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Assessment of Short Term Environmental Impacts on Dredging in a Tropical Estuary

Abstract

Dredging, while earlier an art, is at present a scientific subject that successfully reflects human skills. This artificial process attempts to win material for beach nourishment, for making roads and railways or for removing settled sediments to facilitate marine transportation. The process, of course, brings about environmental problems in short and long time scales in marine and estuarine environments. This study mainly looks at the short-term impacts of dredging in the estuarine environment of Cochin harbour, India.

As expected, the results indicate only transient changes, mainly during the time of dredging. On the other hand, precipitating or long-acting perpetual fluctuations are time bound reversible and are environmentally acceptable. The estuary being variant in hydrographic features, adds significance to this study in regulating the short-term impacts.

Introduction

Cochin is the second largest port along the west coast of India. Historically, this area is known for trade, commerce and cultural activities with other countries especially Arabia, Portugal and Holland.

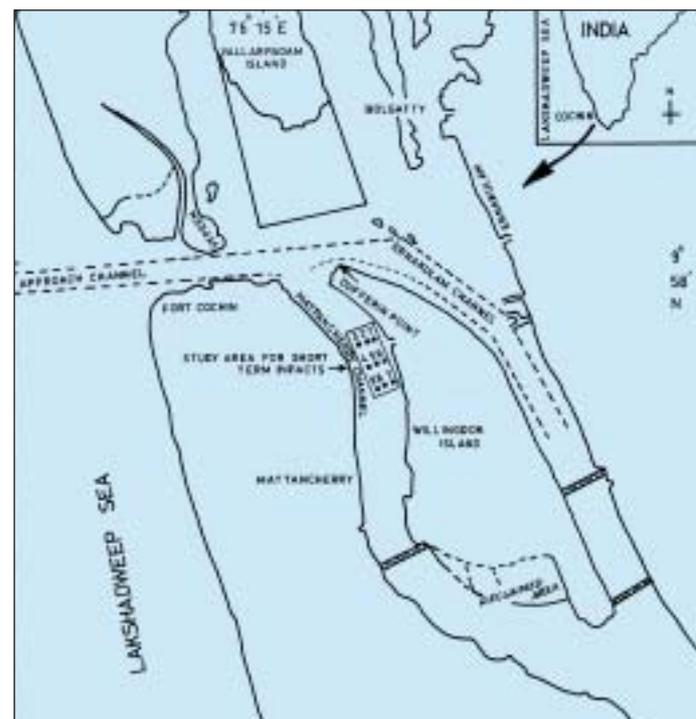
This harbour and neighbourhood environment is quite natural (Bristow 1967) with a free permanent connection (Cochin gut-tidal inlet) with the sea, allowing land drainage derived from terrestrial sources. It has three dredged channels:

- the approach channel oriented along the east-west direction of around 10 km length and 500 m width; and
- two inner channels located on either side of the Willingdon Island, i.e. Ernakulum channel of around 5 km length with a width of around 250-500 m and Mattancherry channel of 3 km long with a width of 170-250 m.

All the three dredged channels are maintained at a depth of 10-13 m. The tropical estuarine environment shows multitudinal features (Rasheed 1997) and is likely to face critical environmental issues related to of inter-tidal land reclamation, pollution discharges and proposed numerous water resources management schemes (Ajith and Balchand 1997).

Though extensive studies have been carried out in Cochin estuary especially on physical, chemical and biological aspects, issues dealing with environmental impacts of dredging were never addressed.

Figure 1. Location map: Study area for short-term impacts.



A detailed picture of the dredging techniques and the sedimentation features are available in reports published by Mathew and Chandramohan (1993), Rasheed and Balchand (1995). The main objective of this study was to investigate the short-term impact assessment of dredging which would also reflect on environmental responses and cures in a short time scale.

For the above purpose, nine stations were selected within the Mattancherry channel of Cochin estuary and eight parameters were thoroughly monitored before, during and after dredging (see Figure 1). The dredging operations were held at station 5 and its very immediate vicinity.

This site was chosen taking into consideration the fact that dredging operations were not held at or in the larger vicinity for more than three weeks fitting in with the scope of this study. The parameters monitored were:

- current speed and direction (at 2 m interval in the vertical);
- salinity (surface, middle and bottom);
- turbidity (at 2 m interval in the vertical);
- transparency;
- bottom sediment textural characteristics;
- nutrient content (surface and bottom);
- abundance of chlorophyll *a,b,c* (surface and bottom); and
- bottom fauna.

The results of monitoring these parameters and a discussion follow (Figure 2).

CURRENTS

The short-term impact of dredging was studied during the ebb phase of the tide. The observed current vectors during the study period indicated surface currents to be higher compared to the bottom values at almost all the stations prior to the commencement of dredging (09/01/96). The near bottom current speeds were lower at all stations (< 20 cm/s) which points out to the penetration of the tide into the estuary along the bottom while flow at the surface was directed seaward. The current vectors are multidirectional when viewed from surface to bottom owing to the inward and outward flow of estuarine waters.

During the time of dredging (on 10/01/96), the tide phase was the same as that of the previous day.

The current vectors indicated more or less similar features compared to that of the observations made before dredging (the previous day). Almost at all the depths, low (1 to 20 cm/s) and intermediate current vectors (21 to 60 cm/s) were observed. Along the bottom, the range of current speed was minimum

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almost at all the stations (<15 cm/s) compared to the higher surface values. After the dredging operations, observations were made on 11/01/1996, when the tidal conditions were once again very nearly similar to the prior two days. The surface current vectors showed a slight increase in values, but at all other depths, current speeds gradually decreased with increase in depth. The direction of vectors was again multidirectional owing to the prevailing ebb tide conditions.



Figure 2. DCI Dredge VIII cruising out of the Port of Cochin toward the discharge area offshore.

SALINITY

Salinity, also measured along with currents before (09/01/96), during (10/01/96) and after (11/01/96) the dredging operations, indicated changes of very limited magnitude in the context of dredging operations. Before the commencement of dredging operations, the surface salinity at all the stations showed high values (>27.0) except at station 7 where it was 21.0.

The mid-depth salinity values gradually increased (31.5 to 34.0) except at station 7 (27.0). Along the bottom layer, salinity gradually increased from 31.0 to 34.0. At the time of dredging, the observations made at the ebb phase of the tide indicated no appreciable changes in salinity values. The day after dredging, the observations on salinity showed no conspicuous changes – the salinity distribution maintained the same pattern as the days before and during dredging. At this estuarine harbour, salinity fluctuations are the resultant of tidal-freshwater interactions, season-wise.

TURBIDITY

The most commonly observed changes in water quality during dredging are the rapid increase in turbidity. This aspect is very important in tropical estuarine and coastal waters as these estuaries receive and store large amounts of suspended load from perennial rivers.

Likewise, Cochin estuary also receives large amounts of river inputs from Periyar on north and Muvattupuzha on south and also additionally from Pamba, Manimala, Meenachil, and Achankovil on a seasonal basis, which leads to siltation at the harbour region. Previous studies had indicated that the natural turbidity in the surface waters of this harbour was less than 30 mg/l (Gopinathan and Qasim 1971). Of course, in monsoon,

i.e. during the rainy season from June to September, the load content may go up to values like 100-120 mg/l or more.

In the study of the short-term impact on turbidity caused by dredging the following occurred:

- Observations at station 1 before the commencement of dredging showed that turbidity does increase with an increase in depth (surface < 5 mg/l; middle 20-30 mg/l and bottom 30-40 mg/l). But during the time of dredging, the turbidity showed a sharp increase which is clearly observed in Figure 3. The turbidity values at certain depths were more than 100 mg/l, which is generally detrimental to the aquatic organisms. After the stoppage of dredging, the turbidity values showed a decrease to normal values.
- At station 2, similar features but at a higher range of values were observed – even higher values like 300 mg/l at the time of dredging.
- At station 3, during dredging, the surface turbidities increased to more than 120 mg/l; however on the bottom, a decrease of turbidity was observed during the same time.
- At station 4, during dredging, turbidity increased towards the bottom with peak values at certain sub-surface layers.
- At stations 5 and 6, turbidity sharply increased with depth during the time of dredging and most of the values were above 60 mg/l.
- Interestingly, station 7, located upstream of the dredging site, did not show an increase in turbidity during the time of dredging.
- At station 8 an increase of turbidity up to 4 m was noted during the time of dredging but no change was noted for greater depths.
- An increase of turbidity was noted at all depths except at the surface during the dredging time at station 9.

Figure 3. Reading from bottom to top, turbidity values at stations 1–9, before , during and after dredging.

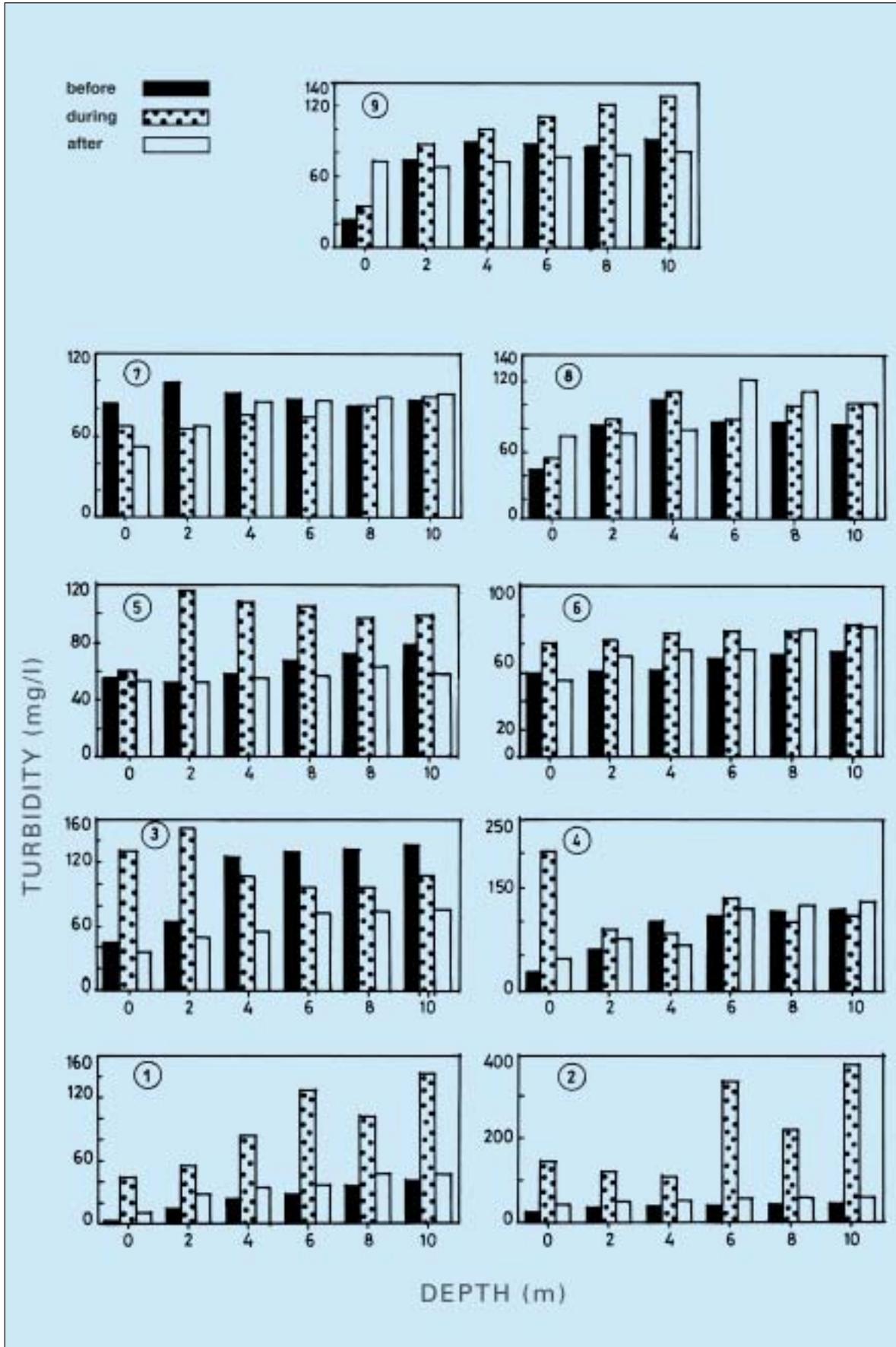


Table I. Extinction Coefficient before, during and after dredging.

Stations	1	2	3	4	5	6	7	8	9
09/01/96 (Before)	2.26	2.62	2.62	2.27	1.57	1.55	3.54	1.78	1.60
10/01/96 (During)	1.89	6.80	1.70	11.30	1.78	2.00	1.89	1.72	1.65
11/01/96 (After)	1.89	2.00	1.85	2.00	1.89	1.65	1.55	1.54	1.60

The facts indicate that upstream stations (7 to 9) are not being affected for the given stage of tide, i.e. ebb phase.

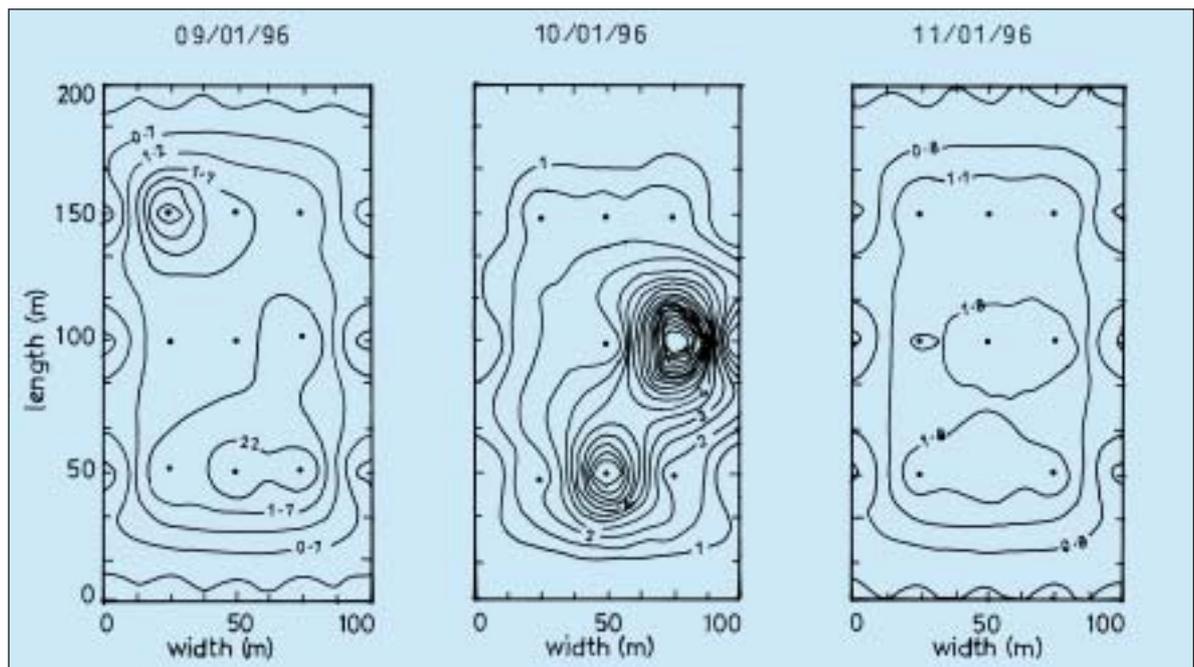
From the above results, it is ascertained that change of water quality owing to dredging will not leave a permanent impression. The turbidity change was transient and localised. But the main concern will be to know how it affects the biota. Certain earlier studies have revealed that some of the estuarine and coastal organisms (may have) adapted to a small change of turbidity but rapid changes of above nature in a particular range may have highly detrimental effects to the propagation of organisms, especially on growth and reproduction (Sherk 1971). Increased turbidity will also adversely affect the production of phytoplankton as it interferes with photosynthesis by limiting light penetration. (Bray 1979; Johnston Jr. 1981). The benthic algae are particularly susceptible to inhibition resulting from decreased light intensity (Windom 1976), and the increase of turbidity probably will affect fish gills by its clogging action and can also clog the membranes of filter feeding organisms (Bray 1979).

TRANSPARENCY

The short-term impact on the transparency/extinction coefficient at the dredging site was also assessed for three days, i.e. before (09/01/96), during (10/01/96) and after (11/01/96) dredging operations. The variation of the extinction coefficient is shown in Figure 4 as 2D plots made at 0.5 intervals. The values are also provided in Table I. Just prior to dredging, the transparency was high, giving low values of the extinction coefficient (1.55 to 2.62) which indicates the presence of clear waters before the dredging operations. The exception was the high extinction coefficient value (3.54) observed at station 7 indicating the presence of turbid waters owing to some probable local action.

During the time of dredging, the extinction coefficient was very high (11.3) at station 4, followed by 6.8 at station 2, indicating the presence of high turbidity in the surface waters. The 2D plot showed two pools of high extinction coefficients at stations 2 and 4. Observations made in the aftermath of dredging operations indicated high transparency with low extinction coefficients.

Figure 4. 2D plot of extinction coefficient on the three days.



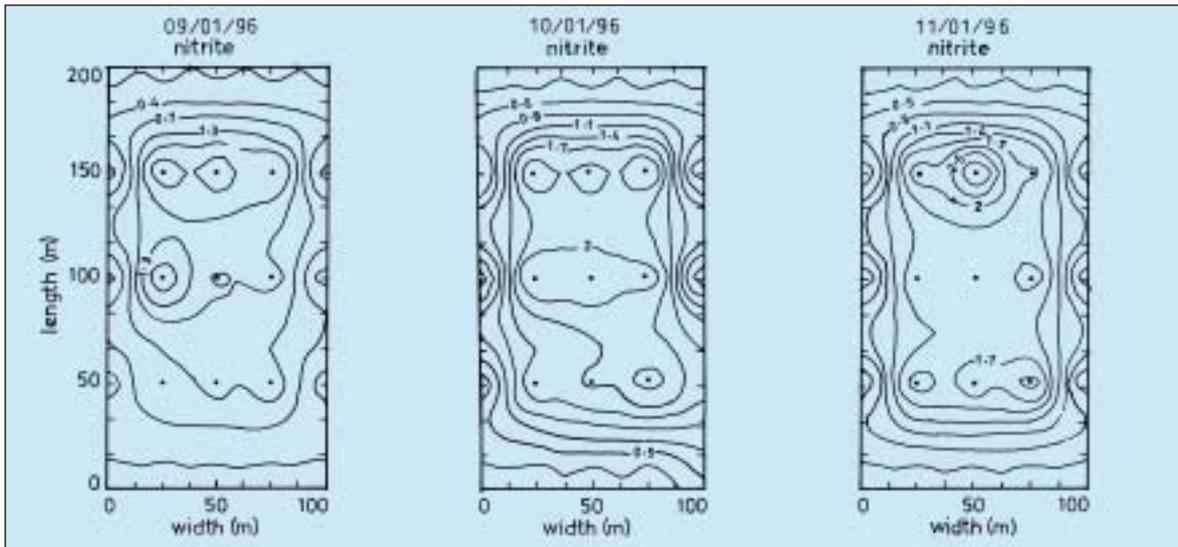


Figure 5a. 2D plot of nitrite at surface during the three days of the investigation.

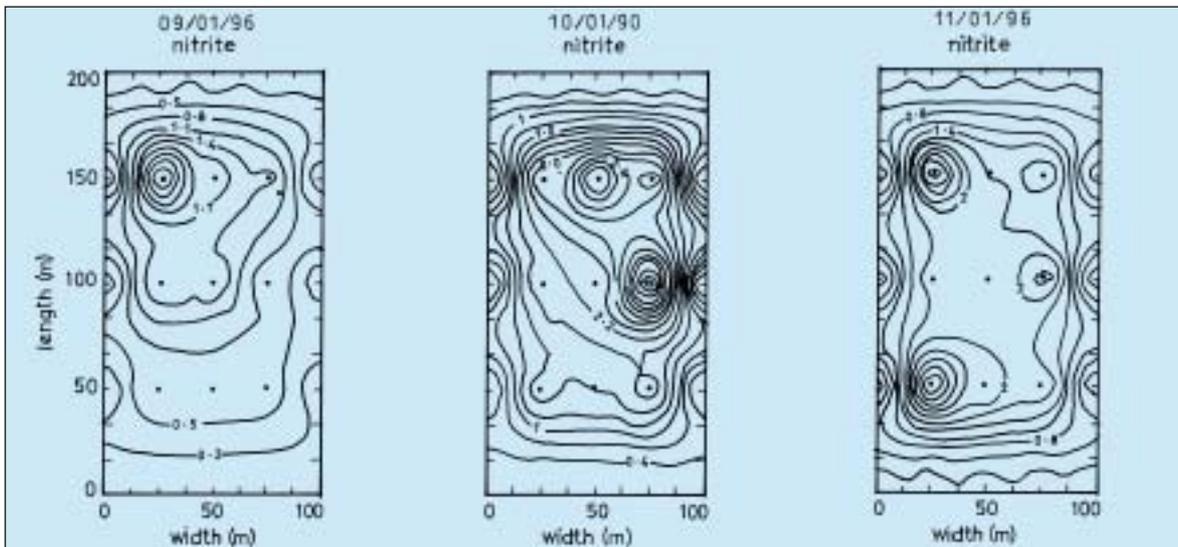


Figure 5b. 2D plot of nitrite at bottom during the three days of investigation.

No closed isolines were observed at any of the stations, which indicates a trend in the turbidity to gradually attain normalcy in the estuarine regions soon after stoppage of dredging.

SEDIMENT TEXTURAL CHARACTERISTICS

The analyses of samples collected the day *before dredging* at stations 5 and 6 indicated that fine silt played a dominant role. Coarse silt was very low compared to clay fractions and at station 5, the values on standard deviation, skewness and kurtosis showed that the sediment was poorly sorted, very finely skewed and very leptokurtic but the sediments at station 6 showed very poorly sorted, coarse skewness and platykurtic.

The analysis of sediments collected *during dredging* showed that very fine silt mixed with the clay fractions were of higher percentage when compared to the observations of the previous day. At station 5, the sediments were poorly sorted, nearly symmetrical and mesokurtic. At station 6, the sediments were poorly sorted, finely skewed and mesokurtic.

After the stoppage of dredging, the next day, very fine silt fractions dominated the sediment texture in the study area. The sediments at station 5 were poorly sorted, nearly symmetrical and mesokurtic. At station 6, sediments were poorly sorted, finely skewed and very leptokurtic. Also there was an increase in the percentage amounts of very fine silt and clay size sediments when compared to the dredging time samples. At station 6, very fine silt

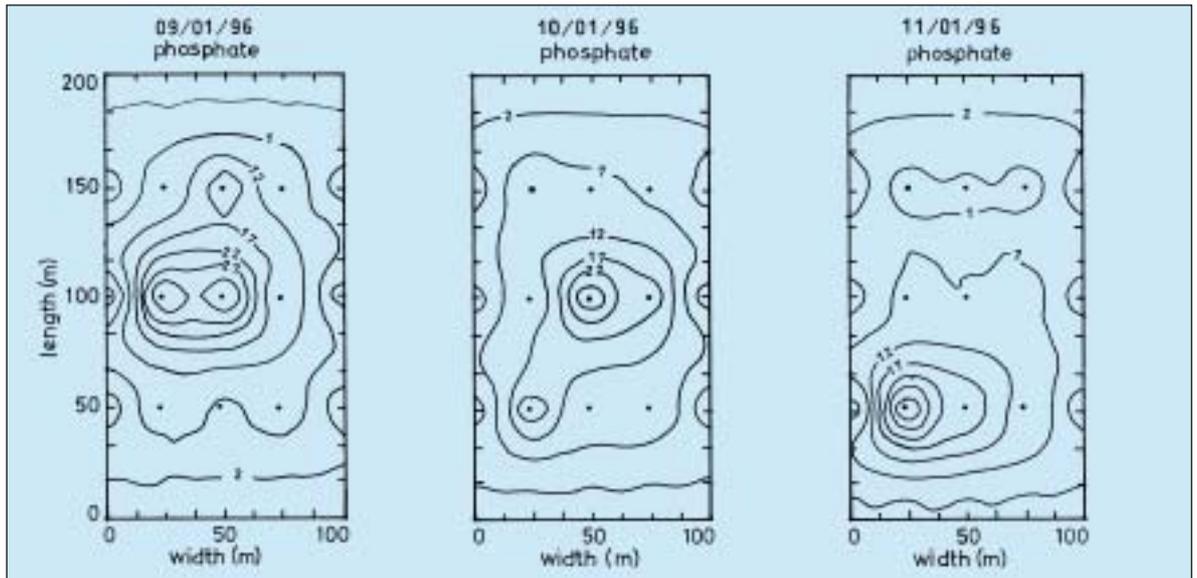


Figure 6a. 2D plot of phosphate at surface during the three days of investigation.

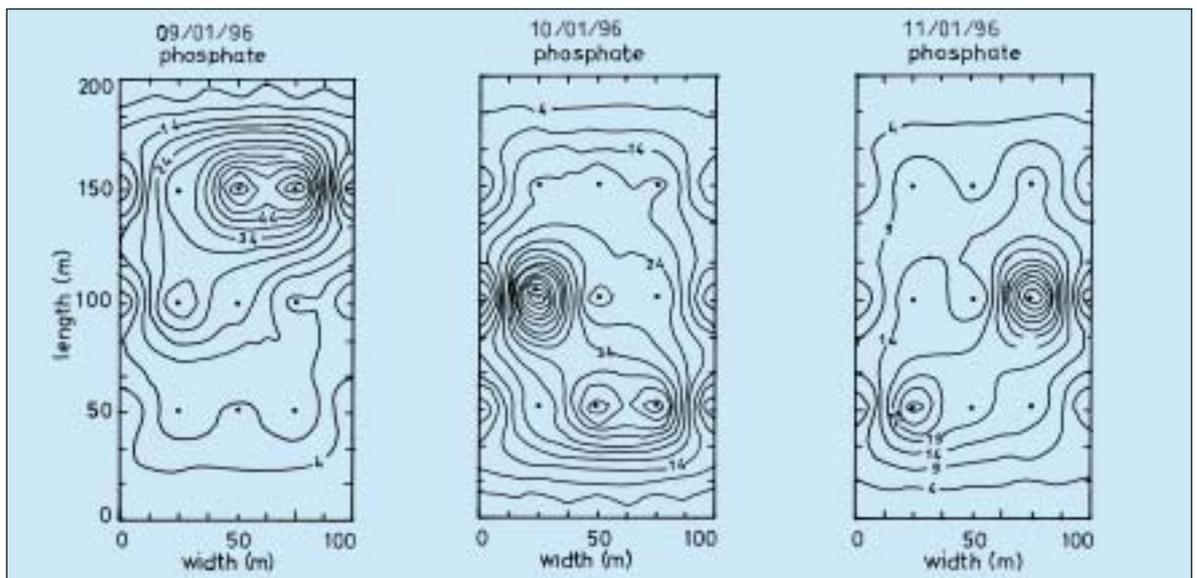


Figure 6b. 2D plot of phosphate at bottom during the three days of investigation.

increased from 27 to 37 percent whereas clay fractions increased from 14 to 18 percent.

NUTRIENTS

The nutrients carried to the sea by rivers are the principal agents for maintaining the fertility of the oceans. Within estuaries, the continued inflow of nutrients via the rivers must frequently be assessed for their importance in maintaining productivity especially since most rivers carry some amounts of polluted loads in addition to elements leached from the land sites. Recent studies have thrown better light on nutrient transformation in coastal water bodies (Matsukawa and Sasaki 1986;

Matsukawa 1989; Gopinathan *et al.* 1994; Gouda and Panigrahy 1995) and on recycling within estuaries (Thornton *et al.* 1995; Kronkomp *et al.* 1995).

a) Nitrite

According to Windom (1976) both polluted and unpolluted fine grain sediments of coastal and estuarine areas contain high concentrations of soluble nutrients (phosphorous and nitrogen). This may be a result of the accumulation of organic detritus, which decompose to regenerate and recycle the nutrients. The study conducted by Windom (1975) in Intracoastal Waterway maintenance dredging analysis showed that no increase of nutrients (ammonia, nitrite and phosphate) were noticeable. May (1973) also reports similar results

for phosphorous in Mobile Bay. However, in some instances, nutrient release mechanisms do not favour increase of nitrite or phosphate on dredging.

To study the short-term impact of dredging on dissolved nutrient content, observations were made before, during and after the dredging operations.

The results indicated in Figure 5a point out that the analysis before the start of dredging at surface showed maximum concentration of nitrite as 1.87 $\mu\text{gat/l}$ at station 6 followed by 1.83 $\mu\text{gat/l}$ at station 7. The minimum value was observed at station 1 as 0.71 $\mu\text{gat/l}$.

During dredging, the sediments (rich in nutrients), on resuspension to the surface waters, released nutrients in the dissolved form and their presence was noted as an increase in the content in the water column. The maximum value was 2.37 $\mu\text{gat/l}$ at station 6 followed by 2.35 $\mu\text{gat/l}$ at station 9. A day after the dredging, the observations showed that the nitrite content persisted slightly enhanced at station 8 (2.95 $\mu\text{gat/l}$), which indicates the continued release of nitrite to the upper water column. At most of the other stations, values showed a gradual decline.

In bottom waters, prior to dredging, nitrite content showed a higher value at station 7 (3.3 $\mu\text{gat/l}$) and the minimum was at station 4 (0.66 $\mu\text{gat/l}$) (see Figure 5b).

Comparing these values to that of surface, the nitrite content at bottom was more or less enriched in concentration. During the dredging time, the substrata are totally disturbed and release of nutrients to the bottom waters enhanced the content of nitrite. The values of nitrite showed a sharp increase at all stations; the maximum value was observed at station 4 (5.4 $\mu\text{gat/l}$) followed by 4.4 $\mu\text{gat/l}$ at station 9. Two close sets of isoline patterns are quite evident at station 4 and station 8 in Figure 5b as presence of enriched resources.

After dredging operations, the next day, the peak values had shifted to stations 1 and 7 as 3.58 and 3.47 $\mu\text{gat/l}$ in concentration. Two close sets of isolines appear around these stations. The results indicated that normal values of nitrite are not attainable after one day of dredging and the mechanism of nitrite uptake and release may be a slow process.

b) Phosphate

The variation of phosphate in surface waters before, during and after dredging is shown Figure 6a. In the surface waters, before commencement of dredging, considerable content of phosphate was observed which revealed that this nutrient element in estuarine region may act as a sink or source. The concentrations observed at stations 5 and 6 are at the upper extent of range, 37.5m gat/l as indicated by rapidly closing

isolines of proximity at these locations. The content showed a decrease at other stations.

During dredging time, the surface values drastically reduced; the highest value was noted at station 5 as 31.05 mgat/l . One day after the dredging (11/01/96), no consistent increase or decrease could be observed except at station 5, where the value drastically reduced. The highest value was observed at station 1 as 36.00 mgat/l .

The change of phosphate content in the bottom waters during the three days of study is shown in Figure 6b.

The results before dredging showed that higher values occurred at all the stations compared to surface values. The highest value was observed at station 9 (63.05 mgat/l) which is evidenced by the pattern of isolines around that station. During the time of dredging, still higher values were observed at station 6 (79.50 mgat/l). After the stoppage of dredging, no drastic changes were noted but the values gradually reduced compared to those observed during dredging.

This aspect may indicate the adsorption/absorption of phosphate onto the resuspended particulates and the extent of geochemical control which would play an important role in the distribution of nutrients. Unlike nitrite, absolute values of phosphate do not significantly indicate release mechanisms but the change in content (increase/decrease) play a dominant bio-environmental role.

Chlorophyll

a) Chlorophyll a

Analysis of chlorophyll *a* before, during and after dredging showed that higher values were observed in bottom waters compared to the surface waters. Before dredging, the surface samples contained <10 mg/m^3 , but bottom values at four stations (stations 4, 5, 7, 8) showed >10 mg/m^3 . Investigation continued during dredging on 10/01/96 gave surface values higher than 10 mg/m^3 only at stations 1, 2 and 3. With regard to bottom waters all stations except station 7, 8 and 9 gave values higher than 20 mg/m^3 and peaked around the main dredging site (stations 4, 5, 6). Study conducted after dredging indicated that the surface waters regained the original status on the very next day (11/01/96). The bottom waters also showed similar tendency as that of surface waters except at station 2.

b) Chlorophyll b

Before dredging, in surface waters, the values of chlorophyll *b* was below detectable limits at some locations. In bottom waters it was around 5 mg/m^3 .

During dredging, surface waters showed <10 mg/m^3 except at stations 2 and 4. In bottom waters, the content showed > 20 mg/m^3 except at stations 7, 8 and 9.

Table II. Number of organism per 0.05 m² before, during and after dredging.

Stations	Before (09/01/96)									During (10/01/96)									After (11/01/96)								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Species																											
A. Polychaeta																											
Nephtys sp	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Neries sp	1	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prionospio sp	45	-	1	-	-	-	-	-	-	-	4	-	-	2	-	-	-	-	1	-	-	-	-	1	4	3	-
Lumbriconeries sp	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-
B. Crustaceans																											
Amphipod	1	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
C. Nematodes																											
Total	47	-	1	-	-	1	-	-	-	-	4	5	-	4	-	-	-	-	2	-	-	1	-	1	6	4	-

Table III. Species diversity before, during and after dredging.

Stations	Before (09/01/96)	During (10/01/96)	After (11/01/96)
1	0.2	-	0.6
2	-	-	-
3	-	0.6	-
4	-	-	-
5	-	0.6	-
6	-	-	-
7	-	-	0.6
8	-	-	0.5
9	-	-	-

Both in surface and bottom waters, chlorophyll *b* gave peak values at station 2. After completion of dredging operations, the surface waters readily regained the conditions prior to dredging while bottom waters, particularly at stations 1 and 2, did not reach the ambient conditions prior to dredging.

c) Chlorophyll *c*

Chlorophyll *c* also showed a nearly similar tendency as that of chlorophyll *a*, but the values were found to be a little on the higher side than that of chlorophyll *b*. Before dredging on 09/01/96 the values generally showed the surface and bottom waters to contain <10 mg/m³. During dredging, on 10/01/96, chlorophyll *c* in the surface waters, gradually increased and a peak was observed at station 2; but in bottom waters, values were above 30 mg/m³ except at stations 8 and 9, followed by higher values at stations 2 and 5 (>120 mg/m³). The observation after dredging indicated

a decrease in values towards the riverine side.

The surface values were below detection limits except at stations 1 and 2. Bottom values showed content greater than >10 mg/m³ except at stations 7, 8 and 9. The maximum value was observed at station 1.

The higher values of chlorophyll *a*, *b* and *c* in bottom waters may be a result of the introduction of benthic flora into those particular locations by the churning up action caused by dredging. The higher values in the surface waters may be a result of the influence of bottom waters moving towards the surface during dredging.

The increase of chlorophyll *a* supported by changes in nutrients may bring about higher productivity but this will not likely happen in reality owing to a decrease of light penetration caused by an increase in turbidity.

The other two types of pigments, namely chlorophyll *b* and *c*, exhibited increases during dredging time as compared to values prior to start and after stoppage. Established relationships between primary production and chlorophyll *a*, *b* and *c* are well documented elsewhere (Uye *et al.* 1987).

BOTTOM FAUNA

The short-term impact on benthic fauna reveals that before dredging, polychaete was the dominant group (Tables II and III) especially at station 1 (45 Prionospio Sp was observed). At stations 3 and 6, single specimens of polychaete were noted. A total of 49 organisms were observed and the species diversity at station 1 was 0.21. At stations 2, 4, 5, 7, 8 and 9, no organisms



Figure 7. DCI Dredge V III at work in Cochin Port.

were observed. During dredging, the polychaete was the dominant group but much fewer organisms were detected; crustaceans ranked second.

No organisms were observed at stations 1, 4, 6, 7, 8 and 9 of the dredging locations. The species diversity was 0.69 at station 5 and 0.67 at station 3. The observations made on the next day of dredging (11/1/96) showed that polychaetes ranked first, followed by crustaceans and nematodes.

A higher number of organisms were observed at station 7 of the dredging site. A few more organisms also appeared at stations 1, 4, 6 and 8 of the study area. At other stations, no organisms were observed. The species diversity showed a higher value at station 1 followed by station 7 (0.64) and station 8 (0.56).

Conclusions

1. Based on the information presented in this article short-term dredging impacts indicate that immediately after dredging there is a likelihood of inhibition or reduction of bottom fauna. The abundance of bottom fauna otherwise is also controlled by many other biological factors and is species-selective as well. A drastic reduction of organisms belonging to the species *Prionospio* was observed. Another interesting result associated with aftermath of dredging was that the species diversity index increased compared to timings prior to and after desilting operations.
2. The other salient features relate to transient localised changes in turbidity, transparency and sediment textural characteristics. As regards nutrient content, certain forms of the life-supporting elements rapidly change whereas others are dominant. Of major significance are changes in the chlorophyll *a*, *b* and *c* contents which have a predominant influence on productivity in coastal estuarine water bodies – an increase of pigments supported by changes in nutrients may set forth a tendency for higher productivity, but this is counteracted by the decrease of light penetration caused by an increase in turbidity.
3. The positive aspects of studies of short-term impacts relate to the conducive excavation activities afforded maintenance forms of dredging at Cochin harbour. The short-term impacts also rule out the development of acute toxicity when dredged soil was excavated from within the harbour region.
4. Furthermore, the operations have been aesthetically clean, low noise and do not interfere with historical or archeological areas which are numbered but significant in Cochin.

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