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Limnological variation of three lagoons: a case study from a Ramsar Wetland in Sri Lanka

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Abstract

The objective of the present study was to compare the temporal changes of key limnological parameters of the major lagoons {Malala (650 ha), Embillakala (450 ha) and Bundala Lewaya (550 ha)} in the Bundala National Park (first Ramsar wetland in Sri Lanka). Key limnological parameters have been studied over 12 months in temporal and spatial scale (December, 2000 – December, 2001). All the analyses were carried out according to the standard methods described elsewhere. Water level, drainage systems, magnitude of the forest patches, sediment loading, sediment retention, salinity, micronutrient levels and turbidity have rendered a unique ecological identity to each lagoon. Malala and Embillakala lagoons underwent oligohaline (0-10 ppt), estuarine (10-30 ppt) and euhaline (30-40 ppt) phases while Bundala Lewaya underwent estuarine and, euhaline and hyperhaline (>40 ppt) phases during the study period. Chlorophyll a and GPP (Gross Primary Productivity) level also vary among lagoons indicating upstream biological changes. Bundala Lewaya was less productive than other two lagoons indicating the disruption of the ecological integrity. Zooplanktons have showed marked differences of their abundance and composition at temporal and spatial scales. Copepods were dominating in all three lagoons. Copepod abundance was not correlated with any of the parameters studied indicating their puzzling behavior in the lagoons. Correlation analysis showed the complex relationship between physicochemical parameters and biological characters of each lagoon. This study has noted the significant differences of the physico-chemical parameters and zooplankton abundance among the lagoons within the same landscape indicating the requirement of precisely planned management strategy for each lagoon.

Introduction

In coastal wetlands, lagoons play the dominant role in functioning of wetland systems (Leonel and Henrique, 2001). Coastal lagoons, situated between land and the sea, are influenced by both adjacent marine and terrestrial environments.

Comparisons of temporal variations and spatial variations of various physico-chemical parameters in lagoons with a special reference to biological parameters acquired a better understanding of wetland systems (Ramsar Convention Bureau, 1997; Konstantinos, 2001; Blomqvist, 2001; Leon, 2001).

Bundala National Park was the first Ramsar wetland in Sri Lanka and acquired the Ramsar status in 1993 and it has been recognized as a key habitat for migratory waterfowl (Benthem, *et al*, 1993; Ramsar Convention Bureau, 1997). Generally climate of the park area can be considered as hot and dry (Benthem *et al*, 1993). Maha Lewaya (260 ha), Koholankalala (390 ha), Malala (650 ha), Embillakala (430 ha) and Bundala Lewaya (520 ha) are shallow brackish water lagoons (figure 1). In wetlands located in arid areas biodiversity was underestimated and receive less attention by limnologists & conservation organizations (Brendock & Williams, 2000). Although wetlands in dry lands are an important, valuable and interesting component of global water resources, there are no comprehensive texts are available on ecology of wetlands in dry lands. Failure to recognize the biodiversity of wetlands in dry lands and their conservation needs may result in extinction of many species (Brendock & Williams, 2000). Previous investigations have reported some hydrological and biological characters such as salinity, conductivity, nitrate levels and pH in Bundala lagoon systems (Jayakody and Jayasinghe, 1992; Benthem et al, 1993; Jayawardhena, 1993). However, the study of spatial and temporal variations of ecological characteristics of Bundala water bodies has been largely neglected. Insufficient data describing water bodies of Bundala National Park on the basis of identifying seasonal variations and relationships with the biotic community may critically influence the conservation and management programs. The objectives of the present study were to investigate the general limnological characteristics of Bundala Lewaya, Malala lagoon and Embillakala lagoon. Present study focused on Malala lagoon, Embillakala lagoon and Bundala Lewaya since they are a good representation of aquatic ecosystems in Bundala National Park. In this study we showed the temporal changes of the limnological characters of each lagoon. Lagoons showed a distinct ecological identity in relation to limnology though they are in the same landscape.

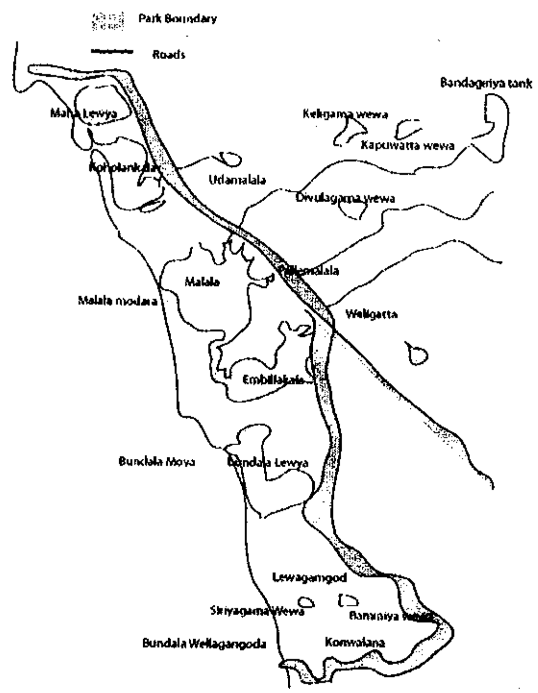

Figure 1 - A schematic diagram indicating important water bodies of Bundala National Park and its surroundings

Methodology

Study period and sampling criteria

Sampling criteria was designed based on the information collected in the preliminary investigation carried out during August 2000 to November 2000 in Malala, Embillakala and Bundala lagoons. Detailed survey was started in December 2000 and has been continued up to December 2001. Random sampling was carried out to find out zooplankton composition of lagoons. Spatial variation of physico-chemical parameters and key zooplankton species were studied along the transects. Data were collected on weekly basis in each lagoon. Each lagoon was visited four times per month for data collection. Weekly data of each month were pooled and presented on monthly basis.

Selection of transects and random sampling sites

Each lagoon was divided into hundred parts on a map. Each part was approximately equal in size. Twenty-four sites were selected from each lagoon using a table of random numbers. Random sampling was carried out at these predetermined sites.

It was hypothesized that the salinity may vary from the land end of the lagoons towards the sea. A transect was selected from the north to the south of Malala lagoon (towards the sand bar). The approximate length of the transect was 2.5 km (figure 2). The distance between two sampling sites was approximately 200-250 m along the transect. In Embillakala lagoon a transect of 1.6 km in length was also selected from the north to the south (figure 2). Ten sampling sites were established approximately at 160 -200 m distances from each other. In Bundala Lewaya approximately 1 km long transect was laid towards the sand bar (figure 2) and ten sampling sites were established approximately at 100 -150 m distances from each other. Also note that the transects were laid down on the midline of each lagoon. At each sampling site, water samples were collected at sub-surface level (since the lagoons were shallow water bodies) by using cleaned 1L plastic bottles, standard plankton nets and Eikmann grab, to analyze physico-chemical parameters and biological parameters.

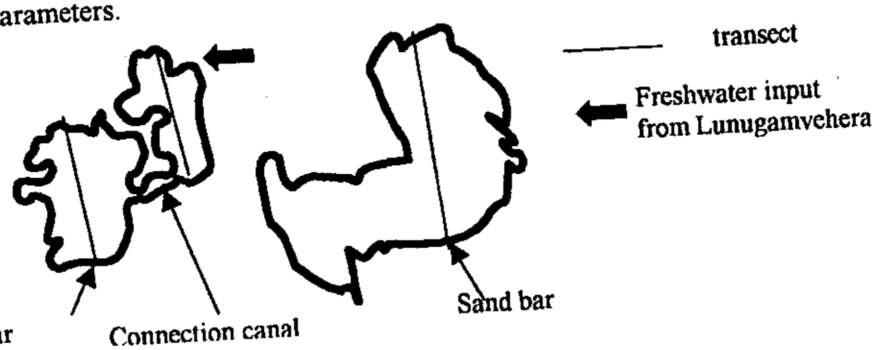

Figure 2 - Schematic diagram indicating the study transects in Malala, Embillakala and Bundala Lewaya.

Physical measurements

Schematic diagrams were drawn to resolve the physical characters of lagoons such as lagoon area, lagoon perimeter and distribution of aquatic vegetation. Original maps were modified after Benthem *et al* (1993), as it existed during study period. Descriptive physical characters of the surroundings of lagoon were investigated by paddling a small canoe along the perimeter and along transects of Malala and Embillakala lagoons. Bundala Lewaya was investigated by walking along the perimeter and the selected transect. Forest cover was mapped by paddling a small canoe along the perimeter of Malala and Embillakala lagoons and by walking along the perimeter of Bundala Lewaya. Forest cover was estimated as the % of covered perimeter of each lagoon. Distribution of aquatic macrophytes was mapped by paddling a small canoe along the perimeter and the indicated transects of Malala and Embillakala lagoons and by walking along the perimeter and the selected transect of Bundala Lewaya. Aquatic macrophyte cover was considered high if % area covered by vegetation was over 30 % of the total lagoon area. Aquatic macrophyte cover was considered low if % area covered by vegetation was lower 5 % of the total lagoon

area. Each lagoon was divided into five parts as central, north, south, east and west. If the equal % of aquatic macrophyte cover encountered in each portion, distribution of aquatic macrophyte was considered random.

Physico-chemical parameters

Water quality assessments were carried out using standard methods mentioned elsewhere (Wlison 1973; Mackereth *et al.*, 1989; Jacqueline & Edmudson, 2000) and the laboratory analysis were carried out at the Department of Zoology, University of Ruhuna, Matara. Three samples were taken for each parameter at each sampling site along the transects, at a one particular sampling occasion.

Biological characters

Zooplanktons were sampled using standard plankton nets with mesh sizes 0.14mm and 0.3mm. Filtered zooplankton were fixed with 70% alcohol and later subjected to microscopic investigations. Identifications zooplanktons were made using standard taxonomic keys (Fernnado, 1972; Harding and Smith, 1974; Abeywickrama, 1979; Abeywickrama, 1986; Pennack, 1989; Fernando, 1990). Zooplanktons were enumerated using Sedgwick rafter cells using 3 sub samples (1ml for each) of each sample (10ml).

Statistical analysis

Three sampling replicates were taken for each parameter at each site. Mean value of each parameter has been calculated. Mean values were compared using the statistical package SPSS version 10. Pearson correlation coefficient and levels of significance were calculated using SPSS version 10 in order to find out correlations among physico-chemical parameters and abundance of key zooplankton species (Christina, *et al.*, 2000). Monthly variations of each parameter were compared by ANOVA using SPSS version 10 statistical packages.

Results

Lagoon morphology

Water volume, water depth, sediment thickness, forest cover, size of the buffer zone and nature of the lagoon perimeter, water inlets, water outlet, macrophyte coverage showed features specific to each lagoon (Table 1). The channel connecting Embillakala and Malala lagoon was approximately 2.5 km in length and maximum width of 6 m. Margins of this channel were infested by diverse group of aquatic macrophytes predominated by *Typha* sp. Many crocodile nests were found on either side of the banks of the channel. Many bird species forage and rest along the banks of the canal (detailed data not presented).

Table 1 - Comparison of various physical factors of Malala, Embillakala & Bundala Lewaya

Physical factor	Malala	Embillakala	Bundala Lewaya
Maximum perimeter* (km)	5-6	4-5	4
Mean Depth* (m) (± SEM)*	3.5 ±1.3	1.5 ± 0.5	0.5 ± 0.08
Mean Sediment thickness* (cm) ± SEM	102 ± 28.2	78 ± 2.3	40 ± 2.1
Abundance and Distribution of aquatic macrophytes*	30% Random/ relatively high	40% Random/ relatively high	No significant occurrence
Forest cover (Approximately)	Almost total perimeter covered	¾ perimeter covered	½ perimeter covered
Fresh water inlets	Via Embillakala, Malala Oya, Weligatta Ara	Lunugamwehera	No specific inlets

*According to the data collected in the preliminary investigation

Lagoon water quality along studied transects

Mean values of the each studied physico-chemical parameter in three lagoons for each month are given in bar diagrams. In July 2001, Bundala Lewaya was not sampled because it was dried up.

Three lagoons underwent gradual as well as drastic changes of the water depth during the study period (figure 3). The amount of suspended solids gradually increased in Malala and Embillakala lagoons during the study period while Bundala Lewaya comprised a low level of suspended solids (figure 4). In December 2000, mean dissolved phosphate levels significantly differed in the three lagoons (F=12.3, p<0.05). In December 2000, when Embillakala and Malala lagoons contained a big volume of water, dissolved phosphate level was very high (varied between 240 - 508µg/l and 134 – 167µg/l in Embillakala and Malala lagoons respectively). In November and December 2001, dissolved phosphate level was high in Bundala Lewaya (varied between 163.4 – 206.4 µg/l). In February 2001, dissolved phosphate levels of Malala and Embillakala lagoons (respectively 75 - 119µg/l and 40 - 201µg/l) reached to the level of Bundala Lewaya indicating that reduction of water volume played a significant role in terms of dissolved phosphate level. But in Bundala lewaya factors other than water volume might have an effect in determining the dissolved phosphate level (figure 5).

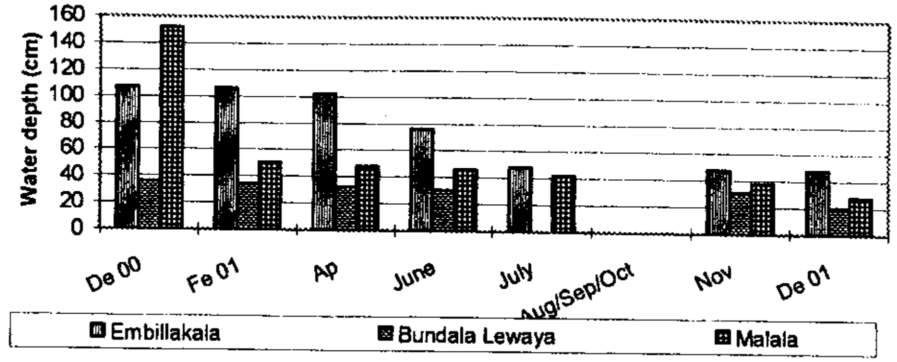

Figure 3 - Variation of monthly mean water depth recorded in the three lagoons during study period. (De00-December 2000, Fe 01 -February 2001, Ap-April 2001, June- June 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December 2001).

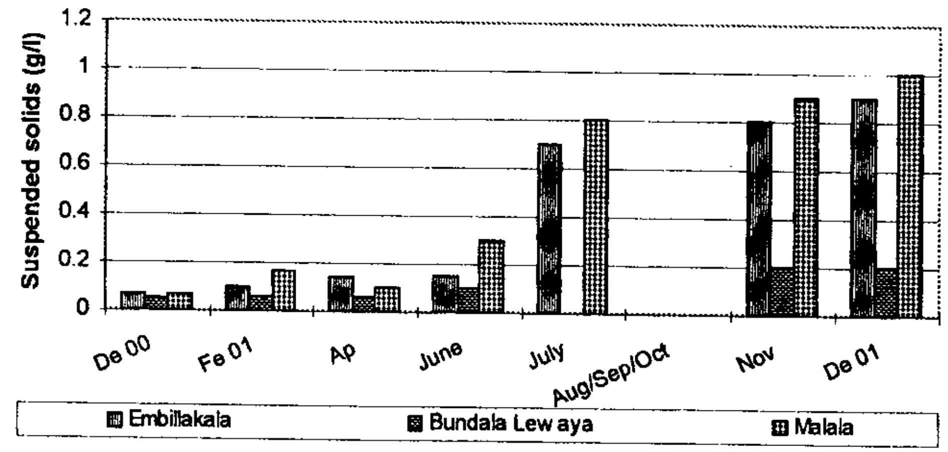

Figure 4 - Variation of monthly mean suspended solids of three lagoons during study period. (De00-December 2000, Fe 01 -February 2001, Ap-April 2001, June- June 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December 2001).

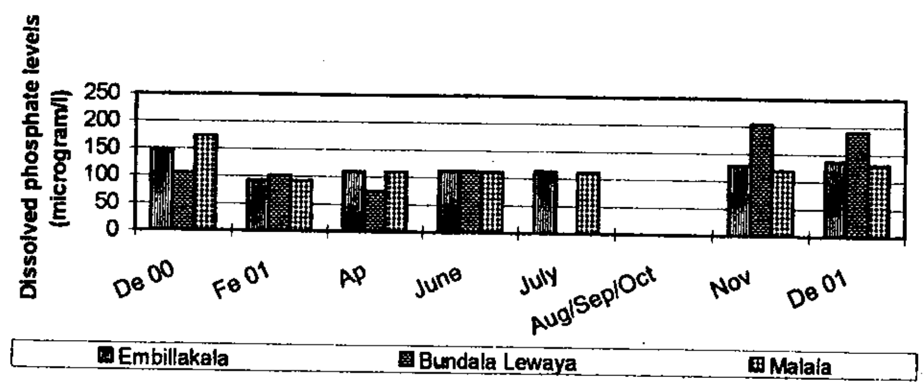

Figure 5 - Variation of monthly mean dissolved phosphate levels recorded in the three lagoons during study period. (De00-December 2000, Fe 01 -February 2001, Ap-April 2001, June- June 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December 2001).

Water nitrate level was very high (178 - 584μg/l) in Bundala Lewaya when compared with Malala (203 - 271μg/l) and Embillakala (221 - 331μg/l) lagoons indicating an unseen nitrate source. With the reduction of water volume in February 2001, water nitrate level reduced in Malala and Embillakala lagoons. In Embillakala and Malala lagoons, almost similar fluctuations of water nitrate level had been noted (figure 6). Dissolved oxygen level of Bundala Lewaya was low (1.2 – 9.3 mg/l) during study period when compared with other two lagoons. In Malala lagoon and Embillakala lagoons, DO level was high (10-15 mg/l) (Data not shown).

In Malala and Embillakala lagoons, salinity ranged (0.5-1 ppt) in December 2000 and was significantly increased in February 2001($F=8.26$, $p<0.05$) and from April 2001 gradually increased significantly ($F=14.2$, $p<0.01$). In December 2000 mean salinity of Bundala Lewaya was about 15 ppt and significantly increased throughout the subsequent months up to 41 ppt in June 2001 ($F=23.1$, $p<0.01$). Following the drought from November 2001 and December 2001 the mean salinity further increased up to 42 ppt (figure 7).

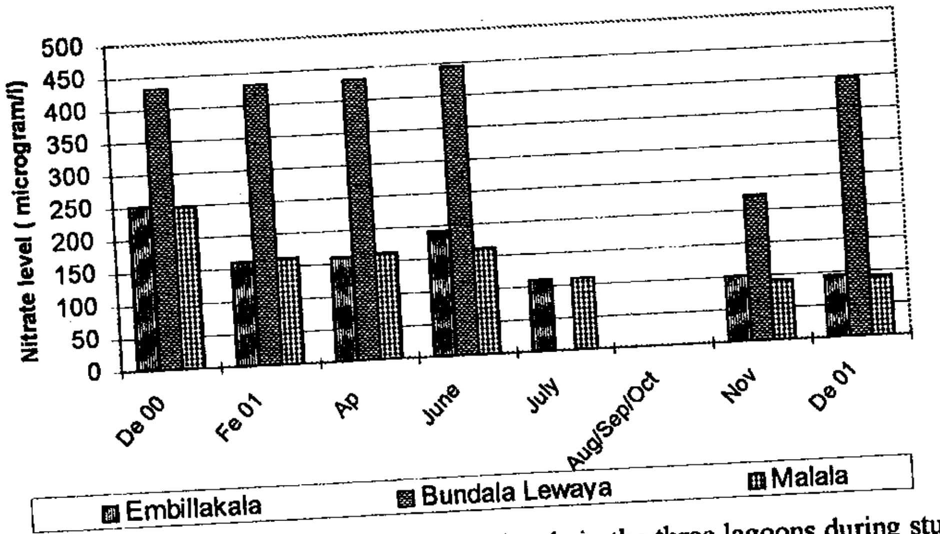

Figure 6 - Variation of monthly mean nitrate levels in the three lagoons during study period. (De00-December 2000, Fe01-February 2001, Ap-April 2001, June-June 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December 2001)

In Malala and Embillakala lagoons, mean water temperature remained just below 29°C but in Bundala Lewaya, it was around 31°C and increased up to 31.8 °C in December 2001 (data not shown). Total alkalinity varied significantly in Bundala Lewaya when compared with the other two lagoons ($F=8.6$, $p<0.01$). Malala and Embillakala lagoons showed almost similar levels of variation in total alkalinity during the study period (Data not shown.).

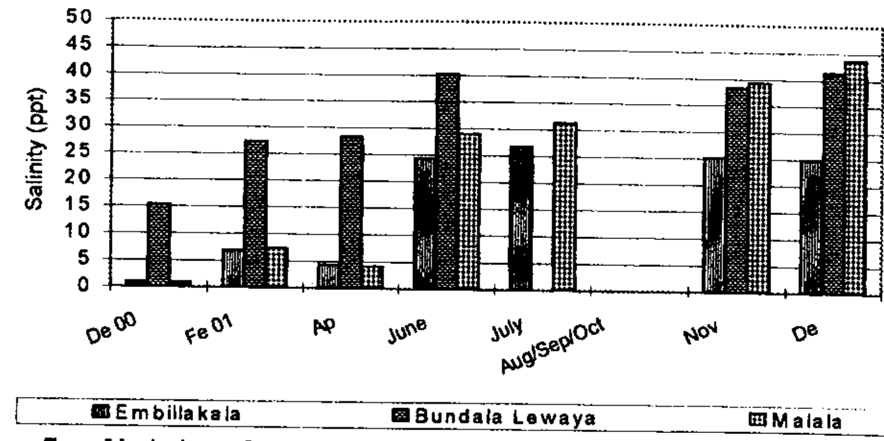

Figure 7 - Variation of monthly mean salinity recorded in the three lagoons during study period. (De00-December 2000, Fe01-February 2001, Ap-April 2001, June-June 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December 2001)

Key biological characters of lagoons

Chlorophyll a, Gross Primary Productivity and Zooplankton

In Embillakala and Malala lagoons mean Chlorophyll a concentrations vary in a similar way. As water level reduced, chlorophyll a level also reduced. Bundala Lewaya contained a low level of Chlorophyll a (0.01 – 0.09μg/l) during the study period (figure 8). Variation of monthly mean Gross Primary Productivity among lagoons significantly changed during the study period (figure 9).

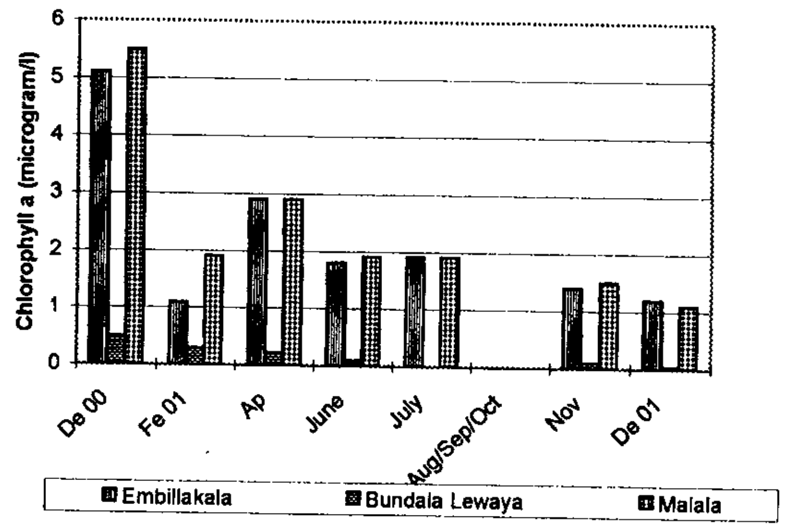

Figure 8 - Variation of monthly mean Chlorophyll a recorded in the three lagoons during study period. (De00-December 2000, Fe01-February 2001, Ap-April 2001, June-June 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December, 2001

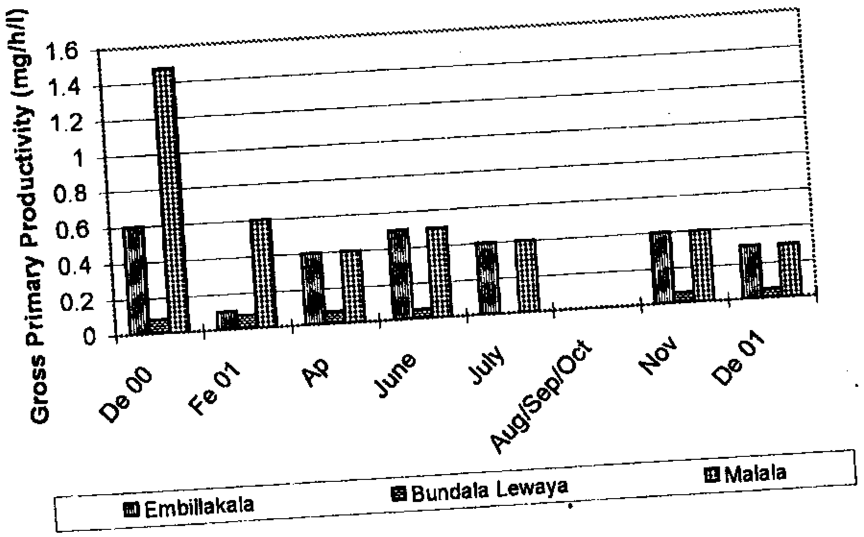

Figure 9 - Variation of monthly mean Gross Primary Productivity recorded in the three lagoons during study period. (De00-December 2000, Fe01-February 2001, Ap-April 2001, June-June 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December, 2001

Zooplankton

In average, copepods dominated during the study period in the three lagoons (figures 10, 11 and 12). Copepods were the most abundant zooplankton group in Malala lagoon during the study period (Mean density 86.5 ± 4.6) and Embillakala lagoon and Bundala Lewaya accommodated mean densities of copepods as 17 ± 2.2 and 78.2 ± 4.3 respectively. *Pseudodiaptomus annendalei* (Sewell, 1919), *Acartiella minor* (Sewell, 1919), *Helidiaptomus* sp. (Kiefer, 1932), *Microcyclops varicans* (Sars, 1863), *Eudiaptomus* sp. (Kiefer, 1932), *Cyclops minutus* (Claus, 1857), copepodites and copepod nauplii were recorded in all three lagoons. Analysis of variance showed that temporal variation of abundance of zooplankton taxa significantly differs in each lagoon (F=14.6, p<0.01). Bundala Lewaya showed the most prominent seasonal changes of abundance of zooplankton taxa when compared with other two lagoons (F=10.6, p<0.001).

In Embillakala lagoon no parameters were found significantly correlated with Chl a. In Embillakala and Malala lagoons rotifer abundance were negatively correlated with alkalinity and temperature. Copepod abundance was not correlated with many of the parameters except pH in Embillakala lagoon.

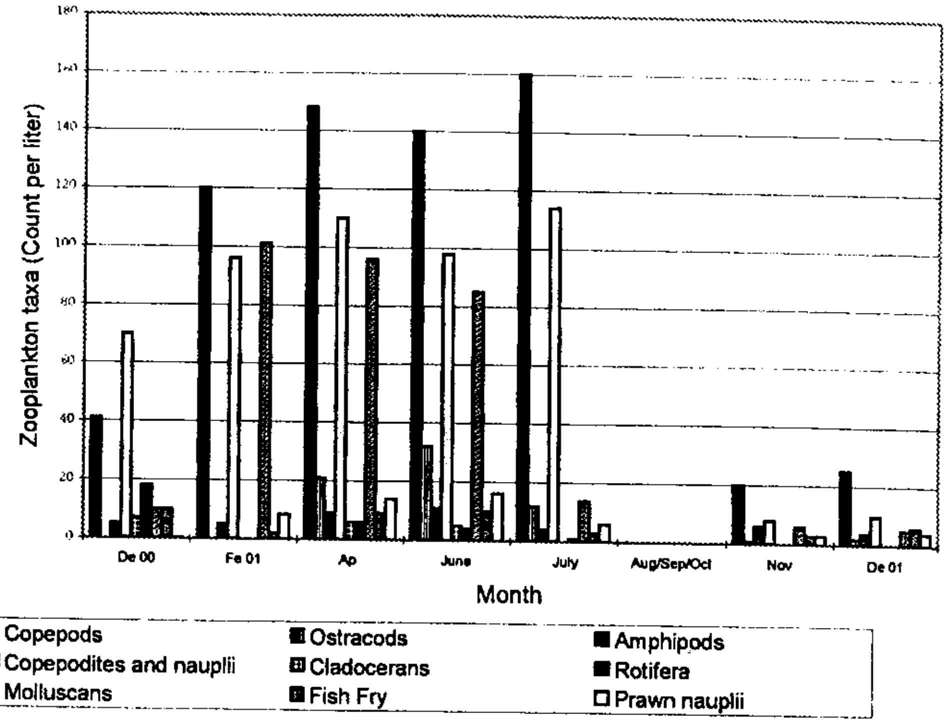

Figure 10 - Monthly variation of the density of major zooplankton taxa in Malala lagoon during study period. (De00-December 2000, Fe 01- February 2001, Ap-April 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December 2001)

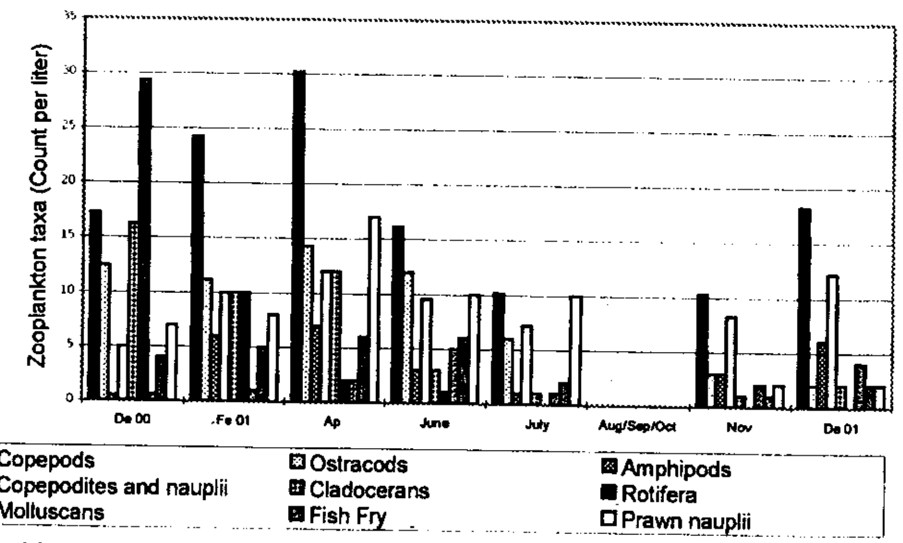

Figure 11 - Monthly variation of the density of major zooplankton taxa in Embillakala lagoon during study period. (De00-December 2000, Fe 01- February 2001, Ap-April 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December 2001)

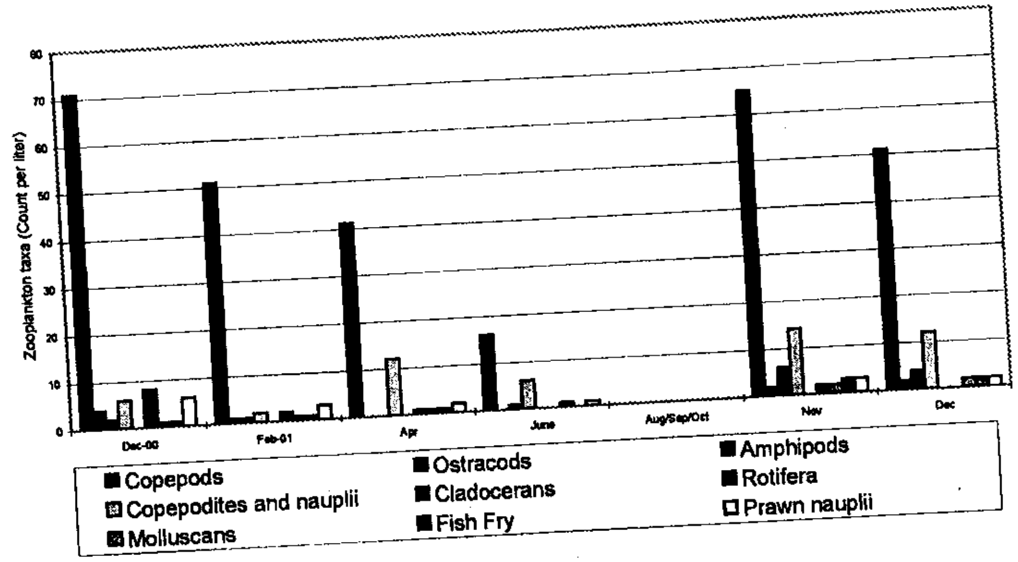

Figure 12 - Monthly variation of the density of major zooplankton taxa in Bundala Lewaya during study period. (De00-December 2000, Fe01-February 2001, Ap-April 2001, June-June 2001, July-July 2001, AugSepOct-August, September, October 2001, Nov-November 2001, De-December 2001)

Discussion

It has been shown that healthy aquatic environments have a dense forest cover (Prakash *et al*, 1999). A dense forest cover environs Malala lagoon, Bundala Lewaya and Embillakala lagoon at least in some parts. This may indicate the importance of Malala, Embillakala lagoons and Bundala Lewaya for wild life survival. People claimed that diminishing biodiversity in Bundala Lewaya was caused after the onset of release of saltern effluents into the Bundala Lewaya (Personal communication with neighbors).

Correlation among various physico- chemical parameters and zooplankton abundance

Present study reveled correlation among various physico-chemical parameters and zooplankton abundance indicating the complex behavior of each lagoon (table 2).

Table 2 - Correlation among several physicochemical parameters and zooplankton abundance

Lagoon	**Parameter**	**Negatively correlated**	**Positively correlated**
Embillakala	Salinity	Depth, Secchi depth, Rotifer abundance	PH, Alkalinity, Temperature Amphipod abundance
Bundala Lewaya		DO, GPP, Chl a, Rotifer and pre nauplii abundance	Temperature
Malala lagoon		Nitrate level, DO, Suspended solids, Chl a, Rotifer abundance	Alkalinity, Temperature
Embillakala	Depth	Secchi depth, DO, Abundance of ostracods and pre nauplii	Alkalinity, Suspended solids
Malala		PH, Alkalinity	Nitrate level, DO, GPP, Chl a Ostracods and Cladoceran abundance
Bundala lewaya	Nitrate	Amphipod, pre nauplii	
Embillakala			Chla, Ostracods, rotifers, molluscs
Malala			DO, GPP, Chl a and rotifer abundance
Bundala Lewaya	Dissolved phosphate		Suspended solids, amphipod abundance, mollusca abundance
Malala lagoon		Odstracod and pre nauplii abundance	
Bundala Lewaya	Chl a		Temperature, DO, GPP, Rotifer abundance

It has shown that neighboring lagoons are similar in species composition (Suarez, *et al* 2001). Although species composition was more or less similar in three lagoons, present study revealed that monthly variation of the physico- chemical parameters and key biological features of lagoons are not similar even though they located in the wetland ecosystem. This may indicate the habitat heterogeneity of Bundala lagoons. Distribution and abundance of organisms seems to be primarily determined by the salinity (Thomas, 2002). Research has shown that community structures did not significantly change even when DO, pH, temperature changed significantly, but community structure significantly changed in response to salinity changes (Thomas, 2002). Malala and Embillakala lagoons had the highest Chl a and Gross Primary Productivity indicating highest phytoplankton biomass (Sevim, 2002) while Bundala Lewaya recorded a low Chl a content indicating its low productivity. Although the Bundala Lewaya contained higher nutrient loading, productivity was low indicating an unseen relationship (Sevim, 2002).

Aquatic macrophytes covered a relatively large area in Embillakala lagoon where Lunugamvehera water enters. This may be due to nutrient input via Lunugamvehera water. Previous workers have shown the correlation of nutrient input and aquatic macrophyte density (Havens, *et al*, 2001).

Varying Secchi depth values indicated the temporal change of trophic staus index in each lagoon (Halina and Ryszard, 2002). Aquatic macrophyte distribution in a water body may indicate the expansion of littoral zone (Sanei, *et al*, 2000). According to the physical conditions of Malala and Embillakala lagoon it was clear that some aquatic macrophytes emerged close to middle of water bodies indicating the expansion of the littoral zone towards the middle of the water body. On the other hand, although a shallow watershed, lack of vegetation in Bundala Lewaya indicated its diminishing productivity. Lack of water inputs has been blamed for the low productivity and low water in lagoons (Lewis, 2000). However, Bundala Lewaya harbored the highest density of copepods when compared with other two lagoons. Based on the classification described Francisco and Barry (2003), Malala and Embillakala lagoons underwent oligohaline (0-10 ppt), estuarine (10-30 ppt) and euhaline (30-40 ppt) phases while Bundala Lewaya underwent estuarine and, euhaline and hyperhaline >40 ppt phases. As pointed out earlier, in certain periods Malala and Bundala Lewaya experienced euhaline and hyperhaline conditions. These abrupt changes of salinity might alter the trophic status of the ecosystem (Patricia, 2000). Sudden death of algal mats in littoral area of lagoons has been reported previously owing to increased salinity and affected many organisms unfavorably (Patricia, 2000). This phenomenon was obvious in Malala and Embillakala lagoons and Bundala Lewaya. Some studies have shown the different rotifer and cladoceran species corresponding to distinct environmental conditions (Branco *et al*, 2002). Water depth would not be a major factor in determining the ecological conditions in Bundala Lewaya since depth of water body was very low during study period. Some studies have shown the relationship of nutrient availability and abundance of different zooplankton taxa (Conde-Porcuna, 2002). Copepods were abundant during the study period indicating their wide range of tolerance to varying environmental parameters.

The increased turbidity of water could be primarily attributed to the low water depth and lack of aquatic vegetation and low water levels have been known to increase the sediment resuspension (Roozen, 2003). Malala lagoon, Embillakala lagoon and Bundala Lewaya can be considered as turbid lagoons. Decreased Secchi depth values accompanied with increased suspended solid levels may be due to the extreme

reduction of water volume during latter part of the 2001. This would have also been triggered by the degradation of aquatic plants during that period.

Bundala Lewaya would have been subjected to several changes of its water chemistry due to the intermittent flow from Bundala saltern area. Advantages or disadvantages of this intermittent mix of Bundala Lewaya with saltern effluent have not been addressed yet. Probably it may have profound effects on the system according to the historic records (personal communication with inhabitants, saltern workers, wild life staff and scientists).

According to the results Malala lagoon, Embillakala lagoon and Bundala Lewaya performed in a similar way during December 2000 to January 2001. After the removal of sand bar Malala lagoon and prolonged drought conditions affected Malala and Embillakala differently (Chandana, 2004). Bundala Lewaya lagoon was less influenced by freshwater and was functioned in a different manner compared to Malala lagoon and Bundala Lewaya. Further monitoring of lagoon water quality and biology is required prior to the establishment of proper management programs.

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