Short communication**Physicochemical environment of Malala Lagoon in Southern Sri Lanka**L.P. Titus^{1*}, K.H.M. Ashoka Deepananda² and P.R.T. Cumararatunga²¹ Marine Environment Protection Authority, No. 758, 2nd Floor, Baseline Road, Colombo 09, Sri Lanka² Department of Fisheries and Aquaculture, Faculty of Fisheries and Marine Science & Technology, University of Ruhuna, Matara, Sri Lanka* Correspondence (lankatit@gmail.com) <http://orcid.org/0000-0003-2950-9970>

Abstract Malala Lagoon is the largest of the five enclosed shallow lagoons in Bundala National park, and is one of the most productive of the fifteen lagoons in the Hambantota district, Sri Lanka. It has been vulnerable to human induced pollution for nearly three decades. This paper ascertains the status of physicochemical environment of the lagoon and its temporal variation from 1995 to 1997. During the study period physicochemical and biological parameters measured in Malala lagoon were water temperature, pH, conductivity, Secchi depth, dissolved oxygen, salinity, total alkalinity, dissolved phosphate, and chlorophyll-a, and their mean values were; $27.69 \pm 1.62^{\circ}\text{C}$, 7.93 ± 0.46 , 5.14 ± 3.88 mS/cm, 0.39 ± 0.19 m, 7.83 ± 0.89 mg/L, $2.18 \pm 1.61\%$, 2.14 ± 0.59 mmol/L, 12.25 ± 4.67 $\mu\text{g/L}$ and 8.86 ± 4.62 $\mu\text{g/L}$ respectively. Maximum depth of the lagoon rarely exceeded 2 m during the study period. Due to the shallowness of the lagoon, there were no significant differences ($p > 0.05$) in physicochemical parameters of surface, middle and bottom layers of the water column. Water level of the lagoon showed a significant ($p < 0.01$) negative correlation with electrical conductivity ($r = 0.727$) as well as with the salinity ($r = 0.729$). Water influx to the lagoon showed a significant ($p < 0.05$) negative correlation with conductivity ($r = 0.454$) and salinity of the lagoon ($r = 0.406$). Findings of the study are compared with those carried out over a decade to explore and elucidate the long term changes in the lagoon environment. When compared with the published data from preceding and subsequent studies, it confirmed that the brackish water characteristics of the lagoon are gradually degrading due to pollution caused by natural phenomena and anthropogenic activities adversely affecting the ecological balance and the productivity of the lagoon. These findings could be of great importance when studying long term changes in the coastal waters, which are essential for sustainable coastal planning, with respect to socioeconomic development programmes as well as to identify the impacts of Hambantota port and maritime activities in the area and to understand the trends related to global climate change.

Keywords: Lagoon ecosystem, Pollution, Irrigation influx, Desalination, Nutrient loading**INTRODUCTION**

Malala lagoon (650 ha), which is located in close proximity to Hambantota commercial port, is the largest of the five shallow lagoons in the Bundala National Park (Fig. 1). After the completion of the Kirindi Oya Irrigation and Settlement Project (KOISP), large scale discharges of agricultural water resulted in a drop in salinity to 1-7‰ (Jayakody and Jayasinghe 1992; Cumararatunga and Titus 1998), collapsing the prawn fishery of the lagoon (Matsuno et al., 1998; Kularathna,

1999; Amarasinghe et al., 2002) and causing a significant negative impact on the economically important finfish and shellfish species, including *Caranx sexfasciatus* and *Scylla serrata* (Cumararatunga et al. 1996; Kularathna 1999; Amarasinghe et al. 2002).

Excessive usage of agrochemicals and fertilizer by growing number of farmers in Lunugamvehera and Weheragala irrigation schemes over two decades increased annual drainage discharges with heavy loads of nutrients and biocides to Malala and Embilikala lagoons increasing the toxicity of

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lagoon water (IWMI 1999; Piyankarage et al. 2002; Abeywickrama 2010; Deepananda et al. 2011). Recently implemented land and maritime based infrastructure development projects in the area may also increase the pollution threat. This may alter the ecological balance of the lagoons, which warrants the need for periodical monitoring of the physicochemical environment of the lagoon to ascertain short term and long term variations. Furthermore, torrential rain and massive floods in 1999 and 2000, and Tsunami in 2004 have caused remarkable physical damage to the lagoon (UNEP 2005) resulting in a series of short and long term changes in the lagoon environment, affecting the ecological balance (Abeywickrama 2010). In this context, a thorough understanding of temporal variations in physicochemical parameters of the Malala lagoon is a prerequisite and would be of tremendous importance for all those who are interested in upgrading and implementing management plans. Thus, present study aimed at ascertaining the status and temporal variation of physicochemical environment of the Malala lagoon during 1995-1997, in order to compare those with published literature.

Fig. 1 Map of the study area, showing Malala and Embilikala lagoons. Inset shows the study area in Sri Lanka.

MATERIALS AND METHODS

Seasonal variation of depth, Secchi depth, temperature, conductivity, pH, salinity, alkalinity, dissolved oxygen, dissolved phosphate, and chlorophyll-a content in Malala Lagoon was studied from August 1995 to October 1997. Sampling was done at fortnightly intervals throughout the study period at around 9.00 a.m. Data on rainfall, air temperature, wind speed and tide in Malala region were obtained from the Department of Meteorology and the information on water quantities released through the right-bank channel of Lunugamwehera reservoir to Malala Lagoon was obtained from Irrigation Department. Water level and Secchi depth transparency (Golterman et al. 1978) were measured using a simple depth gauge and a black and white Secchi disk with a diameter of 25 cm respectively. A plastic Ruttner sampler (1 L) was used to collect water samples from three different levels of the water column (surface, middle, and bottom). Temperature, conductivity and pH were measured *in situ*, using a mercury thermometer, an 'Orion' conductivity meter and an 'Orion' pH meter, respectively. Water samples were collected in plastic bottles and transported under chilled conditions for laboratory analyses, wherever necessary. Dissolved oxygen was determined using Winkler method (Strickland and Parsons 1972) for which samples were fixed on site, while salinity was determined by titrating with 0.025 M AgNO_3 solution (Strickland and Parsons 1972). Total alkalinity was determined titrimetrically as described by Mackereth et al. (1978). Dissolved phosphate content was determined using a CECIL spectrophotometer at 750 nm wavelength (Strickland and Parsons 1972). Chlorophyll-a content was determined by filtering 250 ml of water through a GFC millipore filter paper and pigments were extracted in 80% ethanol. Absorbance was measured using CECIL spectrophotometer at 668 nm and 750 nm wavelengths (Vollenweider 1974).

Statistical analysis was carried out using SPSS software package (version 21).

RESULTS

Seasonal variation of climatic and hydrological parameters

The climatic conditions within the geographical area, where Malala lagoon is located, and hydrological parameters of the lagoon water showed temporal variations, even though maximum depth of lagoon was rarely exceeded 2.0 m (Fig. 2). Temporal variation in influx of irrigation water; water level, Secchi depth, water temperature and pH in Malala lagoon and the fluctuations in air temperature, wind speed, rain fall and tide levels in Hambantota are shown in Fig. 3.

Fig. 2 Depth profile of Malala Lagoon at 0.5m equidistance in May 1997.

Mean air temperature in Hambantota district through the study period was 27.7 ± 0.68 °C. The highest air temperature of the area (29.4°C) was recorded in January 1997, while the lowest (26.6 °C) was recorded in December 1995 and January and December 1996, which were during the North-East monsoon period (Fig. 3A). Mean ($\pm$ SD) wind speed at Malala area was 21.15 ± 7.78 km/h, showing the highest value of 50.8 km/h in February 1996. During the North-East and South-West monsoonal periods, wind speed was around 25 km/h, while wind speed dropped below 20 km/h during the first and second inter monsoonal periods of the year, i.e., October-November and March-April, respectively (Fig. 3A). Mean daily rainfall at the Malala area during the study period was $2.68 \pm$

2.60 mm. The highest precipitation in the area (10.7 mm) was recorded in November 1996, which was during the second inter-monsoonal period. During April 1996, rainfall exceeded 5.3 mm owing to the first inter-monsoonal rains. Rainfall in September 1997, which was during the South-West monsoonal period and in October 1997 which was during the second inter-monsoonal period were 8.5 mm and 7.7 mm respectively. No precipitation was recorded in March 1996, January 1997 and March 1997 (Fig. 3B).

Freshwater influx to Malala lagoon from Lunugamwehera reservoir during the period from August 1995 to February 1996 was 97,495 acre-feet/month (1 million cubic metre $\approx$ 810.7 acre-feet). The highest influx (21,093 acre-feet/month), which was also the highest influx throughout the study period and the lowest influx (183 acre-feet/month) was recorded in November 1995 and September 1995, respectively. After that, release of irrigation water to the lagoon varied from 0 to 714 acre-feet/month until November 1996 and since then, considerable amount of fresh water (1,011 to 11,660 acre-feet/month) was received by the Malala lagoon until the end of the study period (Fig. 3B). Mean ($\pm$ SD) tide level in Hambantota district where Malala lagoon is located was 0.35 ± 0.08 m. with the maximum of 0.47 m recorded in October 1997 and the minimum of 0.19 m recorded in August 1995 (Fig. 3C). Mean ($\pm$ SD) water level in Malala lagoon was 1.33 ± 0.38 m. The highest water level (2.00 m) was observed in May 1997 and the lowest (0.55 m) in October 1996 (Fig. 3D). Mean ($\pm$ SD) Secchi depth was 0.39 ± 0.19 m), which ranged between 0.15 m recorded in June and August 1996, and 0.85m recorded in February 1997 (Fig. 3D).

Mean ($\pm$ SD) water temperature of the Malala lagoon during the study period was 27.69 ± 1.62 °C. There was no significant difference ($p > 0.05$) in temperature of the surface, middle and bottom of the water column. Mean ($\pm$ SD) temperature at surface waters was 27.71 ± 1.69 °C, which fluctuated between 25.5°C and 31.5°C. Mean ($\pm$ SD) temperature of the middle of the water column was 27.77 ± 1.67 °C, which ranged between 25.5°C and 31.3°C, while that of the bottom was 27.77 ± 1.65 °C, which ranged between 25.7°C and 31.3°C. The highest values for water temperature in the surface and middle were recorded in April and October 1997 respectively

while the lowest values were recorded in July 1996. The highest and the lowest values for the bottom were recorded in October 1997 and January 1996 respectively (Fig. 3E).

Mean ($\pm$ SD) pH was 7.93 ± 0.46 . There was no significant difference ($p > 0.05$) in pH at surface, middle and bottom of the water column in the lagoon. The pH at surface (Mean $\pm$ SD: 7.93 ± 0.51), middle (Mean $\pm$ SD: 7.94 ± 0.43) and the

bottom (Mean $\pm$ SD: 7.91 ± 0.49) fluctuated from 6.8 to 8.7, 7.2 to 8.6 and 6.8 to 8.6 respectively. The highest pH at the surface, middle and the bottom was recorded in March 1997. The lowest pH at the surface and bottom was recorded in July 1996, while that of the middle was recorded in June 1997 (Fig. 3F).

Fig. 3 Monthly variation of environmental parameters and physicochemical parameters in Malala lagoon. (A) - Air temperature and wind speed; (B) - Rainfall and freshwater inflow from Lunugamwehera Reservoir; (C) - Tide level; (D) - Water depth and Secchi depth visibility; (E) - Water temperature, and (F) - pH

Monthly variations in conductivity, salinity, alkalinity, dissolved oxygen, dissolved phosphate and chlorophyll-a are shown in Fig 4. Mean ($\pm$ SD) conductivity was 5.14 ± 3.88 mS/cm. Mean ($\pm$ SD) conductivity in surface, middle and bottom of the water column were 5.01 ± 4.03 , 5.05 ± 3.98 and 5.35 ± 4.05 respectively. There was no significant difference ($p > 0.05$) in conductivity at the surface, middle and bottom of the water column. However, conductivity of the bottom in May 1997 was very high (9.5 mS/cm) compared to surface (2.6 mS/cm) and middle (2.7 mS/cm) of the water column. The highest surface water conductivity (14.09 mS/cm) was recorded in October 1996 and the lowest (1.22 mS/cm) in January 1996. In the middle and the bottom of the water column, the highest and lowest conductivity values recorded were 14.07 mS/cm in October 1996 and 1.22 mS/cm in January 1996 respectively (Fig. 4A).

Mean ($\pm$ SD) salinity of the Malala lagoon during the study period was 2.18 ± 1.61 ‰. There was no significant difference ($p > 0.05$) in salinity at surface, middle and bottom of the water column. Mean ($\pm$ SD) salinity of the surface water was 2.17 ± 1.59 ‰, which varied from 0.59 ‰ recorded in September and December 1995, and January 1996 to 5.88 ‰ recorded in October 1996. The mean ($\pm$ SD) salinity in the middle of the water column was 2.35 ± 1.7 ‰, which ranged from 0.59 ‰ recorded in December 1995 to 6.48‰ recorded in November 1996. The mean ($\pm$ SD) salinity in the bottom was 2.15 ± 1.60 ‰, which varied from 0.56‰ recorded in February 1996 to 6.40‰ recorded in November 1996 (Fig. 4B).

Mean ($\pm$ SD) alkalinity was 2.14 ± 0.59 mmol/L. There was no significant variation in alkalinity at the surface, middle and bottom of the water column ($p > 0.05$). Mean ($\pm$ SD) alkalinity at the surface was 2.16 ± 0.64 mmol/L, which ranged between 0.9 mmol/L and 3.45 mmol/L. Mean ($\pm$ SD) alkalinity at the middle and bottom of the water column were 2.14 ± 0.58 and 2.10 ± 0.62 mmol/L respectively, which ranged between 1.1 and 3.25 mmol/L. The highest and lowest alkalinity were observed in March 1996 and March 1997 respectively (Fig. 4C).

Mean ($\pm$ SD) dissolved oxygen (DO) in Malala lagoon was 7.83 ± 0.89 mg/L. There was no significant difference in DO in three different water layers ($p > 0.05$). Mean ($\pm$ SD) DO at the

surface was 7.98 ± 0.71 mg/L and it varied from 6.03 mg/L recorded in May 1997 to 9.34 mg/L recorded in September 1995. The mean ($\pm$ SD) DO at the middle of the water column was 7.91 ± 0.77 mg/L, which ranged between 5.92 mg/L and 9.51 mg/L, while that of at the bottom was 7.71 ± 1.17 mg/L, which ranged from 3.27 mg/L to 9.39 mg/L. The highest DO values for the water column were observed in September 1995 while the lowest values for the surface and middle of the water column were recorded in May 1997 and for bottom in June 1996 (Fig. 4D).

Mean ($\pm$ SD) dissolved phosphate in the Malala lagoon during the present study was 12.25 ± 4.67 μ g/L. There was no significant difference in dissolved phosphate levels in the surface, middle and bottom regions of the water column of the lagoon ($p > 0.05$). Mean ($\pm$ SD) dissolved phosphate at the surface was 12.25 ± 5.69 μ g/L and it fluctuated between 5.000 μ g/L and 26.667 μ g/L. At the middle, it was 12.70 ± 5.17 μ g/L and it ranged between 3.333 μ g/L and 22.500 μ g/L. At the bottom, it was 11.67 ± 4.92 μ g/L, which ranged between 5.000 μ g/L and 23.333 μ g/L. The highest dissolved phosphate at the surface and bottom of the water column was recorded in June 1996, and at the middle it was in August 1996. The lowest value was recorded in May 1996 (Fig. 4E).

Mean ($\pm$ SD) chlorophyll-a content at Malala lagoon during the study period was 8.86 ± 4.62 μ g/L. There was no significant difference in Chlorophyll-a content in the surface, middle and bottom of the water column ($p > 0.05$). Chlorophyll-a content in surface waters (Mean $\pm$ SD: 8.76 ± 6.59 μ g/L) varied from 0.592 μ g/L recorded in October 1996 to 26.64 μ g/L recorded in May 1996. In the middle of the water column, mean $\pm$ SD chlorophyll-a was 9.634 ± 5.41 μ g/L and it ranged from 1.776 μ g/L to 24.272 μ g/L, recorded in January 1997 and August 1996 respectively. At the bottom, mean $\pm$ SD chlorophyll-a was 8.61 ± 4.46 μ g/L, and it varied from 2.96 μ g/L to 21.312 μ g/L, recorded in January and July in 1997 respectively (Fig. 4F).

Some climatic conditions in Malala area and hydrological parameters of the Malala lagoon showed correlations ($p < 0.05$) with physico-chemical and biological parameters of the lagoon water (Table 1). Wind speed showed a significant ($p < 0.05$) negative correlation with water

Fig. 4 Monthly variations of physicochemical and biological parameters in Malala Lagoon. (A)- Conductivity; (B) – Salinity; (C) – Total alkalinity; (D) - Dissolved oxygen; (E) - Dissolved phosphate; (F) - Chlorophyll-a

Table 1 Relationship of climatic conditions in Malala area and hydrological parameters of the Malala lagoon with physicochemical and biological parameters of the lagoon water

	Water Temp		pH		Conductivity		Salinity		Alkalinity		DO		Phosphate		Chl-a	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
Influx	-0.064	0.753	0.191	0.479	-0.454	0.026	-0.406	0.039	-0.385	0.085	0.117	0.562	-0.085	0.713	0.074	0.720
AT	0.132	0.512	-0.425	0.101	-0.100	0.641	-0.100	0.627	0.089	0.700	-0.172	0.391	-0.066	0.776	-0.012	0.952
SDD	0.579	0.002	0.353	0.180	-0.274	0.196	-0.234	0.251	-0.425	0.055	0.061	0.763	-0.521	0.015	-0.401	0.042
WS	-0.493	0.009	-0.183	0.497	-0.232	0.275	-0.229	0.261	0.557	0.009	0.225	0.260	0.363	0.106	0.264	0.192
Tide	0.465	0.015	0.437	0.090	-0.094	0.664	-0.012	0.955	-0.258	0.259	-0.249	0.211	-0.329	0.145	-0.072	0.728
WL	0.344	0.079	-0.033	0.904	-0.727	0.000	-0.729	0.000	-0.248	0.279	-0.166	0.407	-0.190	0.409	-0.019	0.926

r = Pearson correlation coefficient; p=significance level at the 0.01 level (two-tailed); AT- Air Temperature; SDD- Secchi Disk Depth; WS- Wind Speed; WL- Water Level; Alk- Alkalinity; Cond- Conductivity

Table 2 Variation of physicochemical parameters of Malala lagoon over a decade from 1991 to 2001 (Mean $\pm$ SD, minimum to maximum or range)

Physicochemical Parameter	1991/1993 IIMI (1995)	1995/1997 Present study	1999/2000 Piyankarage et al. (2004)	2000/2001 Chandana et al. (2001)
Depth (m)	1.0-2.2	1.33 $\pm$ 0.38 0.55-2.00 (n= 47)	1.27 $\pm$ 0.39 0.28-2.25	-
Temperature ($^{\circ}$ C)	-	27.69 $\pm$ 1.62 25.60-31.30 (n=47)	28.8 $\pm$ 1.93 25.2-34.7	-
Conductivity (mS/cm)	-	5.14 $\pm$ 3.88 1.22-14.08 (n=38)	3.04 $\pm$ 2.35 1.84-13.62	-
Salinity (ppt)	14-41(high Level) 7-15 (low Level)	2.18 $\pm$ 1.61 0.59-6.21(n=45)	-	1.06 $\pm$ 0.01 -0.71 $\pm$ 0.02 (inland to sea outlet)
pH	-	7.93 $\pm$ 0.46 7.00-8.60 (n=25)	8.08 $\pm$ 0.35 6.86-8.65	-
PO ₄ ⁻³ (μ g/L)	-	11.72 $\pm$ 5.39 3.33-28.33 (n=32)	48.80 $\pm$ 22.90 16.3-88	75 $\pm$ 2.3 – 121.3 $\pm$ 2.8 (inland to sea outlet)

temperature ($r = 0.493$), and with total alkalinity it showed a significant ($p < 0.05$) positive correlation ($r = 0.557$). Tide level showed a significant ($p < 0.05$) positive correlation with water temperature ($r = 0.465$). Also, water level of the lagoon showed a significant ($p < 0.01$) negative correlation with electrical conductivity ($r = 0.727$) and salinity of the lagoon ($r = 0.729$). Moreover, water influx to the lagoon showed the significant ($p < 0.05$) negative correlation with conductivity ($r = 0.454$) and salinity ($r = 0.406$). In addition, Secchi depth showed a significant negative ($p < 0.05$) correlation with total dissolved phosphate ($r = 0.525$) and chlorophyll-a ($r = 0.401$) and a significant ($p < 0.01$) positive correlation with water temperature ($r = 0.579$).

DISCUSSION

Climatic conditions of the geographic area where Malala lagoon is located and physicochemical & biological parameters of the lagoon showed temporal variations throughout the study period. Comparison of present findings with literature confirms that brackish water characteristics of the lagoon is gradually diminishing, converting Malala lagoon into a freshwater body, and lagoon is subjected to continued accumulation of phosphates (Table 2). Present study is significant, as a comprehensive study of Malala lagoon has not been carried out since 1997, except the studies carried out during 1999-2000 on impacts of anthropogenic activities (Piyankarage et al. 2004), and post-tsunami environmental impact assessment of UNEP/MENR, which focused only on critical environmental issues of the lagoon for short term

relief and recovery activities (UNEP 2005). Present findings are from a comprehensive study carried out over two years on physicochemical and biological characteristics of the lagoon, and their relationship with climatic and hydrological parameters. Hydrology and physicochemical parameters of Malala lagoon were generally accepted to be dependent on monsoon rainfall pattern and local climate of the area prior to the intrusion of fresh water from Lunugamwehera reservoir of KOISP. However, literature reveals that four years after 1987 where irrigation water was released from the right bank canal to Malala lagoon, hydrological regime and physicochemical environment of the lagoon started to change disturbing most of its intrinsic seasonal ecological processes, which have been most prominently observed from 1992 onwards (Matsuno et al. 1998; Smakhitin and Piyankarage 2003).

Freshwater influx and rainfall plays an important role in seasonal variations of physicochemical characteristics of the lagoon. Water level fluctuation in lagoon between 0.55 – 2.0 m indicates the dry zone characteristics. From 1999 to 2000, water level ranged between 0.28 m and 2.25 m due to heavy rainfall (Piyankarage et al. 2004). Water level fluctuation in 1993 at Palatupana Lewaya which is in close proximity to Malala lagoon is almost similar to those observed during the present study (WCP 1994). In contrast, in the Garanduwa lagoon located in the wet zone in Matara District, water level changed within a narrow range of 1.5 - 2.3 during the same period, indicating the differences in hydrology of dry zone and wet zone lagoons (Titus et al. 1999). Low Secchi depth could be mainly attributed to the turbulence of water caused by landward winds blowing from the sea. Present findings are in accordance with the lagoons of southern Sri Lanka that commonly display low secchi depth values, which is confirmed by Amarasinghe (1988) in Lunama, Kalamatiya and Rekawa lagoons; Titus et al. (1999) in Garanduwa lagoon; Silva (1996) in Koggala lagoon and Janaki and Piyasiri (2005) in Bolgoda Lake.

Mean water temperature (28.8°C) and its maximum value (34.7°C), during the period from 1999 to 2000, from Malala lagoon (Piyankarage et al. 2004) are comparatively higher than those recorded during the present study. Amarasinghe (1988) also has recorded similar water

temperatures in 1984-1985 in Kalamatiya lagoon. Fluctuation in pH within a range of 7.0 - 8.6 indicates the changes of water quality from neutral to alkaline conditions. Amarasinghe (1988) recorded almost similar pH ranges in Kalamatiya lagoon. However, pH recorded from Malala lagoon during 1999 - 2000 is much higher than in Kalamatiya and Rekawa lagoons (Piyankarage et al. 2004). Alkalinity recorded in the present study is similar to that observed in the Kalamatiya lagoon in 1984-1985 by Amarasinghe (1988). Also, Titus et al. (1999) recorded that in 1995-1997, DO level in the Garanduwa lagoon was almost similar to that of the Malala Lagoon. Fluctuation of DO within a broad range during the study period is in contrast with narrow range recorded in Negombo lagoon, which was 5.6 - 7.8 mg/L (Silva 1996). Mean conductivity of Malala lagoon and its range recorded during present study are comparable to mean (3.04 ± 2.35 mS/cm), maximum (13.62 mS/cm) and the minimum (1.84 mS/cm) recorded by Piyankarage et al. (2004) for the period 1999 - 2000 under heavy rains and flooding. Almost similar observations have been made in Lunama lagoon, which is also located in the Hambantota District (WCP 1994). Dissolved phosphate concentration recorded during the present study was lower than those recorded in subsequent studies done in 1999 - 2000 (Piyankarage et al., 2004) and 2000 - 2001 (Chandana et al. 2001). This could be due to surface runoff and irrigation inflow containing phosphates leached from agricultural fields. The estimated average phosphate loading to Malala and Embilikala lagoons is 620 kg (Piyankarage et al. 2004). This clearly indicates that there is heavy nutrient loading into these lagoons.

The comparative assessment with published data confirmed that brackish water characteristics of the lagoon is gradually diminishing. Observations made on the salinity in several studies carried out from 1985 to 1997, provide clear evidence for such changes (Jayakody and Jayasinghe 1992; IIMI 1995; Titus et al. 1998b; Chandana et al. 2001). Salinity in the Malala lagoon has been within the range of 10 to 41 ppt during 1985 - 1987 and it has gradually dropped to 1 - 7 ppt in 1991 with the commencement of the Lunugamvehera irrigation and settlement project (Jayakody and Jayasinghe 1992). In a subsequent study, conducted by Jayakody (1994) in 1993 has

recorded a salinity variation of 5 - 10 ppt, while the lowest salinity recorded by IIMI (1995), from 1991 to 1993, has been 7 to 15 ppt, which is a slightly higher range compared to the former study. The upper level of salinity recorded during the latter study have shown a variation between 14 and 41ppt (IIMI 1995). Considering the above observations, it is obvious that lagoon maintained a lower salinity from 7 ppt or above, up to 1993. During the present study (1995 - 1997) mean salinity was much lower than those recorded in the above studies. Unlike the other studies (Jayakody 1994; Jayakody and Jayasinghe 1994; IIMI 1995), the present study quantified the salinity using the data collected from 42 regular sampling occasions at three different levels of the water column in the Malala lagoon within two years from 1995 to 1997 at fortnightly intervals. Also, Chandana et al. (2001) have recorded a salinity variation from 1.06 ± 0.01 g/L to 0.71 ± 0.02 g/L during 2000-2001. Amarasinghe (1988) recorded a similar salinity range in the Lunama lagoon, while a much higher range was recorded in Kalametiya lagoon. The salinity variation recorded in Bolgoda lagoon in 2004-2005 by Janaki & Piyasiri (2005) has been approximately within the same range as recorded in the present study, and the mean salinity recorded in 2006 from Maduganga Estuary in Balapitiya, southern Sri Lanka has been 2.2 ± 1.7 ppt (Deeptha and Sureshkumar 2009) which is much similar to the findings of the present study.

During the present study, salinity was observed to be dropped to < 1 ppt. This salinity drop could be attributed to uncontrolled release of freshwater from Lunugamwehera reservoir, which is also observed by Piyankarage et al. (2002, 2004). This release of water, which contains agrochemicals also is supposed to have made a toxic and intolerable environment for lagoon fish and other organisms inhabiting the lagoon for a long time (Abeywickrama 2010). Freshwater influx and rainfall are responsible for lagoon water level and mixing of allochthonous materials that change the physicochemical environment of the lagoon. This is further confirmed by the significant correlation between freshwater influx and some physicochemical parameters of the Malala lagoon such as conductivity and salinity (Table 1). Broad range of chlorophyll-a content in the Malala lagoon could be due to the presence of heterogeneous phytoplankton community around

the year (Titus et al. 1999). Dense populations of freshwater phytoplankton have been observed during the rainy seasons and predominant marine diatoms have been observed during the drought seasons (Titus et al. 1999).

The paradigm shift in lagoon characteristics have changed the species composition of the lagoon. This is evident by the replacement of marine and brackish water plankton by freshwater species and dominance of freshwater zooplankton in the microcrustacean fauna (Titus et al. 1996, 1998a, 1998b). Kularathna (1999) also observed a replacement of high-value brackish water fish by low-value freshwater fish in 1995 - 1997. Matsuno et al. (1998) reported a decline in the prawn yield in 1991-1992, which was 5 -15 kg/ha as compared to 15 - 30 kg/ha recorded in 1987. Kularathna (1999) reported that in 1995 - 1997, there was no prawn catches from the Malala lagoon. These observations confirm the negative impact of anthropogenic activities on the Malala lagoon ecosystem.

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