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NUTRIENTS, PRODUCTIVITY AND POLLUTION OF PERIYAR LAKE, KERALA, INDIA

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Three-year monitoring of the pollution status of a commercially exploited tropical freshwater reservoir, *Periyar* Lake, *Thekkady*, Kerala, India situated central to a world famous wildlife sanctuary, the Periyar Tiger Reserve included monthly assessment of nitrate nitrogen, *Kjeldal* nitrogen, inorganic phosphorus, silica; primary and secondary production, biochemical oxygen demand, chemical oxygen demand, oil and grease, maximum probable number of Coliform bacteria, count of *Escherichia coli*, pesticide and heavy metal content in the waters. For convenient and systematic studies six permanent sampling stations were fixed in the Lake in accordance with differences in degrees of human interactions within different parts of the Lake. In spite of the increasing anthropogenic influences, the nutrient concentration and primary productivity in the hundred years over artificial Lake remained quite normal in most part of it during the entire period of study, owing to its undisturbed watershed. This suggested the setting up of wildlife sanctuaries around reservoirs as effective watershed management method of commercially exploited lake systems in tropics in general. However, statistically significant fluctuations in certain quality parameters at certain locations and the high amount of oil content found in the lake, suggested the need of careful management and proper monitoring of such systems. Oil spill from motor boats in the lake was found extended throughout the Lake, even up to the core of the sanctuary area. *Coliform* bacteria count was high at all stations during most of the seasons.

Key words: Periyar Lake, Nutrients, primary production, pollution, oil and grease, seasonal changes.

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ПОЖИВНІ РЕЧОВИНИ, ПРОДУКТИВНІСТЬ ТА ЗАБРУДНЕННЯ ОЗЕРА ПЕРІЯР, КЕРАЛА, ІНДІЯ

Трьохрічний моніторинг стану забруднення тропічного прісноводного озера Періар, Теккаді, Керала, Індія, яке експлуатується з комерційної точки зору, що розташовано в центрі всесвітньо відомого заповідника живої природи – Періярського заповідника тигрів, – включає в себе щомісячну оцінку нітратного азоту, азоту за Кьєльдалем, негорганічного фосфору, кварцу; первинної та вторинної продукції, біохімічної потреби в кисні, нафтопродуктів, максимально вірогідної кількості колі-бактерій, кількості кишкової палички, вмісту пестицидів та важких металів у воді. Для зручності систематичних досліджень були встановлені шість станцій відбору проб в озері залежно від ступеня антропогенного впливу всередині різних частин озера. Незважаючи на зростаючий техногенний вплив, завдяки непорушеному вододілу концентрація поживних речовин та первинна продуктивність штучного озера протягом ста років залишається нормальною в більшій частині водойми. Це передбачає створення заповідника живої природи навколо водойми як ефективного метода управління вододілом озерних систем в тропіках, що експлуатуються, в цілому. Однак статистично позначені коливання параметрів певної якості в деяких місцях та велика кількість виявленого в озері

вмісту нафтопродуктів потребує точного управління та контролю за подібними системами. Розливи нафтопродуктів, які з'явилися внаслідок їзди моторних човнів, були знайдені на всій поверхні озера, навіть в заповідній зоні. Кількість бактерій групи кишкової палички була високою на всіх станціях протягом більшої частини сезонів.

Ключові слова: озеро Періяр, поживні речовини, первинна продукція, забруднення, нафтопродукти, сезонні зміни.

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ПИТАТЕЛЬНЫЕ ВЕЩЕСТВА, ПРОДУКТИВНОСТЬ И ЗАГРЯЗНЕНИЕ ОЗЕРА ПЕРИЯР, КЕРАЛА, ИНДИЯ

Трехгодичный мониторинг состояния загрязнения эксплуатируемого с коммерческой точки зрения тропического пресноводного озера Перияр, Теккади, Керала, Индия, расположенного в центре всемирно известного заповедника живой природы – Периярского заповедника тигров, – включает в себя ежемесячную оценку нитратного азота, азота по Кьельдалю, неорганического фосфора, кварца; первичной и вторичной продукции, биохимической потребности в кислороде, нефтепродуктов, максимально вероятного количества коли-бактерий, количества кишечной палочки, содержания пестицидов и тяжёлых металлов в воде. Для удобства систематических исследований были установлены шесть станций отбора проб в озере в зависимости от степени антропогенного влияния внутри различных частей озера. Несмотря на возрастающее техногенное влияние, благодаря ненарушенному водоразделу концентрация питательных веществ и первичная продуктивность искусственного озера в течение ста лет остается нормальной в большей части водоема. Это предполагает создание заповедника живой природы вокруг водоема как эффективного метода управления водоразделом эксплуатируемых озерных систем в тропиках в целом. Однако статистически обозначенные колебания параметров определенного качества в некоторых местах и большое количество обнаруженного в озере содержания нефтепродуктов требует точного управления и контроля над подобными системами. Разливы нефтепродуктов, появившиеся вследствие езды моторных лодок, были найдены на всей поверхности озера, даже в заповедной зоне. Количество бактерий группы кишечной палочки было высоким на всех станциях в течение большей части сезонов.

Ключевые слова: озеро Перияр, питательные вещества, первичная продукция, загрязнение, нефтепродукты, сезонные изменения.

Limnology of tropical reservoirs in general is very significant (Heide, 1982). Construction of dams across rivers and the resultant man made lakes generates harsh ecological aspects (Birsal, 1994). Every aquatic ecosystem is a unique natural feature, and the study of each system in detail is necessary for case-by-case assessment of ecological threats (Hakanson, 2004). Water resources are under pressure and in danger as a result of potential pollution and contamination risks due to over use and misuse of the resources all over the world (Karagul *et al*., 2005). There are reports on long-term decrease in the area of Lake over the last 30 years due to the siltation and climate change (Su and Jassby, 2000). Gulati and Donk (2002) identified fresh water deterioration as a challenging problem in industrialized Western Europe, especially in countries with intensive agricultural practices as well as animal husbandry. Nitrogen in freshwater is found increased over the last one and a half centuries (Rabalais, 2002). Nutrient load is a serious issue in tropical lakes in general (Lind and Lind, 2002). Becht and Harper (2002) reported deterioration of tropical Affrican Lakes due to over exploitation. There is close relationships between catchments area characteristics and lake characteristics (Hakanson *et al*., 2003).

The reservoirs in the Western Ghats in Kerala are unique ecosystems controlled by rainfall rather than temperature; these are oligotrophic having least production potentials, and are physico-chemically and biologically different (Khatri, 1992). However detailed studies of freshwater systems in this region are rare (Sugunan, 1995). Boat activity in freshwater lakes is a serious problem (Hilton and Phillips, 1982). A comparative study of small reservoirs in seven different countries spread over in Africa, Asia and Latin America highlighted the significance of reservoirs as important freshwater wealth of tropical nations such as India (Sugunan, 1997).

Periyar lake system stands as a model to explain certain basic principles of natural freshwater ecosystem management and wildlife management of tropics in general. It is the oldest of all mega reservoirs in India and the broadest reservoir in Kerala, over hundred years of use and has a unique history. The Dam was constructed during 1886-95 according to the Project plan and leadership of a British Visionary, Capt. R E Pennycuick who used his personal resources for the completion of the project (Manoharan 2000). It may be noted that the construction of this Lake enabled the protection of its watershed in its present form (Mackenzie, 1963), representing one of the best of wildlife sanctuaries of Asia and a noteworthy National Park, the Periyar Tiger Reserve (PTR) in the country (World Geographical Encyclopedia, 1989). Though the reservoir beautifies the Tiger Reserve (Asari, 1986), the Lake was never recognized as a natural resource integral to the sustainable management of the PTR. Instead, it has been treated as a mere economic resource. The economic benefits so far received from the Lake were magnificent (Manoharan, 2000). The average annual total water discharge from the Lake varies from 20,000 to 30000 million cubic feet. Water from the Lake serves as the sole source of drinking and of irrigation of land of about 90647 ha for the past 100 years in the adjacent Tamil Nadu State. The average annual production of power from Periyar is 454 Million Units. The ecological and aesthetic value of this system is incalculable. However, there exist conflicts between conservation objectives and the livelihood opportunity of tribal fishermen in the area which is a potential danger to the whole fish life in the Lake (CED Report, 2000). Roopa (1995) made a specific study on the wildlife tourism in the PTR and mentioned the need of monitoring the impact of tourism on the system as a whole including the Lake. The Management Plan (2001) emphasized intensive ecological investigations for its sustainable management; the key to which is the monitoring of nutrient status, primary productivity and other types of organic pollutants in the Lake.

Three-year monitoring of the nutrient content, productivity characteristics and pollution aspects were therefore, important to test the ecological resilience of one of the best protected tropical freshwater system, the Periyar Lake, a very precious water resource which may be considered as a ‘common human heritage’ now subjected to anthropogenic pressures of tourism in the zone. Moreover, the present investigation stands as a model general assessment of the pressure of developmental activities such as tourism on tropical freshwater systems in general. The importance of avoiding conflicts between the management of forests and lakes or reservoirs adjacent to forests is revealed, especially for the sustainable conservation of wildlife in both the systems.

MATERIALS AND METHODS

(a) The Lake

Periyar Lake (Figure 1) lies in the Periyar Plateau of the Western Ghats at 9^0 18^1 to 9^0 40^1 northern latitude and 76^0 55^1 to 77^0 25^1 eastern longitude. The PTR forms the major watershed of the Lake consisting of undulating hills, varying in altitude and the elevation around the Lake is about 800-1200 m and the water surface is situated at about 900 m above mean sea level. The water-spread area of the Lake is 26 km^2 with steep shoreline and a maximum depth of 46 m at the dam site.

(b) Filed Stations

Since morphometry of the Periyar Lake is complex with a lot of dendritic structures along its whole length, and the base of the flooded plane in the reservoir in general has an undulating topography, accounting of spatial variation was not easy in this system. However, six permanent sampling stations were fixed in the lake for convenient monitoring and systematic field study and regular sampling of waters. The stations were designated as Periyar Lake Stations (PLS) – PLS-1, PLS-2, PLS-3, PLS-4a, PLS-4b, and PLS-5 respectively (Figure 1).

(c) Sampling and Laboratory Analysis

Water samples were collected from the lake approximately between 15^{th} and 20^{th} of every month, from April 2002 to April 2005. Direct field measurements and sampling started at 9AM. The order of sampling was PLS-5 first and then PLS-1 to PlS-4 in regular order. The sampling of waters at PLS-5 and PLS-1 were done from the shores and that at PLS-2 to PLS4 (b) were carried out from motor boat. Samples were collected from surface (1-2cm) and bottom (2-10m) regions of the lake. The depth from which the bottom water sample collected was not uniform at all stations. Samplings were always in triplicate from each station for the study of all the parameters. In different seasons the depth varied from 1-3 meters at Stations 1 and 4b, 2-6 meters at station 5; it varied from 6-10 m at Station-2 but it was almost uniformly 10 meters at Station-3 and station 4b. Two liter of water of both surface and bottom were collected from each spot at all stations. Samples were collected in well cleaned polythene bottles of two liter capacity. The bottom samples were collected using a Meyer's water sampler. Bottom samples were transferred to the polythene bottles using a plastic tube. The bottles were packed appropriately in well-insulated boxes filled with ice cubes and were kept in darkness in iceboxes at 4 ^0C till the samples reached the laboratory for analysis. After reaching the laboratory the samples for BOD measurements were immediately incubated and others were kept in a refrigerator for next day's analysis.

Sampling and measurement for BOD was as per the standard methods followed by APHA (1995). Two separate bottles were used for each sample. Oxygen in the first bottle was fixed on the spot immediately after the collection and the second bottle containing water was kept in darkness at 4 ^0C (in iceboxes) till it reached the laboratory. After reaching the laboratory at about 10 PM, the unfixed samples were immediately set for incubation at 20^0C for 5 days and the BOD was accounted afterwards. Chemical Oxygen Demand

(COD) was measured following standard methods (APHA, 1995). Samples for MPN and Faecal *Coliform* analysis were collected from surface water of each station separately in 100 ml pre-sterilized dark bottles, and kept in darkness at 4 ^{0}C in ice boxes till reaching the laboratory (Trivedy and Goel, 1986).Bacterial analysis of samples kept in the fridge was done on next day morning in the laboratory of Microbiology of the Indian Rubber Research Institute, Kottayam, as per the standard procedures of APHA (1995).

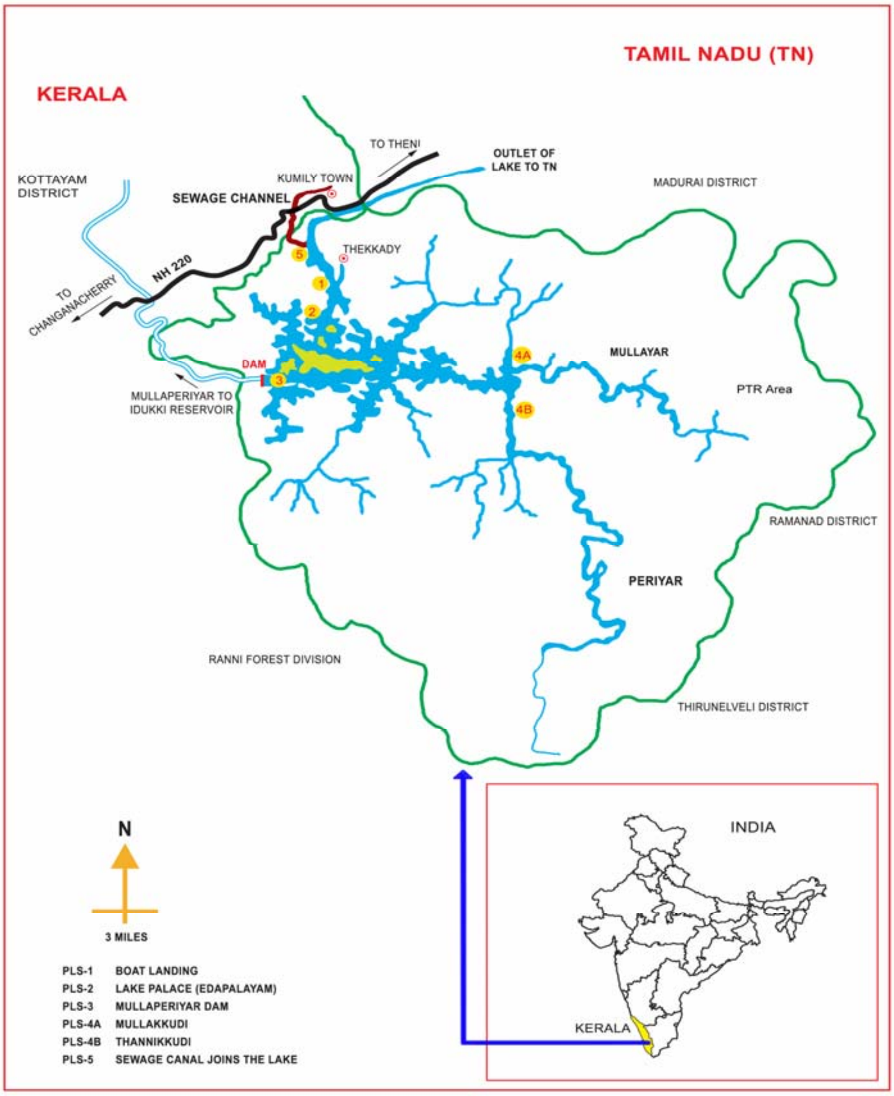

Fig. 1. **Location map of Periyar Lake**

Total Nitrogen was determined by Micro-Kjeldal method (APHA, 1995). Nitrate Nitrogen, Inorganic phosphorus and silica were measured using visible spectrophotometer as per APHA (1995). Separate samples were collected for accounting the Oil and grease content on surface waters and the analyses were carried out in the laboratory according to Trivedy and Goel (1986). Estimation of primary production was carried out for the surface water samples only. Light and dark bottle method was used in this study (Trivedy and Goel, 1986). Of the two light bottles and one dark bottle for each sample, oxygen in the first light bottle was fixed immediately after collection for measuring the initial oxygen content but that of other light bottle and the dark bottle were kept in room temperature; light bottle in open light and dark bottle in darkness for three hrs and then fixed the dissolved oxygen (DO). DO was measured following Winkler iodometric method (Trivedy and Goel, 1986). Secondary production was measured partially and indirectly from that of the data of fish catch. The Data of daily and annual Fish catch were collected directly from the tribal people, and also from the records of the Tribal Welfare Society.

Pesticide residues were analyzed for stations 1, 3 and 4b alone and that too only once during the investigations, in October 2003. Measurements were analyzed by gas chromatography method (APHA, 1995) in the Laboratory of the Department of Toxicology, Tamil Nadu Agricultural University, Coimbatore. Heavy metal content such as lead and mercury were analyzed by Atomic Absorption Spectrophotometer (APHA. 1995) in the Laboratory of the Department of Environmental Science, University of Kerala. This measurement was carried out for water samples from all the six stations, twice during the study period (August and October 2003).

Results of the descriptive measures (average and variance) for all the parameters were calculated seasonwise, stationwise, and yearwise. The data used for seasonwise analyses were the average of the four measurements made in each season. The variations of each particular parameter across stations and that over seasons or years were calculated from ANOVA using the Microsoft Excel.

RESULTS

A. Nutrient Status of the Lake

(1) Nitrate Nitrogen

Seasonwise and stationwise analysis of Nitrate N of surface water showed that the Nitrate N at station 5 was comparatively higher than that of the other stations during all the three seasons. The highest amount of Nitrate N noticed in the Lake was 0.6 mgl^{-1} at station 5 during pre-monsoon of 2002 and the lowest value noticed was 0.1 mgl^{-1} at many stations during all the three seasons in different years. Throughout the period of study the lowest Nitrate content was noticed at Station 4 (b). The fluctuations in Nitrate N over different years at all stations were insignificant during the pre-monsoon and northeast monsoon whereas the fluctuations across different stations were significant during all the seasons. During the southwest monsoon, the fluctuations in this factor over years and that across different stations were significant in the Lake. However, a comparison of the three-year average value of Nitrate N (Table 1) showed that the fluctuations over seasons were insignificant but that across different stations were very significant. In general the nitrate N of the Lake at station 5 was found higher than that of other stations during all seasons. Station-2 showed the second highest value in this parameter during all seasons.

(2) Total *Kjeldal* Nitrogen

Examination of the total *Kjeldal* Nitrogen content of surface waters of Periyar Lake revealed that in the pre-monsoon, the fluctuations in its content in the Lake over years and seasons were insignificant; but the fluctuations over years and seasons were very significant during southwest monsoon. In the northeast monsoon the fluctuations over years were significant but that across stations were insignificant. The highest value noticed during this study was 3.9 mgl^{-1} at station 2 during northeast monsoon of 2004 whereas the lowest value noticed was 1mg L^{-1} at station-4a and 4b during southwest monsoon of 2003. Three-year average value of total Kjeldal N is given in Table 2. In general pre-monsoon quantities were slightly higher than that of the other seasons and the quantity at station 5 was slightly higher than that of other stations. Moreover, significant fluctuations were observed over seasons and across stations in the Lake.

Table 1

Three-year average of Total Nitrate Nitrogen of surface water (mgl^{-1})

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	0.3	0.2	0.2	0.1	0.1	0.4
Southwest monsoon	0.3	0.3	0.2	0.2	0.1	0.4
Northeast monsoon	0.3	0.2	0.1	0.1	0.1	0.4

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.007777778	2	0.003889	3.181818	0.085232	4.102816
Columns	0.191111111	5	0.038222	31.27273	8.52E-06	3.325837
Error	0.012222222	10	0.001222			
Total	0.211111111	17				

Table 2

Three-year average of Total Kjeldal Nitrogen of surface water (mgl^{-1})

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	2.6	2.4	2.4	2.5	1.9	3
Southwest monsoon	1.8	1.7	1.7	1.5	1.6	2.1
Northeast monsoon	2.2	2.2	2.2	2.4	1.5	2.4

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1.623333	2	0.811667	24.59596	0.000138	4.102816
Columns	1.071667	5	0.214333	6.494949	0.006119	3.325837
Error	0.33	10	0.033			
Total	3.025	17				

(3) Total Inorganic Phosphorus

Comparison of total inorganic phosphorus content of the Lake throughout the study period, in all the seasons, showed that its quantity at station 5 remained higher than that at all the other stations and the second highest quantity was at station 2. Yearwise and stationwise fluctuations in inorganic phosphorus content were found significant during the pre-monsoon and southwest monsoon. In the northeast monsoon yearwise fluctuations were insignificant whereas the stationwise fluctuations were very significant. Inorganic phosphorus content in the lake varied from 0.08 mgl^{-1} to 0.1 mgl^{-1}. Three-year average of inorganic P in the lake (Table 3) showed that the fluctuations in it over seasons and across stations were significant.

Table 3

Three-year average of Total Inorganic Phosphorus of surface water (mgl^{-1})

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	0.08	0.04	0.04	0.03	0.03	0.08
Southwest monsoon	0.05	0.04	0.04	0.03	0.03	0.06
Northeast monsoon	0.03	0.02	0.01	0.02	0.02	0.06

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.001678	2	0.000839	9.805195	0.004393	4.102816
Columns	0.004161	5	0.000832	9.727273	0.001345	3.325837
Error	0.000856	10	8.56E-05			
Total	0.006694	17				

(4) Total Silica in the Lake

Total Silica in Periyar Lake waters varied from 0.41 mgl^{-1} (at station 4 B during the southwest monsoon) to 0.01 mgl^{-1} (at stations 1 to 4 B during the northeast monsoon). In general the silica content of the waters was slightly higher in the southwest monsoon at all stations than that during other seasons. In the pre-monsoon the fluctuations in silica content was only slightly significant over years but insignificant across stations whereas in the southwest monsoons the fluctuations over years and that across stations were very significant. However, in the northeast monsoons fluctuations in inorganic P was found insignificant over years but very significant across stations. Three-year average quantity of silica of different seasons (Table 4) showed that the fluctuations in it over different seasons were highly significant but that across stations were insignificant in the Lake.

Table 4

Three-year average of Total Silica of surface water (mgl^{-1})

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	0.1	0.09	0.14	0.17	0.19	0.11
Southwest monsoon	0.2	0.18	0.26	0.24	0.34	0.24
Northeast monsoon	0.01	0.01	0.02	0.01	0.02	0.07

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.1452	2	0.0726	66	1.73E-06	4.102816
Columns	0.0154	5	0.00308	2.8	0.077929	3.325837
Error	0.011	10	0.0011			
Total	0.1716	17				

B. Primary Productivity of the Lake

Macrophyte vegetation which belongs to the categories such as surface or submerged free-floating and rooted with floating Leaves were not found in Periyar Lake system throughout the entire period of study. Rooted submerged plants were found in the shallow periphery alone. They were mostly grasses which get submerged only temporarily during fluctuations of water levels in the Lake. However, in the summer, when certain zones of the lake were found extremely shallow, submerged and emergent Macrophytes were noticed in such regions of Lake. In bottom exposed zones, hygrophyte communities were also noted, which were quite temporary. Therefore, phytoplankton was found to be the major Primary Producers of the Lake and the primary productivity due it was directly assessed. A major share of the secondary production was assessed indirectly from the data of fish catch from the Lake. In a lake surrounded by forests such as the Periyar Lake, secondary production depends on the significant input such as flowers, fruits, litter, and dead or live faunal material including terrestrial insects, animal excreta and partly decayed dead matter and humus containing surface soil. However, no accounting in this regard was made during the present study.

(1) Gross Primary Production (GPP)

The average seasonal value of GPP of surface water varied from 0.17 to 0.36 mgl^{-1} of Oxygen per hr. In general GPP at Stations 2, 3 and 4 A was observed slightly higher in the northeast monsoon than that of other seasons. The GPP at Station 5 was found slightly higher than that of other stations in all seasons. Fluctuations in GPP over different years were insignificant whereas it across different stations were significant during the pre-monsoon and southwest monsoon. In the northeast monsoon the fluctuations in it over years and across different stations were insignificant. Three-year average of GPP (Table 5) of the Lake showed that its fluctuations over different seasons and across different stations were significant in the Lake.

Table 5

Three-year average of GPP of surface water (mgl^{-1} of O_2 /hr)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	0.25	0.24	0.25	0.28	0.24	0.33
Southwest monsoon	0.24	0.25	0.27	0.25	0.19	0.32
Northeast monsoon	0.31	0.31	0.33	0.3	0.27	0.3

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.008211	2	0.004106	6.855288	0.013344	4.102816
Columns	0.011028	5	0.002206	3.682746	0.037699	3.325837
Error	0.005989	10	0.000599			
Total	0.025228	17				

(2) Net Primary Productivity (NPP)

The average seasonal NPP of the surface water was found very low at all stations and the value of it over three years varied from 0.03 to 0.19 mgl^{-1} of Oxygen/hr. No definite trend was noticed in NPP among sampling stations and between seasons at all stations in the Lake throughout the period of study. Fluctuations in it over different years and across different stations were insignificant during all the seasons. However, in the three-year average of NPP (Table 6) significant fluctuations in NPP were observed over seasons and across stations in the Lake.

Table 6

Three-year average of NPP of surface water (mgl^{-1} of O_2 /hr)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	0.13	0.12	0.11	0.11	0.13	0.13
Southwest monsoon	0.14	0.16	0.14	0.11	0.09	0.15
Northeast monsoon	0.13	0.13	0.14	0.11	0.15	0.12

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.000344	2	0.000172	0.488959	0.627191	4.102816
Columns	0.001444	5	0.000289	0.820189	0.56229	3.325837
Error	0.003522	10	0.000352			
Total	0.005311	17				

(3) Community Respiration (CR)

The average seasonal value of CR in surface water over different years ranged from 0.08 to 0.24 mgl^{-1} of Oxygen/hr. As in the case of NPP, the rate of respiration showed no definite trend across sampling stations or seasons in the Lake throughout the entire period of study. Fluctuations in it over years and across stations were insignificant during pre-monsoon and northeast monsoon seasons in the Lake. In the southwest monsoon, its fluctuations over seasons were insignificant whereas its fluctuations across stations were significant. The three-year average value of CR in the Lake (Table 7) showed that there were no significant fluctuations in it over seasons and across different stations.

C. Pollution in the Lake

(1) Biochemical Oxygen Demand (BOD)

BOD is the measure of degradable organic matter present in water and is defined as the amount of oxygen required by the microorganisms in stabilizing the biologically degradable organic matter under aerobic conditions. It is therefore, an important measure of pollution of a water body. Seasonal BOD of surface water of Periyar Lake over the three-year period of study varied from 0.4 to 3.1 mgl^{-1} and that of bottom water varied from 0.7 to 3.1 mgl^{-1}. In the years 2003 and 2005 BOD was found comparatively higher during the pre-monsoon than that at the other seasons. In general, yearly fluctuations in the BOD of surface water were insignificant during pre-monsoon and southwest monsoon whereas the fluctuations in BOD across different stations were significant during both these seasons. However, in the southwest monsoon, there were significant fluctuations in BOD of surface water over years, but the fluctuations in BOD across different stations were found insignificant in the season. Fluctuations in the three-year average value of BOD (Table 8) of surface water were significant over different seasons and across different stations. Fluctuations in seasonal BOD of bottom water over years and across different stations were insignificant during pre-monsoon and southwest monsoon. But in the northeast monsoon, the fluctuations over years were slightly significant but that across different stations were insignificant. The fluctuations in the three-year average value of BOD of bottom water (Table 9) in the Lake were found insignificant over seasons and across different stations.

Table 7

Three-year average of CR of surface water (mgl^{-1} of O_2 /hr)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	0.11	0.12	0.14	0.17	0.11	0.43
Southwest monsoon	1	0.09	0.13	0.14	0.11	0.16
Northeast monsoon	0.17	0.18	0.19	0.19	0.12	0.14

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.040011	2	0.020006	0.388516	0.687866	4.102816
Columns	0.206311	5	0.041262	0.801329	0.573411	3.325837
Error	0.514922	10	0.051492			
Total	0.761244	17				

Table 8

Three-year average of BOD of surface water (mgl^{-1})

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	2	1.1	1.6	1.3	1.8	2.6
Southwest monsoon	1	1.1	0.6	1	0.6	1.4
Northeast monsoon	1.6	1.3	1.2	1.5	1.1	1.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1.863333	2	0.931667	11.99571	0.002204	4.102816
Columns	1.48	5	0.296	3.811159	0.034175	3.325837
Error	0.776667	10	0.077667			
Total	4.12	17				

(2) Chemical Oxygen Demand (COD)

COD of only the surface water of the Lake was measured in the present investigation. In general, the COD at stations 5 and 1 were found quite different from that of the other stations. During the Pre-monsoon season of the entire period of study, COD at Station 5 and 1 over different years were found quite similar and COD at station 5 was only slightly higher than that at Station 1; but during the Southwest and Northeast monsoons the COD at station 5 was found very much higher than that at station 1. In general fluctuations in COD of

Table 9

Three-year average of BOD of bottom water (mgl^{-1})

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	1.8	1.4	1.8	1.1	1.5	2.5
Southwest monsoon	1.1	1.3	1.1	1.7	0.93	1.7
Northeast monsoon	1.6	2	1.8	1.6	1.2	2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.598878	2	0.299439	3.085762	0.090416	4.102816
Columns	1.174694	5	0.234939	2.42108	0.10971	3.325837
Error	0.970389	10	0.097039			
Total	2.743961	17				

Periyar waters across stations were highly significant during all seasons whereas fluctuations in COD of the surface water over years were significant during the southwest monsoon alone. Three-year average of COD of surface water (Table 10) showed that the fluctuations in it over different seasons were insignificant but that across different stations were highly significant.

Table 10

Three-year average of seasonal COD of surface water (mgl^{-1})

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	3.5	1.7	1.5	1.5	1	3.6
Southwest monsoon	2.8	2	1.5	1.2	0.8	3.4
Northeast monsoon	2.6	2	1.4	1	0.9	3.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.181111	2	0.090556	1.815145	0.212557	4.102816
Columns	15.82944	5	3.165889	63.4588	3E-07	3.325837
Error	0.498889	10	0.049889			
Total	16.50944	17				

(3) Oil and Grease in Surface Waters

A measure of Oil and grease leaked out from motor boats in the surface waters is inevitable in assessing the pollution status of the Lake. Seasonal average of oil and grease in surface waters of the lake during the entire period of study varied from 110 to 2282 mgl^{-1}. Oil and grease at station 5 and 1 were found much higher than that at other stations in all seasons during the entire period of study. It was also embarrassing to note that the amount of oil and grease at station 2 was almost equal to that at stations 5 and 1 during certain seasons of some years in the Lake. In general the fluctuations in oil content over the different years of study were insignificant but that across different stations were highly significant during pre-monsoon. However, in the southwest and northeast monsoon period, the fluctuations in oil in the surface waters of the Lake over different years and that across different stations were highly significant. Three year average seasonal value of oil and grease at different stations (Table 11) showed that the fluctuations in it over different seasons and across different stations were highly significant in the Lake.

(4) Microbiology of Water

Monthly counts of bacteria, both the Maximum Probable Number (MPN) of *Coliforms* and the count of *Escherichia coli* (*E. coli*) were determined during 2004 alone. The seasonal averages of these data are given in Table 12 and Table 13 respectively. The MPN recorded at all the stations during the entire seasons were very high. It was highly embarrassing to note that *E.coli* count observed in the Lake was above the water standards prescribed for drinking or recreation purposes at all the stations except at Station-4 (b). The count was extremely high at stations 5 and 1. Water at the station 4b alone was found free from *E.coli.* Its count at station-5 was found extremely high.

Table 11

Three-year average of Oil and Grease of surface water (mgl^{-1})

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	1871.7	1094	1033	471	307.7	1732
Southwest monsoon	1430.3	871	603.3	427	344	1680.7
Northeast monsoon	962.3	663	458.3	310.3	154.7	1080.7

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Rows	700396.92	2	350198.5	12.4605	0.001926	4.102816
Columns	3921021.2	5	784204.2	27.90297	1.44E-05	3.325837
Error	281046.89	10	28104.69			
Total	4902465	17				

Table 12

MPN of Coliform bacteria (No/100ml)

Season	Station-1	Station-2	Station-3	Station-4a	Station-4b	Station-5
Pre monsoon	940+	189	1900+	1910+	A	2487+
Southwest monsoon	2400+	133	1800+	2400+	1900+	2400+
Northeast monsoon	2400+	167	2400+	2400+	2400+	2400+

A = absent

Table 13

Count of Escherichia coli in the Lake (No/100ml)

Season	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station-5
Pre monsoon	146	60	34	43	A	467
Southwest monsoon	152	38	76	70	A	434
Northeast monsoon	132	46	18	78	A	280

A = absent

(5) Pesticide residues and Heavy metals

Contaminated runoff from upland agricultural region permeates through stream and reaches natural waters (Rao 1996). Therefore, a preliminary analysis of water samples each from three different stations representing the end, middle and origin of the Lake was carried out in October 2003 for pesticide residue content. The results revealed that residues of organo-chloro or organo-phosporus pesticides in the Periyar Lake waters were at a negligible non-detectable level.

Wastewater discharged through the sewage system is a recognized source of heavy metal in water (Klein 1974). Since Periyar waters receive wastewater from the Kumily Township at station 5, analyses were carried out for the occurrence of heavy metals such as Lead and Mercury at all the six different stations, twice during the study period (August and October, 2003). However, the quantity of both these heavy metals was found negligible in the Lake waters.

DISCUSSION

Accumulation of Nitrogen and Phosphorus in natural waters is more closely related to external factors such as cultural influences, fertilization and rate of flow (Hutchinson, 1938). Nitrogen is generally considered the primary limiting nutrient for phytoplankton biomass accumulation (Rabalais, 2002). The maximum acceptable concentration of N in water for humans either for drinking or for recreation and aesthetics is 10 mgl^{-1} (of nitrate or nitrate together with nitrite) or 1 mgl^{-1} (nitrite alone) whereas a maximum concentration of 100 mg L^{-1} (nitrate or nitrate and nitrite together) or 10 mgl^{-1} (nitrite alone) is permissible for animals including wildlife (Riordan, 1993). Maximum permitted limit of drinking water level of NO_3 N is 20 mgl^{-1} according to ICMR (1975) and 45 mgl^{-1} according to ISI (1991). Nitrogen content in the Periyar Lake system, the maximum of which noticed during the study period was 0.6 mgl^{-1} of Nitrate or 3.9 mgl^{-1} of total nitrogen, therefore, is not at all alarming. There were similar observations in other water bodies in the Western Ghats (Abbassi et al., 1997). In spite of the increasing anthropogenic influences N concentration found at most stations during the entire period of study was quite low and the reason is nothing but the undisturbed watershed and low residence time of water in the Lake. However, a slightly higher value of both the total Kjeldal form and the NO_3 form of N observed at station 5 followed by station 1 is a clear evidence to suggest that the impact of sewage is spreading to the interior, even up to the station-1 region of the Lake. Since the precious wildlife of the sanctuary reaches up to station 1, this is a serious threat to the conservation of them in the sanctuary.

There was a seasonal trend of a comparatively slightly higher amount of total Kjeldal N during pre-monsoon at all stations, whereas the trend was not visible in NO_3 form of N. Southwest monsoon was the season of the lowest content of total Kjeldal N in the Lake. This observation does not agree with that of Osborne et al. (1987) who found that concentration of P and N increased during higher water levels. Highest amount of Nitrate in rainy season may be due to the addition of nitrogen in the form of runoff water and organic pollution due to sewage entry whereas nitrate depletion in winter and summer may be due to the photosynthetic activity of the alga or due to the oxidation of organic compounds (Blum, 1956). However, in Periyar Lake monsoon had a dilution effect on nutrients in the system and this is mainly due to the undisturbed watershed in the region.

Phosphorus (P) is the primary limiting nutrient in most lakes and reservoirs. It is a major nutrient that triggers eutrophications and required by algae in small quantities (Bandela et al., 1999). Low amount of P limits the growth of all the algal forms most often, but N limits the growth of certain algal species alone, especially those which do not fix N itself. Each P ion promotes the incorporation of seven molecules of N and 40 molecules of CO_2 in algae (Wetzel, 1983). Phosphorus content in surface water of Periyar Lake was found varying from 0.01 to 0.1 mgl^{-1}, during all seasons throughout the entire three year period of study. Phosphorous content of 0.05 to 0.1 mgl^{-1} is threshold of it as a nutrient for natural waters (Jeppesen et al., 1997). But Romero et al. (2002) considered Lake Pamvotis with a P content of 0.11 mgl^{-1} as one of intermediate nutrient status. A water body may be considered as eutrophic if the total phosphorus value ranged in between 20-30 μg per liter (Welch, 1980). P in the Lake (10 to 60 μgl^{-1} at inlet zones and 10 to 80 μgl^{-1} at stations 2 and 3) showed seasonal fluctuations of oligotrophic to eutrophic nature. It is the low residence time of water that is responsible for the major control of eutrophication in the Lake. Maximum accumulation of P was noticed at all stations during the pre-monsoon (season of lowest inflow and out flow rate) and the minimum at northeast monsoon (season of the highest inflow and outflow). Moderate content of phosphorus was noticed during the southwest monsoon. Spatial trends in variations of P in the Lake suggested spreading of the impact of sewage at station 5 to the interior of the Lake. Monsoon in general has a dilution effect on P in the Lake which emphasized the significance of undisturbed watershed around the Lake.

Silica is of significance as a major nutrient for diatoms and may become a limiting nutrient during diatom blooms. Egge and Aksnes (1992) found that diatom dominance of mesocosm communities was directly related to the availability of silicate. Silica additionally limits the growth of diatoms (Schindler, 1978). Therefore, the Periyar Lake water seems to be not favourable for Diatom growth. Analysis of the interrelationships of nutrient content and phytoplankton characteristics will be continued in the next part of the paper. The moderate nutrient content of this hundred years over commercially exploited system revealed its resilience to disturbance owing to its characteristic position in the midst of an undisturbed watershed and the very fast removal of water resource from the Lake for electricity generation.

There are many purposes for studying primary productivity in Lakes. The direct approach that is receiving greater attention in the recent times is the correlation of fish yields with primary production (Liang et al., 1981). Although extensive studies of primary production have been conducted in Africa and temperate regions of the world, relatively few studies have been conducted in the south and Southeast Asia (Talling and Lemoalle, 1998). High light intensity during the day and the much higher temperature contribute to the large difference in primary productivity between tropical and temperate aquatic systems (Lewis, 1987). Primary production is often affected by nutrient availability in tropical lakes (Talling and Lemoalle, 1998). Rain induced high primary productivity has been observed in some African lakes (Melack, 1979; Thomas et al., 2000). Amarasinghe and Viverberg (2002) made a detailed study of the primary production in a reservoir in Srilanka. Primary production in tropical lakes is generally three times higher than in temperate lakes (Lemoalle 1981; Amarasinghe and Viverberg 2002). However, the seasonal averages of GPP (0.17 to 0.36 mgl^{-1} of Oxygen hr^{-1}), NPP (0.03 to 0.19 mg l^{-1} of Oxygen hr^{-1}) and CR (0.08 to 0.24 mgl^{-1} Oxygen hr^{-1}) observed in Periyar Lake were quite low when compared to that of similar tropical or temperate lakes. This is definitely correlated to the low nutrient content of the system. During the three year monthly study, respiration never exceeded the (GPP). In general, the study of primary productivity showed that this Lake system has a low and stable primary productivity, characteristic to an oligotrophic system. In tropical regions the first rains after the start of the rainy season usually carry a lot of nutrients to the reservoir. But in this Lake such an inflow of nutrients and its impact on productivity was not evident either due to undisturbed watersheds or due to the fact that the residence time of water is very short and most of these nutrients do not remain long to a higher accumulation in the system to have such an impact.

Low residence time is owing to the fast pumping down of water resources for its economic uses in the eastern plains in Tamil Nadu. However, the impact of these factors on the hydrobiology of the Lake system and the ecology of the wildlife of the reserve would be a complex issue to investigate further. But the positive role of keeping the watershed as wildlife reserve as a measure to minimize nutrient impact and productivity of the Lake system was quite visible. Therefore, the 'Periyar Model' may be utilized in management systems of Reservoirs and Lakes in general.

In a Lake surrounded by forests such as the Periyar Lake, secondary production depends not only on primary algal productivity, but also on significant input from adjacent forest systems including fruits, litter, dead or live faunal material such as terrestrial insects, animal excreta, partly decayed dead matter, humus containing surface soil and soil organisms. The amount of daily fish catches form this type of an oligotrophic system stands as a good evidence to this fact. Moreover, removal of much of the secondary production from the Lake in the form of fishes might be another reason for the low nutrient content of the system. Both these facts need further investigations to establish better models of economic exploitation of tropical freshwater reservoirs in general.

The fishing activities of tribal in the lake is not yet scientifically organized (Management Plan, 2001). During our three year monitoring of the Lake, what we have gathered was that about 150 tribal fishermen are still daily fishing in the Lake. The common exotics were Gold fish (European Carp – *Cyprinus caprio var. communis*) and Tilapia (*Orochromis mossambicus*, Peters). But the fish catch included endemic species such as the *Masheer* (*Puntius curmuca*) or *Kuyil* and *Kooral* (Tor kudree), both of which are threatened Cyprinids. Data from fishermen in the area during the three year period of monitoring showed that an average of 0.5 to 2 kg of fishes is caught daily by each fisherman (exceptional catch of 10-20 kg also was reported). Therefore, the daily fish catch from the lake was found to be around 75 to 300 kg. Even if the total number of fishing days per month is fixed as 20, the monthly catch is 1500 to 6000 kg and the annual catch would be 18 to 72 tones. The previous calculation of annual fish catch was 12 tonne (Arun, 1999). Since fishes from Periyar Lake are a costly delicacy for diners at Hotels and Resorts in Kumily there is high demand on Periyar fishes in the township and fishing is becoming more and more intensive day after day in the Lake. Though, the fish catch is positively contributing to the removal of huge amount of nutrients from the Lake of both phosphorus and Nitrogen, the present trend of fishing if is continued, there is no doubt that all the endemic fish fauna of the Lake would become extinct very soon. Excessive removal fish fauna will have its deleterious impact on the general biology of the Lake ecosystem as a whole. This suggested the need of an integrated approach in wildlife management in reservoir or lake attached ecosystems in general.

Since it is a generally accepted fact that BOD of very clean waters will be <2 mgl^{-1} (Carvalho et al., 2002), Periyar waters with seasonal average of BOD ranging from 0.4 to 3.1 mgl^{-1} may be considered quite devoid of biodegradable pollutants. This is definitely owing to its position inside the undisturbed PTR.

However a general increase in BOD at station 5 during all seasons throughout the period of study evidence the impact of growing township on the waters.

Oil and grease leaked out from tourist boats was found to be the major pollutant in Periyar Lake. Baker (1971) reported a growth stimulation of phytoplankton following oil pollution. The impact of oil spill in Periyar Lake will also be assessed in the next part of this paper. However, there are reports on the impacts of oil on frogs and turtles following oil spill (Alexander et al., 1981). Oil pollution affects all aquatic organisms including aquatic birds. In birds oil pollution may cause mineral imbalances such as zinc deficiency, which can take the form of immune depression spanning multiple generations (Beach et al., 1982). Werner (1983) reported that an increased oxygen demand by the biological community, nutrient immobilization, a reduction in plant biomass accumulation and a heterotrophically dominated ecosystem as the general effect of oil pollution. There are many reports on the impact of oil on aquatic birds (Eppley, 1992; Warheit et al., 1996; Eppley and Rubega, 1996; Briggs et al., 1997; Neva, 2005). Toxicities of different oil components to freshwater organisms are well known (Bhattacharya et al., 2003). Chronic oil pollution is continuous and hard to track or clean up because it comes bit by bit and it is having a long-term negative effect on wildlife (Vince, 2006). Oil pollution of Periyar Lake, of course, has of chronic as well as acute impacts depending on the season and sites in the Lake. Oil and Grease were found on water surface throughout the Periyar Lake as constant broken film during the entire period of study. Since the seasonal average of Oil and Grease during the three year period of study was found varied from 110 to 2282 mgl^{-1} in the Lake, it is possible that organisms in the Lake may sustain numerous forms of physiological lesions after petroleum hydrocarbon ingestion, although they may not indicate, if any, outward signs of debilitation. Hence, the Lake with its rich endemic fish resources, which also indirectly supports the precious wildlife of the sanctuary and also of migratory water fowls, the impact of oil pollution would be catastrophic to the whole terrestrial and aquatic fauna of the region in the long run. Moreover, the Lake system offers a good chance of studying about all such impacts of oil pollution on phytoplankton, fish and other aquatic bio-resources. The leak out motor oil creates an oil slick on surface water. Loss of amenity value, when a water body is covered in oil can be enormous, and have huge repercussion on the tourist industry. The exchange of gasses across the air water interface is important in regulating concentration of various constituents of ecological and water quality concern (Rakesh and Effler, 2002). It is estimated that the used motor oil causes about 40% of the pollution in U. S. waterways (Paul, 2004). Since Periyar water is also a major recreational resource of tourists visiting the place and also the drinking water resource of hundred thousands of people in Tamil Nadu State, the impact of such pollutants on tourist industry in the future and health of huge mass of people in the long run also must be well examined. The oil content was directly related to intensity of boat activities and the impacts of oil spill in the Lake was found not restricted to the region of boat activity alone but extended throughout the Periyar Lake, several hundreds of meters inside the entire lake, even up to the core of the sanctuary area. There is no doubt that the wild animals which drink from the surface waters are continuously receiving a share of the oil film on surface waters at many points in the lake. Pug-marks of wildlife on oil covered banks are good evidences to the same (Figure 2). In general, the present findings point to those conflicts between internationally supported conservation efforts and economic needs of people of tropics in general.

At all Stations, the highest oil content was observed during the Pre-monsoon; the lowest amount during the northeast monsoon and moderate oil content during the southwest monsoon. Our observations during the three year period have shown that it is in the Pre-monsoon that many wild animals resort to the direct dependence on the main water body of the lake. The increasing accumulation of oil in surface waters during this season is therefore a serious threat to the precious wildlife. There is an urgent need to assess the impact of oil and grease on the endemic fish life in general and on the precious wildlife in the sanctuary in particular. Special emphasis must be given to study the impact of oil on the general health and reproductive biology of endangered wildlife including that of Tiger and Elephants. Therefore, the Periyar Lake offers a good model for studying some major issues of conservations of wildlife biologists in general.

Fig. 2. **Pug-marks of animals in the bank with surface water covered by oil**

The entry of pathogenic microorganisms into drinking, irrigation and recreational water resources poses a risk to human health. Entry of human pathogens into a wildlife sanctuary definitely is dangerous to the sustainable management and conservation of precious wildlife there. Difficulties and expenses involved in the testing for specific pathogens hazardous to humans have generally led to the use of indicator organisms of enteric origin to estimate the persistence and fate of enteric bacteria in the environment (Crane et al., 1981). Total *coliform* densities between 69 to 563 is acceptable for non-contact recreational use such as boating but contact recreation like swimming results in epidemiological outbreaks (Venkiteswaran and Natarajan, 1987). In general, the average seasonal MPN Faecal Coliform count in Periyar water ranged from 133 per 100ml to 2487 per 100ml, except once during Pre-monsoon of 2004, when the Coliform count was found zero at station 4b (major inlet). Count of *E. coli* was totally absent at station 4b during all the seasons. However, presence of Faecal *Coliform* in quite high numbers at this station, during southwest and northeast monsoons revealed that this station is also not safe from bacterial contamination.

E. coli was also common in sufficient numbers (18-467 per 100 ml) in most of the stations during all seasons. Fecal indicators are common in water samples from non agricultural or pristine water bodies because in the absence of controls even one rainfall event cause deterioration of quality for several months (Jameson et al., 2003). The main sources of Faecal Coliform in the Lake may include animal fecal matter, sewage inflow from Kumily Township into the lake at PLS-5, and direct human sources (tribal fishermen and officials living inside the systems). Animal fecal sources can be ignored because such Coliform bacteria in general are not hazardous to animals (Mubiru et al., 2000). But the presence of human sources of fecal bacteria (*E coli*) indicated the chance of spreading of human disease to precious wildlife in the system. Three years of regular monthly visits to the lake system enabled us to collect some other visible signs of tourist impact such as the use of the landing site as an open urinal by some visitors and also an open burning place of solid wastes including plastics. Wild Boars and the Bonnet Macaque were found many times searching the waste dumps near the tourist vehicle-parking site.

Washer men of Kumily Township were found regularly bringing in huge amount of cloths (mostly from the hotels and tourist resorts) to the lake and washing them in different spots in the Canals (near the Station-5). It is a well established fact that wide application of detergents leads to the accumulation of such compounds in water bodies and the environmental disturbances from such compounds induce changes in the structure and function of biological systems (Issa and Ismail, 1995). In the literature we find reports of diverse toxic effects of detergents on different components of aquatic systems (Solovera et al., 1980; Goebel et al., 1981). The detergent influence on aquatic micro flora and fauna in general, may be inhibitory or stimulatory. Yamane (1984) reported that washing agents have an inhibitory effect on algal growth. Adam et al. (1990) and Mohammed et al. (1990) reported that detergents have a stimulatory effect on algal growth. The degree of addition of detergents in to the system at present may not be severe enough to cause pollution form such compounds to affect the biological systems of the lake, but when considering the tourist boom at present and that would happen during future years, the continuous impact would be tremendous. Moreover the chronic impact of detergent compounds on the health and reproductive biology of wildlife is yet to be understood in detail. All these observations point to measures required in tropical sanctuaries in general to keep safe wildlife from human impact.

CONCLUSIONS

In order to ensure sustainable management and optimum exploitation of the aquatic resources, it is necessary to set specific limits for the pollution impact indicators in each individual system and also continuous monitoring of all of them. The goal of all types of monitoring programs shall be the protection of the environment and its resources. Data collected from monitoring programs documents existing conditions, and helps document changes in these conditions over time. Lacking prior knowledge of environmental conditions, monitoring establishes a baseline for future comparisons. The study of nutrient status, primary productivity and pollution status in Periyar Lake showed that, in general, pre-monsoon is the season at which nutrient parameters exceeded the limits of standards (Oligotrophic to Eutrophic) and the monsoon periods, especially the southwest monsoon, is the season of highest fluctuations in nutrient content over years and across different stations in the Lake.

Excessive amount of oil and grease on surface waters were the conspicuous anthropogenic impact from tourism inside the Lake, which is controllable. The low nutrient status and low BOD of Periyar Lake waters proved that, in general, water bodies situated inside undisturbed watersheds such as wildlife sanctuaries have high resilience to disturbance. Therefore, keeping watersheds around reservoirs as wildlife sanctuaries is a safe form of conservation of both aquatic and terrestrial life. However, evidences of pollutions at certain locations suggested that, in the absence of proper care and monitoring, tourist boat activities and leaching of nutrients or wastes from the adjacent townships of the Lake may harmfully affect the waters. Therefore, conservation efforts in wildlife reserves around reservoirs shall include not only the wild flora and fauna of the land systems, but also of the aquatic resources as well; because both the watersheds and water resources in such places represent one integrated system. Careless management of aquatic resources may ultimately collapse the stability of the precious wildlife in the associated terrestrial systems.

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