RUHUNA JOURNAL OF SCIENCE
Vol. 1, September 2006, pp. 16–23
http://www.ruh.ac.lk/rjs/
ISSN 1800-279X

Some Hydrographic aspects of Koggala Lagoon with preliminary results on distribution of the marine bivalve *Saccostrea forskalli*: pre-tsunami status

K. B. Suneetha Gunawickrama and E. P. S. Chandana
Department of Zoology, Faculty of Science, University of Ruhuna, Matara, Sri Lanka,
suneetha@zoo.ruh.ac.lk

Selected hydrographic parameters of Koggala lagoon over a period of four months in 2002-2003 are reported together with the preliminary results on the distribution of a marine bivalve within lagoon. Such data prior to the December 2004 tsunami may provide background information for comparison of post-tsunami conditions. Moderate yet significant variation in most physico-chemical parameters was found among selected sites. Mean salinity decreased from 34.0 *ppt* at the mouth to 11.4 *ppt* at 2150 m into the lagoon indicating pronounced seawater influx and mixing with freshwater. Monthly inter-site variation in salinity was statistically significant ($p<0.05$). The marine bivalve *Saccostrea forskalli* (Chemnitz) was the dominant benthic mollusk with numbers (per m^2) ranging from 111.5 ± 9.7 at lagoon mouth to 23.5 ± 2.1 at 2150m inner lagoon. Density distribution of *S. forskalli* was significantly correlated ($p<0.05$) with the overall variation in salinity ($r=0.889$). Salinity-dependent colonization success of *S. forskalli* demonstrates the dominance of marine conditions in Koggala lagoon.

Key words: Koggala lagoon, hydrography, *Saccostrea*, seawater influx, lagoon dynamics.

1. Introduction.

Coastal wetlands including lagoons are increasingly subject to human interventions that are driven by economic and developmental needs. Such activities may cause natural hydrographic conditions of lagoons to change over time, consequently making a great impact on the wellbeing of the life forms as well. In addition to anthropogenic activities, infrequent natural events like the December 2004 Indian Ocean tsunami may have great impacts on environmental conditions in coastal wetlands. In conservation point of view, it is important to monitor the trends in changes within these ecosystems, while studies looking into such aspects have to rely on previously reported data to have comparative analyses.

Koggala lagoon, a basin estuary located in the southern coast of Sri Lanka (06°00′ N; 80°20′ E) (Anon. 1988) is a nationally important wetland site according to the currently adopted valuation criteria (CEA 1995, 1999). It covers a relatively large surface area (approx. 727 ha) measuring 4.8 km in length and 2 km across, and is relatively deeper (1.0- 4.0 m) compared to other coastal water bodies along the southern coast (Silva 1996). Its innermost region receives a large influx of freshwater from few streams, and the seaward end has a narrow outlet named 'Pol Oya' (CEA 1995) (Figure 1). Various land use practices exist around this wetland, which mainly includes small-scale fishing industry within lagoon and paddy cultivation close to the landward end of the lagoon (Amarasinghe 1998). The Koggala Export Processing Zone (KEPZ), largely focused on textile manufacturing is located within the watershed area of the lagoon.

Presently, the natural outlet of Koggala lagoon has been considerably modified with the construction of an artificial barrier (breakwater) at the mouth. As a result, the outlet has been diverted westward creating an open passage to the sea (approx. 30-40 m wide). It is hypothesized that the lagoon has been subjected to prolonged seawater intrusion affecting its hydrographic conditions. One indication for such a change may be the occurrence of marine bivalve *Saccostrea forskalli* (Chemnitz) in the Koggala lagoon. Scientific information is lacking on their inward distribution.

The tsunami event in December 2004 caused a great environmental damage to the nearby area of the Koggala lagoon. Although the lagoon faced a full-scale impact of the surging wave, no studies have been carried out on the effects of the tsunami on the lagoon so far. Scientific information gathered before the tsunami event is immensely important for such comparisons. The present paper reports selected hydrographic characteristics of Koggala lagoon for a period of four months during 2002-2003 with preliminary results on the density distribution of the marine bivalve *Saccostrea forskalli*.

2. Materials and methods

2.1. Sampling

Nine locations along the approximate lagoon axis were selected for sampling (Figure 1). The distance (m) from the mouth to the consecutive sampling locations (1-9) were 0 (at the outlet), 50, 150, 400, 650, 900, 1150, 1650 and 2150. At each sampling location (1-9), four sites that were approximately 1-2 m apart from each other were selected for replicate sampling (Figure 1). Five consecutive sampling was carried out during the four-month period (12^{th} of November, 7^{th} and 28^{th} of December in 2002, 21^{st} of January and 23^{rd} of February in 2003). Water samples were collected from each site within the first meter of the water column.

2.2. Physico-chemical parameters

In-situ measurements of depth (m), Secchi depth (transparency, cm), pH (by pH meter), water temperature (°C) and conductivity (conductivity meter, in mS/cm) were taken at each sampling site. Water samples were collected for salinity (by $AgNO_3$ titrative method in parts per thousand; ppt), dissolved oxygen (Winkler's method, mg/l) and dissolved phosphate ion concentration (spectrophotometric method; μg/l) to be analyzed in the laboratory. The mean values (n=4) of each parameter at given sampling times were tested for among-location variation and short-term temporal variation using one-way ANOVA ($p<0.05$ was considered significant). All statistical and data analyses were done using Statistica®V 7.0 (Statsoft, USA).

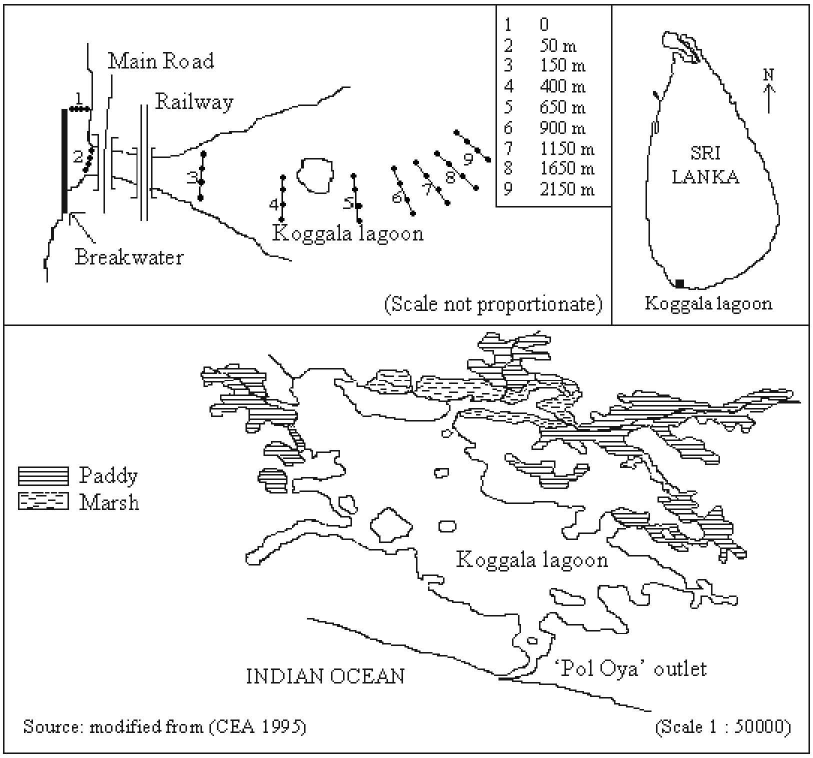

Figure 1 The map of Koggala lagoon showing the selected sampling sites (insert at top left corner).

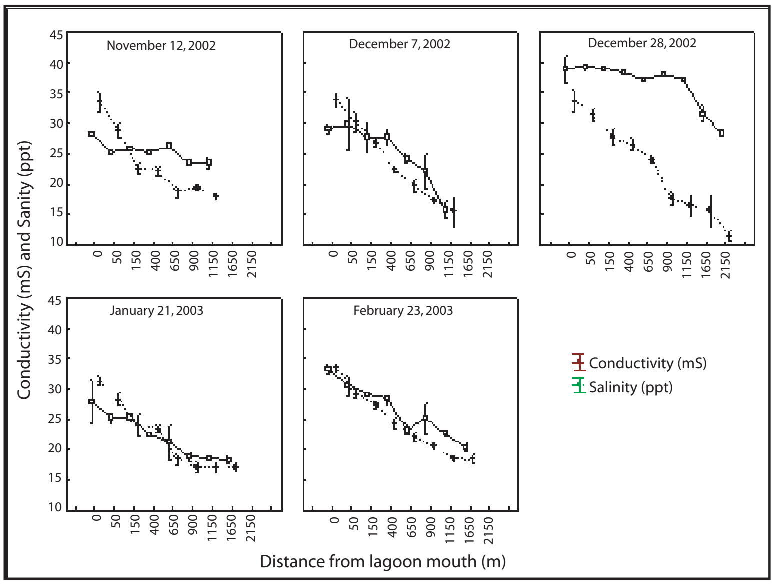

Figure 2 Variation in mean salinity and conductivity at the selected sites of Koggala lagoon over a period of four months during 2002-2003 (±SD, n=4).

Note. (X-axis in the plots is shifted for the two parameters for clarity).

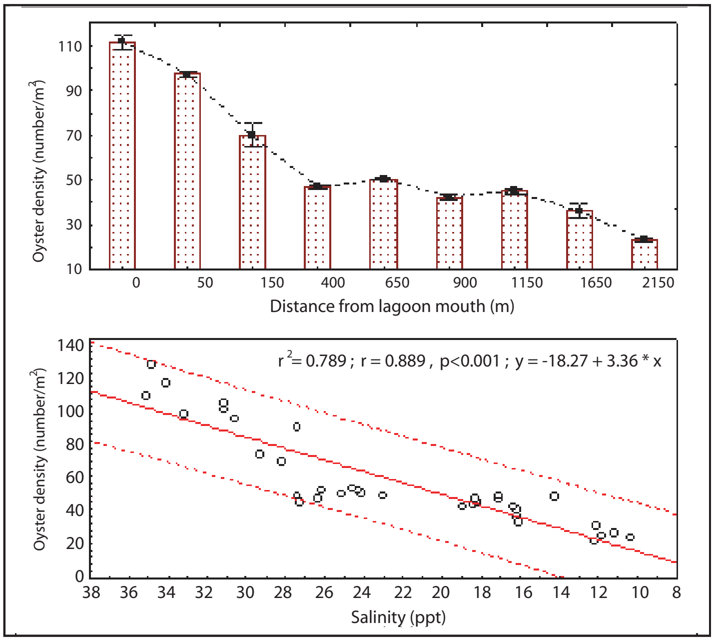

Figure 3 Variation in mean oyster (*Saccostrea forskalli*) density in Koggala lagoon (top) and the plot of regression analysis between oyster density and salinity.

Note. The error bars represent standard deviation (top) while dashed lines indicate 95% confidence limits (bottom).

2.3. Density distribution of *Saccostrea forskalli*

Density of the bivalve (number per m^2) was estimated by placing four random replicate quadrates (1 m^2) at each sampling location, and by underwater observation and counting the numbers *in-situ* (it was easily done at sampling locations where bottom was visible), on one sampling date only (28^{th} December 2002). Statistical correlation of bivalve density with the among-site variation in salinity and conductivity during December 2002 was tested by Pearson's correlation analysis and least square regression analysis.

3. Results

3.1. Lagoon characteristics

The mean depth of the sampling area ranged from 0.69 m near lagoon mouth to 2.9 m at 1.15 km distant from mouth over the four months. Secchi disc transparency of the water column was high over the months ranging between 119 cm (site 4) and 136 cm (site 9). Bottom of the lagoon was visible up to a distance of 150-200 m from the mouth. Frequent rapid inflow of sea water into the lagoon was observed whenever moderate to strong wave action was present while the outflow was less frequent, occurring under very calm sea conditions and low tide.

Among the physico-chemical parameters studied, most displayed sharp gradients from the lagoon mouth towards the inner lagoon. Particularly, conductivity and salinity of lagoon water (Table 1) at each sampling day markedly decreased towards the inner lagoon (Figure 2). Mean conductivity was highest at the mouth (site 1 & 2) under high influence of seawater ranging from 25.3 mS cm^{-1} to 39.4 mS cm^{-1} during the four months. Conductivity at each sampling site was significantly different (ANOVA, $p<0.05$) between the five sampling times (sites 8 and 9 were not included in this test) while along-axis variation was highly significant (ANOVA, $p<0.001$) at all sampling times. Salinity was highest at the mouth and ranged between 31.3 and 34.0 *ppt*, while the lowest salinity of 11.4±0.8 *ppt* was recorded at the innermost sampling site (2.15 km from mouth) during third week of December 2002 (Figure 2). Salinity ranged from 15.5 to 18.5 *ppt* during the four-month period. Significant temporal variation in salinity was found at all sampling locations except at locations 7 and 8. Among site variation in salinity was highly significant in all sampling times indicating a strong salinity gradient (reverse) from mouth towards inner lagoon (ANOVA, $p<0.05$).

Mean water temperature ranged from 28.6 ℃(at the mouth) to 30.1 ℃(innermost site). The lagoon water was largely alkaline with pH varying between 8.7 and 9.6. Although some significant differences in pH were found among sites (results not given) there was no discernible gradient (Table 2). Amount of dissolved oxygen was relatively high (10.0-11.6 mg/l), at some point up to the level of saturation, and no marked among-site variation was found. The concentration of total dissolved phosphate ions was highly variable and significantly different among most of the sites, but no discernible trend was found. During November and December, 2002, significantly high phosphate ion concentration was found close to the mouth (sites 1,2 & 3) compared to inner lagoon (ANOVA, $p<0.05$).

3.2. Distribution of the marine bivalve

The marine oyster *Saccostrea forskalli* (Chemnitz 1758) (Mollusca: Bivalvia) was the dominant mollusk in the littoral areas and benthic regions with some hard substrates. Most submerged rocky substrates (boulders) at the mouth region were covered with the oyster and its distribution has extended up to more than half way into the lagoon (Figure 3). The mean densities (number/ m^2) ranged from 111.5 ± 9.7 at the outfall to 23.5 ± 2.1 at 2.15 km, close to the midpoint of the lagoon axis (Table 1). The among-site variation in the densities was highly significant and correlated with the variation in salinity and conductivity during December, 2002 (Figure 3). 78.9% of the among-site variation in oyster density can be explained by the variation in salinity alone ($r^2 = 0.789$; Pearson's $r = 0.889$; $p<0.001$). Oyster density was significantly correlated with conductivity as well (Pearson's $r = 0.65$, $p<0.001$).

4. Discussion

The observed gradients in salinity and conductivity from the lagoon mouth towards inner lagoon could be attributed to the strong influence of sea water and freshwater fluxes. High rainfall was reported during November in the south region of the country owing to the second inter-monsoonal season (October-November) and the reduced salinity found during December could be attributed to the enhanced freshwater

Table 1 Descriptive statistics of salinity and conductivity together with the oyster density in Koggala lagoon (displayed as mean±SD; the values in each column are respectively from five consecutive sampling times (1: Nov 12, 2002; 2: Dec 7, 2002; 3: Dec 28,2002; 4: Jan 21, 2003; 5: Feb 23, 2003)).

Site		1	2	3	4	5	6	7	8	9
Distance from mouth (m)		(0)	(50)	(150)	(400)	(650)	(900)	(1150)	(1650)	(2150)
Conductivity (mS)	1	28.3±0.1	25.3±0.2	25.9±0.3	25.4±0.3	26.3±0.1	23.6±0.1	23.5±0.8	n.m	n.m
	2	29.2±0.7	29.9±4.5	27.9±2.5	27.8±1.3	24.3±0.6	22.2±3.0	15.7±1.3	n.m	n.m
	3	39.0±2.2	39.5±0.6	39.1±0.1	38.5±0.4	37.4±0.2	38.1±0.1	37.3±0.1	31.7±1.2	28.4±0.3
	4	27.8±3.6	25.3±0.9	25.2±0.7	22.5±0.3	21.2±2.7	18.8±0.8	18.6±0.3	18.3±0.7	n.m
	5	33.2±0.8	30.5±1.7	29.2±0.5	28.3±0.9	23.3±0.9	25.0±2.7	22.6±0.3	20.3±0.5	n.m
Salinity (ppt)	1	33.5±1.6	28.9±0.2	22.6±1.1	22.2±0.8	18.8±0.9	19.5±0.3	18.1±0.6	n.m	n.m
	2	34.0±1.2	30.3±4.5	26.9±0.9	22.4±0.2	19.8±1.1	17.3±0.6	15.5±2.5	n.m	n.m
	3	33.8±1.8	31.5±0.6	27.8±1.4	26.5±1.1	24.0±0.7	17.7±1.2	16.5±1.7	15.7±2.6	11.4±0.8
	4	31.3±0.7	28.3±0.9	24.0±1.7	23.4±0.6	18.4±0.8	17.1±0.8	17.1±0.7	17.2±0.6	n.m
	5	33.5±0.6	29.2±1.7	27.5±0.5	24.4±0.9	22.1±0.7	20.5±0.5	18.5±0.4	18.4±0.7	n.m
Oyster[a]	3	111.5±9.7	97.3±3.8	69.8±15.2	46.8±2.2	50.3±1.7	42.5±2.6	45.0±3.2	36.0±7.1	23.5±2.1

([a] *Saccostrea forskalli* density in number per m^2, n. m.=not measured).

Table 2 Selected physical and chemical parameters of Koggala lagoon displayed as the mean values (within parentheses are the number of sampling times). Among site variation was significant (ANOVA, $p<0.05$) for all parameters.

Site	1	2	3	4	5	6	7	8	9
Distance from mouth(m)	0	50	150	400	650	900	1150	1650	2100
pH	9.5 (3)	9.6 (2)	9.6 (3)	9.1 (3)	8.7 (3)	8.9 (3)	9.0 (3)	9.0 (1)	8.7 (1)
Temperature (℃)	28.6 (5)	28.9 (5)	29.0 (5)	29.1 (5)	29.2 (5)	29.2 (5)	29.4 (5)	29.3 (3)	30.1 (1)
Depth (m)	0.86 (5)	0.69 (5)	1.67 (5)	2.05 (5)	2.16 (5)	2.46 (5)	2.92 (5)	3.40 (3)	2.60 (1)
Secchi depth (cm)	b.v.	b.v.	119 (5)	121 (5)	130 (5)	128 (5)	128 (5)	133 (3)	136 (1)
Dissolved O_2 (mg/l)	10.3 (5)	10.9 (5)	10.0 (5)	10.7 (5)	11.6 (5)	11.5 (5)	11.1(5)	10.7 (3)	10.5 (1)
Phosphate (μg/l)	242.7 (3)	238.4 (3)	225.5 (3)	169.9 (3)	168.2 (3)	137.9 (3)	143.5 (3)	152.9 (1)	208.7 (1)

b.v.= bottom visible

influx from the streams connected to the head region. Characteristics of the Koggala lagoon have been reviewed previously by presenting earlier reported values by Silva (1996). The salinity values reported in the present study in November are apparently higher than those reported during 1981-1982, (min-max: 0.01-18.0 *ppt*) (Silva 1996). The influence of seawater influx enabled by the breakwater seems to have dominated the lagoon water as far as 1-2 km from the lagoon mouth. Evaporation is identified as a governing factor of the characteristics of lagoon waters especially under closed conditions (Hadlec et al. 1988). Therefore, evaporation may affect lagoon hydrography causing higher saline conditions especially during droughts. Under present situation, salinity is likely to be largely regulated by prolonged seawater intrusion but not by evaporation losses. Salinity value as high as 19.6 ppt was reported at the middle of the lagoon during March 1994 (Silva 1996), in agreement with the rise in saline conditions reported during that period (Amarasinghe 1998). The values reported in the present study further support the characterization of Koggala lagoon as a dynamic system having large annual variations in hydrographic parameters (CEA 1995).

Strong inward flow of seawater forced by the near-shore wave action at the koggala lagoon mouth reflected the potential influence of seawater on the lagoon hydrography. Under natural conditions, the lagoon hydrography is strongly governed by the tidal influence and freshwater influx from the head region (Silva 1996). Although the tidal influence on lagoon dynamics still exists, the effect of wave action apparently dominates over it. The predominance of more saline conditions in the lagoon seems to have enabled invasion of some marine species into the lagoon. The marine bivalve *Saccostrea forskalli* has never been reported in previous studies within the lagoon (see CEA 1995). It is a marine species highly abundant in eulittoral to sublittoral zones of many rocky shores around Sri Lanka (Kirthisinghe 1978). The occurrence of this species strongly indicates the environment is presently conducive to their existence within lagoon, and perhaps the lagoon provides better conditions deprived of the near-shore intertidal hardships usually faced by them on rocky shores. The habitat expansion of the oyster inward to the lagoon exemplifies the overwhelming influence of seawater probably lasting over a long period, and hence this marine bivalve could be considered as an indicator organism displaying the dominance of marine conditions within the lagoon. Further investigations are needed in this regard.

Koggala lagoon is known to harbor a diverse fauna as reported previously (CEA 1995, 1999), and thus has a high ecological significance. Several endemic species have been reported and especially a large species diversity of fishes is known to exist (CEA 1995, 1999). Therefore, from conservation point of view, the lagoon bears a high value. As most of the lagoons in southern coastal belt remain closed for large part of the year (Silva 1996), they may serve as separate geographical entities that offer conditions for the inhabiting populations to become locally adapted and becoming isolated from other such populations. This process is of high evolutionary significance. However, in recent times, the existing biodiversity in the Koggala lagoon is reportedly declining owing to various human activities (CEA 1995). Undesirable changes to the lagoon hydrography inevitably cause habitat deterioration for the inhabitants that no longer can tolerate the changed environmental conditions. Recent Indian Ocean tsunami (December 2004) caused great damage to the surrounding area of the lagoon while the lagoon itself has been subjected to the direct impact of the big wave. It seems a timely requirement to investigate the changes that may have occurred due to this natural event, yet such studies have to rely on data gathered prior to the event. In this sense, such data provide important background information for comparative studies. The present results may provide some information from the pre-tsunami era of the lagoon system.

In summary, hydrological conditions studied during the four-month period provide evidence for the dynamic nature of the Koggala lagoon. Strong sea water influence apparently caused by the prolonged opening of the lagoon system and strong onrushing wave action seem to have felt by the lagoon as far as about 2 km from the lagoon outlet. The seawater influence is further indicated by the colonization success of the marine oyster *S. forskalli* within the lagoon, which has not been reported from the Koggala lagoon prior to 1995.

References

Amarasinghe, O. (1998). Profitability of current land use practices in five saltwater exclusion and drainage (WSED) schemes. Report of the SWED project under Southern Province Rural Development project, Sri Lanka.

Anonymous (1988). National Atlas of Sri Lanka, Survey Department, Colombo, Sri Lanka.

CEA (1995). Wetland site report and conservation management plan, Koggala lagoon. Wetland Conservation Project- Central Environmental Authority of Sri Lanka/ ARCADIS/ EUROCONSULT. 1-82 p.

CEA (1999). Wetland Atlas of Sri Lanka. Wetland Conservation Project- Central Environmental Authority of Sri Lanka/ ARCADIS/ EUROCUNSULT. 1-75 p.

Hadlec, R. H., Williams, R. B. and Scheffe, R. D. (1988). Wetland evapotranspiration in temperate and arid climates. In: Hook, D. D., McKee Jr, W. H., Smith, H. K., Gregory, J., Burrell Jr, V. G., DeVoe, M. R., Sojka, R. E., Gilbert, S., Banks, R., Stolzy, L. H., Brooks, C., Matthews, T. D. and Shear, T. H. (eds.), The ecology and management of wetlands, Vol. 1, pp. 146-160, Timber Press, Portland, oregon.

Kirthisinghe, P. (1978). Sea Shells of Sri Lanka: Including Forms Scattered Throughout the Indian and Pacific Oceans. Rutland, VT: C. E. Tuttle.

Silva, E. I. L. (1996). Water quality of Sri Lanka, a review on twelve water bodies. Institute of Fundamental Studies, Peradeniya.