

LIMNOLOGICAL STUDIES OF AND PRIMARY PRODUCTION IN TEMPLE POND ECOSYSTEMS

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Abstract

Three temple ponds with permanent blooms of blue green algae were highly productive. They all showed high alkalinity, hardness, electrical conductivity and pH. Organic carbon and nitrogen were highest in Sarvatheertham pond - 60 to 79.6 mg./l. C and 4.10 to 7.60 mg./l. N. In Tamaraikulam it was 16.5 to 20.3 mg. C/l. and 1.03 to 1.32 mg. N/l. In Sarvatheertham, the gross production ranged from 2.85 to 20.72 g. O₂/m.²/d. Self shading by blanket algae of blue greens reduced productivity in Sarvatheertham, where a persistent thermal and biochemical stratification was noted. Very high organic carbon and nitrogen contents were noted in Sarvatheertham pond. The dry weight of plankton in this pond ranged from 430 to 900 mg./l. Productivity computed from diurnal changes in alkalinity and dissolved oxygen also revealed a high rate in Ayyankulam, Tamaraikulam and Sarvatheertham in descending order. Very wide fluctuations in pH, both diurnally and depth-wise, were recorded in Sarvatheertham and to a lesser extent in the other two ponds. Photosynthetic efficiency was 4.03% in Ayyankulam, 2.09% in Tamaraikulam and 1.56% in Sarvatheertham. By the diurnal oxygen curve method, a gross primary production of 97.5 g. O₂/m.²/d was recorded in Ayyankulam.

Introduction

More carbon is fixed in primary production in aquatic than in terrestrial environments (Lagler *et al* 1962). The incidence of long hours of sunshine, and the higher temperature of the tropics will favour the conversion of solar energy into organic matter through a chain of energy transfers. Temple ponds in South India are a peculiar ecosystem with permanent blooms of blue green algae (Ganapati 1940). These are some of the most productive waters, similar to fort moats (Sreenivasan 1964 a). A

discussion of the temple pond ecosystem and the primary productivity is discussed in this paper.

Material and methods

The temple ponds studied are 1) Ayyankulam pond 2) Tamaraikulam pond, both in Tiruvannamalai and 3) Sarvatheertham pond in Kancheepuram, all in South India. The limnological parameters viz. different forms of alkalinity, pH, DO, hardness, chloride, nutrients, etc. were estimated according to APHA. Organic carbon was estimated by the dichromate oxidation method and organic nitrogen by the Kjeldahl method. Photosynthesis *in situ* was measured by the classical light and dark bottle method between 8.00 and 16.00 hrs., integrating the O₂ production per m³. at each depth interval to obtain yields per m². Diurnal changes in dissolved oxygen, temperature, pH, carbondioxide, phenolphthalein and methyl orange alkalinity were studied every 4 hours. The changes in DO and alkalinity in open waters were computed in terms of photosynthesis by converting the net change in dissolved oxygen or carbondioxide into μ moles of oxygen produced or carbondioxide utilized, as described earlier (Sreenivasan 1964 b). Visible and total radiation for the year were calculated from the chart of the U.S. Weather Bureau (Kimball 1935).

Description of the Temple Ponds

Temple ponds are usually adjacent to Hindu temples and are well paved with granite steps on all sides. In

Table 1. Morphometric and other data on three temple ponds.

	Sarvatheertham	Tamaraikulam	Ayyankulam
Area - ha	1.5	6.0	1.4
Max. depth - m	5.0	5.0	6.0
Average depth - m	2.0	1.0	3.0
Elevation above sea level - m	+15	+20	+20
Location	12° 45' N 79° 00' N	12° 14' N 79° 04' E	12° 14' N 79° 04' E

Ayyankulam and Sarvatheertham this pattern was noted. They were square in shape, all four sides had granite steps, and in the middle of the ponds a tiny granite 'mantap' (open hall) was present. Tamaraikulam, which is larger than the other two, has earthen bunds on three sides and stone steps in part of the fourth side only. It also has a limited submerged weed flora (mainly *Hydrilla verticillata* and *Najas* sp). It is thus an atypical temple tank. The morphometric and physical data are furnished in Table I. All three ponds are used for bathing and washing clothes, but in Tamaraikulam, cattle are also washed and a little faecal pollution occurs.

Physico-chemical parameters

The annual range of certain physico-chemical parameters is furnished in Table 2. All three ponds have a similar high temperature. While free CO₂ occurs in the surface waters of Tamaraikulam on many occasions, in the other two ponds phenolphthalein alkalinity was invariably noted. Methyl orange alkalinity was highest in Tamaraikulam, ranging from 3.68 to 15.84 m.eq/l., next being Ayyankulam with a range of 2.0 to 3.30 m.eq/l.

Table 2. Range of physico-chemical parameters of three temple ponds (surface only).

	Sarvatheertham	Tamaraikulam	Ayyankulam
Temperature °C	23.5 - 30.6	24.0 - 33.5	25.0 - 34.2
P. Alkalinity m. eq/l (CaCO ₃)	0.4 - 1.8	0.0 - 0.26	0.3 - 1.0
M.O. Alkalinity m. eq/l (CaCO ₃)	0.08 - 3.8	3.68 - 15.84	2.0 - 3.3
pH	8.4 - 10.5	8.1 - 9.7	7.3 - 9.1
Dissolved Oxygen mg/l	0.0 - 26.2	0.0 - 24.0	5.4 - 19.2
Total hardness (CaCO ₃) m. eq/l	0.72 - 1.8	1.68 - 6.2	5.28 - 6.28
Electrical conductivity μ mho/cm.	525 - 900	500 - 1850	1075 - 1370
Organic carbon mg/l	60.02 - 79.60	16.50 - 20.30	8.40
Kjeldahl-N mg/l	4.10 - 7.60	1.03 - 1.32	7.56
C/N ratio	8-17	12.5 - 18.5	---

Lower values were noted in Sarvatheertham, 0.8 to 3.8 m.eq/l. The lowest value in this pond occurred during algal photosynthesis. Highest pH values were noted in Sarvatheertham-8.4 to 10.5, followed by Tamaraikulam, 8.1 to 9.7 and Ayyankulam, 7.3 to 9.1. The higher pH values in Sarvatheertham are due to the higher carbonate/bicarbonate ratio and due to lower buffering than in the other two ponds. The same pattern was also noted with regard to the highest D.O. content, Sarvatheertham reaching 26.2 mg./l., followed by 24.0 mg./l. in Tamaraikulam and 19.2 mg./l. in Ayyankulam. Oxygen depletion, even from the surface water occurred in Sarvatheertham during August 1970 and September 1971. Similar depletion occurred once in Tamaraikulam also but not in Ayyankulam. Total hardness and electrical conductivity were highest in Ayyankulam followed by Tamaraikulam and Sarvatheertham. According to Prescott (1960) shallow lakes with ample CO₂, bicarbonate and high hardness often support blooms of *Cyanophyta*. For some lakes in Ceylon, Holsinger (1955) found a positive correlation between conductivity and productivity. Our results seem to support the above authors' observations.

Thermal and chemical stratification was quite marked and recurrent in Sarvatheertham. The stratification was diurnal. The range of variation for a depth of 2 m is amazing. For example, there was a 4°C difference between surface and 2 m., when the pH variation was also largest viz, 2.1 units. Such a large variation of pH is an indication of a highly productive water. For the same depth, the net differences in phenolphthalein alkalinity and methyl orange alkalinity are 44 and 100 ppm respectively. The D.O. variation was on the same scale-16.4 mg./l. All these data indicate that while in the surface photosynthetic processes predominate, just 2 m. below the water is highly reactive in terms of decomposition. On the other hand, thermal stratification was rare in Ayyankulam and the thermocline was narrow and ephemeral. In Tamaraikulam there was no thermal stratification since it was more exposed than the other two ponds. It could be seen that thermal stratification in Sarvatheertham reduces the photosynthetic productivity by preventing overturn and making carbondioxide unavailable, while in the other two ponds higher primary production was due to absence of such thermal stratification. The biochemical stratification was the result of intense photosynthesis.

Diurnal variations were striking in all three ponds. The D.O. rose from 6.00 A.M. to 10.00 A.M. and then a steep

Table 3. Magnitude of diurnal variations in temple ponds (Surface water).

		Sarvatheertham	Tamaraikulam	Ayyankulam
1.	Gross primary production g O ₂ /m ² /12 hrs	0.2 – 23.5 (9.1)	4.7 – 28.52 (12.3)	16.0 – 29.30 (24.0)
2.	Community respiration (surface only) in bottles. mg. O ₂ /1/12 hrs	0.0 – 13.6	6.0 – 45.6	1.8 – 10.4
3.	Productivity in open waters, by			
(a)	Changes in alkalinity μ moles O ₂ /1/hr	40 – 153	35 – 303	16.0 – 184
(b)	Changes in oxygen, μ moles O ₂ /1/hr	9 – 88	1.6 – 71.0	37 – 100
4.	Maximum productivity in euphotic zone (bottle method) μ moles O ₂ /1/hr	0 – 147	13 – 75	52 – 96
5.	Photosynthetic efficiency %	1.56	2.09	4.03

rise was noted, with a peak around 14.00 hrs or on some days at 18.00 hrs. A parallel increase in carbonate and pH was also noted. Bicarbonate decreased inversely with carbonate and pH. A very high diurnal pH variation was noted in Sarvatheertham pond (1.7 units), it was less in Tamaraikulam (1.5 units) and least in Ayyankulam (1.2 units). In Lake George Uganda, Ganf (1972) observed a diurnal variation of only 0.8 pH unit. The ability of the phytoplankton to use the bicarbonate ion, could favour photosynthesis at high pH values. Diurnal temperature changes of a very high magnitude (8.5°C in a day) was recorded in Sarvatheertham but were a little less (5°C/day) in Tamaraikulam. The highest diurnal variations in phenolphthalein and methyl orange alkalinity, of 0.9 and 2.18 m.eq./l. respectively, were recorded in Tamaraikulam. Such variations are indicative of intense carbon fixation during photosynthesis. Comparable data for Sarvatheertham are 0.72 and 0.90 meq./l., rather low compared with Tamaraikulam. The highest diurnal variation in D.O. also occurred in this pond (24 mg./l. in a day). Vertical distribution of carbon dioxide reflects, in a qualitative way, the vertical distribution of oxygen deficit (Hutchinson 1957, Sreenivasan 1965 c). The magnitude of vertical variations was greater in Sarvatheertham, where *Microcystis* formed a blanket, than in Ayyankulam, where the phytoplankton was more uniformly distributed. Talling *et al* (1973), have noted diurnal stratification and deoxygenation in Ethiopian lakes.

Organic matter

The organic carbon and nitrogen (Kjeldahl) of two of the

ponds, have been estimated regularly. The data are furnished below:

	Organic carbon*	Kjeldahl nitrogen*	C/N ratio
Sarvatheertham	60.02–79.6	4.1 – 7.6	8.0–17.0
Tamaraikulam	16.5 – 20.2	1.03–1.32	12.5–18.5

* mg/l

In Sarvatheertham, the very high carbon and nitrogen contents are noteworthy. These substances are responsible for the utilization of dissolved oxygen and its depletion. The weight of plankton was 2.57 to 4.1 g./l. (wet) and 0.43 to 0.99 g./l. (dry), which is pretty high. In Tamaraikulam, though both carbon and nitrogen were lower than in Sarvatheertham pond, they were still higher than in normal ponds. Oxygen depletion was rarer in Tamaraikulam pond. The organic matter in the soil of both ponds, ranging from 6.84 to 9.68%, is very high. The C/N ratio of the soils were low–2.25 to 5.6, indicating rapid decomposition and mineralization (higher degree in Sarvatheertham) and thus releasing the carbondioxide required for photosynthesis.

Productivity considerations

The gross photosynthesis was highest in Ayyankulam, where the phytoplankton was more evenly distributed than in the other two ponds—an average of 24.0 g. O₂/m²/d compared to 12.3 g. in Tamaraikulam and 9.1 g. in Sarvatheertham. The photosynthetic efficiency in terms of total solar radiation for a year was 1.56% in Sarvatheertham, 2.09% in Tamaraikulam and 4.03% in Ayyankulam. In Vellore Fort Moat (Sreenivasan 1964 c), which also suffered from “self shading” as in Sarvatheertham, the conversion was 2.85%. Despite the dense quantity, the blue greens in Sarvatheertham were pale, and always senescent. From figures 1-2, it can be seen that self shading has restricted photosynthesis to the upper 0.5 m. only. Photosynthetic rates are shown in relation to depth (figs. 1-2) for comparison with Fott (1972). In spite of frequent low oxygen tensions and even anoxic conditions, free carbon dioxide was never present in the surface water of Sarvatheertham. This has restricted the photosynthesis. Carbondioxide, essential to photosynthesis, is considered to be sometimes a limiting factor for this process. (Kuentzel 1969, King 1970). From the

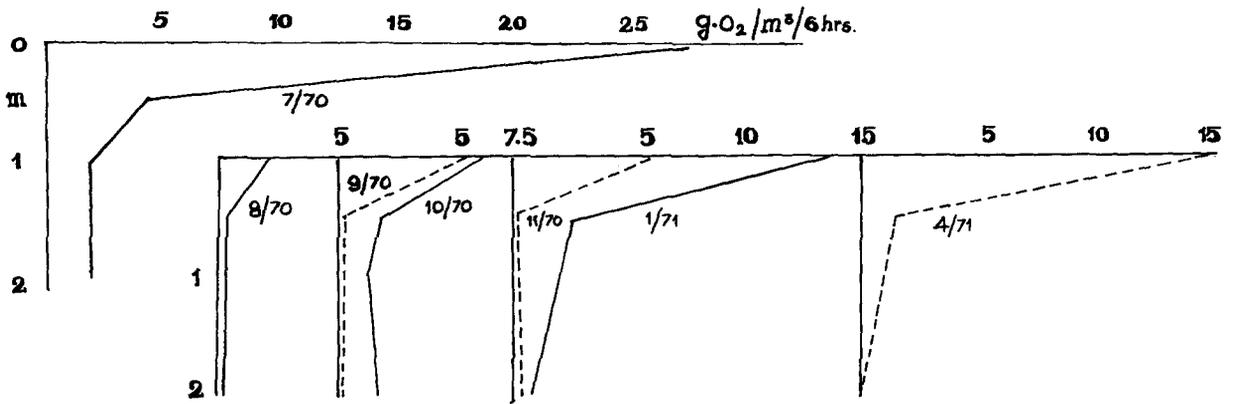


Fig. 1. Depth variations of photosynthesis in Sarvatheertham.

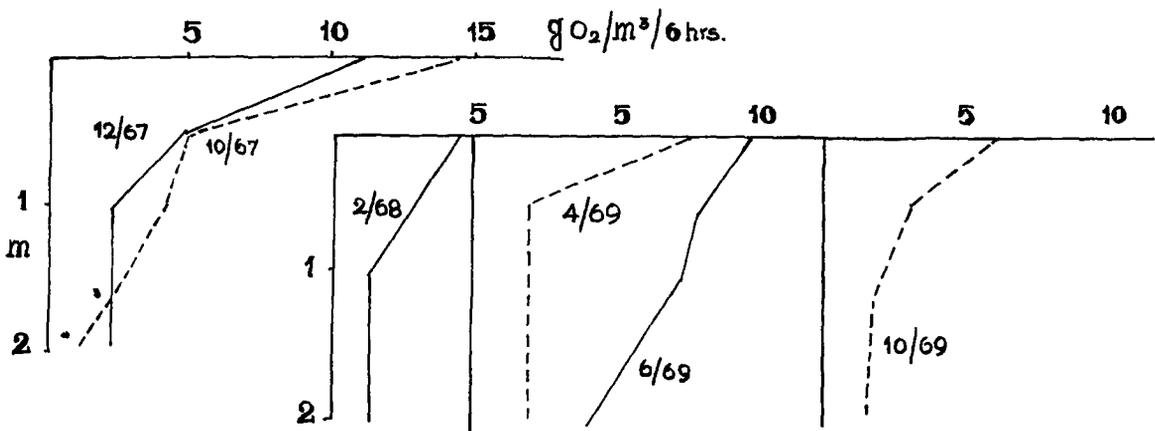


Fig. 2. Depth variations of photosynthesis in Tamarikulam.

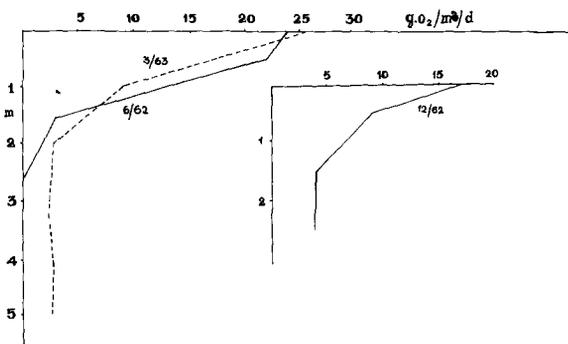


Fig. 3. Depth variations in photosynthesis in Ayyankulam.

diurnal studies of open waters, it is seen that the highest CO_2 utilisation was noted in Ayyankulam—16.0 to 184 μ moles/l./hr of CO_2 . In Sarvatheertham, also, high values were noted—40 to 153 μ moles CO_2 /l./hr and in Tamarai-

kulam it was 35 to 303 μ moles/l./hr. Here, the very high value is also caused by the production of submerged vegetation. An almost similar trend in oxygen production in open waters was noted. It was the highest in Ayyankulam, 37 to 100 μ moles O_2 /l./hr., next in Sarvatheertham, 9 to 88 μ moles, and 1.6 to 71 μ moles in Tamarikulam. Maximum rate of production of oxygen as evidenced by the results of the light and dark bottle method in the euphotic zone, was 0-147 μ moles O_2 /l./hr. in Sarvatheertham, 52-96 in Ayyankulam and 13-75 in Tamarikulam. The very high values in Sarvatheertham are due to the high density of phytoplankton while the zero values are due to self-shading, cloudy weather and senescence. Community respiration was recorded only in the surface water in Tamarikulam and Ayyankulam and at all depths in the case of Sarvatheertham. In this pond, very high respiratory rates—exceeding photosynthesis on many occasions—were recorded. The actual rates ranged from 2.85 to 20.72 $\text{g O}_2/\text{m}^2/12$ hrs which is indeed rather high for a depth of 2 m. Ganf (1972) has recorded a high

Table 4. Range of productivity in the three ponds (figures in paranthesis, average).

	Tamaraikulam		Sarvatheertham	
	Lowest	Highest	Lowest	Highest
Temperature °C	0.9	5.0	3.0	8.5
D.O. mg/l	3.6	24.0	2.4	22.2
pH	0.4	1.5	0.2	1.7
Ph. alkalinity (CaCO ₃) mg/l	12.0	90.0	18.0	72.0
M.O. alkalinity (CaCO ₃) mg/l	30.0	218.0	44.0	92.0

photosynthetic rate of 12 g. O₂/m².d in Lake George, and also a very high respiratory rate (sometimes exceeding photosynthesis, as in our Sarvatheertham pond). High photosynthetic rates have also been reported by others—e.g. 29.0 g. O₂/m². by Copeland & Dorris (1962) for refinery ponds, 26.0 g. O₂/m². in sewage ponds (Bartsch 1960), 43 to 57 g O₂/m².d in Soda lakes of Ethiopia (Talling *et al.* 1973) and 56.91 g. O₂/m². in an impoundment in India (Sreenivasan 1965). In Ayyankulam pond very high photosynthesis of 97.5 g. O₂/m².d was measured by the diurnal oxygen method (Sreenivasan 1964). The high temperatures in Sarvatheertham also leads to a disproportionately high respiration, similar to that noted by Ganf (1972). Dunn (1967) has recorded a high photosynthesis of 1848 mg CO₂/m³.hr from a Malayan pond. This is eclipsed by the 13332 mg CO₂ removed/m³.hr in Tamaraikulam, 6730 mg/m³.hr in Sarvatheertham and 8050 mg. CO₂/m³.hr. in Ayyankulam.

Phytoplankton

Diversity was greater in Tamaraikulam and less in Sarvatheertham. In Tamaraikulam, the blue greens were dominant but diatoms and green algae also occupied a fairly important place. In summary, the phytoplankton of Tamaraikulam consisted of the following important species:

Cyanophyceae: *Microcystis aeruginosa*, *Nostoc macrosperma* (all round the year), *Merismopedia tranquilla* (except in December and April), *Microcoleus vaginatus*, *Spirulina Major*.

Diatomae: *Cyclotella* sp (throughout the period of study), *Amphora ovalis*, *Navicula gracilis*, *Fragilaria* sp, *Synedra ulna*, *Nitzschia palea*, *Pinnularia viridis*.

Chlorophyceae: *Scenedesmus quadricauda* (most of

the year), *Chlorella* sp, *Cosmarium subspicosum*, *Selenastrum westii*, *Staurastrum gracile*.

Euglenophyceae: *Euglena gracilis* and *Phacus acuminatus*.

The phytoplankton of Sarvatheertham was distributed as follows:

Cyanophyceae: *Microcystis aeruginosa* (throughout the year), *M. flos aquae*, *M. pulvereae*, *Microcoleus vaginatus*, *Nostoc commune*, *Spirulina major*, *Tetrapedia* sp, *Merismopedia* sp, *Nodularia* sp, *Oscillatoria* sp, *Anabaena* sp.

Diatomae: *Cyclotella* sp, *Nitzschia palea*.

Chlorophyceae: *Pediastrum simplex*, *Scenedesmus quadricauda*, *Pandorina* sp.

Euglenophyceae: *Euglena* sp.

In this pond, blue green algae usually predominated with the others occurring only sporadically in fewer numbers.

Discussion on productivity and efficiency of energy transfer in photosynthesis

In all three ponds, photosynthetic rates are high. Conversion efficiency (average for the year) was highest, 4.03% in Ayyankulam, next in Tamaraikulam, 2.09% and lowest in Sarvatheertham—1.56%. Paasche (1960) states that 7% of light energy falling on algal cells is utilised, while Talling (1961) cited Oorshot for yields of 6%. In flowing waters, Teal (1962) records a conversion of 6.1% and Elster (1962) found 5.1%. Oswald & Golueke (1960) obtained a 6.2% efficiency in a shallow oxidation pond. Such high efficiencies were noted in shallow, well mixed waters. Sarvatheertham pond, despite the very dense cyanophycean blooms, yielded only a 1.56% efficiency because there was a recurrent and persistent diurnal stratification, both thermal and biochemical. This lack of mixing processes severely restricts the photosynthetic efficiency of aquatic ecosystems. The phytoplankton was observed to be senescent. Also, as stated by Ganapati & Sreenivasan (1972), CO₂ may be a limiting factor where permanent blooms of blue green algae raise the pH to 9-10. A similar lower efficiency was noted in Vellore Fort Moat (Sreenivasan 1964 a) where also 'self shading' by blanket algae was recorded. Prowse (1972) records an efficiency of 5.5% and 7.04% in two Malayan ponds. In Clear Lake, Iowa, Weber (1963) noted a 0.72% efficiency while Rodhe (1957) in Sweden recorded

1.39-1.44%. In a Georgia pond, only a 1% efficiency was observed by Welch (1968). In Loch Leven, an efficiency of 1.1% was measured (Morgan 1972). The photosynthetic efficiency in Ayyankulam is indeed high compared to the ones recorded by Wright (1961), Wetzel (1966), Goldman & Wetzel (1963). Even in fertilized waters of Israel (Hepher 1962), and in polluted waters in Denmark (Nielsen 1955) the rates, though high were a little less than in Ayyankulam. On single days, photosynthetic efficiency of 8.6 to 10) were recorded for Vellore Fort Moat (Ganapati & Sreenivasan 1972). High photosynthetic groups are reported to fix 60 mg. CO₂/dm²./hr (Khanna & Sinha 1972) i.e. 72 g. CO₂/m²./12 hrs, equivalent to 52.1 g. O₂/m²./d. Even without bloom algae high rates of primary production and a high photosynthetic efficiency of 3.6% were achieved, in Chetpat swamp in Madras city due to nannoplankton (Sreenivasan unpubl.). This was a shallow, well-mixed biotope. That temperature among other factors has an effect on the efficiency of photosynthesis is suggested by the fact that in Ooty Lake an efficiency of only 1.55% was found despite the permanent cyanophycean bloom. This was caused by the lower temperature of the water (Sreenivasan 1964 c). Compared to a 2% efficiency achieved in agriculture (Daniels 1956), the temple ponds are more productive and more efficient in the utilisation of solar energy. The vertical variations and to a greater extent the diurnal variations in certain chemical parameters indicative of the metabolism of the ecosystems, can be interpreted to illustrate the large productivity of these waters.

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