COMPARATIVE LIMNOLOGY OF NINE LAKES OF JAMMU AND KASHMIR HIMALAYAS

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Received February 20, 1980

Keywords: Himalayan lakes, ecology, trophic status, stratification

Abstract

Two lakes in the lower Siwalik Himalayas, five in the Kashmir valley and two situated in the high mountains of the Kashmir Himalayas were investigated for their physico-chemical and biological features. The lakes, differing significantly in their morphology and in thermal behaviour, rank from the subtropical monomictic to the dimictic type. The lakes at high altitudes (> 3000 m) have very low electric conductivity which increases with the decrease in altitude. The most dominant ions in water are calcium and bicarbonate. The macrophytic vegetation of the lakes does not show any definite relationship either with altitude or with physico-chemical milieu. In the lakes with low fertility the phytoplankton is dominated by diatoms and Chlorophyceae but in eutrophic lakes Cyanophyceae predominate. The zooplankton population of the lakes is mainly comprised of rotifera. On the basis of general limnological features and the rates of phytoplankton production most of the lakes may be categorized either as eutrophic or in the process of rapid evolution. Only one lake is oligotrophic.

Introduction

The Kashmir Himalayas are extremely important because of their geographical position and for the role they play in the economy of the State. The region abounds in freshwater natural lakes which are important for fishery, agriculture and recreation. So far only a few limnological studies have been undertaken on these lakes (Zutshi & Vass, 1971; Zutshi *et al.*, 1972; Zutshi & Khan, 1977; Khan & Zutshi, 1979).The lakes were investigated during 1974-78 to obtain basic data for future ecological surveillance of the Himalayan region, and to classify the lakes on the basis of their present trophic levels.

Materials and methods

The morphometric features of the lakes were calculated after Hutchinson (1957). The water samples were taken from different depths using a Ruttner sampler. The visibility was determined with a standard Secchi disc, pH-value and conductivity were measured electrometrically, and alkalinity by titration against an acid using methyl orange as an indicator. In the laboratory the water samples were analysed following the methods outlined in APHA (1960). The nomenclature of macrophytic vegetation is after Zutshi (1975). The plankton in the water samples, preserved with Lugol's solution, was counted using a Sedgwick - rafter cell. The net samples preserved in 5% formalin were used for identification of species. The phytoplankton production was estimated using the C-14 technique after Steemann-Nielsen (1952).

Description of the lakes

For the study, two lakes from the lower Siwalik Himalayas of the Jammu region, five from Kashmir valley and two lakes from the alpine region of the Kashmir Himalayas were selected (Fig. 1). The altitude ranges from 604 to 3200 m above mean sea level and geographical co-ordinates of the lakes lie between 32 and 34°N lat. and 74 and 75°E long.

The Siwalik lakes are believed to have originated as a result of damming of the river flowing along the strike valley about twenty to twenty-five thousand years ago (Zutshi & Khan, 1977). The Valley lakes lie in the floodplain of Jhelum river which flows through the Kashmir valley. The lakes have probably originated as a result of meandering of alluvial deposits. They are of postglacial age (Wadia, 1947). One of the high altitude lakes, *viz.*, Nilnag is situated in the foothills of the Pir Panjal range in the south of Srinagar and is probably of tectonic origin. The Alipather, is a glacial lake formed by embankments across the line of drainage (Zutshi *et al.*, 1972). These embankments may have been caused by deposits of avalanche debris from a side slope or by the advance of a side glacier with its lateral moraines.

Hydrobiologia 72, 101-112 (1980). 0018-8158/80/0721-0101$02.40.

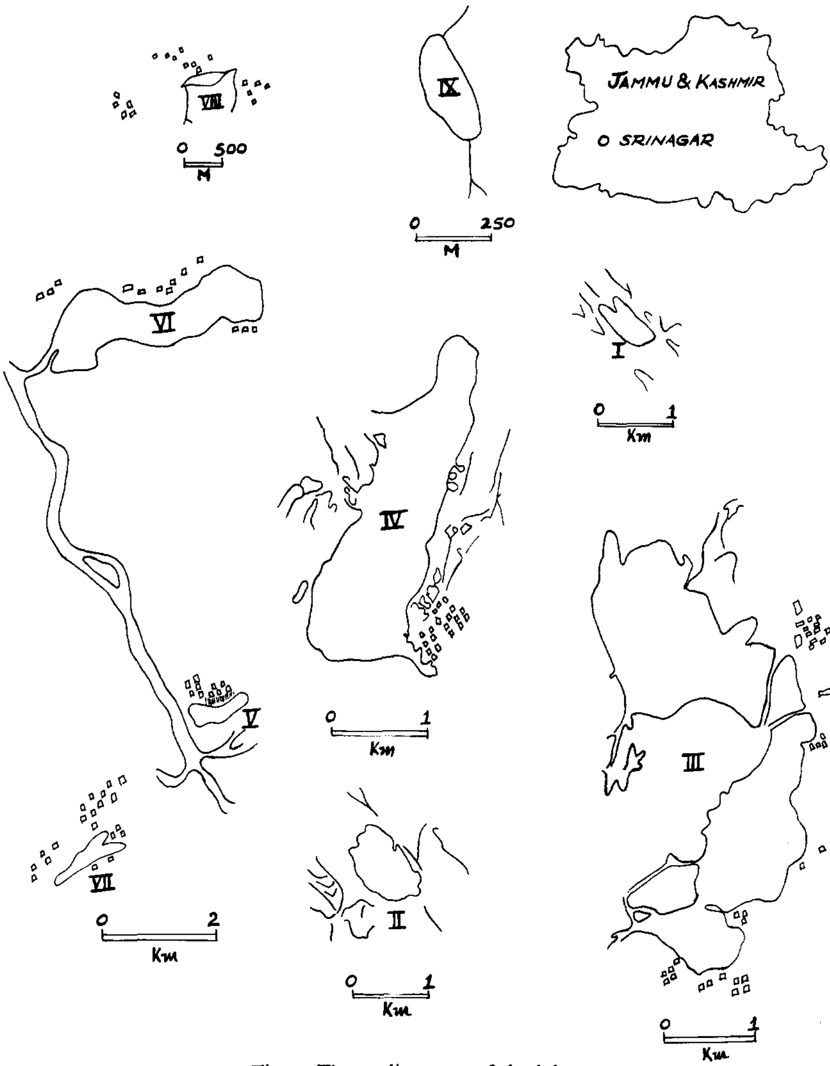

Fig. 1. The outline map of the lakes.

Morphometry, drainage and catchment area

The Siwalik lakes are oval to sub-oval in shape. They are fault basin, non-drainage types. The main supply of water to the lakes is through precipitation, the springs present within the basin being of minor importance. The monsoon period usually extends from early July to September. The excess of rain water spills over the embankments. Seepage losses are minor. Consequently, the water residence time and of the renewal period of the lakes are quite high. The valley lakes, *viz.,* Dal and Anchar, are drainage type lakes. They have low water residence time (0.29). The renewal period is approximately two and a half months. The semi-drainage valley lakes, *viz.,* Manasbal and Naranbagh, have moderate residence time, the renewal time being approximately one year. Trigam is a non-drainage valley lake with high water residence time. The high altitude Nilnag lake has water supply only through precipitation and springs, and the outflow is through a small sluice in the northern part. It is operative during high water level. The Alipather lake receives it water mainly from glaciers in the catchment area. The water level is regulated largely by the supply from the glaciers. The type of the drainage has an important relationship with the biology of the lakes (Zutshi & Khan, 1978).

The catchment area of the Siwalik lakes consists of elevated forest area with moderate vegetation. The sizeable portion of the catchment particularly of Surinsar lake is under agriculture. Mansar lake is being developed for tourism.

The human settlements in the catchment area of the Siwalik lakes have not increased very much recently; however, it is evident that the terrestrial ecosystem has been opened up due to undesirable human activity. The major portion of the catchment area of the valley lakes is inhabited and only a small part is under agriculture. There are no forests around the valley lakes. In recent years the turbidity of the water has increased. Some of the valley lakes are under intense tourist impact (*viz.*, Dal lake) and in the others it is likely to increase, e.g., Manasbal lake. The eastern part of the catchment area of Nilnag lake is covered with pine-fir forest. But the western part has been brought under agriculture. The number of human settlements has also increased significantly over the years. In case of the Alipather lake catchment area has morainic deposits and is devoid of any vegetal cover. There are no human settlements close to the lake and the surroundings are undisturbed. Important morphometric features of the lakes are set out in Table 1.

Climate of the Lake region

The Mansar and the Surinsar lakes are situated in the sub-tropical monsoonic region. The annual rainfall in the area is around 1500 mm, received mainly from July to September. Winter is usually dry and the atmospheric temperature remains well above the freezing point. During summer air temperature varies between 35 and 37°C. The lakes of Kashmir Valley experience a climate with features common with the sub-mediterranean conditions. The annual rainfall is about 750 mm. The rainy period spreads over winter and spring months (Jan-April). Summers are usually dry with mean atmospheric temperature ranging from 28 to 30°C. In winter the air temperature falls below 0°C resulting in occasional freezing of surface water. The high altitude Kashmir Himalayan lakes experience temperate climate. The mean winter temperature remains well below the freezing point. The lake water has thick ice-cover which lasts for about 7-8 months. The ice-free period usually starts from June. In case of the Nilnag lake growing period is from April to November and in case of the Alipather lake from June to October.

Water transparency and thermal structures (Table 2)

The waters of the majority of lakes under investigation are turbid. The maximum Secchi transparency, 5.5 m, has been recorded for Manasbal lake and the lowest value, 0.25 m, was obtained for the Trigam and the Anchar lakes (Table 2). In Nilnag and Alipather lake water transparency is reduced considerably as a result of extraneous matter, particularly silt. In case of Alipather lake silt is of glacial origin. In Trigam lake the light penetration is reduced because of a high planktonic population and in Anchar lake due to the silt from the Sind river. The lakes remain thermally stratified from April to October. The presence of a thermocline, however, is not distinct in all cases. Surinsar and Mansar lakes are warm monomictic. The thermocline is present between 3 and 9 m depth. The lakes circulate in winter. The Manasbal is the only example from the valley lakes of warm monomictic type, resembling the Siwalik lakes in its thermal behaviour. The thermocline is distinct during stratification and lies between 5 and 9 m. Isothermic condition starts from November and lasts till February. Anchar lake exhibits differences in the thermal behaviour within the same basin. The part close to the inflow channel has a high temperature difference between surface and bottom water. However, in the central part of the lake weak stratification develops resulting in a difference of 3°C between surface and bottom water. No thermocline develops. Naranbagh lake also develops weak

Table 1. Selected morphometric features of the lakes.

Lake	I	II	III	IV	V	VI	VII	VIII	IX
Altitude (m)	604	666	1584	1584	1584	1584	1584	2180	3200
Area (ha)	29	45	1250	700	24.3	280	11	6.3	8
Max. depth (m)	26	50	6	2.75	5	12	2.25	6.5	6.5

I. Surinsar II. Mansar III. Dal IV. Anchar V. Naranbagh VI. Manasbal VII. Trigam VIII. Nilnag IX. Alipather (This numbering is followed in the other tables also.)

summer stratification. Dal lake with its many basins does not conform to any single type of thermal stratification. The deeper Nagin basin develops a summer stratification which is very close to that of the monomictic type. The shallow basins of Gagribal and Bod dal develop weak thermal stratification that is short lived. The thermal conditions of the Hazratbal basin are influenced by the inflow water resulting in cold layer of deep water. Trigam lake depicts the pond type of thermal stratification which is characterised by rapid fall of temperature just below the surface water. The high altitude Nilnag and Alipather lakes are dimictic (Hutchinson & Löffler, 1956).

Chemical features of the Lake Waters

The pH of Alipather lake is close to neutral but in other lakes it ranges widely, with high values in the summer months. The lake waters in general are alkaline. The dissolved oxygen concentration of the epilimnion varies seasonally. In case of the high altitude Alipather lake D.O. concentration is usually not very high in summer. Anchar lake has a very high concentration of epilimnic D.O. during summer as a result of vigorous photosynthesis. In many lakes the hypolimnion is anoxic during summer stratification, e.g., in Surinsar, Mansar, Manasbal and Nilnag. The specific conductivity of the lakes varies widely; in Alipather lake it is very low and in Trigam lake very high. The water of other lakes has conductivity values below 400 $\mu S\ cm^{-2}$. Alkalinity values follow almost the same pattern as conductivity.

The average total ionic composition of the lakes indicates that they are of medium hard water types with divalent cations dominating over the monovalents ones (Fig. 2). Calcium is the most dominant cation in the lakes followed by magnesium. The Ca: Mg ratio is quite high. The equivalency order of the cations is:

$$Ca > Mg > Na > K$$

But this sequence, in case of Trigam lake, is different as sodium is dominant over calcium. But the concentration of cations is of the same order as in other lakes. Among the anions, bicarbonate and carbonate dominate over sulphate and chloride. Their order of equivalency is:

$$HCO_3 > Cl > SO_4$$

The concentrations of phosphorus and nitrogen in Alipather lake are very low, in Trigam lake both are high and in the other lakes they are in moderate concentrations. In general, the silicates values in the lakes are low. Total phosphorus concentrations, reported only for the six lakes, show wide seasonal fluctuations (Fig. 3). Some of the lakes exhibit chemical stratification during summer. The hypolimnion in their case has comparatively high conductivity, and values of alkalinity, cations, P and N are also high. The sediments in the Surinsar, Mansar, Manasbal and Nilnag lakes have reduced oxygen concentration till the autumnal circulation.

Biological features of the lakes

A narrow belt of macrophytic vegetation is present along the banks of Surinsar and Mansar lakes. The littoral area in these lakes is much smaller than that of the pelagic zone. The common macrophytes species recorded from the lakes

Table 2. Water transparency and thermal features of lakes.

Lake		I	II	III	IV	V	VI	VII	VIII	IX
Secchi	(m)	1.6–2.7	2–5	.4–5	.25–1.75	1.2–4	2.5–5.5	.2–.6	1.1–2.3	1.2–1.9
Max. temp. surface water	(°C)	31	30	30	28	29	29	30	25	15
Stratification type*		WM	WM	WM–PM	WM–PM	WM–PM	WM	P	D	D
Thermocline depth	(m)	5–9	6–9	ND	ND	ND	5–9	ND	2–4	2–4

*WM: Warm monomictic PM: Polymictic D: Dimictic P: Pond type ND: Not distinct.

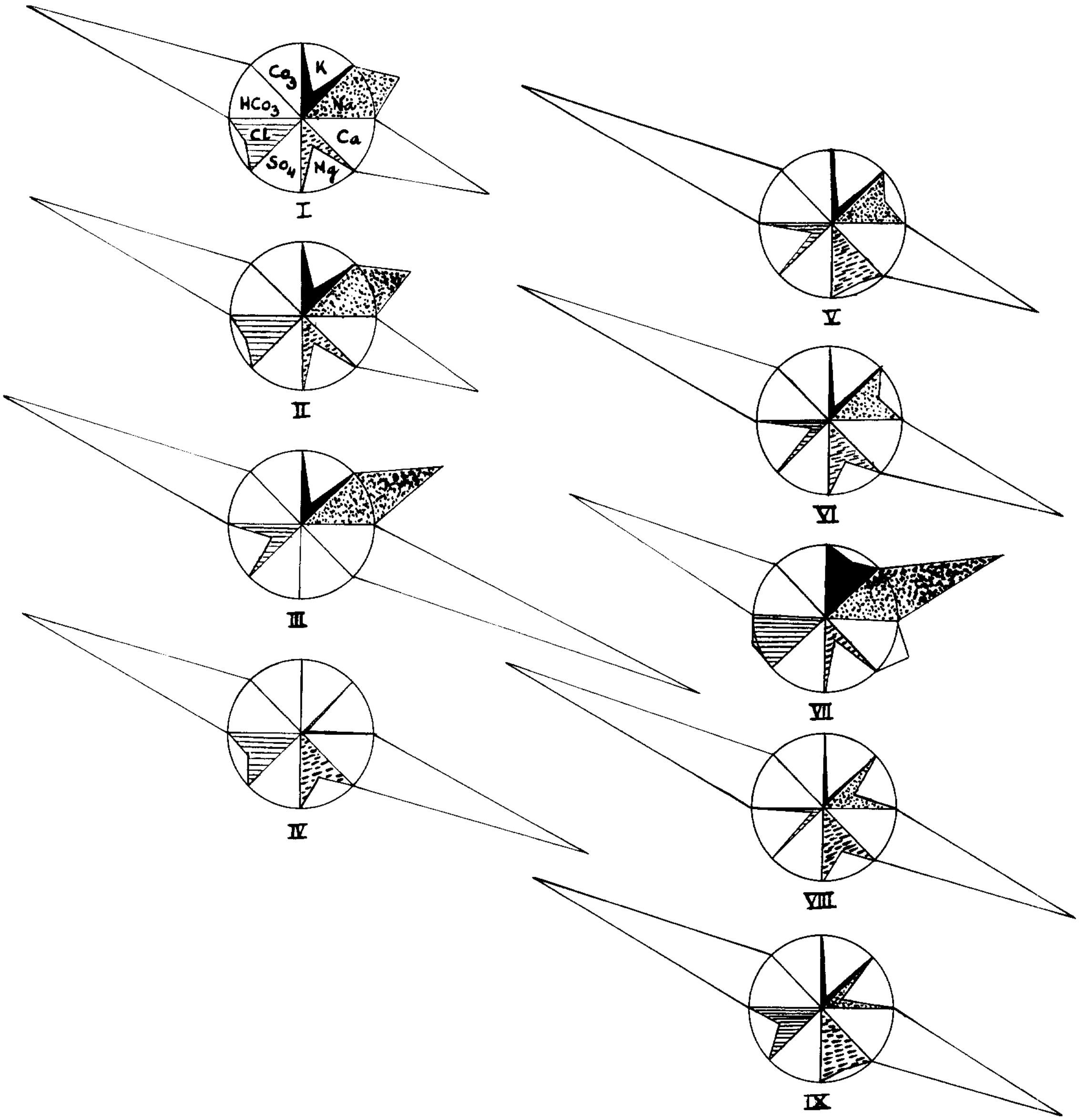

Fig. 2. The Chemical spectrum of the lakes.

are listed in Table 3. Species belonging to Charophyta are very common in the shallow areas of Mansar lake. In Surinsar lake emergents, *viz. Typha angustifolia* and *Phragmites communis* constitute the main macrophytic population colonising the silted regions in the eastern part. In these lakes both the macrophyte growth (vegetative parts) and flowering occur before the onset of monsoon. In winter only a few submersed forms are present.

The lakes of the Kashmir valley support a rich and varied macrophytic vegetation. Zutshi (1975) recorded a number of aquatic associations which are new for the region and Zutshi & Vass (1973) defined the environmental factors determining the ecology and growth patterns of the dominant species. In Dal lake, *Myriophyllum spicatum* and *Ceratophyllum demersum* are the most common submersed forms, reaching their maximum coverage and development during July-August. *Myriophyllum spicatum* is also dominant in Naranbagh lake. However, in Manasbal lake *Ceratophyllum demersum* is the most dominant form, developing monospecific meadows in the lake during

August-September. The other species of lesser importance are *Myriophyllum spicatum* and *Potamogeton filiformis.* Trigam lake supports rich growth of emergents, namely, *Typha* and *Phragmites.* The main floating forms are *Nymphoides peltatum* and *Potamogeton natans.* In Anchar lake submerged forms are not well represented. Only *Myriophyllum spicatum* and *P. crispus* are frequent in some areas. Silted regions mainly support *P. natans* and *Nymphoides peltatum.* The waters of Nilnag lake are colonized by floating forms, e.g., *Polygonum amphibium, Nymphoides peltatum* and *Trapa natans* (Table 3). The macrophytes achieve the maximum growth and development in summer. Alipather lake is devoid of any macrophytic vegetation due to unfavourable environment.

The common phytoplankton species recorded from the lakes are listed in Table 4. In Mansar lake the algal species mainly belong to Cyanophyta, Chlorophyta and Chrysophyta. In winter months (Dec.-Feb.) Chrysophyta and Chlorophyta are the dominant groups but the Cyanophycean forms become quite abundant during the spring-summer period. In Surinsar lake the phytoplankton populations belong to Chlorophyta, Chrysophyta and Pyrrophyta. Chlorophyta contribute a maximum number of species in winter and Chrysophycean forms are very abundant during spring and summer. Species belonging to Chlorophyta, Chrysophyta, and Cyanophyta are quite common in Dal lake but the seasonal patterns are not distinct. However, the dominant populations of the various basins of the lake vary. Chlorophycean forms are very frequent in the Gagribal and Bod dal basins, while Cyanophyta predominate in the Boulevard part. The order in which the various algal classes of Naranbagh lake dominate is Chlorophyta, Chrysophyta and Cyanophyta. The maximum population density is achieved between June and August. In Manasbal lake Chrysophyta, Chlorophyta and Cyanophyta constitute the main phytoplankton throughout the year. Both the maximum number of forms and their numerical abundance are recorded during summer. Cyanophyta is the dominant algal group in Trigam lake with its peak numerical values in summer. Chlorophyta have two peaks, i.e., in May and October, and diatoms are numerically high during early summer. The phytoplankton of Nilnag lake has a summer peak constituted by Chrysophyta, Chlorophyta and Cyanophyta. In Alipather lake only a few forms of algae have been recorded and data on seasonal behaviour of the popula-

Table 3. Distribution of common macrophytes.

	Lakes								
Species	I	II	III	IV	V	VI	VII	VIII	IX
Ceratophyllum demersum	p	p	d	p	d	d	p	p	
Chara sp.	p	p	p	p					
Hydrilla verticillata	p	p	p	p	p	p		p	
Marsilea quadrifolia			p	p				p	
Myriophyllum spicatum	p		d	p	d	p		p	
Nelumbo nucifera var. *alba*	p	p							
N. nucifera var. *rubra*			p	p	p	p			
Nitella hyalina		p	p	p					
Nymphaea alba			p	p	p				
Nymphaea sp.	p	p							
Nymphoides cristatum	p	p							
N. peltatum			p	d	p	p	p	d	
Phragmites communis	p	p	p	p	p		p	p	
Potamogeton crispus	p	p	p	d	p	p		p	
P. filiformis			p	p	p	p			
P. lucens		p	p	p	d	p		p	
P. natans			p	d	p	p	p	p	
P. nodosus			p	p	p			p	
Polygonum amphibium			p	p		p		d	
Trapa natans			p	p	p	p	p	d	
Typha angustifolia	p		p	p	p		p	p	
Vallisneria spiralis	p	p							

p = present d = dominant

Table 4. Distribution of phytoplankton species.

Species	Lakes I	II	III	IV	V	VI	VII	VIII	IX
CHRYSOPHYTA:									
Achnanthes sp.	+	+	++	++		++		+++	
Cocconeis placentula	+	+	+	+++				+	+
Cymbella prostata			+	+	+		+	+	
C. ventricosa	+	+	++	++	++	++		+	+++
Diatoma elongatum	+	+	+	++	+	+	++	+	+++
Fragilaria crotonensis	+++	+++	++	+++	+++	+++	++	+++	+++
Gomphonema montanum			+	++	++	+	++	+	
Gomphonema sp.	+	+	++	++		++		+	+
Melosira sp.	+	+	+	++	+	+		+	
Navicula confervacea			+	+		+			
N. radiosa	+		++	+++	++	+++			
Navicula sp.	++		+		+	+	++	+	+
Nitzschia accicularis	+++	+++	+	+++	+	+++	+	+	+
Synedra ulna	+++	+	++	++	++	++	++	+	++
Dinobryon sp.			++		++	++	++	+++	
CHLOROPHYTA:									
Ankistrodesmus spiralis	+		+	+	+	+	+	+	++
Cosmarium minimum		+++	++	+	+	+		+	
Cosmarium sp.	+++	+	+	++	+	+	+++	+	+
Crucigenia crucifera	+		+			+	+	+	
C. tetrapedia	+	+			+	+	+	+	
Euglena sp.	+		+++	+++		+		++	
Micrasterias radiata			+	+			+		
Pediastrum duplex			++	+		+	++		+
P. simplex	+		++	++		+			+
P. tetras		+	+		+	+			
Phacus sp.			+++	+		+		++	
Scenedesmus bijuga			+	++	+	++		+	
Sphaerocystis schroeteri			+		+	+	+		
Staurastrum sp.	+++	+++	+	+	+++	+	+++	+	+
Staurodesmus cuspidatus			+			+			
Tetradron minimum	+	+	+	+	+	+	+	+	
CYANOPHYTA:									
Dactylococcopsis sp.			+			+			
Merismopedia elegans	+++	+++	+++	++	++	+++		+	+
M. glauca			+	+	+				
M. punctata		++	+		+	+	+	+	
Microcystis aeruginosa	+		+++		+	+++	+++		
Oscillatoria sp.	+	+	++	++	+	+++	+	+	+
PYRROPHYTA:									
Ceratium hirundinella			+		+++	+	++		
Peridinium sp.	+++	+++	++		++	+		+++	+

0–250 individuals/litre = +
251–500 individuals/litre = ++
500-above = +++

tions are not available.

The common zooplankton species of the lakes under investigation are summarized in Table 5. Rotifers and copepods are the main zooplankters in Mansar lake, abundant, respectively, during winter and summer. But in Surinsar lake rotifers dominate throughout the year. Rotifers are quite abundant in Dal lake but copepods and cladocerans remain low. In Naranbagh lake rotifers have two peaks, respectively, in April and October. The populations of copepods and cladocerans remain low throughout the year. The zooplankton of Trigam lake is represented by rotifers, copepods and cladocerans. The peaks of rotifers and copepods occur in spring and autumn and that of cladocera in summer. In Nilnag lake the zooplankton is dominated by rotifers and in Alipather lake a pigmented copepod (*Acanthodiaptomus* sp.) predominates during the ice free period.

The phytoplankton production and the trophic status of the lakes are presented in Fig. 4. Trigam lake has the highest daily production as well as high mean values,

Table 5. Distribution of zooplankton species.

Species	Lakes								
	I	II	III	IV	V	VI	VII	VIII	IX
ROTIFERA									
Ascomorpha eucaudis			+						
Asplanchna sp.	+		+	+	+	++	+		+
Brachionus angularis				+		+	+++	+	
B. quadridentata				+				+	
B. rubens						+	+	+	
Filinia longiseta					++	+	+++	+	
Hexarthra major							+	+	
Keratella cochlearis	+	+	++	++	++	++	+++	+++	
K. quadrata	+					+	++	+	
K. tropica	+	+					+	+	
Lecane sp.			+	++		+	+		
Monostyla sp.			+	+		+			+
Polyarthra major			+	+	+	++	+	+	
Polyarthra sp.			+	+		+			+
P. vulgaris			+						
Trichocerca similis			+	++		+	+		+
CLADOCERA									
Bosmina longirostris			+	+	+	++			
Ceriodaphnia pulchella	+					+		+	
C. quadrangula	+	+			+			+	
Chydorus sphaericus	+		+	+	+		++	+	+
Daphnia pulex		+				+			+
D. longispina	+	+							
D. magna	+								
COPEPODA									
Acanthodiaptomus sp.									+
Acanthodiaptomus denticornis				+	+	+		+	
Cyclops ladakanus						+	+	+	
Cyclops sp.			+	+		+		+	
C. vicinus	+		+		+		+	+	
Diaptomus sp.		+				+			+
Mesocyclops leukarti	++	+	+		+	+	+	+	+
M. varicans			+	+	+				
Thermocyclops crassus	+	+	+		+	+	+	+	

0–250 individuals/litre = +
251–500 individuals/litre = ++
500–above = +++

followed by Surinsar lake. The other lakes almost fall within the same average values. In case of Alipather lake, due to limited production data, no mean values have been calculated. The lakes have been categorized under various trophic levels on the basis of their phytoplankton production values.

Discussion

The Kashmir Himalayan lakes cover a wide range of altitudes and are exposed to climatic conditions varying from sub-tropical to temperate. Consequently, limnological variability is significant.

The lakes differ appreciably in their morphological features. The ratio between the largest and the smallest lake is about 1000 : 1. The mean transparency values of the lakes are low throughout the year. Kant & Anand (1968) reported high turbidity in Mansar lake during moonsoon rains. In the valley lakes low Secchi values are due to the suspended particles carried with the inflow from the catchment area, particularly, during the rainy period, and in the high altitude mountain lakes low values are due to the presence of glacial silt in the water. Löffer (1969) also reported the presence of large quantities of morainic material in the Mt. Everest lakes resulting in low transparency values. But Rodhe *et al.* (1966) recorded high Secchi transparency in the mountain Lakes of Europe. According to Hickel (1973) the Secchi transparency in the Pokhara valley lakes of Nepal is related to the density of plankton population. Yoshimura & Pechlaner (1971) have used water transparency as an index of eutrophication in lakes. In the present investigation no such relationship could be established.

The lakes which are deep and found at low altitude, viz., Mansar and Surinsar, develop stable summer stratification with the presence of a distinct metalimnion. They are subtropical monomictic and resemble the lakes of Pokhara valley, Nepal (Hickel, 1973). But in the shallow lakes stratification is unstable and a thermocline indistinct. Kaul (1977) reported unstable stratification for the shallow Kashmir valley lakes and Kaul *et al.* (1978) classified Dal and Anchar lakes as warm monomictic, without detecting any stable thermocline. According to Crumrine & Beeton (1965), for developing summer stratification, the depth of lakes should exceed 8 m and they should be well protected. Our observations support this view. The lakes investigated are either warm monomictic, dimictic or develop unstable thermal stratification. In this part of the Himalayas 2000 m altitude seems to be the dividing line between the monomictic and dimictic lakes.

The changes in the dissolved oxygen content of the water column of a lake may be of great limnological significance. It is one of the most reliable parameters in assessing the trophic status and the magnitude of eutrophication in an aquatic ecosystem (Edmondson, 1966; Bazin & Saunders, 1971). Data on the hypolimnion oxygen concentration in the period preceding the present study are not available; it is, therefore, difficult to evaluate the eutrophication trends in these lakes on the basis of this parameter. However, the presence of a near-anoxic hypolimnic zone during summer stratification in some lakes indicates enrichment with organic matter. The hypolimnic oxygen utilization results from decompositional consumption of materials both of allochthonous and autochthonous origin. These materials settle in the hypolimnion, resulting in an oxygen deficit (Jones & Bachman, 1974).

The content of electrolytes in lake water decreases with the increase in altitude. The specific conductivity is high in non-drainage valley lakes and low in the mountain lakes. The extent of variation is more than 30 : 1. Löffler (1969) and Hickel (1973) reported low electrolytic content in the waters of Mt. Everest and Nepal lakes. According to Crumrine & Beeton (1975) lakes of highest conductivity also have greater inputs of ground water and lakes with conductivity similar to that of precipitation receive virtually no ground water input. Many workers (Juday & Birge, 1933; Vollenweider & Frei, 1953) related increase in electric conductivity to the state of enrichment. Applying this criterion to Kashmir lakes, it is observed that the lakes at lower altitudes are at a higher level of enrichment than those at higher altitudes. The alkalinity in Kashmir lakes is mainly of the bicarbonate type and shows similar relationship with altitude as conductivity. Freiser & Fernando (1966) state that when total alkalinity is high the bicarbonate system prevails and pH is usually on the alkaline side. This is true far the valley lakes of Kashmir.

The most dominant cation in the lakes of Kashmir Himalayas is calcium, the only exception being Trigam lake, where it is replaced by sodium. This may be due to the drainage pattern and the extent of pollution of this lake. Kaul *et al.* (1978) reported that the magnesium (9 mg/l) content is higher than the calcium (2.2 mg/l) in Mansar lake. This is in contrast with the observations of Zutshi & Khan (1977), who recorded a ratio of 4 : 1 between calcium and magnesium. This is quite close to the ratios recorded for other valley lakes (cf. Zutshi & Vass, 1973; Zutshi & Khan, 1978 and Zutshi *et al.*, 1972). On the basis of their water chemistry, Kashmir lakes could be separated into three groups: lakes of high fertility (Trigam, Surinsar and Anchar), medium fertility (Mansar, Dal, Manasbal, Naranbagh and Nilnagh) and of low fertility (Alipather). This categorization is further supported by the levels of phosphorus and nitrogen in these lakes (Fig. 3).

The macrophytic vegetation of the lakes does not show any definite relationship with altitude. Generally, the lakes with higher transparency develop high density of submersed forms and where water is turbid floating forms dominate. This is noted when the macrophytes of Anchar lake and Dal lake (Table 3.) are compared. This observation is in agreement with that of Zutshi (1975). The excessive growth of *Ceratophyllum demersum* in the Nagin basin of Dal lake and Manasbal lake may be due to cultural eutrophication. Goulder & Boatman (1971) opine that *Ceratophyllum* sp. requires a high inorganic nitrogen level in the medium. This may explain the nuisance level reached by this plant in lakes receiving effluents from domestic and agricultural lands. The presence of Charales along the banks of Manasbal lake may indicate low fertility of its water (cf. Forsberg, 1965).

Kaul (1977) reported very high macrophytic production in the three valley lakes (Dal, Anchar and Manasbal) of Kashmir. This may indicate their high fertility level. But this observation is not in agreement with that of Kaul *et al.* (1972), i.e., these ecosystem are moderately fertile. The

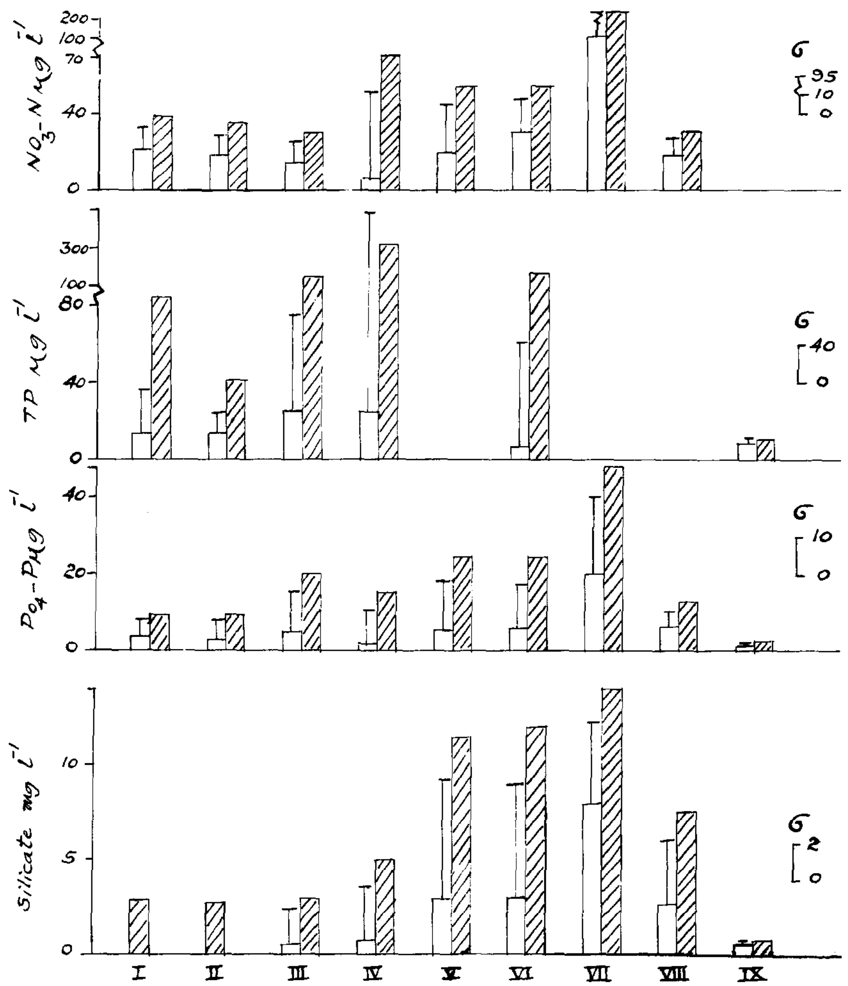

Fig. 3. The minimum and maximum concentration of some important chemical parameters of the lakes. The stripped histrograms depict maximum values and standard deviation has been shown on non-stripped histrograms.

present study supports the latter view.

There is enough evidence in literature to show that the differences in the dominant phytoplankton assemblages of the lakes reflect differences in their trophic levels. Prescott (1939) reported higher population of desmids in oligotrophic lakes, and Rawson (1956) related Chlorophyceae with clear lakes. According to Mitchell & Marshall (1974) dominance of blue-green algae is typical of many eutrophic lakes of Rhodesia. In the present study dominant algal assemblages also show close relationship with the levels of lake fertility. The enriched Trigam lake has Cyanophyceae as its main algal population. But in the less fertile lakes, e.g., Manasbal and Naranbagh diatoms and Chlorophyceae constitute the main population. In Dal lake, the part adjacent to the inhabited area, supports a rich population of Cyanophyceae and the open water is rich in diatoms. The high altitude Alipather lake has a Chlorophyceae and diatom population during the ice-free period. The zooplankton population of the lakes is dominated by rotifers followed by copepods and cladocerans. The dominant groups depict seasonal variation in their numerical density. Nordlie (1976) reported predominance of rotifers in some Florida lakes with reciprocal patterns for rotifers and cladocerans.

The phytoplankton production and the trophic status of the lakes under investigation is set out in Fig. 4. The production values and chemical and biological parmeters of the lakes support this trophic classification. From the present study it is, therefore concluded that the only lake that has reached higher level of eutrophication is Trigam. The two lakes, classified as meso-eutrophic, are under rapid evolution and five are mesotrophic. Only one lake has been classified as oligotrophic. The eutrophication of the Kashmir Himalayan lakes is due to the increased human pressure in their drainage basins.

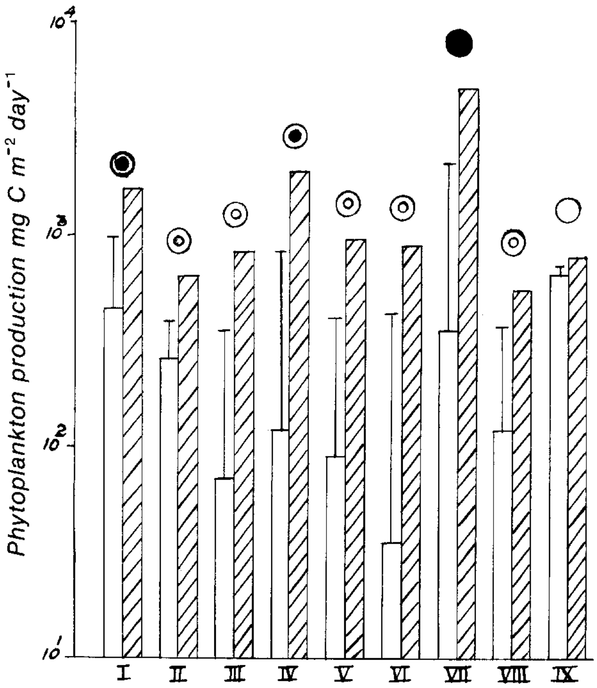

Fig. 4. The minimum and maximum phytoplankton production values of the lakes. The maximum values are represented by stripped histrograms and the mean values are given on non-stripped histrograms. ● represents eutrophic lake, ◉ meso-eutrophic, ◎ mestrophic, and ○ oligotrophic.

Summary

Nine lakes with their altitudes ranging from 604 to 3200 m in the Kashmir Himalayas were investigated for their physico-chemical and biological features. The lower Siwalik lakes are sub-tropical monomictic, the Kashmir valley lakes (alt. 1584 m) are either monomictic or develop unstable thermal stratification. The lakes situated above 2000 m altitude are dimictic. Some of the lakes develop hypolimnic anoxic condition during summer stratification. The electrical conductivity of high mountain lakes is very low as compared to other lakes. The average total ionic composition of the lakes indicates that they are of medium hard-water type with divalent cations dominating over monovalent ones. The order of the cation is Ca > Mg > Na > K and that of anions HCO_3 > Cl > SO_4. The macrophytic vegetation is present in eight lakes and is absent in Alipather lake. In one of the Siwalik lakes (Mansar) Charales are quite dominant. In Kashmir valley lakes *Ceratophyllum demersum* is the most dominant macrophyte - an indication of eutrophication. Diatoms constitute the main phytoplankton population and rotifers are dominant in the zooplankton. The lakes are classified into various levels of trophy based on phytoplankton production and limnological features.

Acknowledgement

The authors would like to express their sincere thanks to Peerzada Ali Mohammad, Principal, S. P. College, Srinagar, for providing laboratory facilities and for his interest in this work. Thanks are also due to the Council of Scientific & Industrial Research, New Delhi, and the University

Grants Commission for providing financial assistance. Miss Rajni Raina and Miss Nirja Vishin helped us in various ways during the preparation of this paper. The counting of the C-14 filters was carried out at the Italian Institute of Hydrobiology, Pallanza for which one of us (D.P.Z.) is grateful to the Director of the Institute.

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