The potential effects of dredging activities and increased silt load on the St. Lucia system, with special reference to turbidity and the estuarine fauna.

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Abstract

Turbidity regimes within the St. Lucia Estuary were investigated over a period of three and a half years. At the same time the potential effects, in terms of increased turbidity and silt load, of the Umfolozi River/St. Lucia Estuary Link Canal were assessed. The possible effects on the fauna of the system are further emphasised by comparison with the effects of dredging on estuarine faunas in other parts of the world. Recommendations are put forward suggesting that impact studies be undertaken before the Link Canal is fully inaugurated. Impact studies should also be carried out to determine the effects of continued dredging on the estuary.

Introduction

The St. Lucia Estuary and its attached Estuarine Lake (Fig. 1a) which supports a large fauna, including 108 species of fish, is 325 km^2 and the largest of its kind in Africa. The narrow estuary (Fig. 1b), some 20 km long, is an important component as any changes there could affect the ecology of the whole system.

Recently Cyrus (1984) and Cyrus and Blaber (1987a and b; in press) have shown that turbidity is an important factor in determining the distribution of juveniles of marine fishes which occur in estuaries. They showed that the 20 most commonly occurring species in Natal estuaries could be divided into five categories according to their turbidity preferences. Clear-water species inhabiting water of $<$10 Nephelometric Turbitity Units (NTU), clear to partially turbid species ($<$ 50 NTU), species of intermediate turbidities (10 to 80 NTU), turbid water species ($>$ 50 NTU) and those indifferent to turbidity (found throughout).

In Lake St. Lucia, when river-flow from the catchment is low and evaporation within the lake high, salinities within the system rise well above that of sea water. As a result a Link Canal between the Mfolozi River, 2 km south of the St. Lucia Estuary, and the lake has been built in order to bring fresh water into the system. Although complete, the Link Canal has not yet become operational. At times the Mfolozi River carries a heavy silt load; if water from the river is diverted into St. Lucia it could lead to increased siltation rates as well as to an increase in water turbidity. This coupled with the fact that dredging operations, the effects of which are unknown, have been undertaken in the system over the past 25 years led to this study being undertaken.

Study site

The study site covered the length of the tidal area of the St. Lucia System (Fig. 1b). Twenty-two sampling sites, stretching from the mouth to Croc Pool, were used to study the turbidity regime of the estuary.

Materials and methods

This study was carried out over the period January 1980 to June 1983 with the most extensive sampling being undertaken during 1981 when the estuary was sampled on a monthly basis.

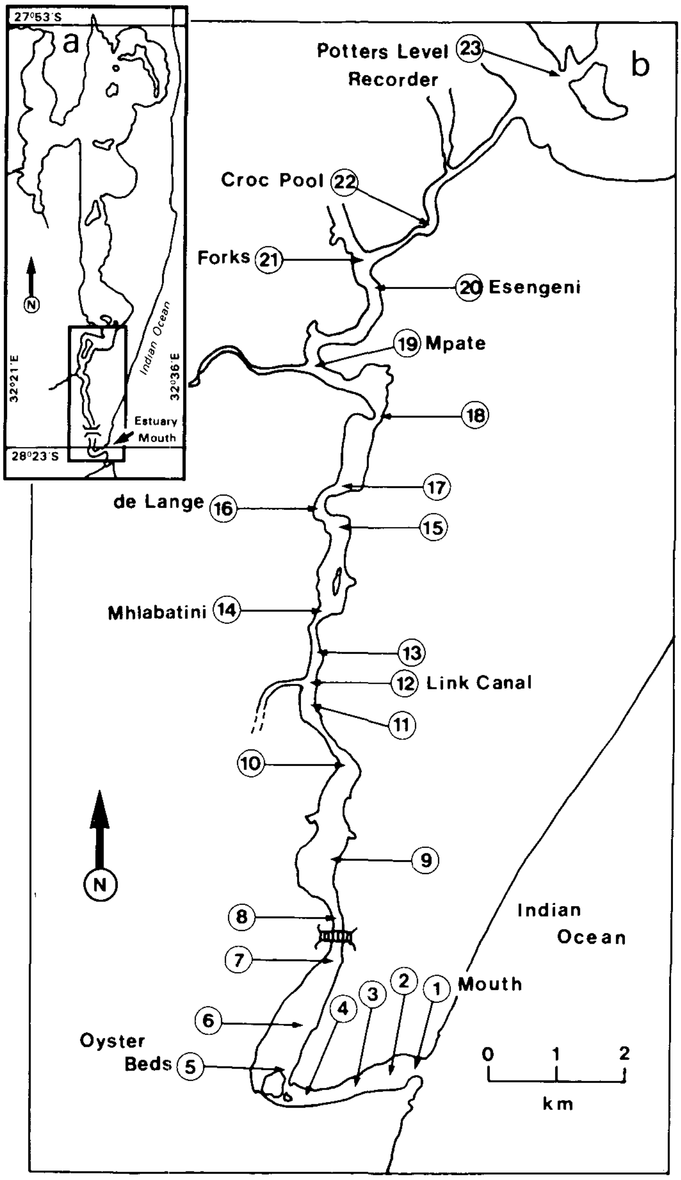

FIGURE 1
a) The St. Lucia System b) St. Lucia Estuary (4 = turbidity sampling sites - Nos. 1 to 11, 13 to 20 and 22 sampled during field trips).

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Measurement of turbidity

A Hach Model 16800 portable turbidimeter was used for field work. Measurement in this instrument is based on the scattering of white light at 90° to the incident beam (McCluney, 1975).

Field sampling

Numerous field trips were undertaken to the study site, during each of these, turbidity samples were collected on rising and falling tides, from 22 sites along the length of the estuary. These sites as well as the position where the Link Canal from the Mfolozi River enters the St. Lucia System are shown in Fig. 1b.

As turbidity is influenced by wind, details regarding daily wind speeds were obtained from the Reclamation Division of the Natal Roads Department.

Earlier works expressed turbidity in terms of milligrams of silt per litre of water, in order to permit approximate conversions for comparison with results obtained in this study, the silt content of water of known turbidities had to be calculated. A series of water samples of varying turbidity were collected from the De Lange's site (Fig. 1b; No. 16) for determining the silt loading of the water.

The turbidity samples were measured and their volumes determined. They were filtered using Whatman No. 40 filter paper which had been dried in an oven and weighed before use. After filtration the turbidity of the water was measured and the samples refiltered if found to be greater than 8 NTU. The filter paper was then dried in an oven to constant weight and the silt content of each sample determined. A linear regression ($y = a + bx$) was used to determine the relationship between turbidity (NTU) and silt content (mg/l).

Results and discussion

Factors contributing to the turbidity regimes of St. Lucia Estuary

Carriker (1967) has listed the four major features which he considers contribute towards the turbidity regimes in estuarine systems. These are: the input of particulate matter from all sources, including loosening of sediments within the system; the results of two layered opposing estuarine circulation patterns; the mixing of fresh and sea water with consequent flocculation of finer particles; and the presence of relatively quiet sedimentation areas.

The points listed by Carriker (1967), coupled with field observations made during this study, indicate that there are four major factors contributing towards the creation of the turbidity regime in St. Lucia Estuary. The four factors, viz. river inflow/lake outflow, substrata, tides and wind are all interlinked. The first two exert the greatest influence in the long term, while rising and falling tides have opposing affects and winds cause seasonal variation in turbidity (Figs. 2 and 3).

The influence of river inflow/lake outflow acts in the following ways: it increases turbidity during high water flow when much sediment is brought down, this in turn increases the substratum sediment load as deposition occurs. Finally it may also cause substantial clearing of estuarine waters when inflow rates are low and lead to mouth closure. The effects of substratum type have been clearly shown by Cyrus (1984) who compared the turbidity regimes of St. Lucia Estuary ('muddy' substrata) with those of the Kosi Estuary ('sandy').

That the four factors influencing turbidity are interlinked has been shown by Shideler (1980) who worked in an estuarine bay on the Texas coast; he found that wind, stirring up substratum deposited by river inflow, was the dominant factor affecting turbidity at the head of Corpus Christi Bay, while at the bay mouth the scouring actions of the tide had the greatest influence.

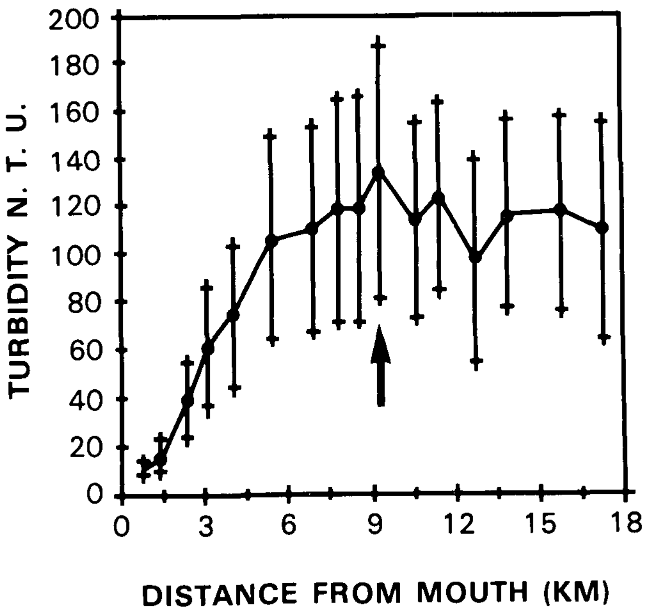

FIGURE 2
Mean turbidity with 95 % confidence limits at 20 sampling sites in the St. Lucia Estuary from 12 data sets collected on rising tides between January and December 1981 (arrow = mouth of Link Canal).

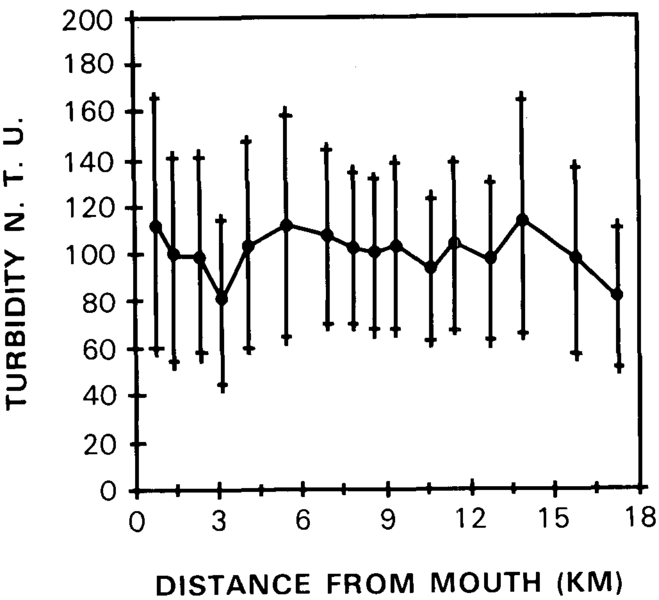

FIGURE 3
Mean turbidity with 95 % confidence limits at 20 sampling sites in the St. Lucia Estuary from 12 data sets collected on falling tides between January and December 1981.

Turbidity in St. Lucia Estuary

Data from the estuary, comprising 1 662 samples in 51 data sets, showed that turbidities range from 2,0 to 568,0 NTU with a mean of 84,2 NTU and a standard deviation of 64,0. Results from twelve monthly turbidity sampling runs carried out during 1981 on rising tides showed that a gradient was always present extending up the estuary. Only five of the 12 sampling runs conducted on falling tides showed a gradient. On rising tides the gradients stretched from 3,1 to 17,2 km (the furthest sampling site) from the estuary mouth with a mean of 10,6 km.

Figs. 2 and 3 show the mean turbidities with 95 % confidence limits for the twelve sampling runs during 1981 on rising and falling tides. They show that significant gradients were always present on rising tides. Recorded turbidities ranged between 2 and 336 NTU on rising tides and 6,5 and 408 NTU on falling tides. Turbidity gradients are only well defined on rising tides (Fig. 2) due to the fact that incoming marine waters are very clear, having a mean of 2,1 NTU (Cyrus 1984). On falling tides a general mixing takes place with no clear gradients being observed (Fig. 3).

The highest turbidity levels recorded were in the area adjacent to the mouth of the new Link Canal (Fig. 1b, Sites 11 to 13) which is clearly seen in Fig. 2. The mean turbidity of top and bottom samples for sites 11, 13 and 14 (Fig. 1b) was 110,4 NTU. It was noted that in all turbidity gradients present on rising tides, the highest turbidity was some distance up the estuary, after which turbidities showed a decrease. The point at which the highest turbidity occurs in an estuary is called the Turbidity Maximum (T.max) (Festa and Hansen, 1978). Inglis and Allen (1957) found that T.max in the Thames Estuary was most often situated at the "mud reaches", an area of high sedimentation. It was observed that although the Link Canal is not yet open the effects of dredging the canal and reshaping the banks have already contributed towards increased sedimentation and turbidity in the area.

Fig. 4 shows mean monthly turbidities, with 95 % confidence limits, recorded at St. Lucia Estuary during 1981, while Fig. 5 illustrates the mean monthly wind speed recorded at the Estuary mouth during the same period. The figures clearly show that with more-or-less uniform substrata present throughout the estuary, the major determinant of turbidity is the wind.

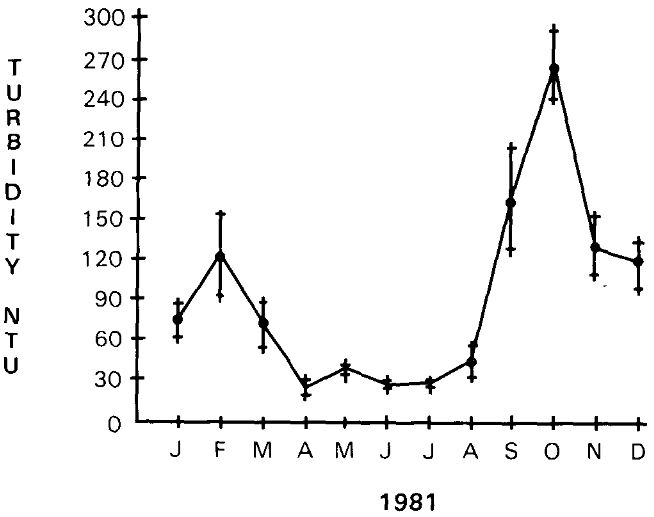

FIGURE 4
Mean monthly turbidity with 95 % confidence limits recorded at St. Lucia Estuary between January and December 1981 (NTU = Nephelometric Turbidity Units).

When the turbidities recorded in St. Lucia Estuary are compared with levels found to be important in determining the distribution of juvenile marine fish in estuaries, it is apparent that St. Lucia must already be considered a turbid water estuary. Cyrus and Blaber (1987a and b) showed that figures > 80 NTU indicated turbid waters.

Turbidity and sediment load

The relationship between turbidity and sediment load was determined from samples collected at the De Lange's sampling site (Fig. 1b – Site 16), St. Lucia, and found to be linear (Fig. 6), with SL = −16,47 + 1,18NTU (SL = sediment load in mg/l and NTU = turbidity in nephelometric turbidity units); $r^2 = 0,93$; $n = 12$ and $P<0,001$. Samples were collected only from this site as it is representative of some 70 % of the substrata of the St. Lucia system.

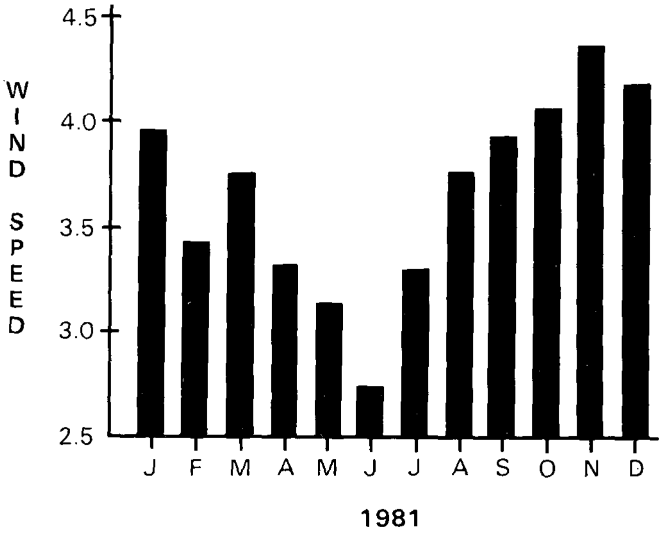

FIGURE 5
Mean monthly wind speed (m/s) recorded at St. Lucia Estuary mouth between January and December 1981 (m/s = metres per second).

Dredging activities at St. Lucia Estuary

Major and long-term dredging by the reclamation unit of the Natal Roads Department has been in progress in the St. Lucia Estuary since 1955. Hutchison (1974) shows areas and dates (up to 1971), when dredging took place. During this time the entire length of the estuary (Fig.1b) was dredged. The main phases with dates and channel sizes are summarised in Table 1. Since 1971 dredging activities have been confined to the lower reaches (R. Taylor, 1983), particularly in the tidal basin and between Honeymoon Bend and the road bridge (Fig. 1b, Sites 4 to 8).

TABLE 1: DREDGING ACTIVITIES IN ST. LUCIA ESTUARY (SAMPLING STATIONS SHOWN IN FIG. 1b).

Area dredged	Dates	Dredged dimensions
Between stations		
4 and 7 West	1962-66	1,8m deep × 90m wide
4 and 7 East	1962-66	1,8m deep × 90m wide
8 and 22	1967-69	1,8m deep × 90m wide
22 and 23	1969	1,8m deep × 30m wide
Beyond 23	1965-67	1,2m deep × 10-20m wide

The excavation of the as yet unopened canal to link the Mfolozi River with St. Lucia Estuary, has been in progress since 1980 with extensive redredging of the canal and reshaping of its banks occurring during early 1983. This has contributed to the highest turbidity levels in the estuary being recorded in the vicinity of the mouth of the Link Canal (Fig. 1b, Site 12).

The potential for future turbidity increases in the St. Lucia Estuary

That dredging causes increased turbidity is obvious from the turbidity 'plumes' which may be seen trailing behind most dredgers. Yagi *et al.* (1977) recorded turbidity increases from 0,75 mg/l ($\pm$4 NTU) before dredging to 700 mg/l ($\pm$607 NTU) at the dredge face, while 60 m downstream water silt content ranged from 2,7 to 150 mg/l ($\pm$16 to 141 NTU). Bohlen *et al.* (1979) calculated that between 1,5 and 3,0 % of the contents of a bucket dredge, similar to the type used to reshape the banks of the Link Canal, were reintroduced into the water. This caused concentrations of suspended particulate matter to reach 400 mg/l ($\pm$353 NTU), the background concentration of 5 mg/l ($\pm$19 NTU) only returning some 700 m downstream (250 m on the surface).

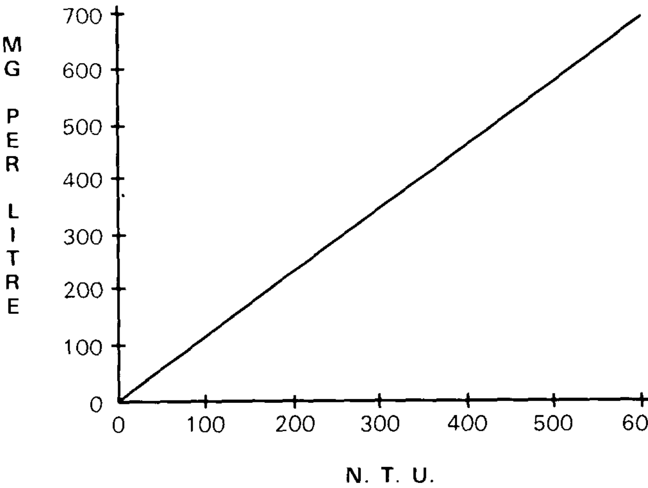

FIGURE 6

The relationship between turbidity and sediment load of the water (NTU = Nephelometric Turbidity Units).

The results from turbidity sampling in the St. Lucia Estuary show that the highest (mean) turbidities (T.max) are situated approximately opposite the mouth of the as yet unopened Mfolozi Link Canal. Disturbance of the substratum caused when the canal was dug has led to increased deposition in the area (Fig. 1b, Site 11 to 14). This appears to have caused the increased turbidity, although no actual deposition figures are available.

It is envisaged that water from the Mfolozi River will be diverted into the middle reaches of the estuary (Fig. 1b, Site 12) during times of rising salinity in Lake St. Lucia. The only data available on turbidity in the Mfolozi River are in the form of sediment loads (Lund, 1976). Fig. 7 shows the mean monthly sediment load (mg/l) for the Mfolozi River over a 27-month period. The maximum figure recorded was 12 000 mg/l ($\pm$ 10 195 NTU), while the mean monthly average between November 1973 and January 1976 was 1 400 mg/l ($\pm$ 1 200 NTU). A stilling basin is being excavated in the Link Canal but this will only be able to remove 50 % of the sediment in the water (Midgley, 1983). The particles removed will all be greater than 0,05 mm in size (Lund, 1976), leading to all the finer particles going through into the estuary.

Once the Link Canal comes into operation it is possible that further sedimentation and associated turbidity increases will occur. The Mfolozi River carries high concentrations of silt, mean value (1973-76) 1 400 mg/l ($\pm$ 1 200 NTU) (Lund, 1976), compared with the mean of 84, 2 NTU for the St. Lucia Estuary (this study). Lund (1976) has suggested that water may be directed from the Mfolozi River into the Link Canal provided its silt content is less than 8 000 mg/l. This is approximately 6 800 NTU, which is 12 times more than the highest value recorded in the St. Lucia Estuary (568 NTU) during the present three and a half year study. The stilling basin will only remove 50 % (all larger particles) of the silt content and thus increased sedimentation will occur in the estuary. The mean particle size of sediment entering the estuary will also be finer due to the stilling basin removing the coarser fractions and this may lead to changes in substratum composition.

Gray and Ward (1982) found that silt flushing of a freshwater impoundment caused turbidity increases from $\lesssim$ 20 to 422 mg/l ($\pm$31 to 372 NTU). This flushing caused a 90 % decrease in chironomid larvae numbers, with changes in populations occurring for many kilometres downstream. It is possible that flushing with highly turbid Mfolozi River water may have similar effects on the fauna of the St. Lucia Estuary.

Lund (1976) calculated that if water coming through the Link Canal has the maximum silt load of 8 000 mg/l and is flowing at the anticipated rate of 30 m^3/s, then the daily silt yield will be 20 000 t. Assuming 50 % deposition in the stilling basin, some 10 000 t of silt will still enter the system per day if the silt load of the water is at the recommended maximum. Much of this will be moved up the estuary on rising tides before being deposited in the upper reaches of the estuary. Such depositions could result in restricted water flow between the lake and the estuary.

Notwithstanding the fact that dredging has been in progress for many years in the St. Lucia Estuary, it is important that an impact study based on the possible effects of increased silt load/turbidity of the water be undertaken before the Mfolozi Link Canal comes into operation. The effects of turbidity on fish distribution (Cyrus and Blaber, 1987a) show how important such an impact study is for the maintenance of the fish fauna of the St. Lucia System.

Quotes from three papers sum up the situation, especially in relation to the St. Lucia Estuary. "Increasing turbidity and siltation seem to be inevitable consequences of human activity in and around our coastal waters. Dredging and filling operations, man-made water currents, the use of motorboat propellers in shallow areas, industrial and municipal effluent flows, and dragline fishing operations may contribute heavily to the loss of water clarity and to increasing siltation in estuarine and other coastal areas", McCluney (1975). "The increased potential for entrapment (of sediments) makes the dredging process partially self-perpetuating", (Palmer and Goss, 1979), hence the effects on the system are continual. Dyer (1972) states "Alteration of the estuarine system beyond natural limits will cause changes that, in many ways, are still unpredictable".

It should be noted that the St. Lucia Estuary forms a narrow link between the sea and a lake system (Fig. 1a) which also contains a true estuarine fauna. Any changes in the estuary may affect the lake fauna, particularly in terms of species numbers, diversity and recruitment.

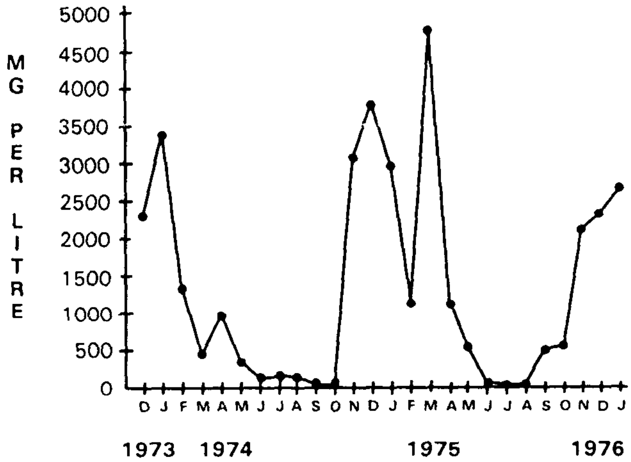

FIGURE 7

Mean monthly sediment load of the Mfolozi River between November 1973 and January 1976, based on data from Lund (1976).

The effects of dredging on the estuarine fauna

For nearly 30 years dredging had been in progress in St. Lucia Estuary, yet no detailed impact studies were undertaken in the system prior to the commencement of or even during the large-scale dredging operations and thus few data are available on any changes which may have occurred. In their reviews covering dredge and fill activities and dredge spoil disposal both Morton (1977) and Johnson (1981) have shown that these activities affect the estuarine environment in many ways and it is apparent that most are deleterious. Increased water turbidity is known to act both directly and indirectly on the fauna and flora of an estuary (Cyrus, 1984).

The only information related to dredging effects available for the St. Lucia Estuary is that given by Hay (1985) who compared the benthic fauna in dredged and undredged areas of the Estuary. He found that the channel areas dredged in the St. Lucia Estuary between 1973 and 1976 (Table 1) are still essentially devoid of benthic animals while the adjacent substrata are densely populated. Concentrations of zoobenthos in the dredged areas were generally < 200 animals/m^2 comprising a single species, while adjacent undredged areas had densities of 3 000 to 5 300 animals/m^2 comprising 7 to 10 species. A similar effect was noted by Taylor and Saloman (1968) who reported that dredging effects on an estuarine area in Florida caused permanent reduction in benthic species diversity and abundance. They found that recolonisation of dredged areas was negligible during the 10 years following dredging.

It is a known fact that dredging has a direct impact on the invertebrate fauna of an estuary. Decreases in numbers and diversity of benthic communities have been reported from many parts of the world: e.g. Gilmore and Trent (1974), West Bay, Texas, USA (natural areas twice the numbers of dredged areas), Johnson (1981), Galveston Bay, Texas; Rosenberg (1977) in a Swedish estuary, and Jones and Candy (1981) in Botany Bay, Australia.

Conclusion

Athough turbidity levels in St. Lucia Estuary are relatively high, this does not mean that increased turbidity will not have a detrimental effect on the fauna. This work has shown that continued dredging, without impact studies being undertaken, coupled with the planned introduction of water from the Mfolozi River could cause turbidities to rise considerably as a result of the sedimentation of fine particles entering the Estuary. When this is considered in the light of other studies on similar problems as reviewed by Cyrus (1984) the overall effects can only, in the long term, be considered to be detrimental to the fauna of the St. Lucia Estuary and possibly the St. Lucia Lake as well. As the St. Lucia System, at 325 km^2, is the largest estuarine system in Africa, all attempts possible should be made to maintain its natural fauna.

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