Oil dispersion and status of planktonic organisms in Koggala Lagoon

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Abstract

A Bangladeshi merchant vessel, Amaanat Shah, was sunk on 8th September 2006, 9 Nautical Miles (NM) away at 90 m depth off the southern coast. This incident caused an oil spill off Koggala coast and oil entered into the Koggala Lagoon. The aim of this paper is to present the oil dispersion and its effect to the status of planktonic community of the Koggala Lagoon. The oil dispersion in narrow tidal inlets like Koggala Lagoon is mainly driven by surface currents, where surface wind dispersion is relatively low. The Estuary Lake Computer Model (ELCOM) along with the Lagrangian partial tracking method was used to study oil dispersion simulations in the lagoon at different tidal periods. The net oil accumulation inside the lagoon was also estimated due to the residual currents. The planktonic organisms have been studied in 2004-2005 in the lagoon to compare the status of plankton community after oil spill.

The model simulations revealed that oil dispersion in the lagoon was relatively larger on the east side. Abundance and diversity of zooplankton was comparatively low where oil was accumulated, particularly in the eastside of Madolduwa. Chlorophyll-a content also decreased up to 1.5 mg m^{-3} in the same area. High chlorophyll-a content of 3.5 mg m^{-3} observed at the lagoon mouth was similar to that recorded in 2004 September.

Keywords: Chlorophyll, Koggala Lagoon, oil dispersion, phytoplankton, zooplankton

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Introduction

Bangladeshi merchant vessel, Amaanat Shah was sunken on 8^{th} September 2006, 9 Nautical Miles (NM) away at 90 m depth off the southern coast of Sri Lanka. This incident caused an oil spill off the coast and oil entered into the Koggala Lagoon (Fig. 01) with the tidal currents. Factors which have proven to be important in determining oil spill impacts and subsequent recovery rates include oil type, oil loading (thickness), local geography, climate and season, the biological and physical characteristics of the area, relative sensitivity of species and biological communities, and the type of clean-up response (Dicks, 1998).

Planktons are free-floating small, usually microscopic, plants (phytoplankton) and animals (zooplankton) in aquatic systems that are unable to swim against currents. Studies have shown that eggs and larval stages of planktonic community are more vulnerable to oil pollution than adults (Dicks, 1998). Even though many commercial species spawn over a vast area, direct effect of oil pollution on plankton has been recorded (IPIECA report, 1997). It has also been shown that planktonic organisms which live in surface waters can be variously affected by oil, but no long-term effects have been recorded due to their huge regenerative potential, as well as immigration from outside the affected area (Dicks, 1998). However, there is no clear evidence that oil pollution has any effects on fish stocks (Alvinge, *et al.*, 2001).

The oil spill off Koggala coast consisted of viscous heavy oil that can harm tiny organisms like plankton through smothering; lighter oils travel with water. Also planktonic organisms, which live in the water column travel with water currents, as they show no resistance to currents. The aim of the studywas to understand the oil dispersion pattern and its influence on the status of planktonic community of the Koggala Lagoon by comparing with previous data.

Hydrodynamic-numerical models are well established in simulating ocean currents in coastal regions. They may be used in a predictive capacity, in which current information is used with predicted wind data to forecast the spill trajectory. This can be done using two main approaches by modelling with the advection-diffusion equation, or using particle tracking.

Oil dispersion in offshore mainly depends on the thickness or "viscosity" of the oil, and the surface winds, waves and currents. An oil slick usually drifts in the same direction as the wind. In the near shore regions and coastal inlets however, bathymetry and tidal currents may play major roles in oil dispersion. Here we used a model to understand oil dispersion into the Koggala Lagoon forced by wind and tidal currents.

Material and Methods

Study area

Koggala Lagoon is situated along the country's southern coast at a distance of 130 km from Colombo. The lagoon covers 7.27 km^2 and has a maximum depth of 3 m. The lagoon consists predominantly of open water and encloses 14 small islands. The third free trade zone in the country, a small air force base and tourist resorts are located in the southern border of the lagoon. The lagoon connects with the sea via a narrow and long natural canal, locally known as the Pol Oya. A groyne near the lagoon mouth facilitates water exchange with the open sea throughout the year. Two streams enter the lagoon at the north, whereas main river input is from the Warabokka Ela (Fig. 1). The total fish production of the lagoon was 7.7 tons during 2004-2005, of which around 47% were prawn varieties (Fernando, 2005).

The spring tidal range inside the lagoon is about 10 cm, which is only 15% of the oceanic tidal range. The phase lag between open sea and lagoon basin is about 1hr 30 min (Jayasiri, 2005). The average salinity level has been reported have to increased from 4.8 psu during 1991-93 to 24.1psu during 2001 and 27 psu during 2004-2005 (Alwis and Dasanayaka,1994; Fernando, 2001; Jayasiri, 2005).

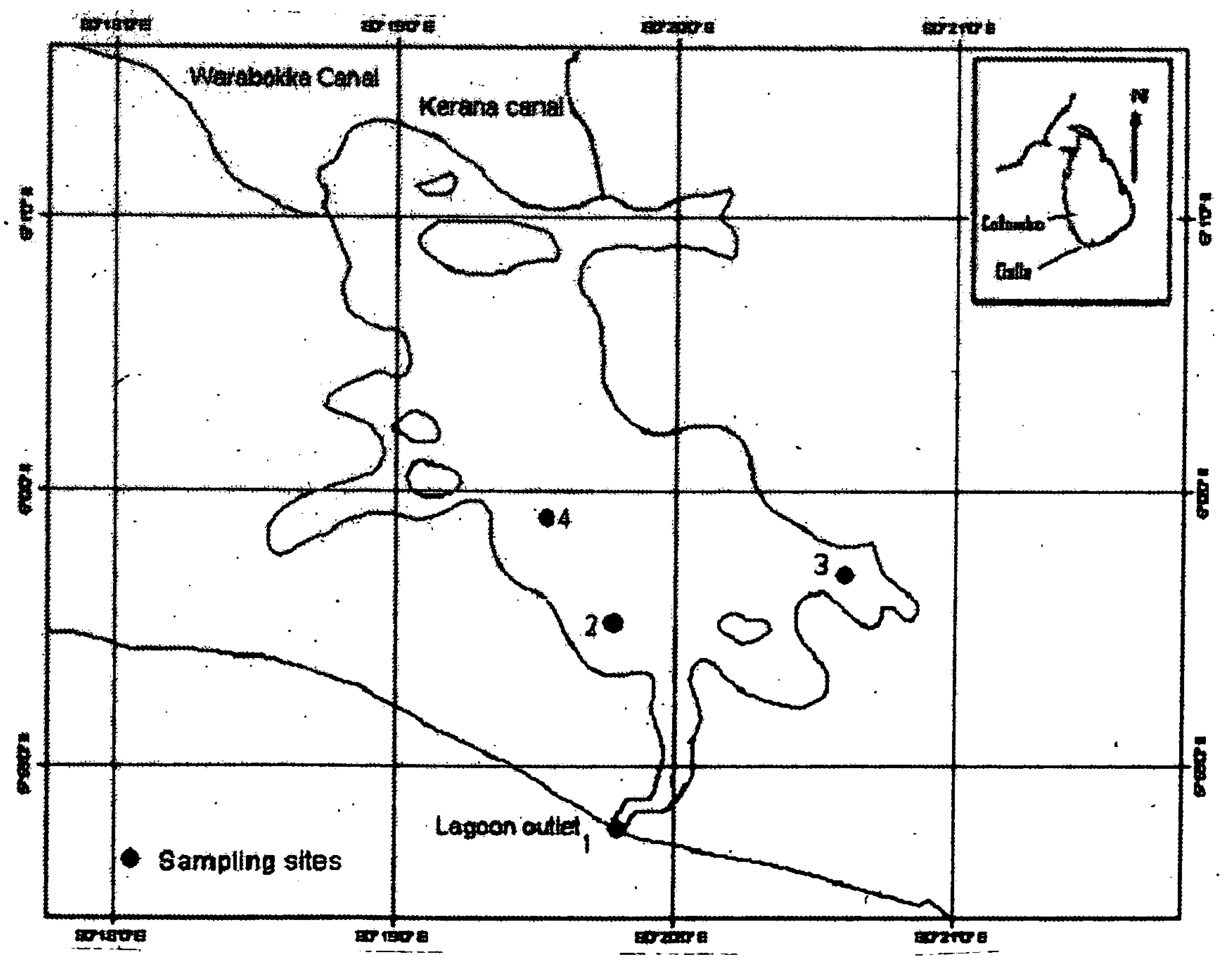

Fig. 1. Koggala Lagoon showing sampling locations

Field visit and Sampling

Field visit was carried out on 19th September 2006 to collect zooplankton (Goswami, 2004) and phytoplankton (Verlencar & Somshekar, 2004) samples at four locations in the Koggala Lagoon. One sample was from the lagoon mouth and 2nd and 3rd samples from east and west of the Madolduwa Island. Fourth sample was from the non-impacted area near the Air Force camp (Fig. 1). In-situ measurements were carried out for Dissolved Oxygen (DO), turbidity and temperature. Water samples were analysed for chlorophyll-a concentration (Parsons and Strickland 1963; Parsons *et al.*, 1984). Phyto and zooplankton samples were analyzed for abundance and composition (Verlencar & Somshekar, 2004; Goswami, 2004).

Modelling of Oil Spill Dispersion

Oil spill dispersion into Koggala Lagoon was simulated using the Estuary Lake Computer Model (ELCOM) along with Lagrangian partial tracking method. Bathymetry data (source National Hydrographic Office, NARA)was used as model input. Prior to the dispersion simulations, the ELCOM program was run to obtain time series surface velocities at grid points forced by wind and open ocean sea level. Grid mesh size was taken as 15 m in both longitudinal and cross axis and time interval Dt, was chosen as 15 sec. Neutrally buoyant conservative particles were released at the open boundary and assumed 3% of 5 cm surface layer with oil. Continuous oil supply was considered at the open boundary. The neutrally buoyant particle displacement at a single time step in longitudinal x direction is $Dx = uDt \pm (2K_x(u)\ Dt)^{1/2}$ and in the y direction correspondingly $Dy = vDt \pm (2K_y(v)\ Dt)^{1/2}$. The turbulent diffusion coefficient, $K_x(u)$ depends on the flow speed and depth of the mixing (Fischer *et al.*, 1979) layer: $K_x(u)=C_d^{1/2}ukd_m$. Particles were free to move between the grid points, and therefore the velocity computed by the model was linearly interpolated for the instantaneous particle positions prior to integration.

Results

Zooplankton abundance

Zooplankton abundance of the Koggala Lagoon varies seasonally and spatially. Previous studies showed that abundance was highest in May and lowest in March (Jayasiri, 2005). Abundance also increased along the longitudinal axis from mouth to head of the lagoon. Zooplankton abundance after ten days of oil spill varied between 17 – 316 indivi./l at four locations studied as shown in figure 2. Lowest abundance of zooplankton was observed at the location (east of the Madolduwa) adjacent to the oil slick in the lagoon. The location from a non-oily area which is location no. 4 showed highest zooplankton density. Zooplankton types recognized during the study period are Calanoid copepods, Cyclopoid copepods, Harpactocoida, Cladocera, Ostracode, Nauplii, Cilliate, Hydrozoa, Foraminifera, Decapoda, Chaetognatha, fish larvae/eggs, Cirripedia, uphausiacea, Cumacea, Polychaeta, Echinodermata, Urochordata and Mollusc eggs/ bivalve eggs.

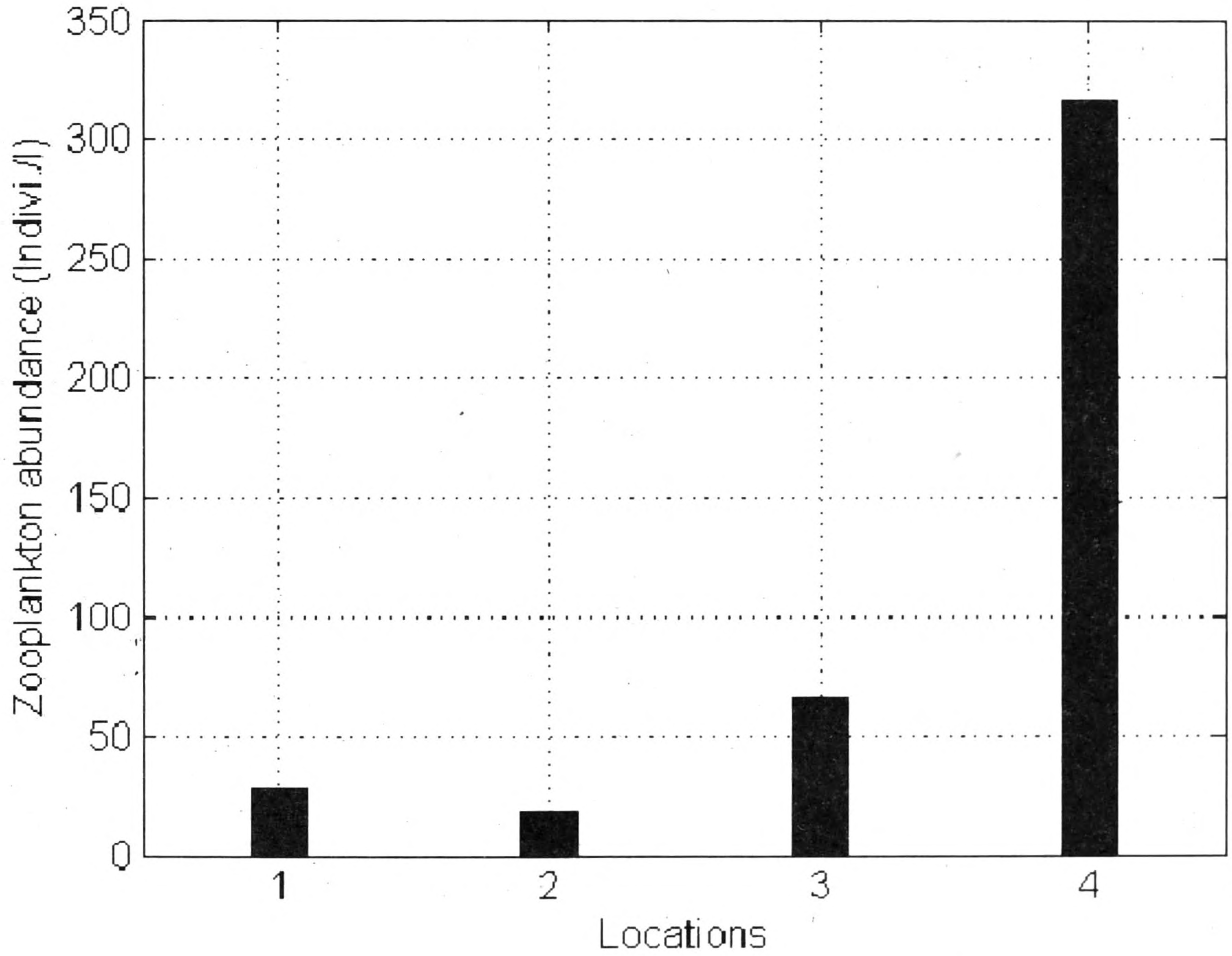

Fig. 2. Zooplankton density after oil spill in Koggala lagoon at four sampling locations

Phytoplankton and chlorophyll-a

Chlorophyll-a (chl-a) content in water which is an indicator of phytoplankton biomass decreased from 3.8 to 1.5 mg m^{-3} at location 2 (Fig.3), but at the mouth, chl-a content has remained high (3.5 mg m^{-3}). There is a good correlation (Pearson r =0.899) between the phytoplankton density and chl-a concentration.

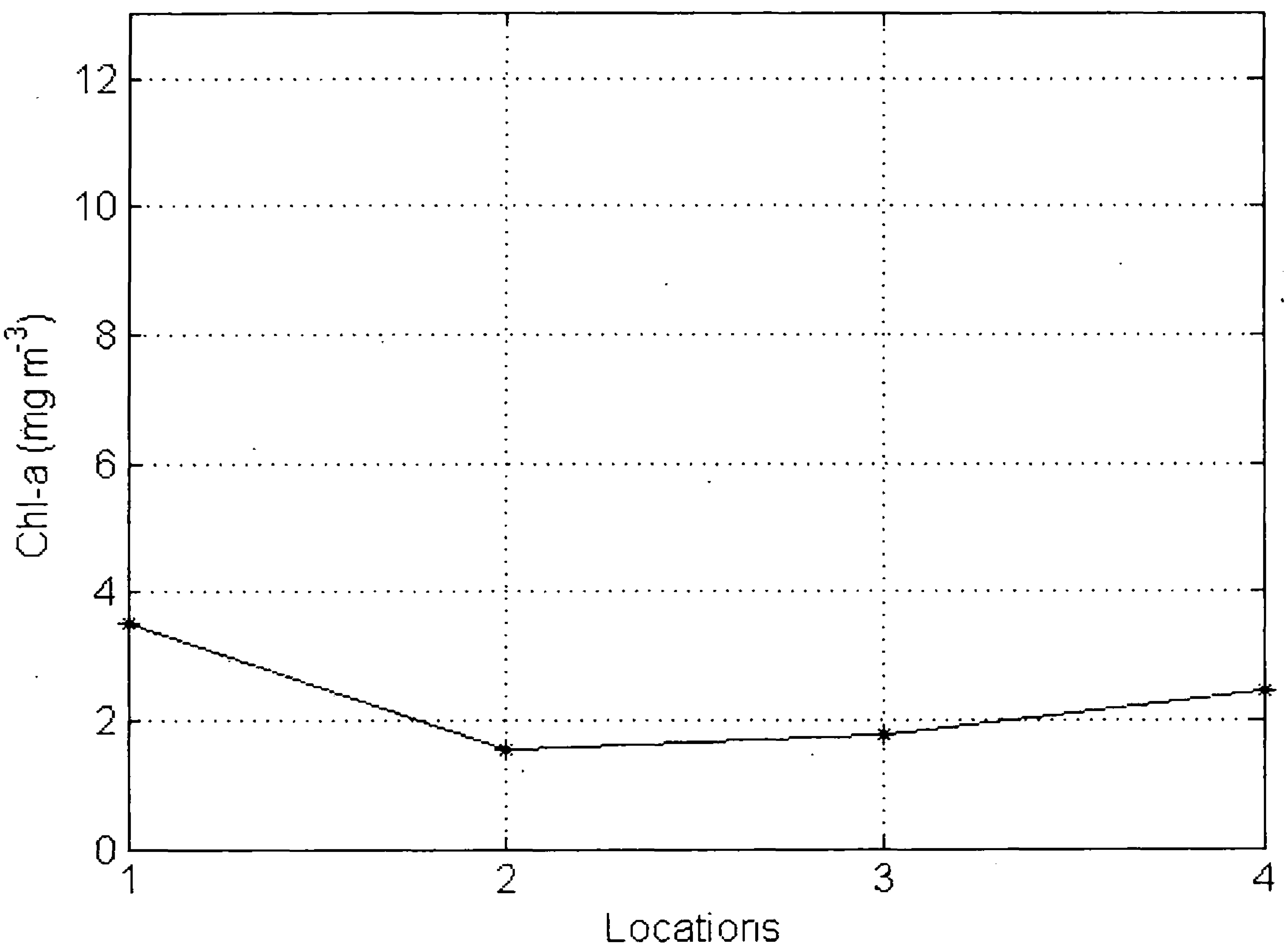

Fig 3. Chlorophyll-a variation in Koggala lagoon after the oil spill, September 2006.

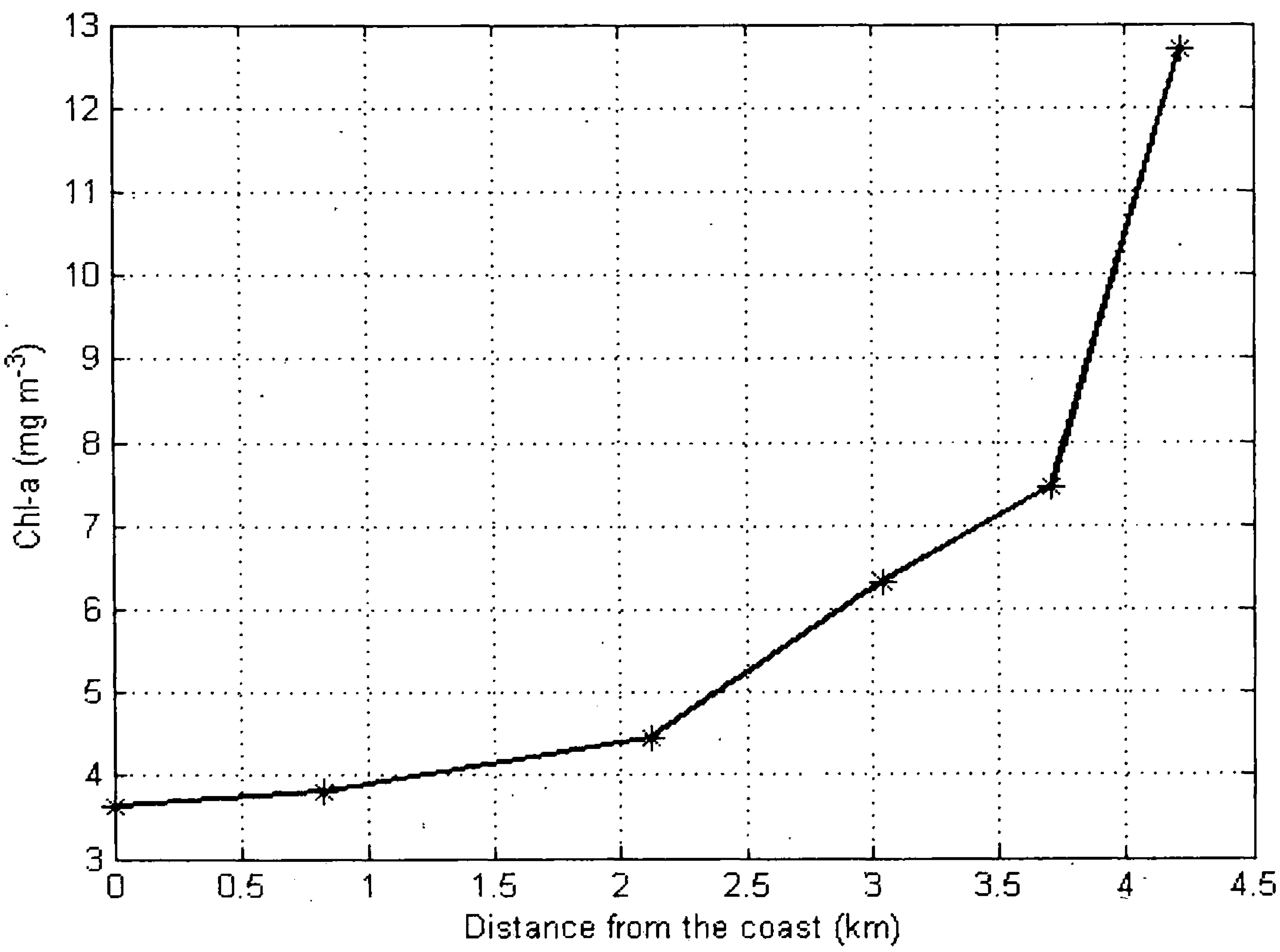

Fig 4. Chlorophyll-a variation in from the mouth to head of the Koggala lagoon in September 2004.

In September 2004, chlorophyll-a varied from 3.7 mg m^{-3} at the mouth to 12.8 mg m^{-3} at the head of the lagoon. A similar chlorophyll-a content was recorded at the mouth after the oil spill, but a lower value was observed at other locations when compared to September 2004, indicating low abundance of phytoplankton. Lower values of both phytoplankton abundance and chlorophyll-a content at location no. 2 indicates the impact of the oil slick on phytoplankton abundance.

Phytoplankton species richness was high (17 genera) at the mouth of the lagoon indicating the dominance of diatoms. Lowest diversity was found at location no. 2 (8 genera).

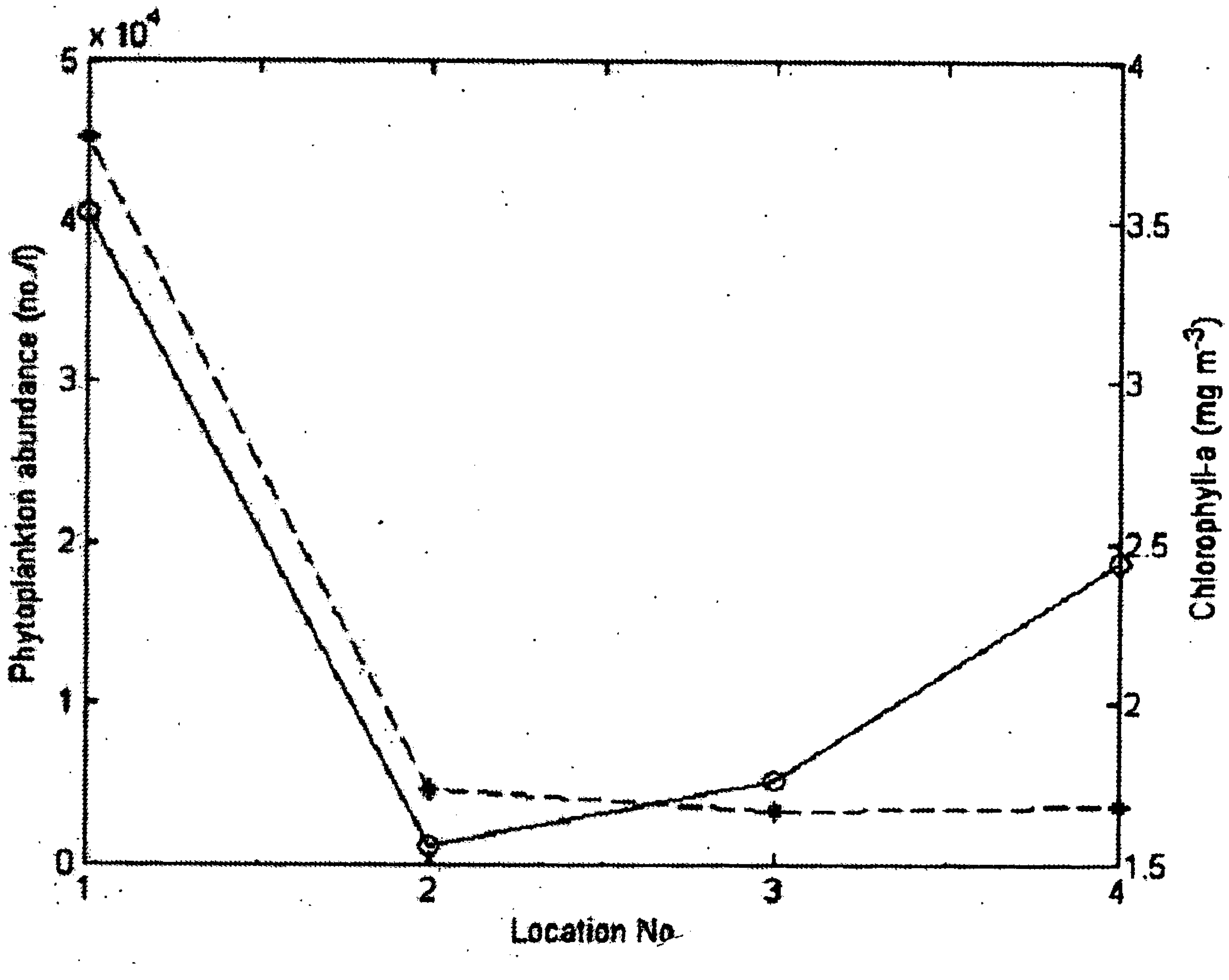

Fig. 5. Chlrophyll-a and phytoplankton density at the four sampling locations in Koggala Lagoon after the oil spill. (Phytoplanton density -------- , Chlorophyll ______)

Phytoplankton species identified in the four sampling locations are categorized under two groups which are Bassilariophyceae (Diatoms) and Dinophyceae (Dinoflagellates). Bassilariophyceae species are *Navicula* sp., *Thalassionema* sp., *Thalassiosira* sp., *Chaetoceros* sp., *Eucampia* sp., *Nitzschia* sp., *Leptocylindricus* sp., *Pleurosigma* sp., *Rhizosolenia* sp., *Cerataulina* sp., *Coscinodiscus* sp., *Asterionellopsis* sp., *Asterionella* sp., *Guinardia* sp., *Melosira* sp., *Bacillaria* sp., *Bèllerochea* sp., *Bellerochea* sp., *Biddulphia* sp., *Striatella* sp., *Dictyocha* sp. *and Dactyliosolen* sp. Also two Dinophyceae species of *Ceratium* sp. and *Peridinium* sp. were recorded in the study area.

Water quality parameters

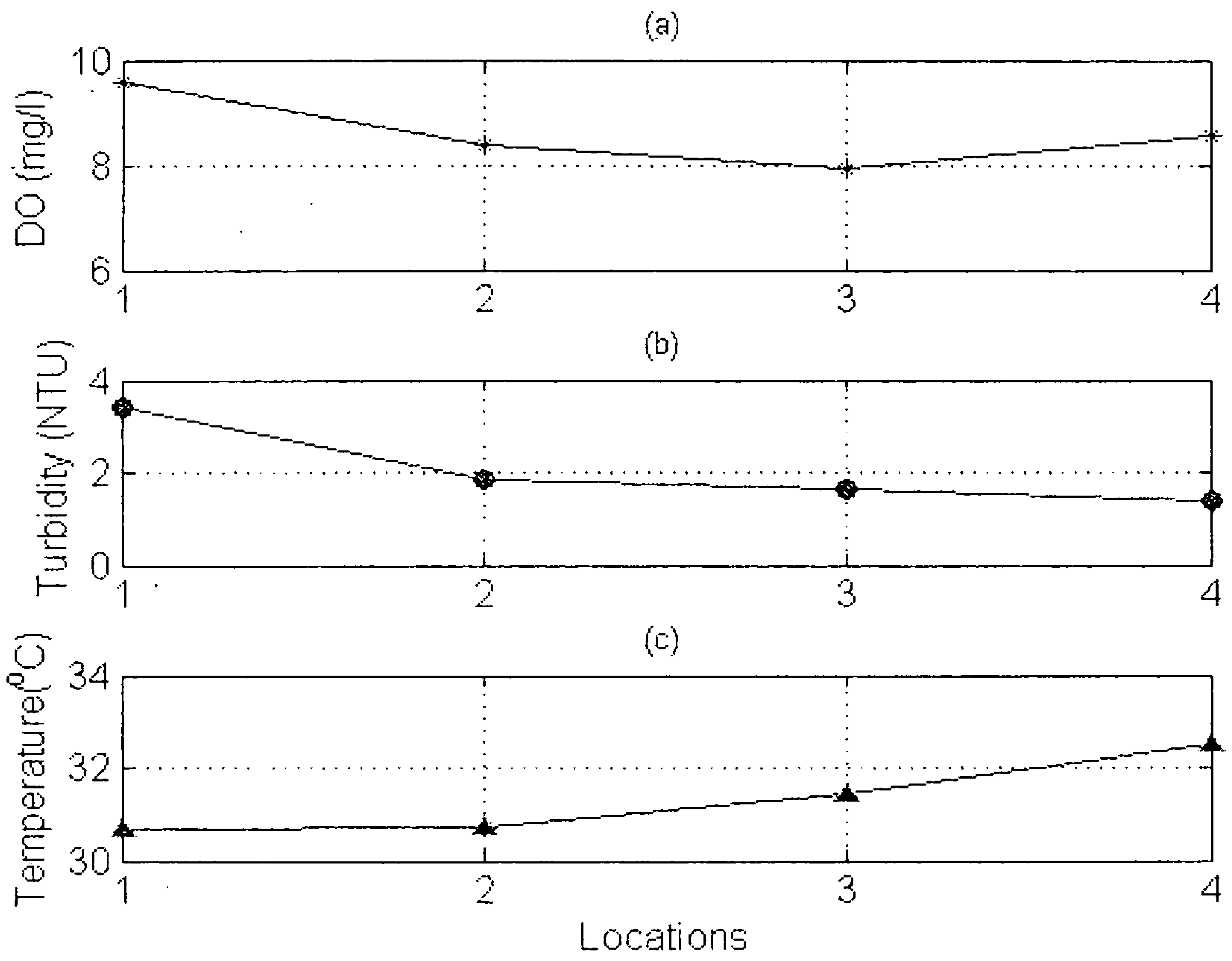

Fig. 6. Variation of water quality after the oil spill in September 2006. (a) DO (b) Turbidity (c) Temperature of four sampling sites in Koggala Lagoon.

DO levels varied from 8.3-9.8 mg/l at the four locations studied indicating acceptable levels for aquatic organisms. Turbidity values ranged from 1.8-2.8 NTU and water temperature varied from 30.6-32.2 °C. The measured water quality parameters are within the range of acceptable levels and no changes from previous studies were observed due to the oil spill.

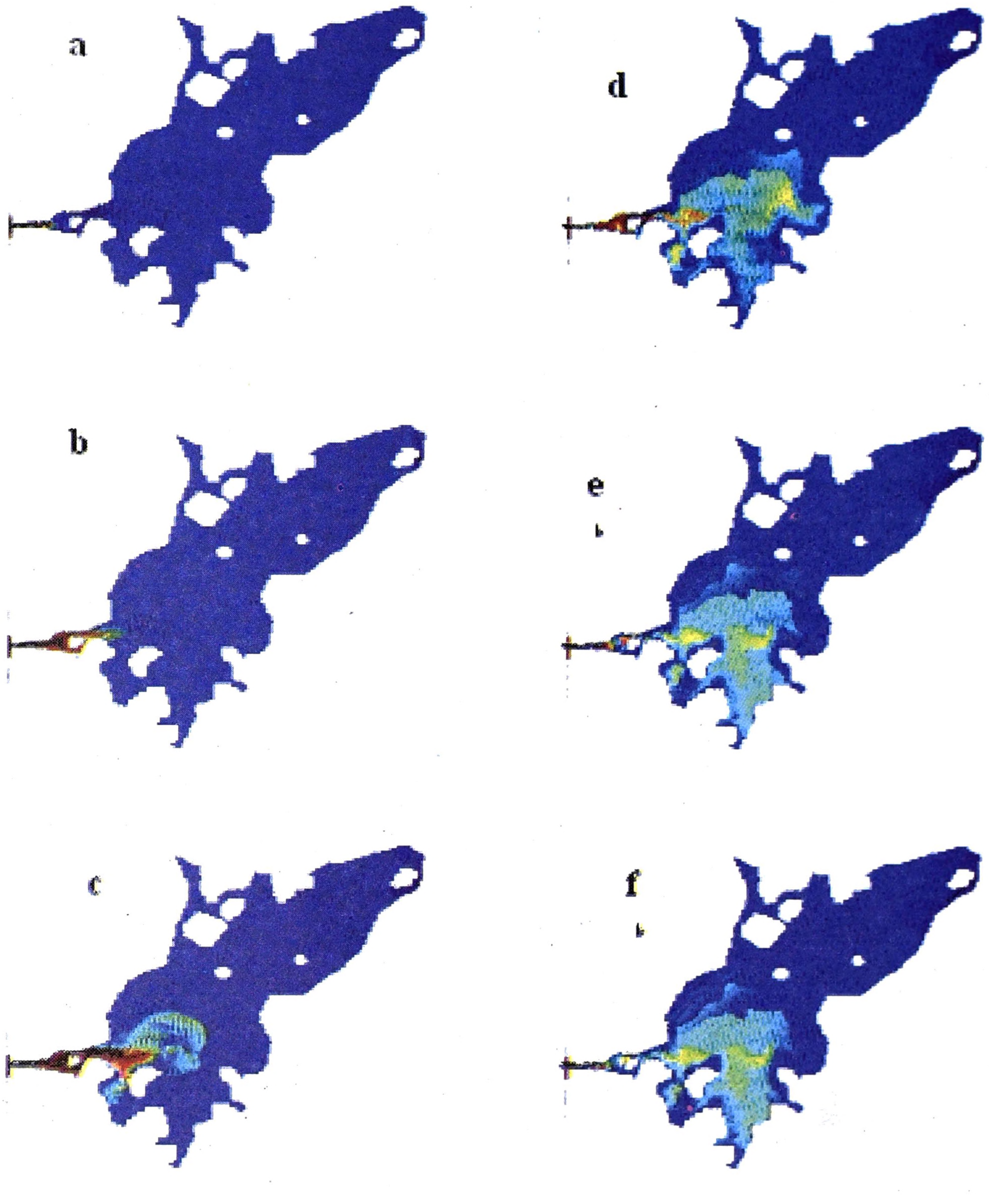

Fig. 7. Oil Dispersion at Koggala Lagoon at Different tidal times (a) at low water, (b) 03 hrs after low water, (c) 06 hrs after low water, (d) at high water, (e) at 03 hrs after high water and (f) 06 hrs after high water

The model simulation of oil dispersion into the Koggala Lagoon at different tidal times are shown in figure 7. Here we assumed continuous oil supply at the mouth and oil transport along the narrow inlet canal by surface current (Fig. 8). The calculated oil transported into the lagoon during flood is about 194 m^3 and removed during the ebb is about 185 m^3.

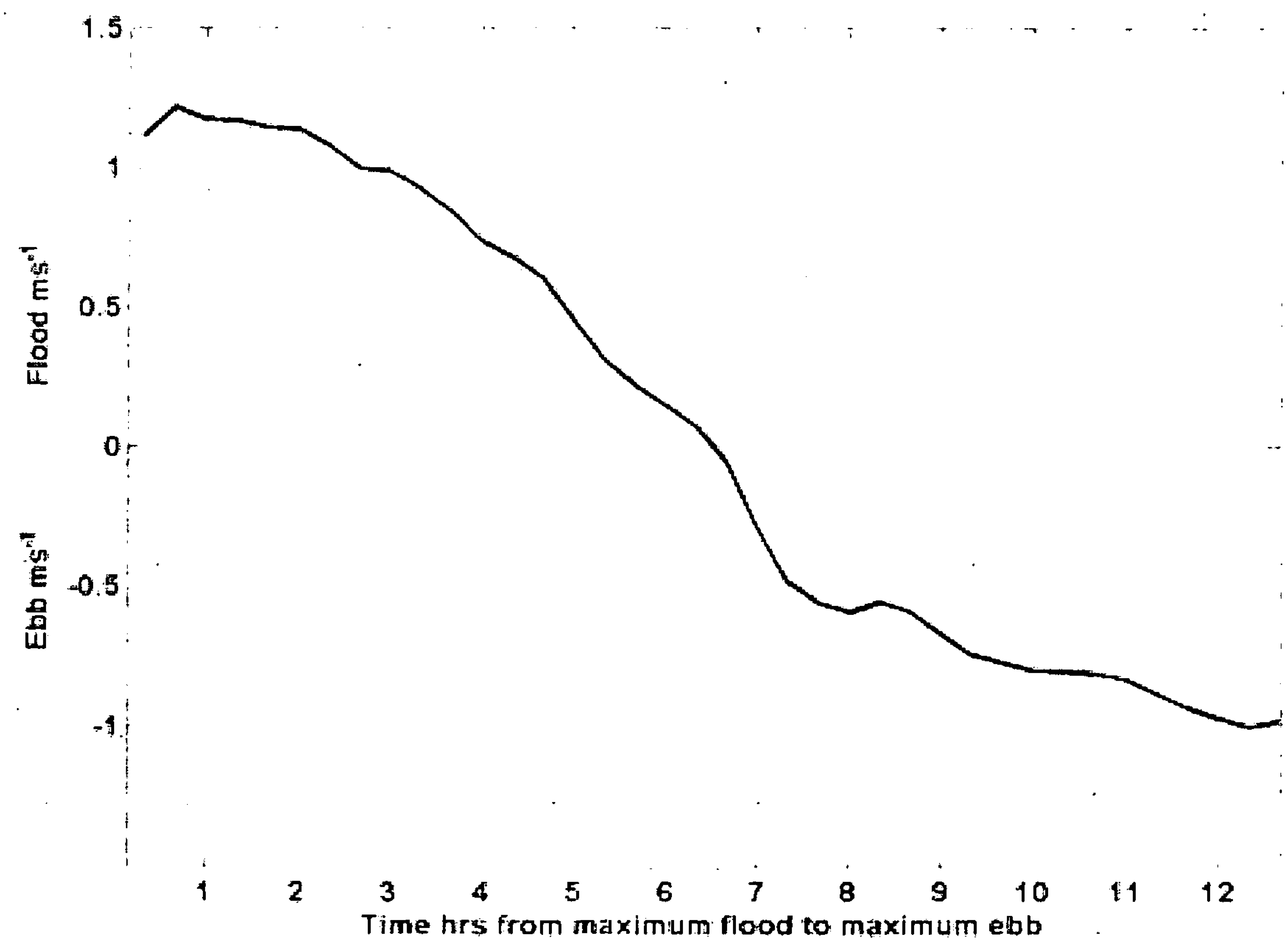

Fig. 8. Surface layer current speed at inlet from maximum flood to ebb.

Discussion

In this study, we have investigated the possible impact to the biological environment in the Koggala Lagoon due to the oil slick from the Bangladesh merchant vessel, Amaanat Shah, which was sunk 9 NM away from the coast. Plankton and water quality status of the lagoon after the spill were compared with previous data to evaluate the impact. The limited number of samples collected after the oil spill prevented a better comparison. Results clearly show the changes of composition and abundance of zooplanktonic organisms, but the phytoplankton status could not be compared due to lack of previous data; only although, chlorophyll-a levels could be compared.

If the oil slick entered the lagoon during the spring tide, it could cause more damage to the ecosystem but the impact was minimized by the low mean sea level in the month of September (Jayasiri, 1998). There was no field data available on amount of oil removed from the lagoon to validate the model results. The observation showed that oil dispersion and accumulation are correlated with field observations. The ELCOM model was run only for one tidal cycle, but for better results we need to run the model for more tidal cycles. Here continuous oil supply at sea mouth is assumed and that the oil is transported along the narrow inlet canal only by the surface current. Never the less continuous oil layer with a thickness of 1 cm to the lagoon was considered during the tidal cycle.

Conclusion

Diversity of taxonomic groups of zooplankton was lower at the location where more oil was concentrated (east side of Madolduwa). Water quality parameters were within the acceptable range. Chlorophyll-a concentration decre
ased at location 2. Also the phytoplankton abundance and diversity was low at location 2 (eastof Madolduwa).

The model runs were made only for single tidal cycle, thus simulated oil slick accumulation inside the lagoon may have been underestimated. The ELCOM model along with lagrangian particle tracking approach can be used to simulate the oil slick dispersion in narrow tidal inlets such as Koggala Lagoon.

Acknowledgements

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