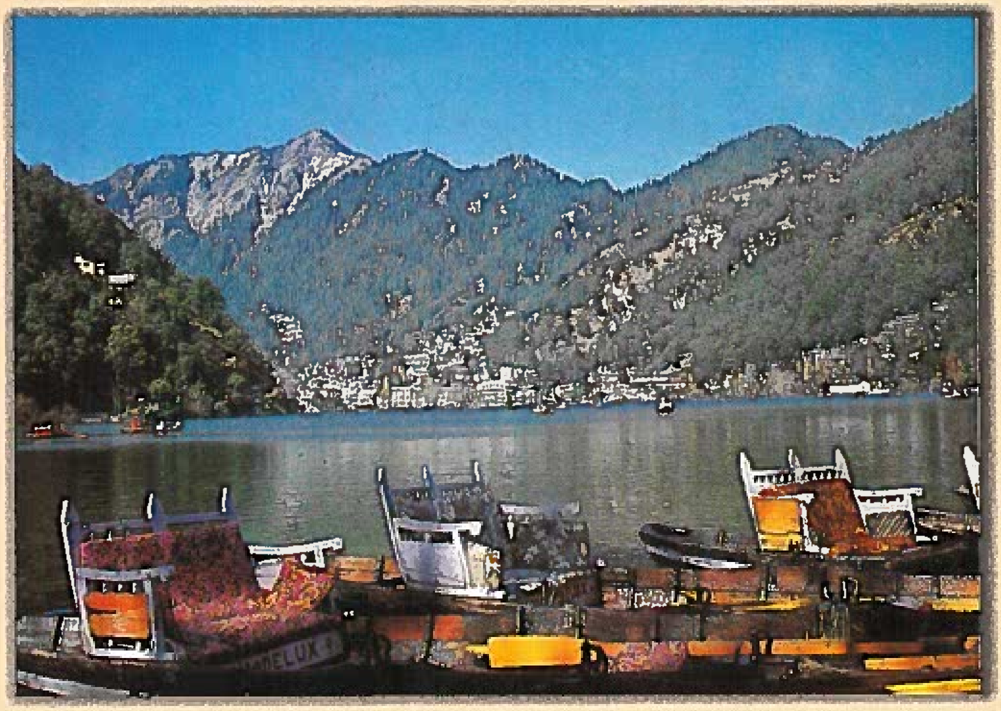
FISHERY RESTORATION IN NAINITAL LAKE



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राष्ट्रीय शीतजल मात्स्यिकी अनुसंधान केन्द्र

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FOREWORD

The world is on the threshold of what could be a new era of ecological awareness and environmental activism. A new synthesis has evolved during the past decade that has rekindled the interest of the world in issues related to the enviornment. The exploitation of natural resources, if not ecologically sound, could have adverse impacts on human ecosystems and welfare. Inversely, the pathologic growth of human ecosystems could lead to the deterioration of natural ecosystems. In this context water is a vital resource, which makes possible the survival of living things. The availability of water often determines the rate of economic development and also sets its limits. The rivers, lakes, man-made reservoirs, underground aquifers and wetlands constitute the inland water resources that are essential for agriculture, industry, settlement and energy production. Increasing demand for water for human activities has in recent years exerted tremendous pressure resulting in the deterioration of both the quality and quantity of available freshwater resources. The onslaught of this kind faced by aquatic ecosystems in hills has been very significant, that being more in systems having a direct linkage with tourism. In this context, the case of famous Nainital Lake is important.

The lake located in the beautiful town of Nainital attracts lakhs of tourists annually and is very vital for the economic benefit of people of this famous town. Therefore, it is very important that the lake and its biodiversity are protected and conserved for posterity. In order to develop any management action plan, detailed information about the system, its production functions and fishery should be generated. Several workers in the past have generated information on various facets of Nainital Lake that is documented. However, the scientists of the National Research Centre on Coldwater Fisheries located at Bhimtal have investigated this lake in detail with main focus on fishery, which has not been addressed before.

This valuable document "Fishery Restoration in Nainital Lake" summarizes the research work carried out by the scientists and other staff of NRCCWF, covering all aspects of lake ecology, its biodiversity, production function, fishery status and its restoration. The coverage of this publication is ample testimony to untiring efforts of NRCCWF staff. This bulletin will go a long way in executing an action plan for fishery restoration and enhancement in this [illegible]

PREFACE

Nainital lake is considered as the main attraction of this famous town of same name in the state of Uttaranchal. This lake has its important in the socio-economic and cultural life of the people in the region. It is one of the largest natural freshwater lakes in the Kumaon region of the state. A large population lving around the lake depends directly or indirectly upon the lake for their economic sustenance. The lake is rich in biodiversity but currently is under focus *vis-a-vis* its restoration. The onsite benefits of the lake are primarily tourism, boating and supply of potable water to the town. The biological resources of the lake especially fish is not harvested or angled. This total biomass of biotic communities contributes to the autochthonous enrichment of the system, coupled with the allochothonus nutrient loading and higher water retention period have resulted in rapid eutrophication of the system. It is observed that all these processes have deteriorated the water quality and overall health of this famous lake.

In this context restoration of this lake assumes importance. The aim of every ecological restoration action plan is to be re-establish a functional ecosystem, which matures through natural processes over longer period of time. For any such management plan, restoration of all trophic levels is imperative, in which fish assumes importance, both for food and nutrition security. Such a planning process to succeed should have detailed information on different production functions of the system. The existing information on the lake is scattered and diffused while data sets on fishery are totally lacking. Therefore, in the present document, fishery of the lake has been given a main focus both in terms of its potential and enhancement strategies.

This document critically examines the secondary data available on the lake. But is also based on the recent investigations carried out by NRCCWF's scientists who have made significant contribution in the field of fishery limnology. However, some lacunae/omissions in the document with regard to data and its interpretation may have crept in despite our best efforts to examine it critically. We shall be grateful to our readers to suggest improvements/changes to bring out this publication. We express our sincere thanks to all the authors/ organizations, cited as reference in the document, whose data sets after slight modification, have been used in this publication. Due to paucity of time, individual permission from each author(s) could not be obtained. We are thankful to all our colleagues at NRCCWF, Bhimtal, for their help in making this compilation possible.

K.K. Vass, H.S. Raina
& R.S. Haldar

UTTARANCHAL STATE

The Uttaranchal was constituted as 27th State of the Indian Republic on November 09,2000.The state is spread over a geographical area of 53,483 sq.km. in the altitudinal range from 198 m to 7,816 m above the sea level in the Central Himalayas. It is carved out of 13 Northern districts of the erstwhile hilly region of Uttar Pradesh state, is spread over between the Latitudes 28^0 47′ to 31^0 20′ N and Longitudes 77^0 35′ to 80^0 55′ E in the Central Himalayas. Out of its total geographical area of 53,483 sq.km. 88.9 % area is mountainous with population of 8.48 million as per latest census, while the length and breadth of the state is 320 km. and 250 km., respectively. The state comprises four longitudinal physiographic sub-divisions: Trans Himalayan domain; Great Himalayas; Lesser Himalayas and Tarai-Bhabar–Siwalik ranges. The highest mountain peak is the Nanda Devi (7,816 m asl) situated in the Trans Himalayan Zone. The southern Tarai belt (198 m asl) is located in the foot hill in the state. The region embraces a great geographical diversity stretching from "Tarai-Bhabar" and 'Doon' belt in the south to Trans Himalayan range in the north is between Siwalik, Lesser and Greater Himalayan ranges.

The State has two divisions Garhwal and Kumaon, the Garhwal has seven districts, while Kumaon has six . Kumaon region is blessed with scenic beauty and varied natural resources and is situated at the tri-junction of Nepal, Tibet and India. It constitutes a distinct geographical entity of great strategic significance and is spread over 23,000 sq.km area. The altitudinal range varies from 200 m to 7,436 m asl resulting in varying climates in different parts of Kumaon. It is hot and moist in sub-montane region below 400 m (21.0 to 40.0^{0}C at Tarai and Bhabar belts) and cold temperate in highlands, above 2,500 m (6.0 to 20.0^{0}C for higher ranges).

In the Nainital district of this division, among other natural resources there are number of natural freshwater lakes, which are very valuable resource for recreation and fisheries. The lakes *viz.* Nainital, Bhimtal, Naukuchiatal, Khurpatal, Sattal, Garurtal situated at an altitude range of 1290 to 1937 m asl fall within a 25 km radius of the town Nainital. These lakes have varied uses from tourism.

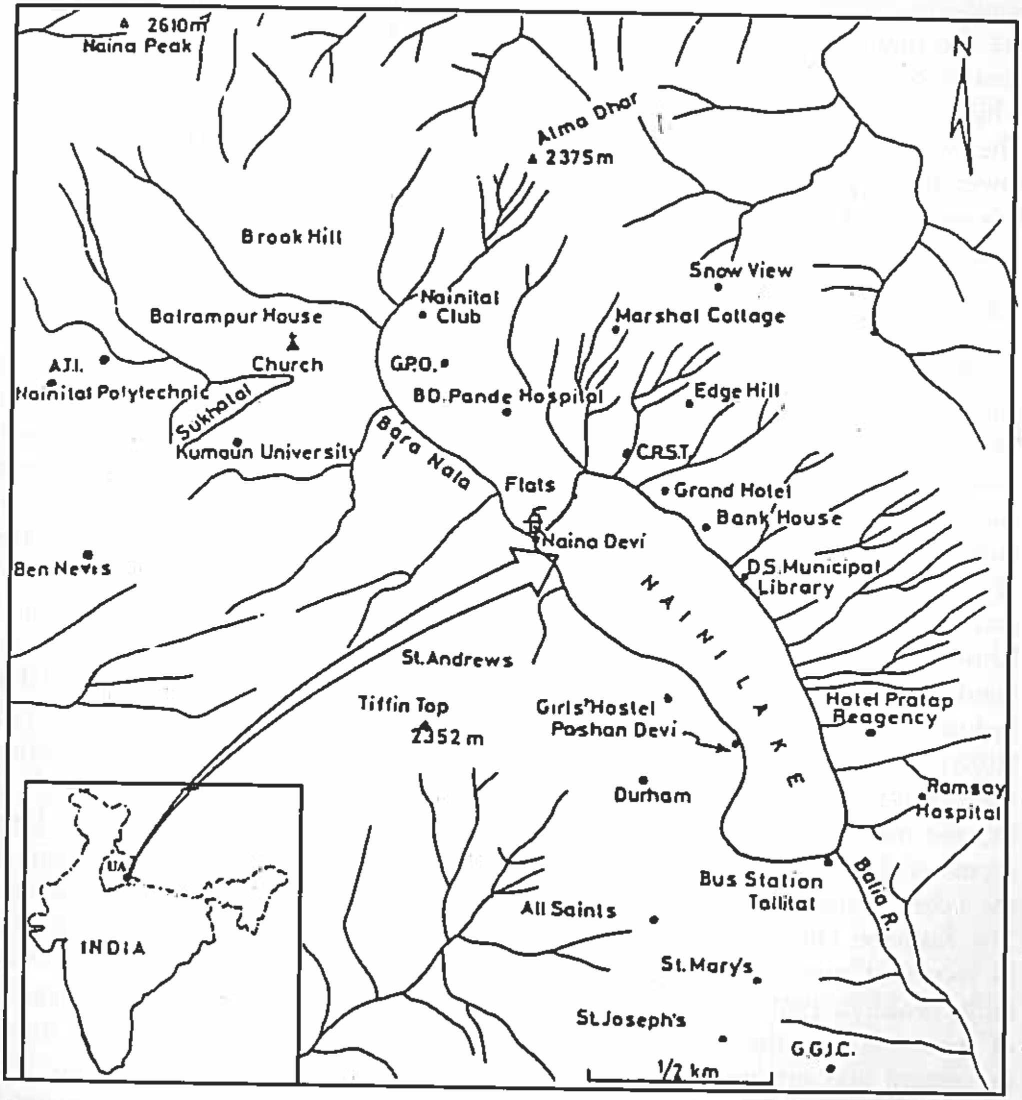
1. THE LAKE NAINITAL

1.1 Introduction

Nainital town is generously endowed with transcendental beauty, which is unveiled in its sylvan landscape with lofty snow-capped peaks, green valleys. The town is divided into two segments, Tallital and Mallital. In the heart of the two lies the beautiful, crescent – shaped Lake also named after the town. The North Mall running along one side of the lake, and the south Mall along the other, connect the two parts. On the shores of the lake, at Mallital stands the beautiful temple of Naina Devi, after whom the town has been named. Despite its dying beauty, and pollution, Nainital is still regarded as the queen of hill stations. The lake located in the heart of town Nainital has been the attraction for tourists since British times. Through time scale it has been impacted by anthropogenic changes. In the present write up an attempt has been made to assess the current status in retrospective and some restoration measures are suggested.

1.2 Geology

The Nainital Lake is characterized by Krol and Tal formations of Upper Mussoorie Group (Valdiya, 1981). The available literature suggests that the lake basin comprises shales/slates, dolomitic sandstones, purple sand stones, quartzite and dolerite (Raina and Dungrakoti, 1975). As per Nachiappan *et al.*, (2000) a regional fault, called Lake fault or Naini fault cuts the deformed synclinal massif into two parts. The Nainital basin is reported to be structurally and stratigraphically a complex area, but essentially consists of carbonate and shale formations (Pant *et al.*, 1985). Shales are the least productive rocks and carbonate rocks vary widely in their water yielding capacity. This condition is reported to lead to development of springs along the fault zone. The perennial Pardhadhara spring located in the Nainital basin, is probably a result of Naini fault that has brought the limestone of Middle Krol against the Manora shales of Lower Krol(Kumar *et al.*,1999). Similar to this, there may be several sub-surface springs emerging in Nainital lake along Naini fault. Domestic water supply to the Nainital town is met through pumping of groundwater from deep tube well [illegible]


2610m
Naina Peak
N
Alma Dhar
2375m
Brook Hill
Snow View
Nainital Club
Marshal Cottage
Balrampur House
Church
A.T.I.
G.P.O.
Nainital Polytechnic
Sukhatal
B.D. Pande Hospital
Edge Hill
Kumaun University
Bara Nala
C.R.S.T.
Flats
Grand Hotel
Bank House
Naina Devi
Ben Nevis
D.S. Municipal Library
NAINI LAKE
St. Andrews
Tiffin Top
2352 m
Girls' Hostel
Pashan Devi
Hotel Pratap Regency
Ramsay Hospital
Durham
UA
INDIA
Bus Station Tallital
Balia R.
All Saints
St. Mary's
St. Joseph's
G.G.I.C.
1/2 km

1.3 Climatic conditions

The climate of the area briefly is characterized by long cold winters with snow, rain, hailstorms as the chief precipitation and short summers. During southwest monsoon, the cyclones with heavy rainfall and the local thunderstorms are the main source of precipitation in Nainital region of Kumaon Himalayas. Nearly 80% of the total precipitation is attributed to the southwest monsoon, while 15% is from cyclones and remaining local disturbances from time to time. The winter precipitation, associated with cyclones, is in the form of rainfall at lower reaches and snowfall on higher elevations. The summer precipitation in this region is usually associated with local thunderstorms caused by atmospheric instability owing to mild diurnal temperature variations.

1.4 Origin of Lake

Kumaon region is known not only for the present day lakes but also for palaeolakes. Recent studies (Kotila *et al.*, 1997, 1998; Kotila and Phartiyal 1999; Phatriyal 1999) indicated that several palaeolakes in the Kumaon Himalaya. According to these workers Nainital lake is considered to be a remnant of a former lake, covering an area from Khurpatal to Tallital. The central sector of the Kumaon Himalaya has many lakes. Different workers broadly group these into a number of basins e.g., Nainital-Sukhatal-Khurpatal basin; Bhimtal-Naukuchiatal basin and Sattal basin. The Nainital group of lakes includes Nainital, Sukhatal and Khurpatal, while the Bhimtal-Naukuchiatal group consists of the Bhimtal and Naukuchiatal lakes. Likewise, the Sattal group consists of a number of Sattal lakes including the Pannatal. However, according to Hukku *et al.*, (1974) and Valdiya, (1988), it is believed that the Nainital lake was the remnant loop of the meandering river, which flowed from the east through Khurpatal and vanished as a result of tectonic movement along the active Manora Thrust. The Sukhatal may have been a part of the Nainital lake at least around the time of its formation. The origin of the lakes around Nainital and Bhimtal has been a matter of considerable debate. The Kumaon Himalaya is characterized by a complex tectonic architecture related to recurrent movements on the active Main Boundary Thrust and related tear faults (Valdiya, 1981; 1988). The Nainital massif was uplifted *en bloc* as a consequence of movement on the Main Boundary Thrust (MBT), triggering extensive mass-movement and gravity gliding on over-steepended slopes. The Nainital lake and other lakes in this District is the product of likewise related neotectonic rotational

Table 1 (A). Meteorological data of Nainital (site Manora peak) for the period 1998-2000.
(Data received from State Observatory, Manora Peak, Nainital-Uttaranchal)

Month/Yr.	Temperature (°c)		Humidity (%)		Rainfall (m m)		Pressure (m/b)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
January, 1998	-1.0	18.0	8	100	2.5	7.5	807.5	816.5
February	4.0	17.5	19	98	2.5	7.5	808.5	816.0
March	3.0	20.0	7	100	2.0	20.5	806.5	817.0
April	11.0	27.5	12	100	3.0	30.0	800.0	816.5
May	10.0	30.0	13	100	2.9	65.0	809.0	815.0
June	16.0	31.5	16	98	1.0	127.0	806.5	814.0
July	17.0	26.5	60	98	1.0	111.5	805.5	812.0
August	13.5	25.0	63	97	2.0	147.0	807.0	813.0
September	13.0	26.0	46	100	1.0	45.0	809.0	816.0
October	11.5	25.0	15	98	1.5	90.0	809.0	816.5
November	8.0	21.5	7	98	1.0	10.5	811.5	817.5
December	3.0	19.0	7	98	—	—	810.5	817.5
January,1999	-3.0	18.0	17	100	2.0	14.0	807.0	815.5
February	2.0	21.5	7	98	—	—	811.0	818.0
March	8.0	25.0	5	98	—	1.0	806.0	815.0
April	14.0	31.0	13	76	—	—	809.0	815.0
May	8.0	30.0	18	100	0.5	62.5	806.0	814.0
June	10.0	28.0	27	97	1.0	67.5	806.0	812.0
July	14.0	24.0	56	98	1.0	157.0	805.0	812.0
August	10.0	25.0	50	99	3.0	61.0	804.0	811.5
September	14.0	23.5	60	100	0.5	76.0	808.5	815.5
October	8.0	26.0	19	95	2.5	36.5	810.5	816.5
November	7.0	24.0	22	97	—	—	811.0	816.0
December	0.0	19.0	12	100	3.5	13.0	809.5	815.5
January, 2000	1.5	17.0	17	100	1.5	15.5	806.5	814.0
February	-1.0	16.0	15	90	1.5	44.5	805.5	812.5
March	2.0	24.0	10	99	3.0	16.0	806.0	815.0
April	9.0	27.0	7	92	6.5	11.0	806.5	813.0
May	10.0	28.0	20	100	0.5	41.0	805.0	813.5
June	14.0	24.0	45	100	2.0	204.5	804.0	810.5
July	14.0	25.0	65	100	2.0	119.0	805.0	810.0

Table 1 (B). Meteorological data of Nainital (site Manora peak) for the period 2001-2002.
(Data received from State Observatory, Manora Peak, Nainital-Uttaranchal)

Month/Yr.	Temperature (°c)		Humidity (%)		Rainfall (m m)		Pressure (m/b)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
January, 2001	0.0	20.5	8	100	—	18.0	804.0	814.5
February	3.0	20.0	8	100	1.5	16.5	806.0	814.5
March	6.0	22.0	16	100	0.5	7.0	805.0	814.5
April	8.0	28.0	15	100	2.5	38.5	808.0	815.0
May	8.0	26.5	24	100	0.1	29.5	806.5	813.0
June	13.0	25.0	48	100	0.5	177.5	806.0	810.5
July	16.5	26.0	51	100	1.0	250.0	806.5	810.5
August	16.0	25.0	74	100	1.0	138.5	805.5	813.0
September	14.5	26.0	37	100	2.0	19.5	808.5	813.0
October	12.0	24.0	25	100	0.5	20.0	809.5	814.5
November	6.0	23.0	16	100	—	1.7	810.0	815.0
December	3.0	18.0	12	100	—	—	808.5	815.5
January, 2002	-1.0	16.5	12	100	2.0	35.0	806.0	815.0
February	-1.3	18.0	7	100	0.6	83.0	808.0	814.0
March	3.5	22.0	15	92	2.0	7.2	807.0	815.0
April	13.5	27.0	18	98	0.6	27.6	807.0	813.0
May	11.0	29.0	7	95	0.5	18.0	803.5	811.5
June	13.0	25.5	22	98	1.0	51.0	804.5	811.0
July	16.0	25.0	30	96	0.7	137.0	804.5	811.0
August	15.0	23.5	59	100	0.4	55.7	805.5	814.0
September	11.0	25.0	24	97	0.5	80.6	808.0	815.0
October	9.5	26.5	21	96	1.1	10.6	810.0	817.0
November	6.5	21.0	19	99	—	—	809.5	816.0
December	-1.0	18.0	7	100	4.5	22.3	805.0	817.0

1.5 Catchment and hydrology

The catchment area of Nainital basin is 4.7 km^{-2} out of which 49.6% is forest, 19.3% is barren, 20.5% is built land, 10.2% is water bodies (Kumar *et al.*,1999).The lake is bound, in the east by the Sher-ka-Danda hill, in the north by the landslide

The stability of these hills around Nainital lake are dependent upon the density of tree species which, is mainly predominant by *Quercus, Cedrus, Cupressuis, Rhododendron* besides a large population of shrubs and herbs. This flora not only add to its beauty on its surroundings but also protect them from the soil erosion, land slides by protecting their soil cover and increases water-holding capacity of the soil. With the result a large number of springs supply water to the lake throughout the year. From the land use data, it is reported that the urbanization and forestry are almost equal and account for about 80% of the total land area.

However, the southeast side is more level and is popularly known as 'Danth' (meaning a dam). Locally, the upper part of the lake is called 'Mallital' and the lower part towards the dam as 'Tallital'. Twenty two (22) seasonal and two (2) perennial open drains feed the lake (Fig. 2). Besides, some underground springs are believed to feed the lake throughout the year. To prevent excessive outflow of water during heavy monsoons, a dam has been constructed at the lower end of the lake. Excess water is discharged from the dam through a single outlet.

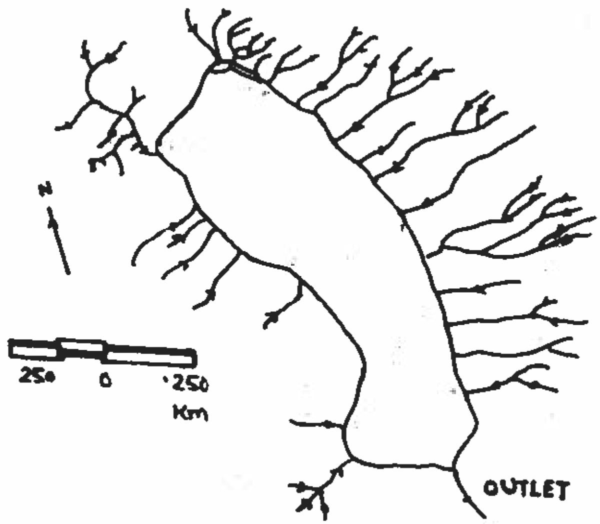


Fig. 2. Sketch map of Nainital lake indicating various drains around the lake

Nachiappan *et al.*, (2000) have extensively estimated the sub-surface components in the water balance of Nainital Lake by using stable isotopic technique and according to them the total inflow show that the sub-surface contributes 50% of the total annual inflow to the lake. The sub-surface outflow is about 55% of the total annual outflow from the lake, clearly indicating that the lake is a *'flow- through'* type, with substantial groundwater inflow and seepage. Hydrogeological investigations indicate that the shale formation, which occupies about 50% of the lake ...

any activity in Sukhatal lake may affect the Nainital lake. The Sukhatal sub-catchment of Nainital does not have any surface outflow and appears to be a closed type. The rainfall received in the sub-catchment is lost through infiltration and evaporation in a short time. Because of the proximity of lake fault to Sukhatal lake, it is possible that most of the water is lost through underground seepage that subsequently recharges Nainital lake. The sub-surface towards the downstream side of the lake may be through the fractures and faults. Seepage from lake may not be occurring through lakebeds as thick layer of fine sediments characterizes them. Therefore, sub-surface outflow may be occurring mainly in the epilimnion zone.

Earlier investigation of Rawat (1987) on bathymetry of the lake recorded the existence of a 100 m long transverse ridge at the mean depth of 18.55 m, subdividing the lake into two parts, and of the presence of knolls (possibly of fallen blocks). The study indicated progressive reduction in the lake capacity due to accumulation of sediments, 5500 m^3 in 80 years at the rate of 67 m^3 /year in the interval 1895-1969 and 78 m^3/year during 1969-1979. According to Sharma (1981), the data for the period 1960-1977 showed accumulation of 0.37 million m^3 of sediments in just 17 years at the rate of 0.022 million m^3/year. It is quite evident that the lake is being filled up at a brisk rate. This is also evident from the growing fronts of 23 deltas identified by

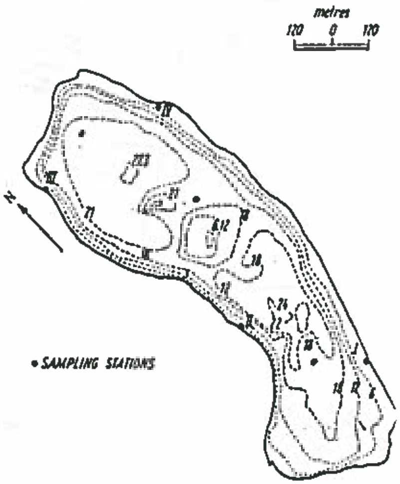


Fig. 3. Bathyymetric map of the lake showing sampling sites, depth in m.

Table 2. Rate of sediment accumulation estimated by sediment balance method in Nainital lake (Kumar *et al.*, 1999)

	Suspended sediment concentration	Total suspended sediment load (m^3)
Inflow through drains	0.41 g/l	1,500

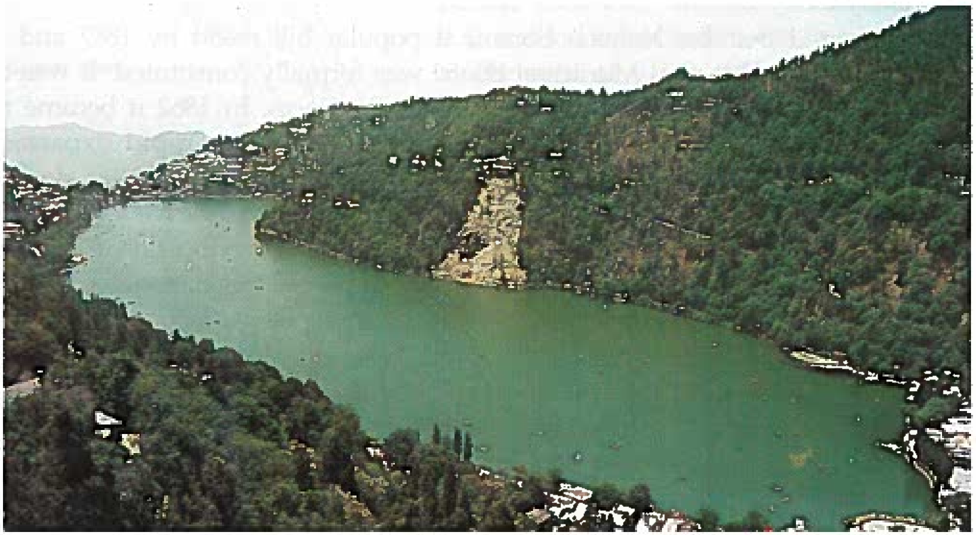
Valdiya (1988). These deltas with hard bottoms have formed at the points of streams and main discharges into the lake.

Recently Kumar *et al.*, (1999) working on estimation of sedimentation rate of this basin using geochronological/radiometric-dating method estimated that life expectancy of lake Nainital as 2, 200 years. According to above workers the mean sedimentation rate for lake Nainital is 0.75 cm/yr, which is comparatively higher than other lakes in this region (Lake Bhimtal: 0.47 cm/yr; 0.37 cm/yr for Naukuchiatal; 0.39 cm/yr for Sattal (Kusumgar and Agarwal, 1989 and Das *et al.*, 1994). This is probably because, unlike other lakes of the region, carbonate rocks, which are highly susceptible to weathering, surround Nainital lake. According to Kumar *et al.*, (1999) if the sediment deposition continues at the same rate, the lake may be filled completely in 2,160 ± 80 years or 2,480 ± 310 year under normal environmental conditions. The suspended sediment concentration inflow into the lake has been estimated to the tune of about 0.41 g/l during normal days and during rainy days is about 1.25 g/l. The sediment outflow from the lake has been computed using the discharge from the lake through the sluices and the average suspended sediment concentration in the epilimnion is about 0.55 g/l with an inflow – outflow (sediment accumulation rate) to the tune of 0.69 cm /year (Kumar *et al.*, 1999).

1.6 Demographic Pressure

It is reported that the Nainital became a popular hill resort by 1847 and on October 3, 1850, the Nainital Municipal Board was formally constituted. It was the second Municipal Board of then North Western Provinces. In 1862 it became the summer seat of North Western Provinces, which led to its rapid expansion. Facilities such as marketing areas, rest houses, recreation centers (clubs, dancing halls etc.) together with the Secretariat and other administrative units, were constructed. It also developed as an important centre for education for British children. By the turn of century, Nainital had come on the national map as a popular hill station. The census of 1901 records a population of 7,609. This population increased very slowly during the first five decades of this century rising to 13,093 in 1951. In 1960, the Government of Uttar Pradesh decided not to shift the capital to Nainital during summer. In the initial stages this proved a great setback for the economy of the town, but it soon revived as a tourist resort. The Indo-Pakistan conflicts of 1965 and 1971 gave a boost to tourism in Nainital since a sizeable number of tourists did not visit Kashmir during these years. The organic and inorganic nutrients are added directly into the system. The lake is multipurpose in character, apart from being a source of drinking water it has significant impact upon the economy of the region. The lake water after proper filtration and chlorination is supplied to the local inhabitants for drinking and other domestic purposes. The resident human population of the township is considerably low (approx. 40,000 residents). In general the pressure of population in hilly regions of Uttaranchal is exhorbitantly high. It is increasing at an annual rate of above 2.72% after 1970. The lake is a summer resort in north India, and attracts nearly 2,00,000 tourists annually. Tourism is the major industry of this region and there is no agricultural or industrial activity within the lake catchment area, however, a significant increase in population occurs during summer and autumn due to the influx of tourists. Therefore, tourism is the main economy of the town, which is directly linked with activities on and off the lake.

Apart from demographic pressure the erosion has been one of the major stresses to the aquatic ecosystem in our hills. Today, the rate of erosion in the Himalayas is amongst the highest in the world. In the Central Himalayas, high sediment production has caused siltation in lakes, reservoirs and canal systems and has led to aggregation, instability and flooding in the low-land river channels. The siltation rate in the Nainital lake has increased 5-7 times compared to that in the Quaternary and Prehistoric periods (Rawat, 1987). The main reasons for



accelerated erosion is loss of vegetal cover, engineering activities, terraced cultivation, overgrazing, forest fires and population pressure. The area is receiving incredibly large amount of sediments every year by mass movements, devastating landslides, rock-fall, debris flow and severe erosion in the catchments. As a result, the lakes are diminishing fast and springs are drying up. Highly crushed, sheared and shattered rocks, recurrently experiencing the mass movements and erosion resulting in environmental degradation and increased flooding, characterize the catchments. Extensive human settlements related to agriculture, monoculture plantation, deforestation and excavation of roads have intensified the erosion and have triggered slope failures on these highly unstable lake catchments.

1.7 Morphology of Lake

Lake Nainital (29⁰ 23′ 09″ N and 79⁰ 27′ 35″ E) is a high altitude (1937 m asl) natural lake located in Nainital District, Uttaranchal, India. It is a crescent shaped lake with a maximum length of 1.4 km and width of 0.45 km. The maximum and mean depth of the lake is 27.3 m and 16.5 m, respectively. It is divided into two sub-basins by a 100 m wide transverse underwater ridge, 7 m below the lake surface. Folded and faulted carbonate rocks of the Krol and Tal formation characterize the lake basin. The Nainital fault and associated fractures have caused shearing and shattering of the rocks responsible for hillslope instability. Almost half of the areal extend of the lake basin is covered with debris generated by mass movements ((Kumar *et al.*, 1999). The surface area of the lake is 0.46 km^2 with maximum capacity of 5.907 million m^{-3}. However, Hashimi *et al.*, (1993) recorded maximum capacity (volume) of the lake to the tune of 8.57 million m^{-3} (computed using the bathymetric map). The average annual rainfall in the basin is 2030 mm.

1.8 Lake sediment

According to Gupta and Pant (1983), the surface sediment of the Nainital lake chiefly comprised organic and mineral matter and on the basis of textural appearance it can be classified as saproper, a glossy black material watery. It gives Hydrosulfide odour. The clay sediment content of the sediment increased with the increasing depth and showed a maximum value of 75% at 18 m depth sediment, whereas it was 40% at 5 m, about 60% at 8 m depth and 62% at 10m depth. The amount of organic matter (% ignition loss) increased with progressive increase in depth. It varied between 18% and 28% (1m –18m depths). Available phosphorus tended to decrease with increasing depth to the extent that it became

Table 3. Main Morphometric features of Nainital lake.

Parameters	Values / Remarks
Altitude	1937 m a s l
Location	29° 23′ N latitude; 79° 27′ E longitude
Surroundings	Three side by hills
Basins	Two, North and South
Shape of basins	V – shaped
Maximum depth	27.3 m and 25. 3 m
Mean depth	16.5 m
Length	1432 m
Width	423 m
Surface Area	48.0 ha
Shoreline	3630 m
Index of volume development	1.78
Index of shoreline development	1.20
Catchment Area	3. 96 km^2
Ratio of Catchment to Lake surface area	1: 8.25
Mean Storage Volume	5907.57×10^3 m^3
South-eastern boundary (Tallital)	A Dam & underneath there is an outlet to drain excess water during monsoon.
Average Annual Precipitation	2030 mm

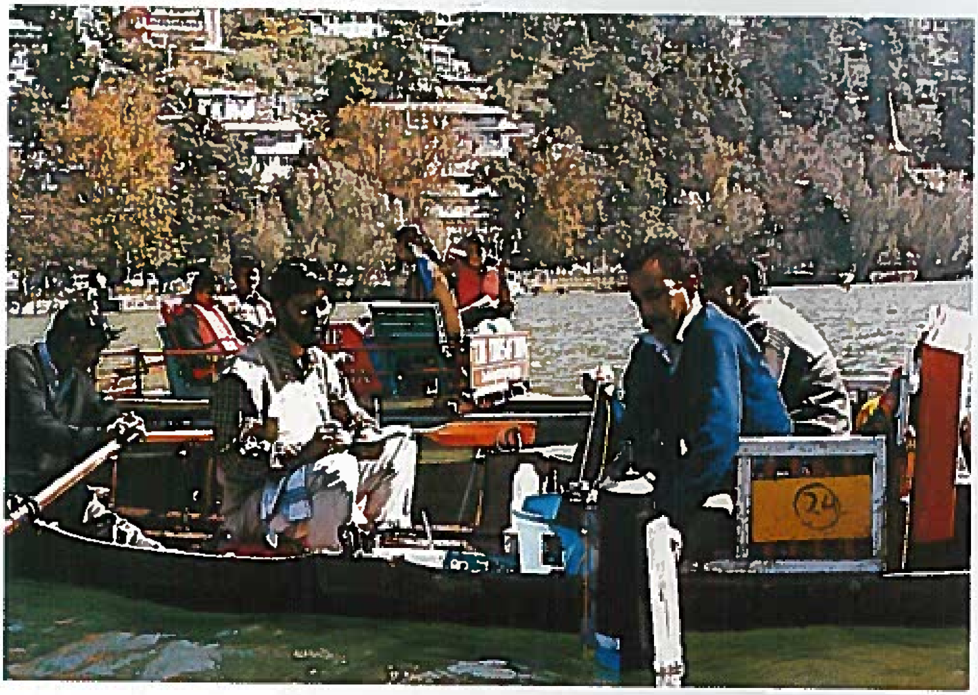
Table 4. Depths–wise cations in sediment of Nainital lake water (Gupta and Pant,1983a).

Depth (m)	Ca ($\times 10^4$ mg kg^{-1})	Na ($\times 10^3$ mg kg^{-1})	K ($\times 10^3$ mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Co (mg kg^{-1})	pH
01	5.7	2.5	3.2	23.99	0.35	0.14	2.16	7.5
03	6.8	3.1	3.7	20.39	0.29	0.09	1.53	7.4
05	8.4	3.3	4.4	18.53	0.26	0.05	1.32	7.2

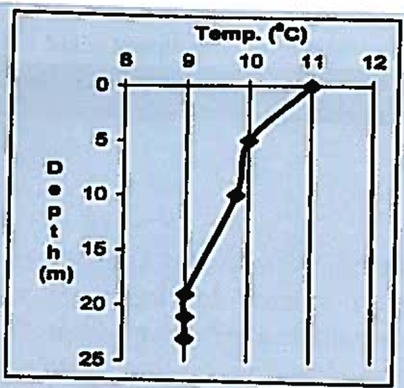
2. ECOLOGICAL STATUS

2.1 Water quality and nutrients

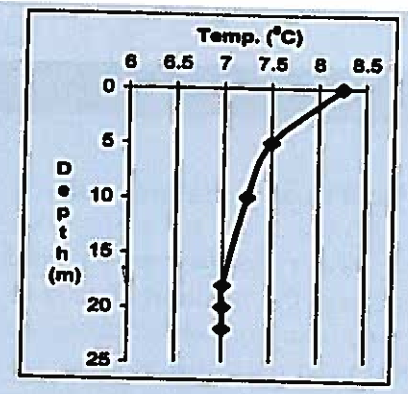
Water quality is very critical for aquatic biodiversity in a lake and in case of fish it is the medium of growth from adult to various developmental stages. The well being of fish stocks in an aquatic ecosystem apart from availability of natural food depends critically on the water quality. Even minor variations in critical physical and chemical features of the water, seriously affect the biological and physiological attributes in fish. Therefore, water quality is very critical for survival of fish stocks. This Institute and other workers have analyzed the lake for such water quality attributes too. The information gathered is produced as under:



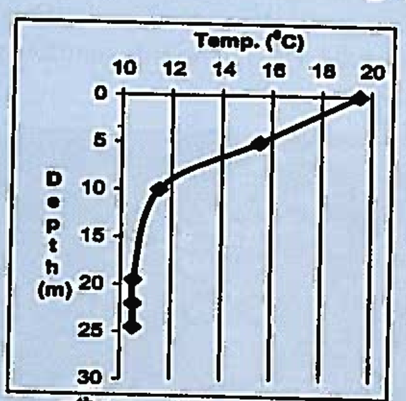
Sampling in lake for limnological investigations



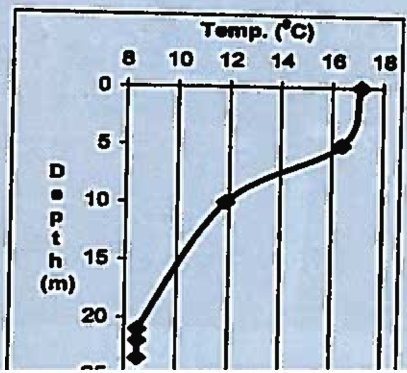
5th Dec. 2000

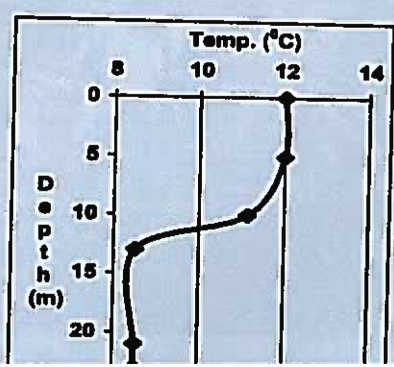


8th Feb. 2001



9th May,2001





year, dividing the whole mass of water into an upper epilimnion and lower hypolimnion.Two markedly separated by a transitional zone called metalimnion or thermocline, the lake becomes homothermal during winter periods (from late November to early March). Surface water temperature fluctuated between 8.0 to 23.5^{0}C, with highest and lowest occurring during July and December, respectively.

The seasonal profile records indicate that lake starts circulating in December at 11.0^{0}C but it maintains a temperature difference of 1.0-2.0^{0}C in a depth column of 25 m. This temperature profile drops to 8.5^{0}C at surface and 7.0^{0}C at 25 m in February. By May, a very stable stratification is set-in with surface temperature at 20.0^{0}C, which drops to 11.5^{0}C at 10 m depth zone and subsequently remains at 10.5^{0}C till 25 m depth zone. In post monsoon months of October and November the surface temperature drops from 17.0^{0}C to 12.0 ^{0}C but the hypolimnion temperature remains around 9.0^{0}C with stable thermocline. Therefore, lake would in fact circulate only for short period, which is not a good sign.

The Nainital Lake, altitudinally situated in a temperate zone reflects the characteristics of tropical/subtropical lake ecosystem. According to the thermal classification of Hutchinson (1967), lake Nainital would be classified as a "*warm-monomictic*" second-class lake. As per observation of Pant *et al.*, (1985) on Nainital lake, not withstanding high insulation in March, the vertical gradient in temperature between surface and bottom waters was only 4.0^{0}C against the gradient of 12.0^{0}C in May. The air temperature during summer did not exhibit marked diurnal fluctuations, whereas during spring it becomes very low in the night. Thus, a considerable amount of heat loss occurred during spring from superficial layers, resulting in low vertical gradients compared to the summers. As only upper waters are influenced by the input of radiant heat, the temperature of deep waters did not fluctuate widely but remained between 11.0 – 12.3 ^{0}C during the warm period. This is in contrast to the temperate water bodies where the temperature of the deep water changes with seasonal weather fluctuations and the phenomenon of inverse stratification is also observed (Hutchinson, 1967).

2.3 Secchi Transparency

Compared to other Kumaon lakes the light penetration in Nainital lake is low, the transparency varied from 35 to 165 cm at littoral and 35 to 185 cm at

Table 5. Changes in water transparency.

Month/ Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1978-79	0.8m	1.2m	0.5m	1.0m	1.8m	2.0m	1.5m	0.9m	1.0m	1.1m	1.4m	1.3m
2000-01	0.8m				0.52m					1.3m	1.5m	1.2m

mainly because during winter overturn period (*isothermy state*) large amount of non-algal suspended solids are leached from the bottom to the surface of the lake coupled by high population of *Chlorella* spp. (2.3 mill. cells/ml, Pant *et al.*, 1985).

A stray comparison of transparency records between 1978-79 and 2000-01 does not give any trend. It appears that waters of Nainital lake were never highly transparent but in the absence of sustained previous data no specific conclusion can drawn on this parameter.

2.4 pH

The water remained alkaline for most parts of the year. In general, the hydrogen ion concentrations were high during June – August and low in winter. The range of variation was from 7.2 – 9.0 in surface samples to 7.5 - 8.6 in zones below 5 m depth. However, the difference in pH between surface and 10 m depth zone in summer period was insignificant (0.5 units), while in other months it was slightly higher 1.0 units. Pant *et al.*, (1985) recorded that there was no specific correlation from surface to the 5 m depth zone, however, higher pH values in the lake coincided with the periods of greater photosynthetic activity evident by the significant relationship between pH and primary production ($r=0.86$; $P< 0.01$). Lower and higher values of pH in this lake during winter and summers, respectively also coincided with the absence and presence of carbonates in the euphotic zone. The NRCCWF's special investigation conducted during 2000-2001 revealed that pH of the lake in different stations and at various depth levels remained in a range of 7.8 – 7.2 during autumn; 8.4 – 7.4 in summer ; and 7.6 – 7.4 in winter between surface to bottom column of the lake. Details of the pH values recorded by NRCCWF are depicted in table 6.

2.5 Free Carbondioxide

Table 6. Physico-chemical features of Nainital lake recorded in different months during 2000-2001. (Danth =Station 1; Centre of the lake = Station 2; Opp. Library = Station 3; and Mallital/Nallah = Station 4).

October 19,2000

Station	Max. depth (m)	Secchi (cm)	Water temp. (°C)	pH	Free CO_2 (mg/l)	Dissolved oxygen (mg/l)
Station 1	10.0	110				
Surface			17.0	7.8	0.0	7.6
5m depth			17.0	7.8	0.0	7.2
10m depth			11.0	7.2	1.6	Nil
Bottom			10.0	7.1	1.8	Nil
Station 2	23.5	118				
Surface			17.0	7.8	0.0	7.04
5m depth			16.0	7.6	0.0	6.96
10m depth			13.0	7.6	1.4	2.64
Bottom			8.5	7.2	4.0	nil
Station 3	21.0	145				
Surface			17.0	7.8	0.0	6.96
5m depth			16.5	7.6	0.0	6.80
10m depth			12.0	7.4	1.6	1.68
Bottom			8.5	7.2	4.2	nil
Station 4	22.0	156				
Surface			17.5	7.8	0.0	6.88
5m depth			16.0	7.4	0.0	6.48
10m depth			11.5	7.4	1.4	1.36
Bottom			8.5	7.2	3.8	nil

November 16, 2000

Station	Max. depth (m)	Secchi (cm)	Water temp. (°C)	pH	Free CO_2 (mg/l)	Dissolved oxygen (mg/l)
Station 1	13.0	150				
Surface			12.0	7.8	0.0	6.24
5m depth			12.0	7.5	0.8	6.24
10m depth			11.0	7.5	1.0	1.52
Bottom			8.5	7.2	2.2	Nil
Station 2	22.5	155				

Station	Max. depth (m)	Secchi (cm)	Water temp. (°C)	pH	Free CO_2 (mg/l)	Dissolved oxygen (mg/l)
Station 3	21.0	152				
Surface			12.0	7.6	0.0	6.00
5m depth			12.0	7.6	1.2	6.00
10m depth			11.0	7.6	1.8	6.00
Bottom			8.5	7.2	4.0	nil
Station 4	23.0	145				
Surface			12.0	7.6	0.0	5.60
5m depth			12.0	7.6	0.0	6.00
10m depth			11.0	7.6	0.0	6.32
Bottom			8.0	7.2	4.2	nil

December 05,2000

Station	Max. depth (m)	Secchi (cm)	Water temp. (°C)	pH	Free CO_2 (mg/l)	Dissolved oxygen (mg/l)
Station 1	19.0	125				
Surface			11.0	7.6	0.0	4.76
5m depth			10.0	7.6	1.0	4.76
10m depth			10.0	7.6	1.6	4.70
Bottom			9.0	7.4	2.0	Nil
Station 2	21.5	125				
Surface			11.0	7.6	0.0	4.86
5m depth			10.0	7.6	1.2	4.86
10m depth			10.0	7.6	1.2	4.72
Bottom			9.0	7.4	1.6	1.70
Station 3	23.5	110	12.0			
Surface			10.0	7.4	0.8	3.60
5m depth			10.0	7.4	1.6	4.00
10m depth			10.0	7.4	2.0	3.66
Bottom			9.0	7.2	4.0	nil
Station 4	22.0	156				
Surface			12.5	7.6	0.0	6.00
5m depth			12.0	7.4	0.0	5.48
10m depth			11.5	7.4	1.0	1.40
Bottom			8.5	[illegible]	[illegible]	[illegible]

February 08, 2001

Station	Max. depth (m)	Secchi (cm)	Water temp. (°C)	pH	Free CO_2 (mg/l)	Dissolved oxygen (mg/l)
Station 1	18.0	79				
Surface			8.0	7.6	1.6	4.80
5m depth			7.0	7.6	2.4	4.68
10m depth			7.0	7.6	2.6	3.68
Bottom			7.0	7.6	3.4	Nil
Station 2	20.0	64				
Surface			8.0	7.6	1.0	4.64
5m depth			8.0	7.6	3.6	3.66
10m depth			8.0	7.6	3.6	2.88
Bottom			8.0	7.6	4.0	2.48
Station 3	22.0	84				
Surface			8.5	7.4	1.4	3.98
5m depth			7.5	7.4	2.6	3.56
10m depth			7.0	7.4	3.2	3.56
Bottom			7.0	7.4	4.8	3.20
Station 4	9.5	88				
Surface			8.5	7.4	2.0	3.90
5m depth			7.5	7.6	3.2	3.10
10m depth			7.4	7.6	3.5	3.00
Bottom			7.0	7.6	4.2	2.58

May 09, 2001

Station	Max. depth (m)	Secchi (cm)	Water temp. (°C)	pH	Free CO_2 (mg/l)	Dissolved oxygen (mg/l)
Station 1	19.5	55				
Surface			19.5	8.4	0.0	8.92
5m depth			15.5	7.8	0.0	7.20
10m depth			11.5	7.2	0.0	3.12
Bottom			10.5	7.4	1.0	2.78
Station 2	19.5	52				
Surface			19.5	8.4	0.0	8.48
5m depth			15.0	7.6	0.4	3.44
10m depth			[illegible]	[illegible]	[illegible]	[illegible]

Station	Max. depth (m)	Secchi (cm)	Water temp. (°C)	pH	Free CO_2 (mg/l)	Dissolved oxygen (mg/l)
Station 3	22.0	50				
Surface			19.5	8.4	0.0	9.40
5m depth			16.0	7.6	0.0	3.04
10m depth			12.0	7.6	1.4	2.80
Bottom			10.5	7.4	2.0	1.68
Station 4	24.5	50				
Surface			19.5	8.4	0.0	9.36
5m depth			15.5	7.6	0.0	2.96
10m depth			11.5	7.4	1.4	2.72
Bottom			10.5	7.4	2.2	1.69

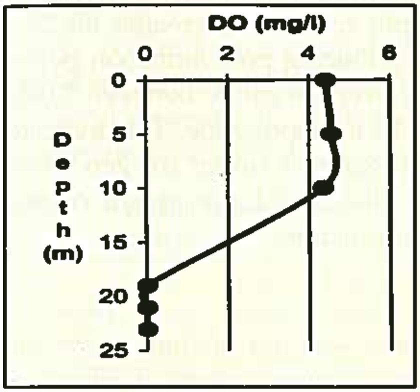
mg/l in the surface waters and from 2.0 to 20.0 mg/l at midlake zones. The value at bottom of the lake varied from 2.0 to 28.0 mg/l. As per Pant (op. cited) the carbondioxide values unlike temperature and pH, recorded rather distinct vertical gradients during winter months. The NRCCWF special investigation conducted during 2000-2001 revealed that values of free carbondioxide remained between 4.8 – 2.4 mg/l in February; nil – 2.2 mg/l in May; nil – 3.8 mg/l in October; and nil – 4.0 mg/l in December from surface to bottom zone of the lake.

2.6 Total Alkalinity

Pant *et al.*, (1985) reported that total alkalinity in Nainital was higher during winters and lower during the summer months of the year. It ranged between 100 – 560 mg/l in the surface waters and from 100 – 585 mg/l at the bottom zones of the lake. These values generally increased with the depth during the thermal stratification period. However, during isothermal conditions the vertical gradients are little marked or totally absent. Values recorded at different stations did not reflect any marked variation in this lake. However, latest investigation made by NRCCWF on the lake during 2000-2001 revealed that there was a marked drop in contents of total alkalinity and values throughout year ranged between 166 - 186 mg/l at surface and 210 - 280 mg/l at bottom zones.

2.7 Dissolved Oxygen

The seasonal oxygen profile of lake indicate that in December the surface to



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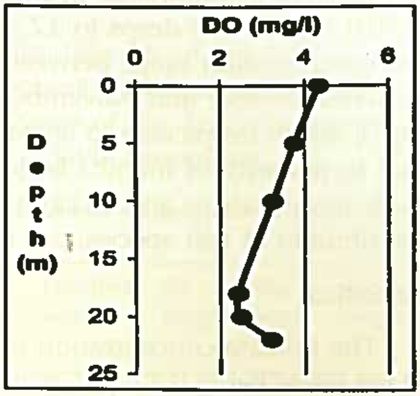
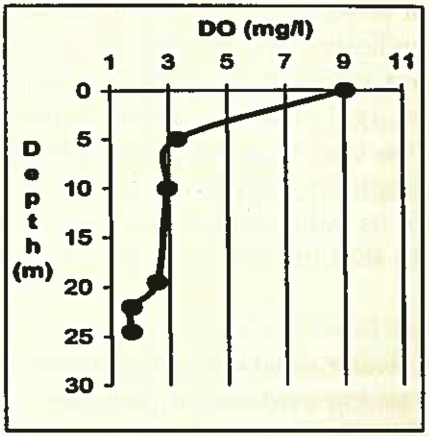
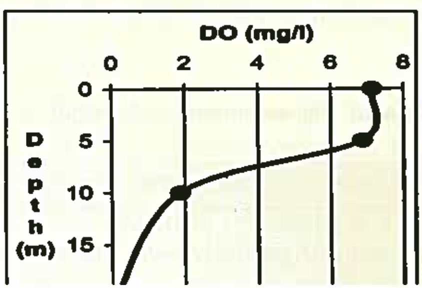
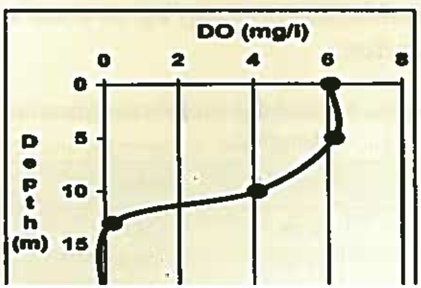


8th Feb. 2001



9th May 2001





of biological communities. In summer during May the surface is well oxygenated at 9.04 mg/l but it drops to 3.2 mg/l by 5 m depth zone and thereafter till 25 m the concentration range between 2.0 to 1.0 mg/l. During post-monsoon period between October and November, the epilimnion oxygen range between 7.0-6.0 mg/l, which drops near to anoxic conditions by 10 m depth zone. This indicates that in majority of months large volume of lake water is under oxygen stress. Both temperature and oxygen profiles in the lake to a large extent control distribution of fish species and their potential production.

2.8 Silica

The Silicate concentration in the Nainital lake was not of high order (the mean value being 0.3 mg/l in the euphotic zone). Lower content of Silica was recorded during spring and summer months. During the spring the diatoms were present and the uptake by them may be the main reason for its low values. However, the significant population of diatoms in winter months too, did not alter much of its values indicating an irregular silicate cycle in this lake. Generally the concentration of Silica values in Nainital lake varied from 80.0-450 µg/l at the surface to 200 – 500 µg/l at bottom zones. It normally showed increasing trend at deeper zone in the lake. It also depicted a typical vertical gradient trend in the concentrations, despite homothermal conditions during winter periods. As per Pant *et al.*, (1985) its values ranged between 3630 – 8880 mg/m^{-2} at the pelagic zones and 1012 to 4832 mg/m^{-2} near littoral zones (shore).

2.9 Metallic contents

Contamination of the water of lake Nainital by metals such as Mn, Pb, etc. is considered to constitute strong evidence of pollution. The levels of Pb. and Mn are higher than the permissible limits of the WHO (1971), and must therefore, be considered hazardous to the consumers (Pant *et al.*, 1981). Annual mean concentration (mg/kg of trace elements in the sediment of Nainital lake is as under:

Table 7. Annual mean concentration of trace elements in the sediment of Nainital lake (mg/kg).

Depth	Mn.	Cu.	Co.	Pb.
01 m	24.0	0.35	2.2	ND
03 m	20.4	0.30	1.5	2.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2.10 General trend

The column wise general water quality of the lake on an average indicate highly disturbing trend, which apparently appears to be conducive for low biological diversity at all the food-chain levels. Some of the data sets generated recently by NRCCWF has been analyzed, is set in table hereunder:

Table 8. Average surface / bottom water quality (these are mean values from four stations on depth profile basis)

Date / Parameter	T.A. (mg/l)	Cl (mg/l)	DOM (mg/l)	TDS (mg/l)	Conductivity µs/25°C	Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	Si (mg/l)
05.12.2000	S.174	S.9.2	S.0.8	S.265	S.539	N.E.	N.E.	N.E.	N.E.
	B.205	B.11.0	B.0.8	B.316	B.636	N.E.	N.E.	N.E.	N.E.
08.02.2001	S.221	S.18.4	S.1.45	S.252	S.504	S.234	N.E.	N.E.	N.E.
	B.227	B.20.0	B.1.70	B.231	B.459	B.283	N.E.	N.E.	N.E.
09.05.2001	S.170	S.18.1	N.E	S.326	S.653	S.223	S.58.1	S.18.6	N.E.
	B.224	B.16.3	N.E	B.381	B.762	B.256	B.60.3	B.25.4	N.E.
19.10.2001	S.185	S.17.8	S.7.6	S.272	S.545	S.139	S.26.0	S.17.7	N.E.
	B.164	B.18.8	B.8.0	B.339	B.678	B.168	B.26.5	B.24.4	N.E.
26.11.2001	S.198	S.16.5	N.E	S.241	S.482.7	S.133	S.30.2	S.13.8	S.9.9
	B.274	B.14.6	N.E	B.282	B.566.6	B.157	B.31.3	B.18.8	B.71.4

2.11 Time scale changes

The water quality parameters in a lake show rapid seasonal changes in certain key parameters. Some of these changes are expected and normal. But over a period of time as the lake system evolves, enrichment takes place either at normal speed or it gets accelerated. In case of Nainital lake it has got accelerated thus inducing significant changes in its nutrient levels. In this context present values of certain nutrients have been compared with earlier records, which are tabulated on table 9.

The time scale changes in above table clearly indicate that total hardness in the lake has always remained high and now shows increased levels. But other parameters especially nitrates and ammonia upto mid sixties were within the reasonable limits but started increasing by mid-seventies onwards and by the year 2000 recorded significant increase in their values. These higher nutrient

Table 9. Time scale changes in certain chemical features.

Year	Total hardness (ppm)	NH_4-N ($\mu g\ l^{-1}$)	NO_2-N ($\mu g\ l^{-1}$)	NO_3-N ($\mu g\ l^{-1}$)
1954	300	19.0	Nil	Traces
1955	300	23.0	Nil	Traces
1956	320	23.0	Nil	Traces
1957	312	27.0	Nil	Traces
1958	300	42.0	Nil	Traces
1959	320	39.0	Nil	Traces
1960	305	46.0	Traces	Traces
1961	302	69.0	Traces	Traces
1962	300	64.0	Traces	Traces
1963	340	60.0	Traces	Traces
1964	336	66.0	6.0	26.0
1965	344	78.0	6.0	39.0
1966	340	87.0	8.0	79.0
1967	343	84.0	9.0	100.0
1968	349	98.0	7.0	210.0
1969	347	126.0	11.0	215.0
1970	345	140.0	15.0	315.0
1971	337	138.0	12.0	280.0
1972	348	144.0	12.0	275.0
1973	368	137.0	15.0	309.0
1974	380	147.0	14.0	305.0
1975	400	156.0	18.0	338.0
1980		192.0	20.0	350.0
1985		250.0	22.0	400.0
1990		380.0	25.0	450.0
1995		420.0	27.0	480.0
2000		550.0	30.0	650.0

again doubled; it appears to be a regular cycle probably correlated with corresponding increase in population and urbanization around the system. While, during the study time of 16 years (1969-1981) the values of nitrite and nitrate too have doubled.

3. FOOD – CHAIN DIVERSITY

The fish population structure, composition and production levels in a lacustrine system, apart from congenial water quality, depend upon the availability of natural food. The fishes can be surface, column, and bottom feeders. Thus insight of food-chain pattern *viz*., phytoplankton, zooplankton, macrophytes, and benthic communities is very much important for any fish stock management initiative. In this context biodiversity aspect of the lake is examined based on the primary and secondary data generated by NRCCWF and other workers.

3.1 Phytoplankton

The chief phytoplankton species represented in various groups of phytoplankton are given in table 10.

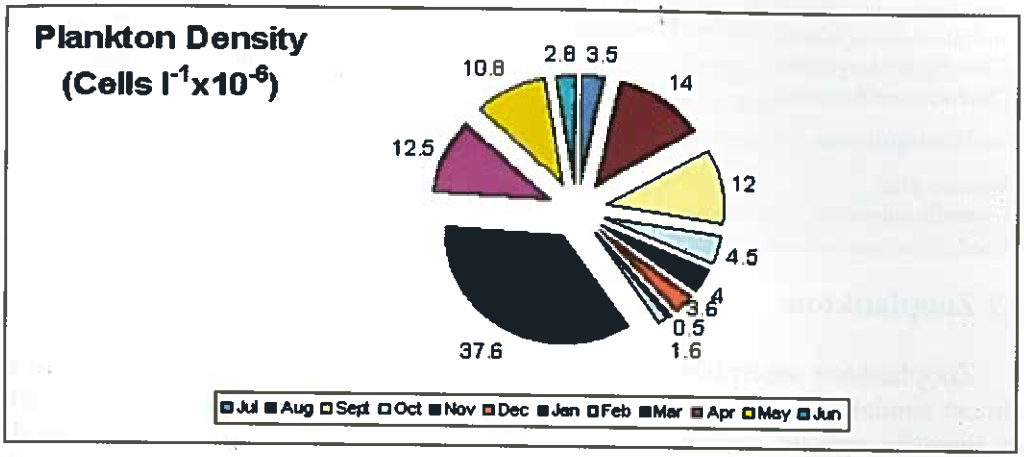
The lake has been reported to support a massive growth of algal phytoplankton often forming visual algal blooms except during winter (Sharma *et al*., 1982). The algal density varied from 2.4×10^{-6} to 37.6×10^{-6} cells l^{-1}. Two peaks were recorded by them, a major of 37.6×10^{-6} cells l^{-1} in March and a minor of 14×10^{-6} cells l^{-1} in August. The spring peak was constituted by chlorococcales and was represented by the blooms of *Chlorella vulgaris*. The dominant population changed from chlorococcales to volvocales during rainy season. At this time there occurred a massive bloom of *Chlamydomonas* sp., which persisted up-to mid-autumn. Thereafter, the algal population declined and the winter season was characterized by the minimal levels of phytoplankton density. Rao *et al*., (1982) recorded *Chlamydomonas* sp., *Closterium acerosum*, *Eudorina elegans*, *Cosmarium* sp., *Zygnema* sp. and *Microcystis* sp. as the chief species in the group. Amongst the group, green algae was most dominant contributed by *Closterium acerosum* and *Chlamydomonas* sp., were numerically the most dominant species. *Closterium acerosum* occurred from September to November and peak abundance of *Chlamydomonas* sp. was recorded in August. While, *Microcystis* sp. peaked during mid-November having a maximum density of 52,480 col. l^{-1}. However, density of phytoplankton according to Rao *et al*., (1982) varied from 0.8×10^4 to 32.6×10^4 cells l^{-1} in surface and 6.0×10^4 to 18.0×10^4 l^{-1} at 5m depth zone of the lake

Table 10. Dominant species of phtoplankton recorded in the littoral zones of Nainital lake.

Chlorophyceae	**Bacillariophyceae**
Ankistrodesmus convolutes	*Amphora ovalis*
Ankistrodesmus falcatus	*Asterionella formosa*
Actinastrum gracillimum	*Cymbella lanceolata*
Chlorella conglomerata	*Diatoma vulgare*
Chlamydomonas cingulata	*Fragilaria cupucina*
Chlorella vulgaris	*Navicula sublinearis*
Closterium acerosum	*Pinnularia nobilis*
Closterium microporum	*Rhopalodia gibba*
Closterium simansis	*Synedra ulna*
Closteriopsis longissima	*Tabellaria*
Chlorococcum humicola	**Cyanophyceae**
Desmidium spp.	*Anabaena spiroides*
Dictyosphaerium	*Aphanocapsa*
Dispora spp.	*Gomphosphaeria*
Nannochloris bacillaris	*Merismopoedia*
Oocystis irregularis	*Microcystis auruginosa*
Oocystis natans	*Oedogonium*
Pandorina granulosa	*Oscillatoria*
Pediastrum duplex	*Spirogyra*
Pediastrum simplex	**Dinophyceae**
Selenastrum gracile	*Ceratium*
Shrodoeria spp.	*Peridinium*
	Chrysophyceae
	Chilomonas

The phytoplankton community generally is constituted by green algae, with relatively lower proportions of diatoms and blue green algae. Chlorophyceae records highest proportion (95%) during spring and late rainy season. The percent contribution of diatoms to total phytoplankton density remains high for a short period during January (78%). The annual mean percent values were: Green algae 83.4; Diatoms 9.4; and Blue-green algae 5.9. Although, the massive blooms of blue-green algae (*Microcystis* sp.) are reported in the lake during autumn and early winter season, they do not form a sizeable part of the phytoplankton density exhibited a major peak in October, which was at variance to cell count peak. This peak was contributed by dominance of blue-green algae, thus the phytoplankton community in Nainital lake is truly characterized by blooms of blue-green algae. The total phytoplankton density recorded month-wise is tabulated as under:

Monthly average phytoplankton density in Nainital lake



Depth-wise yearly mean algal biomass

Depth of water column	Range in g m^{-3} (fresh weight)
Surface	>5.0 – 56 .0
01 m	>5.0 – 40.0
03 m	>5.0 – 30.0
05 m	>5.0 – 25.0
10 m	<5.0 – 15.0
20 m	<5.0 – 10.0

The profile of algal biomass reflects that upper column from surface to 5 m is the main productive zone while the biomass beyond 10 m could be constituted by the algal forms which are physiologically inactive. The highest values occurred during August, coinciding with the maximum phytoplankton production in the

Table 11. Dominant phytoplankton with mean annual percent contribution

Taxa	Contribution %	Group-wise mean percentage	
Chlorophyceae			
Chlorella vulgaris	41.6	Chlorophyceae	83.4
Chlamydomonas sp.	13.2	Bacillariophyceae	9.4
Closterium acerosum	12.2	Cyanophyceae	5.9
Ankistrodesmus convolutes	5.8	Dinophyceae	0.1
Ankistrodesmus falcatus	3.4	Chrysophyceae	0.4
Closteriopsis longissima	3.5	Cryptophyceae	0.8
Chlorococcum humicola	2.0		
Bacillariophyceae			
Synedra ulna	3.2		
Cymbella lanceolata	3.4		

3.2 Zooplankton

Zooplankton assemblage in Kumaon lakes exhibited a tropical seasonality almost similar to sub-temperate situation, yet the species diversity and particularly of limnetic species composition reflected the characteristics of sub-tropical/ tropical waters Raina and Vass (1993). Sharma and Pant (1985) and Pant *et al.*, (1985) during 1977 to 1978 recorded 59 species of zooplankton belonging to 39 genera, involving 48 species of Rotifera, 6 species of Copepoda and 5 species of Cladocera from the limnetic zones of Nainital lake. Out of the major groups, rotifers were the largest contributor and shared 81.4% of the total species content in Nainital lake. The zooplankton population exhibited only a single peak of high dominance ($4.8\ x10^{-5}\ m^{-3}$) during October. Although the seasonal pattern was similar to that of the phytoplankton, low zooplankton population ($0.1\ x\ 10^{-5}\ m^{-3}$) was recorded during January to March. During this period population was dominated by Copepods contributing about 84.2% (28.3% cyclopoids; 55.9% diaptomids), whereas rotifers and cladocerns contributed only 10.5 and 5.3%, respectively to the total plankton population. A list of zooplankton recorded in the lake is decpicted in table 12.

Among the rotifers the most important species were *Horaella brehmi, Filinia aseta, Keratella tropica, and Asplanchna brightwelli,* whereas *Diaphanosoma excisum* was the only dominant cladocera. The Cyclopoids

Table 12. Dominant species of zooplankton recorded in the littoral zones of Nainital lake.

Rotifera

Asplanchna brightwelli
Brachionus bidenlatas
Brachionus caudatus
Brachionus dedutata
Brachionus nilsoni
Cephalodella forficula
Cephalodella gibba
Cephalodella intuta
Cephalodella auriculata
Colurella obtusa
Colurella adriatica
Dicranophorus robustus
Euchlanis dilatata
Horaella brehmi
Keratella cochlearis
Keratella tropica
Lepadella ovalis
Lecane bifastigata
Lecane cengulata
Monostyla closterocerca
Monostyla bulla
Monostyla ventralis
Mytilina ventralis
Philodinavus paradoxus
Philodina roseola
Rhinoglena frontalis
Rotaria tridentata
Testudinella frontalis
Testudinella patina
Trichocerca cylindrica
Trichocerca ratus

Cladocera

Alona affinis
Alona rectangula
Alonella excisa
Chydorus gibbus
Chydorus sphaericus
Daphnia longiremis
Diaphanosoma exisum
Leydigia acanthocercoides
Moina micrura
Simocephalus vetulus

Copepoda

Cyclops vicinus
Eucyclops agilis
Mesocyclops leuckarti
Microcyclops varicans
Phyllodiaptomus blanci
Tropocyclops prasinus

Table 13. Percentage Composition of zooplankton during different seasons.

Seasons	Zooplankton Groups		
	Rotifera	Cladocera	Copepoda
Spring	73.0 (68.0 – 77.0)	4.8 (10.0 – 12.5)	18.3 (16.5 – 22.5)
Summer	70.8 (67.5 – 75.0)	11.0 (11.0 - 13.5)	17.5 (17.0 – 25.0)
Autumn	68.0 (64.0 – 73.0)	9.0 (7.0 – 12.0)	23.0 (22.0 – 30.1)
Winter	56.6 (52.0 – 63.0)	4.5 (4.0 – 6.5)	38.9 (32.0 – 47.0)

Cladoceran period with *Daphnia,Bosmina* and *Ceriodaphnia* dominating and December and January as a general low zooplankton population and high Myxophyceae *(Chroococcus)* period. The Nainital lake, typical warm sub-tropical ecosystem, has typical sub- tropical species like *Mesocyclops leuckarti, Eucyclops serrulatus, Tropocyclops prasinus, Diaphanosoma excisum, Alona affinis*, constituting important components of zooplankton community in this lake. According to Sharma and Pant (1985) usual perennial forms represented the Crustacean, while the population of other groups slightly varied from season to season. However, community coefficient in different months did not reflect any significant changes in zooplankton community.

As per recent study conducted by Gupta and his team (2001), recorded twenty-seven taxa of zooplankton in this lake. Of these, 17 belong to rotifera, 6 to cladocera and 4 to copepoda. Indicating that rotifera was dominant in terms of number of species (63%), followed by cladocera (22%) and copepoda (15%). The monthly variation in species richness in different groups of zooplankton did not vary significantly during 1999 and 2000.The specific species in Nainital lake are: *Philodina roseola, Rotatoria tridenta, Euchlanis dilata, Anuraeopsis fissa, Asplanchna brightwelli, Colurella obtusa, Mytilina ventralis, Philodinavus paradoxus, Microcyclops varicans, Tropocyclops prasinus, Cyclops vicinus, Diaphanosoma excisum.*

3.3 Zooplankton Bi

of *Daphnia longispina* reflects that the environment of lake is highly enriched. The occurrence of *Diaphanosoma excisum*, and near absence of *Daphnia* spp. from Nainital lake probably suggest a sequence of succession or biodiversity shift from *Daphnia* to *Diaphanosoma*. Further, *Diaphanosoma* spp., being smaller in size can more efficiently utilize nanoplankton than the net phytoplankton. Similar observations have also been reported by Zyblut (1970) in European waters. Sharma and Pant (1985) recorded 57 species comprising 46 Rotifera, 06 Copepoda and 05 Cladocera. *Chydorus sphaericus* has been commonly utilized as an indicator of eutrophic conditions, is frequently recorded in this system. Although it is primarily a littoral species that often appears in the limnetic zone when an extensive blue-green algae bloom is in progress, utilizing the algae as a substrate. The toxicants from municipal sources or from algal metabolites are concentrated in limnetic zones to inhibit zooplankters. A combination of lower flushing time, abundance of nutrients and suitable foods, and diluted toxicants may provide the most favourable conditions for maximal development of the zooplankton community through the year. *Mesocyclops leuckarti* occupies a pivotal position in the basic food web of the Nainital lake, is sole carnivore feeding mainly upon rotifers and juveniles of the other crustaceans. The value of other crustacean plankters as eutrophic indicators is limited by region's specificity. However, Gupta (2001) has listed *Daphnia longispina* from Nainital lake, but has not clearly specified the site of the lake where it was collected, looks that at some pockets population is there. *Phyllodiaptomus blanci*, which constituted above 60% of the

Table 14. Average biomass (mg m^{-3}) and species diversity.

Seasons	Zooplankton biomass (mg m^{-3})	Species diversity (average / range)	Remarks
Spring	89.3* (2.0 –260.0)	2.08 (2.0-2.25)	* Low values recorded in March and high values in May
Summer	306.6* (250.0-370.0)	1.9 (1.8-2.1)	* Biomass values recorded were fairly well represented.
Autumn	446.6* (220.0-650.0)	0.4 (0.2-0.7)	* Low values recorded in Nov. and

Table 15. Maximum and average biomass production of zooplankton groups/species.

Groups	Maximum biomass (mg m^{-3})	Main zooplankton species	Percentage of the total annual mean biomass (mg m^{-3})
i) Rotifera	157.9	*Asplanchna brightwelli*	60.7
ii) Cladocera	366.7	*Daphnia longispina*	-
		Diaphanosoma excisum	16.7
iii) Copepoda	408.9	*Phyllodiaptomus blanci*	29.8
		Mesocyclops leuckarti	27.4
		Eucyclops serrulatus	17.9

total zooplankton standing population (biomass) particularly at euphotic zones (Pant *et al.*, 1983) in Nainital lake has not been presently recorded by any worker.

3.4 Species diversity

A maximum of 59 species in Nainital lake were reported. Copepods did not show any seasonal variation, as most of them were perennial. While, Rotifera decreased from 31 (June) to 7 (January). Cladocera represented by 5 species in June were completely absent in winters. With the onset of spring and warmer temperature in the lake, the species exhibited an increasing trend in numbers. The species diversity index in Nainital lake varied between 0.25 (January) and 2.25 (June) with an annual value of 1.5 (Sharma and Singh, 2001). The total species and the individual groups except copepoda, exhibited pronounced periodical variation in their species composition. The lower species diversity is associated with the larger zooplankton standing crop in Nainital lake indicating higher trophic status of the system.

3.5 Overall biological trend in Nainital lake

According to classification proposed by Patalas (1972) the crustacean plankton community (Diaptomid and Cyclopids and Cladocerns) structure in Nainital lake falls under category III/IV, indicating increasing complicity. In this category these organisms are well adapted to low oxygen concentrations and often used as indicators of the organic pollution. According to Sharma and Pant (1985) *Asplanchna priodonta, Harringia rousseleti, Dicranophorus robustus and*

Table 16. Qualitative variations among zooplankton groups from littoral and limnetic zones.

Group	Summer	Autumn	Winter	Spring
Littoral zones				
Rotifera	15.0	10.0	5.0	10.0
Cladocera	4.0	1.0	-	3.0
Copepoda	2.0	2.0	2.0	2.0
Limnetic zones				
Rotifera	3.0	2.0	2.0	2.0
Cladocera	1.0	1.0	-	-
Copepoda	2.0	2.0	2.0	2.0
Common species				
Rotifera	7.0	4.0	3.0	12.0
Cladocera	-	-	-	-
Copepoda	2.0	2.0	2.0	2.0
Total				
Rotifera	25.0	16.0	10.0	24.0
Cladocera	5.0	2.0	-	3.0
Copepoda	6.0	6.0	6.0	6.0

drains of the lake are absent in profundal zones clearly indicated the characteristics of a polluted state of limnetic zones of the lake. These species according to above authors can act as biological indicators of water pollution in Nainital lake.

Sharma and Pant (1985) have reported a significant correlation between phytoplankton concentration and the number of zooplankton species; water temperature and dissolved oxygen concentration and number of zooplankton. The rotifer have been shown to have a more significant relationship with the phytoplankton population in Nainital lake (r=0.92). This is mainly due to the fact that in Nainital lake nanoplankton forms more than 60.0% of the total phytoplankton population and rotifers will be utilizing number of these nanoplankton as food due to their small size.

aquatic biota, results in the transfer of the matter and energy from one trophic level to the subsequent ones. Further, these organisms reflect the environmental condition of an aquatic ecosystem as they are sedentary in nature and spend most of their life burrowing or attaching themselves or in the bottom of restricted places. Distribution of the benthic communities in a particular ecosystem is primarily related to temperature, water quality, availability of food and life cycle pattern, while its variation in space is related to sediment texture and degree of pollution.

3.6.1 Composition

Investigations made by Gupta and Pant (1983b and 1986)) reported that the inshore macrozoobenthic communities in the lake comprised 30 taxa, belonging to Porifera, Turbellaria, Oligochaeta, Hirudinea, Odonata, Trichoptera, Coleoptera, Diptera, and Gastropoda. Out of these, Diptera was reported to be the largest contributor (26.7%), followed by Oligochaeta and Coleoptera (16.7% each), to the total species content. Amongst the groups, 12 species were most ubiquitous: *Tubifex tubifex, Chironomus plumosus, Gyraulus convexiusculus, Lymnaea acuminata, L. auricularia, Viviparus bengalensis, Glossiphonia weberi, Hemiclepsis marginata* (Hirudinea), *Forcipomyia* spp. (Diptera), *Bidessus* spp. (Coleoptera) and *Procladius* spp. Five species were numerically most important: *Chironomus plumosus, Tubifex tubifex, Limnodrilus* spp., *Glossiphonia weberi* and *Viviparus bengalensis.* Two peaks have been reported for population during the year. The first peak recorded during summer (May to June) mainly contributed by *T. tubifex* and second winter peak (December) dominated by *Chironomus plumosus.*

Pant *et al.*, (1985) has also reported that macro invertebrates are totally absent from the profundal zones of the lake. This absence is due to anoxic conditions at the mud-water interface and high quantum of organic-matter. According to these workers, *Tubifex-Chironomus* association characterizes the community, while chironomid population is generally replaced by tubificids at the deeper strata. The population of tubificids 32.4% recorded at 1 m depth, increased to 74% at 7 m depth. The amount of organic matter (dry weight) increased from 18% at 1 m depth to 25% in the 7-18 m bottom zone. Clay particles too, increased and attained a maximum of 75% in sediment from 18 m depth. The high proportion of clay particles perhaps harmed the chironomids by blocking their feeding apparatus and, hence, does not allow them ...

Table 17. Percentage Composition (ranges) of various groups of macrozoobenthos.

Group	Seasons			
	Summer	Autumn	Winter	Spring
Turbellaria	nil - 0.2	0.2 – 0.3	0.1 – 0.3	0.1 – 0.3
Oligochaeta	38.0 – 80.3	6.2 – 50.4	4.1 – 81.0	51.4 – 81.7
Hirudinea	0.9 – 5.8	0.8 – 4.0	0.5 – 0.8	0.2 – 0.5
Odonata	nil – 0.1	nil – 0,2	nil – 0.1	nil – 0.1
Trichoptera	-	nil – 0.4	0.2 – 0.9	0.1 – 0.9
Diptera	14.9 – 54.4	nil – 63.3	60.0 – 82.5	12.7- 44.1
Gastropoda	1.0 – 5.8	1.0 – 9.4	9.9 – 12.2	1.8 – 4.4

deeper zone of the lake that cause the high organic demand at the mud – water interface (Gupta and Pant, 1983). Thus, the shift in community structure can be attributed to the high pollution load consisting of organic matter in the Nainital lake.

3.6.2 Density and biomass

The average standing crop of macrozoobenthos recorded by Gupta and Pant (1983b) was 1655 numbers m^{-2} in Nainital lake. Oligocheata and Diptera were the chief components of benthic population contributing above 46% each to the total standing stock. Other groups were not fairly well represented except for a minor contribution of Gastropoda (5.9%) to the total density. In general Oligochaetes were dominant from March to August and dipterans from September to February. While, in other Kumaon lakes (Bhimtal) Oligochaeta alone contributed more than 70% to the population and Diptera just below 20%. The higher standing macrobenthic crop in Nainital lake was associated with higher primary productivity (Sharma, 1980) and to a higher amount of organic matter deposited in the sediment (annual mean 23.7%).In Nainital lake, *Chironomus plumosus and T. tubifex* were numerically important species contributing 41% and 40%, respectively to the total population.

Gupta (2001 mss) reported 18 taxa of macrozoobenthos from the lake. Out of these 11 are reported as abundant, 5 as occasional and 2 as rare. Ten important taxa recorded are *Tubifex tubifex*, *Chironomus plumosus*, *Limnodrilus* spp., *Hemiclepsis* *plumosus* (71%) among the total population. Relative abundance of various groups of benthos on an annual average basis revealed that Diptera was numerically most dominant (48%) followed by Oligochaeta.

Benthic biomass (dry weight) in Nainital lake was above 4.3 g m^{-2}, this level is slightly higher than 4.0 g m^{-2} fixed for categorization status of lake systems (Cole, 1974). Gupta (mss) recorded an average annual benthic biomass of 4.8 g m^{-2} during 1999-2001.It varied greatly from 0.08 g m^{-2} (August) to 11.78 g m^{-2} (December). Based on annual average biomass of various groups Diptera contributed 37.5%, followed by Oligocheata (26.8%) and Gastropoda (24%). The dominance of taxa in terms of their mean biomass were *C. plumosus*, *L. acuminata*, and *T. tubifex*.

Table 18. Mean annual density of important zoobenthic groups/species.

Group/species	Population density (no. m^{-2})	% Composition
Group		
Oligochaeta	769	46
Diptera	754	46
Gastropoda	97	06
Others	35	02
Species		
Chironomus plumosus	674	41
Tubifex tubifex	663	40
Limnodrilus acuminata	44	03
Unidentified Oligochaetes	82	05

3.6.3 Profile distribution

Based on the investigations carried out on Nainital lake in the past and recently by NRCCWF and Gupta (2001 mss), it is inferred that the average species diversity of macro invertebrate community (across depths and months) varied from 0.2 to 1.9.The highest values were recorded in January and the lowest during April. In general, the diversity was high at 1 m depth and declined with the increasing depth, recording lowest value at 7 m depth. On biannual mean, the diversity index of macrozoobenthos community was 1.25 whereas concentration

Table 19. Relationship of different community attributes with water depths. (annual average)

Water depth	Total No. of species	Total No. of taxonomic groups	Total density (no. m^{-2})	Biomass ($g\ m^{-2}$)	Diversity index
1 m	30	09	3371	14.6	2.4
3 m	16	05	2161	2.0	1.4
5 m	11	03	941	0.5	1.2
7 m	07	02	249	0.2	1.2
9 m & below	-	-	-	-	-
Average			1655	4.3	1.6

Table 20. Depth-wise distribution of chief macrozoobenthic organisms.

Macrozoobenthic taxa	1m	3m	5m	7m
Dugesia	15	-	-	-
Tubifex tubifex	935	1076	496	144
Limnodrilus	63	28	1	-
Branchiodrilus	2	-	-	-
Glossiphonia weberi	40	1	-	-
Hemiclepsis marginata	15	-	-	-
Barbronia weberi	4	-	-	-
Libellula quadrimaculata	1	-	-	-
Anax junius	1	-	-	-
Mystacides sepulchralis	11	-	-	-
Hyphoporus asper	21	-	-	-
Helochares lintus	2	-	-	-
Tropisternus	2	-	-	-
Bidessus sp.	26	1	-	-
Chironomous plumosus	1574	829	238	56
Procladius sp.	59	45	28	8
Viviparus bengalensis	105	3	-	-
Lymnaea acuminata	170	7	-	-
L. auricularia	4	-	-	-
Gyraulus convexiusculus	92	10	1	-

3.7 Bacterial load

The high pollution load in lake supports a large number of microbes as well. The microbial population exhibited a clear seasonality being maximum during warmer months and minimum in winter. High population of coliform bacteria is possibly due to the dumping of faecal matter into the lake through drains or surface run off. The lake water with constant presence of more than 5000 MPN/ 100 ml of coliform bacteria including *Escherichia coli* in its untreated state round the year could be considered as contaminated and unsafe for human consumption. Pant *et al.*, (1981) and Pant and Sharma (1983) recorded a large number of coliform bacteria from Nainital lake round the year, maximum recorded in July $11x10^{-5}$/

Table 21. Microbial population in Nainital lake water.

Variable	Winter	Spring	Summer	Spring
Fungi (no./ml)	24	252	265	256
Actinomycetes (no./ml)	1021	1255	1125	1085
Bacteria ($x 10^{-3}$/ml)	21.75	22.00	22.62	22.14
Coliform group ($x 10^{-5}$ /100ml)	0.46	1.36	3.72	1.47
Escherichia coli ($x 10^{-5}$ / 100ml)	0.40	0.96	3.05	0.81

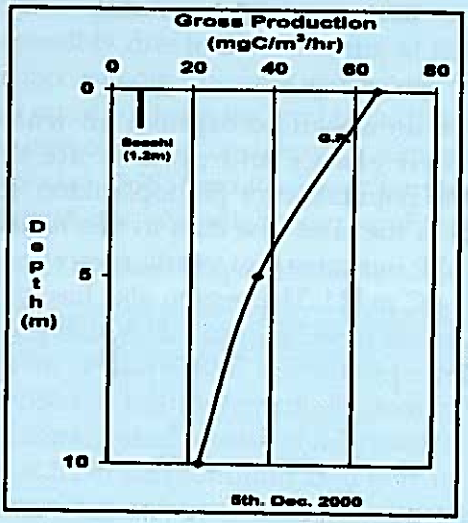
100ml.The high density of bacteria is due to large amount of the sewage that enters into the lake. Even feacal matter of human origin, damped or randomly deposited in the catchments area, is carried with surface run off, during rain storms into the lake. As per ICMR (1963) norms a value of 6.0 mg/l BOD in the surface waters is taken as a critical point for classifying a lake system as polluted. In Nainital lake, BOD values have been reported to range from 7.0 – 18.5 mg/l in the surface water. This value has been reported to touch 40.0 mg/l on a few occasions that too in winter months, coinciding with the fish kill in this system.

4. PRIMARY PRODUCTION

4.1 Phytoplankton

The main source of primary carbon in an aquatic ecosystem on which subsequent trophic levels depend for their energy and growth, are the phytoplankton. In the lake Nainital sizeable population of phytoplankton are reported which fix carbon at various levels of the lake. The data in this regard estimated by different workers and NRCCWF indicates that yearly mean gross production was in the range of 85-1110.5 mg C $m^{-3}d^{-1}$. The system also has high level of respiratory loss, which ranged between 185 – 947 mg C $m^{-3}d^{-1}$ with highest gross production of 1965 mg C $m^{-3}d^{-1}$ and net production of 873 mg C $m^{-3}d^{-1}$. This would mean that more than 60% of carbon photosynthesized is used in respiratory loss and at times respiratory loss is very high. This reflects a negative trend in the system. The depth profile production data indicates that maximum productive zone is between surface to 3 m depth while between 3 m to 6 m it is marginal and beyond this depth it is negligible. Any positive production trend at >6 m depth would be mainly contributed by nano-plankton and photosynthetic bacteria, which would be developing at such depths under oxygen stress. This would mean that in the lake, surface to 6 m depth zone is the productive zone and remaining zone between 6 m to the mean depth zone of 18 m is non-productive zone. The production estimates at such depths would be even difficult to assess by C-14 technique due to heavy suspended matter in the lake and low transparency. The total net carbon production is estimated at 307.4 g C m^{-2} y^{-1}, which works out to 3.07 tonnes Carbon $h^{-1}y^{-1}$ in the lake. In terms of energy the net phytoplankton production is estimated at $2.9x10^{6}$ g cal m^{-2} y^{-1} this is a sizeable energy for sustaining other food-chains, provided this energy is converted without any environmental limiting factors operating within the system. The typical depth profile of production data on some dates is given seperately. All the seasonal productivity profiles indicate high carbon at surface, which drops significantly by 5 m depth zone.

4.2 Macrophytes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(mgC/m³/hr)
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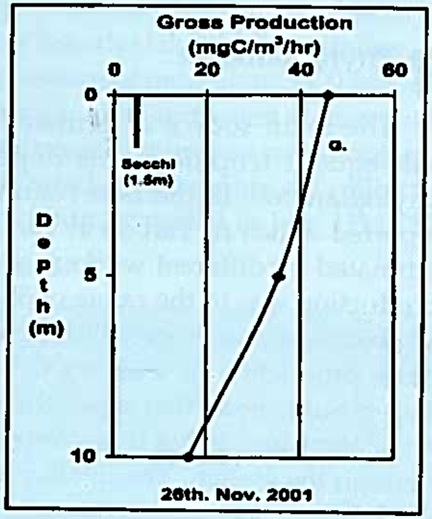
5
10
Depth (m)
Secchi (1.2m)
G.P.
5th. Dec. 2000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(mgC/m³/hr)
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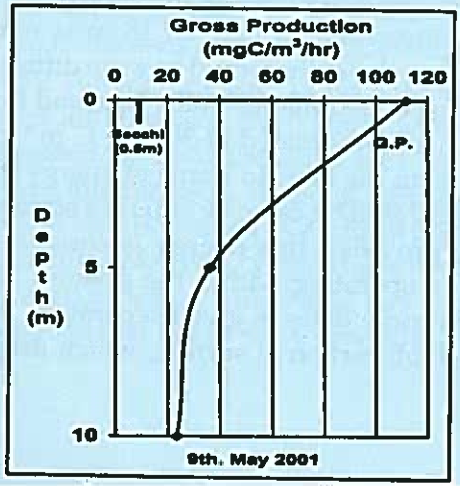
0
5
10
Depth (m)
Secchi (1.5m)
G.
26th. Nov. 2001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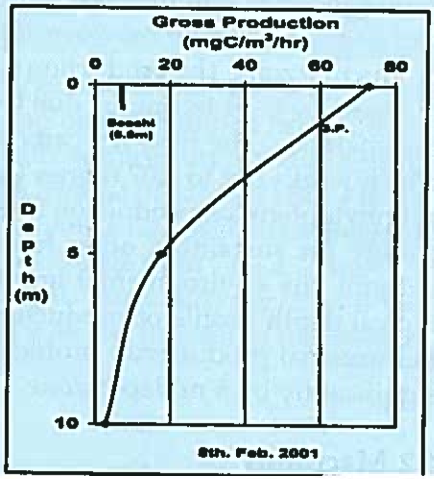
0
5
10
Depth (m)
Secchi
G.P.
9th. May 2001


Gross Production
(mgC/m³/hr)
0 20 40 60 80
0
5
10
Depth (m)
Secchi
G.P.
8th. Feb. 2001

respectively during first and second year. The net production reported by the author was 277 and 672 g m^{-2} in two years. The rate of biomass increment was 1.14 g m^{-2} d^{-1} during 244 days of growing period in first year while it was 3.17 g m^{-2} d^{-1} in 212 days during second year, and maximum biomass increment respectively for two years has been reported at 2.60 and 16.62 g m^{-2} d^{-1}. At site II biomass of submerged community was reported to range from 20.7 to 70.0 g m^{2} in the first year and from 23.5 to 150.3 g m^{-2} in the second year. The annual net production was 90.2 and 141.5 g m^{-2}, respectively in the first and second year in a growth period of 215 and 181 days. For these years minimum rate of biomass increment was 0.42 and 0.78 g m^{-2} d^{-1} and maximum rate of increment was 0.92 and 1.97 g m^{-2} d^{-1}. The average seasonal trend in biomass production is set in table 22.

Table 22. Monthly average records of submerged macrophyte biomass.

Months	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.
Biomass gm^{-2}	50	65	95	135	55	55	50	65	65	70	60	40

In terms of dry weight biomass the production on a yearly basis is quite significant. Further, the carbon production and energy made available by macrophytes to the system is nearly 50% of what is contributed by phytoplankton communities. This gives the lake a very good energy reserve for other food chains to sustain, provided no other environmental constraints exists.

Table 23. Net production of submerged macrophytes in the lake.

<table>
<tr><th rowspan="2">Stations</th><th colspan="2">Years</th><th rowspan="2">Mean of two years</th><th rowspan="2">Mean of stations (biomass)</th><th rowspan="2">Mean for lake</th><th rowspan="2">Mean in terms of Carbon</th><th rowspan="2">Mean in terms of Energy</th></tr>
<tr><th>1st Year</th><th>2nd Year</th></tr>
<tr><td>Station - I</td><td>277g m^{-2}</td><td>672g m^{-2}</td><td>474g m^{-2}</td><td rowspan="2">295g m^{-2}</td><td rowspan="2">2.9 t/ha</td><td rowspan="2">118 g C m^{-2}</td><td rowspan="2">1.1×10^{6} cal m^{-2}</td></tr>
<tr><td>Station - II</td><td>90g m^{-2}</td><td>142g m^{-2}</td><td>116g m^{-2}</td></tr>
</table>

4.2 Specific observations on plankton

the resources of the ecosystems should be very low; if species constituting more than 90% of the annual standing stock are considered dominant for the present purposes, there are only 6,4 and 5 species in the phytoplankton, zooplankton and macrozoobenthos, respectively. The dominance *vs.* diversity curve for phytoplankton in the nearby mesotrophic lake Bhimtal (Sharma *et al.*, 1982) and for zooplankton in another local lake, Sattal (Pant *et al.*, 1985) is far less steep than that for lake Nainital. The existence of few types of individuals in large numbers indicates that the concerned water body is polluted. The lake is undoubtedly passing through the bloom stage of ecological succession where smaller autotrophic organisms (nanoplankton) tend to dominate over the larger ones. Since respiration exceeds production and the ratio between the two is less than 1, the developmental sequence of the lake can also be called as heterotrophic succession. Most of the biological energy passes through the detrital pathways derived from autochthonous and allochthonous sources. The mean annual ratio between phyto and zooplankton biomass is 3.3 and between phytoplankton and herbivores, it is 4.6. If biomass is treated as measure of crude production, the relationship among the three trophic levels suggests that herbivore is inefficient while carnivore is efficient, because of this primary production remains unutilized by dominant herbivorous zooplankters whereas *Mesocyclops leuckarti*, the sole carnivore, feeds efficiently on rotifers and juveniles of other copepods.

According to Patalas (1972) and Vass *et al.* (1989) the crustacean plankton community (Diaptomid and Cyclopids and Cladocerns) structure in Nainital lake falls under category III/IV, indicating increasing complicity. These organisms are well adapted to low oxygen concentrations and often used as indicators of the organic pollution. *Daphnia*, which is inhabitant of oligotrophic waters, is totally absent in Nainital. Perhaps the lack of suitable food due to the mass growth of unpalatable species led to the elimination of this organism, and, in the course of time, *Diaphanosoma* appeared and found these food particles to be excellent source of nourishment. *Asplanchna priodonta, Harringia rousseuleti, Dicranophorus robustus, and Didymodactylus carnosus* recorded by Sharma and Pant (1985) from Nainital lake reflects comparatively higher trophic status of the system as compared to other Kumaon lakes where these species are not recorded. Certain species of zooplanters like *Bodo, Bursaria, Philodina, Oxytricha, Spirostomum, Epistylis, Brachionus, Keratella* etc. reported by Pant *et al.*, (1981) in appreciable quantity particularly near and around the inlets of open drains of the lake and absent in biodiversity in Nainital. According to Sharma and Pant (1985) there is significant correlation between phytoplankton concentration and the number of zooplankton species; water temperature and dissolved oxygen concentration and number of zooplankton. The rotifer shows a more significant relationship with the phytoplankton population in Nainital lake (r=0.92) compared to Bhimtal (r=0.72). This is mainly due to the fact that in Nainital lake nanoplankton forms more than 60.0% of the total phytoplankton population and rotifers will be utilizing large number of these nanoplankton due to their small size.

5. FISH & FISHERIES

5.1 Importance of Fish

5.1.1 Fish and Environment

The lakes and rivers provide a necessary supply of drinking water, resulting in development of settlements along their banks. They provided a defensive barrier, a means of transport and communication between communities. The fish were harvested for food. Later, weirs were installed at intervals along the length of rivers and mills built to harness water power. These changed the general pattern of water velocities as well as formed barriers to the passage of migrating fish–barriers were used to trap and harvest the migrating fish stocks. As human population increased, so the landscape was changed, increasing amounts of water were abstracted for public supply, industry and land irrigation. All these activities have caused radical changes in the physical nature of our rivers and lakes. The fish stocks in riverine and lacustrine habitats have different behavioural attributes. The species composition vary, their feeding and breeding biology is different which affects their physiological and growth attributes. Therefore, fish species normally nurtured in riverine environment will not easily adjust to lacustrine environment, with regard to many features. This demands specific management strategies for river and lake.

5.1.2 Fish for food security

Fisheries sector occupies a very important place in the socio-economic development of the country. It has been recognized as a powerful income and employment generator as it stimulates growth of number of subsidiary industries, besides, being a source of protein rich food for all sections of society. At present, this sector is providing gainful employment to about 5.96 million people of which 2.40 million people are full time, 1.45 million part-time and 2.11 million are occasional fishermen. Another 3 to 3.5 million people are believed to be engaged in the ancillary industries like boat building, fish processing, marketing, gear

About 80% of inland production has been reported through aquaculture. The National average productivity from the FFDA supported aquaculture ponds has risen from about 500 kg ha^{-1} y^{-1} in 1974-75 to about 2200 kg ha^{-1} y^{-1} during 1998-99. It is envisaged that by the end of IX plan (2001-2002), the average yield from the FFDA ponds would increase to about 3000 kg ha^{-1} y^{-1}.

5.1.3 Fish for nutrition security

Thanks to the green revolution that the per capita availability of food grains has increased but only for those who have the access to food with required buying power. Moreover, all the increase in food grain production and availability has come from wheat and rice. It has failed to eradicate the malnutrition. Nearly 26 percent of the rural farming households, mainly sub-marginal and marginal farmers are nutritionally deprived. Nutrition security thus goes beyond food security. It demands adequate provision of calorie and protein as well. To ensure nutritional security, increased availability of diverse types of foods of animal origin including fish besides cereals are essential. With saturation in the area under the cereal production, a diversification process was set in. In the course of time, aquaculture and fisheries emerged as valuable alternatives for profitable integration between crop and livestock farming. Fish is one of the best sources of protein. Importance of fish as a source of high quality, balanced and easily digestible protein as well as several other nutrients has been well established. Fish provides most of the gross and essential proteins, fats, minerals, vitamins, and essential amino acids. Poly-unsaturated fatty acids (PUFA) may account for about 15-25% of the total fatty acids and EPA and DHA together account for about 90% of the total PUFA. These constituents are known to reduce serum cholesterol levels and also prevent excessive platelet aggregation. Fish is the best food for balanced nutrition. It is not only "brain food" but is excellent for growth and development of human body and prevents several nutritional deficiencies namely protein energy malnutrition (PEM), B-complex deficiency, iodine deficiency (IDO) etc., with low carbohydrates and sodium contents. Fish is also reported to reduce cancer risk.

5.1.4 Fish as indicator of environment

The fast changing scenario of our inland water resources in the country especially by water abstraction and land use profile through reclamation for fisheries. The demand for sensitive and specific biological indicators to assess the impact of pollutants on ecosystems has led to a number of sophisticated analytical methods and many bio-indicators are now-a-day's under use for the environmental monitoring programmes.

The growth condition of fish is primarily a total impact of its environment and food availability. Therefore, in their studies on the Ganga river system Vass *et al.*, (1998) observed fish *Rita rita* as a reliable indicator for riverine environment. This study clearly showed the usefulness of fish as bio-indicator by adopting multiple approach, *viz.*, toxicant contamination, bioaccumulation in fish organs, histological changes, and general growth performance of the fish species. This gave an effective relationship between the contaminated environment and the stressed health condition of the test fish. Therefore, fish can be an important tool in bio-monitoring of an aquatic ecosystem, its Kn factor in fish would indirectly reflect the state of health of the lake.

5.1.5 Fish an eco-friendly organism

The fin fish or shell fish uses water as a medium of growth it does not consume water as most of the agriculture or horticulture activities utilize. Further, in open-waters especially in lakes, rivers and reservoirs, the fish helps in productivity management. It removes the nutrients from the system, grazes on the food chain thus keeping the population of phytoplankton and zooplankton under control. Some species also convert the aquatic weeds into fish protein. All these activities directly and indirectly helps to maintain good water quality because most of the permissible water quality standards are very critical for fish and its survival during its different developmental stages. Any stress in the water quality renders the fish stocks prone to infection and disease. It affects its reproductive physiology and overall growth. Therefore, fish as such is an eco-friendly animal in our open-water aquatic ecosystems. In fact the pollution, water abstraction and engineering structures across our open-water systems have been the prime reasons for decline in the populations of various important fish species in our ecosystems across the country.

5.2 Fish diversity in lake

Both Garhwal and Kumaon regions of the Uttaranchal state are bestowed

Snow-trout: *Schizothorax richardsonii* is endemic to Himalayan region and is known to occur in almost all lakes in Kumaon region including Nainital lake. There is only one species among the snow-trout group *Schizothorax richardsonii,* which is widely distributed from 600 m–2000 m asl in Central Himalayas. Menon (1971) reported *Schizothorax kumaonensis* from Nainital lake. The species is of smaller size. This species, as per Menon is restricted to Kumaon hills and has probably got evolved due to their long separation and change in living conditions. Alongwith these species *Raiamas bola* was another very important fauna of this lake. The fish was normally caught in good numbers and consumed locally and played a vital role in supplementing nutrition requirement of the people living in this region besides providing them a little income, who because of limited cultivable lands are under employed. It was generally caught through conventional methods and has a local market. Presently, this species has totally dwindled from this system.

Mahseers: *Tor putitora* and *Tor tor* are one of the finest groups of food and sport fishes in this region. Sir Ramsay successfully undertook transplantation of mahseer in Kumaon lakes during last decade of the 20th century. Among the two, *Tor putitora* was the dominant species in Nainital lake in the past but has declined now. In addition to the above *Tor chelynoides* was also recorded from the system in the past. Besides being a food fish, it was also one of the best sport fish in this lake.

Carp Fishery: The introduction of the common carp *Cyprinus carpio* in upland Kumaon lakes / wetlands was made about 4-5 decades back, obviously to increase the fish production. Today the species has dominated catches in majority of systems. In Nainital also it is reported in good proportion. From time to time there have been other introductions like Indian major carps, and Chinese carps (Silver and Grass carps) in the lake.

Chinese carps

Common carp

5.2.1 Species Composition

Fish diversity in the Nainital lake in retrospective is described in two groups:

i) Indigenous species
ii) Introduced species

Indigenous fauna: It is presumed that migration of fish species in this region must have occurred during the formation of Himalayas, perhaps during first Interglacial period, with the melting of snow, turbulent streams must have been formed in Central Asia. The favourable environmental conditions during second interglacial period resulted in east-west drainage; the faunal elements migrated westwards as far as Kashmir, covering central Himalayas also. In Hi isolated in these regions and evolved into a large number of species endemic in the upland and flatland waters. It is obvious that riverine fauna was the indigenous fauna of this region and with the tectonic movements certain loops of the meandering rivers (Hukku *et al.*, 1974 and Valdiya, 1988) got transformed into lakes where the original fauna got trapped and evolved into a new population in isolation. Similar fauna

Table 24. Indigenous & Introduced piscine fauna of Nainital lake.

Subfamily	Indigenous	Introduced
Cyprinidae	*Labeo dero* (Hamilton-Buchanan)	*Cyprinus carpio* (Linnaeus)**
	Labeo dyocheilus (McClelland)	*Carassius auratus* (Linnaeus)**
	Raiamas bola (Hamilton- Buchanan)	*Carassius carassius* (Linnaeus)* *
	Puntius conchonius (Ham.-Buchanan)	*Ctenopharyngodon idellus* (Valenc.)**
	Puntius ticto (Hamilton)	*Hypophthalmichthys molitrix* (Valenc.)**
		Tor chelynoides (Hamilton)*
		Tor putitora (Hamilton-Buchanan)*
		Tor tor (Hamilton-Buchanan)*
		Catla catla (Hamilton-Buchanan)*
		Labeo rohita (Hamilton-Buchanan)*
		Cirrhinus mrigala (Ham.-Buchanan)*
Rasborinae	*Barilius barila* (Hamilton-Buchanan)	
	Barilius bendelisis (Ham.-Buchanan)	
	Barilius barna (Ham.-Buchanan)	
Schizothoracinae	*Schizothorax richardsonii* (Gray)	
	Schizothorax kumaonensis (Menon)	
Garrinae	*Crossocheilus latius* (Ham.-Buchanan)	
	Garra gotyla gotyla (Gray)	
	Garra lamta (Ham.-Buchanan)	
Nemacheilinae	*Nemacheilus beavani* (Gunther)	
	Nemacheilus botia (Ham.-Buchanan)	
	Nemacheilus corica (Ham.-Buchanan)	
	Nemacheilus montanus (McClelland)	
	Nemacheilus multifasciatus (Day)	
	Nemacheilus rupecola (McClelland)	
Poeciliidae		*Gambusia affinis* (Baird & Girard)**

must have also got distributed to Kumaon lakes up-to Bhimtal. The indigenous and introduced/exotic fauna of this lake is given in table below:

Table 25. Group-wise Fish diversity in the lake.

Group/ Subfamily	Indigenous fauna	Transplanted within India	Introduction exotic	Present Status	
				Indigenous*	Exotic**
Cyprininae	05	06	05	02	03
Rasborinae	03	-	-	-	-
Schizothoracinae	02	-	-	01	-
Garrinae	03	-	-	-	-
Nemacheilinae	06	-	-	-	-
Poeciliidae	-	-	01	-	01
Total	19	06	06	03	04

* *Puntius conchonius* and *Puntius ticto* dominant at littoral zones and *Schizothorax richardsonii* recorded on rare occasion that too from clear part of the lake

** *Cyprinus carpio*, *Ctenopharyngodon idellus* (Grass carp), *Hypophthalmichthys molitrix* (Silver carp) are predominant species; and *Gambusia affinis* densely on the margins of the lake does not invade profundal zones.

5.2.2 Food and feeding of existing fish stocks

Keeping in view the food-chain dynamics in the lake as discussed above we find that some of the required food items for the fish species are available in the lake. The details of general feeding behaviour and other biological traits of these fishes are set in table 26.

5.3 Actual and Potential Fish Production

5.3.1 Actual Yield

The actual fish yield estimations in a lake are worked out on the basis of samples collected from regular fishing conducted in the system or sustained ological features of fish species available in Kumaon lakes.

Biological Features			
Feeding behaviour	Breeding behaviour	Growth pattern	General
Typical herbivore-Column feeder at some stage resort to bottom feeding as well. Diatoms, green algae, insect larvae and small crustaceans are main food. Juveniles subsist on crustaceans, aquatic insects and planktonic algae.	Breeds twice in a year, pre and during monsoon Exhibit local migration for breeding Breeds in shallow areas on the gravel, shingles and sand. Juveniles prefer areas having stream flush	Slow grower attains maturity in 3+yr	Primarily riverine stock. Introduced in lakes & reservoirs. Species established in lakes as local stock. Fish normally avoid low temperature (< 7°C). Species totally declined in Nainital lake.
Typical herbivore-detritophagus–rasp mainly on diatoms, other algae, microbiota, attached on stones etc. Juveniles feed on small benthic crustaceans and insect larvae. (diatoms, green algae, alongwith crustaceans as the principal food).	Breeds once in a year during monsoon period. Exhibit spawning migration. Spawns on gravel beds of the pools in tributary.	Slow grower. Attains maturity in 3+yr.	Basically riverine stock. Indigenous fauna of Kumaon lakes. Population drastically declined in all Kumaon lakes.
Planktophagous fish. Fry and adult prefers flagellata, dinoflage-latta, diatoms, Myxophyceae, Protozoa	Breeds once in a year. No record of breeding in lake environment.	Comparatively fast grower. Attains maturity 2 + yr. Grows above 1.5 kg/Yr.	Stocked in Kumaon lakes to control algal blooms.

Biological Features			
Feeding behaviour	Breeding behaviour	Growth pattern	General
& decayed macro vegetative matter. Juveniles feed on unicellular algae.			
Feeds on aquatic weeds Preferably on *Hydrilla, Ceratophyllum, Myriophyllum, Potamegeton)*	Breeds once in a year. No record of breeding in lake environment.	Fast grower . Attains maturity in 2 +yr. Grows above 1.0 kg/Yr.	Stocked to control weeds.
Typical omnivore-bottom feeder. Juveniles feed on small crustaceans and algae etc.	Many times in a year. Submerged vegetation serves as breeding requisites.	Fast grower. Above 1.0 kg /Yr.	Typical lake fish. Dominant in fish catches in all Kumaon lakes
Larvicidal fish and also feeds on zooplankton .	Many times in a year.	Prolific breeder	Introduced to control the growth of malarial mosquitoes in Kumaon lakes. Dominate littoral zones of lakes.

Table 27. Angling license issued per year by Nagar Palika Parishad (Nainital).

Year of issue	License issued
1993 – 1994	34
1994 – 1995	47
1995 – 1996	17
1996 – 1997*	39

* Angling banned as per Administrative order and not resumed till date.

fishing has been banned no attempt has ever been made by any institution or research worker to investigate fish population structure. Whatever information is available is based on records of NRCCWF or other individual efforts. As per the records made available by the Nagar Palika Parishad, Nainital, the license for angling to individuals was issued. The records from 1993 to 1997 made available are produced in table 27, but records prior to 1993 seems to have been destroyed as per routine departmental practice. But these license records do not reflect any information on the fish species caught or their number or weight. The license was issued on a yearly basis against a payment of Rs.100 per license. As per the conditions, angling was allowed for 5 days in a week except for Tuesday and Saturday and not permitted during breeding season, without specifying any month. The angler was permitted to fish between 8A.M. to 4 P.M. only. No yield estimates can be worked out on such information.

This method of fishery management is not based on any scientific norm. Further, as per records available with Nagar Palika Parishad some fish seed was stocked into the lake, but no information is available about the species stocked their inter-specific ratio and rate of stocking in the lake. But it is expected that

Table 28. Information on seed stocking as maintained by Nagar Palika Parishad.

Date of seed stocking	Numbers released
18 . 04 . 1985	50,000
05 . 03 . 1987	2,000

only those species were stocked, the seed of which was easily available in the hatcheries located in the plains of erstwhile Uttar Pradesh. The seed stocking details are given in table 28.

The seed between 1985 to 1988 was stocked by the Nagar Palika Parishad but records about species stocked is not known, it is presumed that Common carp (*Cyprinus carpio*) seed was released into the lake. After 1988 no stocking was undertaken by Nagar Palika Parishad but Johri *et al.*, (1989) reported that 2,000 fingerlings of sliver carp were stocked. This was followed in the year 1997 by stocking of sliver carp fry by the scientists of Fisheries College, G.B. Pant Agriculture University with an objective to control algal blooms in the lake, at the instructions of the then Governor of U.P. But none of these stocking activities were based on any production dynamics requirement of the lake. Even after stocking the seed, no attempt was made to undertake experimental fishing in the lake from time to time to evaluate the stocks and their population structure.

5.3.2 *Experimental Fishing*

There is only one record of experimental fishing, which was carried out by NRCCWF after obtaining a special permission from the district administration, Nainital. This one time observation could not be repeated due to objection raised

Table 29. Catch composition of experimental fishing in lake on October 20, 2001.

Fish species	No. fish caught	Total wt. (kg)	Length range (mm)	Weight range (kg)
Cyprinus carpio (Common carp)	50	98.100	295-610	0.9-4.0
Ctenopharyngodon idella (Grass carp)	1	6.300	740	6.300
Hypophthalmichthys molitrix (Silver carp)	23	88.100	560-680	3.2-4.5
Schizothorax richardsonii (Snow-trout)	1	0.500	340	0.500

Experimental fishing for population studies

by local environmentalists on experimental fishing initiative of NRCCWF, to assess fish population structure in this lake. The data generated from one time study is given in table 29.

Six numbers of gill nets (75 m x 8 m) were used in this fishing. The nets with knot to knot mesh size of 2.4 to 5 inches were employed to catch the big size fishes. The nets were operated along Thandi Sarak from Hanuman Ji Temple towards Naina Devi Temple being relatively undisturbed area of the lake. The maximum catch as indicated in the table was up-to 1m depth of the net but the nets were lowered up-to 8m depth column of the lake, hardly any fish was gilled / caught below 1m of the net. Indicating that fishes usually remain at the upper region where water quality especially dissolved oxygen is comparatively near to optimal. This one time record cannot be considered for estimation of the annual fish yield from the system. Even if we use this one time data and assuming only 100 fishing days in a year we land up a figure of 300 kg $ha^{-1}y^{-1}$ which is very

Table 30. Percentage composition in experimental fishing.

Parameter	Common carp	Grass carp	Silver carp	Snow trout
In terms of total numbers	66.6	1.36	30.6	1.36
In terms of total biomass	50.8	3.26	45.6	0.30

The length and weight of fishes caught during experimental fishing indicate that they are in the age group of 3 to 9 yrs. (*Schizothorax richardsonii* approx. of 9+ yr., Grass carp and Silver carp of about 3+ yr.each and Common carp about 4+ yr.). Implying that transplanted stocks of exotic carps appear to have established. These species except common carp would not breed in the lake system. Similarly occurrence of one snow-trout indicates previous population, which may be still surviving under stressed conditions, but it may not breed in the system. But one time experimental fishing cannot answer most of the fish population questions. If the observation of Pant *et al*., (1983) who reported *Schizothorax richardsonii, Tor tor* and *Cyprinus carpio* as main fishery in the lake is examined in the present context, the scenario appears to have changed markedly. Still regular catch data is of prime importance to manage and forecast the fishery of this important lake.

5.3.3 Potential yield

As discussed above the actual fish yield estimations from the lake is difficult due to paucity of required data. However, an attempt has been made to indirectly estimate the potential on the basis of food-chain energy available in the system. Based on the energy conversions of the total net primary productivity data as per the published work on the lake, it is estimated that contribution of phytoplankton productivity is 2.9×10^6 g cal m^{-2} y^{-1} while macrophytes contribute additional 1.1×10^6 g cal m^{-2} y^{-1} totaling to 4.0×10^6 g cal m^{-2} y^{-1} as the basic energy source to sustain secondary and tertiary food-chains. Since the fish species in the system mainly feed on primary and detritus chain, this cumulative energy is available to them for sustenance and growth. If we consider all the energy losses through different pathways operating in the lake and with known conversions from the published records (Vass & Zutshi, 1983), it is estimated that at 0.5% conversion efficiency between total primary productivity and fish, the Nainital lake has a potential to a fish yield of 167.5 kg $ha^{-1}y^{-1}$ but on a conservative

5.3.4 Constraints in achieving potential

It is clear from above that lake has significant potential to raise and sustain fish biomass but in the absence of actual estimates on fish production data from the lake it is rather difficult to know as to what percentage of potential is currently achieved. But based on the existing limnology of the lake it is expected that it would be far below the potential. The main likely reason for a such a situation being that, a large volume of lake between 6m down to mean depth of 18 m being oxygen stressed area. Unless the minimum critical level of dissolved oxygen is available to fish its survival and overall physiology will be distressed. The concentrations of other water quality parameters have also increased to level which cause stress to fish stocks. The permissible levels of some water quality parameters for stocks of coldwater fisheries are set in table 31.

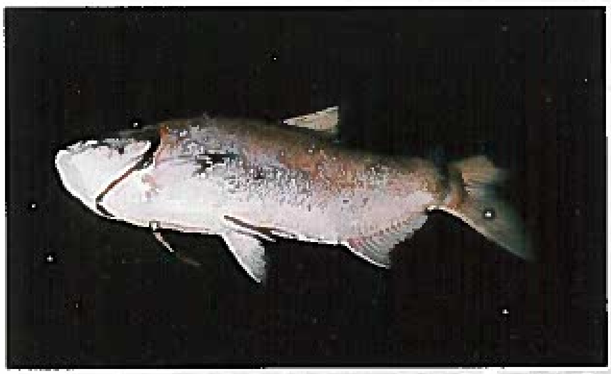
From the data set in the table 31 it is noted that for most of the parameters, the existing concentrations of Nainital lake are much higher than the permissible recommended levels. Thus fish would invariably remain restricted to the upper layers, which is also supported from the data generated by the experimental fishing conducted by NRCCWF. Further, in the upper layers the shift in phytoplankton populations have resulted in the dominance of those species, which normally do not constitute the food items of stocks available in the lake. The stressed water quality has also resulted in disease and infection among fish stocks. Pant *et al*., (1983) reported that fishes (*Schizothorax*, *Cyprinus carpio* and *Tor*) caught from the lake were infected with *Saprolegnia* and with trematodes. No information on natural recruitment in the lake is available but it is expected that apart from *Cyprinus carpio* no other economic species would naturally breed in the system. Lastly the complete ban on fishing either, commercial, experimental or angling has also resulted in not knowing the current fishery status of the lake, thus an indirect constraint for not achieving the potential. Pant *et al*., (1983) while discussing the fish productivity of the lake, also expressed that blue-greens, *Microcystis* and *Anabaena* being unpalatable are not consumed by the important fish species *Schizothorax*, *Tor* and *Cyprinus carpio* and *Puntius* of the lake. So large quantity of energy fixed by these organisms is not used by the grazers and after decomposition settles at the bottom sediments, resulting in accumulation of organic matter. Moreover, majority of the species present in the lake are primarily herbivore, remain confined to the epilimnetic waters because profoundal and deeper zones are uninhabitable due to toxic gases and anoxic conditions. Since

Table 31. Permissible water quality standards for fish species available in hills.

Parameter	Salmonids/ Snow-trouts	Cyprinids/ Mahseer	Remarks
Temperature (°C)	Increment not more than 1.5°C Temperature not to exceed 21°C for more than 90% time	Increment not more than 3°C Temperature not to exceed 28°C for more than 90% time	Sudden variation should be avoided Species requiring coldwater for reproduction have upper limit of 10°C during breeding season.
Dissolved oxygen (mg/l)	50% samples > 9 100% samples > 7 If D.O. values fall below 6 mg / l	50% samples > 8 100% samples > 5 If D.O. values fall below 4 mg / l	It should be daily mean value (to be achieved). Identify the cause and take remedial action.
pH (units)	6 – 9	6 – 9	Variation should not be more than 0.5. No increase in those substances whose toxicity enhances with pH.
Suspended solids (mg / l)	Average value < 20	Average value < 30	Higher levels during floods to be excluded.
Biochemical oxygen demand (mg/l)	Average value < 3	Average value < 6	Harm to fish is by low DO and higher BOD.
Total phosphorus (mg/l)	No specific value set	No specific value set	Inputs to be regulated to prevent eutrophication.
Nitrites (mg /l NO_2)	Average value < 0.01	Average value < 0.03	Becomes toxic at low Chloride levels.
Total Ammonia (mg /l	< 0.04 (ideal) < 1.0 (imperative)	< 0.2 (ideal) < 1.5 (imperative)	Causes toxicity in combination with other factors

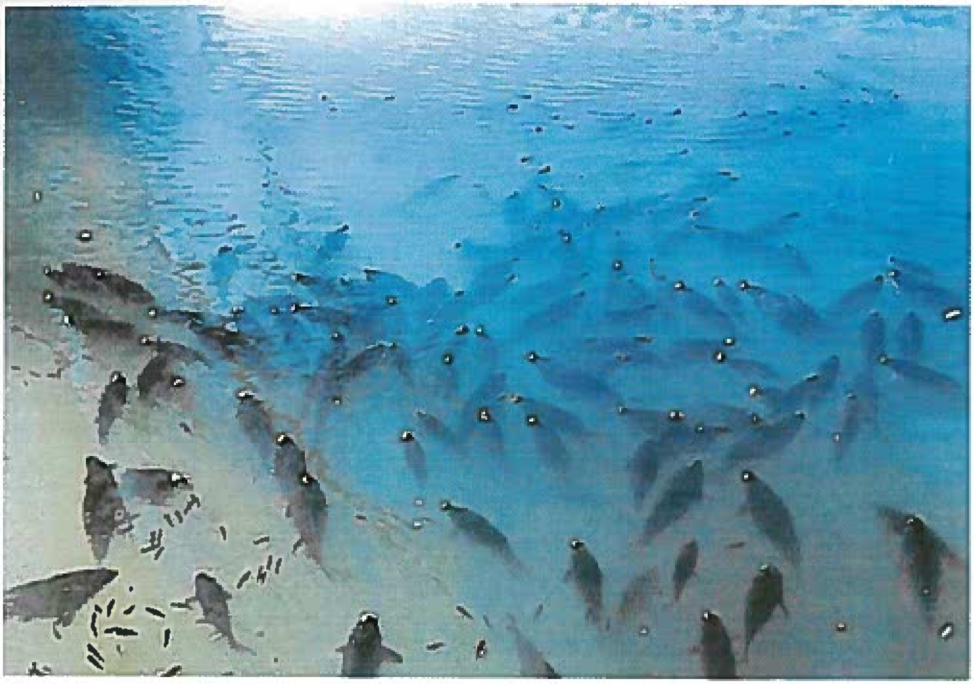
Parameter	Salmonids/ Snow-trouts	Cyprinids/ Mahseer	Remarks
Total Zinc (mg/l Zn) at water hardness (mg/l $CaCo_3$)			Toxicity reduces as hardness increases
10	< 0.03	< 0.3	
50	< 0.20	< 0.7	
100	< 0.30	< 1.0	
500	< 0.50	< 2.0	
Dissolved Copper (mg / l Cu) at water hardness (mg/l $CaCo_3$)			Toxicity reduces as hardness increases
10	< 0.005		
50	< 0.022		
100	< 0.040		
500	< 0.112		

5.4 Winter fish kill



Affected *Hypophthalmichthys molitrix* (Silver carp) during winter in the lake

Fish kill in Nainital lake has been reported by many workers. This feature has now become a regular phenomenon, particularly in winter months. Das and Pathani (1978) and Raina and Petr (1999) reported fish kill in this lake, they attributed it to high phytoplankton blooms (*Chroococcus* sp.), high turbidity and low dissolved oxygen concentrations. This bloom clogs



Surfacing of fishes in the lake during winter kill period (under distress)

very high (14.0 mg/l) in the daytime due to high phytoplankton biomass, very high oxygen consumption during night causes depletion in early morning hours, resulting in fish kill. During winter of 2001-2002 scientists of NRCCWF also investigated winter fish kill, as per their findings, Nainital lake was in highly anoxic conditions recording only 7-21% dissolved oxygen saturation in the entire column of the lake even during isothermal period (January), indicates system to be stressed. The values of dissolved oxygen during winter ranged between 0.5-0.6 mg/l at bottom layer to 3.0–4.3 mg/l at surface water during morning hours. On some occasions, in early morning hours in winter months, even the surface oxygen was 1 mg/l or less. The hydrogen sulphide restricted to hypolimnion region prior to

winter, cumulatively make the fishes come to surface and gasp for oxygen, become stressed/inactive and fall easy prey to local people, who kill the bigger ones on a mass scale. The un-wanted ones like *Gambusia, Puntius* die on surface and decompose back into the system. During winter kill, *Hypophthalmichthys molitrix* and *Cyprinus carpio* alongwith *Puntius conchonius, Gambusia affinis* are mainly affected species. The main reasons are i) the detritus remains undistributed and undergoes partial biodegradation under anaerobic conditions; ii) least flushing of enriched column water even during monsoon rains (may be only surface column is drained with no impact on lower layers); iii) and consequently toxic substances such as NH_4 and H_2S are produced and the fish mortality oc-

Broadcasting of lime into the lake

curs from time to time particularly during winter, when density barrier of the lake is broken. The winter fish kill in the lake is manifestation of its extreme environmental condition. Nagdali and Gupta (2002) while investigating the impact of mass mortality of mosquito fish in Nainital lake indicated that mortality of this species was related with the fungal infection. It is believed that fungal zones in the lake are least affected. The degree of fungal infection was so severe that the gills were choked and fishes died due to lack of gaseous exchange through gills. This mortality even influenced the planktonic chain leading to changes in other eutrophication related features and had an impact on the nutrient status of the lake during this particular period. As per observations of Nagdali and Gupta (2002) the population of *G. affinis* normally re-establishes after three months of winter mortality, due to its prolific breeding capability in this lake.

5.5 Problem of *Gambusia affinis* (Mosquito fish)

Throughout the world the introductions have caused both positive and negative impacts on the indigenous fauna. Kumaon lakes including Nainital lake about a decade back were stocked with *Gambusia affinis* at the instructions of authorities in Malaria Control Organization with an objective to control malaria in the region. The *Gambusia* being the fish of lacustrine habitat is known for its ability to withstand wide environmental conditions of temperature, oxygen and nutrients. It is a typical larvicidal fish and also known to feed voraciously on zooplankton. In Nainital lake it confines itself towards littoral zones forming dense population and avoid invading limnetic zones. It is a prolific breeder and produces young ones many a times in a year. Meyer (1965) while discussing the role of introducing *Gambusia affinis* into various wild localities, particularly as an agent for the destruction of mosquitoes, pointed out that the effects of *G. affinis* may be very serious. He commented that "when placed in a new environment where natural checks do not occur and native species have no defenses, it may crowd out the natural fauna".

The introduction of *G. affinis* in Nainital lake, which has presently dominated the highly enriched margins of the lake has an impact on the natural balance of previously dominant fish species of *Puntius* alongwith juveniles of other fishes. Its superior competitive ability has lead to competitive displacement of other small fishes inhabiting all along the margins of the lake. This fish as such, does not invade the limnetic zones of the lake and has no impact on important fishes like *Schizothorax richardsonii*, Chinese carps and *Cyprinus carpio* etc. These fishes normally remain in clear limnetic zones and seldom come to littoral zones. Sharma and Singh (2001) reported that Nainital lake has developed large population of *G. affinis*, as a result zooplankton population has decreased, consequently the blooms of phytoplankton have increased. The best way to control *Gambusia*

Central Indian wetlands reported that *Daphnia magna* is very effective in reducing the algal biomass of *Microcystis aeruginosa* under simulated conditions. In Nainital lake *Gambusia* does not constitute fish of any commercial value, but its biomass can be periodically harvested, dried and sold in the market, as is being practiced in other Himalayan states like Jammu & Kashmir, especially in Kashmir. The possibility of its use as fish meal can be examined. But prior to that we must estimate likely biomass potential of this species from the lake.

Nagdali and Gupta (2002), while analyzing the role of *G. affinis* in Nainital lake expressed that complete removal of this species may be one of the key mechanisms to improve the water quality of the lake, though this may not be the sole solution for the water quality improvement. Control of external and internal nutrient inputs along with the application of biomanipulation, eco-technology will work well in improving the water quality of Nainital lake. Bio-manipulation will also reduce the cost/benefit ratio, because of its relatively low implementation cost (Nagdali and Gupta, 2002).

It is abundantly clear that stocks of native fishes (*Tor* and *Schizothorax*) in Nainital lake have declined drastically. The reasons of this decline are complex but connected mainly with rapid ecological degradation and impact of introduced fish species to some extent. Some of the native species appear to compete with or survive in the presence of alien species.

6. RESTORATION AND DEVELOPMENT ISSUES

6.1 Observations and discussion

6.1.1 Morphometric changes of Nainital lake

Rawat (1987) studied morphometric parameters in relation with depth pattern of the lake and indicated that mean depth of the lake has gradually decreased, registering a decrease in area below 25 m surface of the lake. This reduction of the area in the deeper part is mainly due to progressive basin filling by sediments. The gradual reduction of the area in the shallow levels is related to the development of debris fans at the mouths of many streams that drains the slopes of the surrounding hills. Accordingly volume of the lake has considerably reduced in the last 85 years from 31,699 m^3 in 1895 to 26,202 m^3 in 1979. There is thus a reduction of 5,497 m^3 in 84 years. The rate at which the amount of sediment increased in the lake was 63.93 m^3/year between the years 1895 and 1969.This rate has increased to 77.63 m^3/year between 1969 and 1979 ,probably the result of increased human activities on the lake and within its catchments .Based on the present rate of the sediment filling (i.e., 66.37 m^3/year) it can be predicted that the Nainital lake with a capacity of 26,202 m^3 will be completely filled up in about 380 years (Rawat,1987).Some time scale changes recorded on the morphology of the lake are tabulated below:

Parameters	1895 AD	1969AD	1979AD
Sediment depth	27.45 m	26.75 m	25.70 m
Mean depth	21.43 m	20.64 m	18.55 m

Hydrologic data of Nainital lake water

Depth in m	Area in Sq.metres		
	1895 AD	1969 AD	1979 AD
0 (Surface)	1758	1757	1757
05	[illegible]	[illegible]	[illegible]

Table 32. Distribution of water volume in the Nainital lake at different depth groups (after Rawat, 1987).

Depth groups (Meters)	Water volume in Cubic meters		
	1895 AD	1969 AD	1979 AD
0 –05	7516.68	7453.05	8388.19
05-10	7290.99	6709.66	6558.60
10-15	6249.95	5673.04	5478.64
15-20	5289.58	4351.98	4255.20
20-25	3127.51	2119.42	2003.22
Above 25	1724.79	670.27	518.19
Total lake	31699.45	26978.42	26202.04

6.1.2 Trends in biotic communities / indicators

The species richness of the communities of lake Nainital can be arranged in the decreasing order from phytoplankton (69) to macrozoobenthos (30). Species diversity is quite low for all communities viz.phytoplankton (2.0), zooplankton (1.5) and macrozoobenthos (1.0). Obviously the number of dominants partitioning the resources of the ecosystems should be very low; if species constituting more than 90% of the annual standing stock are considered dominant for the present purposes, there are only 6,4 and 5 species in the phytoplankton, zooplankton and macrozoobenthos, respectively .The dominance vs. diversity curve for phytoplankton in the nearby mesotrophic lake Bhimtal (Sharma *et al.*, 1982) and for zooplankton in another local lake, Sattal (Pant *et al.*, 1985) is far less steep than that for lake Nainital. The existence of few types of individuals in large numbers indicates that the water body concerned is polluted. The lake is undoubtedly passing through the bloom stage of ecological succession where smaller autotrophic organisms (nanoplankton) tend to dominate over the larger ones. Since respiration exceeds production and the ratio between the two is less than 1, the developmental sequence of the lake can also be called as heterotrophic succession. Most of the biological energy passes through the detrital pathways derived from autochthonous and allochthonous sources. The mean annual ratio between phyto and zooplankton biomass is 3.3 and between phytoplankton and herbivorous, it is 4.6 If biomass is treated as measure of crude production, the

According to Patalas (1972) the crustacean plankton community (Diaptomid and Cyclopids and Cladocera) structure in Nainital lake falls under category III/IV, indicating increasing complicity. These organisms are well adapted to low oxygen concentrations and often used as indicators of the organic pollution. *Daphnia*, which is inhabitant of oligotrophic waters, is totally absent in Nainital. Perhaps the lack of suitable food due to the mass growth of unpalatable species led to the elimination of this organism, and, in the course of time, *Diaphanosoma* appeared and found these food particles to be excellent source of nourishment. *Asplanchna priodonta, Harringia rousseuleti, Dicranophorus robustus, and Didymodactylus carnosus* recorded by Sharma and Pant (1985) from Nainital lake reflects comparatively higher trophic status of the system as compared to other Kumaon lakes where these species are not recorded. Certain species of zooplanters like *Bodo, Bursaria, Phillodina, Oxytricha, Spirostomum, Epistylis, Brachionus, Keratella* etc. reported by Pant *et al.*, (1981) in appreciable quantity particularly near and around the inlets of open drains of the lake and their absence in profundal zones clearly indicated the characteristics of a polluted state of limnetic zones of the lake. These species according to above authors can act as biological indicators of water pollution in Nainital lake.

Out of the several environmental parameters, food, dissolved oxygen and temperature are the important factors determining the faunistic composition and biodiversity in Nainital. According to Sharma and Pant (1985) there is significant correlation between phytoplankton concentration and the number of zooplankton species; water temperature and dissolved oxygen contraction contents and number of zooplankton. The rotifer shows a more significant relationship with the phytoplankton population in Nainital lake (r=0.92) compared to Bhimtal (r=0.72). This is mainly due to the fact that in Nainital lake nanoplankton forms more than 60.0% of the total phytoplankton population and rotifers will be utilizing number of these nanoplankton due to their small size.

Certain biological characteristics of the lake revealed that there are many organisms which are indicative of biological indicators of water pollution. Amongst the main groups the dominant species recorded from this system are as under:

Phytoplankton	*Chalmydomonas* spp; *Microcystis* spp; *Spirogyra* spp; *Oedogonium* [illegible]

6.1.3 Water quality index

The average values of biological oxygen demand (BOD), a parameter used for indicating pollution, ranged from 7.0 –18.0 mg/l in the surface waters of the lake. Summer months depicted higher values, while lowest was recorded during precipitation/monsoon period. As per the standards, the value of 3 mg/l or more in the surface waters is considered as a critical level and waters having such values are classified as polluted waters (ICMR, 1963). The high concentration of BOD could be attributed to the unchecked disposal of organic matter directly into the system. The higher and lower values of BOD are well correlated with concentration and dilution of lake water during winter and monsoon periods. The release of certain toxic gases was qualitatively assessed during different periods of the year. Ammonia occurred throughout the year in the deeper zones of the lake, relatively high in winter months. While, hydrogen sulphide was recorded through out the year, however, its production at various depth zones in different periods was associated with significant drop in dissolved oxygen concentrations. Pant *et al.*, (1981) reported release of methane gas bubbles from deeper zones to the surface layers particularly during winter months, presumably resulting from extreme anoxic conditions in deeper waters. Probably, the detritus remains undisturbed and undergoes partial biodegradation under anaerobic conditions. Consequently toxic substances, such as NH_3 and H_2S etc., are produced and the fish kill occurs.

6.1.4 Production functions

Most of the times, the productivity was nil at 6 m water depth. The biannual mean of gross production Pg (across months and depth) was 561 mg C m^{-3} d^{-1}. There was no significant difference between annual mean values of Pg in two successive years. The mean values (across depths) varied from 85-1294 mg C m^{-3} d^{-1} during the first year and from 88-927 mg C m^{-3} d^{-1} during the following year. Seasonally, the maximum Pg was recorded in March and the minimum in January during both years. Thus, seasonal variations during both years were significant ($p<0.01$). Two peaks, in October and March characterized the seasonality in Pg. During the first year, the magnitude of March peak was greater than that of October, but in the following year both the peaks were almost of the same magnitude. As it could be expected, the biannual means (across months) of Pg declined with water depth. However, the values at 0m and 1m depths were almost same. The correlation coefficient indicated a significant negative relation (r= 0.98) at 6m or below.This is clear manifestation that the eutrophic zone extends up to between 3.0 – 6.0 m. The productivity is high in March and August. This conforms to the bimodal peak of algal populations. The highest Gross and Net productivity recorded was 1965 and 873 mg C m^{-3} d^{-1}, respectively, while highest respiration values were recorded in March to the tune of 1099 mg C m^{-3} d^{-1}. On the basis of Production and Respiration ratio, the whole lake is consumptive (if P/R =1.0 the ecosystem is stable; if value of P/R >1.0 an indication of accumulation of organic matter and P/R <1.0 value disappearance of organic matter). If all the values of Production and Respiration are summed together, for the lake upto 6m,the P is 34466 and R is 30191 and hence the lake upto 6m is productive P/R ratio being 1.14. The depth of the lake (average) is 18.0m. The productive zone is restricted upto 6.0m,the rest being consumptive. Between 6.0 – 18.0 m at least half of the lake volume is totally consumptive. There is no harvesting of biomass at any level.

The plankton food chains are remarkably short in Nainital lake, this is attributed to the stressed environmental conditions (Pant *et al.*, 1983). The total herbivore biomass never exceeds the phytoplankton biomass. The annual ratio of phytoplankton to zooplankton (P/Z ratio) is 3.3,which is considerably higher than reported in other Kumaon lakes (below 1.0)The ratio of phytoplankton to herbivore zooplankton is 4.6, suggesting that a major portion of primary production remains unutilized by the herbivore in this lake. The blue-greens alone contribute 35.4% to the total annual mean phytoplankton biomass of the lake, and most of them (viz., *Microcystis* and *Anabaena*) being unpalatable are not consumed by the important food fishes (*Schizothorax richardsonii*, *Cyprinus carpio* and *Puntius conchonius*). The utilization of the food depends upon the relative abundance of developing stages of the fish and the prey. Since most of the energy in the plankton component is dissipated through the decomposer chain, very little energy is available to sustain the biomass of the fish in this lake.

6.2 Fishery development

6.2.1 Restoration of declined species

Any fishery rehabilitation or management programme in a lake system require information on behaviour of stocks. But due to non-existent policy on fishery management for this lake, non-availability of regular scientific data on fish populations, the existing data being patchy, it is ...

It would imply that whatever existing fish biomass is in the lake, is allowed to grow, get diseased, eventually die and decompose within the system, thus adding annually to the nutrient load. Winter fish kill of stocks has been regularly reported from the lake. But no effort has been made to study the population structure, catch composition and breeding cum maturity behaviour of existing populations in the lake. Therefore, there is urgent need to undertake population studies in the lake with proper permission to carry our regular experimental fishing by using different gears. This should be a priority activity.

Exclusively, carp fishes are found in the lake and among them the important food fish are: *Schizothorax, Cyprinus carpio* and *Hypophthalimichthys molitrix.* The first species is a herbivore whereas the latter two are omnivore. Since the profoundal zone is uninhabitable due to pollution, toxic gases and anoxic conditions, these fishes remain more or less confined to the epilimnetic waters. Omnivore fish feed on a variety of food items. However, the utilization of the food depends upon the relative abundance of the developing stages both of the fish and their prey species. Since most of the energy in the plankton component is dissipated through decomposer chains, very little is available to sustain the biomass of fish. It is therefore believed that the Nainital lake has lost the potential to increase the productivity of indigenous fishes.

Because of stressed water quality in the lake the fish stocks that were reported to be available in lake in the past have drastically declined but such information is based on qualitative information and no reliable quantitative database is available. Based on qualitative information it can be concluded that indigenous Himalayan species (mahseer and snow-trout) have almost finished from the system. In order to rehabilitate these species in the lake, two pronged strategy should be planned, first to make efforts to improve the water quality of the lake in which restoration of oxygen balance will be critical; second to plan stocking and harvesting strategy involving stocking size, number per hectare, species combination. For improving the water quality, especially in the entire hypolimnetic zone of the lake, one can resort to selective discharge technology, it may work. But with regard to fishery the one possible disadvantage, is the likely effect of high phosphate and low oxygen / anoxic concentrations in the discharge stream. If that stream contains important fishery or is used for any other purposes, then special precautions are necessary.

research on lake waters, during the last two decades. Such developments have helped to overcome some of the technical problems, and acquiring useful insight into the causative factors behind the eutrophication and the resilience of the lakes to amelioration. This knowledge has certainly provided impetus to lake restoration. Despite this, non-point nutrient discharges, especially from domestic sewerage remains a major challenge to lake restoration.

In the Kumaon, the growing demands of local residents to meet the challenge of increasing tourism and other development programmes have increased pressure on all most all the lakes particularly on lake Nainital. This lake has been witnessing a dramatic increase in recreation. Amongst the Himalayan lakes, Nainital is perhaps the most ecologically damaged system caused by the input of sewage. It cannot fully recover even if the pollution discharge into the lake is diverted. However, based on reliable database on various characteristics, generated by different workers on the Nainital lake, some of the suggested restoration measures are as under:

Yatching as a tourist activity in summers

6.2.2.1 Reduction of external nutrient loads

Wastewater treatment and diversion of nutrients from lake inflows are the foremost techniques used to reduce external nutrient loading. The present status of water quality of Nainital lake tends to indicate that the lake is significantly eutrophic and this level has increased with increase in accumulation of nutrients in waters particularly NO_3- N and Phosphate. However, based on the studies on reduction of external P loads indicates that even though the in-take P may not be lowered in response to a decrease in the external loading, an improvement

Point source of pollution of the lake

with low nutrient levels and preferably rich in Ca and HCO_3. Dilution as a restoration tool, therefore, implies necessarily reducing the concentration of nutrients in lake water to limited concentration. The use of nutrient –poor water for this purpose also reduces the suspended seston to achieve the best dilution effects, the timing of the flushing is important. In addition, the quantity and quality of the water to be used needs to be worked out before hand. Although the technique has great potential, it depends greatly on the sustained availability of good quality water. Winter season, when algal growth is generally at a minimum and more water is available, flushing is preferred.

6.2.2.3 Siphoning of the hypolimnion

Water can be used to obtain some degree of recovery of Nainital lake. The hypolimnion has higher contents of Phosphorus and other nutrients than the epilimnion due to pronounced release of nutrient from the sediments under anaerobic conditions. The nutrient rich water has to be released in a zone where water is not used for human consumption otherwise, it would require treatment. Moreover, bathymetry map can be made to locate the zones for siphoning. This

6.2.2.4 *In-situ measures*

Internal P loading from the sediments invariably affects lake recovery. Careful removal in the upper, often loose, sediment layers, is quite expensive, and although immobilization of P in the sediments by chemical fixation is an alternative to sediment dredging. These techniques have been attempted in many lakes in Europe.

Sediment dredging in Nainital lake

6.2.2.5 *Aeration of hypolimnetic water*

In Nainital lake nutrients are released more rapidly under anaerobic conditions, internal loading is a major problem in this lake. The rate of Phosphorus release from the sediments can be reduced by a shift from anaerobic to aerobic conditions in the hypolimnion. This method in Europe has given very effective results, particularly that lake which develops thermocline. In the initial phase, mechanical aerator or ozoniser cum aerators can be tried to assess the improvement of the lake.

start establishing themselves, but sustained stocking is needed because there are no natural breeding grounds of these species within the lake. This restoration of biodiversity will be a major achievement

As per the primary production estimates of the lake, the pattern of food chain, biologically the system is quite rich and this energy can be converted into fish biomass provided scientific management is applied. The production enhancement is quite possible to the tune of 35-70 kg ha^{-1} which will give us an anticipated biomass of more that 2 tonnes from the lake and fish will have the market value of Rs. 2.00 lakh. The production of right sized fingerlings for the lake can be ensured through cage culture of seed at suitable places in the lake. Assuming to achieve a yield of 70 kg $ha^{-1}y^{-1}$ and expecting an average growth rate of 250 g per fish per year due to climatic constraints and allowing 20% additional stock for losses the fingerling stocking should be 340 per hectare. This can be executed in two phases. In phase-I it should have a ratio of 40:60 common carp and silver carp and after the water quality improves during phase-II the stocking ratio should be 30:50:10:10 common carp, silver-carp, snow-trout and mahseer. But the existing biological productivity cannot be effectively transformed into fish biomass unless the water quality and nutrient load is reduced to the desirable levels. It is clearly observed that any fish rehabilitation programme will not prove a success unless the acceptable standards are met with. The fishery development and enhancement in the lake will accrue social benefits to the local population. In a tourist place like Nainital the fish produced from the lake will help to establish fast-food joints based on fish products for the tourists, this will help generate local self-employment also.

6.3 Policy support and Action Plan

Fisheries management is a term and practice widely used among fisheries biologists and fisheries related workers. It is a practice with socio-economic objectives, constrained by biological feasibilities. In this process fish stock management is a practice with biological objectives, constrained by socio-economic factors. These management issues are based on following assumptions:

- Fish populations respond to physical and chemical characteristics of habitat.
- Fish populations are at the habitat's carrying capacity

In order to translate above assumptions, following action plan is proposed which can help in ecological management of system and develop fish stocks.

Therefore, scientific fishery development action plan for the Nainital lake can be successfully implemented if the necessary policy support is provided. The first issue is that fishery management in the lake has to be under the control of nodal department in the state. The ownership / control of the water body needs to be re-examined, because preservation of general lake environment and fishery management are interlinked processes. The stocking / harvesting schedule of fishing from the lake should be decided by the technical experts, the population management involves lot of scientific information which should be left to development departments with a committee of technical experts. Some nodal department can be made responsible for licensing mechanism for sport fishing, this needs to be regulated with regard to bag limit and stocking of desirable size of sport fishes for making it sustainable. Any action on fishery management should not exclusively be an administrative decision. In order to rehabilitate the indigenous species in the lake, a hatchery and farm complex should be developed preferably near Bhimtal or any other nearby suitable place to artificially breed the fishes and produce required quantity of seed for stocking.

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