ECOLOGY AND FISH YIELD POTENTIAL OF SELECTED RESERVOIRS OF KARNATAKA

Central Inland Capture Fisheries Research Institute
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Foreword

The future of inland fisheries development in India largely rests with the scientific management of reservoirs. Though reservoir resource is vast and has great potential, it is a much neglected sector for various reasons. The reservoir management on scientific lines calls for some expertise in understanding the ecology and fish yield potential. Keeping this in view and also to develop a national reservoir database, the Reservoir Division of CIFRI, Bangalore, has taken up rapid survey of a number of reservoirs covering different river systems in several states.

The inland water resources of Karnataka is one of the richest in the country. The state has two main drainages, *viz.,* east flowing large rivers such as Krishna and Cauvery with their tributaries and the west flowing rivers having a short run. The reservoirs for survey have been selected representing the drainages each one having its own distinct eco-morphological characteristics. I am sure, that the management guidelines indicated will be beneficial to the managers to develop and manage fisheries of these reservoirs on scientific lines. The potential yield predicted for each reservoir is only a first approximation and higher yield levels could be achieved with experience.

I take this opportunity to thank the officials of the Department of Fisheries, Karnataka for the help rendered for the collection of data. Thanks are also due to officials of Irrigation Department for furnishing details pertaining to dams and reservoirs.

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Introduction

Reservoirs are the most important inland water bodies having great potential in substantially enhancing the inland fish production of the country. Fisheries development in reservoirs is labour intensive, environmental friendly and generates additional income from the resource created for other purposes such as irrigation, power generation and water supply to cities and industries. The riverine sector, which traditionally sustained the fisherman community, has been subjected to over-exploitation due to population increase and access to efficient modern gear. With the result, the riverine fish stocks have been depleted and the fishermen remain in object poverty. In order to conserve riverine fish stocks and to improve the economic status of fishermen community, it is necessary to wean away traditional fishermen from river fishing by creating new opportunities for them. In this context the development of reservoir fisheries assumes importance. Being labour intensive, it generates employment opportunities to the poorest of the poor in the society besides providing the much needed animal protein at affordable cost to the rural populations.

The peninsular state of Karnataka is endowed with rich freshwater resources such as rivers, reservoirs and tanks. The river Cauvery originates in the state and traverses a distance of 320 km before entering Tamil Nadu. Important tributaries of Cauvery in the state are the Hemavathy, the Harangi, the Kabini, the Nugu, the Shimsha and the Arkavathy. The river Krishna and its tributaries, the Tungabhadra, the Ghataprabha and the Malaprabha drain the northern and central parts of the state. Besides, there are a number of rivers originating in Western ghats and flowing westwards into the Arabian sea. Most of the rivers have been impounded either for irrigation or for power generation or both. Reservoirs in Karnataka cover an area of 2.15 lakh hectares with 80% of it under large reservoirs (> 5000 ha).

The large potential of the resource for fish production remained untapped due to lack of information on the ecology and fishery potential and improper management. In order to fill the gap in this area and also to develop a database on the reservoirs of Karnataka, the Reservoir Division of CIFRI, Bangalore has taken up selected reservoirs from different river systems during 1995-97 to conduct a rapid survey. The study also collected information on the present status of fisheries management and infrastructure available at different reservoirs so as to formulate guidelines for better management.

Reservoirs selected for study

The eleven reservoirs covered under the survey belong to three main river drainages falling in nine districts and three geographical zones (Malnad, North & South plains) of the state. The reservoirs selected are : Hemavathy, Harangi, Kabini, Nugu, Manchanbele from Cauvery river system; VV sagar, Bhadra, Narayanpur, Ghataprabha and Malaprabha from Krishna river system, and Linganamakki from the west flowing Sharavathy river. Among the Cauvery basin reservoirs (CB reservoirs), Manchanbele is on the river Arkavathy, the easternmost tributary in the state while others are on the respective tributaries originating in Western ghats. Of the Krishna basin reservoirs (KB reservoirs), Bhadra (on river Bhadra) and VV sagar (on river Vedavathi) belong to the Tungabhadra drainage, Ghataprabha and Malaprabha are on the tributaries and Narayanpur is on the main stream of river Krishna. Linganamakki is on the river Sharavathi. The location of the selected reservoirs are shown in Fig.1.

Sampling procedure

The survey was conducted during 1995-97 for three seasons *viz*. pre - monsoon (April-May), monsoon (July-August) and post-monsoon (October-November). Each reservoir was covered for two days on each occasion. Data on morphometry and hydrology were collected from the dam authorities. Sampling for water and soil quality and biotic communities was done in lentic zone covering both the banks. Primary productivity studies were conducted in lentic zone. Landing centres were visited and details of fish catch and species composition were collected on the days of sampling.

Location, morphometry and hydrology

Morphometry and other details of reservoirs are presented in Table 1. CB reservoirs are situated at lower latitudes between 11° 58′ and 12° 52′ N and at higher elevations ranging from 755.9 to 890.6 m a msl. In contrast, KB reservoirs are located at relatively higher latitudes between 13° 42′ and 16° 15′ N and lower elevations between 492.2 and 633.8 m a msl. VV sagar is the oldest reservoir having been formed in 1901 while Manchanbele is the most recent one filled in 1991. Among others, Nugu (1958) and Bhadra (1963) are relatively older while Narayanpur (1982) and Harangi (1984) are recent ones. Linganamakki is exclusively a hydel reservoir while all others are mainly irrigation reservoirs with hydel component incorporated in some.

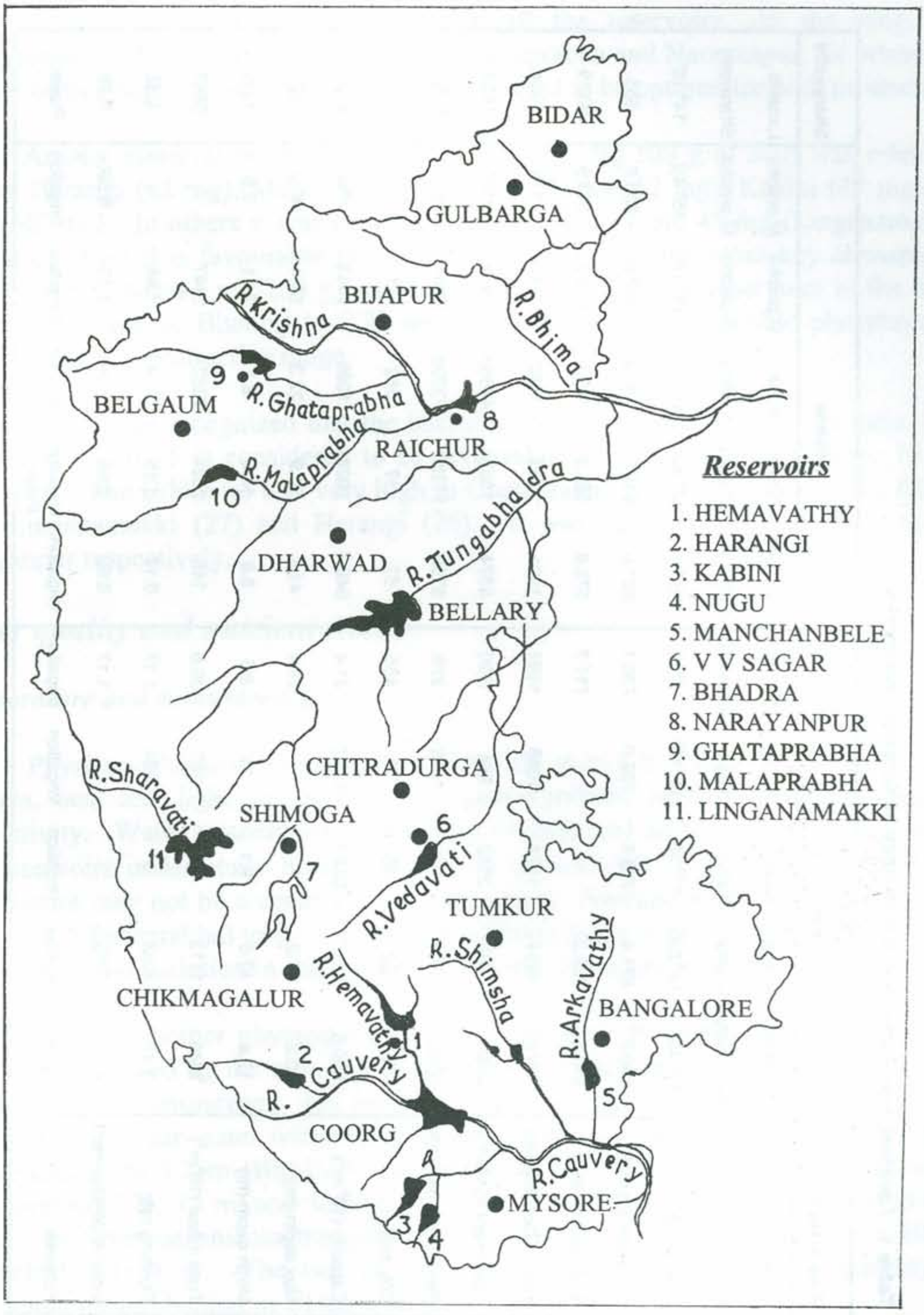


FIG. 1- MAP OF KARNATAKA SHOWING THE LOCATION OF RESERVOIRS

Table 1. Location, morphometry and hydrology of Karnataka reservoirs

River system	**Cauvery**					**Krishna**					**Sharavathi**
Reservoirs	Hemavathy	Harangi	Kabini	Nugu	M.bele	V V sagar	Bhadra	N.pur	G.prabha	M.prabha	L.makki
River	Hemavathy	Harangi	Kabini	Nugu	Arkavathy	Vedavathy	Bhadra	Krishna	G.prabha	M.prabha	Sharavathi
Latitude (N)	12° 40'	12° 29'	11° 58'	11° 58'	12°52'	13°51'	13° 42'	16° 10'	16° 15'	15° 45'	14° 10'
Elevation (m msl)	890.6	871.4	755.9	762.0	736.1	621.0	619.7	492.2	662.9	633.8	555
River Bed (m msl)	850.5	824.2	-	-	711.7	579.6	564.9	469.9	618.7	593.6	502.9
Year of Construction	1979	1984	1974	1958	1991	1901	1963	1982	1977	1974	1964
Catchment (C) (km^2)	2800	419	2142	984	1590	5374	1968	47850	1412	2176	1992
Reservoir area(A) (ha)	8502	1909	6060	1398	329	8759	11250	13200	6837	13578	31728
C/A ratio	33	22	35	70	435	61	17	362	21	16	6
Capacity ($10^6 m^3$)	1050.6	240.7	552.7	154.1	31.4	840.7	2023	1066	1443	1068	4435
Max.depth (m)	40.2	47.2	-	-	24.4	41.4	54.9	22.3	53.4	40.2	52
Mean depth (m)	12.4	12.6	9.1	11	9.5	8.6	18.0	8.1	21.1	7.9	13.6
Total inflow ($10^6 m^3$)	3646	1113	-	283	36.6	145	2324	22824	2147	-	5867
Flushing rate	3.47	4.62	-	1.84	1.17	0.17	1.15	21.4	1.48	-	1.32
Volume development	0.92	0.86	-	-	1.17	0.62	0.98	1.09	1.19	0.59	0.78
Purpose	Irrigation	Irrigation	Irrigation	Irrigation	Irrigation	Irrigation	Irrigation Power	Irrigation	Irrigation	Irrigation	Power

Linganamakki is the largest reservoir with a waterspread of over 30,000 ha and Manchanbele the smallest with an area of 329 ha. All the KB reservoirs are large with Narayanpur, Malaprabha and Bhadra having waterspread of over 10,000 ha. Among CB reservoirs, only Hemavathy and Kabini are large with an area of over 6000 ha, while Harangi and Nugu are in between 1000 and 2000 ha.

Narayanpur, being situated on the mainstream commands extensive catchment, but much of it has been intercepted. Barring Manchanbele, all other reservoirs have catchment situated in Western ghats consisting of hilly valley with deep woods. All the reservoirs are situated in high rainfall zone with the exception of Manchanbele and VV sagar. These two reservoirs lie in the rain shadow region of Western ghats. Most of the reservoirs have uninterrupted catchment with the exception of Narayanpur, Manchanbele and VV sagar. Several reservoirs exist (some are in formation) on the upstream of Narayanpur. Arkavathy river has two reservoirs on the upstream of Manchanbele. Similarly, several tanks have been formed intercepting the catchement of VV sagar. The ratio of catchment to reservoir area (C/A) is very high in Manchanbele (435) and Narayanpur (362), moderate in Nugu (70), VV sagar (61) and Kabini (35) and low in Bhadra (17) Malaprabha (16) and Linganamakki (6). The ratio generally reflects the amount of allochthonous inputs loaded into the reservoir.

Ghataprabha and Bhadra are deeper with mean depth at 21.1 and 18.0 m respectively, while Malaprabha (7.9 m) VV sagar (8.6 m) and Narayanpur (8.1 m) are relatively shallow. In CB reservoirs mean depth varied from 9.1 (Kabini) to 12.6 m (Harangi) with Hemavathy and Nugu having mean depth above 10 m.

The flushing rate (inflow/storage capacity) is very high in Narayanpur. The reservoir gets flushed 21 times in a year indicating that almost lotic conditions prevail in this reservoir during monsoon season till September/ October. In VV sagar the flushing rate is the lowest at 0.17 showing that the reservoir gets annual inflow to the extent of 1/5 of its capacity. CB reservoirs (barring Manchanbele) in general, have higher flushing rate than other reservoirs. Flushing rate gives an indication of the amount of water a reservoir receives in a year in relation to its capacity which in turn reflects on the allochthonous inputs. However, in situations of very high flushing rates, much of the inputs are washed into the downstream. Moderate flushing rate coupled with high C/A ratio will have greater impact on the productivity of the reservoir as these have a bearing on the loading of organic matter and nutrients.

Catchment characteristics

Nature of soil, precipitation and land use pattern in the catchment play a significant role in the productivity of the reservoir. All the tributaries of Cauvery, with the exception of Arkavathy, have their source in Western ghats having dense cover of evergreen forest and high rainfall. Kabini and Nugu originate from the Wynaad district of Kerala. Besides dense forest, plantation crops such as coffee, tea and orange dominate the catchment of these reservoirs. The rainfall ranges between 100 and 200 cm, decreasing from west to east. Predominant soil formation is deep to very deep red, with low to moderate erosion. Temperature varies between 16 and 34° C. Maximum precipitation occurs during May to October, with peak in June.

Harangi has its source in Kodagu district (Karnataka), known for its cool weather and heavy precipitation. Deep to very deep red soil predominates with large extents of coffee plantation and dense forest.

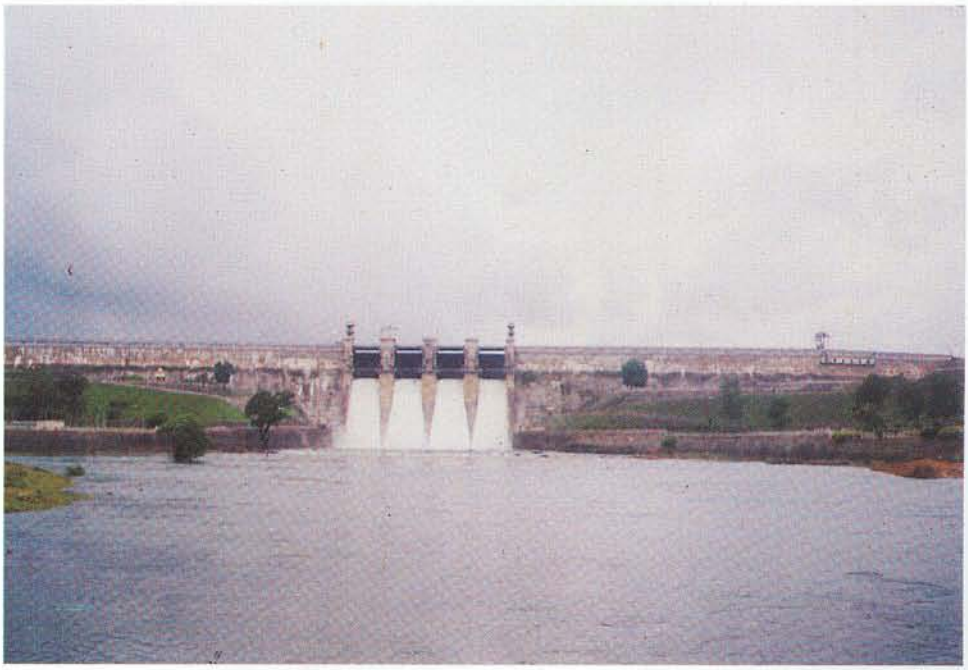
Hemavathy and Bhadra arise in Chikmagalur district where the rainfall varies from 100 to 400 cm, decreasing from west to east. Bhadra flows northeast and joins river Tunga to become Tungabhadra which finally joins Krishna. Hemavathy, on the other hand, takes a southeast course and joins Cauvery. Major area of the land is hilly with forest cover along with coffee plantations and cultivated land. Deep to very deep red soil dominate the catchment which are developed from granite gneiss and ferruginous quartzite and shale with slight to moderate erosion. Soil texture is mostly clay- loam and sandy- clay- loam.

River Vedavati on which VV sagar is situated originates from the hills of Bababudangiri in Chickmagalur district. Rainfall in the catchment varies from 62 to 84 cm, declining from west to east. August- September records over 50% of the rainfall with maximum occurring in September. Temperature varies from 17 (Dec) to 36° C (Apr). There are innumerable tanks in southern part of the catchment consisting of hills, undulating and plain lands. Most of the land is under rainfed cultivation. Sparse to moderately dense forest accounts for significant portion. Geology of the soil is complex and is composed of black and red soil developed from peninsular granite gneiss with moderate to severe erosion.

A view of Linganamakki reservoir

A view of Ghattaprabha (Hidkal) Dam

Exposed shore line of Malaprabha reservoir



A view of Harangi Dam

The catchment of Krishna above Narayanpur dam has two geographic units, hills and undulating plains, the latter dominating. Plains are cultivated both by dryland and irrigated crops. Temperature varies from 22 to 36° C and precipitation ranges from 60-80 cm. Black soil predominate and are well cultivated. Soil is formed from calcereous shale, basal and granite gneiss. Soil texture is clayey to clay- loam and sandy- loam. A large reservoir, the Almatti dam is coming up 65 km above Narayanpur.

Ghataprabha rises in the hill ranges of Sahyadri and flows eastwards. The temperature varies from 14 to 36° C and precipitation is extreme varying from 44 to 285 cm. Soil type is predominantly red-gravelly and non-gravelly with forest, grass and cultivated lands. Forest cover is sparse to medium dense with bushy vegetation.

The catchment of Malaprabha is a narrow valley tapering from upstream to downstream bounded by hill ranges of Western ghats on the west and by their spurs on the east. It consists of hilly and highly undulating lands with very steep slopes to gently undulating lands with moderate slopes to plain lands. It is situated in the transitional precipitation belt on the leeward side of the Western ghats. Hence, the precipitation which was high in Western ghats drops to low values in the east, ranging from 155 to 47cm. Temperature varies from 16 (Dec) to 38° C (May). Soil types vary from black, red and mixed in that order, moderately deep to very deep black clayey subjected to slight to moderate erosion. Major portion of the land is under cultivation, both irrigated and rain-fed.

Physical and chemical characteristics of basin soil

Coarse and fine sand predominate the basin soil in several reservoirs with the exception of Narayanpur. As the catchment of reservoirs (in Western ghats) consists of red soil, with low to moderate erosion, basin texture remained predominantly sandy. Silt deposition has been observed mainly along the river course.

The c hemical characteristics of soil are presented in Table 2. The soil reaction in CB reservoirs having catchment in Western Ghats was acidic with pH in the range 4.9 (Harangi) to 5.8 (Hemavathy) while it was nearly neutral (6.5) in Manchanbele. It was also acidic (pH 5.3) in Linganamakki . In KB reservoirs, it was slightly acidic in Bhadra (5.5) and Ghataprabha (5.8), near neutral in Narayanpur (7.2) and Malaprabha (6.5) and alkaline in VV sagar (8.1). The basin soil of southern Karnataka reservoirs is more acidic than that of northern region. VV sagar being a 90 year old reservoir, the soil had turned alkaline.

Table 2. Chemical characteristics (range & average) of soil of Karnataka reservoirs

Reservoirs	pH	Org C (%)	Total N (%)	C/N ratio	Avail-N (mg/100g)	Avail -P (mg/100g)	$CaCO_3$ (%)
Hemavathy	**5.8**	**1.8**	**0.07**	**28**	**44**	**0.16**	**1.7**
	5.6 - 6.0	1.5 - 2.0	0.05-0.08	22.1-37.8	31.4-59.6	0.10-0.20	1.0 - 2.2
Harangi	**4.9**	**2.7**	**0.1**	**26**	**62**	**0.23**	**2.2**
	4.8 - 5.0	2.3 - 2.9	0.09-0.12	23.8-29.0	60.2-63.6	0.10-0.40	1.8 - 2.7
Kabini	**5.0**	**1.9**	**0.07**	**25**	**49**	**0.30**	**2.4**
	4.9 - 5.2	1.3 - 2.4	0.06-0.08	21.3-29.6	36.4-66.6	0.10-0.60	2.2 - 2.5
Nugu	**5.5**	**1.7**	**0.09**	**20**	**49**	**0.20**	**1.8**
	5.0 - 6.3	1.5 - 1.9	0.07-0.10	15.9-23.2	41.4-54.9	0.10-0.40	1.5 - 2.0
Manchanbele	**6.5**	**1.8**	**0.09**	**22**	**59**	**0.15**	**1.8**
	6.4 - 6.5	1.04-2.41	0.06-0.12	17.0-30.12	55.4-60.2	0.10-0.18	1.0 - 2.5
Narayanpur	**7.2**	**0.7**	**0.05**	**14**	**38**	**0.33**	**1.9**
	6.9 - 7.5	0.6 - 0.8	0.04-0.07	11.4-15.0	26.2-45.4	0.10-0.80	0.8 - 2.8
Ghataprabha	**5.8**	**2.0**	**0.07**	**30**	**38**	**0.28**	**2.3**
	5.6 - 6.3	1.3 - 2.5	0.05-0.08	26.0-35.0	31.9-44.2	0.10-0.50	2.0 - 2.5
Malaprabha	**6.5**	**0.9**	**0.08**	**12**	**39**	**0.32**	**2.1**
	6.4-6.7	0.8 - 1.2	0.06-0.09	10.0-13.3	31.2-46.7	0.10-0.60	2.1 - 2.2
Bhadra	**5.5**	**2.2**	**0.08**	**28**	**52**	**0.15**	**1.5**
	5.3 - 5.6	2.0 - 2.4	0.07-0.09	25.0-31.0	49.0-56.3	0.10-0.19	1.4 - 1.7
V V sagar	**8.1**	**1.9**	**0.09**	**22**	**38**	**0.15**	**6.2**
	8.1 - 8.2	1.8 - 2.0	0.07-0.10	19.2-25.3	35.8-40.3	0.10-0.18	6.0 - 6.3
Linganamakki	**5.3**	**2.0**	**0.07**	**27**	**45**	**0.23**	**1.6**
	4.6 - 6.1	1.1 - 3.4	0.06-0.09	17.1-34.4	26.4-54.9	0.10-0.40	1.2- 1.8

Organic carbon was fairly rich in all the reservoirs in the range 0.7 (Narayanpur) to 2.7% (Harangi). Except for Malaprabha and Narayanpur, all others had organic carbon higher than 1.5%, which is considered to be optimal for high production.

Among essential nutrients, available nitrogen (mg/100 g of soil) was relatively high in Harangi (62 mg), Manchanbele (59 mg), Bhadra (52 mg), Kabini (49 mg) and Nugu (49 mg). In others it was between 38 (Narayanpur) and 45 mg (Linganamakki). The nitrogen level is favourable for production. However, the other key element, the available phosphorus (mg/100 g) was extremely low in all the reservoirs in the range 0.15 (VV Sagar & Bhadra) to 0.33 mg (Narayanpur). The available phosphorus is clearly in the low productive range.

It has been recognized that the bacterial activity is reflected in C/N ratio. The ratio between 10-15 is considered to be favourable for production and above 15 less favourable. The C/N ratio was very high in Ghataprabha (30), Hemavathy (28), Bhadra (28), Linganamakki (27) and Harangi (26). It was 12 and 14 in Malaprabha and Narayanpur respectively.

Water quality and nutrient status

Temperature and transparency

Physico - chemical parameters of water are shown in Table 3. Of the physical features, heat and light are essential for photosynthetic activity, which is basic to productivity. Water temperature depends on latitude and altitude and depth of water. The reservoirs under study being situated in tropical belt (11^{o} 58′ and 16^{o} 15′ N), temperature may not be a constraint for production. Average water temperature varied from 24.3 (Ghataprabha) to 27.9^{o} C (Linganamakki) in the overall range of 22.2 to 32.0^{o} C. The seasonal variation in each reservoir was narrow extending from 3 to 7^{o} C.

Light is another physical factor of importance. Its penetration into the water column is governed by the turbidity caused by inorganic suspensoids and shadowing of plankton. The transparency has been studied in terms of Secchi-depth. Most of the reservoirs had clear water with mean Secchi-depth (S.D.) ranging from 0.9 (Nugu & Manchanbele) to 3.2 m (Bhadra). During the monsoon, the turbidity was highest in Ghataprabha (S.D, 0.1 m) and lowest in Bhadra (S.D, 2.0 m) followed by Harangi (S.D, 1.5 m). In other seasons, the transparency in general was more than 1 m and in Bhadra it reached upto 4 m. The two physical factors, temperature and transparency are favourable for production in all the reservoirs investigated.

Among chemical factors influencing aquatic productivity, pH, alkalinity, dissolved gases like oxygen, carbon dioxide and dissolved inorganic nutrients like nitrogen and phosphorus are considered to be important.

pH

pH in the alkaline side of neutrality between 7.0 and 8.0 is considered to be ideal for productivity. Acidic waters below 6.5 and alkaline waters above 8.5 tend to have low productivity. The average pH in all the reservoirs are well within the range of productivity, Linganamakki was in neutral range (7.1); Harangi, Kabini, Hemavathy and Bhadra were mildly alkaline (7.4-7.7) while Malaprabha, Narayanpur, Ghataprabha, VV sagar and Manchanbele were in alkaline (8.2- 8.5) range. During summer the pH range was higher (7.6-8.8) while during monsoon the values declined. In Narayanpur, Nugu and Malaprabha, summer pH reached beyond 8.5.

Aklalinity, carbonate, bicarbonate and free CO_2

Alkalinity, the acid combining capacity of natural freshwater, is generally caused by carbonates and bicarbonates of calcium and magnesium. With dissolved CO_2, carbonates and bicarbonates form an equilibrium which is of prime importance for the productivity.

Alkalinity below 20 mg/l is considered to be unproductive while productive waters have alkalinity levels above 100 mg/l. Water bodies with alkalinity above 250 mg/l were also found to be unproductive. Among the reservoirs investigated, CB reservoirs had lower values of alkalinity (25-48 mg/l) with the exception of Manchanbele (144 mg/l). Lowest value was recorded in Kabini (25 mg/l) followed by Harangi (35 mg/l), Nugu (40 mg/l) and Hemavathy (48 mg/l). Compared with this, KB reservoirs had higher values. Among KB reservoirs, it was lowest in Bhadra (31 mg/l) and highest in VV sagar (207 mg/l). In Narayanpur (mainstream reservoir of Krishna), alkalinity was recorded at 154 mg/l. In Linganamakki, it was 21 mg/l, the lowest for any impoundment investigated. It could be seen that reservoirs which are situated very close to Western ghats have low alkalinity while in others it has improved.

Free CO_2 was recorded in surface waters on most of the occasions in the range 1 to 6 mg/l. Hence, carbonate was not recorded and alkalinity was mainly due to bicarbonate. The concentration of bicarbonate was highest during summer due to reduced water levels and lowest during periods of high water levels due to dilution. In Linganamakki, alkalinity reached below 20 mg/l during monsoon.

Specific conductivity and hardness

Specific conductivity is a positive correlate of alkalinity. Its concentration and seasonal fluctuations closely followed alkalinity. Among CB reservoirs conductivity was lowest in Kabini and highest in Manchanbelė. Among all the reservoirs, VV sagar recorded the highest value (647 μ mhos/cm), followed by Narayanpur (457 μ mhos/cm). Linganamakki had lowest concentration of ions with a conductivity value of 57 μ mhos/cm.

Most of the reservoirs investigated were soft with the exception of Narayanpur, VV sagar and Manchanbele. Hardness varied from 23 to 93 mg/l in CB reservoirs and from 27 to 187 mg/l in KB reservoirs. Linganamakki showed the lowest value of 18 mg/l. Chloride varied from 9.4 (Linganamakki) to 42.6 mg/l (Narayanpur).

Dissolved oxygen

Among chemical substances in natural waters, dissolved oxygen is of prime importance as a regulator of metabolic processes of plant and animal community and also as indicator of water quality. Oxygen regime, if monitored over a period of time, will give information on the nature of the reservoir and its productivity. However, the diurnal variations of oxygen in reservoirs are not sharp. But vertical variations are significant revealing the richness of bottom deposits. In reservoirs studied the surface waters were well oxygenated with oxygen value of 6.7 mg/l and above. Reservoirs showed variations in oxygen with depth in varying degree. This aspect is dealt separately.

Nitrogen and phosphorus

Among dissolved nutrients, nitrate and phosphate have been widely studied and their role in aquatic productivity has been well recorded. As a constituent of protein, nitrogen occupies an important place in aquatic ecosystem. A concentration of 0.2 to 0.5 mg/l of inorganic nitrogen and 0.05 to 0.2 mg/l of phosphorus have been considered to be favourable for medium to high levels of productivity. The nutrient status of reservoirs covered under the study is of low order with nitrate nitrogen in the range of 0.03 (Narayanpur) to 0.14 mg/l (Harangi) and phosphate between 0.01 (Harangi) and 0.03 mg/l (VV Sagar). Relatively higher values were recorded during post-monsoon months and low values in pre-monsoon months. It is interesting to note that in spite of dense submerged aquatic vegetation in VV sagar, phosphate levels remained high as compared to other reservoirs.

Table 3. *Physico-chemical parameters of water of Karnataka reservoirs*

	Water Temp (° C)	Transp. (m)	Oxygen (mg/l)	pH	Alkalinity (mg/l)	Sp.cond (μmhos/cm)	Hardness (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)	Silicate (mg/l)	Chloride (mg/l)
Hemavathy	**24.8** 22.5 - 27.5	**1.6** 0.5 - 2.2	**7.6** 7.0 - 7.6	**7.7** 7.3 - 8.3	**48** 29 - 78	**147** 100-200	**37** 28.0-50.0	**0.05** 0.01 - 0.11	**0.02** 0.01 - 0.03	**10.2** 8.0 - 13.6	**15.5** 14.0-18.4
Harangi	**25.3** 22.4 - 28.5	**1.7** 1.5 - 1.9	**7.6** 7.3 - 7.8	**7.4** 7.1 - 8.0	**35** 16 - 68	**97** 90 -100	**30** 20 - 43	**0.14** 0.03 - 0.35	**0.01** 0.01 - 0.02	**7.5** 6.6 - 9.2	**11.6** 11.4-12.0
Kabini	**27.5** 24.6 - 32.0	**1.6** 1.0 - 2.0	**6.9** 6.6 - 7.2	**7.5** 7.0 - 7.8	**25** 20 - 36	**90** 60-110	**23** 20 - 28	**0.06** 0.01 - 0.14	**0.015** 0.01 - 0.02	**10.2** 8.7 - 11.8	**13.0** 12.8 - 13.2
Nugu	**27.4** 25.2 - 30.0	**0.9** 0.4 - 1.2	**7.3** 7.0 - 7.8	**8.1** 7.5 - 8.8	**40** 28 - 48	**120** 100-140	**39** 38 - 40	**0.07** 0.02 - 0.14	**0.016** 0.01 - 0.02	**18.0** 10.3 - 22.0	**17.4** 16.8 - 18.0
Manchanbele	**27.3** 26.0 - 29.5	**0.9** 0.72 - 1.0	**7.3** 7.1 - 7.6	**8.5** 8.3 - 8.7	**144** 138-148	**403** 390-420	**93** 84-108	**0.09** 0.01 - 0.25	**0.023** 0.01 - 0.05	**12.5** 7.0 - 21.6	**33.0** 31-34.0
Narayanpur	**25.8** 23.2 - 27.8	**1.1** 1.0 - 1.2	**7.6** 7.5 - 7.7	**8.3** 7.8 - 8.8	**154** 148-160	**457** 440-480	**187** 180-192	**0.03** 0.01 - 0.06	**0.023** 0.01 - 0.03	**21.3** 17.0 - 27.4	**42.6** 40.0-46.8
Ghataprabha	**24.3** 22.2 - 27.5	**1.5** 0.1 - 3.3	**6.9** 6.6 - 7.2	**8.2** 7.8 - 8.5	**32** 24 - 40	**100** 70-150	**27** 20 - 36	**0.07** 0.01 - 0.18	**0.017** 0.01 - 0.02	**12.0** 8.0 - 14.2	**13.1** 12.0-14.4
Malaprabha	**25.0** 22.5 - 27.6	**1.3** 1.0 - 1.5	**7.2** 6.8 - 7.7	**8.4** 8.1 - 8.7	**79** 56 - 92	**203** 120-270	**69** 66 - 72	**0.03** 0.01 - 0.04	**0.02** 0.01 - 0.03	**12.7** 8.0 - 19.8	**14.0** 13.8-14.2
Bhadra	**26.9** 25.2 - 28.3	**3.2** 2.0 - 4.0	**7.8** 7.2 - 8.4	**7.5** 7.3 - 7.7	**31** 18 - 48	**117** 100-130	**29** 26 - 32	**0.04** 0.01 - 0.10	**0.02** 0.01 - 0.03	**11.9** 6.6 - 20.2	**12.9** 11.4-16.2
V V sagar	**26.2** 25.0 - 25.8	**1.2** 1.0 - 1.5	**6.7** 6.4 - 7.0	**8.2** 7.9 - 8.4	**207** 200-210	**647** 550-730	**102** 100-106	**0.04** 0.02 - 0.05	**0.03** 0.01 - 0.04	**11.9** 6.6 - 16.8	**13.3** 13.0-13.8
Linganamakki	**27.9** 26.1 - 30.0	**1.5** 0.4 - 2.3	**6.9** 6.5 - 7.3	**7.1** 6.7 - 7.6	**21** 14 - 28	**57** 40 - 80	**18** 16 - 20	**0.06** 0.01 - 0.14	**0.023** 0.01 - 0.04	**10.5** 6.6 - 15.2	**9.4** 8.2 - 10.0

Thermal and chemical stratification

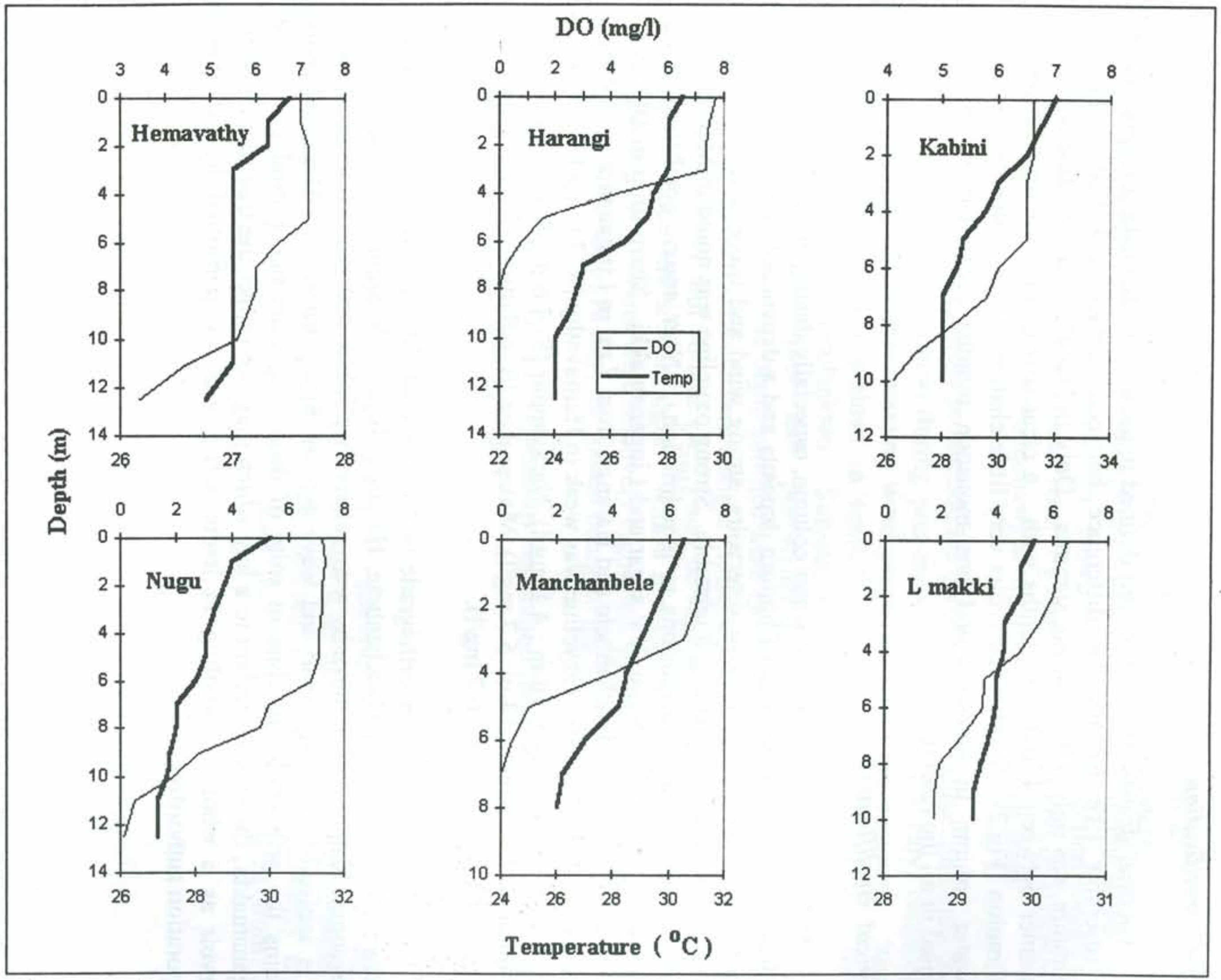
Thermal stratification

Thermal stratification is not well defined in most of the Karnataka reservoirs. In deep reservoir like Bhadra the difference between surface and bottom (25 m) temperature was only 4.0^{o} C during summer. Only in Harangi, thermocline was noted in summer between 4 and 9 m depths with a clear demarcation of epilimnion and hypolimnion (Fig.2). In other reservoirs very little change in temperature was noted in the water column In monsoon and post-monsoon months homothermal conditions prevailed in all the reservoirs.

Chemical stratification

The strength of oxycline in water column, especially during pre-monsoon season, is a clear indication of richness of bottom deposits and a dependable index of reservoir productivity. However, in shallow reservoirs, strong wind and wave action in summer disrupts the stratification making it unstable. Strong oxycline was noted in Manchanbele and Harangi with anoxic conditions in hypolimnion. Near anoxic conditions at the bottom was also noted in Nugu, VV sagar and Linganamakki. Sharp drop in DO levels was noted from 5 m in Manchanbele and Harangi, from 7 m in Linganamakki and from 9 m in Nugu and VV sagar. Oxycline was weak in Hemavathy (S: 7.0 mg/l, 12.5 m: 3.4 mg/l), Kabini (S : 6.6 mg/l, 10 m : 4.1 mg/l), Narayanpur (S: 7.6 mg/l, 10 m : 6.4 mg/l), Ghataprabha (S: 7.0 mg/l, 14 m: 5.7 mg/l), Malaprabha (S: 6.8 mg/l, 13 m :5.8 mg/l) and Bhadra (S: 8.4 mg/l, 25 m : 6.7 mg/l).

Oxygen profile was orthograde in Ghataprabha, Malaprabha, Narayanpur and Bhadra and clinograde in Manchanbele, Harangi, Nugu , VV sagar and Linganamakki. Narayanpur, Kabini and Hemavathy were relatively shallow with sprawling lentic sector and is subjected to strong wind and wave actions during summer. This, probabaly, explains the orthograde oxycline in spite of these reservoirs being productive. In Linganamakki, the studies pertain to a bay which may not reflect the true picture of the reservoir as a whole. Sampling in lentic sector was not permitted by the Power Corporation authorities.


DO (mg/l)
Hemavathy
Harangi
Kabini
Nugu
Manchanbele
L makki
DO
Temp
Depth (m)
Temperature (^{o}C)

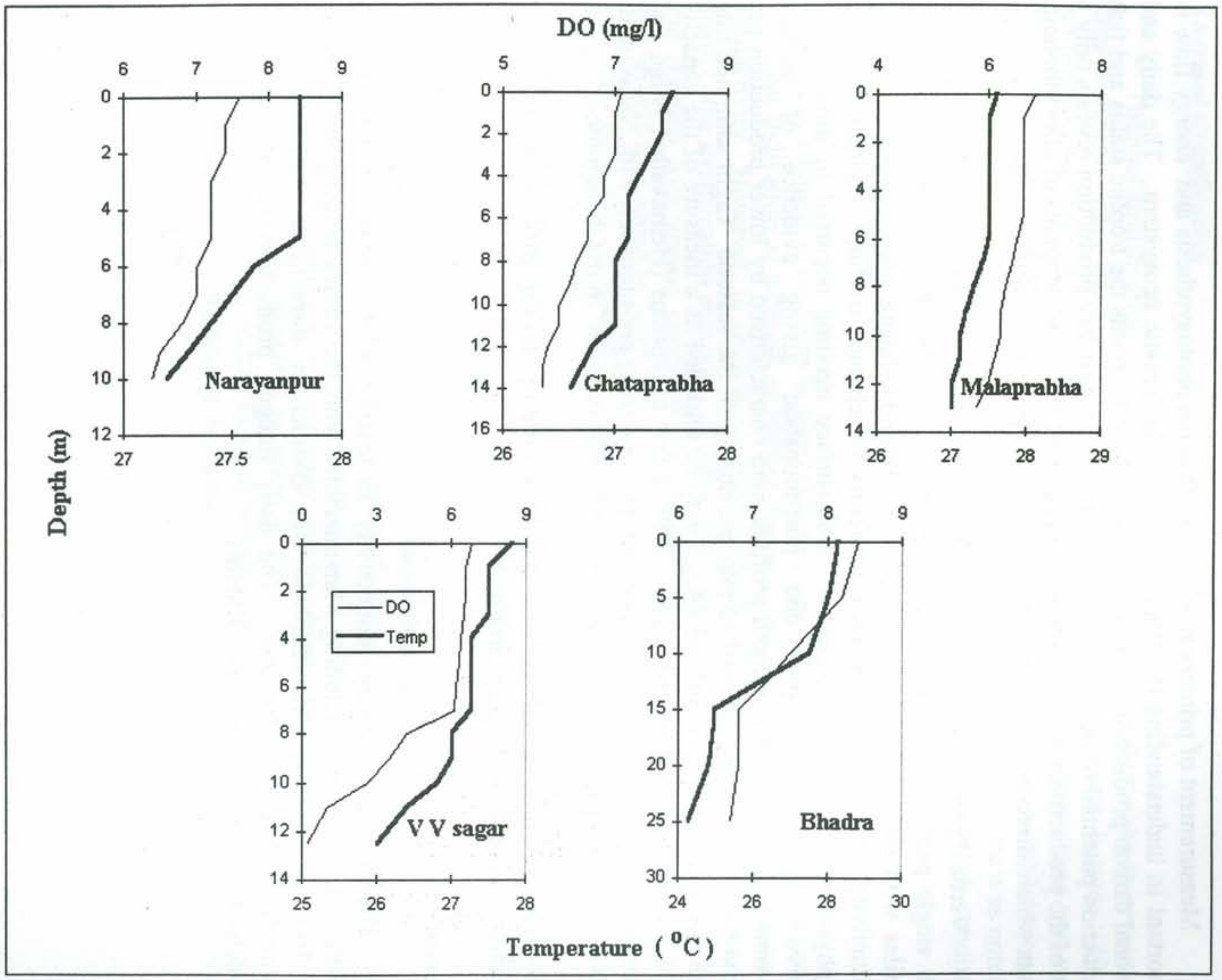


Fig. 2. *Stratification in Karnataka reservoirs (cont'd)*

Primary production

Measurement of primary productivity through photosynthesis and energy flow is important in understanding the trophic status of the aquatic ecosystem. The daily and seasonal carbon production of a system can be used to assess the trophic status and fish production potential of aquatic ecosystem. However, primary production reveals only a part of the productivity since reservoirs receive generally large amounts of allochthonous inputs which directly add to the productivity at the primary consumer level.

Vertical profiles of gross production are given in Fig.3. Production-depth profiles with single peak were common during post-monsoon. On the contrary, dichotomous profiles with more than one maxima were common during pre-monsoon. Bimodal productivity profiles are explained in terms of change in light regimen and the ecophysiology of the phytoplankton. Sub-surface maxima occurred in most of the reservoirs both during pre- and post-monsoon giving evidence of surface photoinhibition. Most of the depth profiles were characterised by lower production per unit volume and absence of marked maxima during all the seasons. Light saturated rate of photosynthesis per unit volume (A_{max}) may be regarded as a measure of the capacity of lake to produce and sustain algae. With a few exceptions (Hemavathy, Nugu and Manchanbele), A_{max} values were relatively higher during pre-monsoon with Narayanpur showing the highest of 178 mg , the lowest being 20 mg C/m^3 /h in Ghataprabha.

Gross production (P) and community respiration (R) for different reservoirs are depicted in Fig. 4 and P-R ratio in Fig. 5.

Cauvery system

Hourly gross primary productivity in reservoirs of Cauvery system did not exhibit wide variation (excluding Manchanbele) with the values ranging between 140 and 160 mg $C/m^2/h$. Manchanbele was distinct in showing a markedly higher production of around 300 mg. The daily integral production varied from 2339 (Manchanbele) to 1117 mg C/m^2 (Kabini).

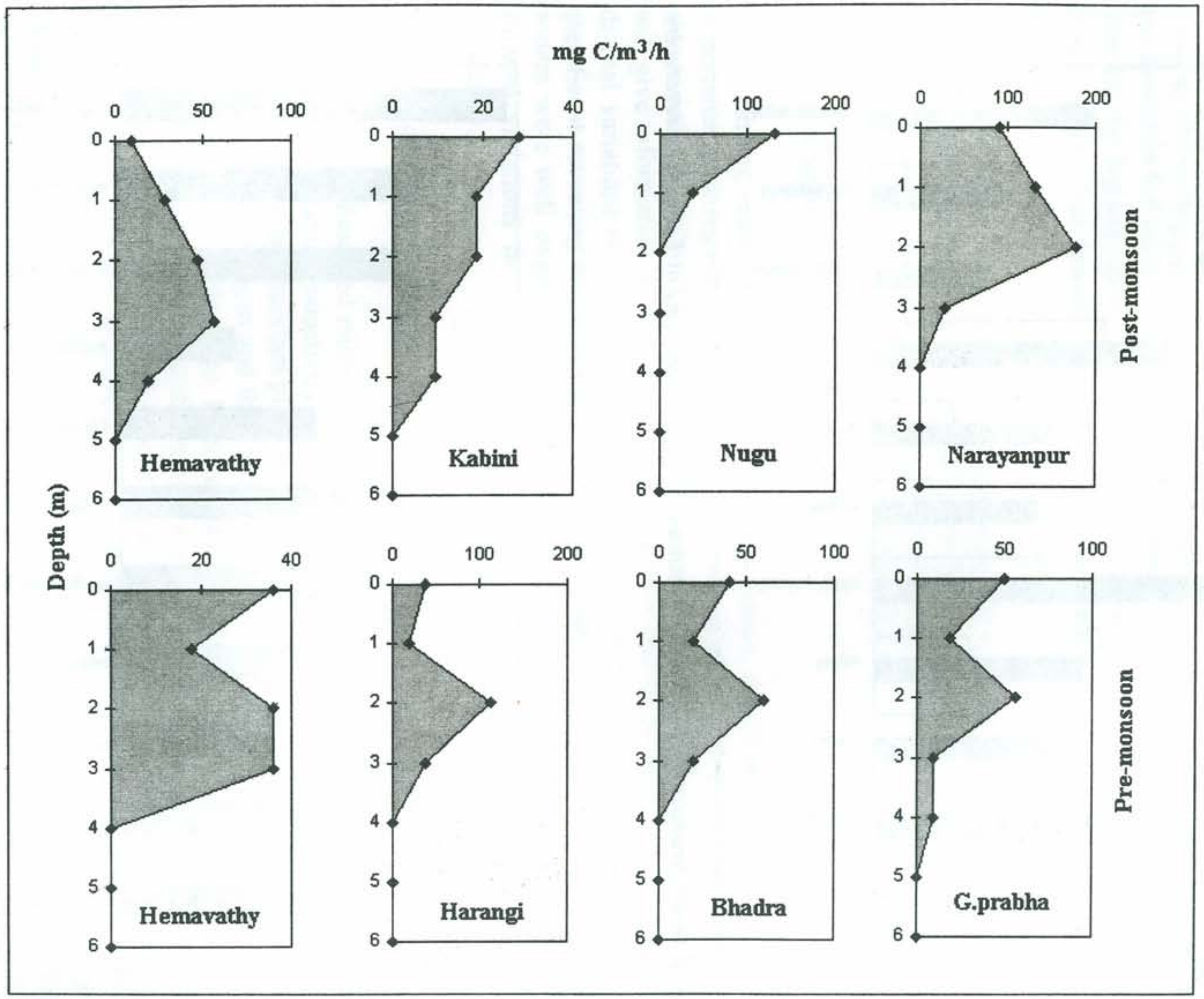


Fig. 3. *Vertical distribution of gross production in Karnataka reservoirs (select profiles)*

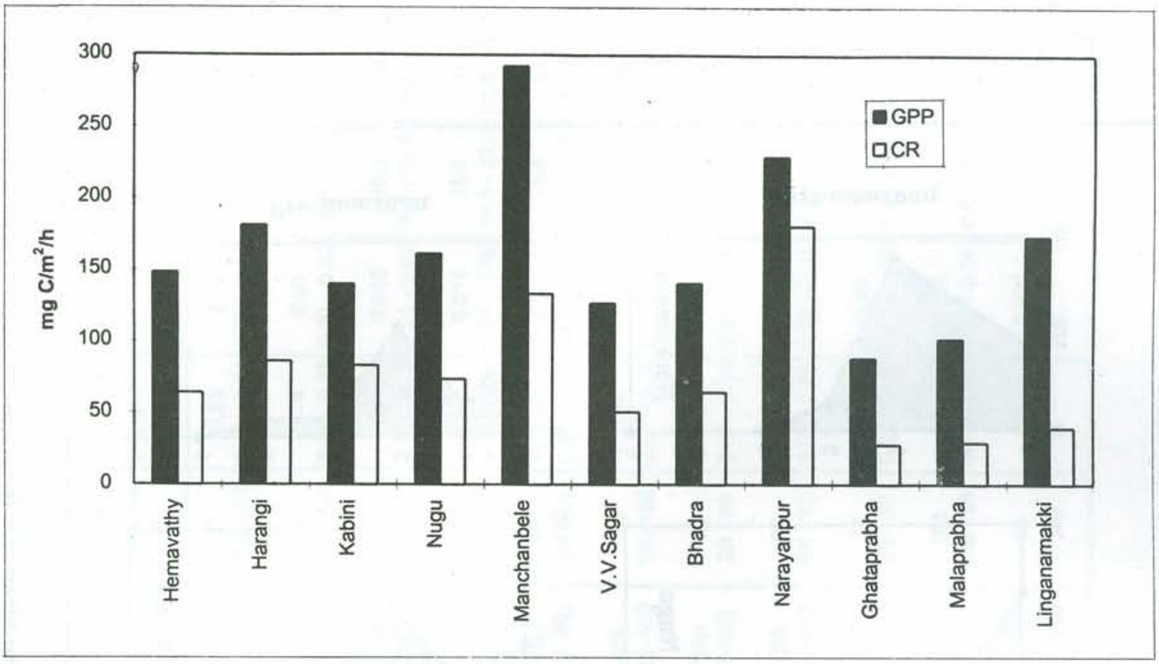


Fig. 4. ***Gross production (GPP) and community respiration (CR) in Karnataka reservoirs***

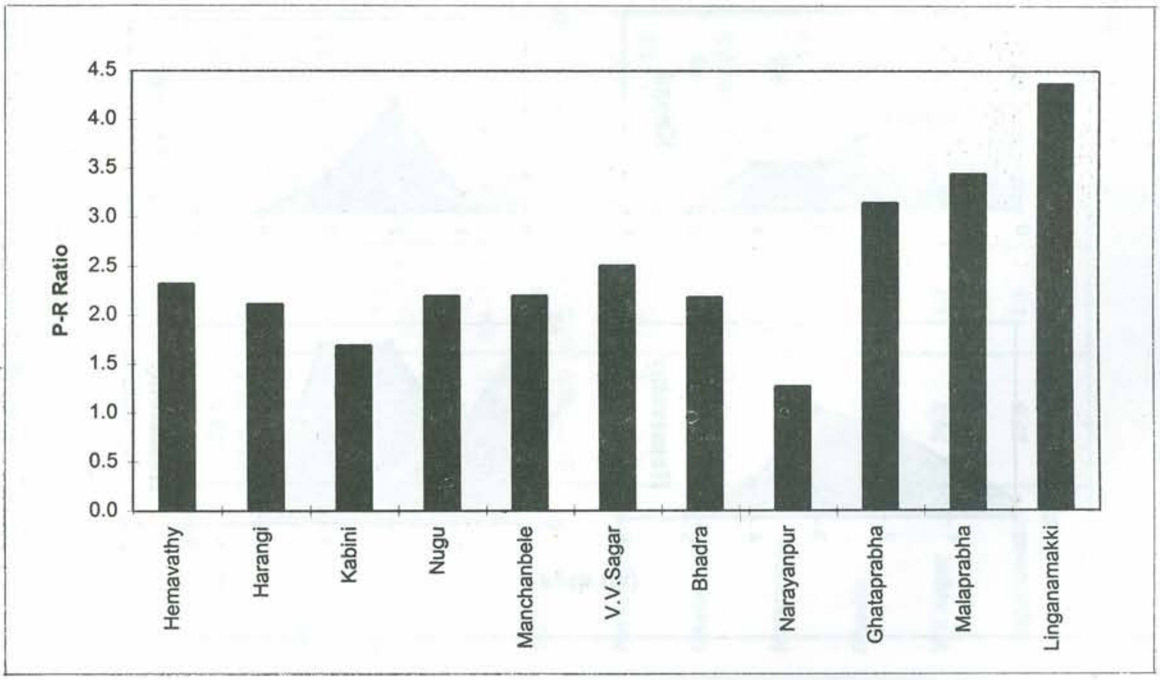


Fig. 5. ***Gross production (P) to community respiration (R) ratio in Karnataka reservoirs***

Net production varied from 60 (Nugu) to 237 mg C/m^2/h (Manchanbele) and was distributed over a much narrower depth than gross production. Average community respiration rates in the euphotic zone were high and were more or less similar among the reservoirs (around 60 to 80 mg C/m^2/h) with the exception of Manchanbele which showed comparatively higher rate of around 130 mg. Gross production to community respiration ratio (P:R) did not exhibit wide fluctuation (1.7 to 2.3) indicating that the reservoirs are perhaps in the medium productive range.

Krishna system

Among the reservoirs under Krishna system, hourly integrated gross primary productivity was highest in Narayanpur (229 mg) and the lowest in Ghataprabha (88 mg). Average community respiration rate fluctuated between 28 (Ghataprabha) and 181 mg C/m^2/h (Narayanpur). The P-R ratio varied from 1.2 (Narayanpur) to 3.4 (Malaprabha). Based on P-R ratio, Ghataprabha and Malaprabha are less productive than other reservoirs. Net production ranged from 47 to 79 mg indicating low amplitude of variation. The daily integral gross production varied between 700 and 2000 mg C/m^2.

Linganamakki reservoir

The average hourly gross production rate was 173 mg (1387 mg C/m^2/d). The P-R ratio in Linganamakki reservoir was the highest (4.3) among the reservoirs surveyed indicating that the contribution of respiration to gross production was quite low. Average net production was 125 mg C/m^2/h.

Seasonal variation

Gross production was maximum during monsoon in Hemavathy, Kabini, Manchanbele, Bhadra and Linganamakki, whereas Nugu and Ghataprabha recorded the production maximum in pre-monsoon. Considering all the reservoirs and seasons, highest production of around 500 mg C/m^2/h was recorded in Manchanbele (monsoon) and the least in Ghataprbha (56 mg C/m^2/h) in post- monsoon. The seasonal variation was wide in the case of Kabini, Manchanbele, Bhadra and Linganamakki (the ratio of maximum to minimum was 3.7 to 4.1) whereas the same was negligible in Harangi (ratio : 1.1).

Summarising, primary production of Manchanbele and Narayanpur is in the higher range, that of Ghataprabha and Malaprabha in the lower range and that of the rest of the reservoirs in the medium range.

Correlation matrix

Correlation matrix prepared between primary production and various abiotic variables of water and soil (Table 4) showed that no single parameter could be correlated with production. Between soil and water, pH of soil is positively correlated with pH of water, conductivity, alkalinity and PO_4-P; organic carbon with NO_3-N of water. Available nitrogen showed positive correlation with NO_3-N of water, while available P did not show any correlation with any parameters of water quality.

Among the morphometric and drainage parameters, only C/A ratio showed strong positive correlation with gross production. The regression equation between C/A and gross production (GP) has the following form :

$$\mathbf{GP = 1355 + 2.666\ C/A\ (n = 11, r = 0.8607^{**})}$$

The high significance of 'r' value indicates that the equation can be used as a model to obtain productivity of reservoirs of Karnataka from C/A ratio. The advantage of the model lies in its simplicity, as the morphometric and drainage parameters could be obtained from dam authorities.

Biotic communities

Plankton

The abundance of plankton (qualitative and quantitative) and its diversity are presented in Fig. 6 & Table 5. The values presented are an average of three seasons. The standing crop (ml/m^3) was highest in Malaprabha (2.37) followed by Manchanbele (1.91) and Nugu (0.77). The crops were moderate in Hemavathy, Kabini, Harangi, VV sagar and Narayanpur and low in Linganamakki and Ghataprabha. Post-monsoon samples showed maximum crop and monsoon the minimum. In general, two plankton pulses occur in Indian reservoirs, one during post-monsoon months (Sept-Oct) and the other during pre-monsoon (Feb-May). The reservoirs of Karnataka more or less conformed to this general trend.

Table 4. *Correlation between abiotic and biotic variables in Karnataka reservoirs.*

	WATER								SOIL				
	Temp.	**DO**	**pH**	**Cond.**	**Alkal.**	**PO_4**	**NO_3**	**SiO_2**	**pH**	**Org. C**	**Avail. N**	**Avail. P**	**GPP**
Temp.	1.000												
Oxygen	0.432	1.000											
pH	-0.561	-0.060	1.000										
Cond.	-0.404	-0.156	**0.623***	1.000									
Alkal.	-0.453	-0.142	**0.661***	**0.995****	1.000								
PO_4	-0.184	-0.344	0.358	**0.759****	**0.747****	1.000							
NO_3	-0.095	0.157	-0.265	-0.308	-0.287	**-0.635***	1.000						
SiO_2	-0.393	0.245	0.563	0.384	0.398	0.282	-0.443	1.000					
pH	-0.381	-0.226	**0.690***	**0.938****	**0.936****	**0.824****	-0.527	0.446	1.000				
Org. C	0.434	-0.023	-0.619	-0.386	-0.426	-0.392	**0.695***	**-0.737****	-0.548	1.000			
Avail. N	0.249	0.491	-0.378	-0.333	-0.322	-0.568	**0.787****	-0.389	-0.601	**0.646***	1.000		
Avail. P	-0.233	-0.085	0.119	-0.185	-0.154	-0.302	-0.174	0.285	-0.066	-0.535	-0.382	1.000	
GPP	-0.327	0.375	0.161	0.330	0.370	0.138	0.312	0.304	0.091	-0.092	0.462	-0.214	1.000

* Significant at 1%

** Significant at 5%

Phytoplankton

Though zooplankton was generally dominant, phytoplankton was also significant in Hemavathy, Malaprabha, Manchanbele and Bhadra reservoirs (Fig. 6a). The initial phytoplankton dominance in Hemavathy persisted even after 13 years of its formation. Four groups *viz.,* myxophyceae, chlorophyceae, dinophyceae and bacillariophyceae represented phytoplankton. Among the four groups, chlorophyceae was predominant, especially in Malaprabha, Manchanbele and Hemavathy (Fig. 6b). Next to chlorophyceae, dinophyceae was important in all the reservoirs except those from northern part of the state, *viz.,* Narayanpur, Ghataprabha and Malaprabha. It occured in significant density in VV sagar, Nugu, Harangi and Manchanbele. Myxophyceae, which is generally abundant in tropical reservoirs, was not very significant in reservoirs of Karnataka. Chlorophyceae was represented by 21 forms of which *Ulothrix* and *Pediastrum* were important. Diatoms were represented by 10 forms and they occurred rarely. *Ceratium hirundinella* is the only species representing dinophyceae. *Microcystis* represented myxophyceae (Table 5).

Zooplankton

A pulse of zooplankton was recorded invariably during post-monsoon (Sept-Oct) when the water levels stabilized. It also occurred significantly in summer months. Copepoda, cladocera, rotifera and protozoa represented zooplankton, generally in the stated order of abundance. Copepods and cladocerans together accounted for the bulk of zooplankton except in Linganamakki (Fig.6c). Among copepoda, calanoids (*Diaptomus*) occurred in all the reservoirs while cyclopoids (*Cyclops*) were not recorded in most of KB reservoirs and Linganamakki. Copepods were prevalent in Malaprabha, Manchanbele and Nugu. *Diaptomus* and *Cyclops* along with their nauplii represented the group copepoda.

Cladocerans occurred in significantly in Nugu, Ghataprabha and Harangi. Of the 8 genera recorded *Bosmina, Moina* and *Diaphanosoma* were distributed in most of the reservoirs.

Rotifers were prevalent in Malaprabha, VV sagar, Manchanbele and Narayanpur. In VV sagar and Narayanpur rotifers accounted for about 30% of the planktonic organisms. This group was not significant in CB reservoirs. Of the 7 forms recorded, only *Brachionus* and *Keratella* were common (Table 5).

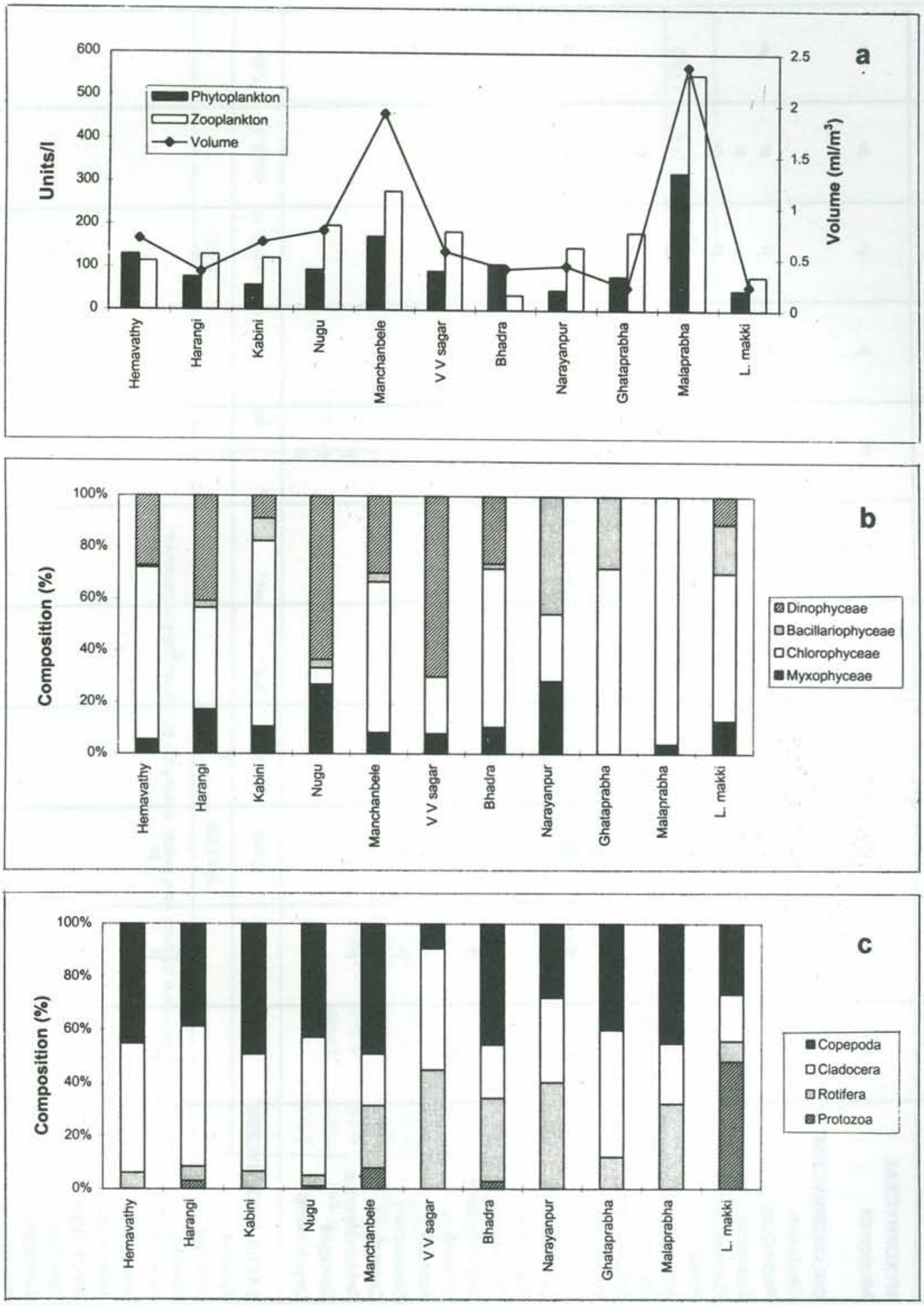


Fig. 6. *Plankton abundance (a) and composition (b & c) in Karnataka reservoirs*

Table 5. Plankton diversity in different reservoirs of Karnataka

	H.vathy	Harangi	Kabini	Nugu	M.bele	V V sagar	Bhadra	N.Pur	G.prabha	M.prabha	L.makki
MYXOPHYCEAE											
Microcystis	P	P	P	P	P	P	P	P	P	P	P
CHLOROPHYCEAE											
Closterium		P									
Pediastrum	P		P		P		P	P	P	P	P
Zygnema							P			P	
Pachycladon	P		P				P		P	P	
Nitella											
Arthrodesmus			P				P		P		
Oedogonium			P							P	
Sphaerocystis							P				
Micrasterias			P				P				
Ulothrix	P	P	P	P		P	P		P	P	P
Sphaerodinium											
Tetraedron							P				
Cosmarium			P				P		P		
Nephrocystium	P	P									
Desmidium	P				P						P
Actinastrum			P								
Staurastrum		P	P								P
Coelastrum		P									
Ankistrodesmus		P					P				
Spirogyra							P				
Onychonema							P				
BACILLARIOPHYCEAE											
Synedra				P			P				
Amphora									P		
Navicula		P			P						
Pinnularia	P	P	P								
Mastogloia											
Asterionella											
Gonatozygon	P								P		P
Tabellaria									P		
Gyrosigma								P			
Pleurosigma									P		

Table 5. (Contd)

	H.vathy	Harangi	Kabini	Nugu	M.bele	V.V.Sagar	Bhadra	N.pur	G.prabha	M.prabha	L.makki
DINOPHYCEAE											
Ceratium	P	P	P	P	P	P	P		P	P	P
			P								
PROTOZOA											
Arcella		P			P		P				P
Centropyxis				P	P						P
Difflugia				P	P						
ROTIFERA											
Keratella			P	P	P	P		P		P	P
Brachionus	P	P	P	P	P	P	P	P		P	P
Trichocerca											
Filinia		P			P			P		P	
Pompholyx					P						
Diplois		P									
Trichotria										P	
CLADOCERA											
Bosmina	P	P	P	P	P	P	P	P	P	P	P
Moina	P	P	P	P	P		P	P	P	P	P
Daphnia		P		P						P	
Diaphanosoma		P	P	P	P			P	P	P	P
Alona				P							
Polyphemus				P							
Macrothrix										P	
Ceriodaphnia				P	P						
COPEPODA											
Diaptomus	P	P	P	P	P	P	P	P	P	P	P
Cyclops	P	P	P	P	P					P	

Three forms occurred in the group protozoa. In Linganamakki, protozoans accounted for about 30% of the organisms. *Arcella* and *Difflugia* were the most common forms.

Diversity indices

Plankton samples were subjected to species diversity analysis to have an idea on how the individuals of a species are distributed among the species inhabiting as a community in an ecosystem and the stability of the ecosystem. Various diversity indices are given in Table 6 . The Shannon-Weaver Index (H) reported as the most useful among the various diversity indices varied from 2.2428 (Bhadra) to 3.4398 (Ghataprabha). Barring Ghataprabha, all other reservoirs had the value below 3 indicating that the aquatic fauna and flora were free from any stress.

The concentration of dominance 'c', indicative of the relative abundance of species in stand, ranged from 0.1066 (Ghataprabha) to 0.2382 (Harangi). The variety index (d) expresses the species richness of the variety component, showed high values in Ghataprabha, Malaprabha, Hemavathy, Harangi and Narayanpur (0.8412-1.5222) and low values in Nugu (0.4853) Bhadra (0.4292) and VV sagar (0.5167). The equitability Index (J'), another indicator of diversity, showed narrow range (0.8031-0.9810).

Macrobenthic invertebrate fauna

The sampling for bottom fauna was confined to lentic sector for want of facilities. In reservoirs, bottom fauna is generally poor in lentic sector due to its depth and release of water creating unstable conditions. Intermediate sector and bays harbour relatively rich fauna.

Soil texture and accumulation of organic matter play significant role in the development of bottom fauna. In most of the reservoirs, sand, gravel and stones dominated the bottom. In VV sagar marginal areas are rich in loose soil and humic substances. In Narayanpur, sandy loam to clayey loam dominated the bottom soil. In Manchanbele, bottom is characterised by the presence of black loose soil subjected to oxygen deficiency for greater part of the year.

Bottom fauna was relatively rich in Kabini, moderate in Narayanpur and Nugu and poor in other reservoirs, (Table 7). In Bhadra and Harangi fauna was not encountered in the lentic sector. It varied from 20 (VV sagar, Ghataprabha, Linganamakki) to 1044 organisms/m^2 (Kabini). Dipteran larvae (other than

Chironomids) were dominant in Kabini and Nugu and small gastropods in Narayanpur. Chironomid larvae occurred in Kabini, Manchanabele, Nugu and Ghataprabha, bivalves in Malaprabha and Ghataprabha and oligochaetes in Kabini, Linganamakki and Nugu. Overall, all the reservoirs barring Narayanpur, are poor in molluscan fauna.

High shoreline development, vegetation association and variable slopes generally produce large number of benthic habitats in reservoirs. In Linganamakki, in spite of highly dendritic shore line, benthic fauna was poorly developed. The poor abundance of chironomid larvae is indicative of absence of soft decaying vegetation at the bottom. Oxygen deficiency at the bottom in Harangi and Manchanbele also have not produced good population of chironomids. The high concentration of molluscs in Narayanpur is probably favoured by high alkalinity. In VV sagar small gastropods (pulmonates) occurred in good quantity in association with aquatic weeds, but the same were not encountered in the grab samples.

It is paradoxical that in spite of rich organic matter deposits, bottom fauna has not developed to the desired level in many reservoirs. Probable reasons could be the texture of the soil with low pH and inadequate sampling.

Aquatic macrophytes

Aquatic macrophytes, in general, do not get a foot-hold in reservoirs due to steep water level fluctuations. In some reservoirs macrophytes appear during post-monsoon months in certain sheltered areas and disappear as the water level recede. Such situation occurred in Hemavathy, Kabini and Nugu. *Hydrilla, Vallisneria* and *Potamogeton* are the common hydrophytes encountered in Hemavathy and Kabini in lotic and intermediate sectors. Lentic zone was devoid of any vegetation. In VV sagar a permanent cover of dense submerged aquatic weeds was recorded in the littoral regions all over the reservoir extending upto a depth of about 2 to 3 m. *Hydrilla, Potamogeton* and *Vallisneria* were the more dominant forms. Large number of insects, insect larvae and gastropods (*Limnea, Planorbis*) were found to be associated with the weeds. Ageing and stable water levels throughout the year appear to have contributed for the development of aquatic vegetation in this reservoir.

Table 6. ***Diversity indices of plankton***

	H	C	d	J'
Hemavathy	2.9819	0.1432	0.9733	0.9407
Harangi	2.6678	0.2382	0.9534	0.8031
Kabini	2.5872	0.1944	0.6807	0.9216
Nugu	2.3622	0.2203	0.4853	0.9138
Manchanbele	2.6181	0.1823	0.7131	0.9326
V V sagar	2.2777	0.2128	0.5167	0.9810
Bhadra	2.2428	0.2215	0.4292	0.9659
Narayanpur	2.8902	0.1457	0.8412	0.9634
Ghataprabha	3.4398	0.1066	1.5222	0.9296
Malaprabha	2.8807	0.1742	1.1258	0.8035
Linganamakki	2.4576	0.1957	0.5988	0.9507

Table 7. Bottom macrofauna (organisms/m^2) in reservoirs of Karnataka

Reservoir	*Chaoborus* larvae	Other dipteran larvae	Gastropods	Bivalves	Oligochaetes	Total
V V sagar	-	-	20	-	-	20
Bhadra	-	-		-	-	-
Narayanpur	20	-	300	20	-	340
Ghataprabha	20	-			-	20
Malaprabha	-	-	-	40	-	40
Hemavathy	-	-	40	-	-	47
Harangi	-	-		-	-	
Kabini	50	965	4	-	25	1044
Nugu	20	300	-	-	20	340
Manchanbele	27	20	-	-		47
Linganamakki	-	-	-	-	20	20

Fishing effort, catch and catch composition

Water management of reservoirs is under the control of irrigation department except Linganamakki, where it is under the Power Development Corporation of Karnataka. However, the fishery development and management of all reservoirs are under the control of the Fisheries Department. Fish seed is stocked by the department depending on the availability and licences are issued for exploitation by levying the prescribed annual fee which varies from Rs.750 to 1000 per unit. One coracle (manned by two people) and 300 m of gill net form a unit. The fishing effort varies from reservoir to reservoir and is mainly dependent on the availability of quality fish. Though co-operative societies have been formed at each reservoir, they remained non-functional. Fishermen dispose off their catch through middlemen. There is no agency monitoring the catch and catch composition at any of the reservoir. During the survey, catch and catch composition were recorded for only two days in each season which hardly portrays the correct picture. Fishing was either at low level or completely suspended during the sampling programme in some reservoirs. Fishing effort and catch composition for each reservoir are summarised below.

Hemavathy reservoir

This reservoir is well exploited with about 100 licenced units. Besides local fishemen, parties from Chickmagalur district migrate temporarily during the peak fishing season, making temporary settlements. When compared to Kabini, fishing intensity is of low order.

During early years of formation, weed fishes (*Oxygaster* spp.) and catfishes dominated the catches. Stocking of catla, rohu and common carp changed the catch composition with predominant occurance of *C. carpio, C. catla, L. rohita* along with minor catfishes *like O. bimaculatus* and *M. cavasius*. Peak fishing activity is during early monsoon months. Catla appears to grow fairly well as it has been estimated to attain 70 cm (6.5 kg) in 2 + years.

Harangi reservoir

Fishermen settlements exist around the reservoir. Fishing is done intermittently based on the availability of fish. Fishing activity was not observed during Pre-monsoon (Apr-May) & monsoon (Aug-Sep) .Peak fishing appears to be during June, October and February-April. As per the official agencies about 6 t of fish were caught during March to October 1995, consisting of catla, rohu, mrigal and common carp. Catla is reported to grow exceedingly well in this reservoir.

Kabini reservoir

Around 300 coracles operate during peak fishing. Catches are assembled at 7 to 8 landing centres of which four are important. Catches are being collected by a contractor from the neighbouring state of Kerala. Fishermen live around the reservoir in 3 to 4 settlements which included those migrated from Tamil Nadu. Parties from Tungabhadra reservoir also operate few shore seines (alivi) during January to March. Licences are issued on monthly basis. Peak catches occur during June when large amounts of migrating fish were caught during first floods.

Catla, common carp and rohu dominated the fishery. Others included *W. attu, O. bimaculatus, M. armatus, M. cavasius N. notopterus* and the tilapia (*O. mossambicus*). All the carps recorded excellent growth in the reservoir. Tilapia appears to have entered accidentally and established in the reservoir.

Nugu reservoir

Fishery in Nugu is being exploited by FFDA with hired fishermen. No fishermen settlements exist around the reservoir. Poor communication facilities have come in the way of proper exploitation. FFDA conducts fishing for few days in different periods transporting the catch to nearby towns. About 20 fishing units operate in each period. Major carps especially catla, rohu and common carp are reported to form the catch. Tilapia has also established and contributed significantly.

Manchanbele reservoir

There is no organised fishing in this resevoir. No efforts have been made to establish a fishery. The indigenous fish consisted of minor carps and minor catfishes. Tilapia has entered from the tanks in the catchment and established itself as a fishery. A few fishermen parties do fishing and the catches consisted of almost exclusively tilapia. Recently the reservoir has been leased to a society formed by the oustees.

VV sagar reservoir

This is an old and well exploited impoundment. About 85 to 120 fishing units were engaged during peak season establishing 2 to 3 temporary settlements along the reservoir. During the post-monsoon months 13 to 16 coracles were observed at two centres. The catches consisted *of C. carpio, L. rohita, L. fimbriatus, N. notopterus, M. cavasius, C. reba, C. marulius* and *M. armatus. C. carpio* occured in the size range 50-90 cm with dominance of 70-80 cm group. This size probably belongs to 3+ age group. *L. rohita* occured in the size range 61-76 cm, probably belonging to 2+ age group. *L. fimbriatus* occured in the size range of 30-46 cm with dominant size at 30-36 cm, probably belonging to 1+ age group.

The growth of *C. carpio* and *L. rohita* appears to be good. The vast stretches of aquatic vegetation seem to be favourable for the growth of *L. rohita* as it offers good substrate for periphyton. Similarly miscellaneous species like *N. notopterus*, murrels seem to thrive well. Natural recruitment has been observed in *L. fimbriatus* as well as in all miscelleneous fishes, but in *L. rohita* and *C. carpio* it appears to be doubtful. Presence of submerged vegetation offers ideal conditions for the breeding and successful recruitment of *C. carpio.* But the size composition in the catch did not show any signs of recruitment of this species.

Bhadra reservoir

Peak fishing is mainly confined to certain seasons commencing from pre-monsoon months till the onset of floods. Fishing activity is generally low during monsoon and post-monsoon months. Lentic sector, being very deep is often shunned by fishermen. The catch mainly consists of indigenous species such as of *Tor khudree, Puntius jerdoni (=P. pulchellus = P. dobsoni), M. seenghala, M. cavasius, P. kolus and O. vigorsii.* Major carps (catla and rohu) are reported to occur during first floods. Juveniles of *T. khudree* and *M. seenghala* were recorded during October.

Narayanpur reservoir

About 200 units operate in the reservoir with varying intensity in different seasons. Catches are landed at 11 centres. The catches are pooled and iced at Handergal by the merchants and despatched to different destinations as far as Mumbai. Peak catches occur (15-20 kg/unit) during March to April. Predominant species were *M. aor, R. pavimentata,* and *L. fimbriatus.* Stray specimens of catla (2 kg) and rohu (1 to 1.2 kg) also occurred.

Ghataprabha reservoir

This reservoir is poorly exploited. The low fishing effort appears to be due to poor catches . No fishing activity was observed during post - monsoon sampling. Some fishing units (about 15) operated small meshed monofilament gillnets during June-July landing indigenous species.

Malaprabha reservoir

There are about 9 fishing villages around the reservoir. During peak fishing season (July-Aug), 50 coracles are reported to operate for landing about 500 kg per day. In the lean season only 10 coracles are operated landing about 100 kg/day. Major carps and miscellaneous fishes occured in the catches.

Linganamakki reservoir

About 200 coracle units are engaged in the exploitation of the reservoir. Main fishing season is May to August. About 129 licences were issued but the actual fishing units were much higher. As the reservoir is large and spread over, aproach to several points is rather difficult due to poor communication facilities.

P. kolus was the dominant species during pre - monsoon and monsoon season. Besides *P. kolus* catch included *C. catla, L. rohita, C. mrigala, C. carpio, W. attu, O. bimaculatus, M. armatus and C. marulius.* Several weed fishes *especially P. mahecola, Puntius spp., D. aequipinnatus, M. cavasius* also occurred. *P. kolus* occurred in the size range 20-39 cm, *C. catla* 70-85 cm and C. carpio 23-25 cm.

Manchanbele reservoir

Fish catch of Hemavathy reservoir

C. carpio communis **from Kabani reservoir**

Assorted fish catch from Linganamakki reservoir

During post-monsoon months (October) tilapia (*O. mossambicus*) was recorded at Hasarmukhi landing centre. According to fishermen, tilapia occurred for the first time and it appears to be a case of deliberate stocking. Fish catches are disposed off to the middlemen who advance them loans.

Productivity status and fish yield potential

Information on the fish yield potential is *sine qua non* for initiating reservoir management. Timeliness in estimating potential is considered more important than the precision of the estimate, at least during the earlier periods of fisheries development. The estimate is a first approximation which enables the manager to initiate the management process. On the basis of the performance of individual fish species the initial estimates may be refined and yield potentials adjusted suitably either at higher or lower level depending on the situation. Several empirical models are available to estimate the yield potential of reservoirs. However, each model has its own limitations in prediction in a particular situation. The most widely used one is the morphoedaphic index (MEI) of Ryder (1965). Though it has been developed basically for natural lakes, it has also been found useful for reservoirs, especialy to those in Africa and Srilanka. (Henderson and Welcomme 1974, Wijeyratne and Costa 1981). Some suggestions have been put forward to use the African model for Indian reservoirs. However, it should be remembered that the African model is not reservoir specific as it was developed using data sets of lakes and reservoirs. Moreover, Ryder (1982) has clearly stated that the MEI models should be developed on regional and infra-regional basis with the available data sets to improve its precision. In the Indian context, MEI model failed to predict the yield with any degree of precision. Such a situation is expected since alkalinity and conductivity, the positive correlates of total dissolved solids, the main parameter in MEI, are not dependable indices of productivity in Indian reservoirs. Reviewing the existing models, Moreau and De Silva (1991) expressed the view that morphometric features have a greater potential for development of predictive models than biological parameters in Asian reservoirs. According to them, watershed area by itself or in combination with other morphometric features such as mean depth appears to have potential for development as a fish yield predictor in models for the management of Asian reservoirs.

Ramakrishniah (1990) modified MEI model incorporating the drainage parameter, the ratio of catchment to reservoir area (C/A), for a data set of 19 reservoirs and it was found to have a high predictive value. The new model has been called morphodrainage index (MDI) and has been successfully employed to get yield potential of some Indian reservoirs (Ramakrishniah et al. 1998).

In the present study, three models have been employed to arrive at an estimate of potential yield *viz*, morphodrainage index (MDI), trophodynamic model of Melack (1974) and 0.2% of gross primary production as potential yield. The Melack model for Indian reservoirs has been developed from a limited data set (reservoirs and lakes of Tamil nadu) and hence its precision could be of low order.

The transformation of solar energy through primary production by chlorophyll bearing organisms provide a dependable estimate for assessing the potential energy resources of aquatic ecosystems. However, this method has a limitation in man-made lakes since much of the organic matter inputs from allochthonous source are directly utilized and adds to the productivity at the primary consumer level. Nevertheless, the pattern of energy flow in different reservoirs (Table 8) enables to understand the efficiency of the systems and their relative productivity status. Natarajan (1979) suggested that 1% of the gross production provides a fairly dependable limnological guide to fish productivity in reservoirs. However, even in best managed Indian reservoirs fish yield levels never exceeded 0.2% of gross primary production (Natarajan and Pathak 1983). In view of this, 0.2% of gross production has been considered as potential yield in the present study. Yields obtained from the three models are presented in Table 9 for purpose of comparison.

The productivity status and yield potential of each reservoir have been discussed in the following text.

Hemavathy reservoir

The reservoir was formed in 1979. First investigations on the ecology and fisheries were undertaken by the University of Agricultural Sciences, Bangalore, during 1984-86. The present study clearly showed some changes in soil and water quality of Hemavathy. The organic content of soil increased significantly from 0.6 to 1.8%. Similarly, alkalinity of water improved from 35 mg/l to 48 mg/l in a span of a decade. However, PO_4 - P decreased from 0.04 to 0.02 mg/l. The concentration of plankton remained more or less static but individual groups showed some changes. Thus, dinophyceae and copepods increased while cladocerans declined.

Table 8. Bioenergetics in Karnataka reservoirs

Parameters	Cauvery River System					Krishna River System					Sharavathi
	M.bele	Hemavathy	Harangi	Kabini	Nugu	N.pur	V V sagar	Bhadra	G.prabha	M.prabha	L.makki
Radient energy 10^6 K cal/ha	7716	7731	7701	7742	7742	7616	7694	7705	7618	7596	7659
Primary production 10^6 K cal/ha	85.37	43.22	52.85	40.77	47.01	66.87	36.98	40.99	28.62	22.64	50.62
Photosynthetic efficiency (%)	1.1	0.56	0.69	0.53	0.61	0.88	0.48	0.53	0.38	0.39	0.66
Organic carbon dep. 10^6 K cal/ha	412	403	605	426	381	157	426	493	448	202	448
Fish prod. potn. 10^6 K cal/ha	0.23	0.19	0.14	0.11	0.13	0.18	0.1	0.11	0.08	0.08	0.14

Table 9. *Fish yield potential (kg/ha) of Karnataka reservoirs by different models.*

	Melack's model	0.2% of GP	MDI model
Hemavathy	36	85	25
Harangi	44	104	22
Kabini	34	80	29
Nugu	38	92	38
Manchanbele	85	168	180
V V sagar	32	72	42
Bhadra	34	80	20
Narayanpur	59	131	175
Ghataprabha	25	47	20
Malaprabha	27	58	23
Linganamakki	42	99	18

The moderate C/A ratio (33), flushing rate (3.47) and the land use pattern in the catchment have all contributed to the enrichment of Hemavathy reservoir. Though basin soil is acidic and poor in nutrients, organic carbon is high which is favourable for productivity. However, oxycline is not sharp in pre-monsoon months as is generally expected in reservoirs with rich bottom deposits. Probable reasons for the absence of stable oxycline could be absence of thermal stratification, sprawling lentic sector without protection from the heavy premonson winds.

The fish food resources such as plankton and bottom macrofauna are in moderate levels. Some patches of macrovegetation were observed in the intermediate zone and bays during post-monsoon months. A permanent establishment of aquatic weeds is unlikely in view of sharp water level fluctuations.

As per different models, the potential yield varied from 25 to 85 kg/ha. The low yield prediction through MDI could be raised to higher level in view of the fast improvement of soil and water quality due to inputs of organic matter from the catchment. The productivity is bound to increase further in the years to come. An yield of 50-60 kg/ha could be considered an achievable target with proper management.

Harangi reservoir

The reservoir has been impounded in 1984. It has a limited catchment with C/A ratio of 22. The catchment has dense forest cover interspersed with coffee and orange plantations. The flushing rate is the highest among CB reservoirs. The higher organic load it receives from the catchment is reflected in the rich soil organic carbon (2.7%) and available nitrogen (62 mg/100 g). The steep fall in DO levels in water column reaching anoxic conditions beyond 7 m depth is also attributable to the rich organic matter at the bottom. In summer, water is reported to turn black due to release of H_2S. Essential nutrients, nitrates and phosphates, are however in poor concentration. Gross primary production has been estimated at 14.5 g/day, the third highest after Manchanbele and Narayanpur. Plankton production is moderate with predominant zooplankton presence. Bottom fauna has been poorly developed.

The reservoir could be put under productive category considering the nature and anthropogenic activities in the catchment. The yield potential by various models has been estimated in the range of 22 to 104 kg/ha. Considering the size and other productive attributes the achievable target could be around 60 to75 kg/ha.

Kabini reservoir

Kabini has been impounded in 1974. It is relatively shallow with mean depth of around 9 m, lowest among CB reservoirs. The C/A ratio is modest at 35. Dense forest cover with coffee and tea plantations and heavy rainfall characterize the catchment. Though no data are available on the flushing rate, it is expected to be high, at par with Hemavathy and Harangi. As the catchment is in the high rainfall zone the reservoir gets filled up early by July. Organic carbon content of soil is rich (1.9%) and available nitrogen moderate (49 mg/100 g). Alkalinity is low (25 mg/l) and nutrients are poor. Oxycline is not well marked probably due to heavy pre-monsoon winds and shallow conditions. Gross organic carbon production is estimated at 1.1 g/day. Zooplankton is fairly rich and bottom macrofauna is richest among all the reservoirs investigated. Aquatic vegetation occurs in shallow regions during post-monsoon season. The multispecies fishery of the reservoir is well exploited.

The predicted yield from differnt models varied from 29 to 80 kg/ha. Considering all the productivity features, the achievable yield could be in the range of 50-70 kg/ha. with the possibility of further improvement in the coming decades.

Nugu reservoir

It is a 1400 ha, 40 year old impoundment with a mean depth of 11.0 m and relatively high C/A ratio. Organic carbon content of soil is in the productive range (1.7%), whereas available nitrogen is moderate (49 mg/100 g) and available phosphorus low (0.33 mg/100 g). Alkalinity of water is average (40 mg/l) but essential nutrients are poor. Strong oxycline develops during summer and post-monsoon season indicating the productive character. Gross production is estimated at 1.3 g/day. Plankton is relatively rich with predominance of zooplankton. However, bottom fauna is poor in lentic zone and moderate in other regions.

Predicted fish yield from different models ranged from 39 to 92 kg/ha. Considering the age, size and other productivity characteristics, an yield of 80-100 kg/ha could be an achievable target.

Manchanbele reservoir

This is a small and new impoundment with high C/A. However, much of the catchment has been intercepted by two reservoirs on the upstream of Arkavathy. Flushing rate is rather low. Another negative feature is that the catchment is subjected to granite quarrying and periodical droughts. It is relatively deep with a volume development above 1. Organic carbon of soil is rich (1.8%), available N moderate (58 mg/100 g) while available P is poor (0.15 mg/100g). Total alkalinity is highest (144 mg/l) among CB reservoirs. Essential nutrients are in poor concentration as in other reservoirs. Strong oxycline with anoxic bottom (below 5 m) occurs in pre- and post-monsoon months. Gross production is richest (2.3 g/day) among the reservoirs investigated.

The yield potential is estimated to be high in the range of 170 to 180 kg/ha. With proper management, the yield levels could be reached to much higher levels than the predicted ones.

Bhadra reservoir

This is a large and deep impoundment, constructed in 1963, having an area of over 10,000 ha and mean depth of 18 m. The C/A ratio is low. Deep hilly forest, coffee and tea plantation crops and high precipitation characterise the catchment of Bhadra. Basin soil is sandy and gravelly, rich in organic carbon (2.2%). Available N is moderate and available P is poor. Alkalinity of water is low (31 mg/l) as also of essential nutrients. Oxycline is weak in deep lentic zone. Plankton concentration is low with phytoplankton having an edge over zooplankton. In spite of 30 years of its formation, soil texture is predominantly sandy and gravelly with poor development of bottom macrofauna. However, carbon production is good at 1.1 g/day.

The morphometric and drainage characteristics of Bhadra point to its oligotrophic nature with low to medium production potential. Ageing has not contributed significantly, probably due to limited allochthonous inputs. The predicted yield ranges between 20 and 80 kg/ha. Considering the size and allochthonus inputs the yield potential could be in the range of 30 to 40 kg/ha.

VV sagar reservoir

It is a century old shallow reservoir. Though C/A is fairly high, much of it has been intercepted in course of time by large number of tanks. Barring the source of Vedavati, large part of the catchment is situated in rain shadow zone subjected to periodic droughts. Stable conditions in reservoir level prevail over greater part of the year as the flushing rate is extremely low. Annual inflow constitute only 20% of the capacity. Being a very old impoundment, the reservoir must have been subjected to morphometric and hydrographic changes. However, no data are available to quantify the changes. Soil is rich in organic carbon (1.9%) but poor in nutrients. Alkalinity of water is the highest (207 mg/l) among all the reservoirs surveyed, while nutrients are at low levels. Oxycline develops during summer. Dense growth of submerged aquatic vegetation covers over 30% of the reservoir. Carbon assimilation is moderate at 1.0 g/day, so is plankton production with predominance of zooplankton. The reservoir could be considered heading towards eutrophy.

The predicted yield potential varied from 32 to 72 kg/ha. If the aquatic macrophytes are recycled the fish productivity would be much higher. An yield 60-70 kg/ha or even more could be obtained with proper management.

Narayanpur reservoir

It is a large mainstream reservoir, impounded in recent years. Though it has a very high C/A ratio, accumulation of organic matter in the soil has not been high. The reasons could be the extremely high flushing rate at 21.4 and total emptying of the reservoir during 1996 for purpose of repairs. During June-October, the reservoir virtually remains in lotic condition with hydraulic retention time of 8-10 days. The Almatti reservoir, which is coming up 65 km upstream of Narayanpur, with its large storage capacity (175 TMC ft), is likely to reduce the flushing rate of Narayanpur to some extent and stabilize water level. This will have a salutary effect on the productivity. The alkalinity is high (154 mg/l) as also its correlated parameters, the conductivity and hardness. Oxygen profile is orthograde, rather unusual for a mainstream reservoir with extensive catchment. Possible reasons are shallow and sprawled lentic sector devoid of protection from winds, absence of thermal stratification and strong pre-monsoon winds which together might have effected quick turnover of water column. Primary production is high (1.8 $g/m^2/day$) and is next only to Manchanbele. Plankton population is moderate with predominance of zooplankton. Benthic fauna has not been well developed, probably due to dewatering of the reservoir.

The potential yield estimated on the basis of MDI and thermodynamic model are 175 kg and 131 kg/ha respectively. Considering the negative aspects such as interception of catchment and very high flushing rate, the yield potential may be scaled down to 100-130 kg/ha.

Ghataprabha reservoir

Ghataprabha is the deepest among the reservoirs surveyed and also has a moderate catchment with C/A around 21. The catchment is characterised by red soil with sand and gravel texture, poor in nutrients and low to moderate forest cover. Basin soil is red with predominance of sand and pebbles and low in nutrients. Alkalinity and nutrients of water are in low concentration. Oxygen distribution is orthograde. Carbon production is low at 0.7 $g/m^2/day$. However, plankton density is moderate with dominance of zooplankton. Benthic macrofauna is poorly developed. The reservoir is in oligotrophic status with low productive potential.

Predicted yield from different models varied from 20 to 47 kg/ha. The achievable yield could be in the range of 30-40 kg/ha with good management strategy.

Malaprabha reservoir

Malaprabha is the largest among KB reservoirs and also the shallowest, having formed in 1974. It has a modest catchment (C/A ratio,16) consisting of predominantly black soil under intense cultivation. As the catchment is situated in the rain shadow region of Western ghats, the flushing rate is expected to be of low order. Organic carbon and available nitrogen of soil are moderate. Total alkalinity of water is relatively high while concentration of essential nutrients are low. Organic carbon production is of low order (0.8 g/day) but plankton production is richest among all the reservoirs. Bottom fauna is poor. Except for the high concentration of plankton, all other parameters point to the low to medium production potential of the reservoir.

The yield has been predicted to range between 23 and 53 kg/ha. An yield between 30 and 40 kg/ha could be considered achievable with good management.

Linganamakki reservoir

Linganamakki is the largest of the reservoirs surveyed with an area of over 30,000 ha and a mean depth of 13.6 m. Its storage capacity is the largest among the reservoirs of Karnataka. It has a very limited catchment at its disposal with C/A ratio at 6, a negative factor for productivity. Shore line is highly dendritic throwing into a number of coves and bays, a plus point for productivity. Though the catchment experiences high rainfall, the flushing rate is low. The soil pH is acidic with fairly high organic carbon, moderate available nitrogen and low phosphorus. Alkalinity of water is the lowest (21 mg/l) among the reservoirs investigated. Essential nutrients are in traces. However, oxygen stratification is clinograde with a sharp reduction in oxygen below 4m. Organic carbon production is moderate (1.4 $g/m^2/day$), but poor in plankton density. Bottom soil consisted predominantly of sand and gravel with poor development of bottom macrofauna.

Linganamakki has remained oligotrophic in spite of being over 30 years old. The primary production has not been reflected either in the plankton or in the bottom fauna. Large number of uncleared tree stumps in the reservoir are likely to form a substrate for the periphytic community. Morphometric and drainage characteristics predict an yield of 18 kg/ha while primary production estimate is 99 kg/ha. It is unlikely that such high yields could be obtained from the reservoir considering its size and unfavourable C/A ratio. Its productivity level could be low to medium with a potential yield of about 30-40 kg/ha.

Considering all the productive characteristics, the yield potential of different reservoirs could be summarized as below.

Status of productivity	*Yield (kg/ha)*	*Reservoir*
High	100 - 150	Manchanbele, Narayanpur
Medium	50 - 100	Nugu, Kabini, Harangi, VV sagar, Hemavathy
Low	30 - 50	Malaprabha, Bhadra, Ghataprabha, Linganamakki.

Pollution scenario

Rapid industrialization, poor environment management in the catchment make the reservoirs vulnerable to ecodegradation. In addition to direct discharge of industrial, municipal, thermal and agricultural wastes, the pollution load carried by upstream rivers is also accumulated in the reservoirs. The extent of pollution is generally determined by biological oxygen demand (BOD), chemical oxygen demand (COD) and concentration of heavy metals.

It was noticed that, the average BOD and COD values were in the range of 0.5 to 1.5 mg/l and 4.0 to 25.0 mg/l respectively. Higher values were encountered during pre-monsoon in all the reservoirs. Harangi and Narayanpur showed high values of BOD and COD in pre-monsoon months indicating signs of pollution.

Heavy metal pollution was not so significant as revealed from the data (Table 10). Zn concentration in water ranged from 0.03 (VV sagar) to 0.11 mg /l (Bhadra), Cu was mostly found during pre-mosnoon to an extent of 0.02 mg/l in Linganamakki, Cd was negligible and Pb was significant during monsoon in the range 0.06 (Nugu) to 0.09 mg/l (Linganamakki).

In sediments, Zn was the most predominant element and it ranged from 25.2 mg/l (VV sagar) to 224.9 (Manchanbele). Cd was mostly found in pre-monsoon ranging from 2.9 (Linganamakki) to 4.2 mg/l (Bhadra) and Pb was relatively higher in Bhadra (62.0 mg/l) and least in Linganamakki (40.2 mg/l). The heavy metal concentration both in water and sediment are within the permissible limits.

Management guidelines

The indigenous fishes of Cauvery and Krishna river systems are not adequate to realise the yield potential of reservoirs. Hence, it is absolutely necessary to stock major carps to maximise production at a sustainable level. However, there are apprehensions that Gangetic major carps are inimical to native species, though such misgivings appear to be based on insufficient information. The objective of stocking, besides aiming at maximising yield, should also consider preserving the biodiversity of the system. In general, tributaries (being seasonal) harbour few species of commercial importance and hence, addition of new species is likely to improve the species diversity as against the main river. The problem of preserving biodiversity should be tackled in the mainstream reservoirs. In the present investigation, barring Narayanpur, all the reservoirs are on tributaries.

Table 10. Heavy metals (range and average) in Karnataka reservoirs

Reservoir	Water (mg/l)				Sediment (mg/l)			
	Zn	Cu	Cd	Pb	Zn	Cu	Cd	Pb
Hemavathy	**0.04** 0.016-0.077	**0.01** ND -0.014	**0.01** 0.011-0.016	**0.08** 0.070-0.097	**142.8** 57.8 -217.5	**34.8** 31.60-47.50	**3.8** 3.50-4.65	**44.8** 30.00-55.60
Harangi	**0.07** 0.023-0.129	**0.01** ND -0.020	**0.01** 0.011-0.016	**0.08** 0.080-0.099	**95.6** 88.20-108.45	**30.5** 28.45-35.20	**3.6** 3.20-4.40	**45.6** 39.90-56.20
Kabini	**0.07** 0.01 -0.144	**0.01** 0.001-0.015	**0.01** 0.012-0.017	**0.08** 0.066-0.113	**188.7** 173.11-208	**70.6** 65.55-78.70	**2.9** 1.70-4.45	**42.7** 36.15-49.05
Nugu	**0.06** 0.017-0.090	ND -0.009	**0.01** 0.012-0.016	**0.06** 0.056-0.079	**200.5** 187.65-220.95	**44.8** 44.45-46.25	**4.0** 3.80-4.65	**47.2** 45.30-51.90
Manchanbele	**0.06** 0.03 -0.09	ND -0.02	**0.01** 0.013-0.016	**0.09** 0.09 -0.105	**224.9** 217.8-235.0	**42.2** 39.4 -57.45	**2.9** 1.45-4.75	**52.1** 49.35-59.50
Narayanpur	**0.05** 0.050-0.064	0.001-0.004	**0.01** 0.010-0.013	**0.07** 0.060-0.096	**137.7** 132.45-142.50	**63.3** 59.80-67.50	**4.0** 3.80-4.65	**47.3** 46.00-49.00
Ghataprabha	**0.03** 0.020-0.054	ND -0.001	**0.01** ND -0.011	**0.07** 0.060-0.093	**164.8** 159.15-173.25	**135.3** 117.70-167.40	**4.0** 3.89-4.10	**41.6** 40.40-44.35
Malaprabha	**0.04** 0.040-0.056	ND -0.001	**0.01** 0.010-0.011	**0.08** 0.080-0.091	**170.0** 168.20-171.90	**63.4** 60.20-68.15	**3.0** 0.01 -4.80	**55.8** 49.80-66.75
Bhadra	**0.11** 0.046-0.189	ND -0.011	**0.01** 0.010-0.017	**0.06** 0.056-0.098	**193.4** 193.20-194.55	**65.5** 64.30-67.15	**4.2** 4.00-4.35	**62** 54.75-67.55
V V sagar	**0.03** 0.020-0.041	ND -0.001	**0.01** 0.010-0.013	**0.08** 0.070-0.101	**25.2** 23.90-28.50	**50.5** 48.80-54.65	**4** 3.90-4.40	**42.4** 40.20-45.45
Linganamakki	**0.04** 0.042-0.048	ND -0.02	**0.01** 0.013-0.017	**0.09** 0.085-0.124	**195.2** 164.75-240.0	**58.8** 44.70-76.50	**2.9** 0.01-4.90	**40.2** 29.55-65.85

As per the records of the Fisheries Department of Karnataka, stocking of major carps and common carp has been done in varying degree in all the reservoirs, barring Narayanpur and Manchanbele. Stocking appears to be fitful and the material consisted predominantly of common carp followed by rohu and catla. Scant attention has been paid regarding the suitability of the species and needs of the reservoir. There is no agency monitoring the catch. In the absence of reliable data on catch and catch composition from any reservoir, no effort has been made to assess the impact of stocking. Sporadic occurrence of common carp and major carps has been recorded in the catches. The present yield of reservoirs appears to be very low and is only a fraction of the potential. A judicious stocking and exploitation policy is called for to realise the potential.

Catla should be stocked in all the reservoirs. It should form the dominant component except in VV sagar, Bhadra and Hemavathy. The performance of rohu in reservoirs, in general, has not been very encouraging especially in oligotrophic ones. The growth of rohu has been impressive in old reservoirs with rich periphytic flora and fauna. A limited presence of aquatic vegetation is particularly suitable for the growth of the species. It may do well in VV sagar. Hence, rohu should form the dominant component of stocking in VV sagar, next to catla in Nugu, Kabini, Hemavathy, Narayanpur and Linganamakki. Mrigal should be given adequate representation, especially in Ghataprabha, Malaprabha, Harangi, Linganamakki and Bhadra. Common carp may be stocked in VV sagar, Hemavathy, Kabini, Harangi and Malaprabha. The species should be avoided in reservoirs with large catfishes and poor bottom fauna.

The Deccan mahseer, *Tor khudree,* is an important sport fish of peninsular rivers. It has been subjected to increasing environmental stresses due to a combination of factors like reservoir formation, heavy exploitation and wanton destruction of the habitat. The need to conserve and propagate the species has been recognized in the state. A mahseer hatchery is being established at the site of Harangi reservoir. When it becomes operational, mahseer seed will be available for stocking the reservoirs. Suitable reservoirs for the species are Harangi, Kabini, Nugu and Bhadra.

Stocking of grass carp in VV sagar should be considered to utilise the submerged aquatic vegetation. No other species is as affective as grass carp in checking the spread of vegetation in water bodies. The species may not pose any threat to indigenous species and is not likely to propagate in the reservoir. Controlling aquatic vegetation with grass carp will not only add to the productivity but also reduces the silting of the reservoir.

The size of fish seed stocked is critical in reservoir ecosystem to enhance its survival. A size of 10 cm and above is ideal for quick growth and better survival. About 200-300 fingerlings per hectare may be stocked in large reservoirs and 300-400 fingerlings in medium and small reservoirs. Average area [(FRL + DSL)/2] or 60% of the full reservoir area may be considered for computing the stocking.

Stocking should preferably be done during post - monsoon (Sep-Oct), when the water level stabilizes and a spurt in zooplankton occurs. Common carp may be stocked in pre-monsoon months.

Natural breeding and recruitment of stocked species varies from reservoir to reservoir. Breeding is no guarantee for successful recruitment, as survival depends on many factors. In general natural recruitment is not dependable in reservoirs, especially in those on tributaries, which warrants stocking on continuing basis.

Once the fishery is established, fishermen should be rehabilitated around the reservoir at suitable settlements. At present the community migrate from reservoir to reservoir with their families living in temporary settlements under trying conditions. The children also migrate with them and participate in the activities connected with fishing and marketing. A permanent settlement is a must to allow the children to attend school and other childhood activities.

Though there is a mesh regulation, it is not generally enforced. Strict mesh regulation should be enforced preventing the exploitation of small sized stocked species. Small-meshed nets could, however, be operated in certain seasons and in certain areas to exploit the minor carps and minnows under supervision. The best season for such operation would be the period of low water levels.

A seed rearing farm has been constructed at most of the reservoirs. However, many of them have become non - functional. The functional ones at Bhadra and Kabini cater to the needs of smaller water bodies in the area. It is necessary to strengthen infrastructural facilities for stocking and exploitation of each reservoir.

At present licences are issued by the department to fishermen for exploitation. It is desirable that the existing cooperative societies are activated and the reservoir leased out to the society for management. The fishermen should also be made partners in the management.

Data on such aspects as species-wise fish landings, fishing effort and details on stocking should be collected to create database for each reservoir as it is an essential prerequisite for reservoir fisheries development.

Reservoirs of Karnataka have been sanctuaries for some species of *Puntius*. In recent years there has been some decline of these species owing to periodic recruitment failure and competetion from stocked carps. Steps should be taken to rehabilitate these species to their earlier levels. Seed production of indigenous carps such as *L. fimbriatus, P. dubius, P. jerdoni, P. carnaticus* and *C. cirrhosa* should be undertaken to preserve the biodiversity of the peinsular rivers.

New systems of culture such as pen and cage, should be introduced to utilise the reservoirs comprehensively and get enhanced fish production; pen culture to raise fish seed and cage culture for raising table fish. Pen culture is suitable in reservoirs which have shallow bays and get filled up early in the season (July/Aug) and retain that level for 2 to 3 months(Oct-Nov). Reservoirs suitable for pen culture are : Kabini, Hemavathy and Narayanpur. Cage culture is suitable for all reservoirs. It is worthwhile giving the ownership of cages to individual fishemen with financial help from NGOs and commercial banks. This will bring additional income to fishermen.

Tilapia (*O. mossmabicus*) has been recorded in several reservoirs. It may not get established in the long run due to water level fluctuation and presence of predatory fishes. Absence of predatory fishes and lack of competition from other species in Manchanbele reservoir have offered congenial environment for the proliferation of tilapia where it has established itself firmly as a dominant fishery. The species should be controlled as there is every likelihood of it entering the main river affecting endemic fish fauna.

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