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INFLUENCE OF SALTWATER BARRAGE ON TIDES, SALINITY AND CHLOROPHYLL *a* IN  
COCHIN ESTUARY, INDIA

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**ABSTRACT**

Thanneermukkam Barrage is constructed in the southern arm of Cochin estuary. It prevents salt intrusion to further upstream and regulates river discharge downstream. The characteristics of the estuary when the barrage was opened and closed are discussed. The analysis showed that the closure of the barrage caused amplification of tides in the immediate vicinity and up to 10 km farther downstream. When barrage was closed, the northern region of TB transformed from ebb dominant system into a flood dominant system. During high discharge period, the barrage was opened and salinity intrusion was exponentially dependent on river discharge. During dry period, the reduction in river flow compounded with the closure of barrage resulted in the increase of salinity concentration downstream. While the oceanic salinity was observed at ocean-end station, about 13 occurred at the river-end station when the barrage was closed. The hydrodynamic control on phytoplankton biomass was also evident. Higher surface chlorophyll *a* levels were observed at higher salinity during the barrage closed period and the residence time was estimated for 4 days during this period.

***Additional index words:*** Estuary, saltwater barrage, Tidal amplification, salinity intrusion, chlorophyll  
*a*

## INTRODUCTION

There are many estuarine systems of backwaters along the west of coast of India. These water bodies are fed by rivers that originate in the Western Ghats (Mountain ranges on the west coast of India). The Cochin estuary is one of the above types of water bodies with two openings to Arabian Sea. This system extending from Munambam (10°10'N, 76°15' E) in the north, to Thanneermukkam (09°30' N, 76°25' E) in the south over a length of ~80 km. The regional tidal regime is micro-tidal, with an average range of 1m (Qasim and Gopinathan., 1969). The tides are mixed with semi-diurnal dominance, with form number varying from 0.85 to 0.91 (Revichandran *et al.*, 2011). The rivers that discharge freshwater in this estuarine system are Periyar in the north; Pampa, Achankovil, Manimala, and Meenachil in the south; and Muvattupuzha, at the central estuary. Thanneermukkam Barrage (TB) is a salinity barrier (commissioned in 1976) in the upstream part (~40.6 km away from Cochin inlet) of Cochin estuary. It was constructed to prevent the entry of saline water into the polders of Kuttanad region of Kerala coast to facilitate agriculture of paddy fields during summer season. The widest (about 5 km) and the shallowest (1 m) areas of the backwaters are seen in this region. The overall length of the structure (approach road, sluice gates, masonry, etc.) is of about 1.5 km. The actual width of the TB portion alone is around 800-850 m and the sill is at an elevation of 3.38 m below MSL. There are around 63 sluice gates; each gate is of around 12.5 m in width. The opening and closing process of the 63 gates of TB is gradual, taking place over a time frame of around 3-4 days.

Among the six rivers mentioned above, four rivers viz., Meenachil, Manimala, Achankovil and Pamba drain to south of TB. When TB is closed during the dry season (January-April), although river discharge is minimal, the river supply from these rivers is hindered to north of TB. However, the shallow regions, south of the TB becomes freshwater dominated due to runoff from the rivers. Thus, TB acts as a river discharge regulator in the system. Therefore, TB when closed separates freshwater regions south of it from saline water regions of Cochin estuary. The exact date of closure of TB is decided based on salinity increase in the area adjacent to TB and the barrage is opened when the river flow increases. Prior to the commissioning of TB, it was possible to cultivate only one crop of paddy a year. A second crop in about 300 ha of the paddy area, cultivation of cocoa, plantain, and vegetables as inter-crops in coconut garden became feasible with the availability of fresh water round the year at the upstream.

The construction of TB has resulted in drastic and ecological changes in Cochin estuary. The barrage has reduced the extent of backwaters nursery grounds by 25% which led to the total collapse of the juvenile shrimp fishery of Kuttanad region (Kannan, 1979). An area of 69 km<sup>2</sup> of brackish water lying south of TB has been economically cut off from backwaters (Gopalan, 1991). The periodical opening and closing TB has seriously deteriorated the ecology of the Cochin estuary especially in the southern part of the barrage as evidenced by the depletion of clam beds (Arun *et al.*, 2009). Construction of TB across Cochin estuary altered the flow patterns and hence enhanced the growth of prevalence of indicator and pathogenic bacteria within the region (Mohamed Hatha *et al.*, 2008). Tidal flushing is restricted due to closure of TB in summer which has eventually resulted in the accumulation of toxic contaminants like heavy metals in the sediments in the area (Harikumar *et al.*, 2009). Proliferation of weeds and water hyacinths upstream has affected the navigation and severely restricts the natural flushing of pollutants (Revichandran *et al.*, 2011).

It is for the first time efforts are made to understand the influence of TB on the hydrodynamics of the estuary using in-situ data. Here, we discuss the tidal amplitude variations, tidal asymmetry, salinity and chlorophyll *a* distribution in the southern arm (from Cochin inlet to TB) of the estuary during the ‘open’ and ‘closed’ conditions of TB. An attempt is also made to investigate the residence time of Cochin estuary for different river flow conditions. This enables us to assess the hydrodynamic controls on phytoplankton biomass.

## **DATA SETS AND ANALYSIS**

We obtained the data sets from major measurements conducted during the period 2007-2008. In the year 2007, 40 days long field efforts were designed to characterize variations in tidal levels. Sea level data were measured at 15 minute intervals at three locations (A,B,C) (Figure. 1) in the southern arm of Cochin backwaters during 30 March, 2007, 0000 hrs to 8 May, 2007, 2345 hrs (Julian day 89-128). Station C is located about 1.5 km away from TB. TB was kept closed during the measurements from 30 March, 2007 to 4 April, 2007 (Julian day 89-94). During the period 5 April, 2007 to 8 April, 2007 (Julian day 95-98), the sluice gates (63 in number) were gradually opened resulting in intrusion of sea water into the southern backwaters. From 9 April, 2007 to 8 May, 2007 (Julian day 99-128), the sluice gates were completely open and as a result the tides forced from the Cochin inlet were felt even in the southern most region. Out of the 40 days data, the first six days pertain to ‘completely closed’

condition, next four days to ‘being opened’ condition and the remaining thirty days to ‘completely open’ condition (Figure. 2). Harmonic analysis was conducted on the sea level data for the open period (30 days), to extract the amplitudes and phases of 26 independent constituents and 8 related constituents using the software TASK2000 (Tidal Analysis Software Kit). These constituents were used to predict the tides for the six days ‘closed’ period of TB. Due to short tidal records, the observed (‘closed’ period) and predicted (‘if open’ period) data for six days were analyzed to extract the amplitudes and phases of only two constituent bands – centered on semi-diurnal ( $M_2$ ) and diurnal ( $K_1$ ).  $M_2$  and  $K_1$  constituents contain energy from other semi-diurnal constituents (egg.,  $N_2$ ,  $S_2$  and  $K_2$ ) and diurnal constituents (egg.,  $O_1$ ,  $P_1$ ) respectively (Pugh, 1987; Shetye *et al.*, 1995).

The second data set comes from the high speed up-estuary transects (Stations 1 to 6) along the channel’s center-line from June 2008 to May 2009 (Figure. 1), during the spring and neap tidal phases. The closing of barrage began on 27 Dec, 2008 and by 31 Dec, 2008 it was fully closed. The sluice gates were partially opened on 29 Mar, 2009 and the barrage was fully opened by 31 Mar, 2009. The CTD was lowered from a speed boat (40 km/hr) at various depths covering six stations along the southern arm of the estuary. A SBE Seabird 19 plus CTD was used for recording salinity (conductivity  $\pm 0.001$  S/m) profiles with a bin size 0.2m. For the present study, the salt intrusion length  $L_2$  is taken as the upstream distance (in km) of 2 PSU isohaline (length from Cochin inlet along the river channel to the point where the bottom salinity was 2 PSU).

In addition, monthly surveys were conducted at stations 1-6 during the mid of each month from June 2008 to May 2009 (Figure. 1). Discrete bottle samples of surface waters were taken for the measurement of salinity and chlorophyll *a*. Water samples were filtered for the subsequent determination of chlorophyll *a* and phaeopigment concentration. Surface salinity was measured with salinometer.

The residence time  $Tr$ , defined as the time required for the total mass of a conservative tracer originally within the whole or a segment of the estuary to be reduced by a factor of  $e^{-1}$  (i.e., 0.37), is given by (Luketina *et al.*, 1992):

$$Tr = \frac{(V + P)T}{(1 - b)P + RT/2}$$

where V is the low tide volume of the whole or a segment of the estuary, P is tidal prism, T is the tidal period, R is the river discharge, b is the return flow factor. The tidal prism of Cochin inlet is estimated at  $107.8 \times 10^6 \text{ m}^3$  during Indian Summer Monsoon (ISM) (June -September),  $18.6 \times 10^6$  during moderate runoff months (October to December) and  $31.5 \times 10^6 \text{ m}^3$  during dry season (Rama Raju *et al.*, 1979). Semi-diurnal period (12.42 h) is the predominant tidal period. Return flow factor (b) is the fraction of ebb water returning to the estuary during the subsequent flood tide and can be taken as 0.5 following S.C.C.C. (1985) and U.S.E.P.A. (1985). The volume of southern arm of the estuary is taken as 360 million  $\text{m}^3$ .

The daily and monthly mean river discharge data for the year 2008-2009 were sourced from the Central Water Commission, Government of India, for six gauging stations corresponding to six major rivers. The discharge was high during ISM with little runoff during dry periods (Figure. 7a). For the present analyses, the river discharge is the sum total of the runoff of rivers flowing into the southern arm of the estuary. The daily mean discharge was used for statistical analysis and for computation of residence time.

## RESULTS AND DISCUSSION

### Tidal propagation

The observed de-measured sea level data at the three stations for forty days (Julian days 89-129) are presented in Figure. 2. The sea level variability was found to be higher at the Cochin inlet (station A) and decreased towards the upstream direction. The spring-neap variability in the sea level was obvious at stations A and B. Evidently, during the barrage closed period; the tides get amplified very much at C and to a lesser extent at B too. It is interesting to point out that the observed tidal range at neap phase during the TB 'closed' period was found to be much higher than the spring phase for the TB 'open' condition.

The amplitude and phases of major tidal constituents derived from one month data at three stations are shown in Table 1. The amplitude of the tidal constituents was higher at station A compared

to stations B and C.  $M_2$  tide dominated the  $K_1$  tide at A whereas at B and C these two constituents were almost comparable in magnitude. The mean spring range was higher at A than neap range but they were comparable at B and C. The form number indicates that there is a slighter increase of dominance in diurnal constituents in the upstream stations when compared to the inlet station. The downstream and farther most upstream regions of this estuary is ebb dominant mainly due to the large width of the channel in these regions where large volume of water is stored during the high tide. The ebb and flood dominance remain the same at stations A and B respectively during both the open and closed period of TB. Interestingly, the station C was transformed from ebb dominant to flood dominant during the closed period of TB. The increase of  $M_4/M_2$  amplitude ratio at this station also indicated higher degree of distortion of tides when the TB was closed (Table. 1). Flood-dominant systems infill the estuary, while ebb-dominant systems flush sediment seaward (Boon and Byrne, 1981; Aubrey and Speer, 1985; Manoj *et al.*, 2009). Change in ebb and flood dominance in this region due to the opening and closure of TB can influence sediment transport pathways and the morphological evolution.

The residuals (difference between the observed tide and the predicted tide) for the 40 days period (including the 6 days ‘closed’ period) are presented in Figure. 3. During the TB ‘closed’ period, even though we did not observe any conspicuous feature at A, distinct wave like patterns were observed at B and C. It shows that the periodicity of this wave is not effectively filtered by tidal analysis. The amplification of these signals was most likely as a result of standing wave formation. To understand this aspect, in detail, and to quantify the amplification, we performed harmonic analysis of tidal signals during the ‘closed period’ and the ‘if open’ period (Table 2 and Figure. 4). The analysis showed that diurnal and semi-diurnal tidal bands got amplified by a factor of 2.6 and 1.6 times at station C when TB was kept closed. The strong amplification signatures of the above two bands were also seen at station B.

### **Salinity distributions and variability**

The salinity transects revealed the dynamics of salinity intrusion under various river discharge conditions and tidal phases. The monthly mean discharge into the southern arm of Cochin estuary during the observation is presented in Figure. 7a. The observations began on 19, June 2008 when the barrage was open. The maximum salinity gradient was marked at station 1 near the inlet and it declined to zero at the station 6 near TB. The salt wedge formation which began in neap of June (Figure. 5b) became more prominent in July as a consequence of high run-off (Figure. 5c). Stratification evolved in the water

column of the estuary allowed the low saline river water at the surface to flow over the high dense water at the bottom. During ISM, salinity (18-34) was intruded into the estuary only through the bottom waters of near inlet stations. All the other stations remained well mixed and salinity profiles were as low as 0.05 until September.

From October to December (Figure. 5i-5m), with the decreasing trend in river flow, the saline water was pushed further upstream. The active displacement of isohalines commenced. A consistent increase in the salinity (~ 3 PSU) was discernible towards upstream. The river flow conditions prevented the intrusion of salinity to station 6. However, during the spring phase of December (Figure. 5m) the river discharge decreased further and the salinity at station 6 was 2 PSU.

The closed period survey began with neap phase of December (Figure. 6a). The peak dry season (January-March) occurred when the river flow was about 30-40 m<sup>3</sup>/s (Figure. 6b-6g). The gradual closing of the barrage compounded with the reduction in the river flow and the tides forced from Cochin inlet triggered the horizontal salinity transport. At least salinity of 14 PSU remained at upstream throughout the closed period which indicates the increase of concentration of salinity compared to high discharge period. The TB was opened in April and the flow from four rivers was allowed to enter the system. Consequently drop in salinity found at station 6, in April and May.

### **Salinity intrusion and river discharge for high and moderate runoff periods**

The above results suggest that the salt intrusion is strongly dependent on river discharge rather than tide during the high and moderate runoff months (TB open period). Minimum salt intrusion of 10 km was attained during the peak monsoon month July when the river discharge was 1118.2m<sup>3</sup>/s. As the river discharge start decreasing in the following months, the salinity field began to expand toward upstream. The maximum salt intrusion was observed under minimum runoff conditions (32m<sup>3</sup>/s) on 19 December, 2008. Salinity intruded until TB achieving an L<sub>2</sub> value of 40.6 km (Figure. 5m).

TB was closed on 23 Dec 2008. Salinity >2 PSU were observed at all stations from 27 Dec 2008 (Figure. 6a-6k). The salinity increase was seen even in the upstream end regions. Several regression equations between salt intrusion and daily mean river discharge were considered. Best results were obtained between L<sub>2</sub> and R using a third order polynomial regression ( $r^2=0.87$ , Figure. 7b). Similar relationship using a second degree polynomial is found in Strymon River estuary (Haralambiduo *et al.*,

2010). Comparing the results of Strymon River estuary, the salt intrusion in Cochin estuary is much more sensitive to changes in river discharge. This is a typical feature of estuaries along the Indian coast line that are influenced by the ISM (Shetye, 2011). Therefore, the empirical equation relating salt intrusion ( $L_2$  in km) and river discharge ( $R$  in  $m^3/s$ ) during TB open period was determined as:

$$L_2 = -6 \times 10^{-08} R^3 + 0.000 R^2 - 0.119 R + 44.50$$

From Figure. 7b it is obvious that the trend in salt intrusion is exponentially decreasing with increasing river discharge when  $R < 400$  and steadily decreasing when  $R > 400$ .

### **Chlorophyll *a***

Figures.8-9 illustrate the seasonal surface concentrations of suspended chlorophyll *a* and salinity along the transect stations of southern arm of Cochin estuary. The trend of salinity intrusion discussed above was also reflected in the observations of surface salinity. Longitudinal distributions of surface salinity in all months showed the upstream progression from coastal waters to brackish or fluvial waters. During the ISM, very low salinity was observed along the surface of the estuary (Figure. 8a-8g). The surface salinity was zero throughout the estuary during July owing to the greater freshwater runoff. During the period October –November, the freshwater runoff was relatively low. As a result, surface salinity of  $> 30$  was seen at ocean-end stations and the salinity of river-end stations also increased (Figure. 8e-8g). From January –March (Figure. 9a-9c), high surface salinity levels were noted at all stations. The spatially averaged surface salinity were maximum (19.95) in February. During April-May surveys (Figure. 9d-9e), TB was re-opened and the river flux into the estuary increased. Consequently, the salinity decreased relatively throughout the southern arm of the estuary.

Chlorophyll *a* levels showed large spatial variability (Figure. 8-9). During TB open period, elevated levels of chlorophyll *a* were observed at the river-end stations 5 and 6 (Figure. 8a-8d). During peak runoff period of July, chlorophyll concentrations of  $7.4 mg/m^3$  were found at upstream end station 6 and of  $4 mg/m^3$  at near inlet station 1. This could signify the dominance of fresh water species advected into the system as a result of freshwater runoff. This situation continued from October to November also but chlorophyll *a* concentrations at stations 5 and 6 increased further to about  $14 mg/m^3$ . During December survey, TB was closed. Coincidentally, the surface chlorophyll *a* at stations 5 and 6 drastically decreased ( $\sim 3 mg/m^3$ ). Stations 3 and 4 were brackish and contained high chlorophyll



concentrations (Figure. 8g). In January, the river flow was very low and there was an overall decrease of chlorophyll *a* (average of 3 mg/m<sup>3</sup>) along the surface of the estuary (Figure. 9a). The low runoff ensured strong saline intrusion which might have provided stress to various organisms. However, the biomass increased at the ocean-end stations by February (13 mg/m<sup>3</sup> at Cochin inlet) whereas decreased at stations 5 and 6 (~3mg/m<sup>3</sup>) (Figure. 9b). Thus, the distributions of chlorophyll *a* were in converse to the TB open period. The higher chlorophyll *a* levels were observed at oceanic salinity indicating the dominance of marine species. When TB was again opened in April, the little river discharge from the four rivers entered into the system. Although suspended chlorophyll *a* levels were higher at station1 (13 mg/m<sup>3</sup>), the concentrations (9mg/m<sup>3</sup>) increased at stations 5 and 6 as well. This possibly arose because the different salinity ranges could have supported a more diverse species population with relatively higher biomass (Figure. 9d-9e).

River discharge is related to the flushing rate and there is a statistically significant negative correlation between discharge and biomass accumulation (Filardo 1985). The residence time was 3 days during high river flow period (June-September) and 11 days during moderate river flow period (October-December). During the low river flow period (January-May), the residence time was highest and ranged from 13 to 14 days. The above discussions of chlorophyll *a* clearly depict the hydrodynamic controls on the biomass. Despite the nutrient enrichment of the estuary during ISM as a result of terrestrial runoff (Joseph S. and Ouseph P.P., 2008), the average surface chlorophyll *a* levels were relatively lower during monsoon (June-September) than during peak dry season. We have speculated on tentative grounds that high flushing during monsoon resulted in low chlorophyll concentration in surface layers where salinity was low. The most likely source for higher chlorophyll *a* concentration in the river-end stations were freshwater runoff from rivers south of TB, although these algae would also be rapidly flushed once they were discharged into the estuary. However, when the discharge decreased during October-November, the flushing reduced and the more residence times favored the sustainability of species in the estuary. During the dry season, the low discharge and the highest water residence conditions resulted in relatively higher biomass accumulation.

## **SUMMARY AND CONCLUSION**

In the present paper, we could bring out the amplification effect on tides when TB was kept closed using a limited 6 day data on sea level. The amplification was to such an extent that the neap phase range

during the closed condition was more than the spring phase range during the open condition. Our study shows that TB has significant role in transforming an ebb dominant region to a flood dominant region, and this can lead to morphological modification of the estuary.

TB acts as a salinity barrage for regions south of it but acts as a freshwater regulator to the estuarine region north of it. During the open period, the salt intrusion was strongly dependent on river discharge in high and moderate runoff months. The position of salinity intrusion was highly dynamic with the distance of upstream intrusion inversely related to river discharge. During dry season, the salinity was regulated by controlled discharges from four rivers south of TB. When TB was completely closed, there was a reduction in the freshwater runoff as the flow from four rivers was impeded. The concentrations of salinity increased throughout the southern arm including the upstream regions.

Chlorophyll *a* levels showed large spatial variability and were dependent on the hydrodynamics of the estuary. It seems that freshwater species dominated upstream which were higher during high runoff months. During dry season, the ocean-end stations exhibited high chlorophyll implying the dominance of marine species. The biomass was generally low during high runoff survey whereas relatively higher during low runoff surveys. With the rapid flushing of Cochin estuary in monsoon season, it is hypothesized that it was not possible for several algal cell divisions to occur before algae were flushed. Under the low discharge and the highest water residence, the estuarine environment supported relatively higher biomass accumulation.

Sarma *et al.*, 2009 documented that the river discharge can alter the trophic status of the estuary influencing the plankton metabolic rates. They found that a net heterotrophy with low gross primary production (GPP) occurred during the peak discharge period in the tropical monsoon driven Godavari estuary. Cochin estuary is same kind, however, without complete cessation after monsoon. In Cochin Estuary, the ratio of primary production to community respiration ranges from 0.05 and 8.5 seasonally (Thottathil *et al.*, 2008). Since TB regulates the river discharge, this barrage can influence the metabolic activity of the estuary. The present study is a persuasive evidence of the hydrodynamic controls on the accumulation of phytoplankton biomass. These findings highlight the need for future studies focusing on the changes in the phytoplankton metabolic activities associated with the opening and closing of TB using a daily measurement strategy.

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**Figure. 1.** The Cochin estuary (West coast, India), showing stations and extent of backwaters, having two inlets to Arabian Sea Munambam (north) and Cochin inlet (middle of the extent of back waters). The time series stations and monthly stations are discerningly marked in the backwaters.

**Figure. 2. (a)** Monthly mean river discharge from January to December. **(b)**Polynomial regression between 2PSU isohaline length and river discharge

**Figure. 3.** Sea level for the period Julian day 89 - 128 (March), 2007 at Stations A-C. The ordinate scale for Station A is different. The box indicates the period during which the barrage was in "being opened" condition (5th April, 2007 to 8th April, 2007 (Julian day 95-98)

**Figure. 4.** Residual sea level for the period Julian day 89 – 128 (March), 2007 at Stations A-C. The period 99-128 was used for obtaining the tidal constituents.

**Figure. 5.** Observed and predicted sea level for the period Julian day 89 – 94 (March), 2007 at Stations A-C. The predictions are based on one month data during which the Thanneermukkam barrage was open (Julian Day 99-128 (March)).

**Figure. 6.** Longitudinal synoptic distribution of salinity measured monthly twice (one spring, one neap) during TB is opened condition starting from June 2008 to December 2008. The Cochin inlet is pointed at “0”. The 2 PSU isohaline is highlighted.

**Figure. 7.** Longitudinal synoptic distribution of salinity measured monthly twice (one spring, one neap) during TB is closed condition starting from december2008 spring observation to May 2009. The Cochin inlet is pointed at “0”.

**Figure. 8.** Monthly surface salinity, surface chlorophyll *a* starting from June 2008 and ending December 2008

**Figure. 9.** Monthly surface salinity, surface chlorophyll *a* starting from January 2009 and ending May 2009.

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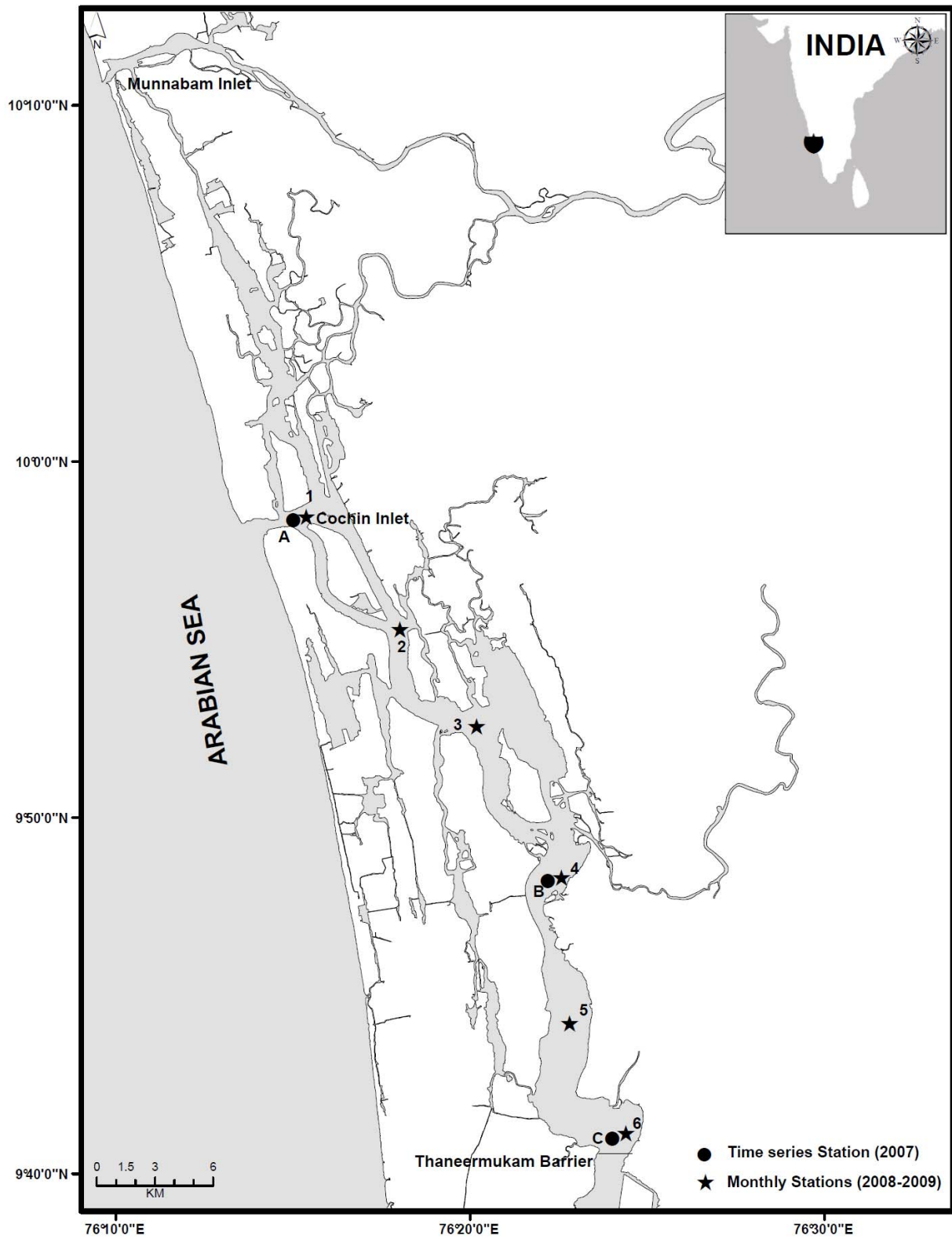


Figure 1

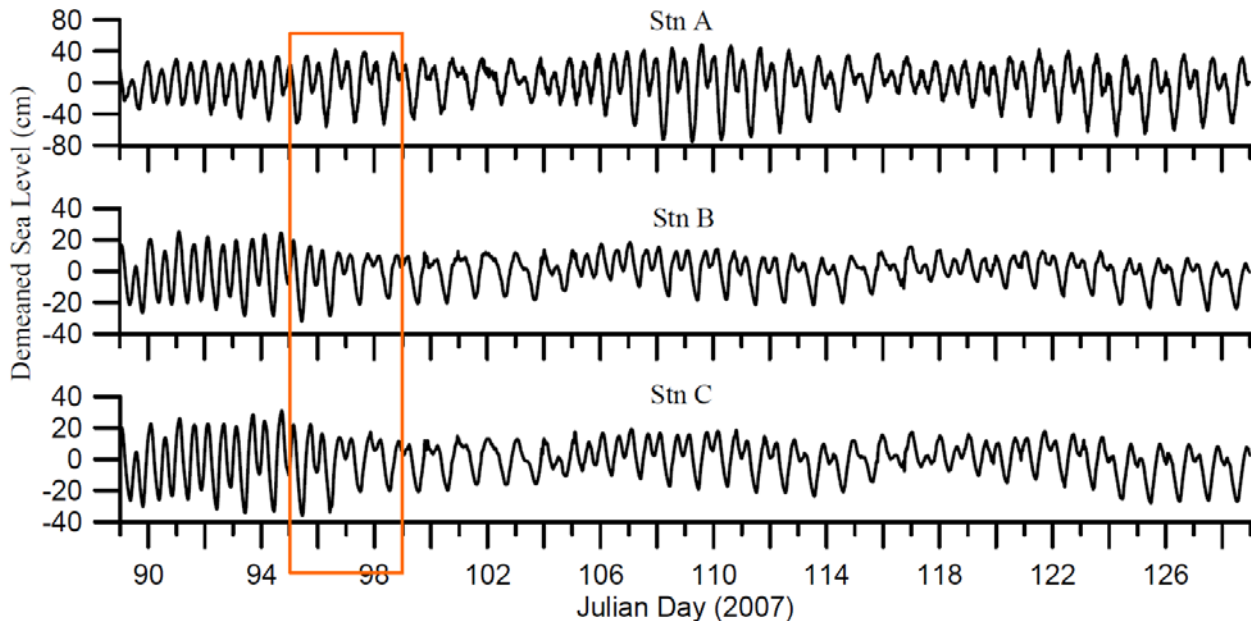


Figure 2

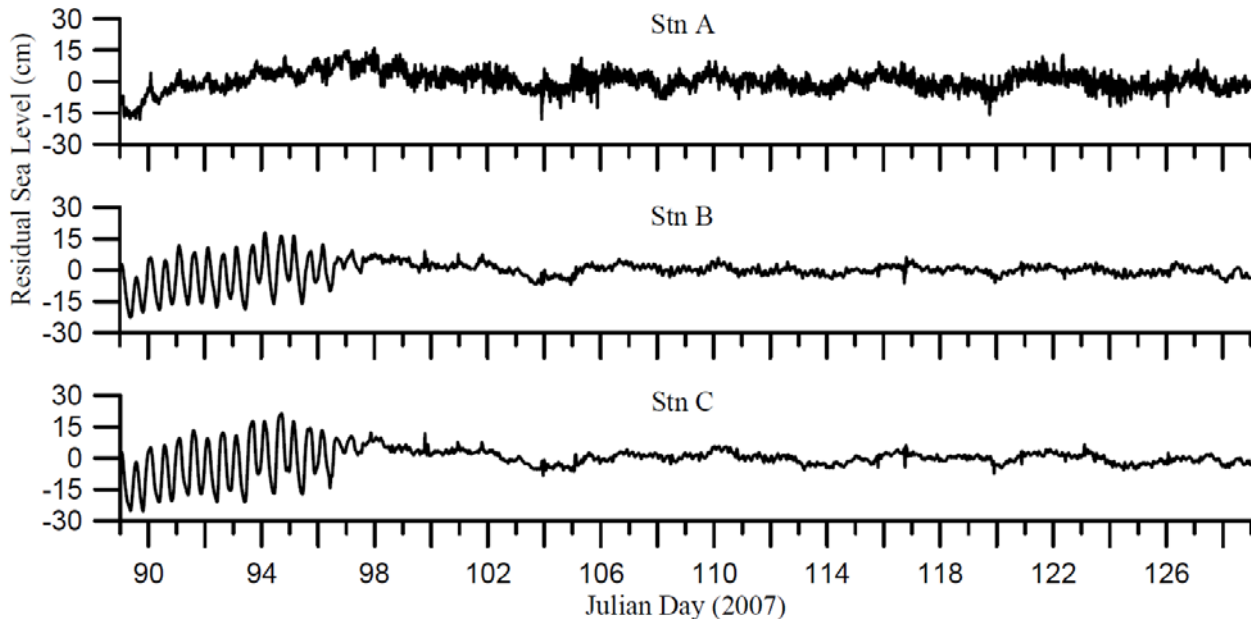


Figure 3

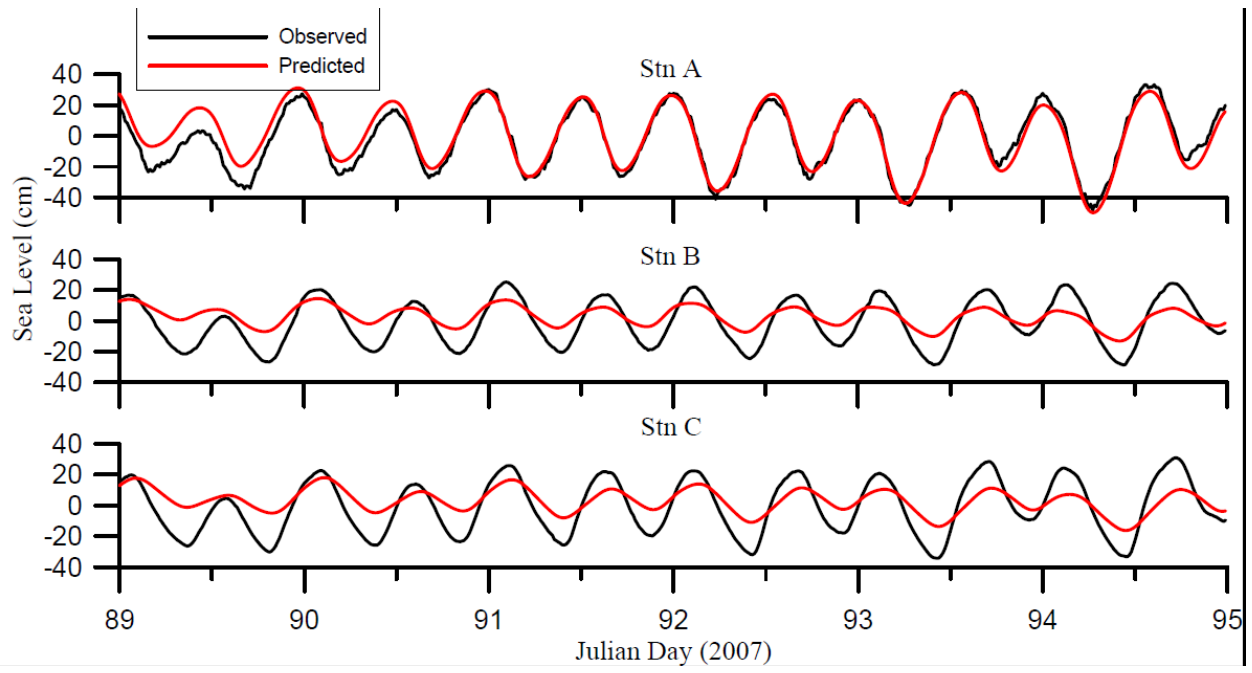


Figure 4



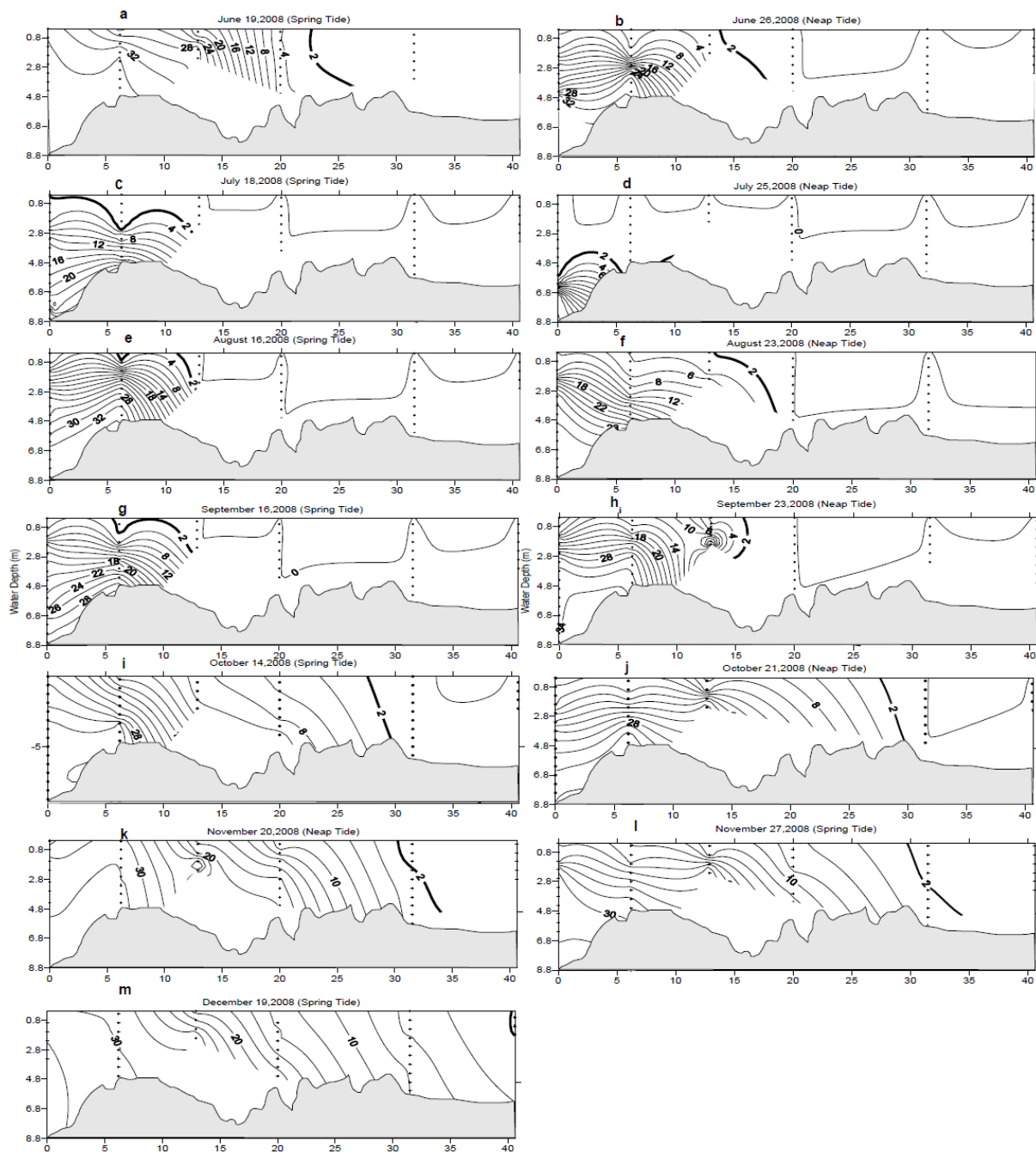


Figure 5

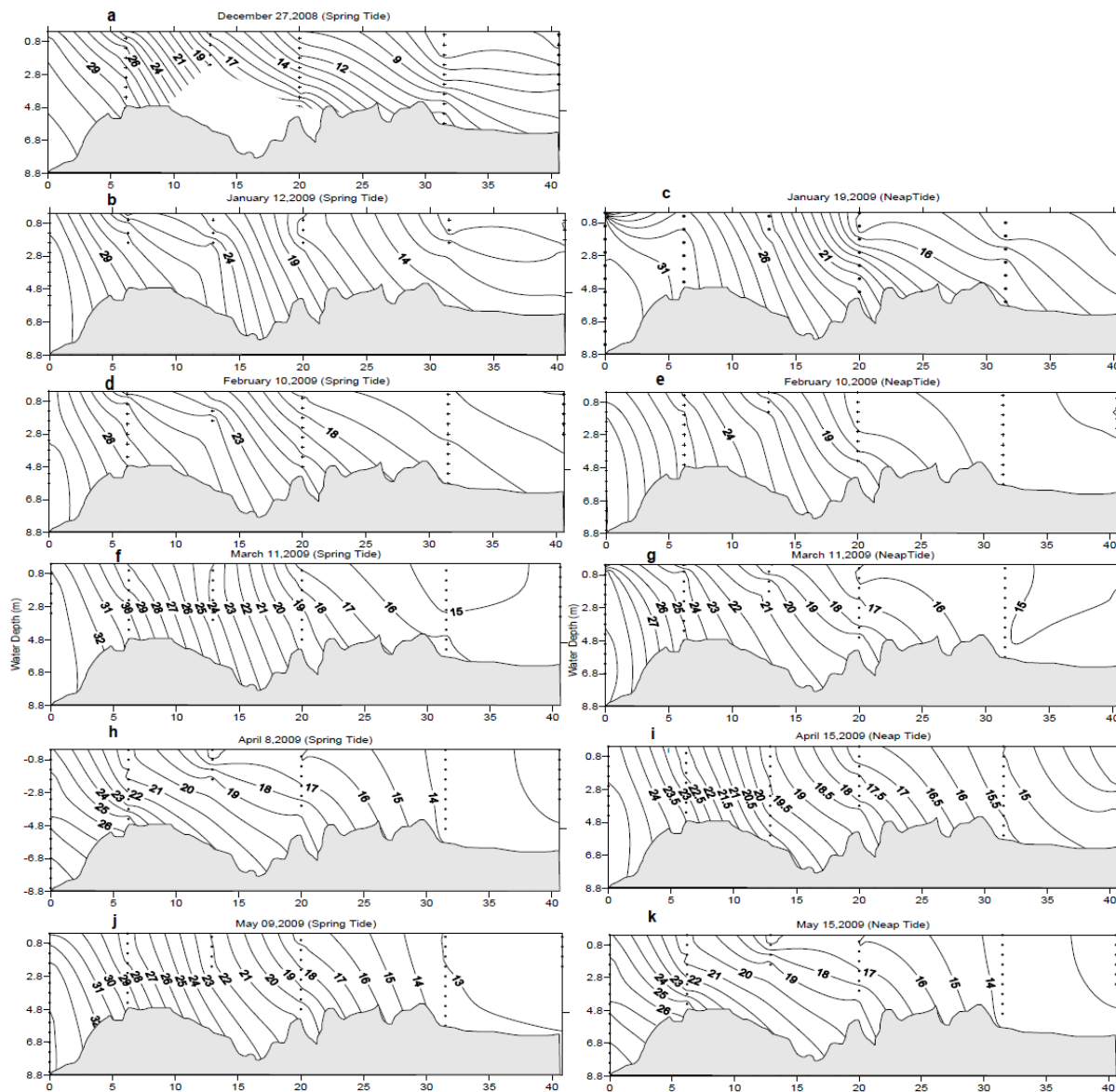


Figure 6

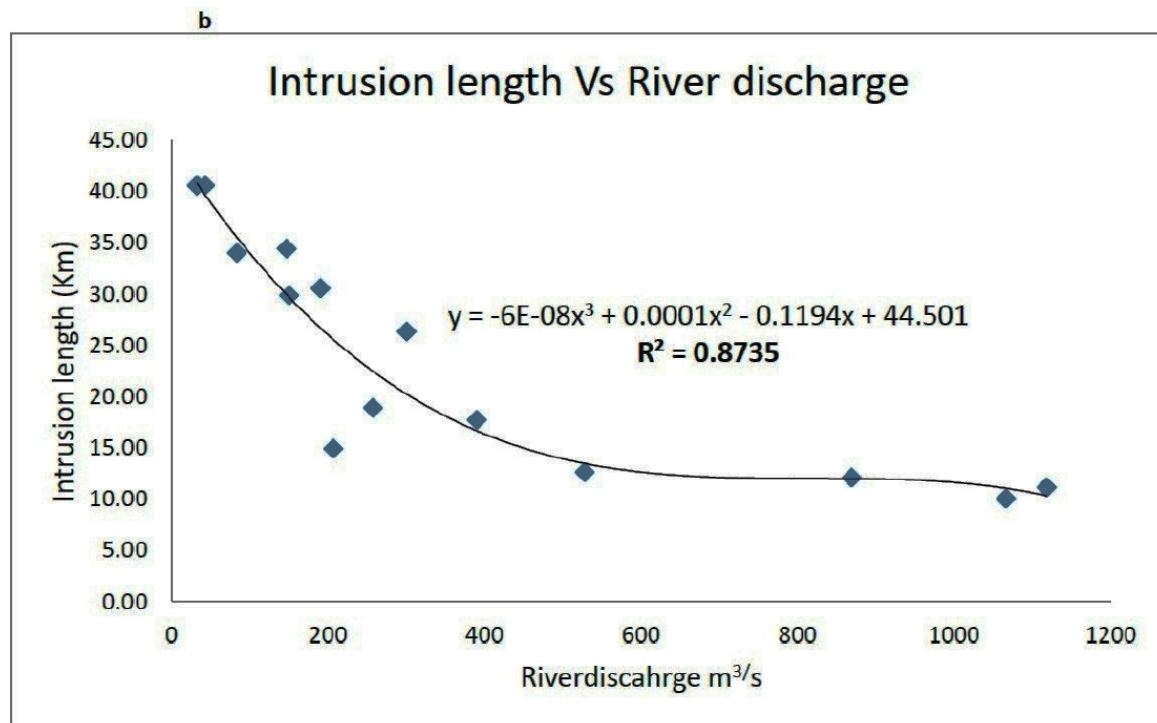
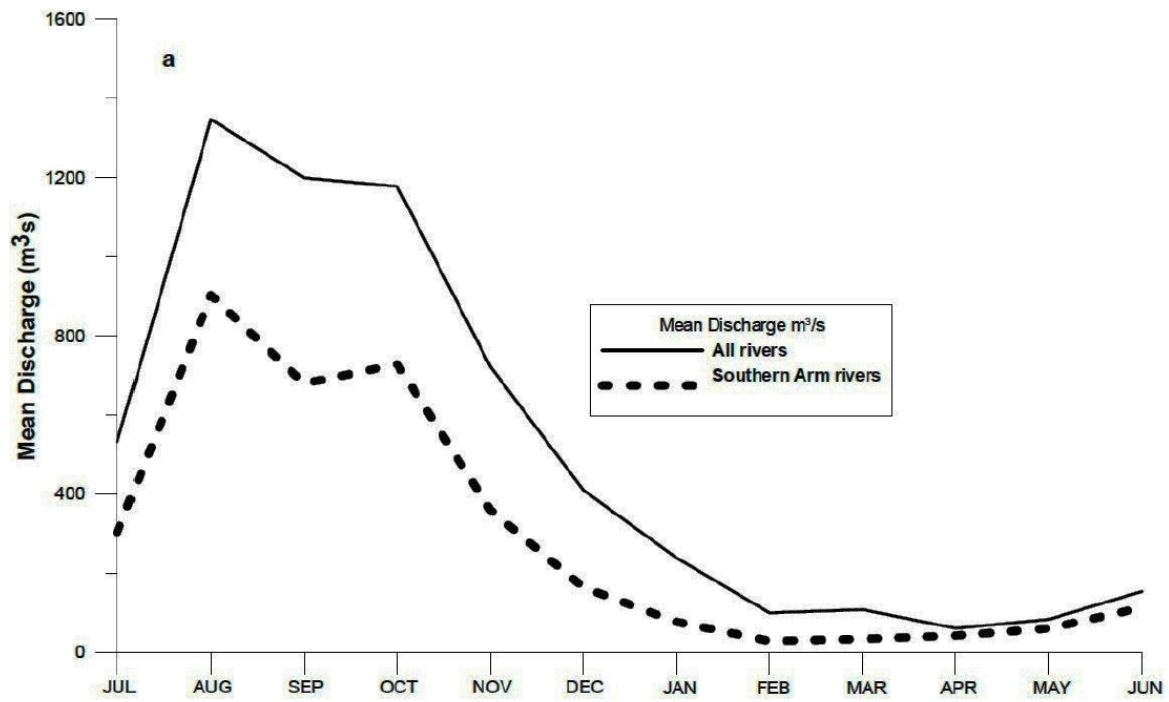


Figure 7

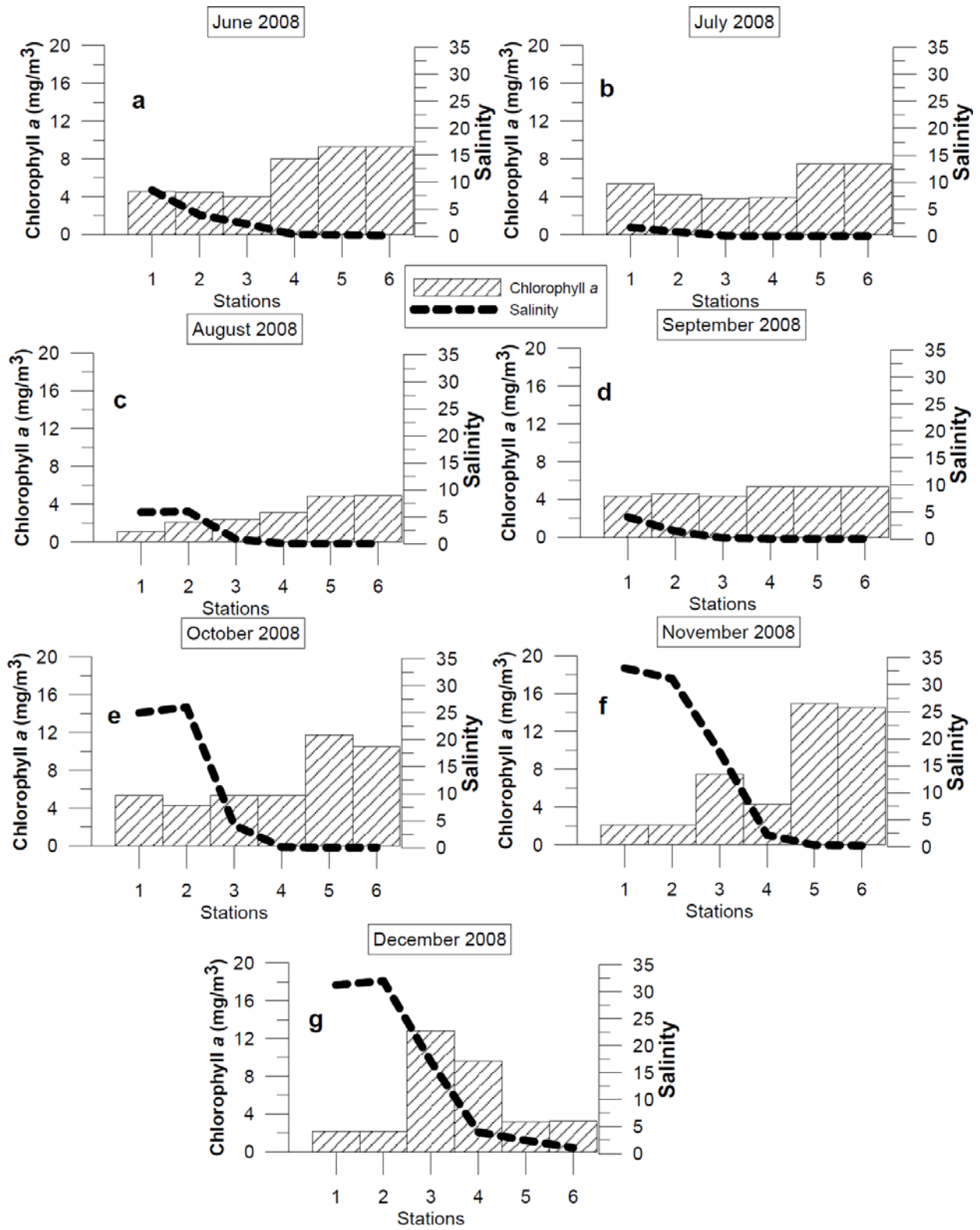


Figure 8

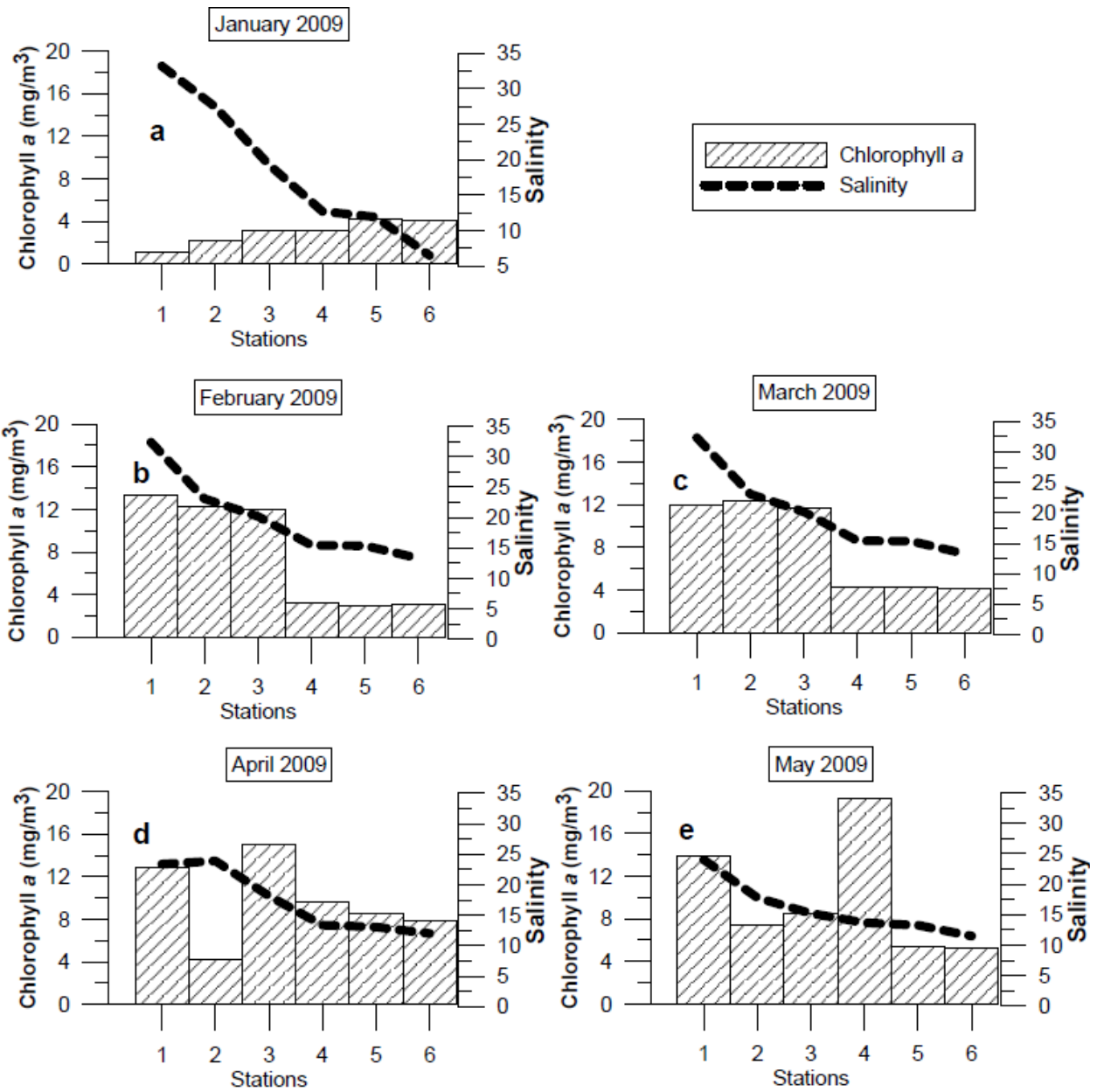


Figure 9

Table 1

Constituents	Stations Closed period			Stations Open period		
	A	B	C	A	B	C
O <sub>1</sub>	8.8 (55.8)	5.3 (89.3)	5.9 (89.8)	9.3 (61.6)	3.6 (91.6)	3.7 (107.2)
K <sub>1</sub>	18.1 (62.5)	12.8 (106.3)	14.8 (96.9)	17.8 (61.8)	6.9 (127.8)	8.7 (131.0)
N <sub>2</sub>	4.9 (303.6)	1.6 (25.0)	1.6 (49.8)	4.9 (303.6)	1.6 (25.0)	1.6 (49.8)
M <sub>2</sub>	27.0 (341.4)	17.2 (63.0)	19.5 (65.7)	23.8 (339.5)	7.0 (59.2)	7.4 (89.9)
S <sub>2</sub>	8.6 (37.6)	6.2 (125.6)	7.5 (125.9)	8.5 (36.1)	2.0 (115.0)	2.5 (146.8)
M <sub>4</sub>	2.3 (140.3)	0.7 (108.3)	0.9 (85.1)	1.17 (98.3)	0.15 (325.2)	0.33 (352.7)
Form Number	0.41	0.77	0.77	0.84	1.17	1.25
Mean Spring Range (cm)	71.2	46.8	53.0	64.6	18.0	19.8
Mean Neap Range (cm)	36.8	22.0	24.0	30.6	10.0	9.8
2M <sub>2</sub> -M <sub>4</sub> (Degrees)	182.6	17.8	46.0	220.7	153.2	187.1
M <sub>4</sub> /M <sub>2</sub> (cm)	0.08	0.04	0.05	0.05	0.02	0.04

\*\* Values within brackets are the phase angles

Form Number =  $(O_1+K_1)/(M_2+S_2)$ ; Mean Spring Range =  $2*(M_2+S_2)$ ;

Mean Neap Range =  $2*(M_2-S_2)$

Table 1 . Amplitudes (cm) and phases (°) during "closed" (March 30- April 4, 2007 ;Julian day 89-94) and "open" periods (April 9-May8, 2007 ;Julian day 99-128) at Stns A-C

Table 2

Station	Diurnal (C)	Diurnal (O)	Amplification	Semi- diurnal (C)	Semi- diurnal (O)	Amplification
A	7.5	5.8	1.3	25.7	25.8	1.0
B	5.6	2.6	2.2	18.8	7.4	2.5
C	6.8	4.3	1.6	22.1	8.6	2.6

Station	Diurnal (C)	Diurnal (O)	Change in Phase (°) (O-C)	Semi- diurnal (C)	Semi- diurnal (O)	Change in Phase (°) (O-C)
A	45.2	36.2	-9.0	9.8	8.2	-1.6
B	94.8	112.0	17.2	101.9	89.6	-12.3
C	78.9	104.5	25.6	102.2	121.2	19.0

Table 2. Changes in the tidal bands (amplitudes /phases) caused by the "closed" bund vis-à-vis "if open" bund during the six days period (Julian day 89-94).

(C) – Closed period; (O) – If open period