bicarbonate (mg/l)	27.69	15.37	20.00	14.64	28.06	18.06	107.36	87.47	68.32	30.01
Chloride (mg/l)	0.75	0.44	0.97	0.60	1.28	0.50	4.40	3.53	8.00	5.76
Sulfate (mg/l)	n.d.[a]	n.d.	2.8	n.d.	1.7	n.d.	0.9	1.0	n.d.	1.0

[a] n.d. = not detectable

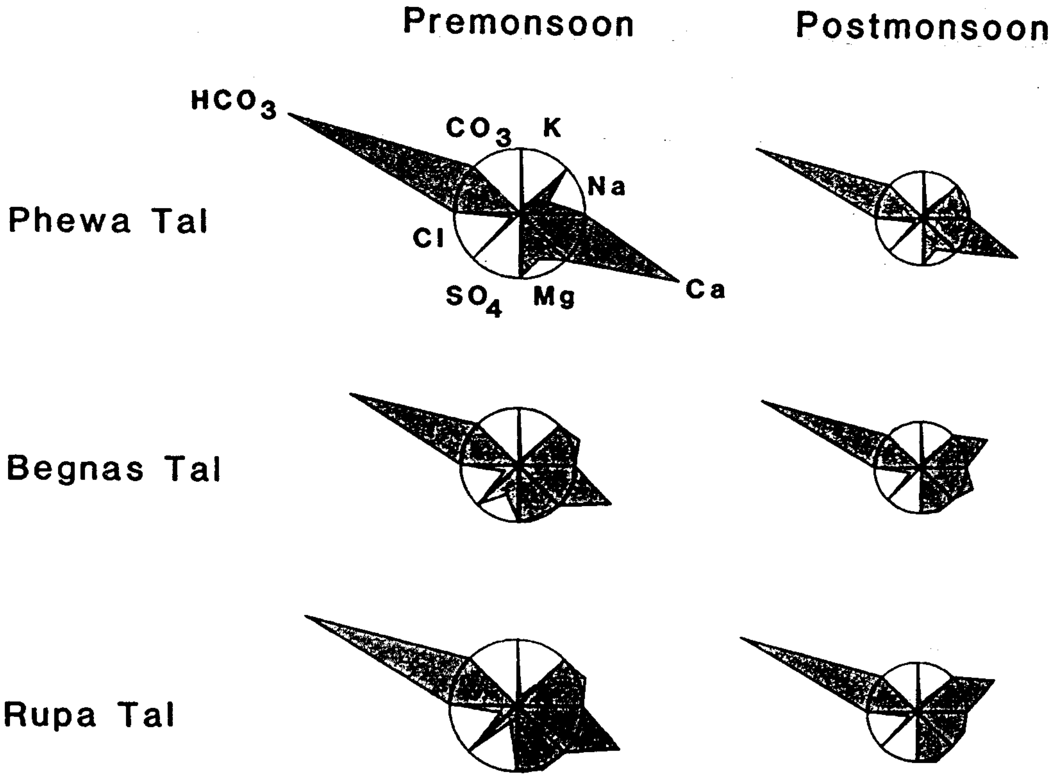

Fig. 1. Pre- and postmonsoon ionic diagrams of Phewa Tal, Begnas Tal, and Rupa Tal. Total ionic concentration in each diagram is proportional to the premonsoon concentration (1.041 meq/l) in Rupa Tal (modified after BROCH & YAKE 1969).

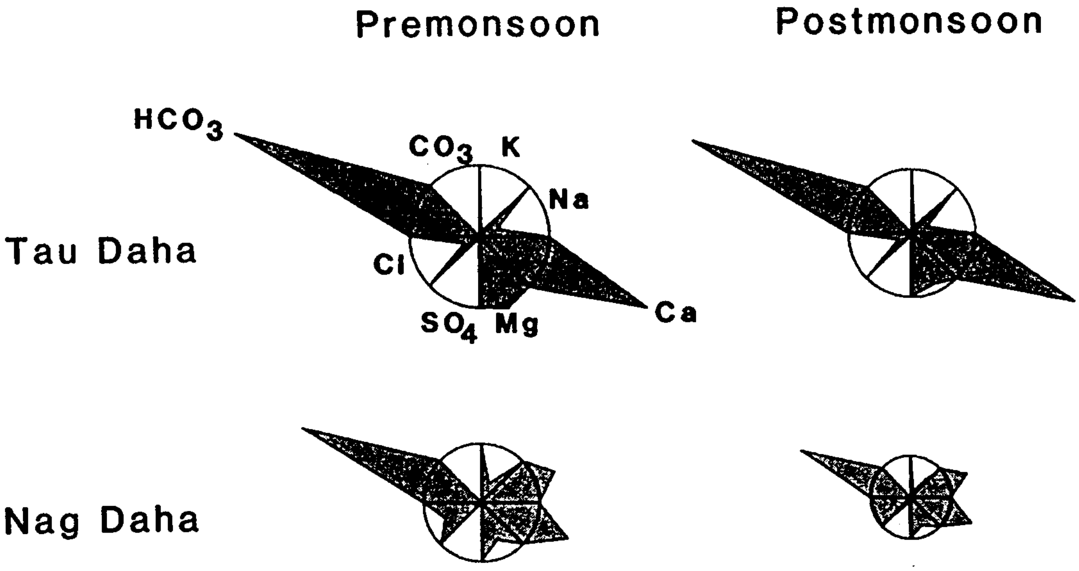

Fig. 2. Pre- and postmonsoon ionic diagrams of Tau Daha and Nag Daha. Total ionic concentration in each diagram is proportional to the premonsoon concentration (3.898 meq/l) in Tau Daha (modified after BROCH & YAKE 1969).

in Begnas Tal and Rupa Tal and anions were predominately bicarbonate in all three lakes (Fig. 1). Divalent cation values were substantially less than in Tilitso and other lakes in the high mountain region 50 km to the north where calcium ranged from 20—62 mg/l and magnesium from 6—72 mg/l (ISHIDA 1986). Much higher values (EDTA hardness 91—100 mg $CaCO_3$/l) have also been reported from Lake Rara in western Nepal by OKINO & SATOH (1986). HICKEL (1973 a) also found the Pokhara Valley lakes poor in electrolytes (electrical conductivity $<50\,\mu S/cm$; alkalinity <0.06 mv/l). Low salinity in these lakes is attributable to the metamorphic geology of the Pokhara Valley, which is dominated by chloritic phyllite and schist with some calcareous and arenaceous sediments (SHARMA 1977). Higher calcium concentrations in Phewa Tal are likely the product of two factors: more extensive calcareous deposits in the Phewa Tal watershed as compared to those of Begnas Tal and Rupa Tal (SHARMA 1977), and inflow of calcium-rich water from a diversion of the Seti River (J. R. JONES, unpublished data), which drains an area of the Himals (SHARMA 1977).

Premonsoon electrolyte concentrations in Tau Daha and Nag Daha were 3 to 5 times higher than in the Pokhara Valley lakes (Table 1). Calcium was the dominant cation and bicarbonate the dominant anion in both ponds, but sodium and chloride were major components of salinity in Nag Daha (Fig. 2). Higher salinity in the Kathmandu Valley ponds may be related to a more fertile vivianite geology (SHARMA 1977) and perhaps greater human use of the ponds.

Based on nutrient and chlorophyll-a concentrations, Phewa Tal is mesotrophic and Begnas Tal and Rupa Tal are eutrophic (VOLLENWEIDER & KEREKES 1980). This assessment agrees with that of ISHIDA (1986). In general, premonsoon nutrient and chlorophyll-a values were lowest in Phewa Tal and highest in Rupa Tal (Table 1). Chlorophyll-a concentrations in both Tau Daha and Nag Daha were substantially less than in the Pokhara Valley lakes, even though TP and TN values were similar to those in Begnas Tal and Rupa Tal. HICKEL (1973 b) considered Tau Daha relatively unproductive compared to

Table 2. Predominant phytoplankton in pre- and postmonsoon samples from lakes in the Pokhara and Kathmandu valleys.

	Premonsoon	Postmonsoon
Phewa Tal	*Melosira granulata*	*Melosira granulata* *Diatoma elongatum* *Ulothrix subtilissima*
Begnas Tal	*Microcystis aeruginosa* *Melosira granulata*	*Microcystis aeruginosa*
Rupa Tal	*Microcystis aeruginosa* *Synedra* spp.	–
Tau Daha	–	*Fragilaria pinnata* *Fragilaria construens*
Nag Daha	–	*Sphaerocystis schroeterii* *Merismopedia punctata*

Nag Daha and other small ponds in the Kathmandu Valley. Phytplankton samples collected from the Pokhara Valley lakes were dominated by diatoms in Phewa Tal, and by a mixture of diatoms and blue-greens in Begnas Tal and Rupa Tal (Table 2).

Temperature profiles in Phewa Tal (Fig. 3) were similar to those taken by HICKEL (1973 a) in March and May 1968, with a metalimnion developing around 3 m. Dissolved oxygen in Phewa Tal was near saturation above 4 m, but dropped rapidly below that depth. Chlorophyll-a increased slightly from a surface value of 11.6 to 17.6 μg/l at 7 m.

Postmonsoon conditions

Two changes marked postmonsoon salinity in the Pokhara Valley lakes: a 34—46 % decrease in total salinity (Table 1) and a change in relative cationic proportions (Fig. 1). Ionic dilution is likely a result of hydrologic flushing by heavy surface runoff during the monsoon. Based on precipitation, lake volume and watershed descriptions (HICKEL 1973 a, SWAR 1980), lake volumes were replaced at least 3—15 times between spring and fall sampling. Lake levels were higher in the fall than spring, which may also contribute to the observed dilution. A warmer hypolimnion and cation dilution throughout the water column in Phewa Tal (Table 3) suggests that water movement is extremely dynamic and that considerable advective mixing occurs during the monsoon. Dilution effects associated with monsoon rains have been previously noted in several Indian lakes (SINGH 1981, 1985, BANERJEE et al. 1983). Ionic dilution in the Pokhara Valley lakes was accompanied by a relative increase in the proportion of sodium compared to calcium in all three lakes (Fig. 1). This shift in ionic proportions represents a small change in measured concentrations and may be a consequence of surface runoff over the metamorphic materials in these watersheds.

Ionic proportions in the Kathmandu Valley ponds did not change in postmonsoon samples, but dilution was evident (Fig. 2). Salinity in Tau Daha declined only slightly (17 %), compared to a 53 % decrease in Nag Daha. The larger watershed, and likely greater flushing rate, may account for greater ionic dilution in Nag Daha.

Total phosphorus decreased in the Pokhara Valley lakes, but total nitrogen concentrations were similar to those measured before the monsoon except in Rupa Tal where TN declined. Ratios of TN:TP in premonsoon samples were ≤ 10 in all lakes which suggests nitrogen might limit algal growth, whereas a postmonsoon ratio of 16:1 in Phewa

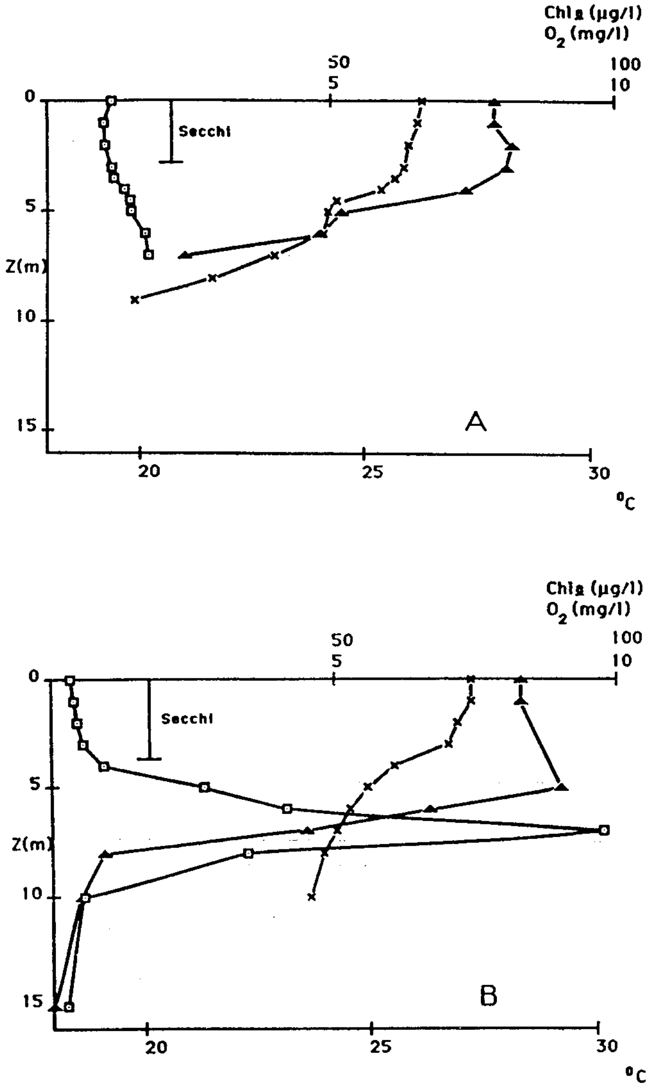

Fig. 3. (A) Premonsoon and (B) postmonsoon vertical distribution of chlorophyll-*a* (□), dissolved oxygen (▲), and temperature (X) in Phewa Tal.

Table 3. Postmonsoon vertical distribution of selected variables in Phewa Tal.

Z (m)	Chlorophyll-*a* (µg/l)	Phaeophytin (µg/l)	Volatile Suspended Solids (mg/l)	TN (mg/l)	TP (µg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Bacteria (× 10^6 cells/ml)
0	3.2	0.7	1.4	0.12	4	2.53	0.58	1.49	0.42	4.09
1	4.3	0.5	1.3	0.18	14	2.56	0.59	1.24	0.40	3.95
2	4.3	0.4	1.4	0.23	14	2.51	0.59	1.25	0.38	3.68
3	4.4	0.6	1.7	0.36	12	2.39	0.59	1.28	0.40	3.32
4	9.0	1.8	1.8	0.20	8	2.34	0.62	1.20	0.39	4.00
5	26.5	2.4	3.5	0.30	12	6.21	0.77	1.22	0.49	4.08
6	41.4	0.2	3.7	0.28	9	3.96	0.67	1.14	0.43	4.16
7	97.6	1.0	2.9	0.32	12	3.63	0.64	1.12	0.48	3.87
8	34.2	2.0	1.0	0.37	8	4.10	0.65	1.20	0.45	2.70
10	5.4	2.3	–	0.43	4	2.96	0.60	1.06	0.46	1.06
15	2.3	1.9	–	–	–	4.67	0.81	1.42	0.57	–

Tal and Begnas Tal could reflect either nitrogen or phosphorus limitation (Smith 1980). Surface chlorophyll-*a* concentration was less than half in Phewa Tal, but was similar to premonsoon levels in Begnas Tal and Rupa Tal. Postmonsoon transparency was greater in all three lakes. Phytoplankton composition was dominated by diatoms in Phewa Tal, and blue-greens in Begnas Tal.

Both TP and TN were higher in postmonsoon samples in Nag Daha, whereas TP was half and TN similar to premonsoon samples from Tau Daha. Chlorophyll-*a* values were similar to premonsoon levels in both ponds. *Fragilaria* species comprised most of the phytoplankton in Tau Daha, while green and blue-green species dominated in Nag Daha.

Temperatures in Phewa Tal were higher in the postmonsoon profile, but the top of the metalimnion remained at around 3 m (Fig. 3 B). Metalimnetic oxygen was highest at 5 m and fell sharply below that depth. Postmonsoon distribution of bacteria varied little with depth (Table 3) and was similar to the vertical distribution found by Ishida (1986) in September 1984.

The vertical distribution of chlorophyll-*a* in Phewa Tal featured a narrow metalimnetic maxima approaching 100 μg/l at 7 m in contrast to epilimnetic values of less than 5 μg/l (Fig. 3 B). Subsurface chlorophyll peaks of the magnitude observed in Phewa Tal have been reported for other lakes (Fee 1976, Ichimura et al. 1968, Eberly 1964). Moll & Stoermer (1982) suggested that formation of subsurface chlorophyll maxima is directly related to trophic state. According to their hypothesis, subsurface maxima tend to occur in oligotrophic and mesotrophic lakes in which surface waters have become nutrient-poor. Phytoplankton layers normally occur between 0.01 and 5 % of surface light intensity. Fee (1976) proposed that the position of subsurface maxima was primarily tied to light penetration and secondarily related to nutrient supply in Canadian Shield lakes. Both Fee (1976) and Moll & Stoermer (1982) presented evidence that subsurface chlorophyll layers were comprised of live, actively photosynthesizing algae and not senescent cells that had settled from the epilimnion.

The presence of a metalimnetic chlorophyll peak in Phewa Tal is consistent with these ideas. Light transmission at the depth of the peak was about 5 % (estimated as three times Secchi transparency). Total nitrogen increased with depth and although the vertical distribution of total phosphorus was patchy, total phosphorus was higher at 5—7 m than at the surface (Table 3). Measurements of phaeophytin as a percentage of total pigment concentration averaged 17 % in the upper 4 meters, 4 % between 5 and 8 m, 35 % at 10 m, and 76 % at 15 m. Volatile suspended solids also increased substantially between 5 and 7 m. Chlorophyll-*a* as a percentage of volatile suspended solids averaged 0.3 % in the upper 4 m and increased to 3.4 % at 7 and 8 m. Plankton samples collected at 6 m were composed entirely of *Diatoma elongatum* v. *tenuis*.

Although fragmentary, we believe these data suggest that the metalimnetic chlorophyll layer was an active zone of photosynthesis. Our premonsoon profile, as well as that of Hickel (1973 a), indicates that such a layer may begin to develop in the spring and persist until the lake destratifies. Chlorophyll-*a* values reported by Ishida (1986) at 5 m and above and at 10 m and below are similar to our own, so it is possible that a similar chlorophyll peak existed the year before our study, however, no samples were taken between 5 and 10 m. If the development of a metalimnetic chlorophyll peak is an annual event in Phewa Tal, the low transparency and maximum phytoplankton density seen by Hickel (1973 a) in December shortly after destratification may, in part, result from mixing of the metalimnetic layer.

Acknowledgements

This material is based on work supported by the National Science Foundation under Grant No. INT-8407884 and the Missouri Agricultural Experiment Station (Project No. 184). We thank P. L. Joshi, Bikash Shrestra and Tek Gurung for help in the field and Bruce Perkins for help with laboratory analyses.

References

American Public Health Association, 1980: Standard methods for the examination of water and wastewater. — 15th ed., APHA, New York, 1133 pp.

Banerjee, D. K., Bhatia, B. & Haq, I., 1983: Comparison of seasonal and diurnal patterns of some physico-chemical parameters of the open and closed parts of Loktak Lake, Manipur, India. — *Intern. J. Environmental Studies* **21**: 243—250.

Broch, E. S. & Yake, W., 1969: A modification of Maucha's ionic diagram to include ionic concentrations. — *Limnol. Oceanogr.* **14**: 933—935.

D'Elia, C. F., Steudler, P. A. & Corwin, N., 1977: Determination of total nitrogen samples using persulfate digestion. — *Limnol. Oceanogr.* **22**: 760—764.

Eberly, W. R., 1964: Further studies on the metalimnetic oxygen maximum with special references to its occurrence throughout the world. — *Invest. Indiana Lakes Streams* **6**: 103—139.

Fee, E. J., 1976: The vertical and seasonal distribution of chlorophyll in lakes of the Experimental Lake Area, northwestern Ontario: implications for primary production estimates. — *Limnol. Oceanogr.* **21**: 767—783.

Hickel, B., 1973 a: Limnological investigations in lakes of the Pokhara Valley, Nepal. — *Int. Revue ges. Hydrobiol.* **58**: 659—672.

— 1973 b: Phytoplankton in two ponds in Kathmandu Valley, Nepal. — *Int. Revue ges. Hydrobiol.* **58**: 835—842.

Ichimura, S., Nagashawa, S. & Tanaka, T., 1968: On the oxygen and chlorophyll maxima found in the metalimnion of a mesotrophic lake. — *Botan. Mag. Tokyo* **81**: 1—10.

Ishida, Y. (ed.), 1986: Studies on distribution, adaptation and evolution of microorganisms in Nepal Himalayas (second report). — Kuzo Dogura, Kyoto. 71 pp.

Knowlton, M. F., 1984: Flow-through microcuvette for fluorometric determination of chlorophyll. — *Water Resources Bulletin* **20**: 795—799.

Moll, R. A. & Stoermer, E. F., 1982: A hypothesis relating trophic status and subsurface chlorophyll maxima of lakes. — *Arch. Hydrobiol.* **94**: 425—440.

Okino, T. & Satoh, Y., 1986: Morphology, physics, chemistry, and biology of Lake Rara in West Nepal. — *Hydrobiologia* **140**: 125—133.

Prepas, E. E. & Rigler, F. H., 1982: Improvements in quantifying the phosphorus concentration in lake water. — *Can. J. Fish. Aquat. Sci.* **39**: 822—829.

Sartory, D. P. & Grobbelaar, J. U., 1984: Extraction of chlorophyll-a from freshwater phytoplankton for spectrophotometric analysis. — *Hydrobiologia* **114**: 177—187.

Sharma, C. K., 1977: Geology of Nepal. — 2nd Ed., Educational Enterprises, Ltd., Kathmandu.

Singh, R. K., 1981: Physico-chemical characteristics and macrophytes of Naukuchiya Tal, a mid altitude lake of Kumaun Himalaya (India). — *Trop. Ecol.* **22**: 40—53.

— 1985: Limnological observations on Rihand Reservoir (Uttar Pradesh) with reference to the physical and chemical parameters of its water. — *Int. Revue ges. Hydrobiol.* **70**: 857—875.

Smith, V. H., 1982: The nitrogen and phosphorus dependence of algal biomass in lakes: An empirical and theoretical analysis. — *Limnol. Oceanogr.* **27**: 1101—1112.

Swar, D. B., 1980: Present status of limnological studies and research in Nepal. — In: Mori, S. & Ikusima, I. (eds.), Proceedings of the First Workshop of Limnology in Developing Countries, Kuzo Dogura, Kyoto.

U.S. Environmental Protection Agency, 1979: Methods for chemical analysis of water and wastes. — U.S. EPA-600/4-79-020, Cincinnati, 460 pp.

Vollenweider, R. A. & Kerekes, J. J., 1980: Background and summary results of the OECD Cooperation Program on Eutrophication. — In: Restoration of Lakes and Inland Waters, U.S. EPA 400/5-81-010, pp. 25—36.

Wetzel, R. G., 1983: *Limnology* (2nd ed.). – Saunders College Publishing, Philadelphia. 767 pp.

Authors' addresses:

Mr. K. Lohman, Dr. J. R. Jones, Mr. M. F. Knowlton, School of Forestry, Fisheries and Wildlife, University of Missouri, Columbia, Missouri 65211, U.S.A.
Mr. D. B. Swar, Fisheries Development Center, Pokhara, Nepal
Ms. M. A. Pamperl, Carolina Power and Light, New Hill, North Carolina 27562, U.S.A.
Mr. B. J. Brazos, Department of Civil Engineering, University of Missouri, Columbia, Missouri 65211, U.S.A.