Part - III

1. Circadian Rhythm in Primary Productivity of Spirogyra setiformis and physico-chemical parameters.
INTRODUCTION

It has been known for many years that both plants and animals show daily fluctuation in behavioural and physiological patterns. Circadian rhythm is one class of daily rhythm to which organisms are highly sensitive and is under the control of an endogenous timing mechanism known as "Circadian clock". Circadian rhythm shows that the periodic length is the same at different constant temperatures and it can be synchronized to or entrained by external light-dark cycles whose periodic lengths are reasonably close to that of the endogenous rhythm. For the last two decades investigations on circadian rhythm have led to considerable amount of information about the ubiquity, adaptiveness and organization of the systems at the physiological and organismic levels. Reynolds, 1920; described two types of biological rhythms i.e. (i) Rhythm related with periodic changes in environment i.e. day and night, tides and seasons, (ii) Rhythm inherent in organism and independent of environment that is age cycles. According to Reynold, 24 hours rotation of earth includes light and darkness is called circadian rhythm.

and Dutta Munshi, 1980; Saha, 1981). No work has been done on the circadian rhythm of physicochemical parameters as well as productivity of alga, *S. setiformis* of fish pond at Sambalpur. Therefore the present study has been made to investigate the circadian rhythm in fish ponds of Sambalpur fish farm.

At Sambalpur, spring season is short and lasts for few days only. Therefore the seasonal conditions are divided into summer (March, April, May and June), rainy (July, August, September and October) and winter (November, December, January and February). The observations are made at the optimum seasonal period i.e. 15 and 16, May (summer), 15 and 16, August (rainy), 15 and 16 January (winter) for one year 1984.
MATERIALS AND METHODS

To investigate circadian rhythm in physico-chemical parameters, sample water from the surface was collected at equal time interval for 24h day regime i.e. between 0800h to 1000h, 1200h to 1400h, 1600h to 1800h during day time and once at night between 0200h to 0400h and then immediately analysed after Strickland and Parsons, 1979; for the determination of dissolved oxygen content, free carbon dioxide and total alkalinity. Temperature was recorded with the help of centigrade thermometer. pH was determined by BDH universal pH indicators. Other parameters were measured by the standard methods followed after APHA, 1975; Kedusia, 1980; Trivedy and Goel, 1984 etc. as already put forth in Part II. Field observations were generally made in the middle of each season.

Circadian variations in Primary Productivity of *S. setiformis* were made by collecting fresh samples in the middle of each season at different hours of a day-regime. The water sample was directly taken into plastic container provided with just enough pond water to cover the specimens as container filled with water would soon stagnate and destroy the sample (Knudsen, 1966). The bottles were then closed by lids and covered over by black papers while it is transported back into the laboratory. The specimens were immersed in chlorine water (25 ppm) for two minutes and washed in triple aquadist (Venkataraman, 1969). Isolation of the healthy adult specimens of *S. setiformis* was made after examining under compound microscope. Then 100mg of *spirogyra* was weighed after completely soaking the external water content by clean white dry blotting papers. Thereafter the same procedures were followed as described in the chapter of Primary Productivity. However the incubation period in this study was 2h, at equal interval i.e. 0800h to 1000h,
1200h to 1400h, 1600h to 1800h for 12 hours during day time and for 12 hour (1800h to 0600h) at night. To measure Primary Productivity, oxygen method by light and dark bottle technique (Gaadiner and Gran, 1927) was followed. Thereafter dissolved oxygen was estimated by modified Winkler's volumetric method (Ellis et al, 1948). Oxygen values were converted to mg l⁻¹ and then to their carbon value by applying the equation (Agarwal 1980) as follows:

\[
\text{Production mgL} = \frac{O_2 \text{ mg} \times 0.375}{PQ} \\
PQ = 1.25
\]

Production values were expressed as g m⁻² day⁻¹ assuming 12h photoperiod and were then converted to g m⁻² day⁻¹ for comparison of data.
The data containing circadian variation in physico-chemical parameter and Primary Productivity in fish ponds at Sambalpur fish farm have been given in Table-2.

Water depth:

Water depth was maximum in rainy and minimum in summer. However water depth did not show any remarkable variations during the circadian rhythm.

Weather:

Weather was bright sunny during summer, clear and bright during winter, cloudy and frequent sunny during rainy season.

Air and water temperature:

Air temperature varied between 21.8°C to 37.9°C, being maximum in summer and minimum in winter.

Air temperature was minimum (35°C, 21.8°C and 31°C in summer, winter and rainy respectively) at morning and maximum at noon (37.9°C, 27°C, 34°C respectively in summer, winter and rainy) during all the three aforesaid seasons. Declining values of temperature from noon towards night were observed.

Water temperature varied between 21.5°C (between 0800h to 1000h in winter) to 37°C (between 1200h to 1400h in summer) and followed same trend as in case of Air temperature.

pH:

Maximum pH values were observed in summer (pH 8 to 8.5). Higher values (pH 7.5 to 8) were also obtained in winter. However in rainy day pH was low (pH 6.5 to 7.5). In both winter and rainy days high pH was
### Table 26: Circadian Rhythm in Primary Productivity and Physico-chemical parameters

<table>
<thead>
<tr>
<th>Season</th>
<th>Day</th>
<th>Time</th>
<th>Productivity (g cm⁻² day⁻¹)</th>
<th>Autotro- N.P.P. (g cm⁻² day⁻¹)</th>
<th>Air temp (°C)</th>
<th>Water temp (°C)</th>
<th>pH</th>
<th>Free CO₂ (mg l⁻¹)</th>
<th>HCO₃⁻ (mg l⁻¹)</th>
<th>CO₂ (mg l⁻¹)</th>
<th>Acidity</th>
<th>Chloro- Hardness</th>
<th>Perma Total</th>
<th>Total</th>
<th>Total Weather</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer</strong></td>
<td>15th Morn</td>
<td>May 1000h</td>
<td>77.328</td>
<td>55.056</td>
<td>22.272</td>
<td>0.712</td>
<td>35</td>
<td>34</td>
<td>8</td>
<td>40</td>
<td>4.96</td>
<td>29.2</td>
<td>134.71</td>
<td>131.2</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>15th Morn</td>
<td>May 0900h</td>
<td>Noon 1200h</td>
<td>62.078</td>
<td>45.868</td>
<td>16.11</td>
<td>0.74</td>
<td>37.9 37</td>
<td>7.5</td>
<td>70.4</td>
<td>7.6</td>
<td>30</td>
<td>111.8</td>
<td>160</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>15th Morn</td>
<td>May 1000h</td>
<td>Noon 1200h</td>
<td>40.544</td>
<td>41.216</td>
<td>-0.672</td>
<td>1.017</td>
<td>37  36.5</td>
<td>8</td>
<td>48</td>
<td>8.32</td>
<td>32.8</td>
<td>177.25</td>
<td>152</td>
<td>73.2</td>
</tr>
<tr>
<td></td>
<td>15th Morn</td>
<td>May 1000h</td>
<td>Night 0200h</td>
<td>13.557</td>
<td>3.881</td>
<td>9.676</td>
<td>0.286</td>
<td>36.8 37</td>
<td>8</td>
<td>60</td>
<td>7.36</td>
<td>83.2</td>
<td>125.49</td>
<td>106.4</td>
<td>73.6</td>
</tr>
<tr>
<td><strong>Rainy</strong></td>
<td>15th Morn</td>
<td>Aug 0800h</td>
<td>Noon 1200h</td>
<td>48.319</td>
<td>42.510</td>
<td>5.809</td>
<td>0.88</td>
<td>30.5 31</td>
<td>6.5</td>
<td>36</td>
<td>5.84</td>
<td>30</td>
<td>56.7</td>
<td>64</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>15th Morn</td>
<td>Aug 1000h</td>
<td>Noon 1200h</td>
<td>40.444</td>
<td>40.069</td>
<td>0.375</td>
<td>0.991</td>
<td>34  33</td>
<td>7.5</td>
<td>24.8</td>
<td>6.88</td>
<td>32.8</td>
<td>28.36</td>
<td>116</td>
<td>112</td>
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<tr>
<td></td>
<td>15th Morn</td>
<td>Aug 0800h</td>
<td>Noon 1200h</td>
<td>36.836</td>
<td>36.603</td>
<td>0.233</td>
<td>0.994</td>
<td>30  29</td>
<td>7.5</td>
<td>36</td>
<td>5.52</td>
<td>54.4</td>
<td>49.63</td>
<td>140</td>
<td>68</td>
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<tr>
<td></td>
<td>15th Morn</td>
<td>Aug 1000h</td>
<td>Night 0200h</td>
<td>3.431</td>
<td>3.063</td>
<td>0.368</td>
<td>0.893</td>
<td>27.4 27.5</td>
<td>6.5</td>
<td>64</td>
<td>1.12</td>
<td>118.4</td>
<td>31.90</td>
<td>113.6</td>
<td>71</td>
</tr>
<tr>
<td><strong>Winter</strong></td>
<td>15th Morn</td>
<td>Jan 0800h</td>
<td>Noon 1200h</td>
<td>58.861</td>
<td>50.552</td>
<td>8.309</td>
<td>0.859</td>
<td>21.8 21.5</td>
<td>8.0</td>
<td>24</td>
<td>6.4</td>
<td>116</td>
<td>100.67</td>
<td>160</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>15th Morn</td>
<td>Jan 1000h</td>
<td>Noon 1200h</td>
<td>69.663</td>
<td>60.84</td>
<td>8.823</td>
<td>0.873</td>
<td>27  26</td>
<td>8.5</td>
<td>14</td>
<td>9.2</td>
<td>80</td>
<td>106.35</td>
<td>134</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>15th Morn</td>
<td>Jan 1000h</td>
<td>Noon 1200h</td>
<td>68.696</td>
<td>62.094</td>
<td>6.602</td>
<td>0.904</td>
<td>26.4 26</td>
<td>8.5</td>
<td>9.6</td>
<td>12.0</td>
<td>30.4</td>
<td>92.17</td>
<td>152</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>15th Morn</td>
<td>Jan 0800h</td>
<td>Night 0200h</td>
<td>15.168</td>
<td>11.357</td>
<td>3.811</td>
<td>0.749</td>
<td>24  24</td>
<td>8.5</td>
<td>16.8</td>
<td>9.6</td>
<td>151.2</td>
<td>135.2</td>
<td>72</td>
<td>60</td>
</tr>
</tbody>
</table>
recorded at noon between 1200h - 1400h whereas in summer just the reverse case did occur as pH was lowest (pH 7.5) at 1200h to 1400h.

**Dissolved oxygen content:**

Dissolved oxygen concentration was high during winter which varied between 6.4 mg/l to 12 mg/l and low in rainy days (1.12 mg/l to 6.88 mg/l). Whereas in winter dissolved oxygen content was comparatively higher than rainy season. In summer and winter dissolved oxygen content was gradually increasing from 0800h to 1800h. Thereafter it got decreased at night. In rainy season the increase in dissolved oxygen content occurred at noon only, then it was decreased and lowest values were recorded at night (0200h - 0400h).

**Free Carbon dioxide:**

Circadian variations in free CO$_2$ was observed in summer. This varied between 40 mg/l to 70 mg/l. In winter this free CO$_2$ ranged from 9.6 mg/l to 24 mg/l and in rainy from 24.5 mg/l to 64 mg/l. No linear relationship was observed in all the three seasons. In summer maximum value was shown between 1200h to 1400h and lowest (0800h to 1000h) at morning. Whereas in winter high value was obtained at morning and lowest between 1600h - 1800h. In rainy season highest value was recorded at night (0200h-0400h) at lowest at noon (1200h-1400h).

In summer and winter, circadian variations showed that free CO$_2$ concentration decreased from noon (1200h-1400h) to evening (1600h-1800h) and then again get increased at night (0200h-0400h). Whereas in rainy season values increased from 1200h to 0400h (highest value recorded was 64 mg/l$^{-1}$).
Total alkalinity:

(a) Bicarbonate (HCO$_3^-$) alkalinity:

Total alkalinity was observed highest at night (0200h to 0400h) irrespective of all the three seasons (83.2 mg/l$^{-1}$ in summer, 151.2 mg/l$^{-1}$ in winter and 118.4 mg/l$^{-1}$ in rainy).

In summer and rainy season alkalinity increased from morning (0800h) to night (0400h) i.e. 29.2 mg/l$^{-1}$ to 83.2 mg/l$^{-1}$ in summer and 30 mg/l$^{-1}$ to 118.4 mg/l$^{-1}$ in rainy season. Whereas in winter alkalinity decreased from morning (0800h) to evening (1800h) and then increased at night.

(b) Carbonate (CO$_3^{--}$) alkalinity was found absent during circadian rhythm study:

Chloride:

During circadian observation of 24h day regime chloride content does not show any remarkable variations. In summer, chloride value increased from morning (134.71 mg/l$^{-1}$) to evening (177.25 mg/l$^{-1}$) and then followed the declining path at night (125.49 mg/l$^{-1}$). In rainy season the case was reverse showing a decrease from morning to evening (56.7 mg/l$^{-1}$ to 49.63 mg/l$^{-1}$) and night was the decreasing pathway (31.90 mg/l$^{-1}$) in summer.

In winter the chloride was lowest at night (74 mg/l$^{-1}$) at 0200h to 0400h but the value increased from morning (100.67 mg/l$^{-1}$) to noon (106.35 mg/l$^{-1}$).

Hardness:

Circadian rhythm in hardness did not follow any definite trend during the three different seasons. In summer the hardness was maximum
between 1200h - 1400h (160 mg/l$^{-1}$) and lowest between 0200h - 0400h (106.4 mg/l$^{-1}$). Whereas in winter lowest value (134 mg/l$^{-1}$) was recorded between 1200h - 1400h and highest value (160 mg/l$^{-1}$) between 0800h-1000h.

In rainy season, the water showed higher values of hardness (140 mg/l$^{-1}$) between 1600h - 1800h and low values were obtained (64 mg/l$^{-1}$) in the morning between 0800h - 1000h.

Permanent hardness also did not obey any definite principle in respect to circadian rhythm and varied from 73.2 mg/l$^{-1}$ (at 1600h-1800h) to 92 mg/l$^{-1}$ (1200h - 1400h) in summer, 72 mg/l$^{-1}$ (0200h - 0400h) to 132 mg/l$^{-1}$ in winter (1600h - 1800h) and 60 mg/l$^{-1}$ (at 0800h - 1000h) to 112 mg/l$^{-1}$ (1200h - 1400h) in rainy season.

**Acidity:**

Acidity was observed more at night (between 0200h - 0400h) in summer (56 mg/l$^{-1}$) and winter (45.6 mg/l$^{-1}$) whereas in rainy season higher value were recorded between 1600h - 1800h (in evening).

In summer the acidity increased from morning (0800h - 1000h) to night (0200h - 0400h) within the range of 22 mg/l$^{-1}$ to 56 mg/l$^{-1}$ respectively. In the winter the acidity decreased from 0800h to 1400h (28 mg/l$^{-1}$ to 18 mg/l$^{-1}$) and rose upto 45.6 mg/l$^{-1}$ (0400h). In rainy season it decreased from 0800h to 1400h (76.8 mg/l$^{-1}$ to 56 mg/l$^{-1}$). Then alternate increase and decrease were observed between 1600h - 1800h and between 0200h to 0400h.

**Total, dissolved and suspended solid:**

Total, dissolved and suspended solid (mg/l$^{-1}$) did not show any definite trend.
Total solid (mg/l) ranged from 160 mg/l to 200 mg/l in summer, 80 mg/l to 240 mg/l in winter and 120 mg/l to 800 mg/l in rainy season.

Total dissolved solid was maximum (400 mg/l) in rainy at noon (between 1200h - 1400h) and minimum (20 mg/l) in winter at night (between 0200h - 0400h). Whereas total suspended solid recorded highest in rainy (400 mg/l) between 1200h to 1400h as in total dissolved solid and minimum (20 mg/l) in summer between 0200h to 0400h at night.

**Productivity:**

Circadian rhythm in Primary Productivity followed a definite trend and showed remarkable changes in the circadian observation of 24h day regime. In summer at 34°C the values of N.P.P. and G.P.P as well as Autotrophic Respiration were maximum (55.056 g/m² day⁻¹, 77.328 g/m² day⁻¹ and 22.272 g/m² day⁻¹ respectively) during morning (0800h-1000h). The lowest values were found during night hours 3.881 g/m² day⁻¹ for N.P.P., 13.557 g/m² day⁻¹ for G.P.P. and for Autotrophic Respiration it was the negative values (-0.672 g/m² day⁻¹) found in dusk (1600h to 1800h). However both N.P.P. and G.P.P. values gradually decreased from morning to night. N.P.P : G.P.P ratio accordingly varied and was more in day hours than during night.

In winter both G.P.P. and Autotrophic Respiration became highest (69.663 g/m² day⁻¹ and 8.823 g/m² day respectively) at noon (1200h-1400h). The N.P.P. value was highest (62.094 g/m² day⁻¹) at 1600h to 1800h when highest water temperature was recorded (26°C). The lowest N.P.P., G.P.P and Autotrophic Respiration values were recorded during night (1800h to 0600h) at low ambient temperature (24°C). N.P.P : G.P.P
gradually increased from morning till afternoon and again minimised in night.

In rainy season, ranging from 0800h to 1000h at 31°C water temperature, N.P.P., G.P.P. and Autotrophic Respiration became highest (42.510 g m⁻² day⁻¹, 48.319 g m⁻² day⁻¹, 5.809 g m⁻² day⁻¹ respectively). The lowest N.P.P., G.P.P. values were recorded at night and at 1600h to 1800h, in case of Autotrophic Respiration, when the temperature was 29°C. Similar trend of increasing N.P.P.; G.P.P as in winter was found from morning to dusk and was decreased during night at 27.5°C.

While comparing among three different seasons it was found out that the mean N.P.P. and G.P.P. values showed highest (46.210 g m⁻² day⁻¹, 53.097 g m⁻² day⁻¹ respectively) in winter than summer (36.530 g m⁻² day⁻¹ and 48.452 g m⁻² day⁻¹) and lowest in rainy season. In case of Autotrophic Respiration highest (11.846 g m⁻² day⁻¹) values were obtained in summer than winter and lowest (1.696 g m⁻² day⁻¹) in rainy season.
DISCUSSION

The factor affecting the maximum depth of water in rainy season and minimum depth in summer season during circadian observation is related to seasonal variations. In rainy season the seasonal rainfall balances the depth of the pond (Augatin, 1979) whereas in summer minimum depth is due to evaporation of water by high atmospheric temperature and winter season shows moderate depth. This may be due to dry weather minimising the runoff water into the pond. Water depth remains comparatively more at night due to less evaporation and high content of atmospheric moisture.

Weather condition exhibits rhythmicity according to seasonal variations. Unlike other physico-chemical parameters it does not show any remarkable deviation from its seasonal law either in day or in night hours.

Colour of ambient water varies in different season. This may be due to colloidal components, such as iron, humins, suspended matters and luxurient growth of several various plankton in the aquatic milieu (Jhingran, 1978; Voznaya, 1981). In winter (January) water is clear and transparent which may be due to settling down of residual matters, high phytoplankton population and used up of nutrients for organic production and windaction (Nayak, 1982). All these may be indirectly related with solar radiation. The water tastes sweet with vary faint odour due to heavy sewage load into pond.
During summer water is clear in morning (0800h - 1000h) and then gradually becomes dirty. This may be due to decrease of water depth, abuse of water by local people (domestication, swimming bathing and fishing etc.). The water has a putrefactive odour and bitter taste in this season.

In rainy season water becomes heavily dirty throughout the day regime due to run off of rain water from the catchment areas, clay, rock, minerals, humus and inorganic materials, silts, silica, dust, waste materials etc. The odours remains unchanged with rhythmicity which is earthy throughout the day.

Among the physico-chemical parameters, temperature is important for bringing about diurnal fluctuations as well as high circadian rhythmicity, through its increase and decrease are influenced by seasonal law.

Air temperature increases during summer and decreases during winter. This also increases from morning towards noon and than decreases towards night (Agrawal, 1980; Jhakar et al, 1981; Saha, 1981 and Sharma, 1981).

Water temperature accordingly shows circadian rhythm of increasing during day and decreasing at night showing peak values between 1200h - 1400h (Nasar, 1977; Agrawal, 1980; Jakhar et al, 1981; Saha, 1981; Sharma, 1981). Water temperature usually show lower value than air temp. during three different seasons, except at night hours (0200h - 0400h) whereas in winter between 0200h - 0400h both air and water temperature are found to be equal. This may be due to liberation of free CO₂ and energy as a byproduct of respiration.
occurring at night and thus balance the temperature equal to air temperature. Ganapati, 1955, 1975; Nasar, 1977; have observed that a thermal stratification can be created temporarily during day and be broken during night (Sharma, 1981). Variations between air and water temperature are less than 2°C (Bohra, 1979 and Singh and Seha, 1981).

Variations in temperature during circadian rhythm further may be correlated to some other factors as such (i) amount of sunlight (Young and Zimmerman, 1956; Geiger, 1965; Macan and Moudsley, 1966; Martin, 1972; Purriot, 1972; Rajmankova, 1973), (ii) air temperature (Geiger, 1965; Macan and Moudsley, 1966; Moss, 1969; Martin, 1972; Saad and Samir 1979; Gahtori et al., 1981; Seha, 1981; Nayak and Patra, 1982), (iii) Wind velocity (Young and Zimmermann, 1956; Moss, 1969), (iv) wave action (Hillbricht et al. 1979).

pH shows very less diurnal fluctuation during the 24 hour day regime (Michael, 1967; Jhingran, 1978). pH of pond water has been observed much lower during rainy season. This may be due to addition of nutrients, silica and residues with water body from surface area and bank soils by surface run off water (Dwivedi et al., 1977; Kant and Anand, 1977; Jafferis et al., 1979; Seha, 1981). Highest value in winter and summer may be due to the temperature, high planktonic growth and alkalinity as well as (Ruttner, 1953; Jhingran, 1978) and high dissolved oxygen content.

During circadian observation pH varies between 6.5 to 8.5 and can be considered as safe range (Since the permissible range given by WHO and ICMR is 7.0 - 8.5).
Water pH gradually increases up to 1400h during the day time and remains constant up to night. However, pH decreases at night in winter and rainy season respectively whereas it decreases from 0800h to 1400h in summer, lowest value recorded at noon is 7.5. This may be due to high biotic respiration at noon and liberation of more carbon dioxide.

In rainy season the pH is more during day time and less at night (George, 1961; Michael, 1964; Verma, 1967; and Jakhar et al, 1981). Sumitra, 1969 observed and opined that pH does not show any circadian variation. Comparatively high pH observed during day time in winter and rainy season may be due to higher rate of photosynthetic activities of autotrophs present in the pond water.

Dissolved oxygen content in water is important as it is essential for all aquatic biota and also acts as indication of pollution at low concentration (\( \leq 5 \text{ mg/l}^{-1} \)).

Circadian fluctuation in dissolved oxygen content has been found in form of oxygen pulse. All the three seasons show higher dissolved oxygen content during day time and the lower value observed at night between 0200h - 0400h. The most important causative factor may be the photosynthesis. During day time aquatic phytoautotrophs in the process of photosynthesis release oxygen while consuming free carbon dioxide and at night when photosynthesis ceases, the photoautotrophs consume oxygen and release carbon dioxide through respiration (Hutchinson, 1957; Agrawal, 1980; Nayak and Patra, 1982). Similar observations are made by Hutchinson, 1957; Dwivedi et al, 1977; Jakhar et al, 1981; Saha, 1981; Sharma 1981. In rainy season much lower value (1.12 mg/l^{-1}) was recorded. This may be associated with maximum consumption of dissolved oxygen both by autotrophs and heterotrophs.
Much higher value (6.4 mgl\(^{-1}\) - 12.0 mgl\(^{-1}\)) of dissolved oxygen concentration has been found during winter which may be due to blooming phytoplankton (Saha, 1981) and favourable physico-chemical conditions like temperature and weather condition by which elementary oxygen diffuses to the medium and the oxygen is produced due to photosynthesis (Ruttner, 1953; Welch, 1962; Munawar, 1970 a; Herbert and Anderson, 1971; Nasar and Munshi, 1974; Wetzel, 1975; Saha, 1981).

During rainy season dissolved oxygen concentration is observed much lower (1.12 mgl\(^{-1}\) to 6.88 mgl\(^{-1}\)) which may be associated with unfavourable weather condition, low rate of diffusion, presence of high total solid matter (800 mgl\(^{-1}\)) and organic and inorganic ingradient in water (Boralkar, 1981) as well as low rate of photosynthesis, low pH in rainy season also a causative factor for low dissolved oxygen content (Sankhla and Vyas, 1982).

Summer also shows comparatively low dissolved oxygen content. Whipple and Parker (1901) indicate that decay of organic matter is most vigourous in warm weather which causes diminution of oxygen in summer. Boralkar in 1981 opined that it is due to biological abuse of water. Pearsall, 1923; Kato, 1941; Gonzalves and Joshi, 1946; Ruttner, 1953; George, 1961; Welch, 1962; Michael, 1964; Munawar, 1970; Nasar and Munshi, 1974; Bohra and Bhargav, 1976; Nasar, 1977 and Jheshker et al, 1981; proposed that high air and water temperature cause lowering of oxygen concentration. Boralkar, 1981; Pearse, 1950; and John, 1978; opined that sewage contamination with biogenic and chemical wastes and organic decomposition in the medium cause reduction is dissolved oxygen content.
Oxity values below 7 mg l⁻¹ is an indication of low productivity (Hutchinson, 1957) but renders safe stage for biotic communities (Bennet, 1971). Kedusia, 1980 suggested that tolerance limit of dissolved oxygen is 3 mg l⁻¹. So in the present study though the dissolved oxygen value fluctuates diurnally it remains with tolerance limit except at night (0200h - 0400h) during rainy season.

In the present study free carbon dioxide shows fluctuation with circadian rhythm. During summer circadian rhythm, free carbon dioxide is found to be high. This may be due to high organic decomposition at the bottom (Voznaya, 1981) at high respiratory activity of the biotic community in the medium. The value may also be increased by the addition of organic pollutant and sewage contamination (Boralkar, 1981). Whipple and Parker, 1902 have suggested that low dissolved oxygen content also creates high free CO₂ content of the medium.

Comparatively higher concentration of free CO₂ is observed during rainy season. This may due to the low dissolved oxygen content of the medium as proposed by Whipple and Parker, 1902; Brige and Judey, 1911; Pearsall, 1930; Ganapati, 1943; Gonzalves and Joshi, 1946; Rao, 1955; Saha et al, 1959 and Munawar, 1970. Jhingran (1978) gave his opinion that the concentration may increase due to atmospheric diffusion, surface runoff and water content.

Much lower value of free CO₂ observed during winter may be due to high dissolved oxygen content and maximum phytoplankton population (Verma, 1967; Saha, 1981).

Besides, free CO₂ concentration shows high diurnal variation. In winter and rainy season free CO₂ is decreased from morning (0800h) to
noon (1400h) and then increase and reaches highest value at night (0400h). Which can be argued by the statement given by Verma, 1967; Dwivedi et al, 1977; Agarwal, 1980; Saha, 1981; as photosynthesis is stopped at night resulting an increase of free CO$_2$ level.

Decrease of free CO$_2$ value at noon (1200h - 1400h) may be caused due to increase of photosynthesis and low respiratory activity. Because of the temperature at noon during winter and rainy is not adverse for photosynthesis.

In summer the reverse case has been obtained at noon (1200h-1400h). Much higher values (70.4 mg/l$^{-1}$) are recorded which may be argued taking the opinion of Verma (1967) that at summer noon the temperature remains high (37$^\circ$C). This may cause photosynthetic retardation unlike winter and rainy season when uptake of CO$_2$ are minimised. Higher values of free CO$_2$ at noon are also associated with low pH during 1200h-1400h and acts as a buffer, keeping the pH of the aquatic medium near neutral point, pH 7.5 (Khalaf and MacDonald, 1975; Singh and Saha, 1981). Presence of free CO$_2$ during circadian rhythm shows absence of CO$_3$$^{2-}$ alkalinity. It is suggested by Alikuni, 1957; Dwivedi et al, 1977; and Saha, 1981 that alkalinity below 100 mg/l$^{-1}$ is an index of low productivity.

Low alkalinity value during summer (29.2 mg/l$^{-1}$ - 83.2 mg/l$^{-1}$) may be due to high free CO$_2$ concentration. Comparatively high dissolved oxygen content and also rich planktonic sediments and less macrophytic growth are also associated with it. Rainy season also shows comparatively lower alkalinity values which may be due to inflow of upland materials into the pond containing soil and nutrients and low pH of the medium (Jhingran, 1978). High alkalinity of water is recorded in winter.
because of high pH and high macrophytic growth. This causes lowering of free CO$_2$ concentration and ultimately increases the alkalinity of the medium (Atkin, 1926; Pringsheim, 1946; Rao, 1955; Zafar, 1964; Pearsall 1980).

Diurnal variation in alkaline content shows high values at night (0200h - 0400h) though there is simultaneous increase in free CO$_2$ also at that time (0200h - 0400h). The fact is given by Singh (1960) that excess quantity of free CO$_2$ converted into H CO$_3$ with the ceasure of photosynthesis and thus the alkalinity increases at night. Further the fact is clear by taking into account the dissolve oxygen content at that time.

Circadian rhythm in chloride content shows maximum value during summer. This may be argued with the fact that both air and water temperature are high during summer (Singh, 1960; Gonzalves and Joshi, 1964; Zafar, 1964; Mehrotra, 1966; Ray et al, 1966; Munawar, 1970 a). Boralkar, 1981 opined that high organic decomposition, rapid evaporation and stagnant condition of water increase the chloride content. Nayak(1982) has also observed the same facts. Trivedy and Goel (1984) suggests that the increased value is due to abuse of water by man and animal during the season.

In rainy season minimum value has been recorded. This may be due to extra addition of upland water and lowering of temperature (John, 1978; Saad and Samir, 1979).

Winter also shows lower concentration of chloride content. Stagnant water may be associated with low temperature and good weather (Zafar, 1964).
During diurnal observations it is observed that lowest value obtained at night (0200h - 0400h) in all the seasons may be associated with low temperature at night.

In summer the concentration increases from down (0800h) to dusk (1800h) and decreases at night. It may be due to increase and decrease of ambient water temperature. The fact is also true for winter season as it decreases from morning to night. Though the chloride content shows diurnal fluctuation it does not exceed the degree of pollution range throughout the 24h day regime in all seasons and remains within limit (against 200 mg/l, WHO, 1963).

Hardness in rainy season shows highest values (134 mg/l - 160 mg/l). The cause may be water stagnation, low water temperature, free CO₂ and high alkalinity. In rainy season hardness decrease due to addition of rain water from uplands and low pH which varies between 64 mg/l to 140 mg/l during a day.

Summer season shows comparatively higher values of hardness. This may be due to abuse of water by men and animals. The range of variations is 106.4 mg/l - 160 mg/l, which decreases the spirogyra population in the pond.

It does not show any definite trend during diurnal observations. Summer and winter show less hardness at night (0200h-0400h) than day time (0800h-1800h) which may be associated with low dissolved oxygen content and less chloride concentration. In summer highest values are observed at noon (1200h-1400h) because of much abuse of water by men and animals. Whereas winter shows higher values (160 mg/l) at morning hours (0800h-1000h). This may be associated with very low water temperature.
In rainy season circadian observations show lowest hardness in morning (0800h-1000h) which is due to low pH (6.5) and low alkalinity of water. Thereafter hardness increases upto 1800h with the increase of both pH and alkalinity and against it decreases at night (0200h-0400h) with the decrease of pH and chloride content (30.90 mg/l). However alkalinity still shows an increasing trend.

Permanent hardness also follows the same path of circadian trend as in temporary hardness, except in rainy season when highest value are observed between 1200h to 1400h. This may be due to lowering of free CO$_2$ content of water and due to low rate of nutrients uptake by the phytoplankton.

In rainy season highest acidity (56 mg/l - 76.8 mg/l) is recorded. This may be correlated with low pH (6.5-7.5 mg/l$^{-1}$) that controls the acidity cycle of water (Manivasakam, 1985). In winter lowest values (45.6 mg/l) are observed. The causative factor for this may be high phytoplankton growth resulting reduction of free CO$_2$ concentration of water. It is in addition associated with high alkalinity during the season. Summer season shows comparatively higher acidity than winter. The most important factor is the increase of free CO$_2$ concentration resulting from respiration of high plankton population, low rate of photosynthesis and high temperature of water.

Acidity shows remarkable circadian changes throughout the study. In summer the acidity increases from morning to night (0800h-0400h) with the lowering of photosynthetic rate and ultimately stopped at night resulting high free CO$_2$ concentration (Verma, 1967) as well as acidity content. In winter, acidity decreases from 0800h to 1400h as may be the
increase rate of photosynthesis at noon (1200h - 1400h). The acidity increases up to night (Verma, 1967; Dwivedi et al., 1977; Agarwal, 1980; Saha, 1981).

In rainy season, high acidity values are observed between 1600h-1800h which may be due to cloudy weather and lowering of temperature affecting photosynthesis which causes increased acidity.

Total solids of water is one of the important factors as it regulates the penetration of solar radiation into the depth of water and thus indirectly controls the life of all the biota present in the photic medium. During investigation, the highest values are observed during rainy season which may be due to addition of runoff water (Boralkar, 1981). Howland (1931) opined that salt concentration increases with increased water level. Transeau, 1913; Voznaya, 1926; and Lind, 1938-45 also supported this view. Summer shows high total solid matter. The factor causing such condition may be the decrease of water level (Gonzales and Joshi, 1946) and heavy organic putrefaction. In winter minimum level of total solid are observed. This may be due to stagnancy of water, high phytoplankton population and high rate of photosynthesis which combinedly help in purification of water (Nasar, 1977).

Dissolved and suspended solid also follow the same trend as total solids showing high value during rainy season than summer and than winter.

Diurnal variation shows that in summer lowest total solid are recorded between 0800h-1000h and in winter at night (0200h-0400h). Which is associated with lowering of temperature and stagnant condition of water. The value increases during day time. This may be due to abuse by
men and animals. In rainy season also the higher values are observed at noon.

In case of dissolved solid the lowest value obtained between 0800h - 1000h during summer and rainy and between 0200h - 0400h during winter may be related with wind action, low dissolved oxygen content (Manivasakam, 1985) as well as by the interference of biogeochemical cycle. Chu (1943) proposes that range of total dissolved solid for freshwater content is 19.2 mg/l to 374.0 mg/l.

Lowest suspended solid are observed in the night (0200h - 0400h) throughout the year, due to stagnant condition of water and highest value observed between 1200h - 1400h (noon) may be due to the interference of local people as well as swarming during day time.

The Primary Productivity of Algae in winter is highest. This may be due to the bright weather (Goldman, 1960; Goldman and Wetzel, 1963; Sreenivasan, 1965; Valcha and Bhatnagar; Vanisree and Radhakrishna, 1982), high illumination (Goldman, 1960), optimum water temperature (Saijo and Kawashima, 1964; William and Murdoch, 1966; Vanishree and Radhakrishna, 1982), high transparency (Huchinson, 1957), maximum growth of phytoplankton (Kilham, 1971; John, 1978; Kant and Anand, 1978; Singh and Kohli, 1981), less water flow and nutrient factors at limiting range (Ketchum, Ryther, Yentsch and Carwin, 1958).

Summer is associated with high organic decomposition, high water temperature, high algal population and high scum formation as well as the sewage inflow. These do not permit the high Primary Production. During rainy season heavy rainfall, poor illumination high turbidity, sharp runoff water usually disturb and kill the phytoplankton sediments
and cause low transparency (Nayak, 1982). This in turn provides an unhealthy conditions for the increase in the rate of production in the medium. Therefore, the G.P.P. values are reported low (Vanishree and Radhakrishna, 1982).

The maximum circadian rhythm in N.P.P. and G.P.P. values in summer is between 0800h to 1800h at 34°C and in winter between 1200h to 1400h at 26°C and in rainy season between 0800h to 1000h at 31°C. It seems the ambient water temperature may have certain effect on the production of algae since the temperature in between 26°C to 31°C appears to be sound. Whereas the minimum productivity during night may be coupled with the consumption by autotrophs as well as consumer levels and total absence of photosynthesis.

During the morning hours in summer and rainy season highest G.P.P. and N.P.P are obtained then slowly declined in the afternoon showing lowest production at night. However in winter N.P.P. and G.P.P. values increase in the afternoon (1200h - 1800h) being supported by Talling, 1957; Vollenweider, 1965; and Agarwal, 1980. The plausible reasons put forth by the authors - The highest temperature at noon may increase the rate of respiration, whereas the productivity will not be affected as phytoplankton does avoid high water temperature in favour of their plastid and physiological processes.

The autotrophic respiration, becomes higher during daytime at 0800h to 1400h, which may be due to the high temperature which may accelerate the rate of respiration and also because of active function made by the organisms during day than night when pH values become lowest.
It may be summarised that the circadian rhythm acts positively on the ecophysiology of plankton in the pond ecosystem. This on the long processes governed by certain hormones or might be genetically based and accordingly followed by the internal clock, otherwise called "Biological Clock".