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PRODUCTIVITY OF WATER BODIES WITH REFERENCE TO COAL MINE AND ALLIED EFFLUENTS

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Introduction

Ecology may be defined as the science of the interrelation between living organisms and their environment (Allee *et al* 1949) and it is this interrelationship that is of prime importance in consideration of the natural resources of the earth. In Asian waters in general, and in Indian waters in particular many of these parameters are poorly understood and the successful utilization of these resources is now - and will in future - be dependent upon contemporary attitudes to ecology in the region.

Biological production is the key to the extent to which such resources may be utilized - for whatever purpose - and it is here intended to discuss ecological and biological production both in general terms and with particular reference to the impact of coal mine drainage and coal washeries effluents of Dhanbad coalfield area. There are numerous factors affecting production, both positively and negatively, and such factors are subtly different from those influencing production in the typically more comprehensively studied temperate regions. By an understanding of these factors that affect and regulate production and determine the ecology of any

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aquatic system whether lotic or lentic, we can aim at a planned and sensible utilization of the regional resources. All too often a failure to understand has led, in the past, to environmental disasters. As a consequence we in the long term are the sufferers.

Production and its efficiency and a thorough understanding of ecology are of paramount importance in the tropical aquatic system, where much of the supply of protein comes from fisheries. The total water surface of the earth is somewhere around 36000 million ha with about 500 million in fresh waters (Henderson, 1978). The total marine food harvest, according to an early report by Holt (1975) is estimated to be about 60 million tons, the average catch approaching 2 kg/ha/year while the freshwater catch averages rather more (12-16 kg/ha) (Henderson, 1978).

The whole yield of aquatic systems harvested by man in the form of aquatic life depends upon the 'primary production' of the water bodies from which they come. Primary production of an aquatic system is the ability of water to support the production of organic materials from inorganic ones. Primary productivity is the path through which the energy enters into its unidirectional path of flow through various trophic, levels in the ecosystem in form of chemical energy from the ultimate source of energy - the sun. The radiant energy from solar system falling on the surface of waters is trapped bymicrophytes - the phytoplankton - through the process of photosynthesis and the radiant energy is then stored into the microphytes in form of organic matter. The harvest of predatory organisms which occur at higher trophic levels depends on the production of microphytes through a series of transfers of material - each step called trophic level and the whole relationship of eating and being eaten is called food chain. As only a fraction, say 10-20 percent of the productivity of one trophic level can be transferred to the next, the proximity of harvested forms to the base of the chain is an important factor in determining the usable productivity or potential yield of the waters concerned.

An overall view of these variations can be obtained by examining some figures of Ryther (1969) who used these principles to estimate the potential yield of fish from world's oceans (Table 14.1A.).

Table 14.1A : Use of Trophodynamics Model to Estimate Fish Production by Three Ocean Provinces Defined According to Level of Primary Production (After Ryther 1969 from Regier 1973)

Variables	*Open ocean*	*Costal zone*	*Upwelling areas*	*Total*
Percentage of Ocean	90.0	9.9	0.1	100
Area (km^2 x 10^6)	326.0	36.0	0.36	362
Mean primary production gc/m^2/year	50.0	100.0	300.0	-
Total primary production kg C x 10^{12}/year^{++}	16.3	3.6	0.1	201
Trophic levels	5	3	1.5	-
Mean efficiency, %	10.0	15.0	20.0	-
Fish production kg x 10^9 fresh weight	1.6	120	120	214

* 1-Includes offshore, non-upwelling areas of high productivity,
++ corrected figure.

General Precepts

The Indian subcontinent comprises a predominantly tropical environment and because of generally stabilized climatic conditions throughout the central tropical region as a whole, with high temperatures, high rainfall and bright illumination, the productivity of waters of this region is more or less continuous and quite different from climatically induced variable rates of production found in temperate climates (Fig 14.1). Table 14.1B includes the data on primary production showing very clearly the ranges of microphytic production in different regions. It is clear that the shallow water bodies of oriental region most productive in comparison to water bodies of different latitudes. In this region similar to the general features of tropical climate, however, production can reach levels high enough to result in dramatic surges in the species abundance so that algal bloom, particularly of the blue green algae *Microcystis aeruginosa* and *Oscillatoria rubens* occur in fresh waters with some higher value of nutrients. These, in turn, influence the abundance of secondary and tertiary consumers and hence the secondary and

Table 14.1B : Range of Primary Production in Microphytic Communities of Shallow Freshwaters in Various Regions.

Region	*Subregion*	*Mean depth* (Z^{-}) *m*	*Gross Primary production* (P_c) *mg. C/m²/day*	*Annual gross primary production g C/m²/yr*	*Authors*
Tropics	(i) Tropics in general	2.5-5.0	158-15200	620-840	Goldman (1959), Kurasawa (1958), Jalling (1965), Ganf (1972), Imevbore *et al* (1972), R.S.A.F.B. Team (1972), Burgis *et al* (1973).
	(ii) Oriental in particular	(A) 0.9-3.0	1210-17550	- -	Ganapati (1972), Ganapati and Sreenivasan (1972), Nasar and Dutta Munshi (1975), Sarkar *et al* (1977), Sinha (1988), Gorai (1978),
		(B) 3.4-18.3	1601-3228	- -	Ganapati and Pathak (1972) Ganapati and Sreenivasan (1972).
Temperate	(i) American	1.0-20.0	60-13,200	90-760.1	Steemann Nielsen (1955), Rodhe (1958), Kristiansen and Mathiesen (1961), Wetzel (1966a and b), Efford (1972), Wetzel (1975), Kelly *et al* (1977).
	(ii) European	1.2-14.0	0-11,000	14-520	Nygaard (1955), Steemann Nielsen (1955), Rodhe (1958), Jonasson and Mathiesen (1959), Duthie and Kirton (1970), Steel *et al* (1973), Johnasson (1972), Morgan (1972), Moskalenko and Votinsev (1972), Wetzel (1975), Zutshi (1976).

tertiary productions. Thus community structure can fluctuate widely and is brought about by the competitive interaction existing between opportunistic undergoing remarkable changes in population structure. Such a balance is also influenced by the generally longer breeding seasons of tropical species (Morton 1978). This situation is exacerbated by the greater degree of adaptive radiation that has taken place in most of the principal aquatic families, resulting in a profusion of species, each exploiting a narrower niche in the environment as a whole (Fig. 14.2).

In the tropics, in general, as pointed out by Morton (1978) each species occupy a narrow niche might be considered more individually susceptible to the deleterious effects of man's activity in the aquatic environment. Alternatively, however, there is correspondingly greater variety of species possessing at least the potential for successful exploitation by man as a resource. Thus it is now very clear that water bodies of this area possess an enormous potential for the successful exploitation of resources in one hand while to the impacts of human activities - the pollutional one being the first and foremost. One of the major polluting source of water bodies of coal field area of Dhanbad is the coal mine drainage and effluents from coal washeries in mining area as well as sewage.

Present Study

The present study has been carried out on coal mine drainage and coal washeries effluent receiving water bodies of Jharia Coalfield to analyse their impact on primary production. The physicochemical characteristics of coal mine drainage and coal washeries effluent have been presented in Table 14.2 and Table 14.3 respectively. The various parameters have been analysed following standard method (APAH, 1967 and Trivedy and Goel, 1984). The primary production has been estimated by light and dark bottle experiment (Strickland and Parson, 1968), and while calculating the data for gross primary production the photosynthetic quotient has been assumed to have a value of 1.2 (Westlake 1963, Strickland 1965). The data so recorded have been presented in Table 14.4 in terms of gram carbon/m^3/day and net primary production and community respiration as percentage of gross primary production has been calculated. Table 14.5 includes the data on seasonal variation in gross primary production, net primary production and

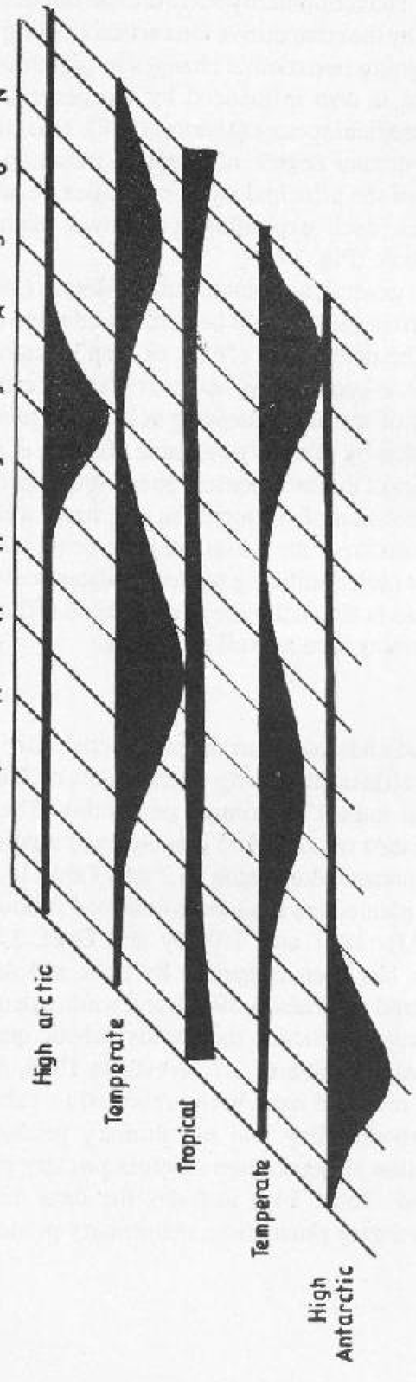

Fig.14.1 : Cycles of Production at Different Latitudes (after Friedrich 1969)

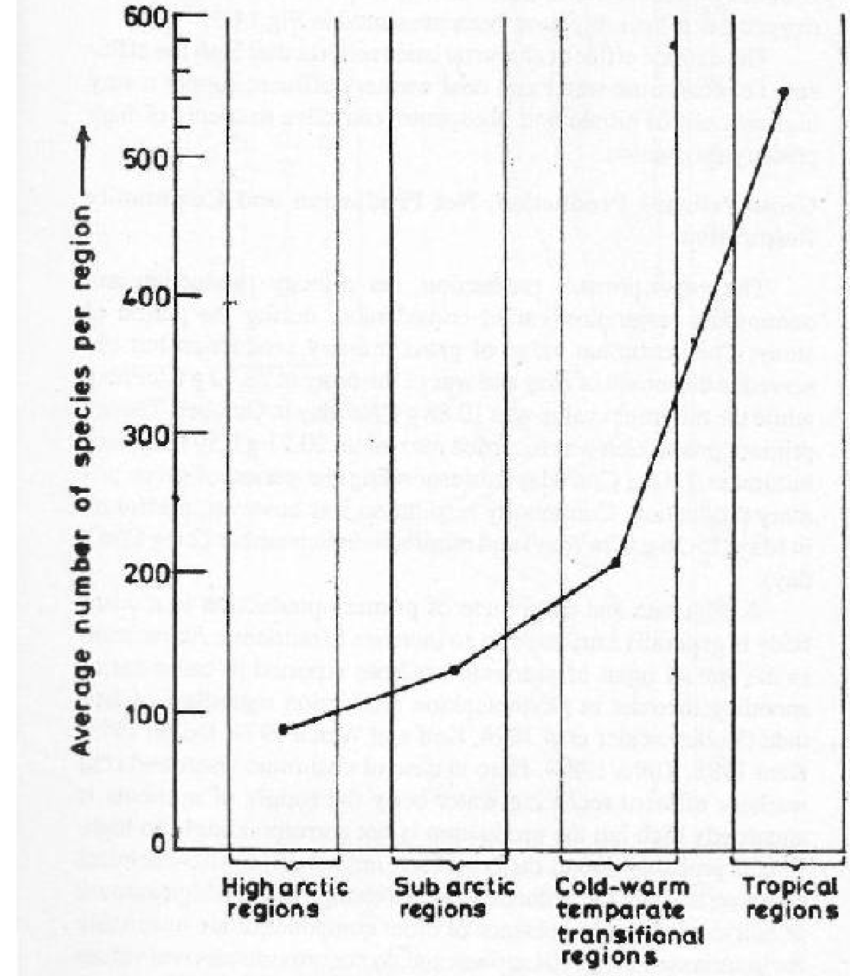

Fig.14.2 : The Average Number of All Species of Prosobranch Gastropods from Large Areas at Different Latitudes (after Thorson 1972)

community respiration values in terms of gram carbohydrate/m^2/day. In Table 14.6 seasonal variation in gross primary production in terms of K. Cal./m^2/day based on gram oxygen/m^2/day and gram carbohydrate/m^2/day and the photosynthetic efficiencies based on both oxygen based data and carbohydrate based data. The data obtained on production and community respiration in terms of gram oxygen per m^2 per day have been presented in Fig 14.3.

The data on effluent characteristics reflects that both the effluents i.e. coal mine water and coal washery effluent supply a very high amount of nitrate and phosphate, causative nutrients of high primary production.

Gross Primary Production, Net Production and Community Respiration

The gross primary production, net primary production and community respiration varied considerably during the period of study. The maximum value of gross primary production has observed in the month of May and was of the order of 28.72 g C/m^2/day while the minimum value was 10.88 g C/m^2/day in October. The net primary production was recorded maximum 20.21 g C/m^2/day) and minimum 7.57 g C/m^2/day corresponding the period of gross primary production. Community respiration was however, maximum in May (15.26 g C/m^2/day) and minimum in September (2.0 g C/m^2/day).

A high rate and magnitude of primary production in a water body is generally attributed to an increase in nutrients. An increase in the annual input of nutrients has been reported to cause corresponding increase in phytoplankton production regardless of latitude (Vollenweider *et al* 1974, Kelf and Welch 1974, Dillon 1975, Kant 1985, Sinha 1988). Here in case of coal mine water and coal washery effluent receiving water body the supply of nutrients is apparently high but the production is not correspondingly so high. This is probably due to the combined impact of physico-chemical characteristics of the effluents which although contain high amount of nutrient yet due to presence of other components, are unsuitable for luxuriant microphytic growth and do not provide survival values to the planktonic communities of the receiving system. According to Rodhe (1969) the enormous storage of nutrients, mainly bound to mud, is one of the reasons that an immediate or complete reversion of induced eutrophication. In two small Danish lakes, a substantial

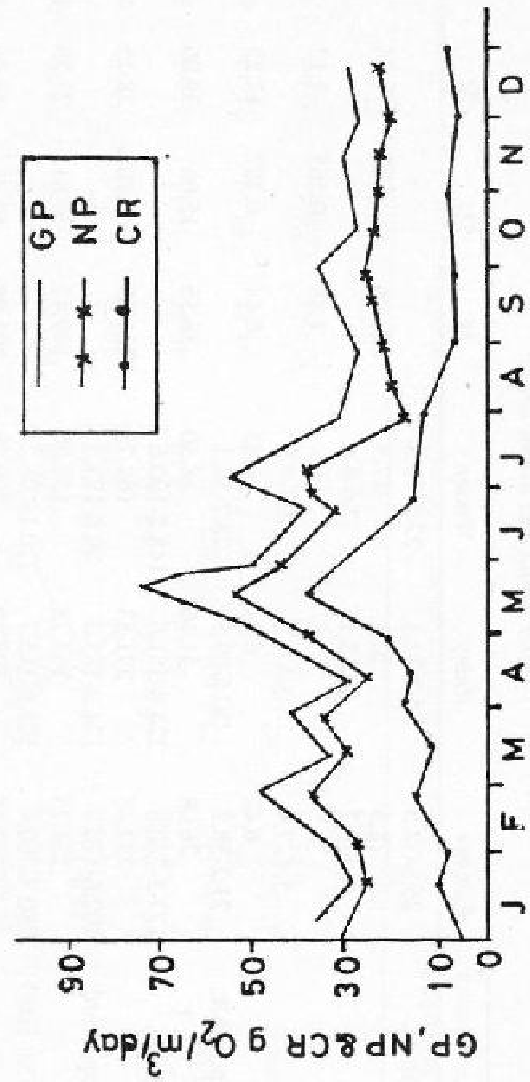

Fig. 14.3 : Seasonal Variation in Gross Production (GP), Net Production (NP) and Community Respiration (CR) of a Coal Mine Drainage Receiving Water Body

Table 14.2 : Physico-Chemical Characteristics of Coal Mine Effluents (Minimum, Maximum and Average) (after Sinha and Sinha 1987)

	Summer	*Rainy*	*Winter*	*M*	*SD*	*CV*	*V*
Temp. °C	26.3-32.5 28.5	25.2-32.3 30.1	27.5-29.5 27.3	28.86	2.678	9.25	7.12
pH	7.5-9.2 8.5	7.2-8.1 7.5	7.6-8.6 8	7.88	0.565	7.17	0.319
DO	5.4.-7.4 6.42	5.4-7.8 6.55	5.3-7.8 6.35	6.44	0.787	12.23	0.60
Phenol. Alk.	21.2-38.2 26.08	30.5-69.5 51.10	28.7-52.1 38.50	38.55	15.06	39.06	226.80
MO Alk.	177.5-280.8 237.45	224.8-351.6 291.53	148.2-190.6 164.78	231.25	65.10	28.15	4238.04
Temp. Hard	102.6-170.7 124.25	124.2-185.3 165.78	99.0-183.5 158.20	149.41	35.81	23.26	1282.35
Perma. Hard	280.7-300.4 293.35	301.6-315.7 308.80	210.1-405.2 309.78	303.98	42.74	14.06	1826.70
Total Hard	400.7-450.8 417.60	425.8-496.1 474.58	209.1-688.6 467.98	453.38	69.46	15.32	4824.69

	Summer	*Rainy*	*Winter*	*M*	*SD*	*CV*	*V*
Dissolved Solids	213.8-515.2	466.2-598.2	240.2-558.2				
	423.77	544.8	424.7	464.42	121.13	26.08	1467.47
TSS	87.2-207.2	98.8-243.2	90.1-292.8				
	135.85	171.57	150.35	152.59	68.91	45.16	4748.58
COD	16.8-23.2	22.8-29.2	11.6-16.6				
	20.2	26.85	15.37	20.80	5.80	27.88	33.67
Chloride	49.9-88.6	24.8-46.8	21.3-50.2				
	65.05	34.68	40.40	46.71	19.15	40.99	366.72
Sulphate	48.1-117.2	75.6-101.2	90.2-143.2				
	80.15	88.98	115.45	94.85	25.13	26.49	631.51
Phosphate	111.2-192.7	82.1-110.6	87.2-152.8				
	151.82	99.27	128.82	126.64	38.84	29.09	1357.18
Iron	1.4-8.5	1.3-2.6	1.3-2.8				
	2.42	1.95	2.2	2.27	0.49	21.62	0.240

M = Annual Mean; SD = Standard Deviation; CV = Coefficient of Variation; V = Variance.
All Parameters are in mg/l.

Table 14.3 : Physico-Chemical Characteristics of Coal Washery Effluent During 1988 (Values in mg/l)

	Months											
Parameter	*Jan.*	*Feb.*	*Mar.*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Temp.°C	27.9	28.2	27.3	28.1	29.2	30.1	31.9	31.0	29.0	29.3	28.2	27.0
pH	7.9	7.6	7.8	7.7	7.8	7.9	7.8	8.5	7.9	7.8	7.8	7.5
Diss. Oxygen	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Tof. Alk.	89.6	75.00	70.0	75.00	80.00	96.00	78.00	87.26	79.60	122.00	87.0	87.00
Tof. Hardness	326.00	360.00	300.00	350.00	350.00	450.00	376.00	375.00	375.00	350.00	346.00	340.00
T.S.S.	1750.00	1550.00	900.00	1600.00	1600.00	2000.00	1900.00	2001.00	1600.00	2100.00	1700.00	1750.00
TDS	1146.00	110.0	1000.00	1700.00	1300.00	1500.00	1200.00	1600.00	1200.00	1300.00	1300.00	1137.00
TVS	827.00	850.0	800.00	1150.00	1000.00	1300.00	900.00	1100.00	1000.00	1200.00	1200.00	1200.00
Sulphate	25.00	10.5	10.00	17.00	25.00	28.00	20.5	25.6	25.00	26.38	25.00	26.00
Chloride	31.00	26.0	25.00	27.00	30.00	36.00	28.0	36.5	37.3	35.00	36.00	36.5
Floride	0.03	0.01	0.01	0.04	0.08	0.15	0.08	0.06	0.08	0.08	0.08	0.09
Amm. Nitrogen	37.5	58.00	30.00	35.00	36.00	37.00	37.00	38.00	42.00	36.5	39.00	36.37
Calcium	76.5	55.00	50.00	75.00	76.00	86.00	86.5	86.5	79.8	86.00	86.00	89.5
Magnesium	56.5	44.00	40.00	47.00	48.00	55.00	49.0	56.3	56.5	49.00	56.00	49.5
Iron	0.32	0.4	0.3	0.35	0.35	0.37	0.34	0.36	0.5	0.39	0.3	0.33
Diss. Iron	0.20	0.15	0.1	0.05	0.15	0.21	0.20	0.24	0.22	0.16	0.2	0.21
Chromium	0.06	0.03	0.02	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Phenol	0.06	0.03	0.02	0.05	0.04	0.08	0.06	0.08	0.08	0.08	0.06	0.08
Oil and Grease	9.6	8.5	8.00	9.00	8.9	9.00	8.7	9.6	9.00	9.6	9.6	9.6
B.O.D	315.00	250.0	200.00	300.00	400.00	400.00	450.00	408.00	406.00	450.0	350.00	357.00
COD	1176.00	1150.00	1100.00	1000.00	1200.00	1200.00	1300.00	1200.00	1250.00	1300.00	1300.00	1150.00

Table 14.4 : Seasonal Variation in Gross Production (GP), Net Production (NP) and Community Respiration (CR) as Gram/C/m^2/day.

Parameter	*Jan.*	*Feb.*	*Mar.*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Gross Production GP	14.06	18.22	15.48	16.57	28.72	15.03	20.92	11.36	13.35	10.83	12.07	11.36
Net Production NP	11.28	14.32	11.28	9.41	20.21	9.41	14.58	8.55	11.32	7.57	9.41	9.11
Community Respiration CR	2.77	3.9	4.2	7.16	15.26	5.62	6.33	2.81	2.0	3.26	2.66	2.88
NP as % of GP	80.27	78.59	72.86	56.78	70.36	62.60	69.69	75.26	84.79	69.89	77.96	80.19
CR as % of GP	19.72	21.40	27.13	43.21	53.13	37.39	30.25	24.73	14.90	30.10	22.03	23.35

Table 14.5 : Seasonal Variation in Gross Production (GP), Net Production (NP) and Community Respiration (CR) as g Carbohydrate/m^2/day.

Parameter	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
GP	35.13	45.53	38.69	41.41	71.77	37.57	52.28	28.39	33.35	27.07	30.17	28.39
NP	28.20	35.79	28.20	23.51	50.50	23.51	36.44	21.36	28.29	18.92	23.51	22.76
CR	6.93	9.74	10.49	17.89	21.27	14.05	15.83	7.02	5.05	8.15	6.65	5.71
NP as % of GP	80.27	78.59	72.86	56.78	70.36	62.60	69.69	75.26	84.79	69.89	77.96	80.19
CR as % of GP	19.72	21.40	27.13	43.21	53.13	37.39	30.25	24.73	14.90	30.10	22.03	23.35

Table 14.6 : Seasonal Variation in Amount of Solar Energy Converted as GP into g $O_2/m^2/day$ and g Carbohydrate/m^2/day as K Cal/m^2/day: Photosynthetic Efficiency (PE) and Percentage of Photosynthetic Efficiency (PPE)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
K Cal/m^2/day of g O_2/m^2/day	138.00	178.84	151.98	162.65	281.88	147.56	205.34	111.50	131.00	106.35	118.49	111.50
K Cal/m^2/day of g Carb/m^2/day	144.033	186.673	158.629	169.781	294.257	154.037	214.348	116.337	136.735	110.987	123.697	116.399
PE on O_2 base	0.01898	0.02076	0.01539	0.01476	0.02417	0.01240	0.1751	0.00996	0.01258	0.01185	0.01562	0.01738
PE on Carbohydrate base	0.01981	0.02167	0.01606	0.01541	0.02523	0.01294	0.18280	0.0104	0.01313	0.01236	0.01928	0.01845
PPE on O_2 base	1.89	2.07	1.53	1.47	2.41	1.24	1.75	0.99	1.25	1.18	1.56	1.73
PPE on Carbohydrate base	1.98	2.16	1.60	1.54	2.52	1.29	1.82	1.04	1.31	1.23	1.92	1.84

decrease of phytoplankton production was observed for the first two years after the diversion of sewage water in 1959 (Johnson *et al* 1962, Mathiesen 1963).

The values of community respiration were also found lower in the water body. This points out that the water body, on the whole, is having very poor biota. The less or oxygen deficient nature of effluent coupled with high COD and toxic substances are the probable reasons for less number of phytoplankton, zooplankton, aquatic insects, fishes and micro and macro benthic fauna of the water body and which ultimately resulted into low respiratory processes. Higher values of community respiration are generally observed in eutrophic lakes (Sreenivasan 1972, Kelly *et al*, Ganf 1972, 1974, Sinha 1988).

Hulber *et al* (1960) and Prasad and Nair (1963) have suggested, and as has been mentioned in general precepts (Fig 14.1) that in tropical waters primary production is moderate throughout the year with little oscillation. However, many authors like Sreenivasan (1964), Vijayraghavan (1971), Laveque *et al* (1972), Nasar and Dutta Munshi (1975) have observed marked seasonal variations in the rate of primary production and community respiration with maximum values during summer and minimum during winter similar to the present observations corresponding to high planktonic growth period and bright illumination period.

Sinha (1988) observed a very high rate of primary production with high community respiration in a water body of the same region having no inflow of coal mine water or coal washery effluent and classified it as highly eutrophic. The low gross primary production along with low community respiration of the coal industry effluent receiving water body is also probably due to lack of allochthonus organic supply to the system. According to Rodhe (1969) eutrophication can be based on allotropic contributions by man, in particular, domestic as well as autochthonus organic supply.

Photosynthetic Efficiency

The photosynthetic efficiency has been calculated from oxygen values and also after conversion of oxygen values into carbohydrate values. On the whole the photosynthetic efficiency based on oxygen values is less by 0.001 or 0.1% than those of carbohydrate values. The range of efficiency values is from 0.99% to 2.52%. A lower range of photosynthetic efficiency has been recorded by Rodhe

(1958) for Lake Erken who reported the values between 0.01% and 0.6%. Ganapati and Sreenivasan (1969) estimated the photosynthetic efficiencies in two man made lakes: Amravathi reservoir and Stanley reservoir in south India. They found the values to vary between 0.2% and 0.67% in the Amaravathi reservoir and between 0.37% and 0.59% in the Stanley reservoir.

A considerably higher value of photosynthetic efficiency varying from 0.06% to 1.44% (Ganapati and Pathak 1969, 1972, Ganapati and Sreenivasan 1972), 0.17% to 1.55% (Ganapati and Sreenivasan 1972, Sreenivasan 1972) and 1.09% to 13.8% (Ganapati 1972, Sreenivasan 1972, Nasar and Dutta Munshi 1975) has been recorded. The lower photosynthetic efficiency value during the present study, however, may be attributed to the high suspended solids being brought into the system through the effluents which decrease the transpirancy and limit the photic/productive zone of the water column. The blanketing effect of suspended solids plays important role in decreasing photosynthetic efficiency causing hindrance in light penetration.

Variations in Primary Productivity

According to Henderson (1978) the productivity of water is primarily a function of nutrient and energy supply to the system. It is probably rather rare that the basic biological productivity of a water body is severely limited by lack of suitable living organisms when the water body provides the conditions of survival of the producers. The production decreases to minimum in water bodies when the survival of producers becomes a question due to adverse impact of human activities such as acidification of water bodies or continuous inflow of toxic effluents which suppress the survival values. Over exploitation by human being of a water source has been found to suppress the production. There is also, however, evidences of significant differences in the ecological efficiencies i.e. the efficiency of photosynthesis, efficiency of conversation of primary production to fish and other aquatic crops which can be related to variation in the structure of aquatic community. In fresh water variation in nutrient availability from one water body to another is result of a number of factors such as geological structure through variation in land use, nature of the catchment area, fertilization through various effluents etc. are very important.

Nutrient Supply

Nutrient input to freshwater rivers and lakes is closely related to the use of catchment area, geological formation of the basin, input through effluents and also to its own standing crop.

Phosphorus and, in special sense, silica are generally regarded as the most critical nutrients for organic production in lakes (Rodhe 1969, Schelske and Stoermer 1972, Schindler and Fee 1974a, Fee 1978, 1979) and phosphorus is the most implicated in lake eutrophication from human activities. In those studies in which annual productivity has been examined in relation to various physical and chemical factors, nitrogen, particular total (Mann 1974), organic or Kjeldahl nitrogen (Herbaeck 1969) has been correlated with phosphorus.

More importantly, the direct nutrient pools in aquatic systems may be several steps removed from the free nutrient in solution. In tropical waters in general, most nutrients are incorporated into living tissue and are transformed by direct digestion/decomposition/absorption cycles (Henderson 1978). A further complication is that excess nutrients are readily taken up by plant cells so that above certain critical levels additional nutrient is taken up by the organisms into the intercellular pools without additional growth (Gerloff 1969).

Thus as shown in the Fig 14.4 when a nutrient is below a critical concentration, any additions to the environment will be immediately taken up in growth with no change in concentration. But once the critical concentration is reached, further addition of nutrients results in higher concentrations in organisms but without added growth. This additional incorporation of nutrient into internal storage has been called "luxury consumption".

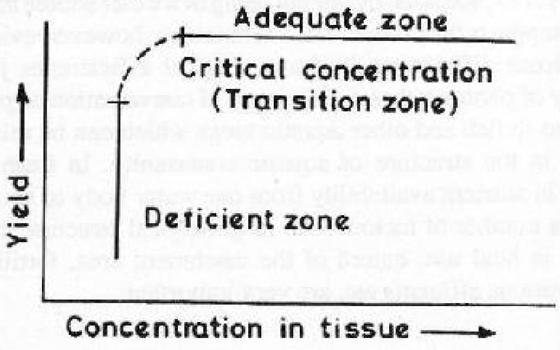

Fig 14.4 : Critical Concentration and Luxury Consumption (after Ulrich 1961).

It is perhaps for such reasons that Total Dissolved Solids (TDS), or its equivalent conductivity, often appears more closely determinate of overall productivity, of lake systems than any of the individual nutrients (Ryder *et al* 1974, Jenkins 1967, Malack 1979). That productivity is not always directly correlated with these measures (Mann 1974, Oglesby 1979) tends to support the hypothesis that the dissolved solids and other such indices of aggregate chemical composition are correlates of the rate of supply of nutrients in a inflow rather than of the net accumulation in the lake in question.

Energy Supply

Solar radiation is another essential ingredient of primary production and an important input to aquatic systems. However, as pointed out by Mann (1974) in his review of the IBP studies on lakes, the importance of solar radiation seems not so much that of an energy supply to photosynthesis as of the energy supply to produce wind and water currents. Except in high latitudes or turbid waters, light is generally more than adequate for photosynthesis. It is thus more important that the general turbulence resulting from current flow and surface heating allows plankton cells to circulate between the lighter and darker regions of the water columns. It is even more important that the water circulation, and particularly the seasonal overturns of lakes, act to bring bottom nutrients to the surface waters. Indeed, physical variability in general may be regarded as contributing to high productivity (Regier and Henderson 1973). The higher productivity of shallow water bodies is probably related to the continual stirring of a larger portion of the bottom by waves as well as currents and making maximum portion photic.

The role of particulate organic material in supplying energy to aquatic systems is not simply that of source. It is also a suitable physical substrata upon which exchange of materials can occur without letting them go free into the water (Khailov and Finenko 1970, Finenko and Zaika 1970). Detrital materials need not originate from outside the system. The remains of phytoplankton, rooted vegetation and zooplankton can also participate in such surface mediated exchange.

Other Factors

Among the other factors which affect the primary productivity of fresh water bodies the most important are those related to structural and other complexity in aquatic systems. Diversity in physical habitat, water level and inflow/outflow etc. lead to diversity in the overlying biological communities.

According to Fee (1978, 1979, 1980), Stockner (1979), Stockner and Shortreed (1978, 1979) Shortreed and Stockner (1981) primary production is affected, apart from the two above mentioned important factors, by a range of physical, chemical and biological factors (i.e. flushing, isolation, etc.) each subject to considerable daily, seasonal, and annual variation. When a water body is perturbed by relatively small or large continuous additions of nitrogen and phosphorus, phytoplankton response can easily be masked by variations induced by other factors, and hence interpretations are often difficult.

Generalization of Indian Scenario

Gopal *et al* (1978) while reviewing the studies on ecology and production in Indian freshwater ecosystems at primary producer level with emphasis on macrophytes have tried to generalize the microphytic primary productivity. According to their review data on primary production of microphytes are available for a number of water bodies ranging from small fish pond and shallow lakes to large lakes and man made reservoirs and rivers. Ganapati and his associates have made extensive studies on freshwaters in south India and have recognised seven main types of freshwater bodies namely, reservoirs and lakes (perennial and periodic), ponds (including fish ponds) temple tanks, rivers, estuaries and sewage stabilisation lagoons (Ganapati 1972, Ganapati and Srivastava 1972, Ganapati and Pathak 1972, Sreenivasan 1965, 1968, 1972, 1974a, 1974b). Kaul and his students have investigated temple lakes in Kashmir (Kaul (1977), Zutshi and Vass (1977) have studied Manasbal lake. Sashi Kant (1985) studied Mansar lake Jammu and similarly many others have studied in different parts of India. But data on primary productivity of industrial effluent receiving freshwater ecosystems and mine drainage receiving systems are virtually nil.

The summarised data (Table 14.7) on normal water bodies or sewage fed systems or temple tanks which also have high organic load reflect that primary production ranges from about 36 mg C/m^2/day to above 17.5 g C/m^2/day. Studies on sewage fed ponds have shown even much higher production particularly at the time of algal blooms. In general, in comparison to deep lakes and big dams the

Table 14.7 : Range of Primary Production of Microphytic Communities of Freshwaters in India (after Gopal, Sharma and Trivedy 1978).

Type of Water body and locality	Mean depth Z, m	Gross Primary production mgC.m^{2}. day^{1} P_G	Net Primary production mgC.m^{2}. day^{1} P_N	Respiration mgC.m^{2}. day^{1} R	R as % of P_G	Photosynthetic efficiency %	Authors
1	2	3	4	5	6	7	8
1. Shallow lakes (Chilwa and Ramgarh, Gorakhpur)	1.25-1.9	36.5-405.0	19.8-210.0	16.6-195.0	45.4-48.1	...	Srivastava and Sahai (1976), Sinha, (1969).
2. Ponds/Fish ponds/ Temple tanks/Sewage ponds (Fish pond Ahmedabad, Fish pond, Bhagalpur Chetpat Swamp, Fort Moat, Vellore and Chinglepur, K.C. Kulam, Tamarai Kulam, Ayyanakulam, Odathurai tanks (All South India)	0.9-3.0	1210-17550	500.0-7795.9*	710.0-287.22*	17.7-33.5^{a} (22.7-7.4.5)^{b}	1.09-13.8	Ganapati (1972) Ganapati and Sreenivasan (1972), Sreenivasan (1972), Nasar Datta, Munshi (1975) Sarkar *et al* (1977)
3. Reserviors (Man-made) Ajwa, Amaravathy, Stanley, Bhavanisagar Sathanur Krishnagiri, Sandynulla, Amhedabad and S. India	3.4-18.3	1601-3228	1360.1-1640.2	964.8-1588.5	41.5-49.2	0.06-1.44	Ganapati (1972) Ganapati and Pathak (1972), Ganapati and Sreenivasan (1972), Sreenivasan (1972).

Table 14.7 (contd.)

1	2	3	4	5	6	7	8
4. Other lakes (South India) (Kodai, Ooty, Yereaud)	2.0-3.0	405-3802	...	...	...	0.17-1.55	Ganapati and Sreenivasan (1972), Sreenivasan (1972), Ganapati (1972)
5. Temperate lakes (Kashmir) (Dal, Anchar, Manasbal)							
Autumn		28.0-306.6	7.2-194.0	15.8-112.5	...	...	Kaul (1977)
Summer	0.6-3.0	26.9-979.0	16.1-529.0	13.6-450.0	...	...	Zutshi and Vass (1977)
Spring		28.0-943.0	25.8-600.0	19.2-343.0	...	...	
6. Rivers (Godavari) (Rajamundry)	3.0-36	280-1232	175.0-542.0	105.0-690.0	43.8-62.4	0.1-0.58	Ganapati (1972)

* including computed values

a - ponds other than fish pond, Bhagalpur

b - Fish pond, Bhagalpur.

shallow lakes, fish ponds, temple tanks are more productive. Ganapati (1972) has presented a very good correlation between the depth of water body and gross primary production. The temperate lakes as in Kashmir are less productive than tropical and subtropical water bodies.

The higher productive values in Indian condition are associated with luxuriant algal growth particularly of *Microcystis aerugina* (Ganapati and Kulkarni 1973, Talling *et al* 1973, Wassink 1975). In spite of the generalization that tropical waters have more or less homogeneous production rates round the year as a matter of fact a good seasonal variation occurs corresponding to algal productive period and energy supply. Any factor which adversally affects microphytic production and nutrient and energy supply retards the production.

The sewage or other similar type of effluents which have high organic load are supportive to production while effluents toxic in nature, such as mine water and coal washery effluent, are suppressive to production by controlling the microphytic propagation. The net production, sometimes, for highly polluted water bodies has been found in negative values owing to high community respiration. Such situation indicates that the system is highly rich in biota and all the needs for survival and propagation are being met with the communities even after being the system polluted. The community respiration values vary from 1 to 2% to more than hundred percent, and similarly the photosynthetic efficiency varies from 0.1% to more than 13% in tropical Indian condition.

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