T

THE INFLUENCE OF TURBIDITY ON FISH DISTRIBUTION IN NATAL ESTUARIES

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(Submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy, in the Department of Zoology, University of Natal, Pietermaritzburg.

The author hereby declares that this whole thesis, unless specifically indicated to the contrary in the text, is his own original work.)

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CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

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ABSTRACT

Studies in other parts of the world have proved that turbidity affects aquatic life and work in Australia and North America has shown that the distribution of some fish species may be determined by the level of turbidity present. This, coupled with the fact that: (i) Natal estuaries are important as nursery areas for the juveniles of many marine fish species, (ii) the estuaries exhibit a wide range of turbidities and (iii) little was known of the effects of turbidity on the fish populations in estuaries, led to this study being undertaken.

Turbidity and its effects on fish distribution in Natal estuaries was investigated from January 1980 to June 1983. Lake St.Lucia, which is predominantly turbid but also has clear water areas, was the main study area. Six other estuarine systems sampled were chosen to cover a wide range of estuarine types and turbidities. Field sampling was undertaken to determine which species were present under different turbidities, simultaneously physical factors which were potentially affecting fish distribution were also monitored. In addition to this, laboratory equipment which enabled a turbidity gradient to be established in a choice chamber tank was used to test the turbidity preferences of 10 common estuarine species for which field data were available. These tests allowed the elimination of all physical factors except turbidity.

Of the physical parameters monitored in the field, turbidity, temperature and food availability in the benthos, were determined as being important in affecting fish distribution within estauries. However, comparison of fish distribution data for twenty species, with these factors showed that turbidity was exerting the major influence. It was also found that fish species occurred in one of five groups, inhabiting either clear, 'clear to partially turbid', intermediate or turbid waters or they were indifferent to turbidity. Laboratory results for eight of ten species tested showed significant agreement with the field data.

The results of this study have shown that turbidity is the most important factor determining the distribution of juvenile marine fish in estuaries and that the greatest number of species are present in waters which are not clear. The attraction to and presence in such systems appears to be related to the fact that turbid estuaries provide protection from fish and bird predators while also acting to reduce intraspecific predation. Of factors attracting juvenile fish into estuaries, turbidity is probably the single most important acting in this respect.

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1. INTRODUCTION.

Turbidity has long been recognized as affecting aquatic life (Wallen, 1951 and in particular fish Ellis, 1931 & 1936). Much of the early work (pre 1940) on turbidity and fish was directed at freshwater species in the U.S.A., where it was recognized that suspended erosion silt may play a limiting role in the environment of aquatic animals that are dependent on light.

During the 1940s workers in the Great Lakes of the U.S.A. came to the conclusion that erosion turbidity was causing changes in the fish populations of some lakes. This was first put forward by Langlois (1941) who proposed that a reduction in abundance as well as an elimination of species had occurred in the more turbid areas of Lake Erie. His findings were supported by the work of Doan (1941 & 1942) who found that turbidity had a marked influence on the catches of sauger Stizostedion canadense by commercial fisheries.

The interpretations of results put forward by both Langlois and Doan were not accepted by van Oosten (1945) who, under the misleading title of "Turbidity as a factor in the decline of Great Lakes fishes with special reference to Lake Erie", attempted to sway readers back to the more traditional line of thought that it was over-fishing that was the major cause of fish depletion in the Great Lakes.

van Oosten´s arguments did not gain universal acceptance and following the above publications much work, which attempted to establish the direct effects of turbidity and what the lethal limits were for different species, was undertaken. Included in these investigations was the work of Wallen (1951), Herbert and Merkens (1961), Neumann et al. (1975) and O´Connor et al. (1976 & 1977), whose studies covered both freshwater and estuarine fish species. Experimental studies related to fish and turbidity are reviewed by Cordone and Kelly (1961), Hollis et al. (1964) and Sorenson et al. (1977). These reveal little besides the results of direct effect experiments, and do not extend

In 1973 Moore published his work on turbidity as an ecological factor in the Kelp faunas of Northeast Britain. From fieldwork he was able to demonstrate that the invertebrate fauna could be divided into clear-water, turbid-water and turbidity indifferent species. This was followed by Swenson *et al*. (1977) who, while investigating the effects of red clay turbidity on Great Lakes fish, found no relationship between turbidity and biomass, but did detect an apparent relationship between turbidity and species composition.

In his now classic work on two common species, walleye *Stizostedion vitreum* and lake trout *Salvelinus namaycush* from Lake Superior, Swenson (1978), using choice chamber tanks with a turbidity gradient, found that one species showed a preference for turbid waters whilst the other avoided them. Swenson (1978) pointed out that turbidity was not exerting a direct effect on the fish but rather that the effect was indirect and in this case led to a behavioural response from the fish.

In a subsequent study Gradall and Swenson (1982) have shown that creek chubs prefer turbid waters and that brook trout appear to be indifferent to turbidity. These studies showed that fish could also be divided into the three turbidity categories proposed by Moore (1973). To date it appears that no additional laboratory work on turbidity preferences of fish has been carried out.

The only work of significance on turbidity and fish distribution in estuarine waters was done by Blaber and Blaber (1980) in Moreton Bay, eastern Australia, where they found that juvenile marine fish inhabiting estuaries could be divided, according to distribution, into the same categories as those of Moore (1973).

Work on turbidity in southern Africa to date has been limited to incidental Secchi data given in many early papers on South African estuaries, studies on factors governing turbidity in freshwater impoundments (Walmsley, 1978 & Walmsley *et al*., 1980) and investigations into the turbidity ranges occupied by various fish species and families which inhabit estuaries: Sphyraenidae (Blaber, 1982), Carangidae

The latter studies showed the need for an investigation to establish what relationships exist between different fish species and water turbidity in estuaries.

Another factor which indicated the importance for such research to be undertaken was that the estuaries of South East Africa are considered to be important as nursery grounds for a number of juvenile marine fish. Wallace _et_ _al_. (1984) have shown that about 100 species are able to utilize estuaries; of these 8 are dependent upon them for their entire life, 22 are entirely dependent on estuaries during the juvenile phase of their life and the juveniles of a further 19 species occur mainly in estuaries but also at sea. Added to this Blaber (1980), and Blaber and Blaber (1980) have postulated that many juvenile marine fish enter estuaries not only for the calm water conditions and apparent abundance of food which exist there, but also because of the protection which turbidity offers them. These factors have been stated by Blaber (1981) as possibly influencing fish distribution in all Indo-Pacific estuaries.

The work of Blaber (1981), in estuaries of the south east coast of Africa, as well as estuaries and shallow water sea areas of eastern Australia and Malaysia, has lead to the suggestion that the occurrence of juveniles of many marine species in South East African estuaries may be related more to water turbidity than to an absolute need for any other factors present within the estuaries.

The main aim of the present study was to establish whether turbidity plays an important role in determining the distribution of juvenile marine fish occurring in Natal estuarine systems. The study of juvenile fish was undertaken because of their overwhelming importance in Natal estuaries. In order to accomplish this three main lines of research were followed:-

(1) To establish by field sampling what patterns of turbidity exist in estuarine systems, what factors affect turbidity and what relationships exist between turbidity and other physical factors (such as wind, salinity, temperature etc.) within these systems.

(2) To establish by field sampling whether juveniles of

turbidities or within specific ranges of turbidity.

(3) To establish by laboratory tests whether any apparent turbidity preferences revealed during field sampling were brought about as a result of turbidity or influenced by other physical variables. These laboratory tests served to identify the effects of turbidity on juvenile fish independent from the effect of other variables such as salinity, temperature etc.. Tests on salinity preference were also undertaken in order to determine to what extent salinity affects the distribution of fish in the estuaries studied.

2. STUDY SITES.

2.1 Introduction.

In a recent attempt to classify Natal´s smaller 'estuaries', Begg (1983) defined five categories as follows:-

Estuary - system tidal, freely connected to the sea, comprising seawater measurably diluted by freshwater.

Bay - system tidal, freely connected to the sea, seawater undiluted by freshwater.

Lagoon - system atidal, separated from the sea but containing seawater measurably diluted by freshwater.

River Mouth - system outwardly open to the sea but atidal (due to elevation) and totally fresh.

Begg (1983) has also discussed the importance of each of these estuarine types to juvenile fish, and concluded that only Bays and Estuaries are really important in this respect, while Lagoons are of limited significance and River Mouths not at all. He is of the opinion that all too often unwarranted generalizations are made as result of the lack of uniformity in terminology, with all systems being referred to as estuaries.

During this study data were collected from the seven estuarine systems listed in Table 1. The main site at which most work was done was Lake St.Lucia and results obtained from there are treated separately from those of the other systems. Their geographic locations are shown in Figure 1. The classification of each system is based on that proposed by Begg (1983) and the prevailing condition of each system at the time of the study is based on the three category classification (good, fair & poor), provided by Begg (1978). The latter has been said to be to a degree subjective in its assessment, as it is based on the amount of disturbance to marginal vegetation, diversity of animal life present, depth as an indication of sedimentation rates, and the appearance of the water, but these factors all contribute to give some idea of the extent to which the different systems are provides some insight as to why variations occurred in some of the fish and physical data collected during this study.

The seven systems sampled, were selected to give as wide a range of estuarine type and turbidity levels as possible. Lake St.Lucia was chosen as the main study site, as it provides a mixture of estuary and estuarine lake and, apart from being a predominantly turbid system, also has clear water areas. Being able to sample a wide range of turbidities within one system over a relatively short period allowed direct comparison of species occurrences and turbidities. At the same time there was to some extent a reduction in the ranges of the other physiccal variables which may have contributed to bringing about the species distributions noted.

Of the other systems sampled, Kosi offered very clear estuarine and estuarine lake conditions. Mlalazi is a predominantly open system with an intermediate range of turbidity, while the Tongati and Mdloti systems are typical of many of Natal´s small estuaries which close seasonally. Mtamvuna and Fafa were the other systems from which additional data were obtained.

Most of the physical details for each of the systems were collected during this study and thus form part of it; they are presented under results in Chapters 4 (St.Lucia) and 8 (all systems). These data provide details of the similarities and differences of the systems studied.

Table 1: Morphometric Data of Estuarine systems studied (Condt.= Condition; Estua.= Estuarine; SC = seldom closed & MC = mostly closed).

System	System Type	Environ-mental Condt.	Catch-ment (km^2)	River Length (km)	Estua. area (ha)	Shore Line (km)	Mouth Condt.
Kosi	Estuary	Good	500	30	3500	53,3	SC
St.Lucia	Estuary	Good	8982	306	32500	347,0	SC
Mlalazi	Estuary	Good	454	54	129	23,7	SC
Tongati	Estuary	Poor	370	40	7,6	4,7	SC
Mdloti	Lagoon	Fair	481	74	13,6	6,5	MC
Fafa	Lagoon	Good	252	66	30,0	6,5	MC
Mtamvuna	Estuary	Good	1582	162	52,7	10,3	SC

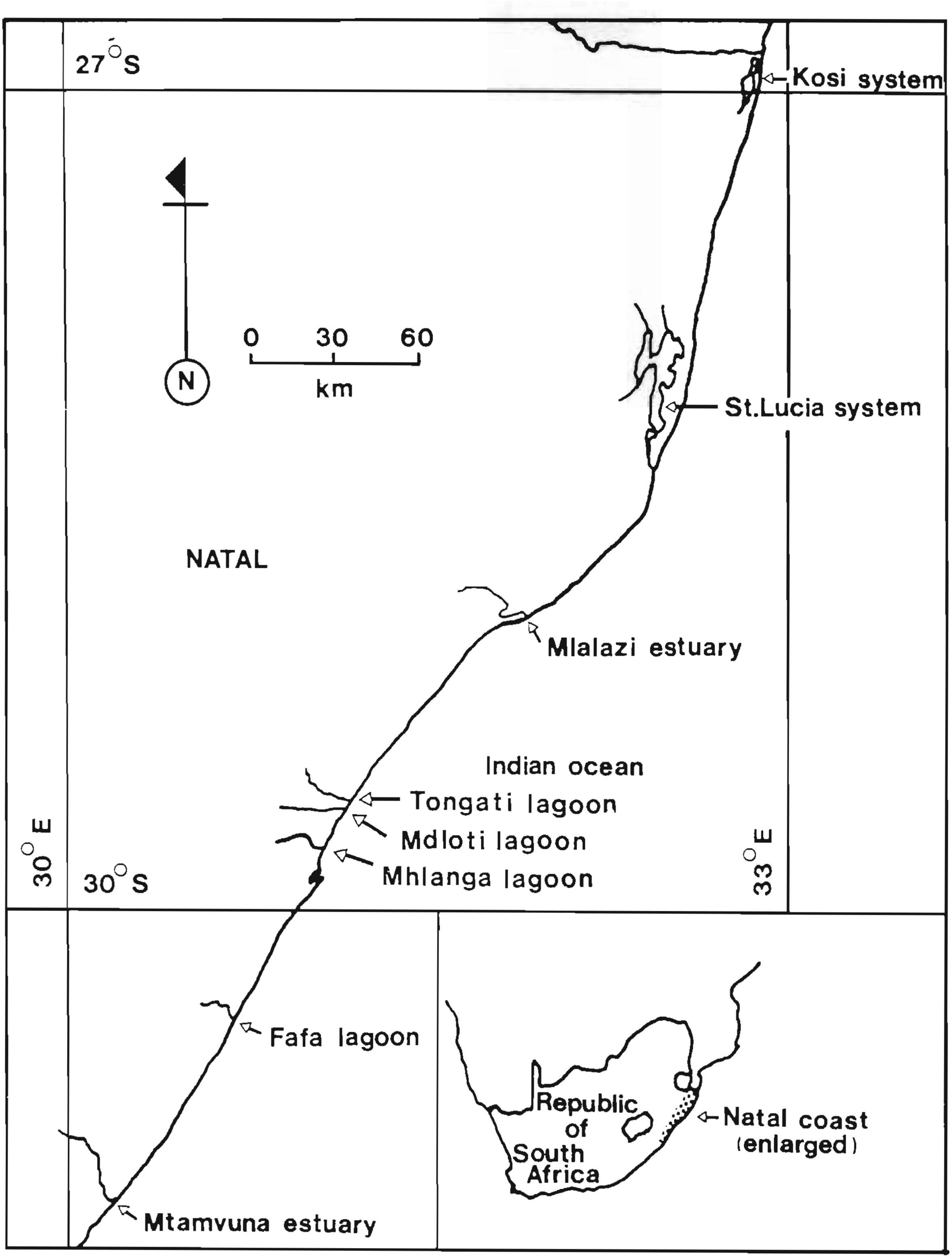

Figure 1: Study sites on the Natal coast.

2.2 St.Lucia - Estuary linked lake system (Figure 2 & Table 1)(Physical data - Chapter 4).

The state of biological knowledge of this system has been reviewed by Whitfield (1977), Begg (1978) and Taylor (1982). Some 108 fish species have been recorded, with juveniles of many marine species being common (Whitfield, 1977). The system comprises two major parts: (i) the Estuary and adjoining channel, known as the 'Narrows', extends from the sea to the furthest point of tidal influence at the southern end of the South Lake, and (ii) the estuarine lake component (Fig. 2). The mouth of this system is kept open as far as possible by dredging during periods of low river inflow. During the study period it was closed from the 19th of April to the 22nd of October 1980. During this period no fish sampling was undertaken.

The average depth below mean sea level is 1,5m and the maximum depth is 2,04m (Johnson, 1977). Freshwater enters the lake via the Mkuze, Mzinene, Hluhluwe, Nyalazi and Mpate Rivers, by direct rainfall and by groundwater seepage from the eastern shores (Hutchison & Pitman, 1977). Salinities within the system fluctuate greatly depending on evaporation and freshwater inflow. During dry years with low inflow the lake level drops below mean sea level and seawater flows into the lake causing an increase in the salinity of the system.

During severe drought high evaporation due to the shallowness of the system causes salinities in the system to rise above that of seawater. During these periods the most saline conditions are found in the northern areas of the lake (Wallace, 1974). High rainfall years cause the lake level to rise above that of mean sea level, the salts are flushed out of the system via the Narrows and the lake salinity is lowered (Kriel, 1967). During the study period freshwater input was low and salinities in South Lake fluctuated between 30 and 45^{o}/oo.

Research efforts at St.Lucia were primarily directed at sampling the South Lake, with additional sampling being carried out at the Estuary Mouth and in the Narrows. South Lake was chosen as it provided, within one system, a wide range of turbidities. The eastern shores are 'predominantly clear' while the western shores are 'predominantly turbid'. At the same time most other physical factors show minimal variation between the sites sampled, all being in the same system.

Although details of these physical factors are given in Chapter 4, the following summary is pertinent at this stage. Turbidity differences are brought about by the fact that substrata on the east have a mean particle size of 150µm while that on the west is 350µm. In addition some 41.4% of winds in the area come from the N.- E.N.E. quadrant, thus blowing directly onto the western shores. This, coupled with the small particle size of the substrata, promotes higher turbidities along the western shores than along the eastern shores. Wave action and wind speed along both shores were of similar amplitude but depended on wind direction.

The salinities vary little between the eastern and western shores, with freshwater seepage on the east causing gradients with differences of between 0,5 and 4,0°/oo across the lake. Temperature differences between the east and west seldom exceed 1,5°C, with neither side being consistently warmer than the other. No differences have been recorded between bottom and surface temperatures throughout the area (Whitfield, 1977).

As would be expected, the differences in substrata have led to slightly different benthic communities occurring on the east and west. The mean standing stocks of benthic animals determined during the study period was four time higher on the western shore than on the east.

Effects of lake level fluctuation were the same on eastern and western shores, with both having littoral areas within 100m of the shore that are less than 1,5m in depth. The North/South seiche action set up by strong winds has an equal effect on both shore areas of South Lake.

Seasonal variations of river inflow into the St.Lucia System have little effect on the South Lake area, other than to bring about minor depth changes and dilutions. The silt content is not affected by that brought into the system by the major rivers, as their silt loads are deposited fairly close to the point where they enter the lake system (I.van or near South Lake.

2.3 Kosi - Estuary linked lake system (Figure 3 & Table 1)(Physical data - Chapter 8).

This system is located in the extreme northeast corner of Natal and consists of four distinct but interconnected lakes which drain to the sea via a usually permanently open estuary. Due to their distances from the mouth and positions in relation to freshwater inflow, each of the lakes is subject to a different salinity regime. Amanzimnyama is always fresh (Blaber, 1978), Nhlange ranges from fresh to 5^{o}/oo (Blaber & Cyrus, 1981), while Mpungwini and Makhawulani show greater variations due to tidal influence. At high tides a salt wedge is usually present, extending from the mouth as far as the entrance to Lake Makhawulani (Fig. 3), a distance of some 6km (Cyrus, 1980).

The fish fauna of this system is well documented and the juveniles of numerous marine species are common. Some 163 species have been recorded in the estuary. These are listed, with short notes on the more common species, by Blaber (1978) and Blaber and Cyrus (1981).

2.4 Mlalazi - Estuary (Figure 4 & Table 1) (Physical data - Chapter 8).

The ecology of this system was investigated by Hill (1966) who recorded 56 fish species and found juveniles of a number of marine species to be common.

The mouth remains open most years, with a ´salt wedge´ present on rising tides. A wide range of salinities occurs depending on river flow and tidal state.

2.5 Tongati - Estuary (Figure 5 & Table 1) (Physical data - Chapter 8).

Virtually no information existed on the fish fauna of this estuary prior to 1981. However during the study period 32 species were recorded (Blaber et al., 1984), with a number of juveniles of marine species also being present.

The mouth of this system seldom closes completely, due to a rocky outcrop in the adjacent surf zone which stops the longshore drift from depositing large amounts of sand across the mouth. As a result the Tongati system is never isolated from the sea for as long a period as the Mdloti system. When river flow decreases during winter the width of the mouth narrows and at times is so restricted that a connection with the sea only occurs during high tide. When the mouth is open a fairly strong 'salt wedge' develops.

2.6 Mdloti - Lagoon (Figure 6 & Table 1) (Physical Data - Chapter 8).

Between December 1981 and November 1982, 29 fish species were recorded in the system (Blaber _et al_., 1984). Prior to this, relatively little information was available on this system. Juveniles of a number of marine species were present.

The mouth of this system closes seasonally but is regularly opened by sugar farmers when levels reach a point where they start to flood cane lands (Blaber _et al_., 1984). Due to its small size and with freshwater continually flowing in over the marine waters, this system has a very marked 'salt wedge' on most tides. This leads to a wide range of salinities being present within the system.

2.7 Fafa - Lagoon (Figure 1 & Table 1) (Physical data - Chapter 8).

The knowledge of fish in this system prior to this study consisted of records of 9 species identified by Hemens _et al_. (1971). This study produced records of 20 species including juveniles of some marine species.

This system previously closed seasonally, but an artificial weir has been built across the southern portion of the mouth and as a result contact with the sea is much restricted, sea water only washing over the weir at high tides. Due to its isolation from the sea, the system tends to be rather well mixed, with low salinities.

2.8 Mtamvuna - Estuary (Figure 1 & Table 1) (Physical data - Chapter 8).

The fish fauna of this system has been investigated by Day (1950) who recorded 18 species and by Hemens *et al*. (1973) who recorded 11. During this study 38 species were netted including many juveniles of marine species.

The mouth of this system remains open throughout the year with a wide range of salinities occurring. It appears that a strong ´salt wedge´ is present under most conditions.

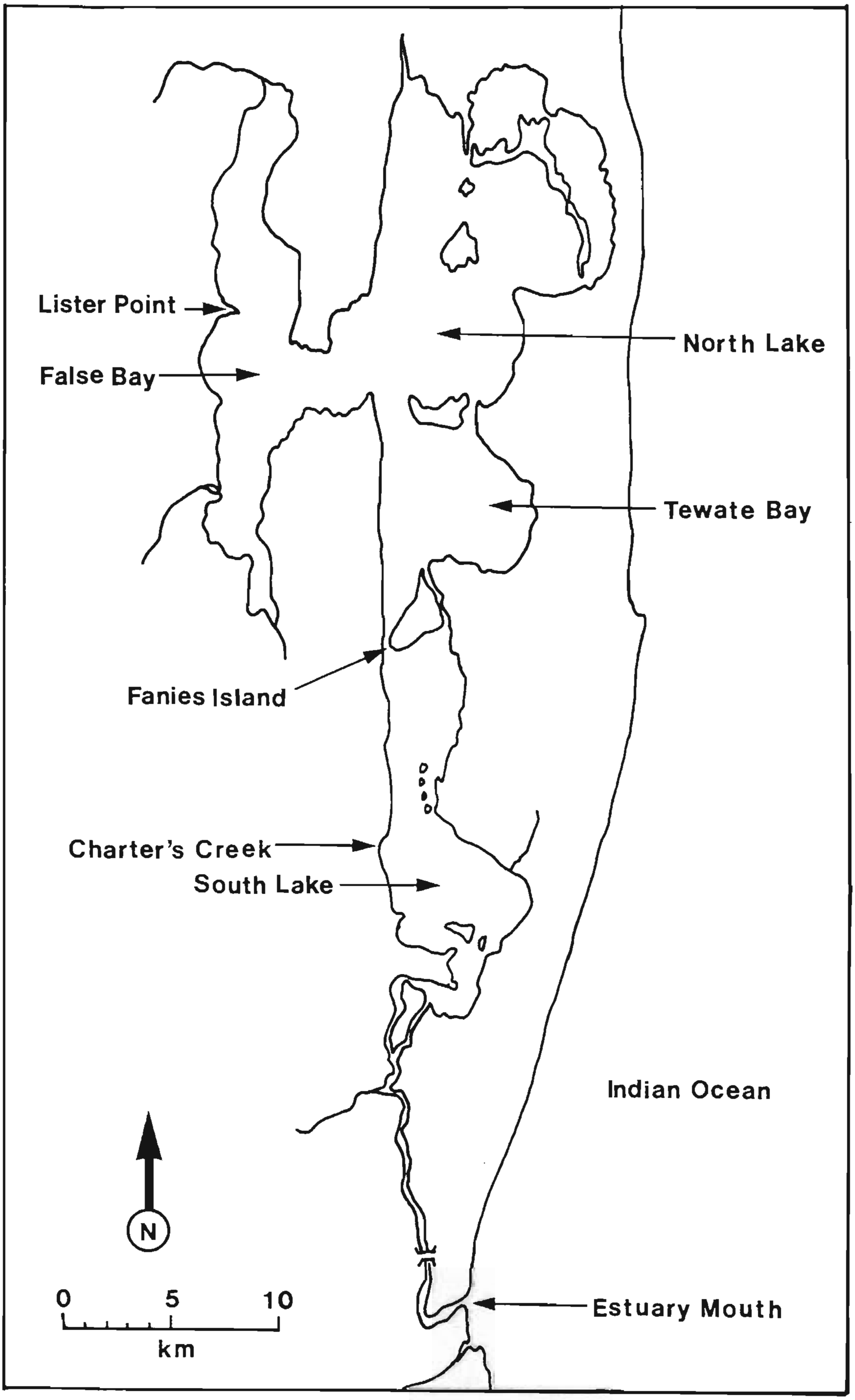

Figure 2: The St.Lucia System.

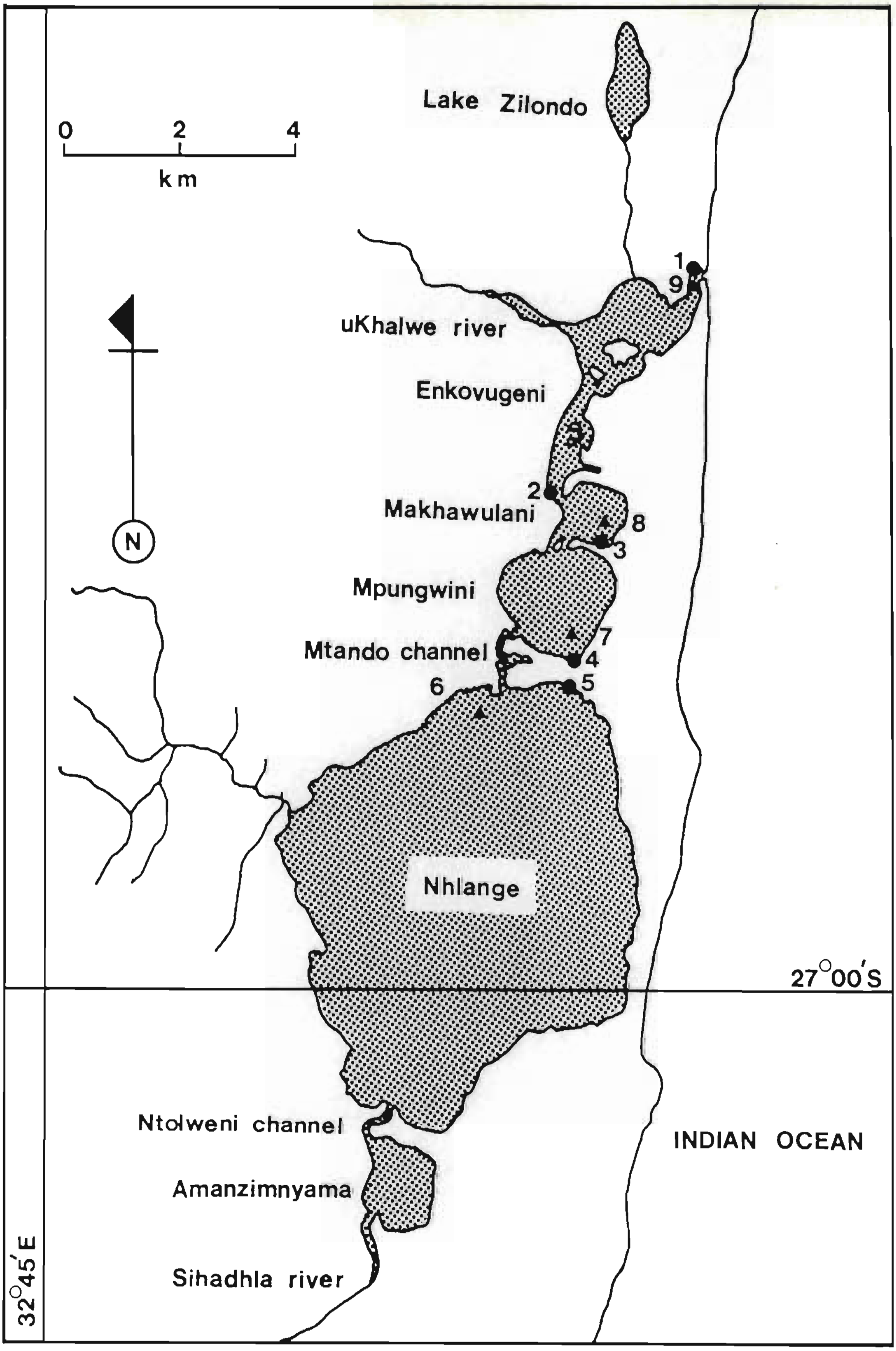

Figure 3: The Kosi System (● = seine netting sites, ▲ = gill netting sites).

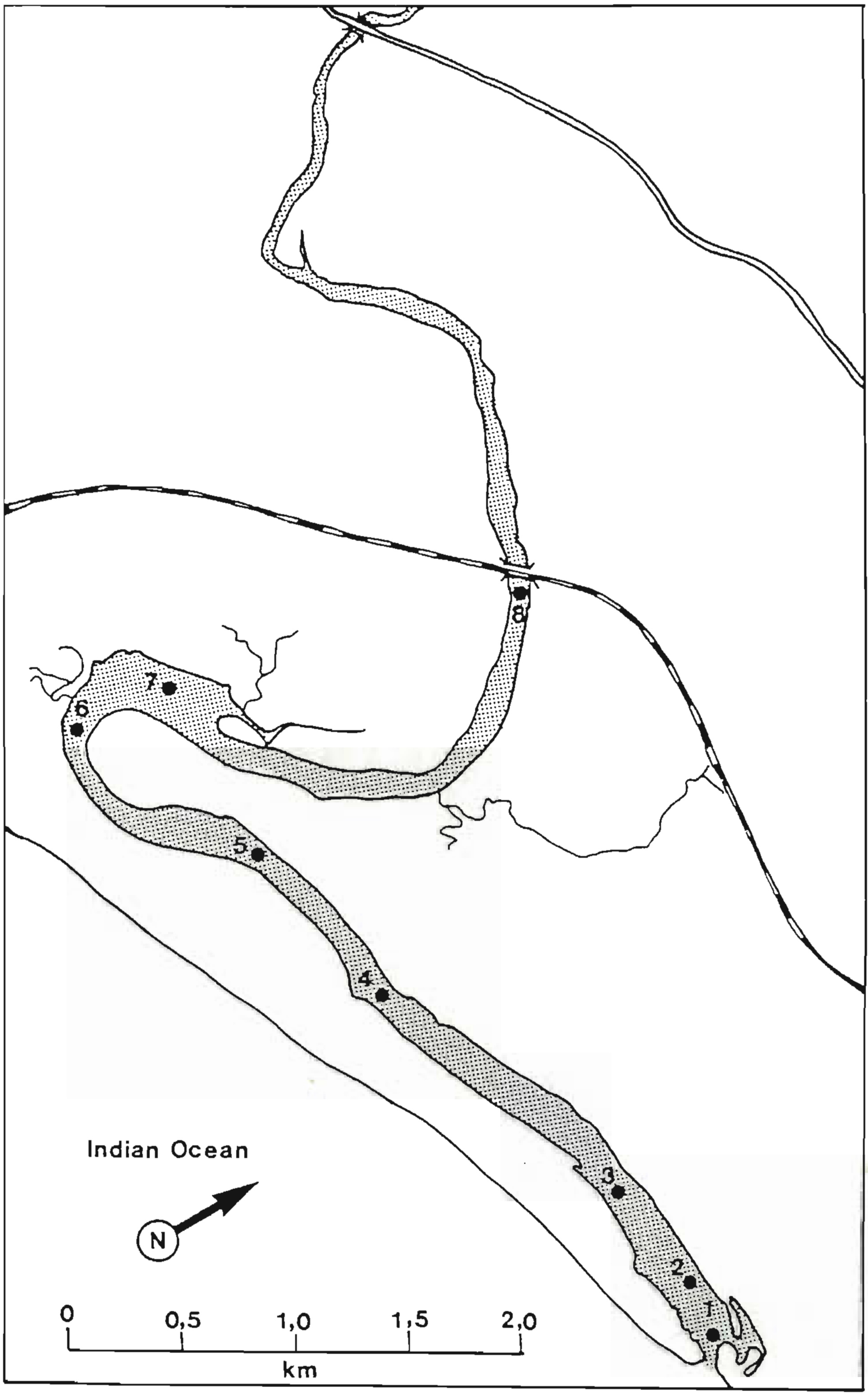

Figure 4: Mlalazi Estuary (● = turbidity sampling sites).

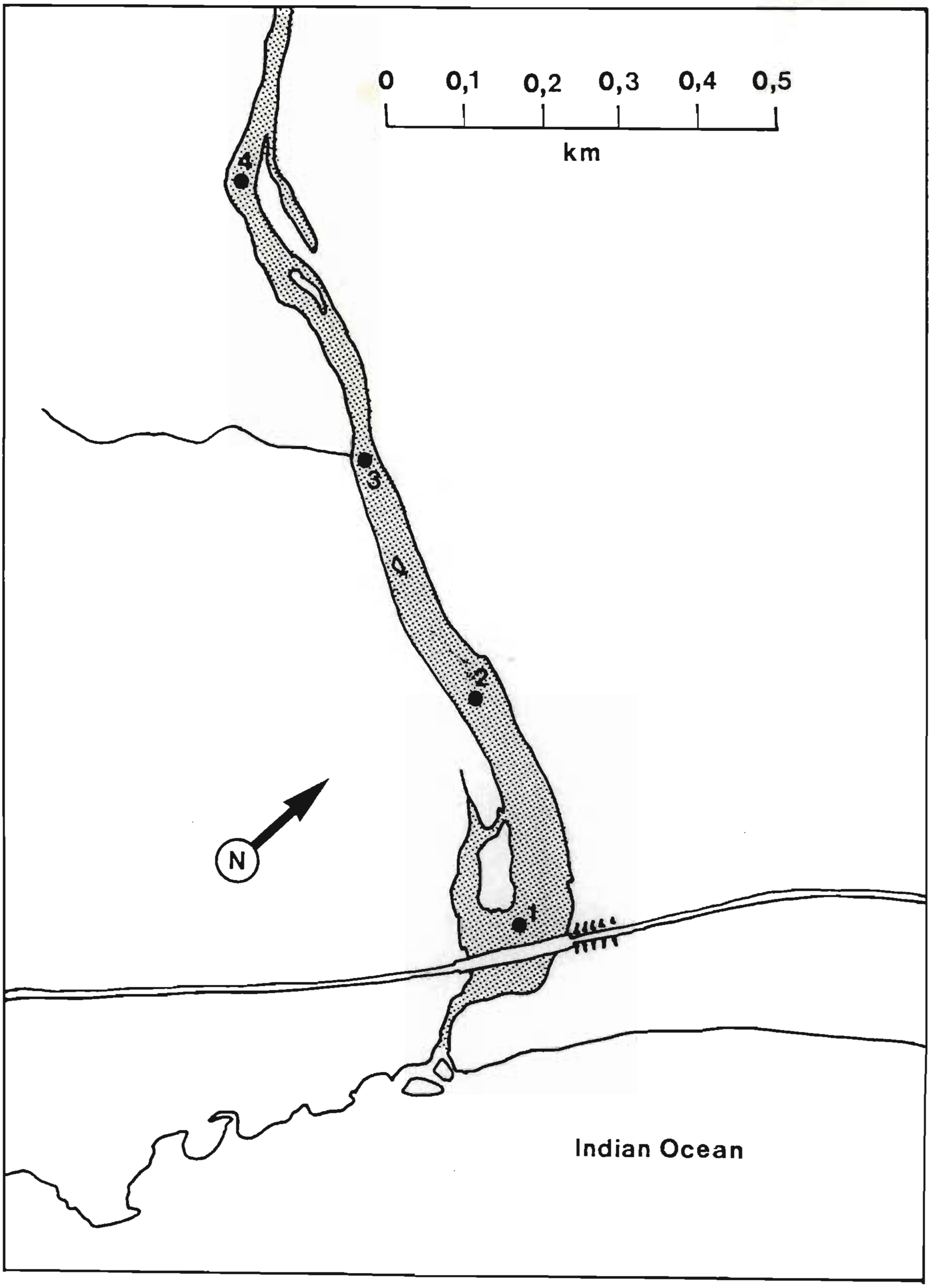

Figure 5: Tongati Estuary (● = turbidity sampling sites).

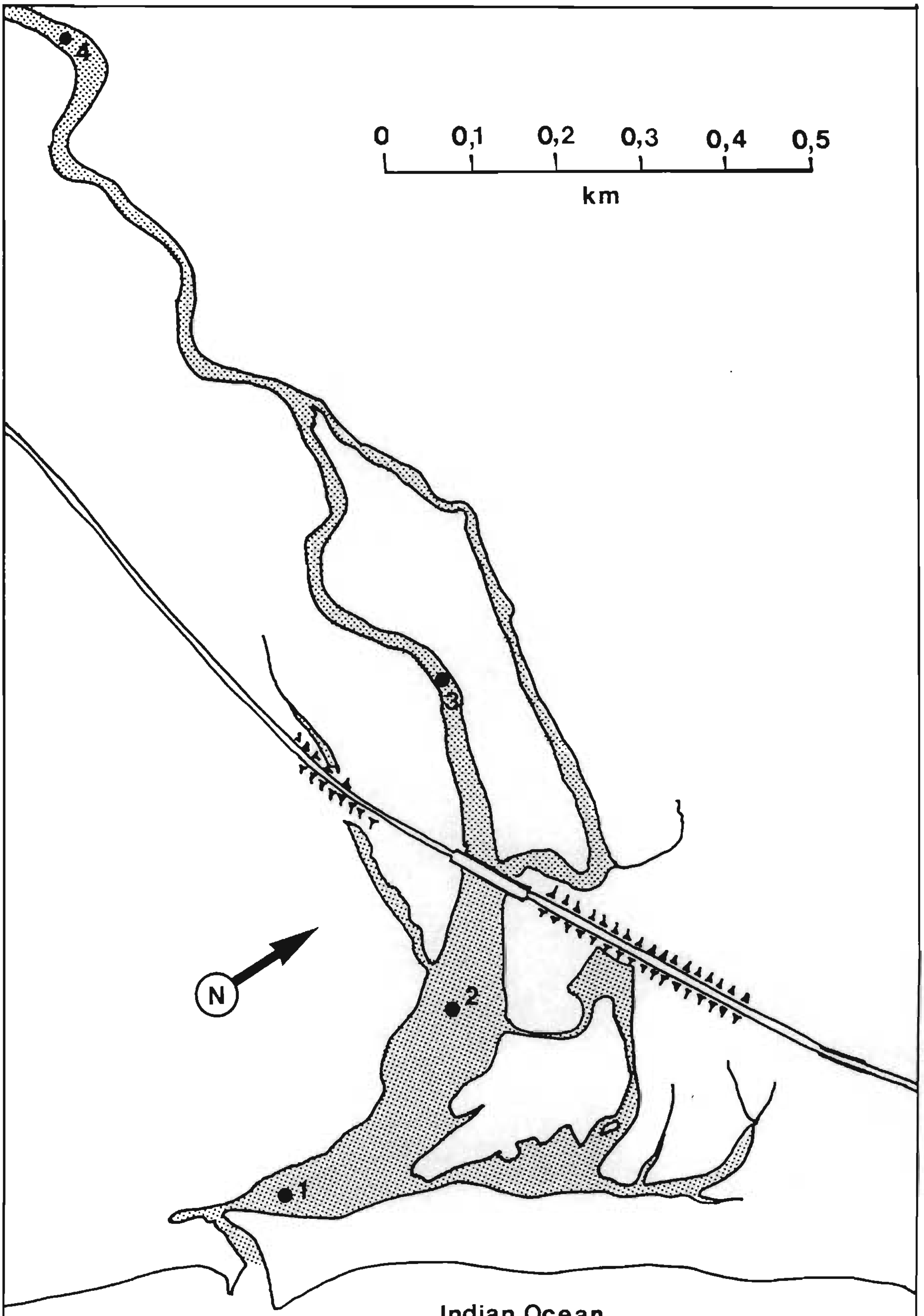

Figure 6: Mdloti Lagoon (● = turbidity sampling sites).

3. MATERIALS AND METHODS.

3.1 Introduction.

This study was carried out over the period from January 1980 to June 1983. During the first two years field work was conducted in a number of Natal estuaries. The main study area was Lake St. Lucia, while the Kosi System, Mlalazi, Tongati and Mtamvuna Estuaries, and Mdloti and Fafa Lagoons (Fig. 1) were also sampled. Experimental work was performed in the laboratory of the Natal Parks Board (N.P.B.) at St.Lucia Estuary from January 1982 to June 1983. During this period additional field data were also collected from the St. Lucia system.

Although field work was directed at determining the distribution of juvenile fish in Natal estuaries in relation to water turbidity, a number of other physical parameters were also measured in order to ascertain whether turbidity was in fact the major factor leading to any fish distribution patterns found. These factors included salinity, water temperature, wave action, wind speed, lake level, substratum particle size and the composition of the benthic fauna.

It should again be emphasized that this study concentrated on the distribution of juveniles of the common marine fish which enter estuaries, in relation to turbidity. Therefore while sampling of physical factors covered most of the area of all the systems studied, the sampling programme was directed at those areas occupied by juvenile fish in the estuarine environment. In the case of the larger systems, where juveniles inhabit the shallow littoral areas, netting was carried out in the area less than 100m from the shore, with the remaining open water areas not being sampled.

3.2 Field sampling and collecting methods.

3.2.1 Fish.

(a) Large Seine Netting.

Netting was carried out using a 70m x 2m x 12mm bar mesh seine. Net laying and hauling procedures were as follows: the net, with 50m nylon warps attached at each end, was positioned on the bow of the ski boat. The loose end of one warp was attached to a stake on the shore or held by a helper.

The boat reversed out at right angles to the shore until the 50 metres of warp was paid out, then a 90° turn was made and the net laid off the front of the boat, parallel to the shore. Once the net was laid the boat made a second 90° turn and headed to the shore letting out the other warp as it went. The net was then hauled in manually with both ends being brought in at the same speed. Speeds of hauling were similar in most instances, except in areas with finer substrata, where it was at times more difficult to pull in the net and more effort was necessary in order to get both ends in at the same time.

The seining depths were all similar in the main study area, South Lake, St.Lucia, but varied to some extent in the other systems. Information on all seining depths are given in Tables 2 to 8. As most of the area occupied by each system sampled was fairly uniform, with clear substrata and no rocky outcrops, the choice of sampling sites was determined by the presence of suitable beaches on which to haul the nets, and by water depth.

(b) Small Seine Netting.

This was carried out using a fry seine which measured 10m x 1,5m x 4mm bar mesh. The systems and depths at which this net was operated have been listed in Tables 2 to 8. Netting methods employed were to walk the net out to the required distance then to walk parallel to the shore so as to get opposite an undisturbed area before walking the net onto the shore. The criteria for small seine site selection were

(c) Gill Netting.

A set of monofiliment gill nets with stretched mesh sizes of 35, 55 and 145mm, each 60m long and 2,5m deep, were used to sample a number of systems. These were laid for a set time period in order that a uniform catch per unit effort could be calculated. Localities and netting depths at which gill nets were used are listed on Tables 2 to 8.

(d) Throw Netting.

In the upper reaches of the smaller systems sampled, a standard type throw net was used to sample areas which were not suitable for gill netting and which had no vegetation free shore line onto which a seine net could be pulled. Catch per unit effort was calculated per throw, based on a minimum of 20 throws from the boat, in each sampling area. Areas at which throw net sampling was done and the depth at the site are listed on Tables 2 to 8.

(e) Measurement.

All fish caught were measured to within 10mm standard length (= to caudal bend) size classes, on a standard fish measuring board, before being returned to the water.

(f) Problems and limitations of the sampling programme and field methods.

During the period that the fish sampling programme was being undertaken a few problems arose which required some modifications in the analysis and interpretation of the results. Due to the variations in size and to some extent the depth of the systems investigated, it was not possible to set up a completely uniform netting programme. As a result the four different methods described above were used depending on the system. It was therefore decided that work would concentrate on the St.Lucia System, with South Lake being chosen as the main study site because it was known to have a wide range of water turbidities and common estuarine fish species present. It was envisaged that, as gill, and small and large seine netting could be carried out at nearly all the chosen sites, this would provide useful comparative altering the programme.

First, during the study period, water input into the lake was below average and as a result the level was below mean lake level for seven months of the year. Consequent upon the system being shallower than the average depth of 1,5m, gill netting operations could not be successfully undertaken. As a result, this sampling method was only used in the deeper areas of the Narrows and the Estuary.

The second factor, which only became clearly evident when the catch data were being analysed, was that the small seine netting on the 'clear' eastern shores was ineffective. As the net was only 10m long the fish were able to detect its approach much quicker in the clear water and were able to escape before the net was pulled up onto the shore. This is clearly shown in section 5.2.3 (Tables 33 & 34) where it can be seen that the differences in the mean number of species and the catch per unit effort (CPUE) for small seine netting on the east and west are considerable, while the large seine results are fairly similar. As a result, the data collected from small seine netting could not validly be used.

The above problems meant that the determination of turbidity preferences had to be calculated from the South Lake large seine data set. This covered a wide range of turbidities and also consisted of a year's sampling. Additional information from other systems which has been used, has only been taken from large seine netting results.

3.2.2 Turbidity.

(a) Introduction.

For many years the measurement of turbidity had to be carried out in the laboratory using filtering and weighing techniques, or in the field using a Secchi Disc. The latter is, to a degree, subjective and only gives a qualitative assessment of water clarity (McCluney, 1975). However, with the advent of the Turbidimeter, also known as a Nephelometer, quick and accurate determinations became possible. The method is based on the scattering of light by suspended particles, al., 1981).

Various definitions have been put forward for turbidity; McCluney (1975) quotes some six. The most appropriate definition is given by the United States Geological Survey (1964):-
'Turbidity is the optical property of a suspension with reference to the extent to which the penetration of light is inhibited by the presence of insoluble material. Turbidity is a function of both concentration and particle size of the suspended material.'.

Standard measurement of turbidity has always been in terms of parts per million (ppm) of suspended sediment (ss) or in grams of sediment per litre, the latter given as dry weight. Most Turbidimeters give readings in one of three units: Jackson Turbidity Units (JTU), Formazin Turbidity Units (FTU) or Nephelometric Turbidity Units (NTU). The former is based on the depth at which a sample has to be placed in a Jackson Candle Turbidimeter to extinguish the image of a burning standard candle observed vertically through the sample. Formazin and Nephelometric Turbidity Units are derived from a standard which is prepared by accurately weighing and dissolving hydrazine sulphate and Hexamethyl-enetetramine in distilled water (McCluney, 1975). This develops a white suspension after 48 hours. Gardner (1981) states that according to the American Water Works Association (1975) NTU measurements are equivalent to the optical JTU measurement.

It would thus appear from the literature that NTU, JTU and FTU are all approximately equal measurements. Throughout this work measurements are given in NTU while figures quoted from references are given in the units used by the author. Tables may be drawn up for converting ppm, g/l and Secchi values to NTU, but these can only be approximate (McCluney, 1975). In many instances in this work, approximate conversion figures (NTU) have been given for values quoted by other workers in the different units. The reason for their inclusion is to provide some comparisons with NTU data from this study.

(b) Equipment used.

A Hach Model 16800 portable Turbidimeter was used for field work and a Monitek Model 21 continuous readout through flow Turbidimeter for laboratory tests. Measurement made with the former is based on the scattering of white light at 90° to the incident beam, while the latter measures the ratio of light scattered at small angles to that in the direct, transmitted beam (McCluney, 1975).

In comparing the two methods of measurement of light scattering, McCluney (1975) mentions that those measuring over small angles are likely to be more accurate (Monitek), but the differences are not significant. The precision of both turbidity meters was ±1% on full scale of 200 NTU

(c) Silt content and turbidity.

As the measurement of turbidity in NTU´s has only recently been adopted, much of the earlier work carried out expressed turbidity in terms of Secchi Disc depth or in milligrams of silt present per litre of water. In order to permit an approximate conversion of published data for comparison with results obtained in this study, the silt content of water of known turbidities had to be calculated. During 1981 a series of water samples of varying turbidity were collected from the de Lange´s site, St.Lucia for determining the silt loading of the water at different turbidities.

(d) Monitoring programme during fish sampling.

Prior to seine netting, water samples for turbidity determination were collected in all systems sampled at approximately 3 and 10 metres from the shore (Tables 2 to 8). The reading at ten metres gave an indication of the general turbidity of the area which was to be sampled by netting, while the three metre sample provided data on turbidity increases which might have occurred as a result of onshore wave action near the shore.

All turbidity determinations were done in the field using the Hach portable turbidity meter, and therefore provided information on the turbidities experienced by the

(e) Daily variation of turbidity.

In order to obtain data on the daily variation in turbidity at any one locality, two stations in South Lake were sampled hourly for a period of 40h. These were Charters Jetty (turbid water locality/western shores; 2-3/12/81) and Ukwakwa (clear water locality/eastern shores; 8-9/7/82) (Fig. 7). During these sampling periods wind direction and strength were measured on site, while four hourly wind speed data from the two wind recording stations on the lake, Estuary Mouth and Lister Point (Fig. 2) were obtained from the Natal Roads Department Reclamation Division.

(f) Turbidity patterns in South Lake, St.Lucia.

Sampling of turbidity, salinity and temperature along transects under different wind directions and strengths was carried out with the view to relating turbidity patterns to the dominant wind directions in the area. The transects (Fig. 7) covered a distance of 38km and were completed in the shortest time possible, usually just over two hours, so that all samples could be collected under essentially similar conditions. From the data collected, turbidity iso-lines under different wind directions and strengths could be plotted and zones of different turbidities identified.

(g) Distribution of turbidity in Lake St.Lucia.

From February 1980 to June 1983 research staff of the N.P.B. collected water samples for turbidity analysis during their monthly monitoring on the estuary and lake. These were taken from 19 sites in the Estuary (Fig. 8) and 18 sites in the Lake (Fig. 2) from which the N.P.B. has been collecting physical data for the past 15 years. Secchi Disc readings taken along with turbidities, between February 1980 and September 1982, were used to establish whether any correlation existed between the two. This was done in order to establish whether it was possible to use old Secchi Disc data, collected before this study commenced, in determining the distribution of turbidity throughout the lake.

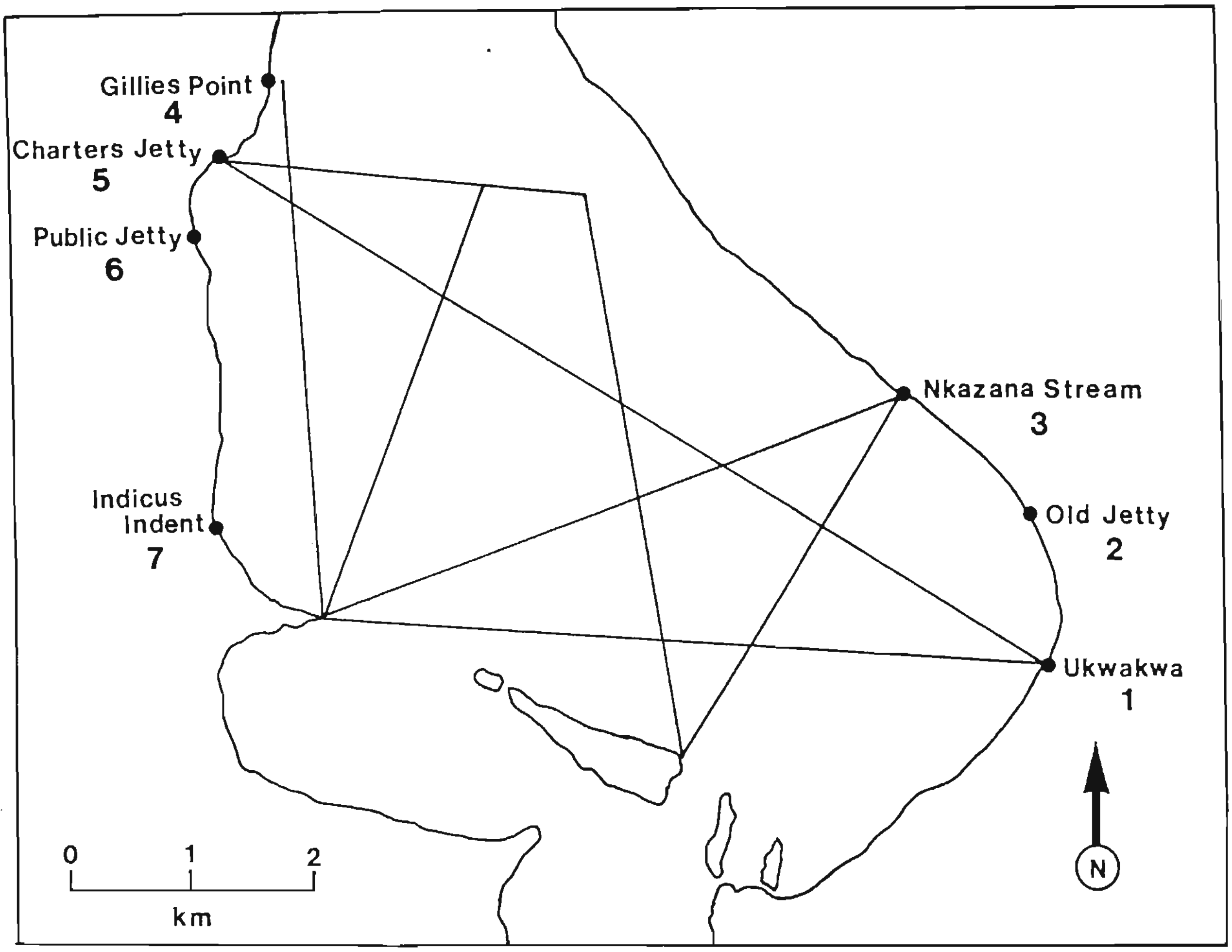

Figure 7: South Lake - St.Lucia (● = seine netting sites, —— = transect lines used for collecting turbidity data for drawing up iso-turbidity contours).

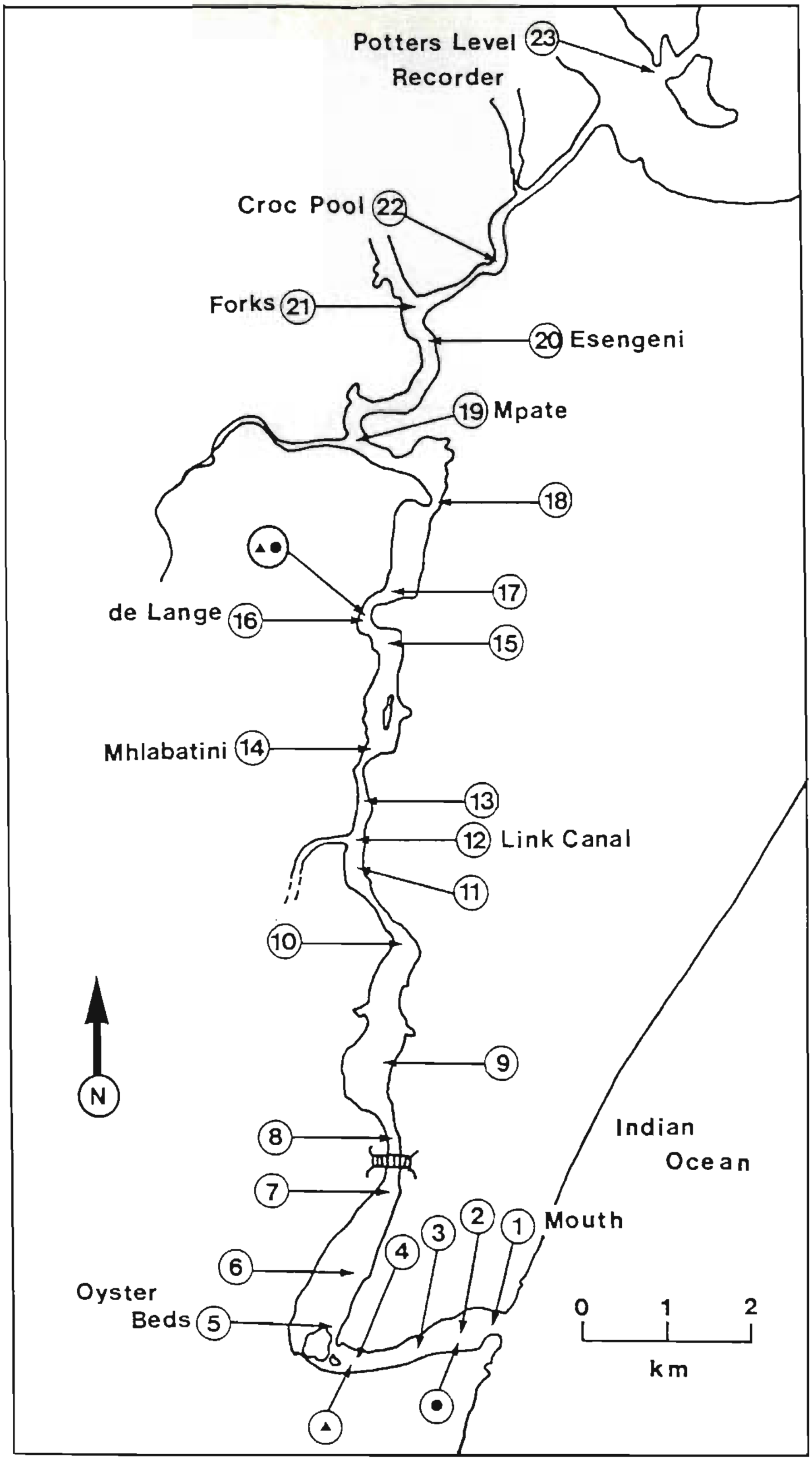

Figure 8: St.Lucia Estuary (⑨ = turbidity sampling sites - Nos.1 to 11, 13 to 20 & 22 sampled during field trips, Nos.1 to 10, 12, 14, 15 & 17 to 23 sampled by N.P.B., ▲ = gill netting sites, ● = seine netting sites).

3.2.3 Water Temperature.

Temperatures were measured using a standard mercury in glass thermometer, held 30cm below the water surface, prior to all seine netting (simultaneously with turbidity), as well as during high and low tide runs in the different estuaries and turbidity transect runs on South Lake.

3.2.4 Salinity.

Salinities were measured with a Goldberg Model 10423 Temperature Compensated Refractometer. Measurements were made simultaneously with those of turbidity and temperature during the sampling programmes mentioned in 3.3 below.

3.2.5 Wave Action.

Prior to seine netting being carried out, an estimate of the wave action along the shore line of the site to be sampled, was made. A scaled rating from 1 to 4 was used: 1 = calm (no waves), 2 = light, 3 = moderate and 4 = heavy wave action.

3.2.6 Wind Speed.

Four-hourly wind speed data recorded by recording anemometers located at the Estuary Mouth and Lister Point (Fig. 2) were obtained from the Reclamation Division of the Natal Roads Department. As both anemometers were situated some distance from the South Lake sampling sites, the wind data they provided at the times of sampling were unlikely to be exactly the same as that at the sampling site. As a result mean monthly wind speeds were calculated and used in the analysis as they were representative of the predominant wind regimes for each month. A summary of wind data covering the four-year period January 1969 to February 1973 was obtained from Hutchison and Pitman (1973) in order to establish

3.2.7 Lake Level.

Lake Level data from the level recorders at Charters Creek and the Old Jetty (Fig.7) were obtained from the Natal Roads Department Reclamation Division. Due to the surface seiche effect set up by the prevailing winds, much daily variation in lake level occurs at all sites. As a result only the mean monthly combined values from the two level recorders were considered representative of actual lake level, and these values were used in the analysis.

3.2.8 Substratum particle size.

The particle size composition of surface substrata were determined by collecting a known volume of substratum to a depth of 20mm and passing it through a series of standard sieves (Endecott's Test Sieves Ltd. London). Substrata from a water depth of 0,5m at each of the seining sites in South Lake, St.Lucia and the Kosi System were analysed this way. Particle size composition was not measured in the other systems sampled during this study, but data were obtained from studies carried out by other workers.

3.2.9 Benthic Fauna of South Lake, St.Lucia.

Benthic samples were collected monthly for a year, from water depths of about 0,7m, at four sites in South Lake. The sites were Ukwakwa and Nkazana Stream (sandy substrata) and Gillies Point and Indicus Indent (muddy substrata) (Fig. 7). A Zabalocki-type Ekman grab which sampled a surface area of 0,0236m^2 to a depth of 4,5cm was used. Four grab samples were taken at each site.

After collection larger organisms were separated by washing the sample through a 1,0mm sieve. A solution of 4% formalin was added to the remainder, the sample stirred into suspension and decanted through a 0,5mm sieve. This procedure was repeated five times to ensure the collection of all formalin and the vital dye Phloxin added to aid sorting and counting in the laboratory.

3.3 Sampling Intensity.

3.3.1 Lake St. Lucia (Figure 2).

During the field work period this system was visited on 16 occasions, including monthly visits during 1981 when the major part of the fish sampling programme was undertaken. Seine and gill netting sites are shown on Figures 7 (South Lake) and 8 (Estuary).

Table 2 gives details of the programme for fish sampling and the measurement of physical data, carried out in the South Lake between January and December 1981. Table 3 gives similar details for Estuary Mouth and Narrows sampling sites.

3.3.2 Kosi System (Figure 3).

Seven visits were made to this system during the study period. The dates, sampling methods used and conditions of the mouth are given in Table 4.

3.3.3 Mlalazi Estuary (Figure 4).

The sampling programme carried out during the four visits to this system is listed in Table 5.

3.3.4 Tongati Estuary and Mdloti Lagoon.

Monthly visits were made to these systems between December 1980 and November 1981. Tables 6 and 7 list dates, sampling methods and mouth conditions at each visit.

Table 2: Sampling programme in South Lake, St.Lucia, January to December 1981 (No. = Number; TU. = Turbidity; TE.= Temperature; SA.= Salinity; WA.= Wave Action; m = metres; X = measured & Sites 1 to 7 shown on Figure 7).

	Mouth	Large Seine		Small Seine		Physical Data			
Date	Condition	Site No.	Depth (m)	Site No.	Depth (m)	TU.	TE.	SA.	WA.
19-21/1	Open	1,3,4,7	1,0	1-7	0,7	X	X	X	X
17-18/2	Open	1-4,7	1,0	1-7	0,7	X	X	X	X
17-18/3	Open	1,3,4,7	1,1	1-7	0,8	X	X	X	X
28-28/4	Open	1,3,4,7	1,2	1-7	0,8	X	X	X	X
27-28/5	Open	1-4,7	1,3	1-7	0,8	X	X	X	X
23-24/6	Open	1-4,7	1,4	1-7	0,8	X	X	X	X
28-29/7	Open	1-4,7	1,5	1-7	0,9	X	X	X	X
18-20/8	Open	1-4,7	1,3	1-7	0,8	X	X	X	X
22-23/9	Open	1-4,7	1,4	1-7	0,7	X	X	X	X
12-13/10	Open	1-4,7	1,5	1-7	0,7	X	X	X	X
02-04/11	Open	1-4,7	1,3	1-7	0,8	X	X	X	X
01-02/12	Open	1-4,7	1,2	1-7	0,8	X	X	X	X

Table 3: Sampling programme at the Estuary Mouth & Narrows, St.Lucia, January to December 1981 (TU. = Turbidity; TE.= Temperature; SA.= Salinity; WA.= Wave Action; m = metres; X = measured; Est.= Estuary; N = Narrows & Sites shown on Figure 8).

	Mouth	Gill Net		Small Seine		Physical Data			
		Depth (m)		Depth (m)					
Date	Condition	Est.	N.	Est.	N.	TU.	TE.	SA.	WA.
22-23/1	Open	3,5	3,0	0,75	0,6	X	X	X	X
20-21/2	Open	3,0	2,9	0,75	0,6	X	X	X	X
20-21/3	Open	3,1	3,0	0,75	0,6	X	X	X	X
24-26/4	Open	3,5	3,0	0,75	0,6	X	X	X	X
29-30/5	Open	3,5	3,0	0,75	0,6	X	X	X	X
27-28/6	Open	3,0	2,8	0.75	0,6	X	X	X	X
26-27/7	Open	3,0	2,8	0,75	0,6	X	X	X	X
21-22/8	Open	3,2	3,0	0,75	0,6	X	X	X	X
19-21/9	Open	3,2	3,0	0,75	0,6	X	X	X	X
16-18/10	Open	3,5	3,2	0,75	0,6	X	X	X	X
06-07/11	Open	3,6	3,2	0,75	0,6	X	X	X	X
03-04/12	Open	3,0	2,8	0,75	0,6	X	X	X	X

Table 4: Sampling programme in the Kosi System (No. = Number; TU. = Turbidity; TE.= Temperature; SA.= Salinity; WA.= Wave Action; m = metres & Sites 1 to 9 shown on Figure 3).

	Mouth	Large Seine		Gill Net		Physical Data			
Date	Condition	Site No.	Depth (m)	Site No.	Depth (m)	TU.	TE.	SA.	WA.
04/80	Open	1 - 5	1,7	6 - 9	2,5	X	X	X	X
07/80	Open	1 - 5	1,7	6 - 9	2,5	X	X	X	X
09/80	Open	1 - 5	1,7	6 - 9	2,5	X	X	X	X
12/80	Open	1 - 5	1,7	6 - 9	2,5	X	X	X	X
02/81	Open	1 - 5	1,7	6 - 9	2,5	X	X	X	X
05/81	Open	1 - 5	1,7	6 - 9	2,5	X	X	X	X
01/82	Open	1 - 5	1,7	6 - 9	2,5	X	X	X	X

Table 5: Sampling programme in the Mlalazi Estuary (No. = Number; TU. = Turbidity; TE.= Temperature; SA.= Salinity; WA.= Wave Action; m = metres & Sites 1,3 and 6 shown on Figure 4).

	Mouth	Large Seine		Small Seine		Physical Data			
Date	Condition	Site No.	Depth (m)	Site No.	Depth (m)	TU.	TE.	SA.	WA.
04/80	Open	1,3,6	1,5	1,3,6	0,7	X	X	X	X
08/80	Closed	1,3,6	1,5	1,3,6	0,7	X	X	X	X
03/81	Open	1,3,6	1,5	1,3,6	0,7	X	X	X	X
04/82	Open	1,3,6	1,5	1,3,6	0,7	X	X	X	X

Table 6: Sampling programme at the Tongati Estuary, December 1980 to November 1981 (No. = Number; TU. = Turbidity; TE.= Temperature; SA.= Salinity; WA.= Wave Action; m = metres & Sites 1,3 and 4 shown on Figure 5).

	Mouth	Large Seine		Throw Net		Physical Data			
Date	Condition	Site No.	Depth (m)	Site No.	Depth (m)	TU.	TE.	SA.	WA.
15-12	Open	1	2,0	3,4	2,0	X	X	X	X
07-01	Open	1	2,6	3,4	1,5	X	X	X	X
10-02	Open	1	1,7	3,4	1,4	X	X	X	X
03-03	Closed	1	2,2	3,4	1,8	X	X	X	X
07-04	Closed	1	2,2	3,4	1,6	X	X	X	X
05-05	Open	1	2,1	3,4	2,0	X	X	X	X
03-06	Open	1	2,0	3,4	1,6	X	X	X	X
17-07	Open	1	2,1	3,4	1,8	X	X	X	X
10-08	Open	1	2,0	3,4	1,5	X	X	X	X
07-09	Closed	1	0,9	3,4	1,0	X	X	X	X
05-10	Open	1	1,5	3,4	1,0	X	X	X	X
09-11	Open	1	2,0	3,4	1,7	X	X	X	X

Table 7: Sampling programme at the Mdloti Lagoon, December 1980 to November 1981 (No. = Number; TU. = Turbidity; TE.= Temperature; SA.= Salinity; WA.= Wave Action; m = metres & Sites 1 to 4 shown on Figure 6).

	Mouth	Large	Seine	Throw	Net	Physical Data			
Date	Cond-ition	Site No.	Depth (m)	Site No.	Depth (m)	TU.	TE.	SA.	WA.
16-12	Open	1	2,5	3,4	1,5	X	X	X	X
09-01	Closed	1	2,7	3,4	1,5	X	X	X	X
11-02	Closed	1	1,6	3,4	1,0	X	X	X	X
04-03	Open	1	1,7	3,4	1,3	X	X	X	X
08-04	Open	1	1,7	3,4	1,0	X	X	X	X
06-05	Closed	1	2,3	3,4	1,7	X	X	X	X
04-06	Closed	1	2,3	3,4	1,5	X	X	X	X
16-07	Closed	1	1,8	3,4	0,8	X	X	X	X
11-08	Closed	1	1,9	3,4	0,9	X	X	X	X
08-09	Open	1	1,3	3,4	0,8	X	X	X	X
06-10	Open	1	1,8	3,4	0,7	X	X	X	X
10-11	Closed	1	3,0	3,4	2,0	X	X	X	X

3.3.5 Mtamvuna Estuary and Fafa Lagoon.

During the study period only one visit was made to each of these systems. Details of the sampling methods, mouth conditions and physical factors measured are given in Table 8.

Table 8: Sampling programme in the Mtamvuna Estuary and Fafa Lagoon (TU. = Turbidity; TE.= Temperature; SA.= Salinity; WA.= Wave Action; LS (m) = Large Seine, depth in metres; Gill (m) = Gill Net, depth in metres).

Locality	Mouth	Site	LS (m)	Gill (m)	Physical Data			
Date					TU.	TE.	SA.	WA.
<u>Mtamvuna</u>								
18/03/80	Open	mouth	2,5	3,0	X	X	X	X
19/03/80	Open	4km up	2,0	2,5	X	X	X	X
<u>Fafa</u>								
05/03/80	Closed	Mouth	1,3	2,0	X	X	X	X
06/03/80	Closed	2km up	1,5	1,8	X	X	X	X

3.4 Laboratory studies.

Selected species of fish were tested for turbidity and salinity preferences in the N.P.B. Laboratory at St.Lucia Estuary.

3.4.1 Turbidity gradients.

In order to determine the preference for and response of fish to turbidity, independent of other physical variables, gradients were set up in two four-chambered test tanks (Plate 1). The equipment used and the method of operation are discussed below:-

(a) Water circulation and filtration.

Unless otherwise stated all circular flow components in the experimental apparatus referred to are illustrated in Figure 9.

A 220 litre header tank was placed on the roof of the laboratory. Two tubes, each set at a flow rate of 2 l/min., were led from it, one via a 40 litre turbidity mixing tank (45x30x30cm) to a 16 litre turbid water source tank (23x28x26cm) and the other directly to a 16 litre clear water source tank (23x28x26cm). Water from the header tank first passed through a 'Thomas Tube' diatomaceous earth filter (1m long, 15cm diameter) and then a 'Fulflo Model WS-12' water filter with a 5µm filter cartridge, before flowing into the clear water source tank. Final filtering of the clear water was effected by means of two Eheim Circulating Power Filters (Model 2016) which filtered the water at a rate of 4 l/min.

Three tubes led from each of the source tanks to each of the two Test Tanks (Fig. 9). The total inflow rate into each tank was 2 l/min. and this was balanced by an outflow of 0,5 l/min. from each of the tank's four compartments. However, due to the system running on a gravity feed, variations in the head pressure resulted in the outflow from the Test Tanks having to be adjusted from time to time to avoid overflowing. Adjustments were usually made to the tube any turbid water being drawn into the clear water compartment.

The two Test Tanks used were of different dimensions so that fish of different sizes could be tested. The larger had a volume of 135 litres, measuring 150x30x30cm and was divided into four equal chambers by 3mm thick perspex partitions. The chambers were connected by rectangular 7,5x7,0cm apertures in the perspex which were located in a different position on each partition in order to avoid alignment. The two outer apertures were placed towards the bottom, while the centre partition aperture was towards the top. The small tank (78 litres) was partitioned in the same way as the large tank, its dimensions being 125x25x25cm with partition apertures measuring 4x10cm. Both tanks had small glass segments in the corners of each compartment to eliminate right angles.

After flowing out of the test tanks water first passed through the No.1 filter, was then drawn through the No.2 filter by means of an airlift system, operated by a 'Kiho G.A.8500 deluxe air pump', which poured the water through the No.3 filter into a 220 litre sump tank (Fig. 9). The filter material used comprised 'sandwiches' of filter floss 'fillings' between vilene (dressmakers interfacing material). Water from the turbid compartment of the small tank first passed through a continuous-flow fitting on a 'Monitek Model 21 Nephelometer', which had been calibrated against formazin standards, before reaching the No.1 filter.

A 'Guinard EMC-46' automatic sump drainage pump was located in the sump tank; this switched on automatically once a certain water level had been reached, and pumped the water into the header tank, 4,7m above, at a rate of $6m^3/h$. The total flow rate through the test tanks was 4 l/min., the sump pump cut-in level was at a depth of 33cm and the cut out level 11cm. This led to the pump being activated every 20 to 25 minutes when the flow system was in operation.

(b) Turbidity input and maintenance.

A plastic cylinder containing concentrated homogenized silt was positioned in the turbidity mixing tank. The silt

8). This was baked dry in an oven, followed by soaking in water over night before being homogenized with a 'Waring' Commercial Blender. Turbidity mixing was achieved by switching on an airlift pump which carried water from the mixing tank and passed it into the silt source cylinder.

A stirrer in the cylinder kept the silt mixed, while another in the mixing tank kept the silt in suspension as it passed out to the Turbid Water Source Tank. Water passed out of both source tanks via six tubes, three from each going to one of the two test tanks (Fig. 9). The tubes were all set at different flow rates and each contributed a percentage flow, to the different test tank compartments (Figure 10). The mixing of clear and turbid water entering the two middle compartments at different rates, caused a turbidity gradient to be set up in each of the test tanks. This gradient was maintained within a desired range by monitoring the water coming from the turbid compartment of the small test tank on the continuous turbidity readout of the Monitek Nephelometer and then passing water over the silt source when greater turbidity was required.

Once all tubes flowing into the test tanks had their flow rates set, turbidity gradients were set up with varying maximum turbidities. On each occasion the turbidities in all 8 compartments (two tanks) were measured. In this way Table 9 was compiled, which allowed the turbidity in any of the compartments to be calculated provided one had a reading for the turbid compartment of the small tank from the continuous flow readout. Slight variations in gradient figures occurred when the turbidity gradient was reversed in the test tanks. These were taken into account and the compartment ranges are shown in Table 10.

The system could be run up to a maximum of 200 NTU, but, after preliminary test runs and once fieldwork results had been assessed, all tests were carried out at turbidity maxima varying between 80 and 110 NTU. It was found that when run at these levels the silt cylinder held sufficient for the gradient to be maintained over a period of at least 10 hours. During most of the test runs the clear compartments remained at <5 NTU.

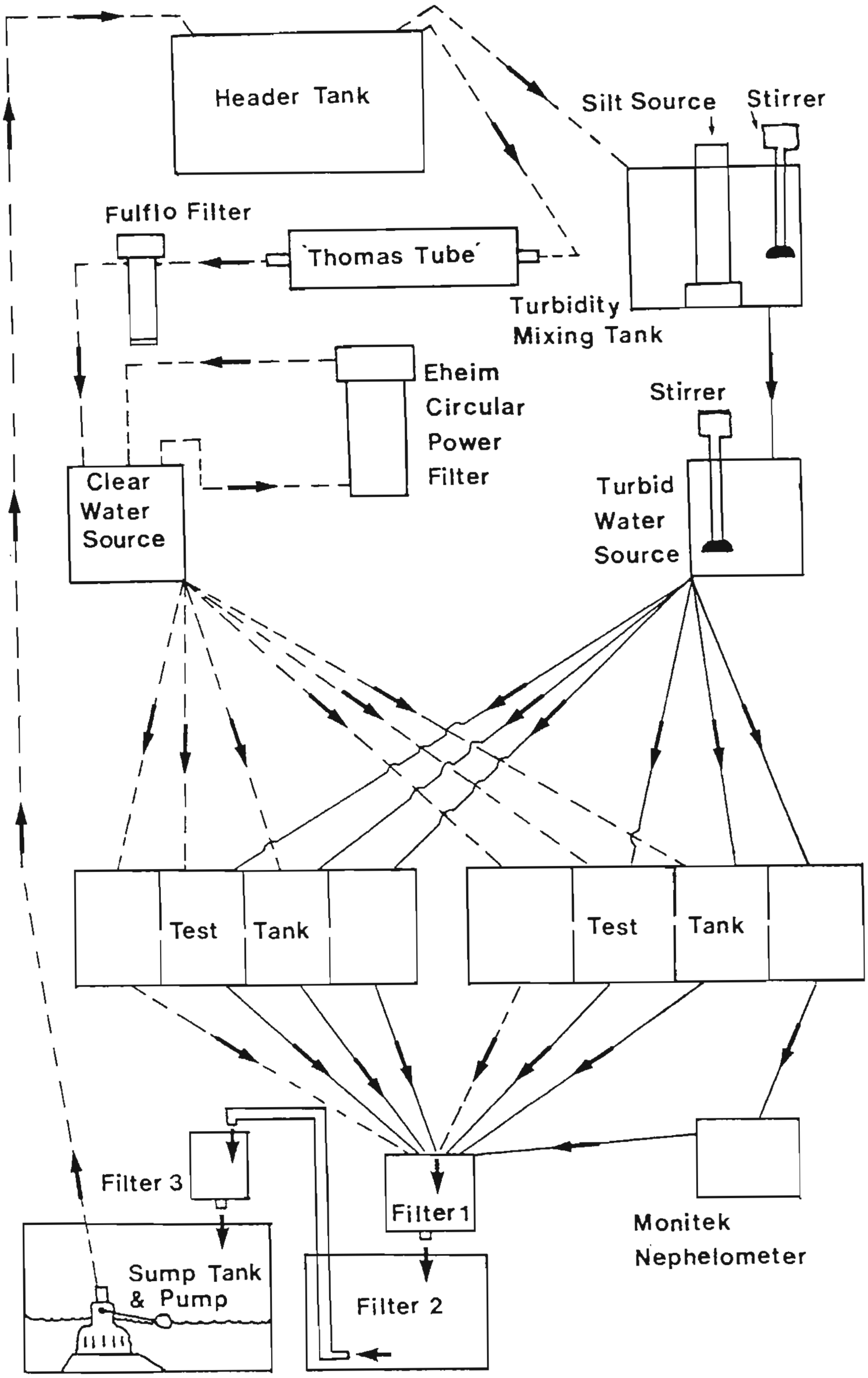

Figure 9: Diagram of experimental apparatus used to test turbidity preference of juvenile fish (◀━ = direction of water flow, - - - = clear water, ─── = turbid water.

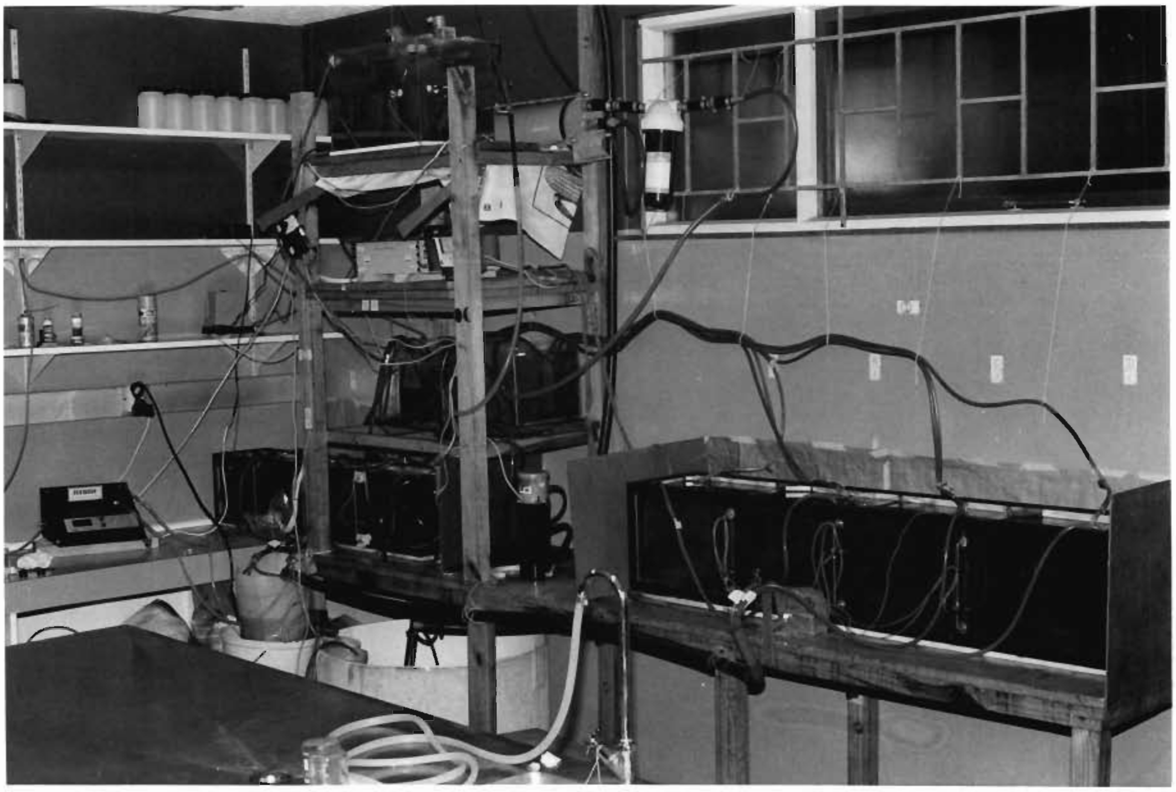

Plate 1: Experimental apparatus used for testing turbidity preference of juvenile fish.

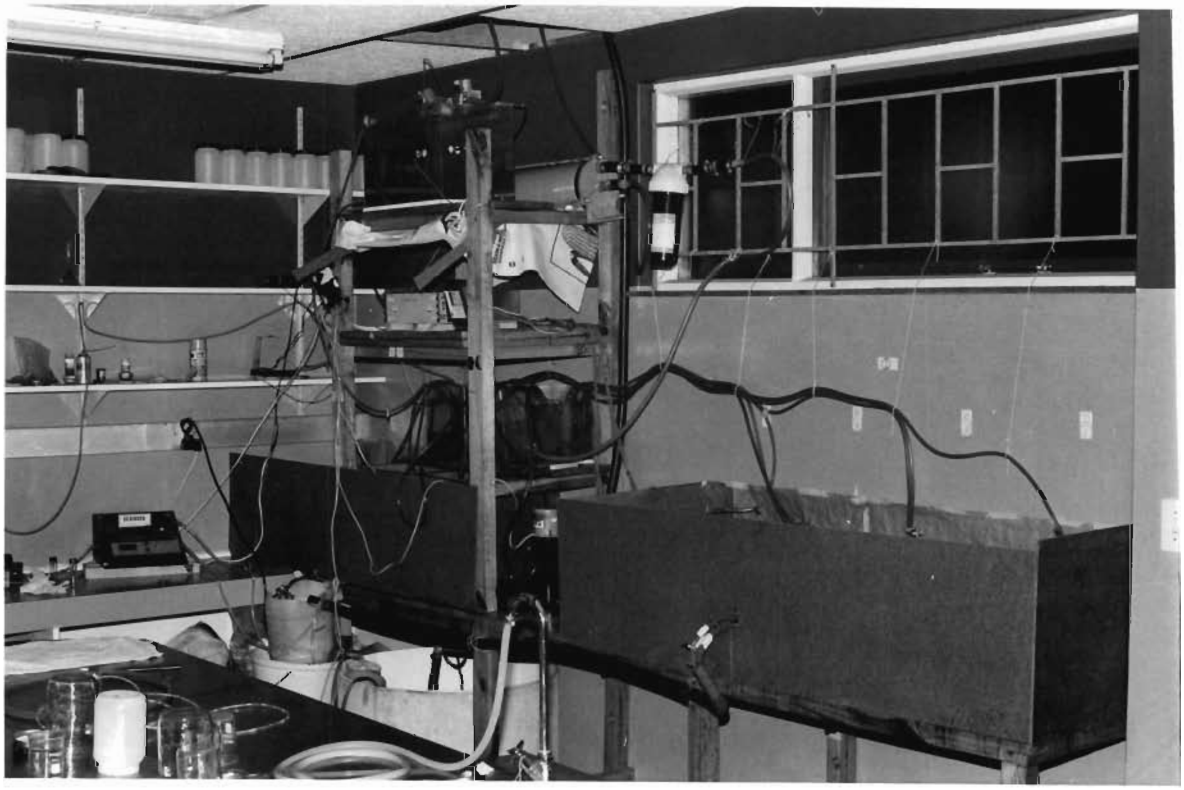

Plate 2: Choice chamber tanks with partitions up to minimize disturbance during test runs.

100% CLEAR	60% CLEAR 40% TURBID	40% CLEAR 60% TURBID	100% TURBID

Figure 10: Percentage flow contribution of turbid and clear water to the four compartments of the test tanks.

Table 9 : Turbidity gradients (NTU) in large and small Test Tanks under varying maximum turbidities in compartment 4 of small tank.

TANK	SMALL				LARGE			
	CLEAR			TURBID	TURBID			CLEAR
COMPARTMENT	1	2	3	4	1	2	3	4
	<10	7	14	20	28	25	12	<10
	<10	9	20	30	38	31	12	<10
	<10	11	26	40	45	32	15	<10
	<10	15	30	50	48	39	16	<10
	<10	16	37	60	60	43	18	<10
	<10	19	43	70	70	45	19	<10
	<10	21	46	80	80	47	20	<10
	<10	28	53	90	90	53	21	<10
	<10	30	58	100	98	60	24	<10
	<10	35	59	110	112	68	27	<10
	<10	38	60	120	115	70	29	<10
	<10	45	70	130	122	74	31	<10
	<10	52	76	140	124	86	37	<10
	<10	59	82	150	125	99	44	<10

Table 10: Turbidity ranges recorded in each compartment of the test tanks during experimental runs (NTU = Nephelometric Turbidity Units).

Compartment	A	B	C	D
Range (NTU)	<10	10 - 50	51 - 80	80 - 110

(c) Monitoring fish movement in the test tanks.

In order to record which compartment of the tank was frequented by a fish at any given time, a trip device using infra-red beams was used. Pairs of beams, one on either side of the aperture in each partition, operated on an on/off basis as the fish swam through. A panel with coloured lights on the monitor indicated the compartment occupied.

In order to obtain maximal sensitivity of the beams under turbid conditions, buffed perspex 'lenses' were placed on the inside of the tank in line with the beams, between the outer glass and the aperture in the partition. This cut down the distance the beam travelled through the turbid water and allowed the turbidity to be raised to 200+ NTU before the density of silt particles began to 'trip' the beams. By running the system at a maximum range of 80 to 110 NTU a wide safety margin was maintained. In order to have a permanent record of fish movements in the test tanks an Esterline Angus Minigraph 8 Track Recorder was connected to the movement monitoring device. Movements in both test tanks were recorded simultaneously with the recorder paper moving at a speed of 2,5cm/h (Fig. 11).

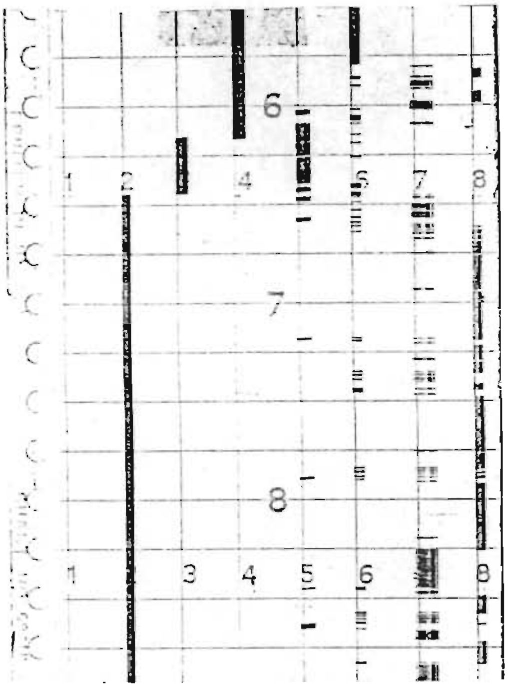

Figure 11: Chart recorder sheet from the Esterline Angus showing movement of fish between different compartments (Figures across - 1 to 4 & 5 to 8 = four compartments of each test tank; Figures down - 5 to 8 = time in hours marked off at 15 minute intervals).

(d) <u>Testing turbidity preference</u>.

Two asbestos (220 l) and four glass holding tanks (one 190 l & three 54 l) were set up in the laboratory. These were fitted with undergravel filters and airlift pumps for filtration and aeration. Layers of granite and marble chips mixed with shell fragments were placed in the tanks which were then filled with freshwater. The water in each tank was mixed to a salinity of between 30 and 36°/oo using 'Synthetica Salt Water Mix'. The airlift filters were then switched on and the tanks allowed to mature for six weeks, during the first week of which 'Sea Mature' was added daily in order to help establish bacteria in the tanks.

Fish were caught by seine netting, mainly in the St.Lucia system, but also the Mlalazi Estuary. Plastic 25 litre buckets, filled with sea water and aerated, were used to transport fish to the laboratory where they were transferred to the holding tanks. After an acclimation period of 24 to 36 hours attempts were made to feed the fish on 'Marpet Staple Fish Flakes' and small pieces of prawn. In most instances they started feeding after 2 to 4 days. Fish were only used in tank tests after they had started feeding regularly and had been in the holding tanks for at least two weeks. Once the tests had been run the fish were returned to the estuary.

In most experiments only one fish was used per tank, with two per tank only being used for certain schooling species for which the latter provided more consistent results. Hardboard partitions were set up around each tank in order to minimize visual disturbance (Plate 2). Fish were placed in tanks 18 to 24 hours before tests began to allow acclimation. During this time the movement monitor and chart recorder were switched on so that it could be determined whether the fish had located the other three compartments during the acclimation period and was not favouring any one. After this the water flow system was set in motion and airlift pump switched on for a short period so that turbid water could be produced in the turbidity source tank.

An attempt was always made to set up the turbidity gradient to the desired maximum (always >80 but never >110 NTU) with an even introduction of turbid water rather than by a sudden large input. The gradient was maintained for the duration of the test run which varied between 2 and 8 hours depending on the silt accumulation on the bottom of the test tanks, since excessive accumulations affected turbidity levels when the fish swam around in the tank. Only activities recorded during the period when the gradient was at its species tested.

Water temperatures were not controlled, with all experimental runs being undertaken during the warmer summer months. During the experimental period water temperatures ranged from 22,5 to 27°C. The salinity of the experimental tanks was maintained at between 30 and 36°/oo.

At the end of each run a tube was set up from the header tank to bypass the turbidity mixing tank and this enabled the turbidity in all compartments of the test tanks to be brought down to 10 NTU within an hour. After this the flow system was stopped and an Eheim Circulating Power Filter and aerator were attached to each test tank. These were run overnight and by the next morning the test tanks had been filtered down to <5 NTU

In most instances the turbidity test was repeated a second time the following day using the same individual, and depending on the position of the fish in the tank, the turbidity gradient was set up in reverse. After the second run the test tanks were cleaned and all materials in filters 1 to 3 washed out before the next run was undertaken. Fish which did not move from the compartment they were in when the test run was started were subjected to a reverse gradient the following day. If still no movement occurred the runs were considered invalid, the fish having been subjected to both clear and turbid waters.

All times and turbidity data relating to the events of each run were recorded on turbidity run sheets. These sheets also recorded the Standard Length (S.L.) of the fish tested, as well as the temperature of the water in the tanks. Table 10 shows the turbidity ranges recorded in the four compartments (both tanks combined) during periods over which test data were used.

Transcription of data from the Esterline Angus was done using a Wild binocular microscope with an eyepiece graticule and set at 6x magnification. From the recorded traces, the exact periods the fish spent in each compartment could be determined. The turbidity run sheets provided information on the turbidities in the different compartments. Periods of less than one minute in any compartment were

3.4.2 Salinity gradients.

Preferences for different salinities and reactions to the presence of a salinity gradient were also tested. All compartments were sealed off by clamping perspex sheets over the apertures in each partition. Water in buckets was mixed to salinities of 40, 30 and 20°/oo using 'Synthetica Salt' mix. These together with a totally fresh input of tap water were siphoned simultaneously, at equal rates, one into each of the four compartments of each test tank, so as to set up a gradient of salinity.

The water was then stirred to reduce layering and the perspex sheets removed. Salinities were then measured in each compartment and recorded on a salinity test data sheet. Gradients in the order of 38, 25, 18 and 7°/oo were usually established after mixing. A single fish was placed in each tank with the chart recorder and aerators working.

Although some mixing took place within the first four hours in the two less-saline compartments and some minor mixing took place in all compartments as a result of fish movement, a gradient with a range of some 20°/oo was maintained in the tanks for twenty hours or more. Preliminary tests showed that most fish found their way around the test tank within the first one to two hours. A period of one hour was thus allowed for acclimation.

The amount that the fish moved also contributed to some extent to the amount of mixing which took place. As a result only data from the four hours following the one hour acclimation period were used in ascertaining salinity preferences. Salinity readings were measured every hour in order to confirm that a salinity gradient was maintained in the tank. Chart recorder analysis was similar to that used in turbidity test data.

3.4.3 Limitations of experimental apparatus.

Due to most of the flow in the system relying on a gravity feed, and to the fact that the header tank level connecting tubes were necessary to prevent the tanks from overflowing. As a consequence the system was not suitable for running in the dark or in simulated night conditions since it was difficult to determine the amount of water being washed over the silt source, thus making it almost impossible to maintain an even turbidity gradient. With the test tanks covered it was also not possible to control their water levels and the possibility of an overflow existed which would have caused damage to the infra red units attached to the side of the tank.

Had it been realized, when the apparatus was in the development stage, that this problem would arise modifications could have been made to overcome them. This would have meant that a set of night runs similar to those run in daylight could have been carried out. The comparison of the two sets of data may have provided information as to whether it is the ′darkness′ caused by the presence of particulate matter or the mere presence of the particles in the water column which cause some fish to show preferences related to water turbidity. However, the fact that it was not possible to do these additional experiments did not affect the main aim of this study, which was to determine the influence of turbidity on fish distribution in Natal estuaries.

3.5 Analytical procedures

All laboratory work associated with the following sections was carried out at the Zoology Department, University of Natal, Pietermaritzburg.

3.5.1 Identification of fish and invertebrates.

Being familiar with most of the common estuarine species made it possible for the identity of most of the fish to be established at the time they were caught. Those identified were released after being measured. Any were preserved in 10% formalin and identified in the laboratory using the keys provided in Smith (1972). Identification of invertebrates collected in benthic samples was made to species level, were possible, using Day (1974).

3.5.2 Benthic analysis

Although the benthic samples from South Lake were collected by myself during the study period, the sorting, identification of specimens, analysis and publication of results were undertaken with the help of three co-workers (see Blaber _et al_., 1983).

Samples were sorted to species as far as possible, counted and dried to constant weight at 60°C and weighed to 0,01mg on a Cahn 29 automatic electrobalance. Molluscs were weighed shell-free after dissolving the shells in a nitric acid solution.

3.5.3 Silt content and turbidity.

The turbidity samples collected during 1981 from the de Lange's site, St.Lucia (Fig. 8) were used to determine the silt loading of the water at different turbidities. Turbidities of these samples were measured and their volumes determined; they were then filtered using Whatman No.40 filter paper which had been oven dried to constant weight 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 at 60°C and the silt content of each sample determined. This gave the amount of silt (mg/l) for known turbidity values (NTU).

3.5.4 Statistical analysis of data.

Although the laboratory tests enabled turbidity interfering, it was nevertheless necessary to determine the relationships between these variables and between them and the different fish species. This permitted an assessment of the influence which each factor had on the other physical factors as well as on the fish distributions which were observed in the field.

A number of statistical procedures were applied to the various data sets, including the results of laboratory studies and the comparison of the field and laboratory data related to turbidity preferences.

(a) Statistical procedures applied to the physical data.

(i) Turbidity and secchi measurements.

A logarithmic curve fitting ($y = a + b \ln x$) was used to establish the relationship between turbidity (NTU) and secchi measurement (m).

(ii) Turbidity and silt content.

A linear regression ($y = a + bx$) was used to determine the relationship between turbidity (NTU) and silt content (mg/l).

(iii) Physical factors in South Lake.

The correlations between the eight physical factors measured monthly at seven sites, were determined using a Pearson's Correlation Coefficient test from the S.A.S. (Statistical Analysis System) statistics package on an IBM mainframe computer. This programme calculated the correlation coefficient (r) which was used to establish what significant correlations existed between the physical factors. The methods and formulae used to calculate the r value are given in Lee and Lee (1982). The probability of r occurring by chance was determined from the 'Significance Table for Pearson's Correlation Coefficient r'.

Relationships between the data from the eastern and western shores for each of the physical factors was determined using F and t tests as described in Lee and Lee (1982).

(b) Statistical procedures applied to the field data.

(i) Comparison of physical data with fish distributions in South Lake.

The correlations between fish catches and physical factors, measured monthly at four sites during 1981, were calculated using three methods. Firstly, by determining the Pearson's Correlation Coefficients (r) as described in 3.5.4 (a) above. The data for this was tested in four different sets; untransformed, ranks of total data set, ranks of summer and ranks of winter. The second method applied was GLM, this is a procedure which uses the method of least squares to fit General Linear Models, it provides a level of correlation based on a calculated F-statistic (Ray, 1982). Stepwise Discriminant Analysis was the third method used, this performs an analysis by forward selection, backward elimination, or stepwise selection. It also provides a correlation level based on the calculation of an F-statistic (Ray, 1982).

In order to determine which of the important physical factors was having the most influence on fish distribution two methods were employed:-

Principle Component Analysis.

This is a multivariate technique for examining relationships among several quantitative variables (Ray, 1982). Factor patterns are generated each of which account for a percentage of the common variance. The values represent the variance explained by the individual factors, these indicate where significant correlations exist.

Canonical Correlation.

This is a technique used for analysing the relationship between two sets of variables, each set may contain several variables (Ray, 1982). This method provides a significance level for each canonical correlation generated. The standardized canonical coefficients for each significant canonical correlation provide information on the significance of each variable within each set of variables. Added to this the correlation between one set of variables and the canonical variables of the second set show which of the former set have significant influence over the second set of variables.

(ii) Comparison of turbidity preferences of common species.

In order to determine whether the common estuarine species could be grouped according to their turbidity preferences, the Principal Co-ordinate and Minimum Spanning Tree analysis, from the Genstat package, was performed using a Univac Computer. This analysis of the catch per unit effort for each species in four turbidity groups, produced a two dimensional plot showing the relationship between the different species in terms of their preferences for different turbidities.

The minimum spanning tree data assists interpretation by indicating in which way the different species are linked in terms of their overall turbidity preferences. The values calculated allowed the linking together of the plotted results of the Principal Co-ordinate Analysis in the form of a dendrogram. This facilitated interpretation when a number of species were positioned close to each other in the two dimensional plot.

(c) Statistical procedures applied to laboratory data.

In order to determine whether the turbidity preference, shown by the different species under test conditions, were significant, two statistical tests were applied. Both tests used the turbidity preference data from the test runs carried out with different individuals of each species.

(i) Analysis of Variance (ANALVAR).

Analysis of Variance as described by Lee and Lee (1982) was used for initial analysis of turbidity preference results. This test also calculates an F value as well as Greater and Lesser Degrees of Freedom (V1 & V2). The probability that the individuals tested occupied the different ranges by chance can be determined from these figures using a 'Significance Table for the F-Test'. This test was also used to determine the significance of the salinity preference data.

be fulfilled when using Analysis of Variance, they are:-

1) The data must follow a normal distribution.
2) The sample variance must be independent of the mean.
3) The components of the variance should be additive.

By using the test described by Lee and Lee (1982), which calculates the Least Significant Difference (L.S.D.), the independence of the mean and variance is not fulfilled. There is therefore a need to transform the data, and following Elliot (1977), where numerous zeros are present then a log (x + 1) transformation should be carried out. It is also recommended that when data are transformed Analysis of Variance tests should be carried out using the Shortest Significant Range (S.S.R.) as this allows the determination of within group significances.

(ii) Ranking Test.

Kendall´s Ranking Concordance test as described in Moroney (1963) was used to determine whether there was a significant measure of agreement between the responses of individual fish of a given species to the turbidity gradient. In this analysis each individual of a species tested ´judged´ the four turbidity ranges offered to it in the test tank. The order of judging was determined by the percentage time a fish spent in each compartment of the test tank during a test run.

The results from all individuals of each species were used to determine the degree of agreement within each species, and expressed as the Coefficient of Concordence (W). This value may then be tested for significance by the calculation of Snedecor´s F and the number of degrees of freedom for the Greater Estimate (V1) and the Lesser Estimate (V2).

Using the F value and the V1 and V2 degrees of freedom the extent of agreement within a species (= between judges) and its significance can be determined by looking up the probability value in a ´Significance Table for the F-Test´. The ranking method therefore allows one to determine to what extent the individuals of each species tested showed the same turbidity preference, thus providing a non-parametric confirmation for the Analysis of Variance.

(d) Statistical procedures used to compare field and laboratory data.

(i) Closeness of fit of the data.

The turbidity preferences shown by the different species in the field (South Lake) and in the laboratory were tested for 'Closeness of Fit' using the Principle Co-ordinate analysis as described in 3.5.4 (b)(iii) above. The similarity measure which ranges from 0 to 1 (1 = most similar & 0 = least similar) provided preliminary information as to which species may have shown a significant correlation between their turbidity preferences in the field and laboratory.

(ii) The Kolmogorov-Smirnov Two Sample Test.

This test, applied to non-parametric data, is used to determine whether two 'populations' are distributed in the same fashion. Details of the formulae used and the principles behind the calculation are given by Anderson and Zelditch (1975). The test is based on the direct comparability of the intervals of the relative cumulative frequency distribution of two samples.

The difference in the relative cumulative frequencies is determined for each interval and the letters Ds are designated to the largest difference. Ds is compared to the tabled values on the 'Critical Values of Ds in the Kolmogorov-Smirnov Test for two samples' for the sample size used and the level of significance required.

If the calculated value is smaller than the tabled value then the hypothesis that the two samples are the same is retained. However, if the calculated value of Ds equals or exceeds the tabled value the finding is significant and the hypothesis that the two samples are similar is rejected. The data for each species used for this test were the overall percentage times spent in each of the four turbidity ranges by all individuals during laboratory tests. This was compared with the percentage catch per unit effort, for the same four turbidity ranges, from the field data.

(iii) Ranking Test

The ranking method as described in 3.5.1 e (ii) above was also used to determine whether there was a significant measure of agreement between results obtained in the field and those from the laboratory tests.

4. TURBIDITY AND RELATED PHYSICAL FACTORS IN LAKE ST.LUCIA.

4.1 Introduction.

Data were collected on eight major physical factors (see sections 3.3.2 to 3.3.9) which were considered as possibly having some effect on the distribution of juvenile fish in the lake. The work in this section was undertaken in order to determine what the levels, ranges, seasonality and distributions were of turbidity and other physical factors in South Lake, St.Lucia. It was intended to use the data collected to establish the importance of each factor in the system and what correlations, if any, existed between the various factors. Those factors considered to be important could then be examined in relation to the fish catch data and from this their influence, if any, on fish distribution in South Lake could be determined.

Correlations between the individual physical variables needed to be taken into account. Where causal relationships explaining such correlations could be established, those variables whose effects on fish distribution were indirect could be eliminated from the analysis.

4.2 Results.

4.2.1 Turbidity.

(a) Turbidity and the sediment load.

The relationship between turbidity and sediment load was determined from samples collected at the de Lange's sampling site (No.16 - Fig. 8), St.Lucia, and found to be linear (Fig. 12), with SL = -16,47 + 1,18NTU (SL = Sediment Load in mg/l & NTU = Turbidity in Nephelometric Turbidity Units), r^2 = 0.93, n = 12 and P = <0,001. Samples were collected from only this site as it was representative of some 70% of the substrata of the St.Lucia system (see (f)

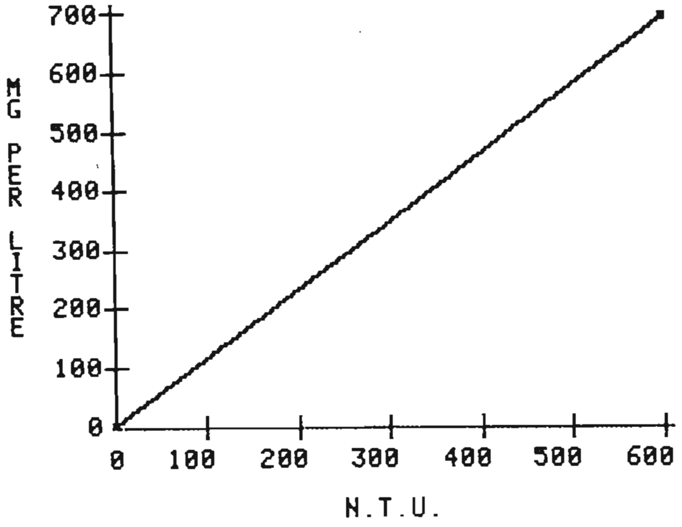

Figure 12: The relationship between Turbidity and Sediment Load of the water.

(b) Turbidity at fish sampling sites.

Results from monthly turbidity sampling in South Lake (Fig. 7) during 1981 showed that turbidities ranging from <10 to >80 NTU were present during all months (Table 11). The means, ranges and Standard Errors for turbidities collected at seven seine netting sites, at distances of 3 and 10 metres from the shoreline, are given in Table 12. Seasonal fluctuations in mean monthly turbidity during 1981, on the eastern and western sides of the lake, are shown in Figures 13 and 14.

(c) Daily variations in turbidity.

Results from hourly turbidity sampling over a 40 hour period at Charters Jetty (turbid water locality) during 12-13/12/81 and Ukwakwa (clear-water locality) during 8-9/7/82 are illustrated on Figures 15 and 16. These figures also show wind speeds recorded at 4h intervals at Lister Point and the Estuary Mouth as well as the hourly wind strengths recorded when samples were collected. Wind strengths were estimated on a scale from 0 to 3,5; approximate equivalents of these are shown in Table 13.

Table 11: Monthly turbidity ranges recorded in South Lake during 1981.

Month	Turbidity range
January	7,1 - 244,0
February	2,5 - 99,0
March	2,5 - 196,0
April	5,5 - 306,0
May	2,5 - 95,0
June	5,5 - 154,0
July	5,5 - 456,0
August	4,0 - 101,0
September	9,0 - 544,0
October	8,5 - 324,0
November	8,5 - 166,0
December	6,0 - 172,0

Table 12: Mean turbidity (NTU) and ranges recorded at seven sampling sites in South Lake - St.Lucia between January and December 1981.

	3m from shore			10m from shore		
SITE	$\bar{x}$	Range	S.E.	$\bar{x}$	Range	S.E.
<u>WESTERN SHORES</u>						
GILLIES POINT	141,7	18-544	42,4	98,9	6,5-324	28,9
CHARTERS JETTY	79,5	10-300	22,9	76,9	10-306	23,0
PUBLIC JETTY	63,2	5-172	18,0	60,6	3,5-198	17,4
INDICUS INDENT	91,0	3-324	29,9	85,2	2,5-324	29,7
<u>EASTERN SHORES</u>						
NKAZANA STREAM	14,0	5,5-40	3,2	11,3	2,5-37	2,9
OLD JETTY	14,8	2,0-41	3,3	9,7	3,5-29	2,0
UKWAKWA	14,1	2,7-35	2,6	10,0	4,0-24	1,5

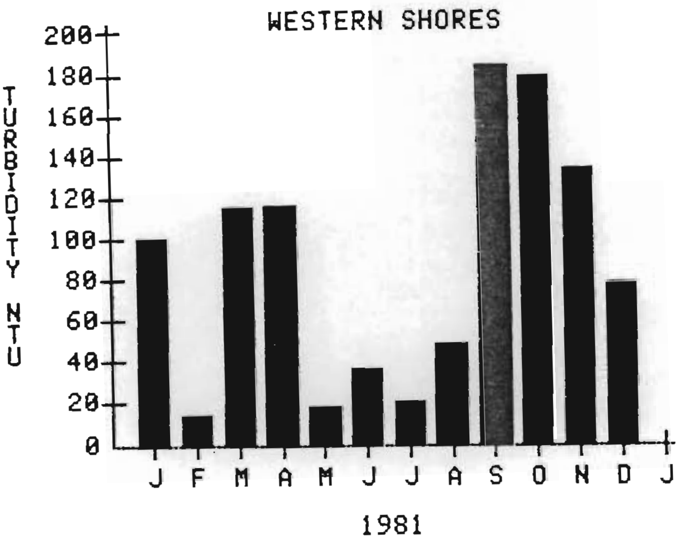

Figure 13: Mean monthly turbidity on the western shores of South Lake between January and December 1981.

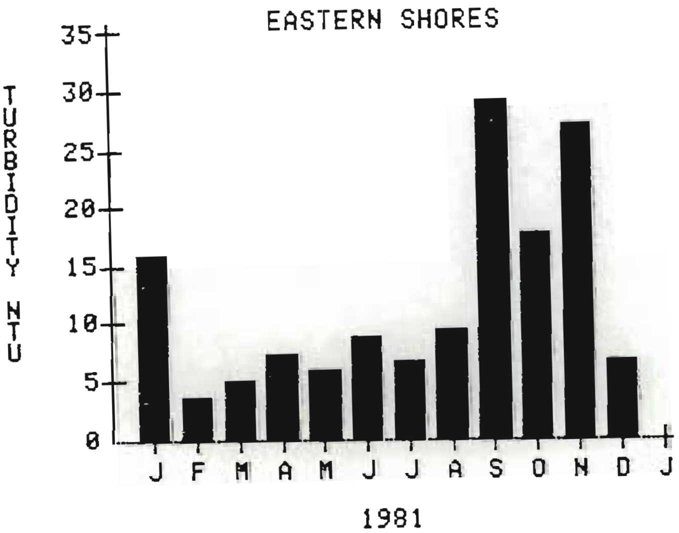

Figure 14: Mean monthly turbidity on the eastern shores of South Lake between January and December 1981.

Table 13: Ratings used for indicating wind strength during hourly turbidity sampling (Figures 45 & 46).

Rating	Wind Strength
0	Calm
0,5	Very Light
1,0	Light
1,5	Light +
2,0	Light ++
2,5	Light +++
3,0	Moderate
3,5	Moderate +

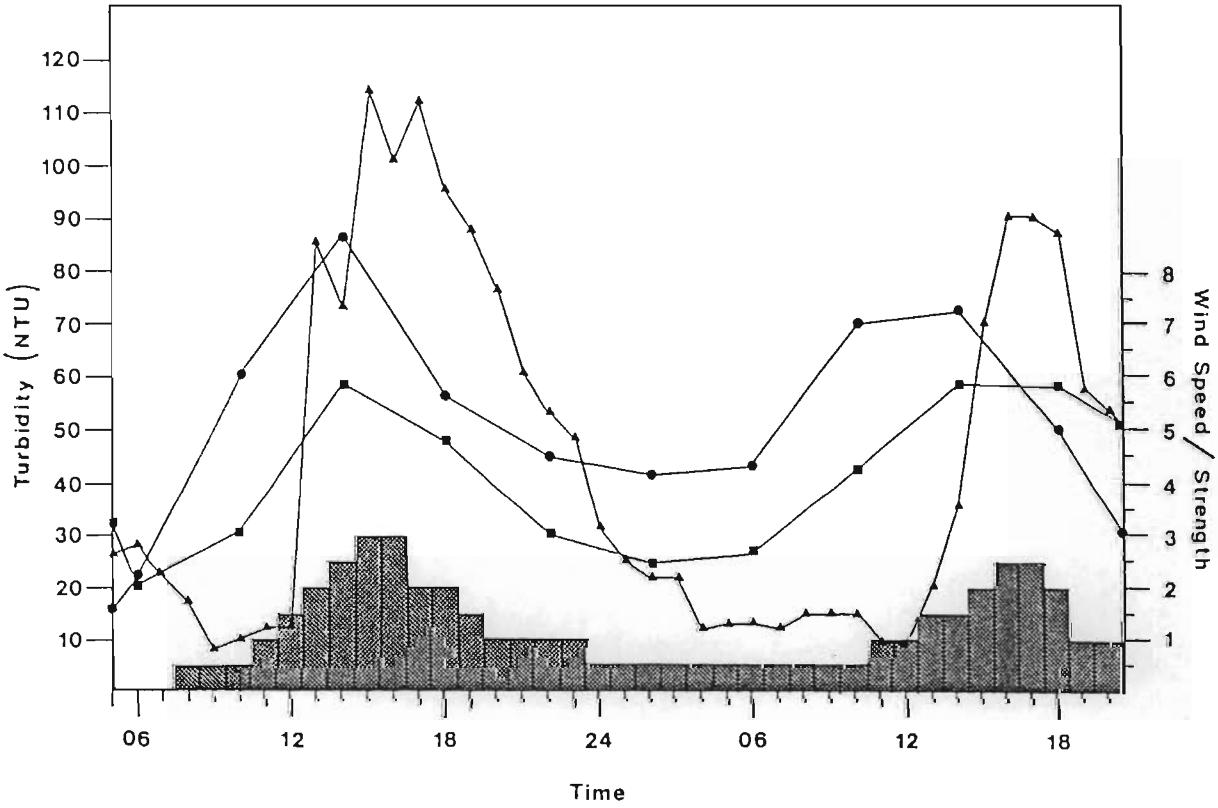

Figure 15: The relationship between turbidity and wind speed/strength at Charters Creek on the western shores of South Lake (▲ = turbidity, ■ = mean wind speed m/s at Lister Point, ● = mean wind speed m/s at Estuary Mouth, ▨ = wind strength at Charter Creek).

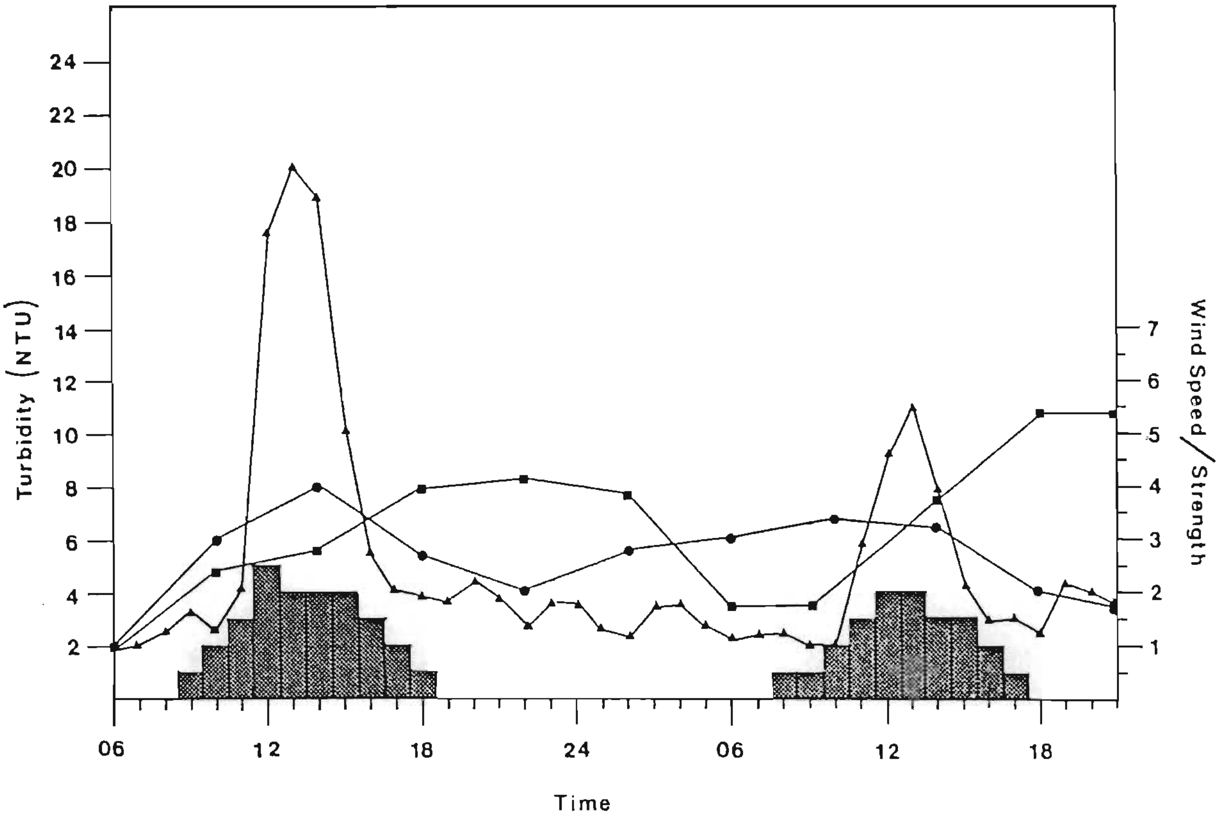

Figure 16: The relationship between turbidity and wind speed/strength at Ukwakwa on the eastern shores of South Lake (▲ = turbidity, ■ = mean wind speed m/s at Lister Point, ● = mean wind speed m/s at Estuary Mouth, ▨ = wind strength at Ukwakwa).

(d) <u>Turbidity patterns in South Lake</u>.

Results from turbidity transect runs carried out under different wind conditions on South Lake were plotted onto 1:50000 maps. This allowed the distribution of various turbidity classes to be illustrated by inserting iso-turbidity lines. The predominant winds of the system (see 4.2.5) are from the N.- N.E. and S.S.W.- W.S.W..

Turbidity distribution under these prevailing winds, as well as during calm conditions, are shown on Figures 17 to 22, while details of conditions at the time of collection and turbidity ranges etc. are given below and in Table 14. Wind direction and strengths mentioned below refer to those recorded on site when the transects were run. Due to the distance of the wind recording stations from South Lake (Estuary Mouth 19km to the South and Lister Point 28km to the North North West), some variations in local wind strengths occurred.

Turbidity transects run under different wind strengths and directions.

(i) Moderate N.E. (Table 14 & Figure 17).

During the run wind speeds of 5,9 (Estuary Mouth) and 7,5m/s (Lister Point) were recorded. The wind had started blowing from the N.E. some 40 hours previously with the wind speed steadily increasing and reaching its peak over the period when the samples were collected. The average wind speed during the preceding 40 hours was 4,0 (Estuary Mouth) and 4,5m/s (Lister Point).

Table 14: Details of turbidity transects run on South Lake (n = number of samples; TURB.= Turbidity; $\overline{x}$ = mean turbidity).

WIND	DATE	RUN TIME	n	TURB. RANGE	$\overline{x}$
N.E. MODERATE	27.07.81	14H09-16H05	86	8,5 - 456,0	113,5
N.E. LIGHT	05.11.81	07H20-09H13	80	8,5 - 95,0	31,6
S.W. MODERATE	22.06.81	15H02-17H01	90	4,0 - 154,0	50,0
S.W. LIGHT	23.09.81	08H00-10H04	80	9,0 - 184,0	55,0
CALM 12 HOURS	18.02.81	05H12-06H58	74	4,0 - 51,0	26,0
CALM 24 HOURS	20.07.81	08H27-10H44	68	4,3 - 14,0	7,6

(ii) Light N.E. (Table 14 & Figure 18).

During the run wind speeds of 3,6 (Estuary Mouth) and 5,9m/s (Lister Point) were recorded. For the preceding 20 hours the wind had been blowing from the N.E. at an average speed of 3,2 (Estuary Mouth) and 6,4m/s (Lister Point). Prior to this, winds were variable S.E. to W.N.W. (20 hours).

(iii) Moderate S.W. (Table 14 & Figure 19).

During the run wind speeds of 4,7 (Estuary Mouth) and 6,2m/s (Lister Point) were recorded. For the preceding 16 hours the wind had been from the S.W. at an average speed of 4,8 (Estuary Mouth) and 5,8m/s (Lister Point). Prior to this the wind had been from the North for more than 20 hours.

(iv) Light S.W. (Table 14 & Figure 20).

3,7m/s (Lister Point) were recorded. For the preceding 40 hours the wind had been variable, switching between N.W. and N.E. with average speeds of 3,2 (Estuary Mouth) and 4,8m/s (Lister Point) recorded. During the day preceding the run the wind had been predominantly from the NE but had dropped by 20H00. It was more or less calm overnight until 07H15 the following morning when the wind came up light S.W..

(v) After 12 hours of calm (Table 14 & Figure 21).

During the run wind speeds of 0,8 (Estuary Mouth) and 1,4m/s (Lister Point) from the W.- S.W. were recorded. During the preceding 40 hours the wind had been out of the W.- S.W. averaging 2,7m/s at the Estuary Mouth and 3,4m/s at Lister Point. The wind had started to drop by 12H00 on the day before the run and relatively calm conditions had prevailed overnight.

(vi) After 24 hours of calm (Table 14 & Figure 22).

During the run wind speeds of 1,0m/s from the W.N.W. were recorded at the Estuary Mouth (no data for Lister Point). During the preceding 40 hours the wind had varied between N. and N.E. at an average speed of 3,0m/s. On South Lake the wind had blown from the N.E. the morning before the run until about 10H00 and had then dropped. More or less calm conditions prevailed from then until the end of the run at 10H44 the following morning.

(e) Turbidity and secchi measurement.

Turbidity readings and secchi measurements collected simultaneously during the period February 1980 to September 1982, were compared for the following sites; Charters Jetty, Old Jetty, Hells Gates, Sengwane and Lister Point. Due to possible effects of varying particle sizes and proportions of mud and silt, the results from each site were first analysed separately. They were fitted to a logarithmic curve and results from all sites were found to be significant, as was the fitting of all the data combined. Table 15 gives the results obtained, while Figure 23 shows the log fitting for the data from all the sites combined.

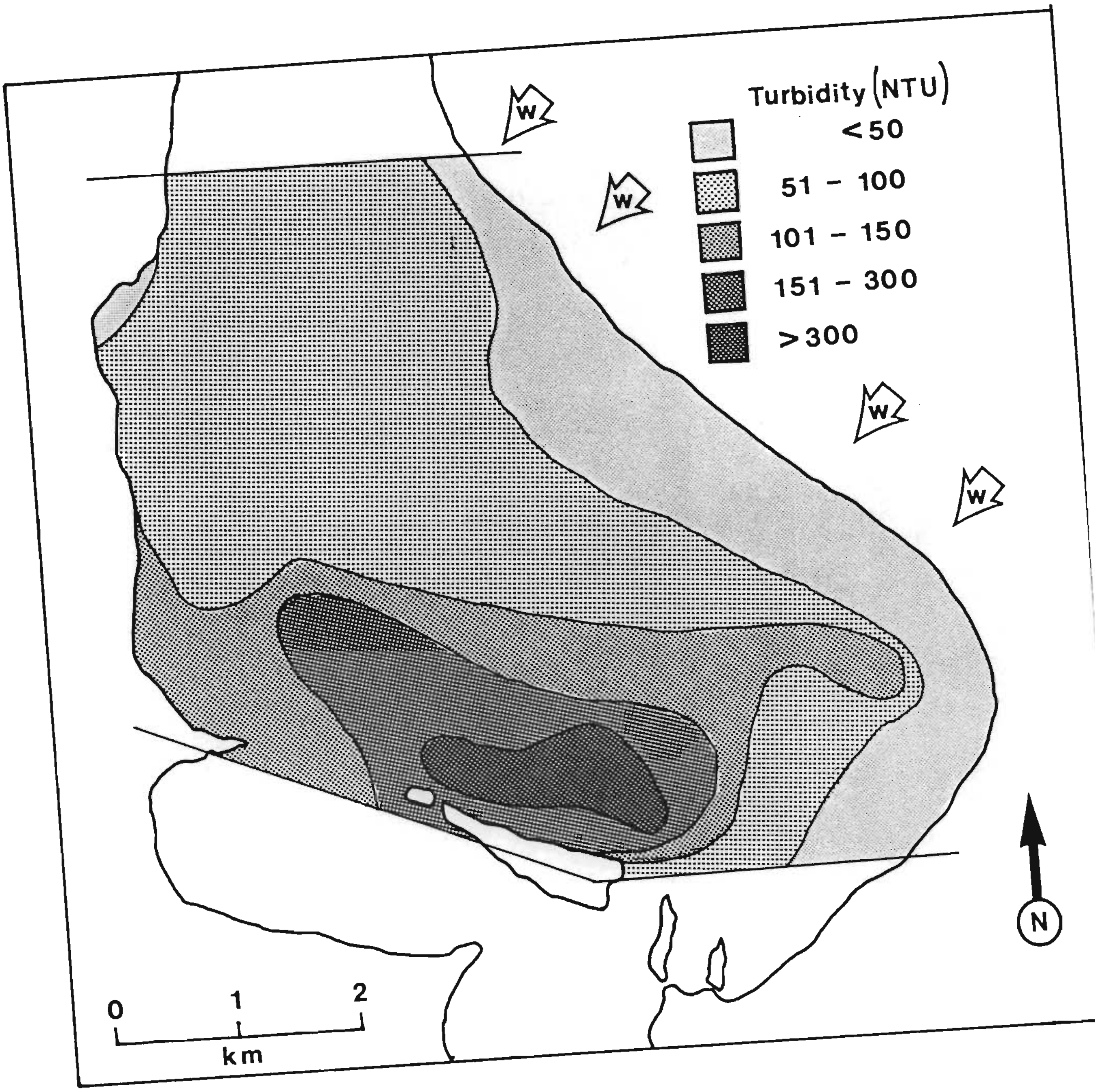

Figure 17: The distribution of turbidity in South Lake - St.Lucia under Moderate N.E. wind conditions (W = wind direction).

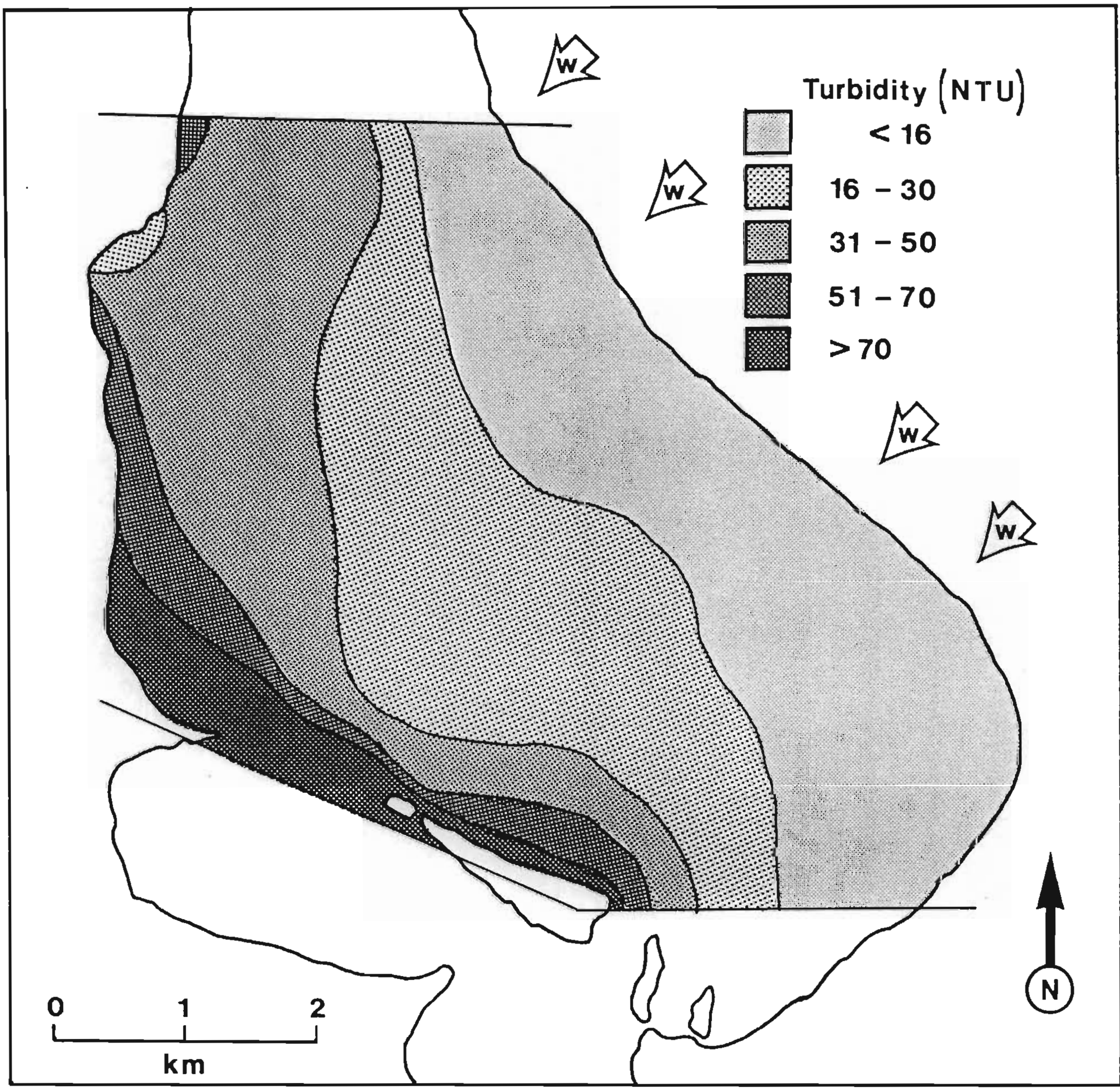

Figure 18: The distribution of turbidity in South Lake - St.Lucia under Light N.E. wind conditions (W = wind direction).

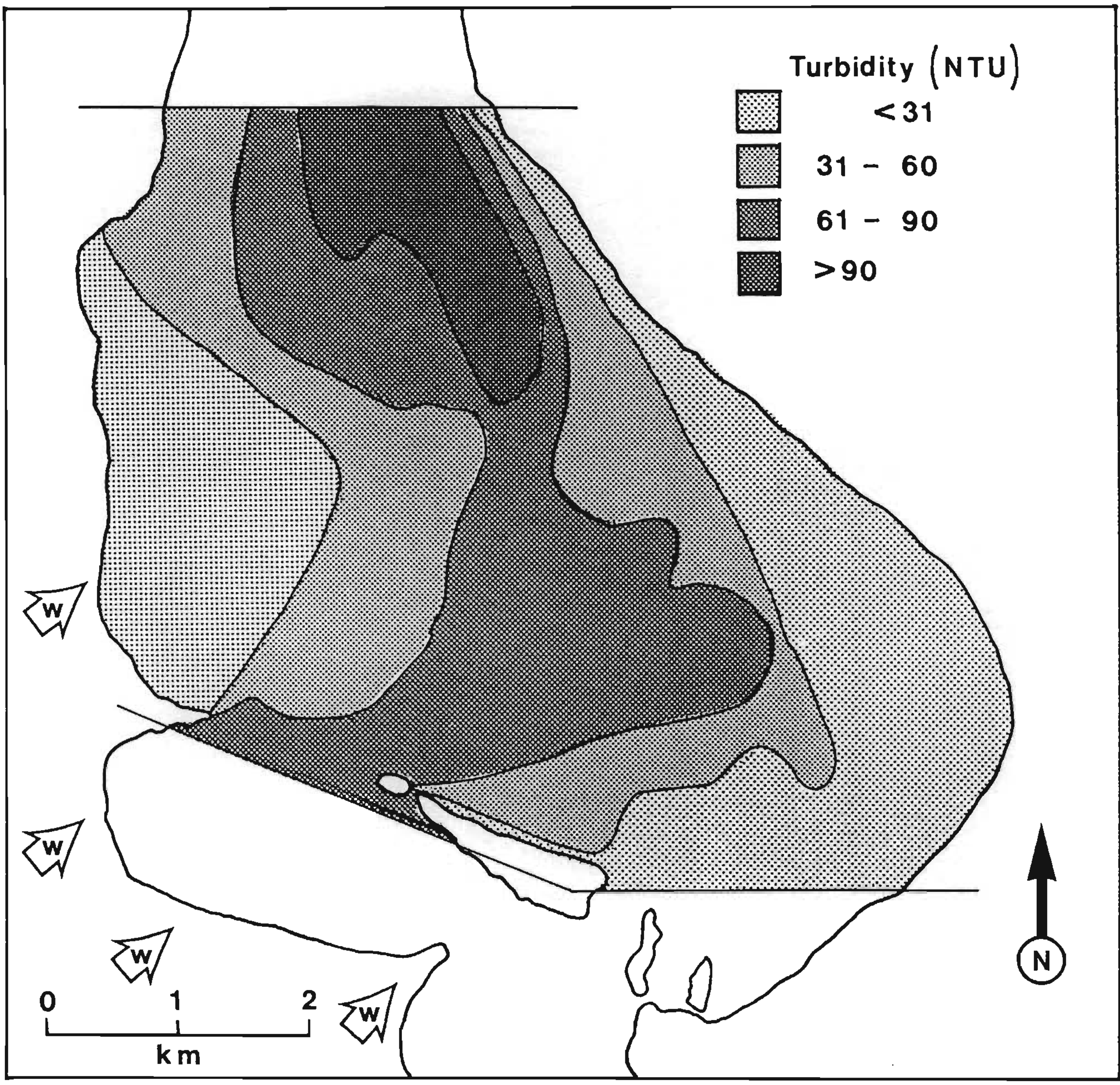

Figure 19: The distribution of turbidity in South Lake - St.Lucia under Moderate S.W. wind conditions (W = wind direction).

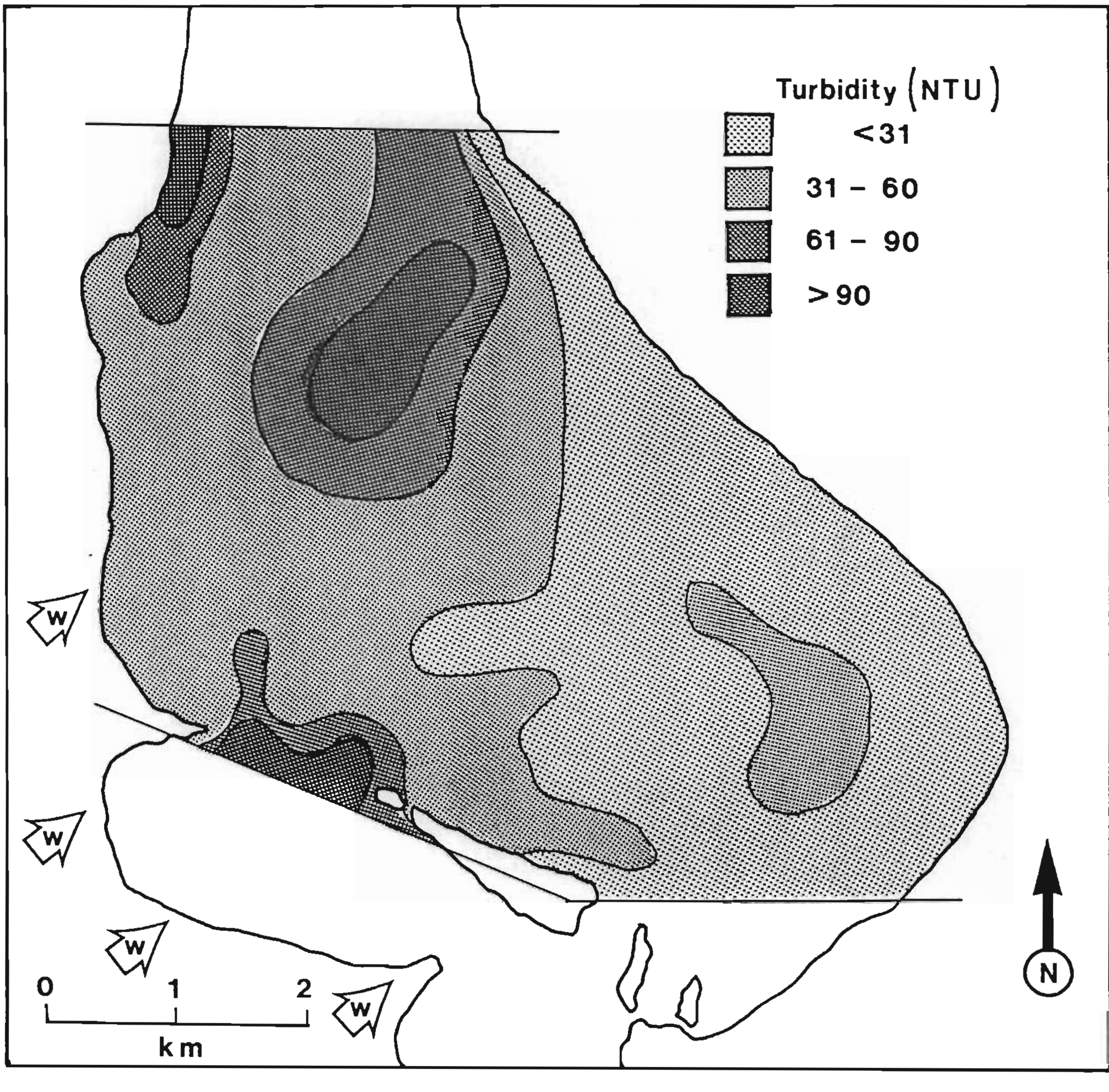

Figure 20: The distribution of turbidity in South Lake - St.Lucia under Light S.W. wind conditions (W = wind direction).

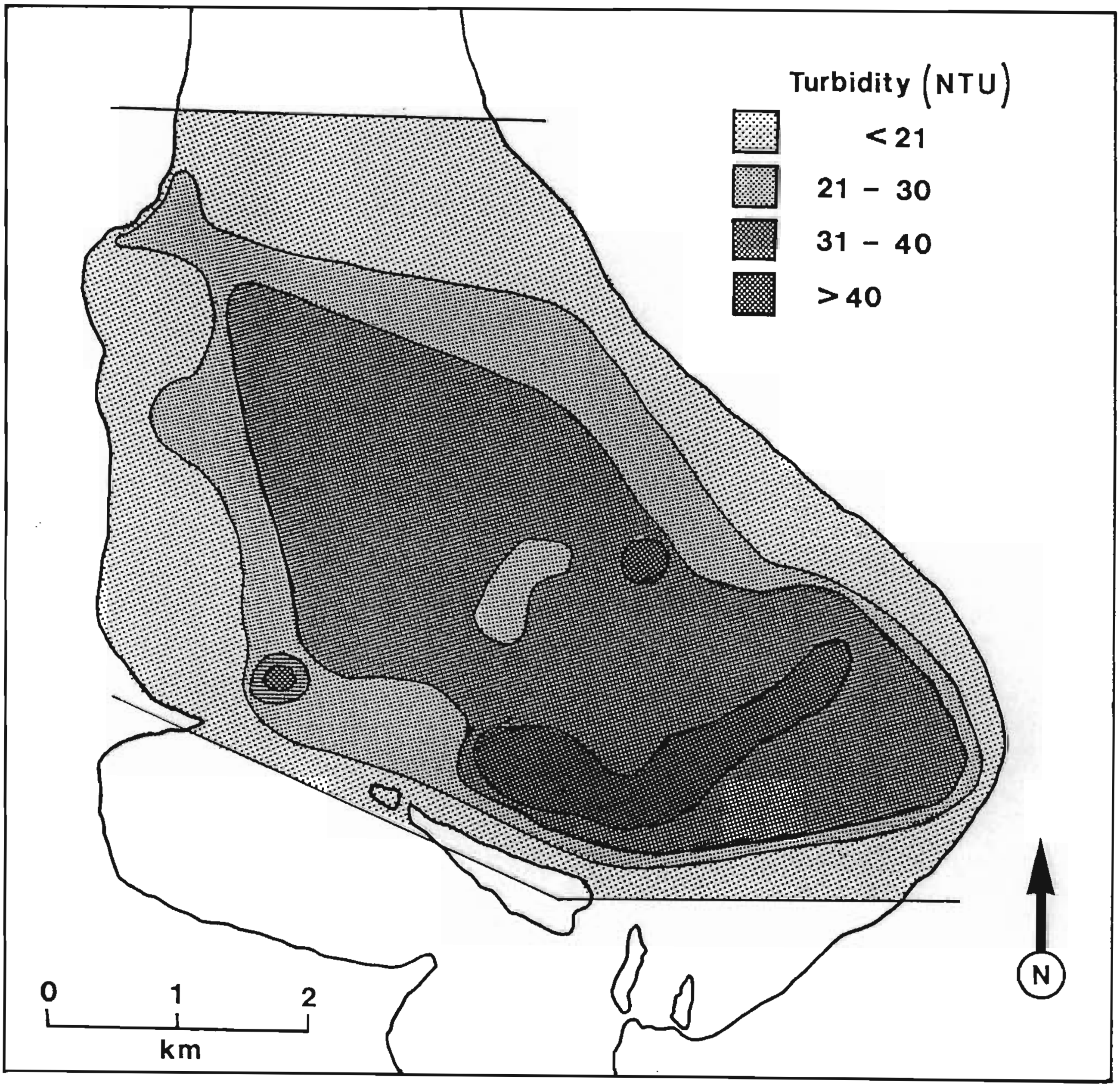

Figure 21: The distribution of turbidity in South Lake - St.Lucia after 12 hours of calm conditions.

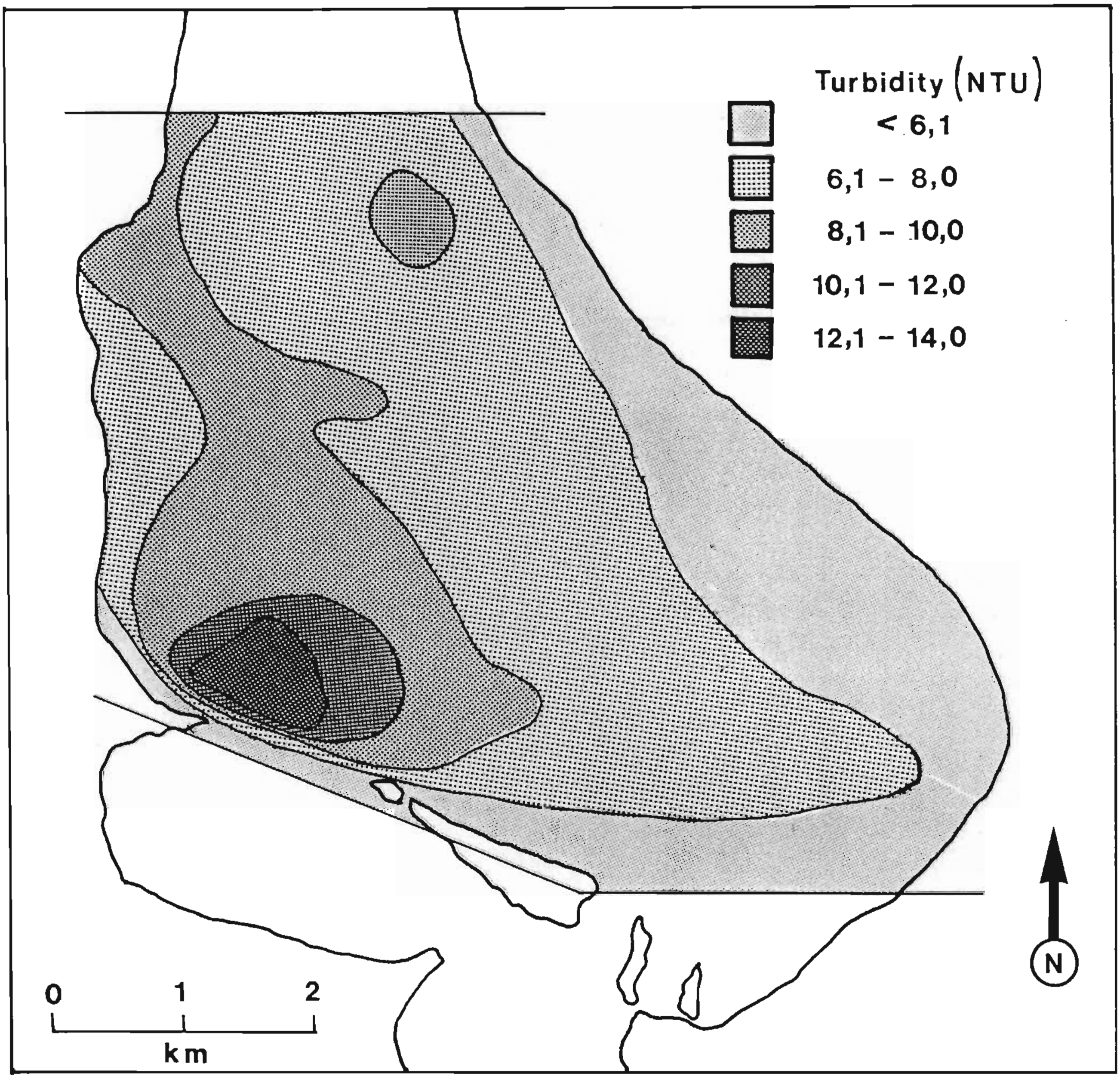

Figure 22: The distribution of turbidity in South Lake - St.Lucia after 24 hours of calm conditions.

Table 15: Results of logarithmic curve fitting to data from five sites (Fig. 24) in Lake St.Lucia, comparing Turbidity (T) in NTU with Secchi Disc (SD) measurements in cm (n = number; r^2 = coefficient of determination, F test: P<0,001 for all plots, Ln = Natural Logarithm).

Site	Locality	SD = a + b Ln T	r^2	n
2	Old Jetty	SD = 176,5 - 39,9 Ln T	0,65	22
3	Charters Jetty	SD = 133,0 - 27,8 Ln T	0,81	22
10	Sengwane	SD = 123,1 - 24,2 Ln T	0,78	15
14	Hells Gates	SD = 117,5 - 22,1 Ln T	0,91	18
17	Lister Point	SD = 141,6 - 28,6 Ln T	0,84	18
All sites combined		SD = 135,0 - 26,8 Ln T	0,74	95

(f) <u>Distribution of turbidity in Lake St.Lucia</u>.

Results of turbidity samples collected for this study, by N.P.B. research staff at Lake St.Lucia from 18 sites (Fig. 24) over a 42 month period, during monitoring runs on the lake, are summarized in Table 16. Mean site turbidities shown in Figure 24 have been divided into three categories; low (<50), intermediate (51 to 80) and high (>80 NTU), also shown are the distributions of ´muddy´ and ´sandy´ substrata.

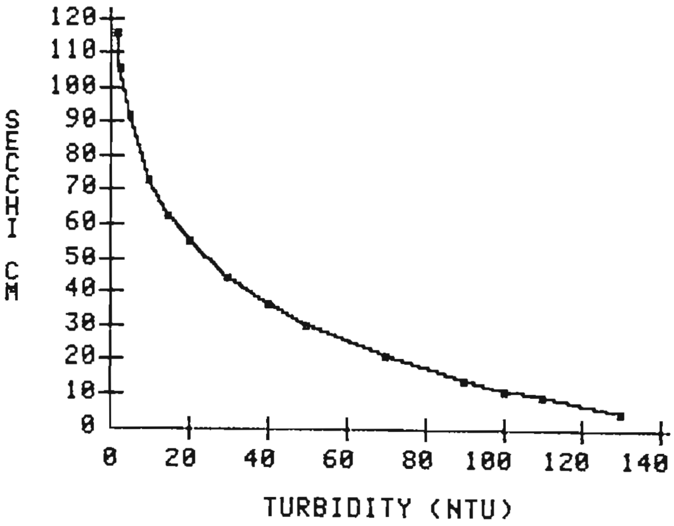

Figure 23: The relationship between turbidity and secchi disc measurement from data collected at Lake St.Lucia, SD = 134,96 - 26,79 Ln T (SD = Secchi Disc, Ln = Natural Logarithm, T = Turbidity in NTU, r^2 = 0,74, n = 95.

Table 16: Turbidity means and ranges for 18 sites (Fig. 24) in Lake St.Lucia from data collected between February 1980 and June 1983 (n = number; $\bar{x}$ = mean turbidity; Is.= Island & R.M.= River Mouth).

SITE	LOCALITY	$\bar{x}$	RANGE	n
1	N. Mitchell Is.	80,1	2,2 - 432,0	36
2	Old Jetty	23,4	2,0 - 74,0	38
3	Charters Jetty	70,9	5,4 - 512,0	39
4	off Vincent Is.	65,1	5,0 - 284,0	37
5	Dead Tree Bay	48,4	4,0 - 181,0	38
6	Fanies Is.	54,8	3,7 - 156,0	39
7	Tewate	27,2	2,5 - 144,0	37
8	Mbizitsheni	56,6	5,3 - 400,0	39
9	Missile Base	66,3	4,5 - 276,0	38
10	Sengwane	172,9	7,6 - 1152,0	36
11	Selly's Mouth	164,2	7,0 - 1312,0	28
12	off Bird Is.	122,5	3,5 - 786,0	36
13	Mkuzi Mouth	230,5	6,5 - 1472,0	24
14	Hells Gates	97,6	3,0 - 456,0	38
15	False Bay South	106,1	7,0 - 464,0	38
16	Hluhluwe R.M.	147,1	2,8 - 736,0	35
17	Lister Point	88,8	2,8 - 800,0	38
18	False Bay North	74,8	2,2 - 976,0	38

4.2.2 Water Temperature

Temperatures ranged seasonally from 16 to 31,5°C and corresponded with records for the system given by Hutchison and Pitman (1973). Measurements taken during lake turbidity runs showed that temperatures were uniform across South Lake with some variation occurring in the very shallow waters along the shore where temperatures were marginally higher. Differences in temperatures recorded during each of the six sampling runs were between 0,5 and 2,0°C, with a mean of 1,0°C. The mean monthly temperature and Standard Error of the measurements taken at the seven sites on South Lake are given in Table 17.

Table 17: Mean monthly water temperature in South Lake during 1981.

Month	Temperature (°C)	Standard Error
January	27,8	0,14
February	28,8	0,13
March	30,1	0,21
April	26,5	0,11
May	21,2	0,23
June	17,8	0,23
July	16,5	0,11
August	15,6	0,38
September	22,6	0,22
October	22,7	0,39
November	27,4	0,46
December	26,3	0,38

4.2.3 Salinity

During the year salinities recorded from seven sites on South Lake ranged from 32,0 to 44,5°/oo. Salinity measurements taken during Lake turbidity sampling runs showed that gradients with salinity differences of between 0,5 and 4,0°/oo ($\overline{x}$ of six runs = 1,75) across the Lake. In all instances the less saline areas were along the eastern shores and the more saline along the western shores of South Lake.

These differences come about as a result of continual freshwater seepage occurring along the eastern shores of the lake (R.Taylor, pers comm.). Mean monthly salinities and Standard Errors, recorded on the eastern and western shores are listed in Table 18. The differences between maximum and minimum monthly salinities ranged from 2,0 to 7,5°/oo ($\overline{x}$ = 3,9°/oo).

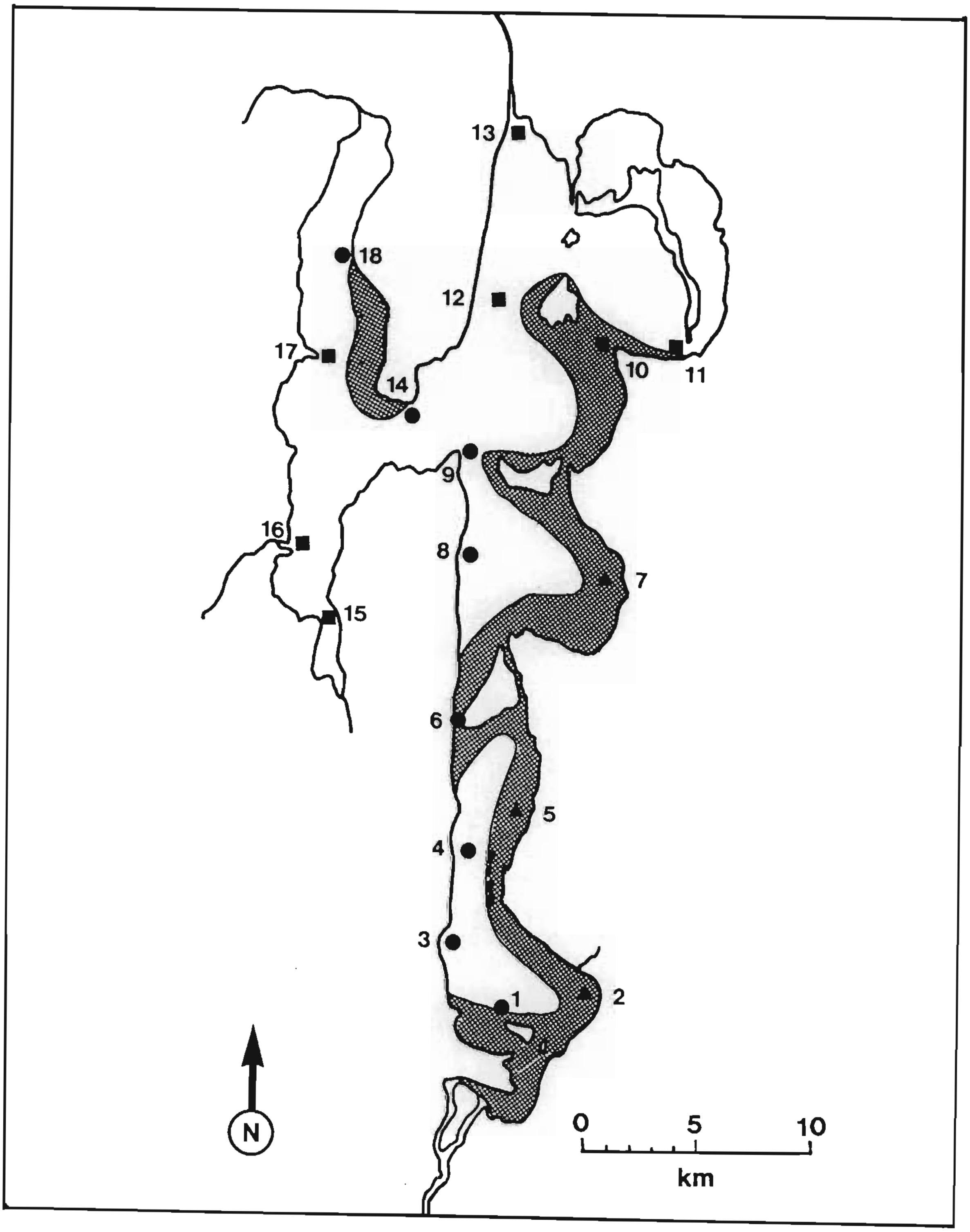

Figure 24: Lake St.Lucia; (a) distribution of 'sandy' (▨) and 'muddy' substrata (☐), data from Taylor (1980) and This Study, (b) Mean turbidities (NTU) at 18 sites grouped as low - <50 NTU (▲), intermediate - 51 TO 80 NTU (●) and high - >80 NTU (■) turbidity localities, based on data collected between February 1980 and June 1983 (1 to 18 = sampling sites - see Table 16).

Table 18: Mean monthly salinities (ppt) recorded on the eastern and western shores of South Lake during 1981.

	Western Shores		Eastern Shores	
Month	$\overline{x}$	S.E.	$\overline{x}$	S.E.
January	43,1	0,25	41,0	0,20
February	34,3	0,16	33,7	0,13
March	41,6	0,68	37,0	0,11
April	43,3	0,07	38,2	0,19
May	35,0	0,20	31,7	0,13
June	38,3	0,48	35,7	0,13
July	40,9	0,06	37,3	0,27
August	42,1	0,06	39,3	0,07
September	33,9	0,21	32,0	0
October	34,5	0,17	33,8	0,07
November	37,5	0,10	36,0	0
December	34,1	0,11	33,3	0,07

4.2.4 Wave Action

Wave action along the shoreline varied considerably depending on wind strength and direction. Table 19 gives the monthly wave action ratings at the seven sites on South Lake when large seine netting was undertaken.

Table 19: Monthly Wave Action ratings at seven site on South Lake during 1981 (1 = calm - no waves; 2 = light; 3 = moderate & 4 = heavy wave action).

Site/Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gillies Point	3	2	3	3	2	3	2	3	4	4	3	2
NPB Jetty	3	1	3	3	2	2	2	1	4	3	4	3
Public Jetty	3	2	4	4	2	2	2	3	3	1	3	3
Indicus Indent	4	1	4	2	2	2	2	1	4	4	3	3
Nkazana Stream	3	1	3	3	1	2	2	2	4	1	4	2
Old Jetty	3	1	2	3	2	2	2	3	4	1	4	2
Ukwakwa	3	1	1	3	2	2	2	1	4	3	2	2

4.2.5 Wind

The mean monthly wind speeds recorded at Lake St.Lucia during 1981 are shown in Figure 25. In order that more accurate interpretations of turbidity patterns could be made the 4-year wind data (1969-73) from Lake St.Lucia, given by Hutchison and Pitman (1973) was consulted. The mean four hourly wind speeds for Lake St.Lucia are given in Figure 26.

Figure 27 shows a Wind Rose for the lake compiled from the data given by Hutchison and Pitman (1973) for two localities in the system, the Estuary Mouth and Lister Point (Fig. 2). Winds from the N.- E.N.E. (41,4%) and S.- W.S.W. (36,6%) quadrants predominate. Table 20 shows the seasonal variation in wind direction, while Table 21 gives seasonal variation in wind speeds.

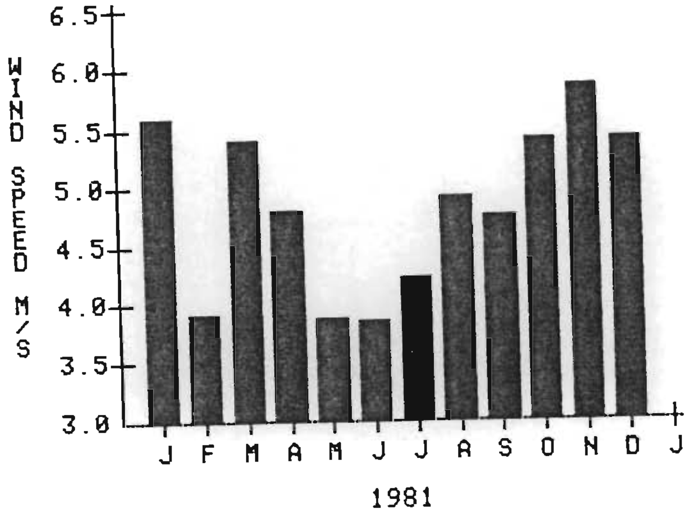

Figure 25: Mean monthly wind speed (m/s) recorded at Lister Point, Lake St.Lucia between January and December 1981 (m/s = metres per second).

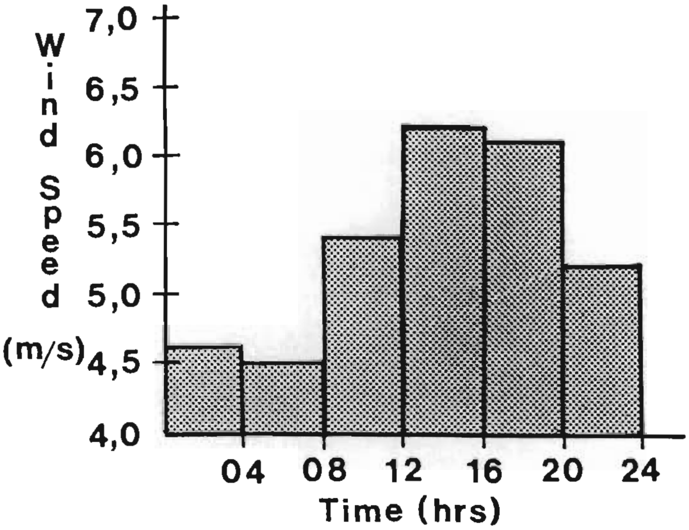

Figure 26: Mean hourly wind speeds (m/s) at Lake St.Lucia based on data from Hutchison & Pitman (1973) (m/s = metres per second).

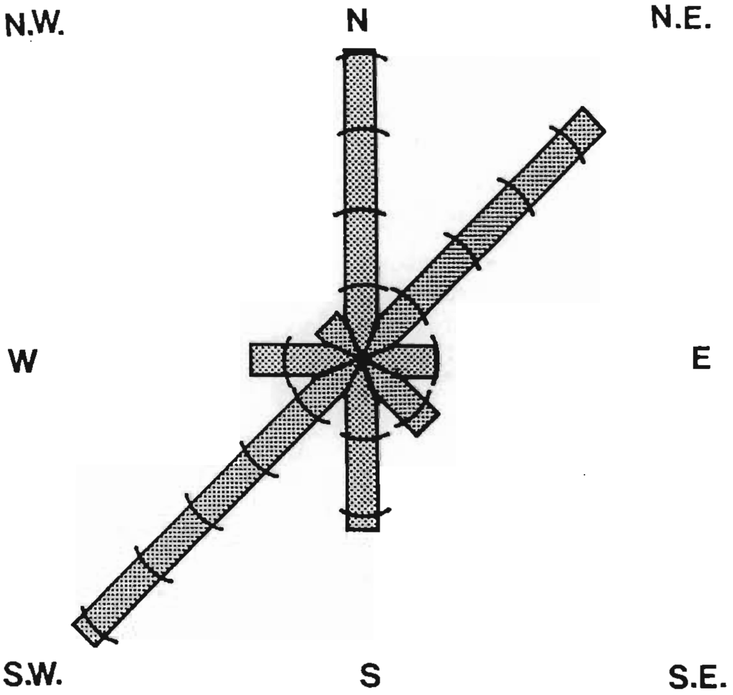

Figure 27: Wind Rose for Lake St.Lucia based on data from Hutchison and Pitman (1973) showing percentage frequency of wind direction with 5% arcs.

Table 20: Seasonal percentage frequency of wind at Lake St.Lucia, based on data from Hutchison & Pitman (1973) (Summer = December to February; Autumn = March to May; Winter = June to August & Spring = September to November, DIRECT. = Direction).

DIRECT.	N-NNE	NE-ENE	E-ESE	SE-SSE	S-SSW	SW-WSW	W-WNW	NW-NNW
SUMMER	17,4	22,1	7,7	7,5	12,8	24,4	5,8	2,3
AUTUMN	18,7	20,8	4,4	6,2	8,5	29,2	8,1	4,1
WINTER	24,3	17,4	3,6	4,0	7,7	26,2	11,1	5,7
SPRING	18,8	24,8	5,4	6,1	13,5	23,9	5,2	2,3
ANNUAL	19,6	21,8	5,4	5,9	10,8	25,8	7,3	3,4

Table 21: Seasonal percentage frequency of various wind speeds at Lake St.Lucia based on data in Hutchison & Pitman (1973) (m/s = metres per second; Summer = December to February; Autumn = March to May; Winter = June to August & Spring = September to November).

WIND SPEED	0-1	2-3	4-6	7-11	12-18	m/s
SUMMER	2,4	18,0	41,2	36,5	1,9	
AUTUMN	6,4	28,4	42,1	21,8	1,3	
WINTER	5,5	28,9	44,3	20,7	0,6	
SPRING	3,9	15,8	39,5	39,2	1,6	
ANNUAL	4,5	22,7	41,8	29,6	1,4	

4.2.6 Lake Level.

During 1981 only minor fluctuations in lake level occurred, with levels ranging from +0,17 above to -0,3 metres below mean lake level. Figure 28 shows mean monthly lake levels at Charters Jetty (Fig. 7) between July 1980 and June 1982.

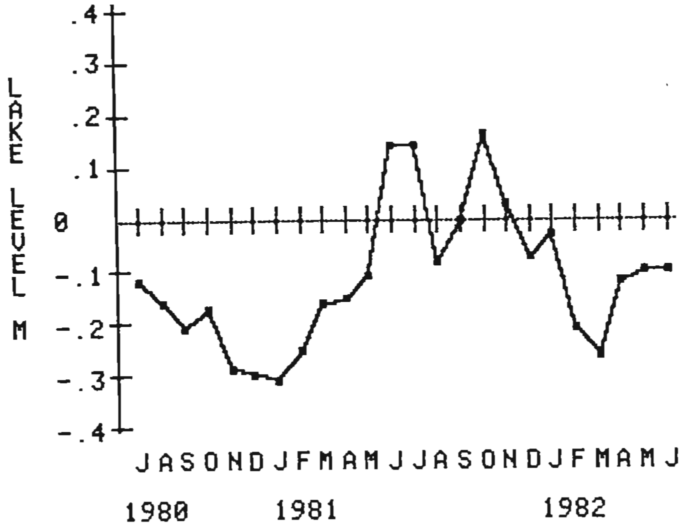

Figure 28: Mean monthly lake levels recorded at Charters Jetty between July 1980 and June 1982 (M = metres, 0 = mean lake/sea level).

4.2.7 Substratum particle size.

The mean particle sizes at the four sampling sites on the western shores were found to be 150µm, while the three sites on the eastern side of the lake had particle sizes of 350µm predominating. The substrata of the St.Lucia system have been referred to two types, ´sandy´ and ´muddy´ (Boltt 1975). In South Lake the western side is generally ´muddy´ whilst the eastern side is ´sandy´; see 4.2.1 (f) and Figure 24 for distribution throughout the system.

Figure 29 was drawn up from field observations as well as details obtained from a 1:10000 N.P.A. Building Services map of South Lake (Drawing No. HYDRO/A/LS/1) dated May 1970. Observations indicate that in the east the sandy substrata overlay the mud. The zone of change in Figure 29 consists essentially of a layer of sand covering the mud. This layer becomes thicker towards the east. This transition is well marked in the northern part of South Lake, particularly if one moves eastwards in a straight line from Charters Public Jetty to a point just north of Nkazana Stream (Line X--X on Fig. 29).

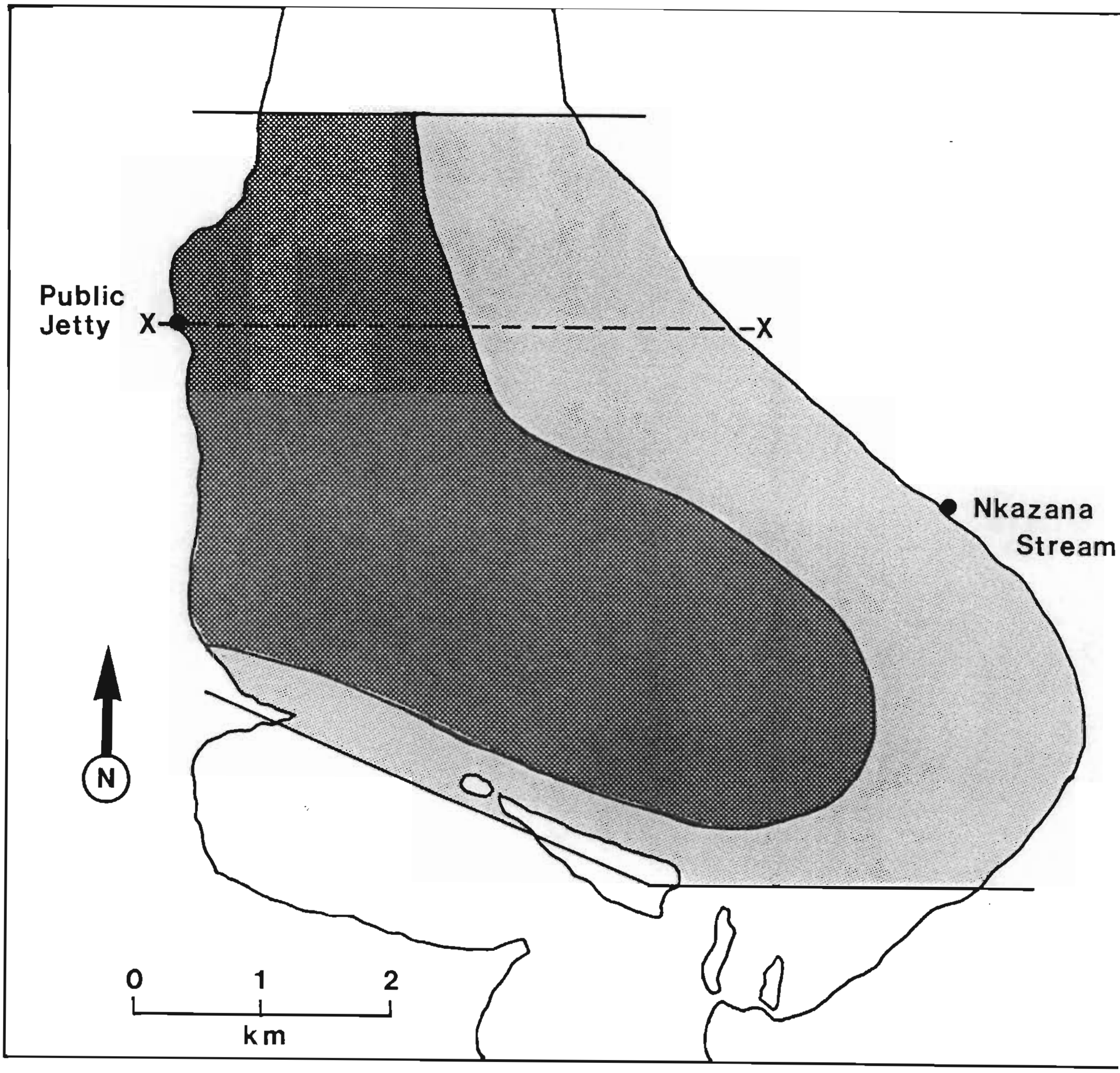

Figure 29: The distribution of ´sandy´ and ´muddy´ substrata in South Lake - St.Lucia based on field observations and details from N.P.A. Building Services map HYDRO/A/LS/1 dated May 1970 (░ = ´sandy´, ▓ = ´muddy´ & X--X = transect line across sand/mud transition).

4.2.8 Benthos of South Lake.

The mean monthly biomass values for the eastern and western shores are given in Table 22; the overall mean biomass for the year (dry mass) was 2,63g/m^2 with mean values for the substrata of the 'muddy' west and 'sandy' east being 4,19 and 1,07g/m^2 respectively. The major contributors to the standing stock were the bivalve Solen cylindraceus and the polychaete Marphysa macintoshi, with a total of 37 taxa being recorded. The taxa present, their densities, distribution and seasonality have been discussed by Blaber et al. (1983).

Table 22: Monthly standing stocks of total benthos (g/m^2 dry weight) in South Lake.

Month	Eastern Shores	Western Shores
January	0,84	3.95
February	1,30	8,55
March	0,87	2,47
April	0,56	5,50
May	3,23	2,85
June	0,85	5,52
July	0,72	1,07
August	1,15	3,12
September	0,67	4,32
October	0,96	3,74
November	0,63	4,20
December	1,06	5,03
$\overline{x}$	1,07	4,19
S.E.	0,20	0,55
Overall mean	2,63	

4.2.9 Correlations among physical factors.

The results of F and t tests carried out to determine whether any significant differences existed between measurements of physical factors made on the eastern shores and those taken on the west are given in Table 23. From this it can be seen that only turbidity, salinity, substratum and benthos occurred at significantly different levels on either side.

Results from the Pearson´s Correlation Analysis (Table 24) showed that there were 6 highly significant correlations (p = <0,0001) and 3 significant correlations (p = <0.01 to <0.005) amongst the physical factors measured in South Lake.

Table 23: Results from F and t tests on physical factor data from the eastern and western shores of South Lake.

	Significance Level	
Physical Factor	F-test	t-test
Turbidity	<0,01	<0,003
Temperature		
Salinity	<0,05	<0,002
Wave Action		
Wind Speed		
Lake Level		
Substrata	-	<0,001
Benthos	0,001	0,003

Table 24: Significant correlations amongst physical factors measured in South Lake during 1981.

	Benthos	Substrata	Wind Speed	Lake Level	Wave Action
Turbidity	+0,005	-0,0001	+0,005		+0,0001
Temperature			+0,0001	-0,0001	
Salinity		-0,001			
Wave Action			+0,0001		
Substrata	-0,0001				

4.3 Discussion.

4.3.1 Turbidity.

The relationship between turbidity and the amount of sediment present in the water was found to be significant. This has meant that old data with turbidity measured as the number of grams per litre of water can be converted so that comparisons can be made between past and present turbidities. It has also been particularly useful for determining the levels of turbidity which may be reached in Natal estuaries (Chapter 8) where the only turbidity data available was in mg/l.

Field results showed that the full range of turbidity (<10 to >80 NTU), which appears to be important in terms of fish distribution in estuaries (5.2.2), was present during all months of the year. Added to this it has been shown that while the waters of the western shores may become very clear during calm weather (Figure 22 & Table 12), the turbidity regimes of the 'clear' east and 'turbid' west are significantly different.

It is apparent from this study that a number of factors combine to produce the turbidity regimes present in South Lake. However, two of these; substratum and wind, play the dominant roles. While substratum is the fixed variable, is not so and its influences may vary daily or seasonally, depending on its strength and direction. Although combining to produce a system′s turbidity regime, these two factors may exert added influence in a number of ways.

Wind plays a major role in the establishment of the turbidity regimes of the St.Lucia system which is enhanced by the fact that the dominant winds blow along the long axis of the lake. This leads to a pronounced surface seiche; the drop in water level over a period of 24 hours has been known to exceed 1,5m in the northern part of the lake (R.Taylor, pers comm.). Owing to the length of lake down which northerly winds blow, longshore fetch causes turbidities to be higher in the southern portion of South Lake on N.E. winds than in the northern parts under conditions of S.E. winds (Figs. 17 and 19). Under calm conditions the whole lake may temporarily settle out (Figs. 21 & 22). However, these conditions seldom last for more than twelve hours. It is interesting to note that even as the lake settles out, the turbidity gradient, clearest in the east with increasing turbidities westwards, remains (Fig. 22).

The variation in turbidities across the lake is illustrated in Figures 17 and 22. By plotting turbidity iso-lines based on data from transect runs it is apparent that a ′clear′ water zone is always present on the eastern side of South Lake. Even when a moderate south westerly is blowing directly onshore, the turbidity over a large area in the east remains under 30 NTU (Fig. 19). Turbidities on the western side show greater variation depending on wind direction and strength. Under south westerly winds the area is more or less sheltered and turbidities seldom rise above 100 NTU (Figs. 19 & 20) while under north easterly conditions turbidities over most of South Lake exceed 100 NTU (Fig. 17).

Results from hourly turbidity samples collected at stations on the eastern and western sides of South Lake showed that daily variation was greatest in the west, where the sediments, which consist of finer particles, are easily stirred up and remain in suspension for some time (Fig. 15). On the eastern side increased wind speed led to only small consist predominantly of large particles dropping out of suspension rapidly as soon as the wind dropped (Fig. 16).

Turbidity peaks followed wind strength peaks recorded on site and at the Estuary Mouth wind recorder (19km to the South) during hourly turbidity sampling. Wind recordings from Lister Point (28km to the North) had peaks corresponding with the western shores turbidities but not with those recorded on the eastern shore. During both sampling periods the mean hourly wind speeds showed peaks similar to those recorded by Hutchison and Pitman (1973), whose data covered the period January 1969 to February 1973 (Fig. 26).

Seasonal variation in turbidity occurred as a result of reduced wind speeds during the winter months, although a turbidity range from <10 to >80 NTU was always present. These effects were more marked in the west as can be seen in Table 11 and by comparing Figures 13, 14 and 25.

Although substratum has been stated to be a fixed variable, there are factors which may bring about changes in, or create new, lake bottom substrata. The important influence in this case would be the deposition in the system of a silt load brought down by rivers from eroding catchments or sediments derived from on site bank and shoreline erosion. The latter appears to have occurred at St.Lucia and is still in progress (I.van Heerden, pers comm.). Silt loads may be deposited on top of sandy substrata and this could eventually lead to a change in the turbidity regime of an area as the silt layer builds up. It appears that silt deposition at St Lucia was, at the time of this investigation, only occurring in the already turbid western and northern areas of the lake.

Results from turbidity transects and hourly sampling stations indicate that turbidities in the eastern parts of South Lake are more stable. This is also shown by the mean turbidity values from the three sampling sites on the eastern shores of South Lake (Table 12). The western parts show more variability and are predominantly turbid, although settling out may occur as wind conditions change. Recorded means from four sites in the west varied considerably (63, 79, 91 & 141 NTU), this variation being related to the locations of the winds.

With a recorded mean turbidity of 51,4 NTU, Lake St.Lucia should be classified as a predominantly turbid system. However, due to the presence of a range of turbidities, it can be subdivided. Data from South Lake and results of studies on the distribution of substrata (Fig. 24), combined with results from the turbidity samples collected throughout the lake by N.P.B. staff for this project, can be used to obtain an overall picture of the distribution of turbidity throughout the system. Furthermore, old secchi data may also be used, as it has been shown that there is a significant correlation between turbidity and secchi depth.

Generally, lowest turbidities (mean <50 NTU) correlate with known areas of 'sandy' substrata. The exceptions are in the eastern part of North Lake at sites 10 and 11 (Fig. 24). These are areas with predominantly shallow water, where wind action may have a more pronounced effect. An extrapolation of data shows that about 30% of the lake has a mean turbidity of <50 NTU. However results from intensive turbidity sampling on the eastern side of South Lake (Table 12) have shown that turbidities are much lower than the figures obtained for that area from the N.P.B. data. An extrapolation taking the South Lake data into account shows that only about 20% of the lake, that area from the eastern side of South Lake to just north of Tewate (Site 7 - Fig. 24) can be classed as 'clear', with mean turbidities approaching <10 NTU.

The remainder of the lake may be classed as intermediate (10-80 NTU) or turbid (>80 NTU). The latter is prevalent in the northern areas and the former the western area of the southern two thirds of the lake (Fig. 24).

4.3.2 Physical factors with the potential to influence fish distribution in South Lake.

Having obtained detailed information on the ranges and levels of occurrence of eight physical factors, these and their correlations with each other should be considered in distribution in South Lake. Once this has been done, then only can an attempt be made to ascertain to what extent the important factors are actually affecting fish distribution.

(a) Turbidity.

This factor showed significant correlations with four others; benthos, substratum, wind speed and wave action. These fall into two categories: (i) turbidity, derived from a combination of particle size of the substratum and wind speed, the latter also being responsible for the level of wave action, and (ii) benthos, substratum and turbidity, the latter two known to contribute to the establishment of a specific benthic fauna in an area (Blaber et al., 1983). Added to the above, it has been established that although a wide range of turbidity (<10 to >80 NTU) is present throughout the year (Table 11), there is a significant difference between the turbidity regimes on the eastern and western sides of the lake. Turbidity must therefore be regarded as potentially an important factor which may be influencing fish distribution in South Lake.

(b) Temperature.

Significant correlations exist between temperature and wind speed and lake level. Both these correlations come about as a result of each of the factors showing seasonal fluctuation. Temperature decreases in winter (Table 17) as does wind speed (Fig. 25) while lake level, which is negatively correlated, shows a decrease in summer (Fig. 28) as a result of high rates of evaporation when temperatures are high.

While these correlations are brought about by the seasonality of the factors, temperature on its own must be considered as being potentially important in determining fish distribution in South Lake. However, it must be born in mind that its influence would affect temporal distribution of particular species rather than a spatial, since temperature differences within the lake were minimal at any given time.

(c) Salinity.

correlation with salinity was substratum (Table 24). This, as shown in 4.2.4 and 4.2.7, was due to freshwater seepage on the eastern shores, which caused salinities there to be consistently lower (<4^{o}/oo) than the west. This, combined with the fact that all sampling sites on the east have similar mean particle sizes which differed significantly from those of the western sites, accounts for the correlation. It can therefore be concluded that this correlation is of little actual significance in terms of influencing fish distribution. Salinities on the eastern and western shore were found to be significantly different as a result of the above, and could therefore also be excluded from consideration.

During the sampling period (1981) the salinity variation (32,0 to 45,5^{o}/oo) was found to be minimal in terms of known fish tolerances. That most species are tolerant of this range of salinities is shown by the fact that they are marine species, which as adults frequent sea water (36^{o}/oo). Added to this, adults and juveniles of these species have been shown to occur in a range of salinities exceeding that recorded during this study. This is shown on Table 25 which lists the salinity ranges recorded for the common estuarine species considered in this study.

Only two out of the 20 species (<u>G.acinaces</u> & <u>M.argenteus</u>) studied have not been recorded throughout the full range of salinities which occurred in South Lake during 1981. They were not recorded in salinities greater than 43^{o}/oo and it is therefore possible that their distribution in South Lake may to some extent have been influenced by the salinities present. This effect must, however, be considered to have been minimal (if occurring at all) due to the fact that salinities exceeding 43^{o}/oo were only recorded during three months of the year, at no more than two of the seven sampling sites on each occasion.

Where the other species are concerned it can be accepted that the ranges of salinity which occurred during the sampling period did not have any influence on the distribution of the fish species studied in South Lake, and this factor may therefore also be excluded.

Table 25: Salinity ranges frequented by marine species which occur commonly in estuaries. Data from Whitfield *et al.*(1981), Cyrus (1980) and This Study.

Species	Salinity range
Gerres acinaces	1,0 - 43,0
Gerres rappi	1,0 - 44,5
Monodactylus argenteus	0 - 43,0
Rhabdosargus sarba	1,0 - 80,0
Rhabdosargus holubi	1,0 - 70,0
Liza dumerili	1,0 - 80,0
Liza macrolepis	1,0 - 80,0
Valamugil buchanani	1,0 - 55,0
Gerres filamentosus	1,0 - 44,5
Caranx sexfasciatus	1,0 - 44,5
Valamugil cunnesius	1,0 - 70,0
Mugil cephalus	0 - 82,0
Leiognathus equulus	1,0 - 44,5
Pomadasys commersonni	1,0 - 75,0
Acanthopagrus berda	0 - 70,0
Terapon jarbua	0 - 75,0
Elops machnata	1,0 - 110,0
Solea bleekeri	1,0 - 65,0
Johnius belengerii	1,0 - 58,0
Thryssa vitrirostris	1,0 - 60,0

(d) Wave Action.

This factor was found to correlate with turbidity and wind speed (Table 24), which was to be expected as the latter is responsible for the amplitude of the waves and the generated water movement is to a large extent responsible for the turbidity levels. As, the waves were only present along the shoreline, they may be considered as having a minimal influence on the species present in the 50 x 70m area sampled by the large seine net, and it appears that the waves affecting fish distribution.

To these reasons may be added that no significant difference was found in the level of wave action occurring on the eastern and western shores. The fact that wave action is dependent on wind speed, means that the occurrence of a particular level of wave action is very variable. For the above reasons it is considered that wave action is not an important factor in determining the distribution of fish in South Lake.

(e) Lake Level.

The only significant correlation with this factor, that of temperature, has been discussed in (b) above. To this can be added that due to the relative uniformity of substrata (Fig. 29), and the uniform depth of the system, lake level changes such as those which occurred during the sampling period (range -0,3 to +0,17m) may be considered to have had minimal effect on the fish distributions in the lake.

(f) Wind Speed.

Although correlating with turbidity, temperature, and wave action, wind speed as such has no direct influence on the distribution of fish in the system. Rather, the factors which it influences, such as turbidity may have had a direct effect. Its correlation with temperature is related to the seasonal variations of the two factors.

(g) Substratum.

Substrata correlation with turbidity and salinity have been discussed in (a) and (c) above. Its correlation with benthos is significant and expected as different substrata support different benthic populations. Substratum therefore has little direct effect on the distribution of fish in the lake, except on a few species of mullet which take in sand grains to obtain food (see 5.3).

(h) Benthos.

The correlation with turbidity and substratum has been discussed in (a) and (g) above and it is concluded that this because of the different benthic communities which occur on different substrata. The difference between the benthic standing stocks (biomass of food available) on the eastern and western shore has also be found to be significant, thus indicating the presence of at least two major benthic communities.

4.3.3 Conclusion.

The investigation into the occurrence, distribution and levels of turbidity in South Lake has shown that a wide range occurs and that there is a significant difference between turbidities on the eastern and western shores. It has been determined that the occurrence of different levels of turbidity was almost entirely due to two factors: substratum (the fixed variable) and wind (speed/direction, which is not fixed). The variability of these factors at St.Lucia have led to the establishment of a number of turbidity regimes which cover a wide range of turbidities.

The data collected on turbidity and seven other physical factors originally considered as possibly having some affect on fish distribution in South Lake have been analysed and their correlations with each other considered. The conclusions reached are that, although there were some significant correlations, only three out of the eight can be considered as possibly having some influence on fish distributions. These factors are temperature, turbidity and benthos (amount of food available). Influences produced by the former factor would however only affect temporal rather than spatial distribution in fish species, while the latter two could influence actual distribution within the system. This is due to the fact that turbidity and benthos occur at different levels simultaneously in different parts of the system.

The effects of these three important physical factors (turbidity, temperature and benthos) on the distribution of fish species in South Lake is considered in Chapter 5.

5. FISH DISTRIBUTION IN SOUTH LAKE, ST.LUCIA, IN RELATION TO TURBIDITY AND OTHER PHYSICAL FACTORS.

5.1 Introduction.

This chapter provides details on the results of seine netting in South Lake. The distribution of juveniles of the 20 most commonly occurring marine species were compared with the distribution of the physical factors, turbidity, temperature and benthos, which were considered in Chapter 4 as being the factors likely to affect fish distribution in the lake. The data on the physical factors as well as seine netting, in terms of CPUE, were subjected to a number of statistical tests in order to determine the role of the three factors in fish distribution. From this the relative importance of turbidity and the other factors could be determined.

5.2 Results.

5.2.1 Distribution of seine data.

(a) <u>In relation to turbidity</u>.

During the field sampling period it was noticed that the CPUE for a number of species showed a distinct drop above or below certain turbidities; consequently when catch data were analysed four natural groupings were apparent. The turbidity ranges determining these groupings were used for determining the turbidity preferences of fish in South Lake and the other Natal Estuaries studied (see Chapter 8). They were also used in laboratory experiments (see Chapter 6). The turbidity groupings were designated as follows: Type A <10, Type B 10 - 50, Type C 50 - 80 and Type D >80 NTU.

The distribution among the turbidity categories of the 61 large seine hauls carried out during 1981 in South Lake are given in Table 26. Catch data from these were used to assess the abundance of juveniles of the 20 common marine species in the different turbidity ranges.

Table 26: Distribution and turbidity of 61 large seine hauls carried out in South Lake during 1981.

Turbidity Range (NTU)	<10	10 - 50	51 - 80	>80
South Lake	28	15	8	10

(b) In relation to temperature.

No significant differences were found between temperatures recorded on the eastern and western shores of South Lake. However, seasonal differences in the lake as a whole were apparent, with highest temperatures occurring during summer and lowest during winter (see 4.2.2). Table 27 shows the distribution of 61 large seine hauls according to season.

Table 27: Seasonal distribution of 61 large seine hauls in South Lake during 1981 ($\overline{x}$ = mean).

Season $\overline{x}$ Temperature ^{o}C	Spring 24,3	Summer 27,6	Autumn 25,9	Winter 16,6
Number of hauls	15	16	15	15

(c) In relation to benthos.

No definite seasonal variations in biomass of benthic animals were evident, but the mean standing crop of animals in the ´muddy´ western sites (4,19 g/m^2) was four times greater than in the ´sandy´ eastern sites (1,07 g/m^2). F and t-tests on the data showed that there was a significant difference between the values of benthic animals present in the benthos on the two shores. Table 28 shows the distribution of large seine hauls on the eastern and western shores during 1981.

Table 28: Distribution of 61 large seine hauls in South Lake during 1981.

Locality Sites	Eastern Shores 1, 2 & 3	Western Shores 4 & 7
No.of hauls	33	28

5.2.2 Distribution of fish in South Lake.

(a) Catches on Eastern and Western Shores.

As results from the measurement of physical data had shown that all sites on the eastern shores were generally similar, as were all sites on the western shores, the CPUE on each shore for the 20 most frequently caught species, is given in Table 29. This Table also gives the percentage catch on each shore. As the eastern shores have been shown to have very low turbidities while the west is predominantly turbid, this Table gives preliminary indications of which species show specific turbidity or benthic preferences.

Table 29: Catch per unit effort of 20 species in South Lake during 1981 (Sites shown on Figure 7).

Species / Sites	Eastern Shores 1, 2 & 3		Western Shores 4 & 7	
	CPUE	%	CPUE	%
Gerres acinaces	11,6	96	0,5	4
Gerres rappi	5,2	93	0,4	7
Monodactylus argenteus	2,1	49	2,2	51
Rhabdosargus holubi	1,6	20	6,4	80
Caranx sexfasciatus	0,4	50	0,4	50
Liza dumerili	6,7	96	0,3	4
Liza macrolepis	20,1	85	3,6	15
Rhabdosargus sarba	25,1	67	12,4	33
Gerres filamentosus	1,4	100	0	0
Valamugil buchanani	0,4	93	0,03	7
Leiognathus equulus	2,2	46	2,6	54
Mugil cephalus	0,3	43	0,4	57
Valamugil cunnesius	0,03	3	1,0	97
Acanthopagrus berda	2,3	40	3,4	60
Pomadasys commersonni	2,5	32	4,7	68
Terapon jarbua	3,1	54	2,6	46
Elops machnata	0,2	17	1,0	83
Solea bleekeri	1,2	6	18,4	94
Johnius belengerii	0	0	1,6	100
Thryssa vitrirostris	0	0	5,3	100

(b) Occurrence in the four major turbidity groups.

The CPUE results, in terms of percentage catch, in each of the four turbidity groups, of the 20 most frequently caught species are given in Table 30. These are ranked with 'apparent' clear-water species at the beginning, intermediate and indifferent species in the centre and 'apparent' turbid water species at the end.

Table 30: Percentage catch per unit effort (large seine netting) of 20 species in four turbidity ranges from South Lake (n = number of fish).

Low [illegible]

Turbidity range (NTU)	<10	10 - 50	51 - 80	>80	n
Gerres acinaces	89,5	10,5	0	0	430
Gerres rappi	60,0	35,0	5,0	0	177
Monodactylus argenteus	64,0	8,0	13,0	15,0	134
Rhabdosargus holubi	65,0	22,0	6,0	7,0	237
Caranx sexfasciatus	54,5	36,5	9,0	0	24
Liza dumerili	51,0	42,0	7,0	0	231
Liza macrolepis	49,0	28,0	14,0	9,0	767
Rhabdosargus sarba	42,0	32,0	23,0	3,0	1143
Gerres filamentosus	23,0	77,0	0	0	40
Valamugil buchanani	20,0	70,0	10,0	0	16
Leiognathus equulus	0	36,0	56,0	8,0	145
Mugil cephalus	5,5	22,0	61,5	11,0	20
Valamugil cunnesius	1,0	4,0	86,0	9,0	28
Acanthopagrus berda	7,0	35,0	48,0	10,0	174
Pomadasys commersonni	17,0	23,0	33,0	27,0	222
Terapon jarbua	36,0	33,0	10,0	21,0	180
Elops machnata	1,0	18,0	66,0	15,0	39
Solea bleekeri	1,0	12,0	32,5	54,5	552
Johnius belengerii	0	0	32,0	68,0	47
Thryssa vitrirostris	0,2	0,4	54,0	45,4	148

(c) Seasonal occurrence.

The seasonal occurrence of species in South Lake, according to large seine catch data, is given on Table 31.

Table 31: Seasonal occurrence of 20 common fish species, in terms of percentage of catch made during each season, in South Lake during 1981.

Species / Season	Spring	Summer	Autumn	Winter
Gerres acinaces	5,9	4,4	50,4	39,3
Gerres rappi	24,4	26,9	2,5	46,2
Monodactylus argenteus	12,0	77,1	10,9	0
Rhabdosargus holubi	17,4	15,5	57,4	9,7
Caranx sexfasciatus	25,0	31,3	43,7	0
Liza dumerili	28,9	45,6	22,8	2,7
Liza macrolepis	1,4	74,4	22,3	1,9
Rhabdosargus sarba	23,2	42,1	27,8	6,9
Gerres filamentosus	66,6	0	33,4	0
Valamugil buchanani	55,5	0	33,3	11,2
Leiognathus equulus	55,2	18,6	24,0	2,2
Mugil cephalus	30,7	38,4	23,1	7,8
Valamugil cunnesius	11,1	33,3	55,6	0
Acanthopagrus berda	5,5	56,3	33,9	4,6
Pomadasys commersonni	29,6	30,3	24,6	15,5
Terapon jarbua	25,2	33,9	9,6	33,3
Elops machnata	20,8	29,2	45,8	4,2
Solea bleekeri	44,5	19,1	23,2	13,2
Johnius belengerii	67,7	16,1	9,7	6,5
Thryssa vitrirostris	30,5	44,2	11,6	13,7

(d) Species accounts.

Details on catches made on the eastern and western shores, within the four major turbidity groupings and during the four seasons of the year are given on Tables 29, 30 and 31. These tables are not referred to when the associations of each species to these factors are given in the species accounts below. The figures which illustrate the CPUE of the 10 species which were tested for turbidity preferences in the laboratory are included in Chapter 7 to allow direct comparison between field and laboratory data. All references made to the occurrence of benthic organisms in South Lake refer to information collected during this study which has already been published (Blaber et al., 1983).

The following provides a brief summary of the distribution of benthic invertebrates, against which food preferences of the various species are discussed. The bivalve Solen cylindraceus was the greatest contributor to the benthic biomass, particularly in the 'muddy' areas on the western shores. Other bivalve species present were widely distributed but were also most abundant in the west. The polychaete Marphysa macintoshi was the second most important contributor to the overall biomass and, although abundant at all sites, had its largest standing crop on the 'muddy' west at Indicus Indent. It was found that there were considerable differences between numerical densities of the dominant taxa of different substrata with Cumacea being the only dominant group on the 'clear' eastern shores. Bivalvia, Polychaeta, Nemortia, Amphipoda, Tanaidacea and Mysidacea were all present in greatest numbers on the 'muddy' western shores.

The accounts below provide details on the turbidity preference, seasonal occurrence and diet, in relation to the distribution of the benthic fauna in the lake, for each species.

Gerres acinaces

This species showed a distinct preference for the eastern side of the lake and for low turbidities as can be seen in Figure 30. It was only found once , during May, on the west at Indicus Indent. This occurrence coincided with the lowest turbidity (2,5 NTU) recorded in the west during this study. The species appears to be seasonal in occurrence visiting the system only during the cooler months.

The main food items taken by this benthic feeder are the siphon tips of Bivalvia. These have been found to make up to 64%, of energy in the diet of this species in Natal estuaries (Cyrus & Blaber, 1983). Its distribution in South Lake did not coincide with the highest recorded densities of bivalves, the latter occurring mainly in the turbid west. Cumacea, which are dominant in the east, were found to make up no more than 1% of the species diet in Natal estuaries

It is therefore apparent that although G.acinaces is seasonally present within the system, turbidity has a greater influence on its distribution than does the location of benthic food items.

Gerres rappi

As with the previous species, G.rappi showed a strong attraction to the clear eastern shores (Fig. 31). Of the three occasions when members of this species were caught off the western shores, two were during periods when turbidities were low (<10 NTU) while the third occurrence was at 80 NTU. Fewer than 5 individuals were involved in each case. The species showed no real seasonal trends, although the catches during autumn were smaller.

Bivalvia siphon tips are important in the diet, although this species feeds predominantly on Amphipoda and Chironomidae larvae when these are present. The former were at their highest densities in the west while the latter were absent from the system. Turbidity, therefore, appears to be responsible for the distribution in South Lake.

Monodactylus argenteus

Catches showed this species to be evenly distributed throughout South Lake. However, as can be seen in Figure 43, the catch was highest in waters with turbidities <10 NTU. A distinct seasonal trend was shown with numbers present being higher during the summer months.

There is no published information on feeding of M.argenteus. However, my own unpublished data collected from South Lake indicate that it feeds predominantly on Mysidacea and filamentous algae, with Copopoda and benthic Crustacea also being taken. The Mysidacea occurred in highest densities on the western shores, which was also where filamentous algae were most evident (pers obs.). It would thus appear that M.argenteus is attracted to the western shore by the availability of its preferred food, but that its actual occurrence there is determined by the presence of clear water.

Rhabdosargus holubi

Most individuals of this species were caught on the 'turbid' western shores. However, turbidity analysis indicates a preference for clear waters (Fig. 45), with 65% of the total catch being made in waters of <10 NTU. The bias towards the west comes about as a result of a large catch being made on that side when the waters in the area were 2,5 NTU, the lowest recorded value for the west. Largest numbers were present in South Lake during autumn when temperatures were begining to fall.

Although taking in small numbers of Amphipoda and Polychaeta, this species is not strictly a benthic feeder. Its food is obtained by the ingestion of large quantities of plant material, which are not digested, but from which the associated epiphytic diatoms are removed (Blaber, 1974). Little aquatic plant material occurs in the east, but large concentration are found in the west (pers obs.) and it must therefore be this that is attracting them. However, their presence in the west coincides with the occurrence of clear water periods, thus indicating that the distribution as a whole is affected by water turbidity rather than the location of food.

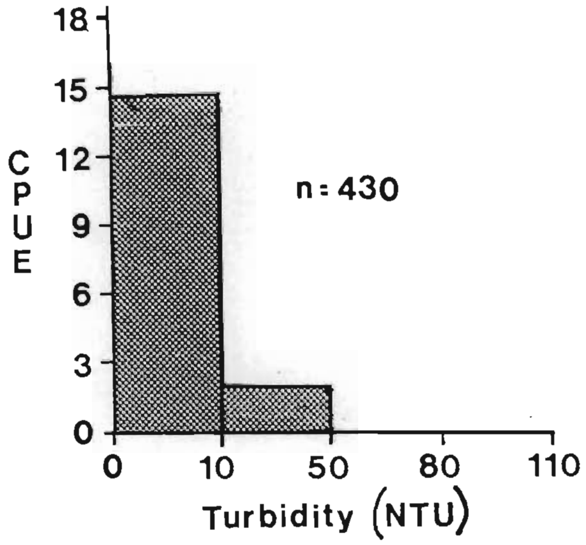

Figure 30: Catch per unit effort (CPUE) of <u>Gerres acinaces</u> in four turbidity ranges (n = number caught).

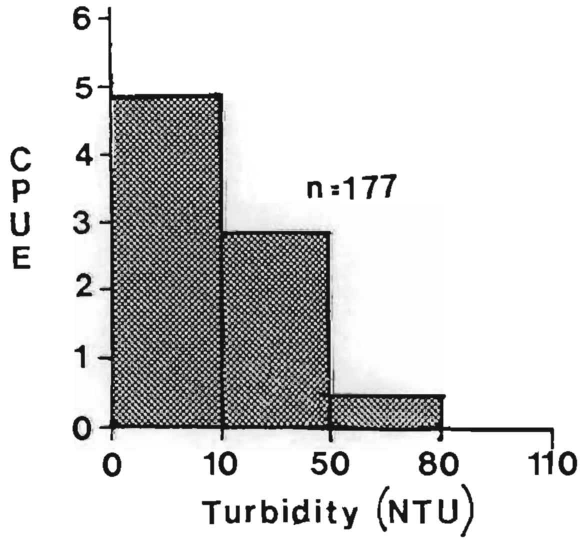

Figure 31: Catch per unit effort (CPUE) of <u>Gerres rappi</u> in four turbidity ranges (n = number caught).

Caranx sexfasciatus

Although the sample size was small the occurrence in catches of this species was similar on the eastern and western shores, all but one individual caught in the latter area were present in waters with turbidities <10 NTU. The species was present in the system during all except the three winter months.

C.sexfasciatus is essential a predatory species which feeds mainly on two small fish species, Ambassis natalensis and Glossogobius giuris, as well as on penaeid prawns. These three items have been recorded as comprising 11, 11 and 32%, in terms of energy, of the diet of the juveniles in Natal estuaries (Blaber & Cyrus, 1983).

While A.natalensis is present in greatest numbers in waters of 10 to 50 NTU, G.giuris occurs mainly where turbidities exceed 80 NTU (pers obs.). The penaeid prawns are most abundant in the ´muddy´ turbid areas of western South Lake (A.T.Forbes, pers comm.). That this species shows a preference for clearer water (<50NTU) can be seen on Figure 32, which shows the CPUE in the four major turbidity groups. It will however move into muddy substratum areas during periods of low turbidity to hunt its favoured prey.

Liza dumerili

Ninety percent of the catch of this species was made on the eastern shores, with a preference being shown for clear to partially turbid waters (Fig. 47). Although a high percentage of the catch was made in the 10 to 50 NTU category, a breakdown of this shows that 83% of the catch was made in turbidities of 10 to 20 NTU. Of the five individuals caught on the west, two were in 6,5 NTU and three were in 52 NTU. Some seasonal trends were evident, with the species being almost absent during the three winter months.

Mullet species feed by sucking up the surface layers of the substratum or by grazing on submerged rock or plant surfaces. In St.Lucia, Blaber (1976) showed that individual species exhibit a marked preference for particles of a certain size. Furthermore, he suggested that the occurrence of a particular food item in the diet may depend upon whether

L.dumerili has been recorded as taking particles within a size range of 100 to 600µm, with the mean particle size being 300µm. In South Lake the main food items recorded for the species were the gastropod Assiminea bifasciata, Foraminifera and large centric diatoms (Blaber, 1976). No information is available on the distribution and densities of the latter two, but the present benthic study has shown that Assiminea spp occurred in small numbers and were evenly distributed througout South Lake.

Sand grain size analysis showed that the eastern shores had a mean particle size of 350µm. The above tends to indicate that the benthos, and in this case the substratum (which is correlated with benthos), may be influencing the species distribution as much as it is being influenced by turbidity.

Liza macrolepis

Largest numbers were caught on the eastern shores, and the species showed a preference for clear to partially turbid waters (<50 NTU), with fewer individuals being caught as turbidity increased (Fig. 49). A seasonal trend was evident, with largest numbers being caught during the summer and autumn months.

The diet of this mullet species in South Lake consisted primarily of small diatoms and filamentous algae, with flagelates and some Assiminea spp also being taken. The observed size range of particles taken in by this species was 50-400µm, with a mean particle size of 250µm (Blaber, 1976). This value lies midway between the means recorded on the two shores and as information is available only on Assiminea, which was only taken in small quantities by L.macrolepis, it is not possible to separate the effects which turbidity and food may have on its distribution. However it is likely that turbidity may have a major influence.

Rhabdosargus sarba

Although 33% of the catch of this species was made on the 'muddy' western shores, a breakdown of the turbidities in which the fish were caught (Fig. 51) showed that the largest

Some seasonal trends were evident, with largest numbers being present during the summer months and then dropping off during winter.

The diet of this species has been studied by Blaber (1984) who found that plant material (56%), Bivalvia (7%) and Amphipoda (20%) were the dominant food items taken by individuals off the western shores. In the east Bivalvia (38%) and plant material (25%) dominated. The occurrence of R.sarba off the western shores appears to be related to the food they ate, as both benthic animals taken had their greatest densities recorded on this side. However the fish was only found to be present in small numbers on the west when turbidities rose above 50 NTU.

The positive selection for clearer waters may also be indicated by the fact that the largest catches were made in clear waters, despite the fact their preferred food was present in higher densities elsewhere in the system.

Gerres filamentosus

This species showed a 100% occurrence on the clear eastern shores within turbidities <50 NTU (Fig. 53). This species was only caught in the system during spring and autumn.

The diet in Natal estuaries (Cyrus & Blaber, 1983) is similar to that of other Gerres species with bivalve siphon tips (59% in terms of energy), Chironomidae larvae (21%) and Polychaeta (14%) being the dominant food items. While Chironomidae larvae are not present in South Lake, the other two groups, which do occur were present at greater densities on the western shores. It appears unlikely that G.filamentosus is being attracted to the clearer water by food availability. As this species captures benthic prey after first making visual contact (Cyrus & Blaber, 1983), this could be a reason for them to choose clear rather than turbid water areas.

Valamugil buchanani

Although the sample size was small, this species showed a preference for the clear waters of the eastern western shores, two were in clear water (6,5 & 11 NTU) and one was in 63 NTU. Analysis of seasonal occurrence showed that none were caught during the summer months.

In South Lake this mullet species feeds mainly on diatoms (large centric, small and pennate), filamentous algae and macrophytes. The recorded size range of sandgrains taken in is 100 to 200µm with a mean of 200µm (Blaber 1976). No details are available on the distribution and abundance of the major food items, but the sandgrains taken in correspond well with the 150µ mean value recorded for the turbid western shores. It is thus possible that the distribution of V.buchanani in South Lake may be influenced more by turbidity than food availability/substrata particle size.

Leiognathus equulus

The percentage catch of this species was similar on both shores; however, turbidity group analysis showed that they were absent from the very clear waters (<10 NTU) and only occurred in very small numbers in the most turbid waters (>80 NTU). The CPUE distribution within the four major groups is shown on Figure 33. Although caught all year round L.equulus showed a marked decrease in numbers during the winter months.

No data are available on the food taken by this species in St.Lucia, but information is available from the Mhlanga Lagoon (Whitfield, 1980a). The dominant food items, in terms of percentage calorific contribution, were Cumacea (56%), Copopoda (27%) and Polychaeta (14%). Assuming that the diets are similar in South Lake, those individuals on the eastern shores may be feeding on Cumacea which are at their highest densities there. Those on the west may take more Polychaeta which had highest densities in the west.

Although the above would tend to indicate that occurrence is being determined by the distribution of the preferred food in the benthos, it does not account for the fact that the species was absent from the very clear waters (<10 NTU) and was only present in small numbers in very turbid waters (>80 NTU). With the mean turbidities on either shore being at or close to the turbidity levels from which preference for intermediate turbidities which is determining the distribution of the species in South Lake rather than food.

<u>Mugil cephalus</u>

This species was caught on both shores; however, its distribution in the four major turbidity groups (Fig. 34) showed a preference for intermediate waters (10-80 NTU). Seine netting showed that it was present during all months with a marked decrease in the numbers caught during winter.

The diet of this mullet species in South Lake consists mainly of the Gastropod <u>Assiminea bifasciata</u>, Foraminifera and large centric diatoms. The recorded range of sandgrains taken in is 50 to 400µm with a mean particle size of 225µm (Blaber, 1976). Apart from <u>A.bifasciata</u> which was found to be evenly distributed in small numbers in South Lake during this study, no details are available on the distribution and densities of the other food items taken.

The mean sand grain size taken is not far off the mean size of 150µm recorded for the western shore. However <u>M.cephalus</u> was caught in almost equal numbers on both shores and showed an apparent preference for intermediate turbidities rather than than clear or turbid waters. It thus seems likely that turbidity is exerting some influence on the distribution of this species in South Lake.

<u>Valamugil cunnesius</u>

Almost all individuals were caught on the western shores, with the species showing a preference for turbid waters (Fig. 35). Seasonally <u>V.cunnesius</u> was present during all except the winter months.

In South Lake the food taken consists of diatoms (large centric, small and pennate) and Foraminifera. The range of sandgrains taken in is 100 to 250µm with a mean grain size of 150µm (Blaber, 1976). Although no information is available on the distribution and densities of the food taken, the mean sandgrain size indicated by Blaber (1976) as important in determining feeding areas corresponded exactly with the mean sandgrain size along the turbid western shores.

species distribution in South Lake as much as it appears to be influenced by turbidity.

Acanthopagrus berda

This species was caught on both eastern and western shores, with turbidity data (Fig. 57) showing that although most individuals were caught in intermediate turbidities (10-80 NTU), A.berda inhabited all turbidities. Data on seasonal occurrence of this species showed that greatest numbers were present during summer and autumn with an almost total absence during winter and spring.

No information is available on the diet of A.berda in South Lake, but it is known to feed on benthic invertebrates and has been recorded as taking Bivalvia and their siphon tips (Day et al., 1981). Bivalvia form the dominant fraction of the benthic biomass of South Lake and this is likely to have contributed to the occurrence of A.berda throughout the system, irrespective of turbidity.

Pomadasys commersonni

This species was caught on both shores with the largest numbers being present in the west. When divided into the major turbidity groups, the catch data showed that preference for a specific group did not exist (Fig. 59). Seasonally P.commersonni was caught in similar numbers throughout the year.

Food taken consists of bivalves, bivalve siphons and Tanaidae (Blaber, 1984). Catch data indicates that turbidity and available benthos in South Lake have no effect on the distribution of P.commersonni which occurs throughout the system.

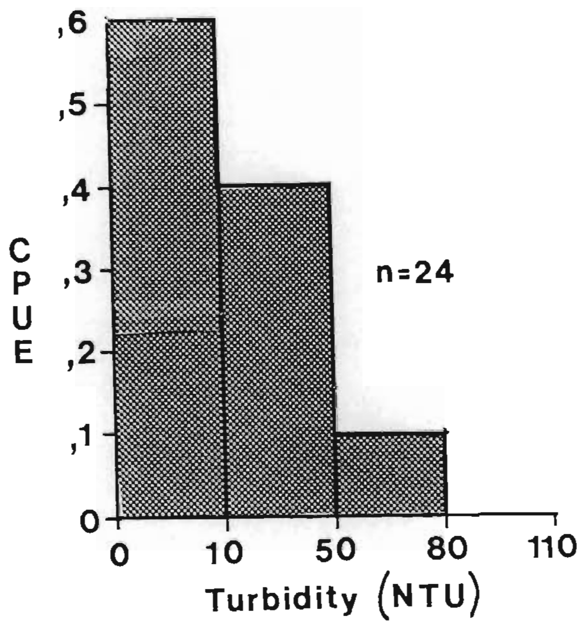

Figure 32: Catch per unit effort (CPUE) of <u>Caranx sexfasciatus</u> in four turbidity ranges (n = number caught).

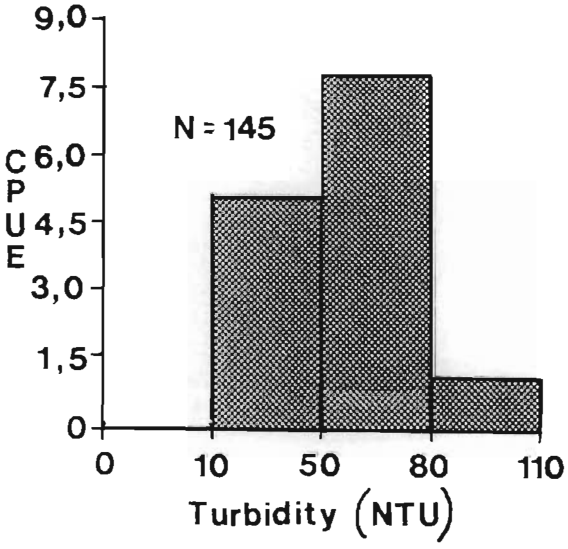

Figure 33: Catch per unit effort (CPUE) of <u>Leiognathus equulus</u> in four turbidity ranges (n = number caught).

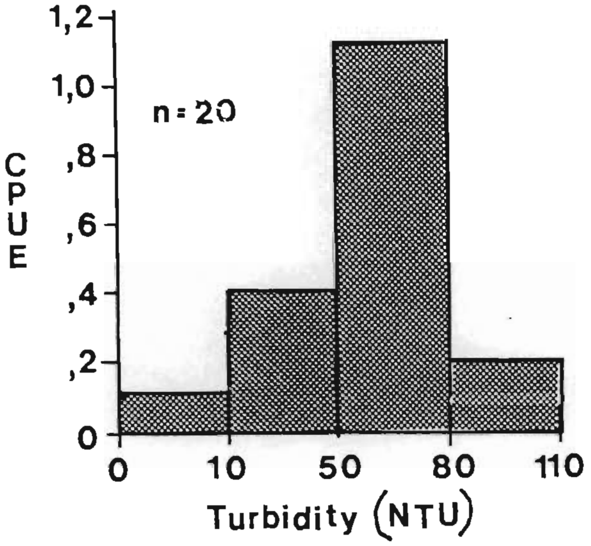

Figure 34: Catch per unit effort (CPUE) of <u>Mugil</u> <u>cephalus</u> in four turbidity ranges (n = number caught).

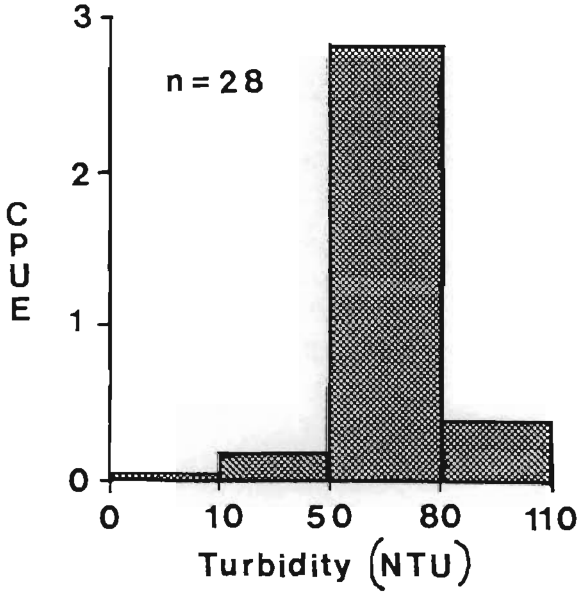

Figure 35: Catch per unit effort (CPUE) of <u>Valamugil</u> <u>cunnesius</u> in four turbidity ranges (n = number caught).

Terapon jarbua

Similar numbers were caught on the eastern and western shores and also within the four major turbidity groups (Fig. 61). Seasonally the species was present in similar numbers during all except the autumn months.

Whitfield and Blaber (1978a) have shown that this species feeds predominantly on scales, taken off live fish, but also takes Amphipoda and Brachyura. The former indicated that *T. jarbua* is not dependent on the available benthos for its food. The fact that it is present in all turbidities indicates that its distribution is not influenced by turbidity.

Elops machnata

Most fish of this species were caught off the western shores, showing a preference for the more turbid waters (>50NTU) and almost entirely avoiding the clear water (Fig. 36) to the extent of even being absent from the western shores when turbidities dropped below 10 NTU. Seasonal analysis of catches showed that smallest numbers were present during the winter months.

E. machnata is essentially a piscivorous predator and in St.Lucia its diet (% dry weight) has been determined as consisting predominantly of three fish species; *Thryssa vitrirostris* (27%), *Gilchristella aestuarius* (20%) and *Johnius belengerii* (16%), with crustaceans (mainly Penaeid prawns) making up 16% (Whitfield & Blaber, 1978b).

The distribution of these food items affects the distribution of *E. machnata* as both *T. vitrirostris* and *J. belengerii* (see below) are common in turbid waters as are the penaeid prawns (A.T.Forbes, pers comm.). However it is possible that this species shows a turbidity preference as it is adapted for hunting in turbid rather than clear waters and therefore its diet would be representative of the common species occurring in turbid waters, such as those it is taking.

Solea bleekeri

This species occurs almost exclusively on the western

(Fig. 37). In the west the smallest numbers, <15% of catch, were always caught during periods when the water had cleared and was below 50 NTU, while only 1% of the catch was made in waters <10 NTU. Some seasonal fluctuations were evident with numbers present falling during the three winter months.

There is no published information on the diet of this species, but personal unpublished data collected from South Lake indicate that more than 80% of the diet is made up of the siphon tips of the bivalve Solen cylindraceus. The occurrence of S.bleekeri therefore corresponds with the highest densities of its prey, which also occurs off the western shores, particularly at Gilly's Point.

The fact that so few individuals were caught on the 'clear' eastern shores is surprising; notwithstanding the fact that bivalve standing stocks were only 25% of those on the west, one would have expected the catch of S.bleekeri on the east to comprise more than 6% (Table 29). Their absence from the east would tend to indicate that a combination of abundance of preferred food and a preference for turbid waters determine the distribution of the species in South Lake. However, the fact that so few individuals were caught on the preferred 'muddy' western shores when turbidities were <50 NTU indicates that turbidity may be playing a dominant role.

Johnius belengerii

This species was totally absent from the eastern shores, showing a preference for the most turbid waters present in the west (Fig. 38). It was also absent from the west when turbidities there dropped below 50 NTU. It showed a distinct seasonal pattern with greatest numbers occurring during spring and summer and lowest during autumn and winter.

According to Whitfield and Blaber (1978b) the Brachyuran Hymenosoma orbiculare (28%) and fish (28%), predominantly G.aestuarius, Glossogobius giuris and I.vitrirostris, were the most important component of its diet. Amphipoda, Bivalvia, Gastropoda and Mysidacea each made up about 8% of the diet. The three fish and all the shores where J.belengerii occurred. Information available therefore tends to suggest that food availability plays an important role in determining the species distribution in South Lake.

However, as with E.machnata above, it is possible that that this species chooses turbid waters as it is best adapted for hunting under these conditions. This is supported by the fact that it was absent when ´clear to partially turbid´ waters (<50NTU) occurred on the western shores which it inhabits. The preference for turbid waters would naturally lead to turbid water species being well represented in the food taken.

Thryssa vitrirostris

This species was entirely absent from the ´clear´ eastern shores and showed a preference for turbid waters (>50NTU) as can be seen from Figure 39. The only seasonal trend noted was a 50% decline in the numbers caught during the autumn and winter months.

T.vitrirostris is a filter feeder; in South Lake juveniles feed exclusively on Zooplankton, with the calanoid copepod Pseudodiaptomis stuhlmanni dominating, but some Mesopodopsis africana (a mysid) are also taken (Blaber, 1979). Any correlations between this species and amounts of food available in the benthos are therefore of little significance. However, S.J.M.Blaber (pers comm.) informs me that during his study on filter feeders in South Lake he found no significant differences between the densities of the zooplankton fauna of the east and west of the lake. This tends to rule out the availability of food as determining the distribution of T.vitrirostris and supports the suggestion that the species actively seeks turbid waters.

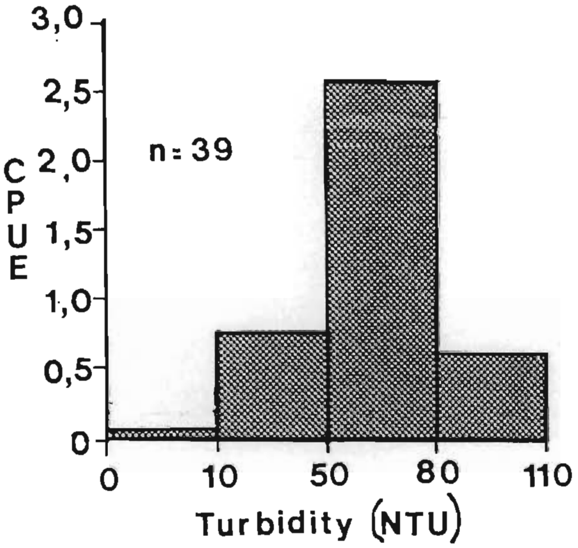

Figure 36: Catch per unit effort (CPUE) of <u>Elops machnata</u> in four turbidity ranges (n = number caught).

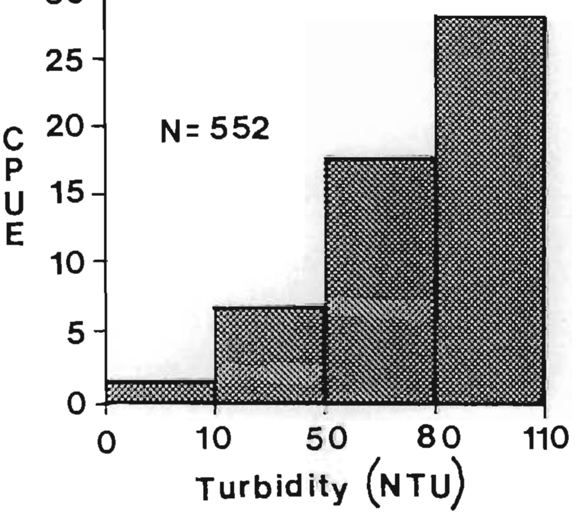

Figure 37: Catch per unit effort (CPUE) of <u>Solea bleekeri</u> in four turbidity ranges (n = number caught).

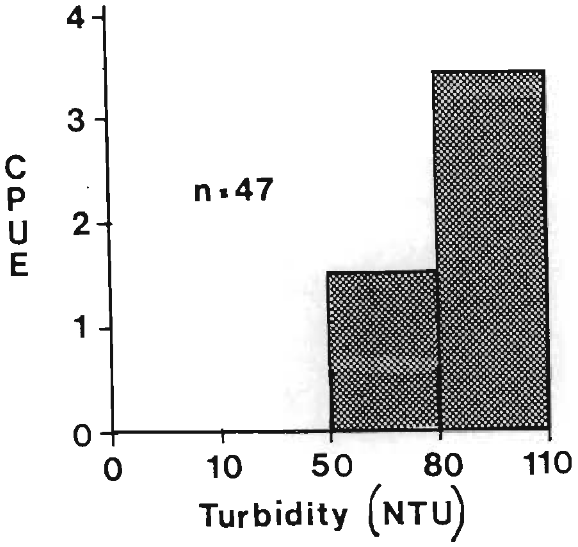

Figure 38: Catch per unit effort (CPUE) of <u>Johnius belengerii</u> in four turbidity ranges (n = number caught)

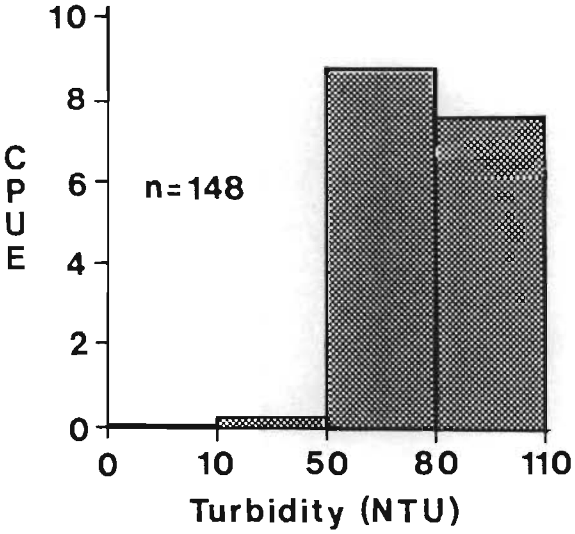

Figure 39: Catch per unit effort (CPUE) of <u>Thryssa vitrirostris</u> in four turbidity ranges (n = number caught).

5.2.3 Species groupings according to turbidity preference.

(a) Principal co-ordinate and minimum spanning tree analysis of turbidity field data.

A principal co-ordinate analysis of the turbidity and CPUE data, was carried out in order to determine whether specific turbidity groupings were indeed present among the species. The results of this analysis are shown on Figure 40. The goodness of fit criterion (T) for the plot of the field data was reasonably good (54,2%). The point locations have been linked using the data from a minimum spanning tree analysis, which shows the relationships between each point by highlighting the ′distortions′ produced by the two-dimensional ordination plot.

The linking of the ordination plot points with the minimum spanning tree data shows clearly the relationship between the species in terms of their turbidity preferences. By comparing the CPUE data for each species (Table 30) in relation to its position on the ordination plot and with those of its nearest neighbours, it was found that the species could be divided into five major groupings as shown in (b) below.

(b) Grouping of species according to turbidity preference.

Although catch data indicated four natural turbidity ranges in terms of fish distribution, the overall results and statistical analysis in (a) above, showed that five distinct groups were present. These were as follows; Clear-water species (common in <10 NTU), ′Clear to partially turbid′ (<50), Intermediate (10 - 80), Turbid (>50) and Indifferent. The five groups are listed below with their approximate turbidity range preferences.

1) Clear water species (common in <10 NTU).

Gerres acinaces (G.a)
Gerres rappi (G.r)
Monodactylus argenteus (M.a)
Rhabdosargus holubi (R.h)

2) 'Clear to partially turbid' species (common in <50 NTU).

Liza dumerili (L.d)
Liza macrolepis (L.m)
Rhabdosargus sarba (R.s)
Valamugil buchanani (V.b)
Gerres filamentosus (G.f)
Caranx sexfasciatus (C.s)

3) Species predominantly in waters of intermediate turbidity (10 - 80 NTU).

Valamugil cunnesius (V.c)
Mugil cephalus (M.c)
Leiognathus equulus (L.e)

4) Species predominantly in turbid waters (>50 NTU).

Elops machnata (E.m)
Solea bleekeri (S.b)
Johnius belengerii (J.b)
Thryssa vitrirostris (T.v)

5) Species indifferent to turbidity (found throughout).

Pomadasys commersonni (P.c)
Acanthopagrus berda (A.b)
Terapon jarbua (T.j)

5.2.4 Species richness and catch per unit effort (CPUE) in clear and turbid waters.

South Lake, St.Lucia, provided a situation where species richness and CPUE could be compared for 'clear' (east) and 'turbid' (west) areas in the same system. Species richness in this case refers to the mean number of species recorded per seine haul in each turbidity group or area. Table 32 shows the CPUE and species richness recorded from large seine netting on the eastern and western shores, while Table 33 shows the results from small seine netting. The recorded species richness and CPUE for four turbidity ranges are shown in Table 34 for both large and small seine.

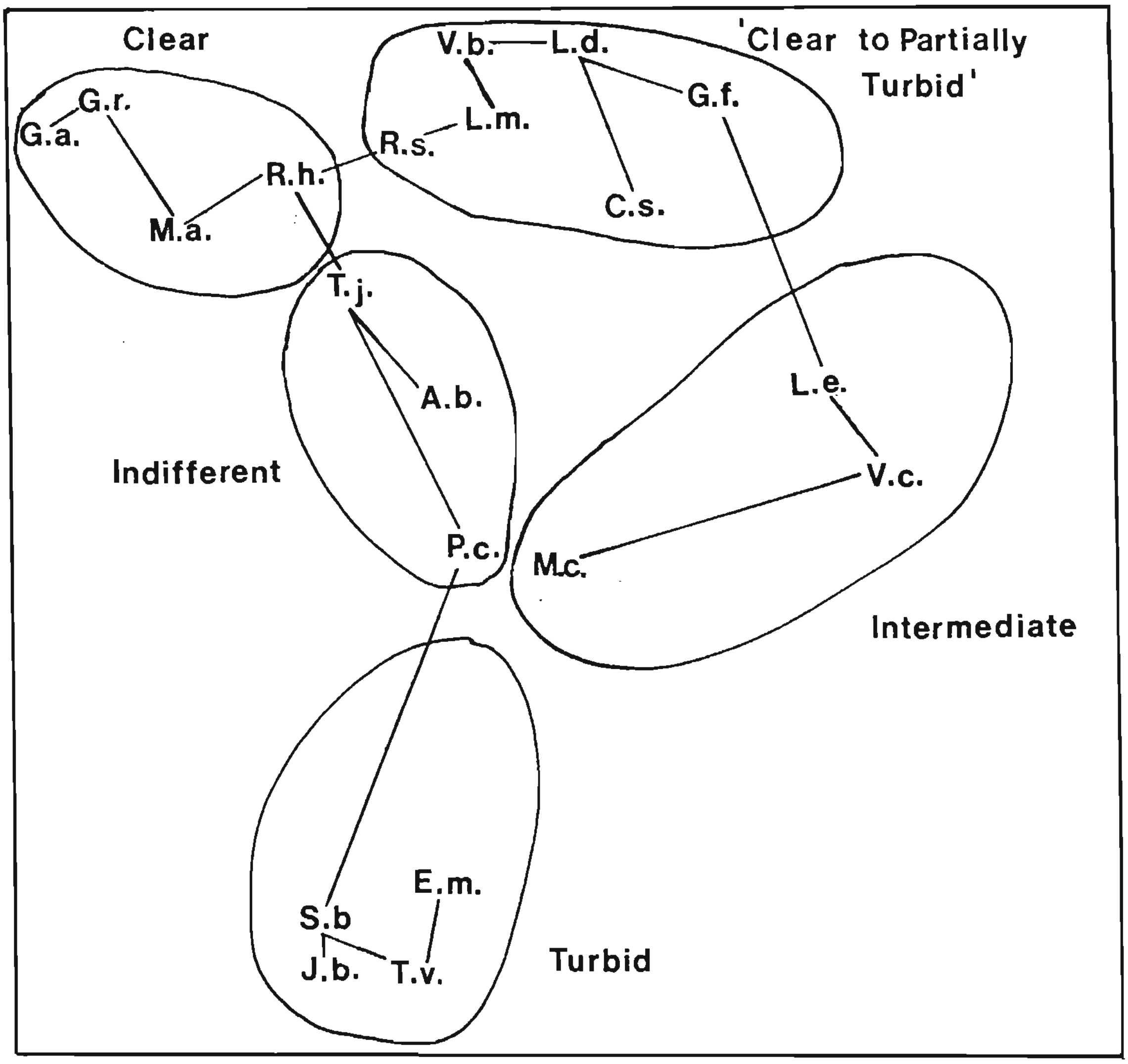

Figure 40: Principal co-ordinate and minimum spanning tree plot of catch data of 20 commonly occurring estuarine species divided into five major turbidity groupings (Letters = abbreviations of species names given in the turbidity groupings on page 109).

Table 32: Species richness and CPUE from large seine netting at five localities (Fig. 7) in South Lake, St.Lucia (CPUE = catch per unit effort; Species = mean number of species caught per seine haul).

Locality	Species	CPUE
<u>West</u> ('turbid')	9,9	96,2
Gillies Point	9,1	69,6
Indicus Indent	10,7	122,9
<u>East</u> ('clear')	7,3	118,6
Nkazana Stream	6,1	92,3
Old Jetty	6,3	71,8
Ukwakwa	9,3	180,0

Table 33: Species richness and CPUE from small seine netting at seven localities in South Lake, St.Lucia (CPUE = catch per unit effort; Species = mean number of species caught per seine haul).

Locality	Species	CPUE
<u>West</u> ('turbid')	7,0	28,2
Gillies Point	6,3	12,8
Charters Jetty	8,6	25,1
Public Jetty	8,5	31,3
Indicus Indent	8,0	44,5
<u>East</u> ('clear')	2,5	10,2
Nkazana Stream	2,8	10,5
Old Jetty	2,5	8,5
Ukwakwa	2,3	11,8

Table 34: Species richness and CPUE in four turbidity ranges at South Lake, St.Lucia from large and small seine data (CPUE = catch per unit effort; Species = mean number of species caught per seine haul).

Turbidity NTU	Large Seine		Small Seine	
	Species	CPUE	Species	CPUE
<10	6,8	138,1	3,7	23,4
10 - 50	10,1	72,7	4,7	28,5
51 - 80	14,5	103,5	7,8	46,0
>80	9,6	78,1	9,0	46,6

5.2.5 Statistical analysis of data.

Chapter 4 identified three factors as being potentially important in determining the distribution of fish in the lake. These were turbidity, temperature and benthos (food available).

(a) Significant correlations.

In order to determine what significant correlations existed between the three physical factors and the 20 fish species, the data were subjected to a range of six correlation tests. This was done so that variations of summer, winter and site could be accounted for. The correlation tests were as follows:-

1] Correlation test on untransformed data
2] Correlation test on ranks of total data sets
3] Correlation test on ranks of summer data
4] Correlation test on ranks of winter data
5] Correlation test on GLM with classes, site and season
6] Correlation test on stepwise discriminant analysis

As the data set comprised numerous zero values for species catches, and the fact that these could affect the significance values of certain correlations, it was decided, on the advice of D.J.Lubinsky (National Research Institute for Mathmatical Sciences - C.S.I.R.), to deviate from the normal procedure of significance acceptance only at the 5% level and to include data significant at 10% or less as well. This would enable a better interpretation of the relationship between the physical factors and the different fish species. Table 35 lists the correlations present between these data sets.

Table 35: Correlations between three physical factors and the occurrence of 20 fish species in South Lake (Numerals 1 to 6 refer to correlation tests used which are listed above, * = p <0,05, # = P <0,10).

Species	Turbidity						Temperature						Benthos					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Gerres acinaces		#									*		#	#		*		
Gerres rappi				#											#			*
Monodactylus argenteus							*	*				*		#	*			
Rhabdosargus holubi										*								
Caranx sexfasciatus							#			#								
Liza dumerili		#		*		*	*	#					*	*		*		
Liza macrolepis							#	#		*								
Rhabdosargus sarba		*		*			*	*			*	*						
Gerres filamentosus																		
Valamugil buchanani										#								
Leiognathus equulus					*					#								
Mugil cephalus								#										
Valamugil cunnesius					*	*	#	#	#				#	*	#			
Acanthopagrus berda							*	*		*				*	*	#		
Pomadasys commersonni																		
Terapon jarbua								*				*						
Elops machnata					*	*	#		*		#							
Solea bleekeri	*	*	*	*		*												
Johnius belengerii	*	*	*	*	*	*							#	*	*			
Thryssa vitrirostris	*	*	*	*	*	*					#		*	*	*	#		
Total species/factor	10						14						8					

(b) Principal Components Analysis.

A Principal Components Analysis of the data on the three major physical factors and twenty fish species showed that only 9 of the 23 Factor Patterns generated, accounting for 76% of the common variance, had Eigenvalues of more than or equal to one. These values represent the variance explained by individual factors, and are given in Table 36 together with the proportion each factor contributed to the score of the common variance. They are the only values which are retained by the Mineigen Criteria as possibly having any important effect.

Table 36: Eigenvalues and variance explained by each of the nine Factors retained by the Mineigen Criteria.

Factor	1	2	3	4	5	6	7	8	9
Eigenvalue	3,69	3,06	2,34	1,97	1,54	1,42	1,27	1,09	1,00
% Variance	16,1	13,3	10,2	8,6	6,7	6,2	5,5	4,8	4,4
Culmulative %	16,1	29,4	39,2	47,8	54,5	60,7	66,2	71,0	75,4

Of the nine Factors only the first two, those with the highest Eigenvalues (Table 36), contained factor loadings (correlations) for the physical factors which were more than +0,40 or less than -0,40. The high values are considered as contributing significantly to the determination of the Factor grouping. Factor loadings reaching + or - 1 have the highest direct or inverse relation with the Factor while those tending to 0 have no relation. The composition of the remaining seven Factor Groups was determined within the species themselves.

Turbidity was the most important physical factor, and the only one showing a significant correlation value, within Factor 1 (Table 37). It showed significant correlations with 9 of the 20 fish species (2 negative & 7 positive). Factor 1 had the highest Eigenvalue and accounted for 16% of the total variance within the correlation matrix (Table 36). Turbidity and seven of the fish species attained their highest correlation values within Factor 1.

Factor 2, which also had a high Eigenvalue (Table 36), accounted for 13% of the total variance. In this Factor however, all three physical factors had high correlation values as did seven fish species, two of the latter having also shown significant values in Factor 1. The correlation values within this Factor indicate that all three physical factors (variables) influenced those fish species within the group which also showed high correlation values.

Table 37: Variables with high correlation values (>+0,40 or <-0,40) associated with the first two Factors of the Principle Components Analysis of major physical and fish data from South Lake (* = highest correlation value for the variable within the whole Factor Pattern)

Variable	Factor 1	Factor 2
PHYSICAL FACTORS		
Turbidity	-0,47 *	0,46
Temperature		0,43 *
Benthos		0,52 *
FISH SPECIES		
Gerres acinaces	0,57 *	
Gerres rappi	0,41	
Monodactylus argenteus	0,60 *	
Rhabdosargus holubi		
Caranx sexfasciatus	0,62 *	
Liza dumerili	0,47	
Liza macrolepis		
Rhabdosargus sarba	0,80 *	
Gerres filamentosus		
Valamugil buchanani		
Leiognathus equulus		0,43
Mugil cephalus		0,54
Valamugil cunnesius		0,60 *
Acanthopagrus berda	0,65 *	
Pomadasys commersonni		
Terapon jarbua		
Elops machnata		0,60 *
Solea bleekeri	-0,46 *	
Johnius belengerii	-0,41 *	0,40
Thryssa vitrirostris		0,60 *

(c) *Canonical Correlations*.

The CPUE of the 20 species were compared with the measurements of the three physical factors by mean of a canonical correlation analysis. This type of analysis can give an overall indication of the importance of each physical factor in determining fish distribution, based on the significance of each of the given canonical correlations.

The results of the canonical correlation analysis of the relationship between physical factors and fish distribution are given in Table 38 based on the 59 data sets collected during 1981. Only the first canonical correlation was significant, with the probability of getting a greater F-statistic than observed if the hypothesis is true being 0,0054. The standardized correlation coefficients for the physical measurements and the correlations between the physical measurements and the canonical variables of the species CPUE are given in Table 39.

Table 38: Results of the canonical correlation analysis comparing three physical factors with the distribution of 20 fish species in South Lake (D of F = Degrees of Freedom, V1 = greater & V2 = lesser D of F).

No.	Canonical Correlation	Variance Ratio	F Statistic	D of F V1	V2	PROB>F
1	0,82634	2,1531	1,7738	60	102	0,0054
2	0,70962	1,0144	1,1642	38	70	0,2839
3	0,49364	0,3222	0,6444	18	36	0,8393

Table 39: Standardized canonical coefficients for physical measurements (= PHYS 1) and correlations between the physical measurements and the canonical variables of the species CPUE (= CATCH 1).

Physical Factor	PHYS 1	CATCH 1
Turbidity	-0,9155	-0,7049
Temperature	0,5252	0,3453
Benthos	0,0021	-0,1699

5.3 Discussion.

5.3.1 Influence of major physical factors.

Details on turbidity preferences have been summarized in Table 30 while those related to temperature are shown in Table 31. Additional information on both these factors are given for each species under the species accounts (5.2.1d). They also contain information of the known diet of the items and the species in South Lake.

Results from large seine netting have shown that the occurrence and distribution of the 20 common fish species can be linked to one or all of the major physical factors. Table 40 summarises the relationship between the physical factors and the fish as determined from the field data and food preferences.

Table 40: The relationship between fish species and physical factors in South Lake as shown by the field data and food preferences (turbidity preference + = turbid, − = clear, ± = intermediate & I = indifferent; temperature preference + = warmer, − = cooler & ± = none; food preference YES = with available food, NO = not related to food & ? = unknown; [ ] = not a benthic feeder.

Species	Turbidity	Temperature	Benthos
Gerres acinaces	−	+	NO
Gerres rappi	−	+	NO
Monodactylus argenteus	−	+	YES
Rhabdosargus holubi	−	−	[YES]
Caranx sexfasciatus	−	+	[YES]
Liza dumerili	−	+	[YES]
Liza macrolepis	−	+	[?]
Rhabdosargus sarba	−	+	YES
Gerres filamentosus	−	±	NO
Valamugil buchanani	−	−	[NO]
Leiognathus equulus	±	+	YES
Mugil cephalus	±	+	[?]
Valamugil cunnesius	+	+	[YES]
Acanthopagrus berda	I	+	YES
Pomadasys commersonni	I	±	NO
Terapon jarbua	I	+	[?]
Elops machnata	+	+	[YES]
Solea bleekeri	+	+	YES
Johnius belengerii	+	+	[YES]
Thryssa vitrirostris	+	+	[NO]

It can be seen from Table 40 that the preliminary analysis of the data showed that 17 of the 20 species were affected by turbidity. Ten avoided turbid waters, five avoided clear waters and two showed preferences for intermediate turbidities. A further three species were apparently indifferent to turbidity. With regard to temperature, 16 of the species were more common during the warmer months, two were more common during the cooler months, while a further two showed no real seasonal trends.

As far as benthos (food) is concerned, eleven of the species were at greatest densities in areas where their food was also at its greatest density, six species showed the opposite trend, while with three species it was not possible to determine their relationship to their food. The latter group consisted entirely of species which were not benthic feeders.

In order to determine to what extent each of the physical factors influences the species distribution, as a group and individually, a number of statistical tests of the data were undertaken. At the outset it was realized that any influence which temperature had would be related to its seasonal fluctuation and therefore it would be affecting temporal rather that spatial distribution of the species in South Lake. As such it could effectively be ruled out as an important factor in terms of distribution in the system. Any species affected by temperature would, when present, have the choice, or be influenced by the range/effects of turbidity and/or food availability. Notwithstanding the above, temperature was included with the other two factors in the statistical tests.

The results of the Canonical Correlation have shown that of the three factors turbidity exerts the greatest overall influence on fish distribution. This has been shown by the high canonical coefficient value, and the fact that turbidity has the highest value, by 50%, of the physical factors in determining the species catch of the first and only significant canonical variable within the data set (Table 39).

The importance of turbidity over the other two factors is also shown by the results of the Principle Components Analysis (Table 37), with its significant correlation within Factor 1 which accounted for the greatest amount of variance within the data set. Correlations within Factor 2 indicated a close relationship between all three physical factors and the fish within the group which had high correlation values.

A number of correlations, found within the Principle Components Analysis, did not show up in the six linear tests for significant relationships between major physical factors combined in Table 41 which gives the full set of correlations between the three factors and the 20 fish species. This Table also shows which of the correlations were in agreement with the results from preliminary analysis of the data.

Table 41: Summary of correlations, from three test, between three physical factors and 20 fish species from data collected in South Lake during 1981 ([-] = negative, [+] = positive & * = agreement with preliminary analysis of field data).

Species	Turbidity	Temperature	Benthos
Gerres acinaces	[-] *	[+] *	[-] *
Gerres rappi	[-] *		[-] *
Monodactylus argenteus	[-] *	[+] *	[+] *
Rhabdosargus holubi		[-] *	
Caranx sexfasciatus	[-] *	[+] *	
Liza dumerili	[-] *	[+] *	[-] *
Liza macrolepis		[+] *	
Rhabdosargus sarba	[-] *	[+] *	
Gerres filamentosus			
Valamugil buchanani		[-] *	
Leiognathus equulus	[+]	[+] *	[-]
Mugil cephalus	[+]	[+] *	[+]
Valamugil cunnesius	[+] *	[+] *	[+]
Acanthopagrus berda	[-]	[+] *	[+] *
Pomadasys commersonni			
Terapon jarbua		[+] *	
Elops machnata	[+] *	[+] *	[+] *
Solea bleekeri	[+] *	[-]	[+] *
Johnius belengerii	[+] *	[+] *	[+] *
Thryssa vitrirostris	[+] *	[+] *	[+]
Total per factor:agreement	14:11	17:16	12:8

Table 41 shows that there is good agreement with the interpretations from the field data and results of the statistical tests. The main discrepancies or lack of correlation come about with species showing intermediate turbidity preference or those that are indifferent to turbidity, while under benthos, those which are not strictly benthic feeder showed least agreement.

However, statistical analysis has shown that, overall, turbidity exerts the greatest influence on fish distribution in South Lake, and this confirms all the initial interpretations drawn from the individual species in the species accounts (5.2.1d). In that section, 13 of the 20 species were more influenced by turbidity, in terms of distribution, than any other factor. A further four species appear to be influenced by turbidity, but insufficient data were available to separate its influences from food availability. The distribution of three species were found not to be affected by either turbidity or food availability.

The use of a Principle co-ordinate analysis provided information indicating that, apart from the four turbidity groupings identified (clear <10 NTU, intermediate 10-80, turbid >50 & indifferent), a fifth distinct group was present. This group consisted of species inhabiting ´clear to partially turbid´ water (<50 NTU). The division of species in South Lake into the five turbidity groupings has been found to provide a good basis for the study of turbidity in other Natal estuaries (see Chapter 8). However, in the international context, the determination of what constitutes turbid water is not standardized and this is discussed in Chapter 9.

5.3.2 Species richness and CPUE.

Although the CPUE results from large seine hauls are similar for the eastern and western sides, the species richness is greater in the ´turbid´ west (Table 32). Data from small seine netting (Table 33) show that both the CPUE and species richness of the ´turbid´ side were more than twice that of the ´clear´.

Similarities in Table 32 and differences in Table 33 result from the fact that on a number of occasions when the ´turbid´ side (west) was sampled conditions were calm and the waters were clear. Table 34 thus gives the best indication of what densities and species richnesses exist in the different turbidities. All data indicate that small seine catches were, to some extent, affected by water clarity and the size of the net, as the fish were able to see it and the netters approaching. This accounts for the fact that more species and greater numbers were caught in the more turbid waters. The large seine data (Table 34) indicate that the intermediate the greatest densities were found in the clear waters (<10 NTU).

While the overall catch data from St.Lucia provided a good indication of species richness and density in the different turbidity ranges, the fact that the clear-water component only occupied a small proportion of the system, and that fish have to move through the predominantly turbid link between the estuary and the lake, to reach clear water, may account for the low species richness. These factors do not appear to affect the number of species in the clear waters (Table 34).

Unfortunately there appears to be no published work on species richness (diversity) or species densities in different turbidities in estuaries, against which the results from this study can be compared. It appears from the work of Blaber and Blaber (1980) that the ratio of clear to turbid waters species was 17 to 15 in Morton Bay, Australia. Although Table 34 provided preliminary details on species richness, it was based on data from all species netted in South Lake during this study. A better indication is obtained by comparing the occurrence of the 20 most common species within the four turbidity ranges. These data show that South Lake, St.Lucia, probably because of the wide range of turbidity present, has greatest species richness in ´clear to partially turbid´ waters (Table 42).

Table 42: Species richness in four turbidity ranges based on field data for 20 species from South Lake (Groups refer to those given in 5.2.2b).

Turbidity Range (NTU)	Group 1	2	3	4	5	Total Species
<10	4	6	-	-	3	13
10 - 50	-	6	3	-	3	12
51 - 80	-	-	3	4	3	10
>80	-	-	-	4	3	7

5.3.3 Comparison with other studies.

In his work on the fauna of kelp beds, Moore (1973) found a good correlation between turbidity and the invertebrate species present. He showed that the fauna could be divided into three major groups according to turbidity preference: clear water, turbid water and turbidity indifferent species.

The present study has shown that the fish fauna of South Lake may be divided into similar groupings. However, due to the turbidity range occupied by some species, as well as the wide range of turbidities present, two additional categories were included. These were for species occupying ′clear to partially turbid′ waters (<50 NTU) and those in an intermediate range of turbidities (10 to 80 NTU).

From the overall results of field data it was possible to divide turbidities into ranges corresponding with the groups mentioned above. These data showed that 80 NTU was the cut-off point above which only species with a preference for very high turbidities were found. A second such point was evident at 50 NTU, with very few ′clear to partially turbid′ water species occurring above this turbidity. The clear-water component favours waters with turbidities <10 NTU. The intermediate species were predominant in the 10 to 80 range whilst turbidity indifferent species were found throughout the ranges recorded.

Work on the distribution of fish in relation to turbidity has been limited. Much has been done on freshwater species by Swenson <u>et al</u>. (1977) and Swenson (1978), who investigated the distribution of a number of species in relation to turbidity in western Lake Superior, U.S.A. In the latter study it was found that two of the major species showed opposite turbidity preferences and as a result there was minimal overlap in their distribution.

Studies on turbidity and distribution of estuarine fish are limited. A number of broader studies on specific groups have included distribution and turbidity, these include; Sphyraenidae (barracudas) Blaber (1982), Carangidae (kingfish) Blaber and Cyrus (1983), Gerreidae (pursemouths)

Mathews and Hill (1979).

The work of Blaber and Blaber (1980) is one of the few estuarine studies in which turbidity and species distribution formed an important part. This work, carried out in Moreton Bay and its associated estuaries on the east coast of Australia, provides useful comparison for the results of this study, due to similar species and genera being present at both study sites. Blaber and Blaber (1980) found that the species present could be divided into four main groups according to their distribution and that the distribution patterns found corresponded closely with the turbidities present in the system. Their results, as well as those from this study of similar species/genera, with the inclusion of <u>Caranx ignobilis</u> which Blaber and Cyrus (1983) found to be affected by turbidity in Natal estuaries, are given on Table 43. The turbidities recorded in the Moreton Bay study ranged from <1,0 to 35 NTU, thus covering a much smaller range than that recorded during this study. For this reason the actual South Lake turbidity range has also been given on Table 43 along with the turbidity classification. Notwithstanding the difference in upper turbidity levels between Moreton Bay and South Lake, it is obvious that the turbidity preferences of the species listed in Table 43 were very similar for both localities.

Blaber and Blaber (1980) also found that fish movement occurred with the drop in turbidity which occurred during winter. Juveniles of turbid water species which were not approaching maturity, moved to the upper reaches of the estuaries where turbidities remained relatively high during winter. In Lake St.Lucia, there was also a distinct drop in mean monthly turbidity during winter (Figs. 13 & 14) when mean turbidities of the turbid areas dropped to between 20 and 40 NTU. However, a complete range of turbidity from <10 to >80 NTU was nevertheless present during each month (Table 11). That fish movement related to turbidity occurred within St.Lucia on an almost daily basis has been shown by the fact that large numbers of clear water species have on occasions been caught on the 'turbid' western shores when the weather was calm and turbidities on the west were low (<20 NTU). See

Table 43: Comparison between the turbidity preferences of six species/genera in Moreton Bay, Australia and South Lake - St.Lucia, South Africa (Groupings - C to P = Clear to Partially Turbid, Indiff.= Indifferent, Int.= Intermediate, Groupings are listed in 5.2.2b).

Species	Turbidity preference		
	Moreton Bay	South Lake	
		NTU	
Thryssa hamiltoni / *T.vitrirostris*	Turbid	>80	Turbid
Caranx sexfasciatus	Turbid	<50	C to P
Caranx ignobilis	Turbid	<80	Int.
Mugil cephalus	Indiff.	10-80	Int.
Gerres oyena/G.rappi	Clear	<10	Clear
Rhabdosargus sarba	Clear	<10	C to P

Mathews and Hill (1979) found that juvenile *Notropis lutrensis* occupied a different turbidity range from the adults. They postulated that this led to a reduction in competition between the different age groups. Blaber and Blaber (1980) found a similar situation in Moreton Bay, two of their turbidity groups had most species with adults occupying areas of low turbidity while juveniles were predominantly in high turbidities. Both adults and juveniles of another group were found in turbid waters and those of a fourth occurred only in clear waters.

Although this study has only been concerned with the turbidity distribution of juvenile fish in Natal estuaries, it is known that there are some species which show a similar pattern to that found by Blaber and Blaber (1980). These include two piscivorous predators, *Caranx sexfasciatus* and *C.ignobilis*, whose juveniles are found in waters of >10 NTU and >50 NTU respectively, whilst larger individuals are present only in the clear waters (Blaber & Cyrus, 1983). These species were also recorded by Blaber and Blaber (1980), who obtained similar results. Blaber (1980) has commented on the low numbers of piscivorous predators present in some turbid estuaries and postulated that the fact that juveniles inhabit turbid estuarine waters may reduce intraspecific predation.

5.3.5 Conclusion.

The main points arising from the field work of this study are:-

1]

Although the three major physical factors each exert some influence on the occurrence and distribution of juveniles of the common marine species in South Lake, turbidity is, overall, the single most important factor. This has been verified by statistical correlations generated from the data collected.

2]

The juveniles of different species show a preference for a particular range of turbidity, and this has lead to the formation of five groups with distinct species compositions.

3]

Highest species richness and density occur in waters with turbidities <50 NTU ('clear to partially turbid').

4]

The results obtained show good agreement with the limited work on the influence of turbidity, carried out in estuaries in other parts of the world.

6. LABORATORY STUDIES.

6.1 Introduction.

Laboratory studies were undertaken in order to corroborate the results of the collected field data. This was necessary as all other variables except the one under consideration, could be eliminated, and thus the results obtained were directly related to the factor being tested. These results could then be compared with those from the field in order to determine whether they strengthened the argument that turbidity affects the distribution of juvenile fish in the lake.

The laboratory studies undertaken consisted of two sections, the first and most important was the testing of turbidity preferences of juveniles of selected marine species which are common in South Lake. Choice chamber tanks within which turbidity gradients were established were used (see Methods 3.4.1). The second part of the laboratory studies consisted of the testing for salinity preference using the same apparatus but with a salinity gradient. These tests were undertaken in order to obtain a measure of the reaction to and preference for salinity by the different species. The results, although not important in the context of St.Lucia where salinity variations were minimal (see 4.4.2c), were potentially of importance when the effects of physical factors on fish distribution in other Natal estuaries were considered. Should salinity preferences exist, they may be particularly important due to the great ranges of salinity which occur within these systems (see Chapter 8).

6.2 Results.

6.2.1 Turbidity test runs.

(a) Species tested.

Ten species were tested for turbidity preferences in species, number of test runs, size range of species tested and total number of hours that members of each species were exposed to a full turbidity gradient (ranging from <10 to >80 NTU). Table 45 shows the percentage time spent in the different turbidity ranges by the individuals of each species tested.

Table 44: Details of ten species tested for turbidity preference (nr = number of individual test runs; nru = number of test runs from which data was used; hrs = hours tested; Size Range as Standard Length in mm).

Species	nr	nru	hrs	Size Range
Monodactylus argenteus	5	5	18,5	62 - 69
Rhabdosargus holubi	10	4	10,5	60 - 71
Liza dumerili	11	10	39,9	95 - 138
Liza macrolepis	10	9	45,0	75 - 154
Rhabdosargus sarba	10	9	47,3	82 - 102
Gerres filamentosus	18	15	98,7	74 - 105
Valamugil buchanani	10	9	48,5	83 - 137
Acanthopagrus berda	10	9	27,3	69 - 90
Pomadasys commersonni	13	13	67,6	78 - 140
Terapon jarbua	10	10	32,7	72 - 105

Table 45: Percentage time spent by individuals of ten species in four turbidity ranges.

Species / Turbidity	<10	10-50	51-80	>80
Monodactylus argenteus	11	41	47	1
Rhabdosargus holubi	56	20	15	9
Liza dumerili	75	15	6	5
Liza macrolepis	30	41	12	17
Rhabdosargus sarba	48	17	25	10
Gerres filamentosus	22	72	6	1
Valamugil buchanani	46	39	11	5
Acanthopagrus berda	21	39	31	9
Pomadasys commersonni	19	21	23	37
Terapon jarbua	39	8	15	37

The turbidity groupings (ranges) used for the experimental work were derived from the results of field sampling carried out in a wide range of turbidities. It was noticed that the catch per unit effort for a number of species showed a distinct decline above or below certain turbidities. When the catch data from all species were put together the following range groupings were obtained; <10, 10 to 50, 50 to 80 and >80 NTU. Results from the laboratory experiments are expressed in terms of the percentage time each species spent in the four turbidity ranges.

(b) Reaction of species tested.

The reaction of the individuals of each species tested are given below, while Figure 41 shows the recorded reaction of a fish to a turbidity gradient and changing turbidities in the choice chamber tank. Figures showing laboratory results from the ten species have been placed in Chapter 7 where field and laboratory results are compared.

All test individuals were kept in holding tanks for at least one week prior to being used for turbidity tests. Most were feeding within 48 hours. Unless otherwise stated, all individuals tested had familiarized themselves with all the compartments of the test tank during the acclimation period before each test run was started.

Monodactylus argenteus (Figure 42 & Table 45).

Only five turbidity tests were carried out with this species, during which it showed a preference for the intermediate turbidity ranges (10 to 80 NTU)(Fig. 42), with a marked avoidance of waters with turbidities >80 NTU. Only 10% of the time was spent in the clear water (<10 NTU).

Rhabdosargus holubi (Figure 44 & Table 45).

As with Gerres filamentosus below, some individuals of this species did not move out of the compartment with increasing turbidity. This occurred on five occasions. It was noticed that if movement did not take place before the turbidity level reached 50 NTU, the fish appeared to become less active, moved towards the bottom of the compartment and did not move until the water cleared at the end of the run. In one or two cases when turbidities had reached high levels, the fish were noted as apparently trying to find the connecting aperture to the next compartment, but were unable to locate it. This, presumably, was because the water was too turbid for them to visually locate the aperture.

showed avoidance of highly turbid waters, with most individuals moving to the clear waters as turbidities started to rise. They remained there for the rest of the run (Fig 44).

Liza dumerili (Figure 46 & Table 45).

This species showed avoidance of turbid waters, even at relatively low levels (25 - 35 NTU). Reaction to rising turbidity in a compartment was rapid and the high percentage time recorded in the clear water compartment (Fig. 46) is due to the fact that most individuals moved to the low turbidity water before the gradient reached the recording level (turbid compartment >80 NTU). When turbidities were cleared half way through runs and then re-established or reversed, rapid movement to the new clear compartment was recorded as soon as the gradient started to become established. In nearly all instances movement away from turbid water occurred before levels reached 50 NTU.

The rapid reaction of this species to rising turbidities is shown on Figure 41, which is a copy of the chart recorder data showing an individual´s movements during part of a test run. Having moved regularly between all four compartments before turbidity was introduced, the fish remained in the compartment which was becoming turbid until its level reached 30 NTU. At this time it investigated the other compartments returning to the most turbid (now 38 NTU) for a short period before moving directly across to the clearest compartment where it remained. Once there, the turbid water input was stopped, the tanks began to clear and turbid water reintroduced at 12H00, this time forming a reverse gradient.

The fish stayed in the ´new´ turbid compartment until the level reached 31 NTU, it then moved, staying in each of the two middle compartments until their turbidity levels reached 23 and 32 NTU respectively, before finally moving into the clear compartment (Fig. 41). After it had been in the clear without moving for 30 minutes the turbid water input was stopped and the system began to clear. The first move into the adjacent compartment took place when its level first move back into the turbid compartment was at level of 25 NTU and the second at 15 NTU.

Liza macrolepis (Figure 48 & Table 45).

Although spending short periods in the two most turbid compartments, L.macrolepis showed a preference for waters with turbidities <50 NTU (Fig. 48).

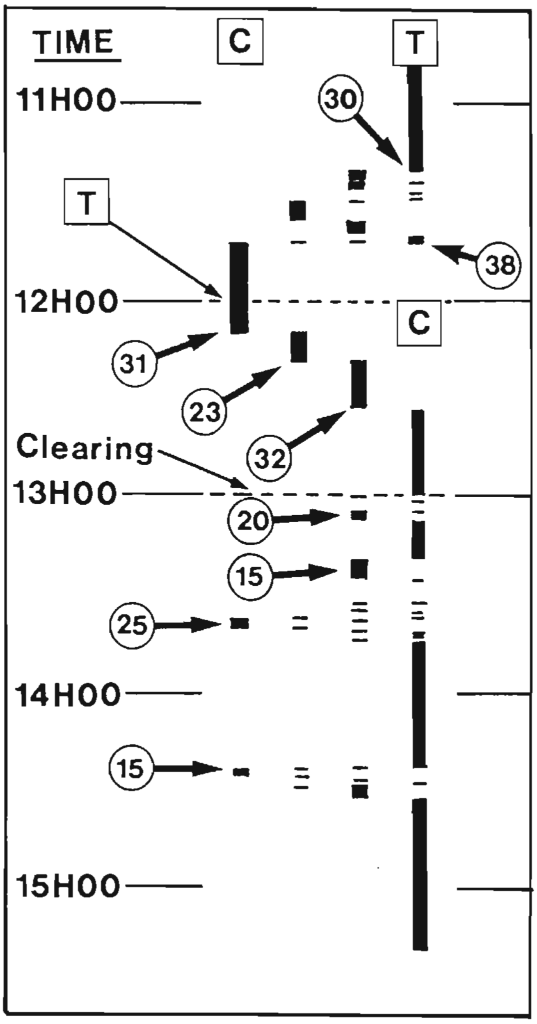

Figure 41: Reaction of Liza dumerili to turbidity gradients and changing turbidity in a choice chamber tank ((15) = turbidity in Nephelometric Turbidity Units at time of leaving or entering compartment, ☐ = orientation of turbidity gradient, C = clear, T = turbid).

Rhabdosargus sarba (Figure 50 & Table 45).

Under turbidity test conditions this species showed a preference for clear water (<10 NTU). However, it did enter the other turbidities for short periods during the test runs (Fig. 50).

Gerres filamentosus (Figure 52 & Table 45).

As can be seen from Table 44 some of the tests with this species were not used for the assessment of turbidity preference. Although individuals visited all compartments during their acclimation period it was found that those which did not react to increasing turbidity (by moving) before turbidities reached 50 NTU, stayed in the compartment in which they were until the water was cleared at the end of the run. In one case the fish appeared unable to located the aperture connecting the next compartment (with the turbidity >80 NTU), and in most instances the fish would simply remain at the bottom of the tank.

From the 15 tests conducted during which movement was recorded, covering 99 hours under turbidity gradients, G.filamentosus showed a definite preference for water <50 NTU (Fig. 52). It is interesting that some 75% of the time spent in the 10 to 50 NTU compartment was in turbidities between 10 and 30 NTU. This means that over 65% of all test time was spent in water under 30 NTU.

Valamugil buchanani (Figure 54 & Table 45).

During all turbidity tests using this species an avoidance of turbid waters was apparent. In many instances movement from rising turbidity had taken place by the time the water was at 30 NTU, with a few individuals staying until the turbidities reached 60 NTU. Valamugil buchanani was found to spend more or less equal time in the <10 and the 10 to 50 NTU compartments (Fig. 54).

Acanthopagrus berda (Figure 56 & Table 45).

No uniform reaction to turbidity was noted amongst the individuals of this species tested for turbidity preference, other than that least time was spent in the most turbid compartment while others stayed in the intermediate turbidities (Fig. 56). It appears that this species is indifferent to turbidity except at high levels.

Pomadasys commersonni (Figure 58 & Table 45).

During the turbidity tests some individuals showed a positive movement toward turbid waters while others moved away from them. This species was found to be very active in the test tanks, with continual movement taking place during runs. During 9 of the 13 runs a preference was shown for turbid waters. All laboratory data combined (Fig. 58), showed a slight preference for turbid waters, but these results would seem to indicate that P.commersonni is indifferent to turbidity.

Terapon jarbua (Figure 60 & Table 45).

As with P.commersonni some individuals showed positive movement towards clear and others toward turbid waters, resulting in the composite picture shown in Figure 60 when all test data were put together. This species was also found to be very active whilst in the test tanks, with much movement taking place and with all compartments being visited for short periods during each run.

It is possible that Figure 60 may reflect an overall movement pattern between the opposite ends of the experimental tank, rather than an avoidance of waters with intermediate turbidities.

6.2.2 Salinity tests.

Tests for salinity preference were carried out on nine of the species caught most regularly during this study. Table 46 lists the species, number of test runs, size range tested and the percentage time spent in each salinity range.

Of the species tested seven showed an apparent preference for waters of <30°/oo. Data on percentage time spent by all individuals of each species in the four salinity ranges showed that within this group L.dumerili, R.sarba and favoured <23^{o}/oo, L.macrolepis and V.buchanani favoured <30^{o}/oo and R.holubi seemed to prefer intermediate salinities (15-22^{o}/oo). The results for A.berda indicated no apparent preference while G.filamentosus was the only species showing an apprent preference for the most saline waters (>30^{o}/oo).

Table 46: Species tested for salinity preference and percentage time spent in each salinity range (nr = number of test runs, S.L.= Standard Length range in mm, h = number of hours under test conditions, ^{o}/oo = parts per thousand).

Species	nr	S.L.	h	Salinity ^{o}/oo <15	15-22	23-30	>30
Liza macrolepis	7	119-165	30	34	30	25	11
Valamugil buchanani	9	96-108	38	30	39	29	2
Rhabdosargus holubi	6	44- 63	27	17	58	9	16
Terapon jarbua	12	67-128	53	44	36	11	9
Liza dumerili	8	85-122	34	43	21	17	19
Rhabdosargus sarba	6	43-123	24	47	19	10	24
Pomadasys commersonni	6	78-140	24	56	8	10	26
Acanthopagrus berda	6	61- 81	25	36	16	10	38
Gerres filamentosus	4	76-106	16	0	0	7	93

6.2.3 Statistical analysis of data.

(a) Turbidity.

Analysis of Variance - L.S.D..

This test given by Lee and Lee (1982) is based on the Least Significant Difference (L.S.D.) and was used for the initial analysis of the turbidity preference results obtained from the individuals of each species tested. From this the significance of replicate results for each species could be determined. The laboratory results, based on the percentage time each individual spent in the four compartments of the test tank, which had turbidity ranges of <10, 10-50, 51-80 and >80 NTU, were compared and the results are given on Table 47.

Two species V.buchanani and L.macrolepis, which from field data were determined as inhabiting 'clear to partially turbid' waters, were re-analysed with laboratory results divided into three categories (<50, 51-80 & >80 NTU). This was done because it was felt that, having a preference for turbidities available in two of the four compartments, would be reflected as random movement between the two favoured compartments, and this would bias the overall pattern. The results of these analyses are also included in Table 47.

Table 47: The significance of replicate results, from individuals of ten species tested for turbidity preference, as determined by an Analysis of Variance test using the Least Significant Difference (nr = number of test runs, V1 & V2 = degrees of freedom, F = calculate F-statistic, # = tested with three categories).

Species	nr	V1	V2	F	Probability
Monodactylus argenteus	5	3	16	5,296	0,01
Rhabdosargus holubi	4	3	32	6,246	0,001
Liza dumerili	10	3	36	15,884	<0.001
Liza macrolepis	9	3	32	5.523	<0,01
Liza macrolepis #	9	2	32	28,710	<0.001
Rhabdosargus sarba	9	3	32	6,246	0,001
Gerres filamentosus	15	3	56	19,912	<0,001
Valamugil buchanani	9	3	32	5,869	<0,01
Valamugil buchanani #	9	2	32	126.110	<0,001
Acanthopagrus berda	9	3	32	3,597	<0,05
Pomadasys commersonni	13	3	48	3,728	<0,05
Terapon jarbua	10	3	32	2,863	-

Analysis of Variance - S.S.R..

Elliot (1977) has recommended that analysis of variance tests should be carried out using the Shortest Significant Range (S.S.R.) test so that the within group significances can be determined. Added to this, it was found that the data base had the mean square for within sample variance greater than the mean, which meant that a log transformation of the data had be carried out. For data with some zeros, Elliot (1977) recomends that log (x + 1) should be used for the transformation. This was done before the data were retested for significance. The results are given on Table 48 which shows the significant correlations existing between each species for the four turbidity groups.

The correlations for *M.argenteus* (Ma) showed that significant differences were present between the intermediate turbidities (10-80 NTU) and the high and low turbidities (<10

& >80 NTU), indicating an Intermediate turbidity preference. In R.sarba (Rs), V.buchanani (Vb), L.macrolepis (Lm) and G.filamentosus (Gf), the within group correlations showed that the choice of ´clear to partially turbid´ water (<50 NTU) was significant. The laboratory results showing L.dumerili (Ld) to favour clear waters (<10 NTU) were also significant, while no significant differences in the time spent in each of the four turbidity ranges by the individuals tested were found for P.commersonni (Pc), A.berda (Ab), T.jarbua (Tj) and R.holubi (Rh).

Table 48: The significance of replicate results between within group turbidity preferences as determined from an Analysis of Variance test using the Shortest Significant Range (all significances only calculated to p<0,05 = *, abbreviations given in text above, # = species also tested in three groups and showing p<0,05 between all three).

Turbidity Ranges <10 1	10-50 2	51-80 3	>80 4	Ma	Rs	Rh	Ld	# Lm	# Vb	Gf	Pc	Ab	Tj
X	X						*			*			
X	----	X			*		*						
X	----	----	X	*	*		*	*	*	*			
	X	X			*					*			
	X	----	X	*	*				*	*			
		X	X	*						*			

Ranking Test.

Kendalls Ranking Concordance Test was used to provide non-parametric confirmation of the results from the Analysis of Variance tests; the results are given in Table 49.

Table 49: The significance of replicate results from individuals of ten species, choosing between four turbidity ranges, as determined by Kendalls Ranking Concordance Test. (nr = number of test runs, V1 & V2 = degrees of freedom, F = calculated F-statistic).

Species	nr	V1	V2	F	Probability
Monodactylus argenteus	5	3	10	6,00	<0,05
Rhabdosargus holubi	4	3	8	2,88	-
Liza dumerili	10	3	25	9,00	<0,01
Liza macrolepis	9	3	22	4,70	<0,01
Rhabdosargus sarba	9	3	22	14,80	<0,01
Gerres filamentosus	15	3	40	6,90	<0,001
Valamugil buchanani	9	3	22	4,30	<0,05
Acanthopagrus berda	9	3	22	1,30	-
Pomadasys commersonni	13	3	34	0,50	-
Terapon jarbua	10	3	22	0,33	-

(b) Salinity.

The data from salinity choice experiments was first tested for significance, using the percentage time all individuals spent in each chamber, on the L.S.D. Analysis of Variance programme. The results from this are given in Table 50, while Table 51 gives the results when the data was tested on the S.S.R. Analysis of Variance programme using Log (x + 1) transformations. The latter was done as the variance to mean ratio was much greater than 1 and the data set contained a number of zeros.

Table 50: The significance of replicate results, from individuals tested for salinity preference, as determined by an Analysis of Variance test using the Least Significant Difference (nr = number of test runs, V1 & V2 = degrees of freedom, F = calculate F statistic).

Species	nr	V1	V2	F	Probability
Liza macrolepis	7	3	24	2,385	-
Valamugil buchanani	9	3	32	3,433	<0,05
Rhabdosargus holubi	6	3	20	4,849	<0,01
Terapon jarbua	12	3	44	8,214	<0,001
Liza dumerili	8	3	28	3,384	<0,05
Rhabdosargus sarba	6	3	20	2,528	-
Pomadasys commersonni	6	3	20	3,403	<0,05
Acanthopagrus berda	6	3	20	2,451	-
Gerres filamentosus	4	3	12	217,333	<0,001

Table 51: The significance of replicate results between within group salinity preferences as determined from an Analysis of Variance test using the Shortest Significant Range (all significances only calculated to p<0,05 = *, abbreviations given in text below).

Salinity Ranges				Species								
<15	15-22	23-30	>30									
1	2	3	4	Lm	Vb	Rh	Tj	Ld	Rs	Pc	Ab	Gf
X	X					*						
X	-	X					*					*
X	-	-	X		*		*					*
	X	X				*	*					*
	X	-	X		*	*	*					*
		X	X		*							*

By comparing Tables 46 and 51 it can be seen that one species, G.filamentosus (Gf) showed a significant preference for salinities close to that of seawater (>30°/oo) while L.macrolepis (Lm), L.dumerili (Ld), R.sarba (Rs), P.commersonni (Pc) and A.berda (Ab) were indifferent to salinity. The remaining three species showed preferences, at significant levels, for lower salinities. V.buchanani (Vb) favoured any water <30°/oo, T.jarbua (Tj) favoured water <23°/oo while R.holubi (Rh) preferred water between 15 and 22°/oo.

6.3 Discussion.

6.3.1 Turbidity.

Initial interpretations of the laboratory test results indicated that of the ten species tested three were clearwater species (<10 NTU), three preferred 'clear to partially turbid' water (<50 NTU), one preferred intermediate turbidities (10 - 80 NTU) while the remaining three were indifferent to turbidity. As can be seen in Table 52, which summarizes the initial interpretations, the results from the statistical tests and the final interpretation of turbidity preferences, the initial indications have, to a large extent, been verified by the statistical tests as being significant.

Table 52: Summary of results from laboratory and statistical tests on ten species of fish from South Lake, tested for turbidity preference (Interp. = Interpretation, ANALVAR = Analysis of Variance, * = $p<0.05$, ** = $p<0{,}01$, *** = $p<0{,}001$, S.S.R. only tested to $p<0{,}05$, INTER. = Intermediate, INDIFF. = Indifferent & C to P = Clear to Partially turbid).

Species	Initial Interp.	ANALVAR		Ranking	Final Interp.
		L.S.D.	S.S.R.		
M.argenteus	INTER.	**	*	*	INTER.
R.holubi	CLEAR	*	-	-	INDIFF.
L.dumerili	CLEAR	***	*	**	CLEAR
L.macrolepis	C to P	**	*	**	C to P
R.sarba	CLEAR	**	*	**	C to P
G.filamentosus	C to P	***	*	***	C to P
V.buchanani	C to P	**	*	**	C to P
A.berda	INDIF.	*	-	-	INDIF.
P.commersonni	INDIF.	*	-	-	INDIF.
T.jarbua	INDIF.	-	-	-	INDIF.

The only differences occurred with *R.sarba* and *R.holubi*. The former appeared to be strictly a clearwater species which has been shown to occur in significant numbers in partially turbid waters. The latter species showed no correlations whatsoever on the within tank comparisons of the individual test data, even though the L.S.D. analysis of variance was found to be significant. This may be due largely to the fact that the number of individuals, on which test runs were carried out, was only four and the sample size was therefore too small. In two species, *L.dumerili* and *V.buchanani*, it was found that, due to their showing a preference for turbidities falling within two compartments, the results were more significant when the data were pooled into three turbidity groups.

It should be mentioned at this point that no laboratory details are presented for species showing a preference for turbid waters for the following reasons: of the four species whose field data (Table 30) showed that they preferred turbid waters, two, *E.machnata* and *I.vitrirostris* could not be kept alive in holding tanks. Although the other two, *J.belengerii* and *S.bleekeri*, could be maintained in the holding tanks, they could not be tested for turbidity preference. The former, a slow moving species, was tested on four occasions but never moved out of the compartment into which it was first placed during the acclimation period. The latter, a sole, was also tested on four occasions, but due to its body being dorsoventrally flattened, it never once tripped the infra red beams when it moved between compartments, so no laboratory data on its turbidity preferences could be obtained.

The laboratory results have shown that with all other physical variables eliminated, the distribution of juveniles of a number of marine species common in estuaries are influenced by water turbidity. Furthermore, turbidity groups which appeared to be important in the field data have also been shown by laboratory investigations to be important. It is therefore considered that the cut-off turbidities of 10, 50 and 80 NTU are significant in terms of fish distribution in South Lake. In Chapter 7 the field and laboratory results are compared and the significant correlations between them discussed.

Very few workers have attempted to establish the turbidity preferences of fish under laboratory conditions and the few studies done have been on freshwater species. The pioneering work in this field was carried out by Swenson (1978) who showed that behavioural changes caused by turbidity influenced fish abundance in Western Lake Superior, U.S.A. He found by laboratory tests that walleye (*Stizostedion vitreum*) showed a distinct preference for turbid waters while lake trout (*Salvelinus namaycush*) avoided turbid waters. These laboratory data were found to correlate well with results from field work.

In a later laboratory study Gradall and Swenson (1982) showed that brook trout (*Salvelinus fontinalis*) were indifferent to turbidity while creek chubs (*Semotilus atromaculatus*) preferred turbid waters (max. tested 56,6 NTU). These results, although from freshwater species, have this study.

Much laboratory work related to turbidity, other than turbidity preferences has been carried out, with most workers having concentrated on establishing lethal limits, sublethal effects and species tolerances of turbidity. Wallen (1951), when investigating the direct effects of turbidity on 15 species of freshwater fish, found that the mean lethal concentration for all species combined was some 98000ppm (roughly 93330 NTU). He noted that very few natural turbidities ever exceeded the lowest lethal turbidity of 16500 ppm (± 15710 NTU) which he recorded. Wallen (1951) gave the highest recorded natural turbidity as 38000 ppm (± 36190 NTU). His work showed that only one of the 15 species he tested had a lethal limit below the highest recorded natural turbidity. As might be expected he recorded that all fish killed by lethal concentrations of suspended sediments died as a result of a lack of oxygen due to sediment particles clogging the gills and restricting oxygen transfer.

Exposure to sublethal concentrations of natural sediments (72 hour; 14,000 mg/l) was found to cause an increase in haemoglobin concentration and red blood cell count in four species of estuarine fish (O'Connor et al., 1977), these increases are similar to the changes in haematology recorded for fish deprived of sufficient oxygen.

O'Connor et al. (1976) determined that turbidity from natural sediments at concentrations of 19,800, 88,000 and 128,200 mg/l were required to cause 50% mortality in three estuarine fish species, white perch (Morone americana), spot (Leiostomus xanthurus) and striped killifish (Fundulus majalis). These figures are approximately 18,860, 83,809 and 122,666 NTU, which are far in excess of any natural turbidities recorded in Natal estuaries, where the highest was 1,472 NTU (this study) with approximately 10,195 NTU having been recorded in the Mfolozi River in March 1975 (Lund, 1976).

The most important fact to have emerged from all studies on the direct effects of turbidity on fish is that the concentrations required to cause death are far above the highest naturally occurring turbidity concentrations. Results

South Lake never reach anywhere near those which are lethal, the levels present do exert some effect on fish distribution.

6.3.2 Salinity.

Statistical tests on the salinity preference data for nine species has shown that the initial interpretations made from the test run results were not strictly correct. This can be seen in Table 53 which summarizes the results. Five species showed no significant differences in their choice of salinity, and of the remaining four species, one specifically selected high salinities (>30°/oo) while the other three selected salinities of <30°/oo.

Table 53: Summary of results from laboratory and statistical tests on nine species of fish, from South Lake, tested for salinity preference (Interp. = Interpretation, ANALVAR = Analysis of Variance, * = p<0.05, ** = p<0,01, *** = p<0,001, S.S.R. only tested to p<0,05, INDIFF. = Indifferent).

Species	Initial Interp.	ANALVAR L.S.D.	ANALVAR S.S.R.	Final Interp.
L.macrolepis	<30°/oo	-	-	INDIFF.
V.buchanani	<30°/oo	*	*	<30°/oo
R.holubi	15-22°/oo	**	*	15 - 22°/oo
T.jarbua	<23°/oo	***	*	<23°/oo
L.dumerili	<15°/oo	*	-	INDIFF.
R.sarba	<15°/oo	-	-	INDIFF.
P.commersonni	<15°/oo	*	-	INDIFF.
A.berda	INDIFF.	-	-	INDIFF.
G.filamentosus	>30°/oo	***	*	>30°/oo

These results indicate that the majority of marine species common in estuaries are not affected by salinity, or will move into water less saline than seawater if they have the choice. This is perhaps to be expected of species which spend the entire juvenile phase of their life cycle, and in some cases time as adults, in estuaries. It is well known that most estuarine species can tolerate a wide range of salinities (see Table 25 and Whitfield *et al*., 1981).

The only species which did not show a preference for less saline waters, or perhaps an indifference to salinity, was *G.filamentosus*. Notwithstanding the fact that it has been recorded in a range of 1 to 44,5°/oo, it showed a significant preference for the most saline waters available, these being around that of seawater (35°/oo). This preference may be related to intraspecific competition within the genus *Gerres*. Cyrus and Blaber (1982) recorded *G.filamentosus* as the dominant *Gerres* species in salinities of 30 to 35°/oo in Natal estuaries, and suggested that it may be outcompeted in lower salinity areas by *G.acinaces* and *G.rappi* which are dominant in low salinities.

These laboratory studies on the salinity preferences of the juveniles of marine species common in estuaries has shown that in general most species are unaffected by the normal salinity ranges occurring in estuaries (<35°/oo) and in some instances will in fact select for lower salinities. That some species do not follow this pattern has also been shown, and reasons for this have been put forward. However, providing salinity ranges occupied by the various species are known and literature on their occurrence in estuaries has been consulted, there should be little problem in determining whether the distribution of a particular species within an estuary will be affected by salinity.

6.3.3 Conclusion.

Laboratory studies using choice chamber tanks in which a gradient could be set up, have provided statistically significant results on turbidity and salinity preferences of juveniles of marine species common in estuaries. These tests allowed the elimination of all physical variables except the one whose effects on the fish were being tested.

Results from the turbidity gradient tests showed that the species could be divided into specific groups according

(<10 NTU), ´clear to partially turbid´ (<50 NTU), or intermediate (10 - 80 NTU) turbidities, with some species being indifferent to turbidity.

A fifth group, showing a preference for turbid waters (>50 NTU), was shown by field data to exist, but none of the species within this group could be tested in the laboratory to determine their preferences.

As far as salinity preferences are concerned, subjecting the species to a gradient in the experimental tank has shown that the majority prefer waters less saline than seawater or are indifferent to salinity. This is to be expected of species occupying estuaries, where salinities may change drastically even on a daily basis.

7. COMPARISON OF FISH PREFERENCES FOR TURBIDITY IN THE FIELD AND THE LABORATORY.

7.1 Introduction.

Having established the turbidity preferences of the juvenile marine fish common in estuaries from field studies (Chapter 5) as well as obtaining statistically significant results on their turbidity preferences from laboratory studies (Chapter 6), this Chapter considers the similarities between the results obtained for each species. Comparison of fish distribution in the field, where they are exposed to all environmental variables with the results of the laboratory tests, where all except turbidity have been excluded, should go a long way toward determining the role of turbidity in establishing fish distribution patterns.

The Kolmogorov-Smirnov two sample test for non-parametric data was used to determine whether any degree of agreement found between the field and laboratory results is significant. The same data was then tested for significance using Spearmann´s Rank Correlation Coefficient in order to provide confirmation of the results from the Kolmogorov-Smirnov test.

7.2 Comparison of field and laboratory data.

Figures showing the results from the field data, in terms of CPUE, and the laboratory, as percentage time spent in each of the four turbidity ranges, are given for each species in Figures 42 to 61. These Figures provide preliminary indications of the similarity between the results from the field and laboratory data sets for each species.

The laboratory results for *M.argenteus* (Fig. 42) were opposite to those obtained from field work, where most individuals were caught in clear water (Fig. 43). If, during acclimation periods, the fish noticed anyone looking over the boards concealing the tank, they would wedge themsel against the wall in a corner of the tank. It is possible that this species, which is usually encountered on the edges of submerged vegetation and around rocky outcrops, may have been using the partially turbid compartments (10 - 50 & 51 - 80 NTU) for concealment.

Both field and laboratory data for R.holubi (Figs. 44 & 45) showed that this species has a distinct preference for clear waters (<10 NTU). Data on L.dumerili from laboratory tests (Fig. 46) showed that it had a distinct preference for clear water (<10 NTU), but the field data (Fig. 47) indicated that this species is as common in clear water (<10 NTU) as in the 10 to 50 NTU category. However, catches in the latter group were nearly all in turbidities of 10 to 20 NTU (see 5.2.1d).

All results for L.macrolepis (Figs. 48 & 49) showed a preference for waters of <50 NTU. Within this range the <10 NTU category was most important in the field data while the 10 - 50 NTU was favoured during the laboratory tests. Although the laboratory tests for R.sarba (Fig. 50) indicated a preference for waters <10 NTU (Fig. 51), field data showed that <10 and 10 - 50 NTU were selected with similar frequencies.

The field and laboratory results for G.filamentosus (Figs. 52 & 53) both showed an identical pattern with greatest preference being shown for the 10 - 50 NTU range. Laboratory tests on V.buchanani revealed a preference for waters of <50 NTU (Fig. 54). A similar trend was evident in the field data, except that more fish were caught in the 10 to 50 NTU range than in <10 (Fig. 55).

Both field and laboratory data for A.berda showed that catches were highest in intermediate turbidities (10-80 NTU) and lowest in very clear or turbid waters (Figs. 56 & 57). Although the laboratory data for P.commersonni showed a marginal preference (not significant) for very turbid waters (>80 NTU) (Fig. 58), the field data (Fig. 59) confirmed that this species is indifferent to turbidity.

Although field data showed that greatest numbers were present in clear waters (Fig. 60), T.jarbua was found to be common in all turbidities and is thus probably indifferent to common in a wide range of turbidities from clear to turbid. The contradictory results obtained in the laboratory (Fig. 61) seem not to be related to turbidity, but rather reflect the high level of activity shown by the individuals of this species. Being indifferent to turbidity, they spent most of their time under test conditions moving between the two ends of the tank. Most of the time spent in the two middle compartments was considered transitory, as it was less than one minute on each occasion, and was therefore not included in the calculation of the percentage time spent in each compartment.

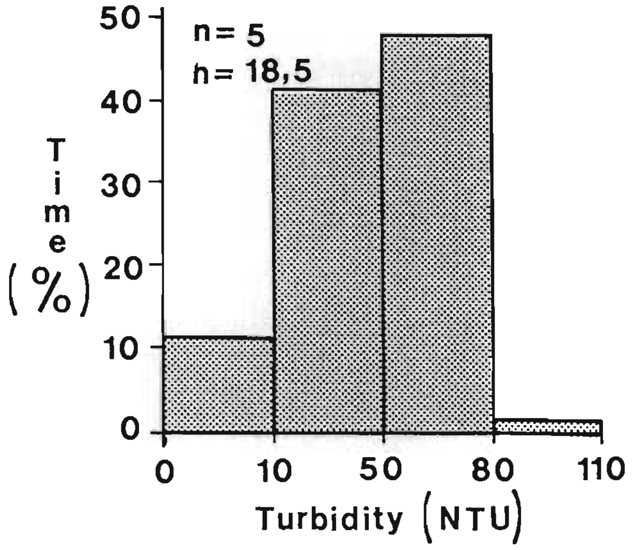

Figure 42: Turbidity preference of Monodactylus argenteus; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

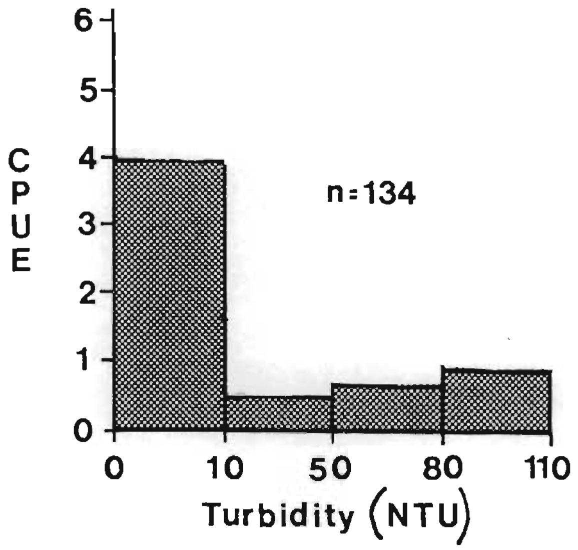

Figure 43: Catch per unit effort (CPUE) of Monodactylus argenteus in four turbidity ranges (n = number caught).

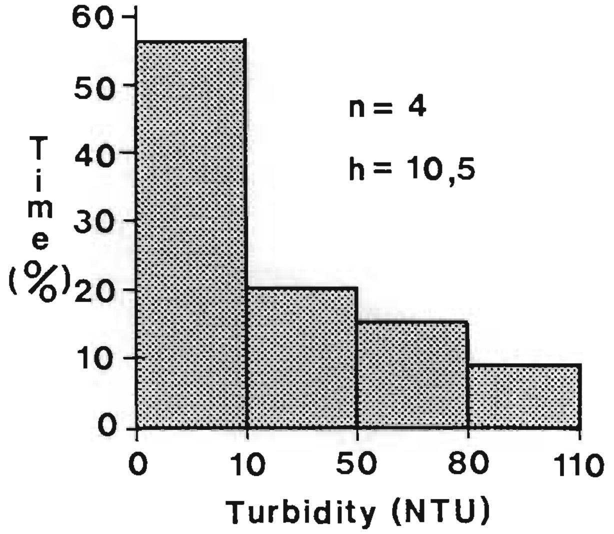

Figure 44: Turbidity preference of Rhabdosargus holubi; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

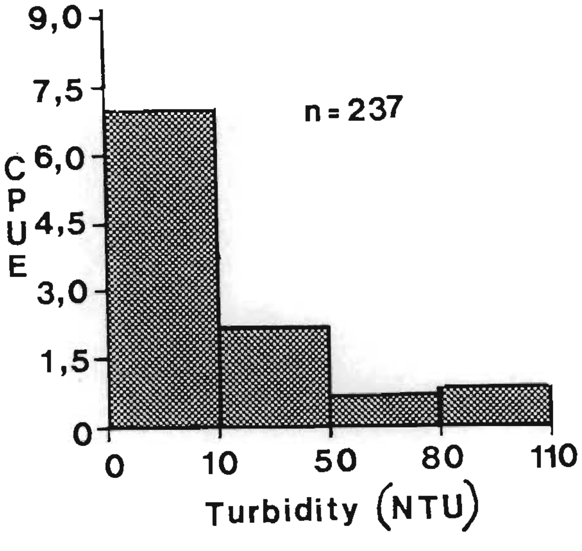

Figure 45: Catch per unit effort (CPUE) of Rhabdosargus holubi in four turbidity ranges (n = number caught).

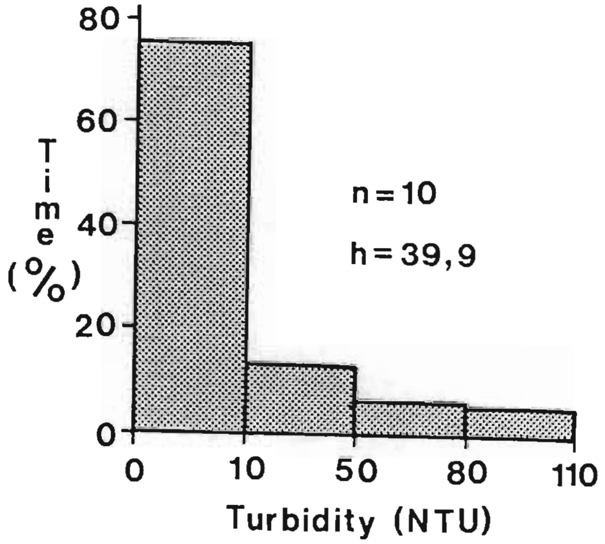

Figure 46: Turbidity preference of Liza dumerili ; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

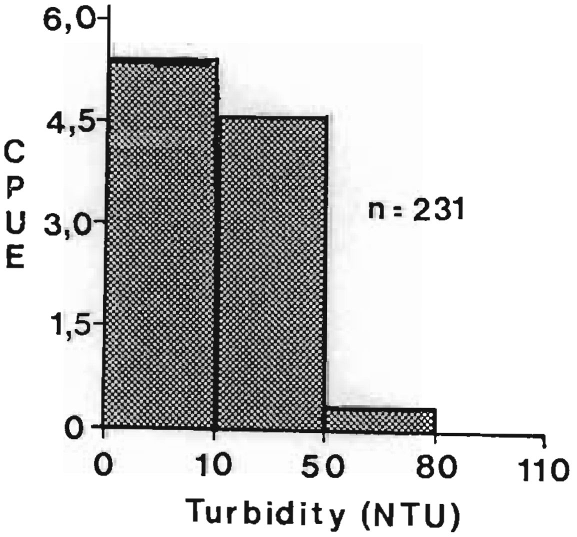

Figure 47: Catch per unit effort (CPUE) of Liza dumerili in four turbidity ranges (n = number caught).

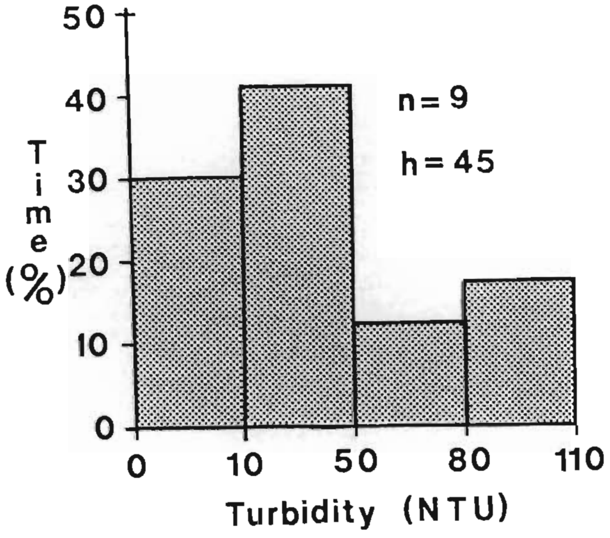

Figure 48: Turbidity preference of Liza macrolepis; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

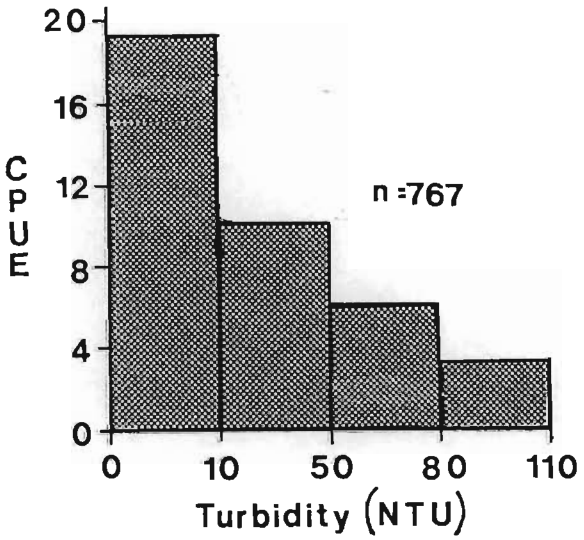

Figure 49: Catch per unit effort (CPUE) of Liza macrolepis in four turbidity ranges (n = number caught).

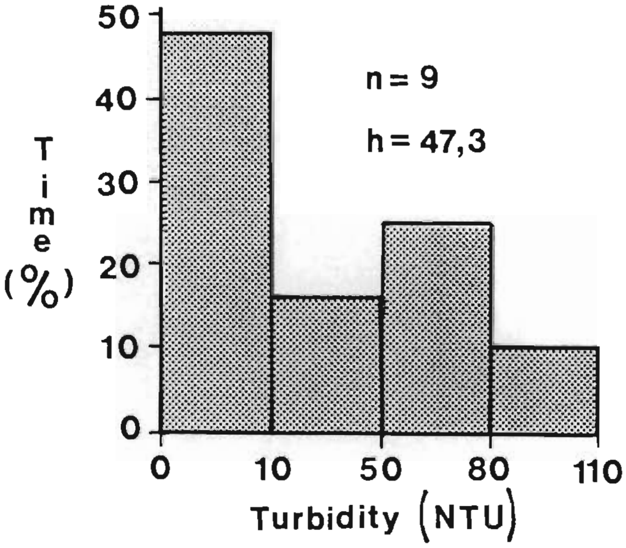

Figure 50: Turbidity preference of *Rhabdosargus sarba*; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

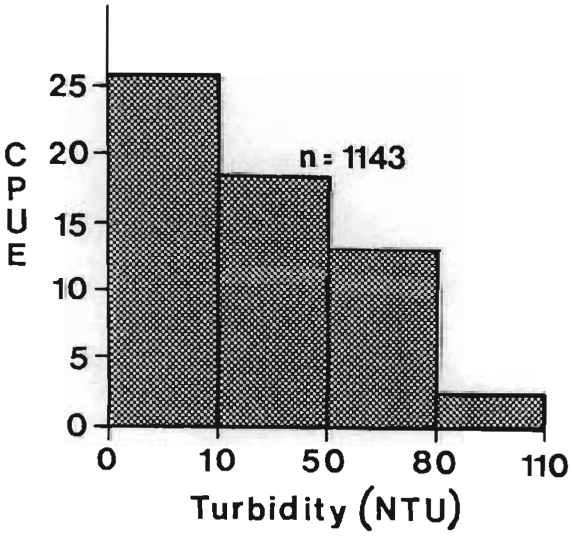

Figure 51: Catch per unit effort (CPUE) of *Rhabdosargus sarba* in four turbidity ranges (n = number caught).

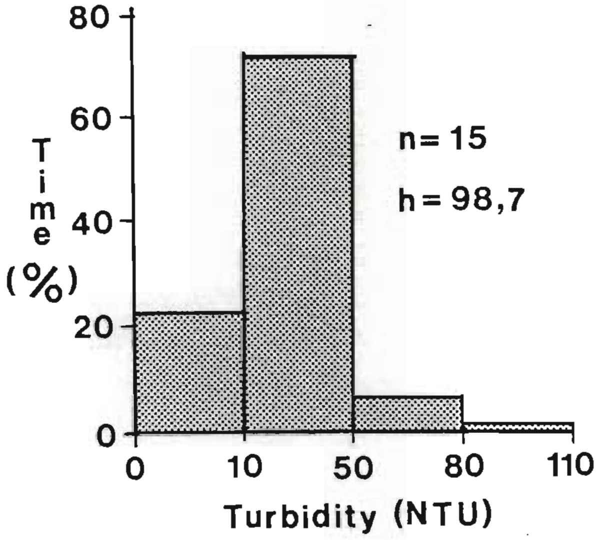

Figure 52: Turbidity preference of *Gerres filamentosus*; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

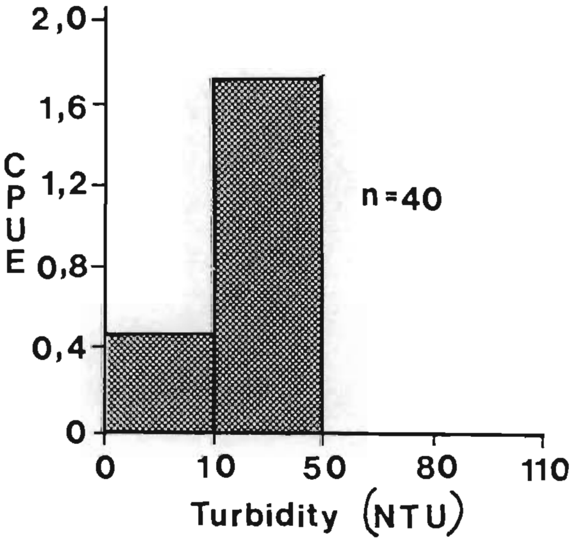

Figure 53: Catch per unit effort (CPUE) of *Gerres filamentosus* in four turbidity ranges (n = number caught).

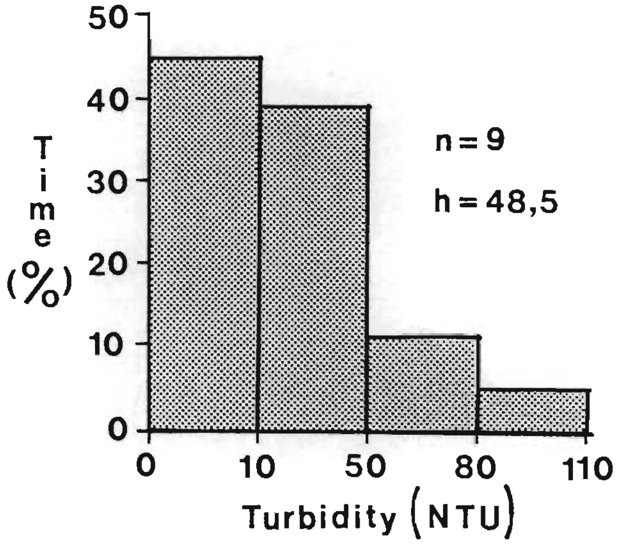

Figure 54: Turbidity preference of Valamugil buchanani; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

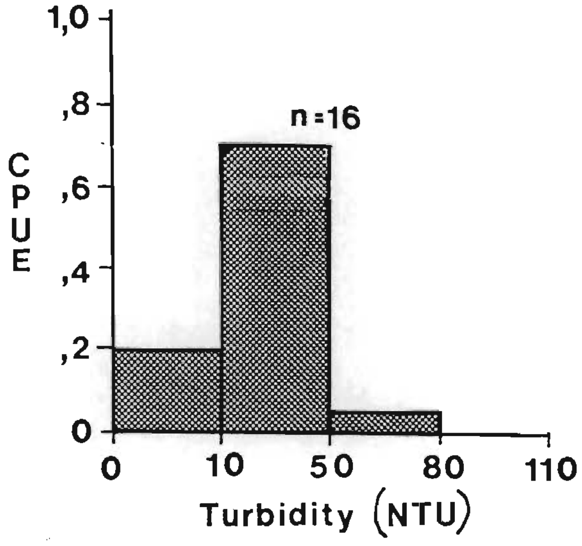

Figure 55: Catch per unit effort (CPUE) of Valamugil buchanani in four turbidity ranges (n = number caught).

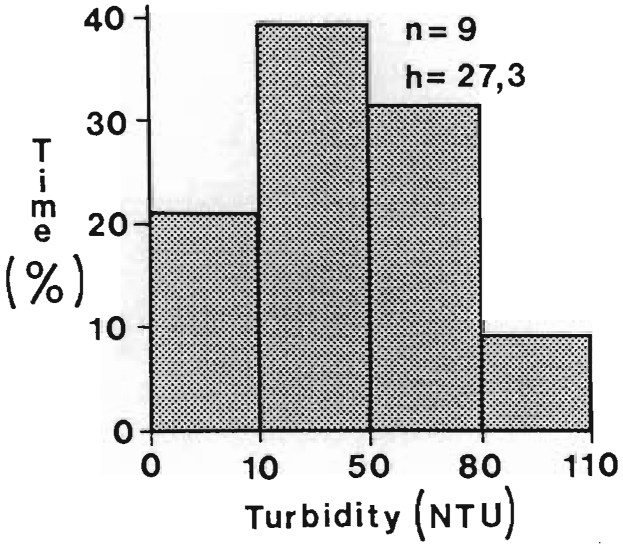

Figure 56: Turbidity preference of <u>Acanthopagrus</u> <u>berda</u>; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

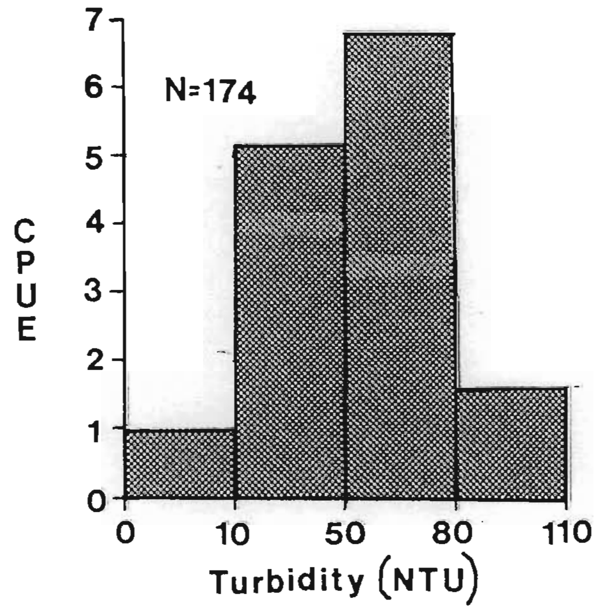

Figure 57: Catch per unit effort (CPUE) of <u>Acanthopagrus</u> <u>berda</u> in four turbidity ranges (n = number caught).

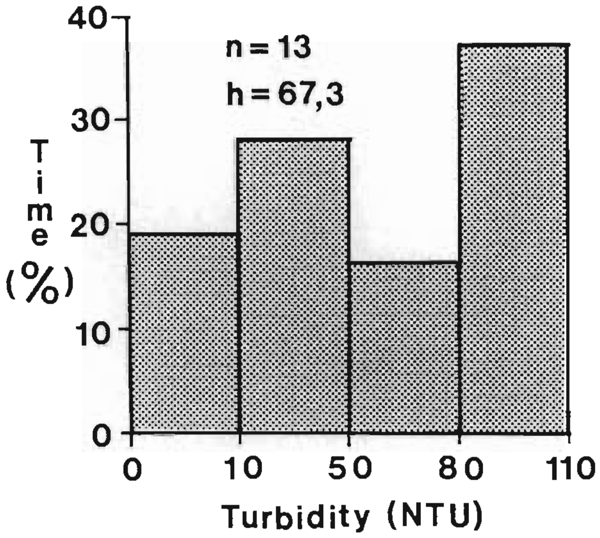

Figure 58: Turbidity preference of <u>Pomadasys</u> <u>commersonni</u>; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

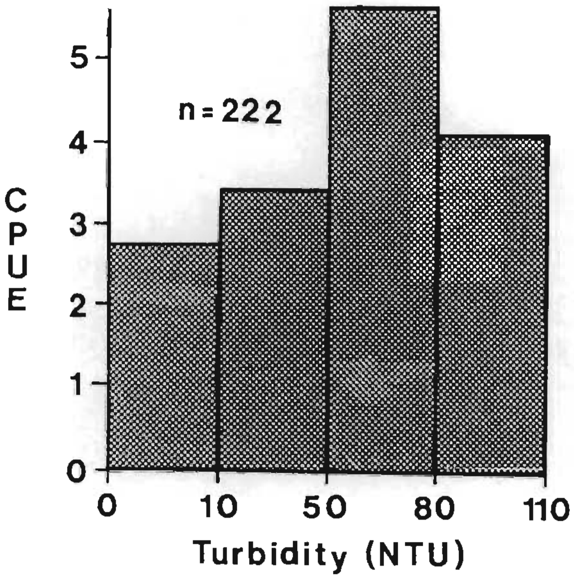

Figure 59: Catch per unit effort (CPUE) of <u>Pomadasys</u> <u>commersonni</u> in four turbidity ranges (n = number caught).

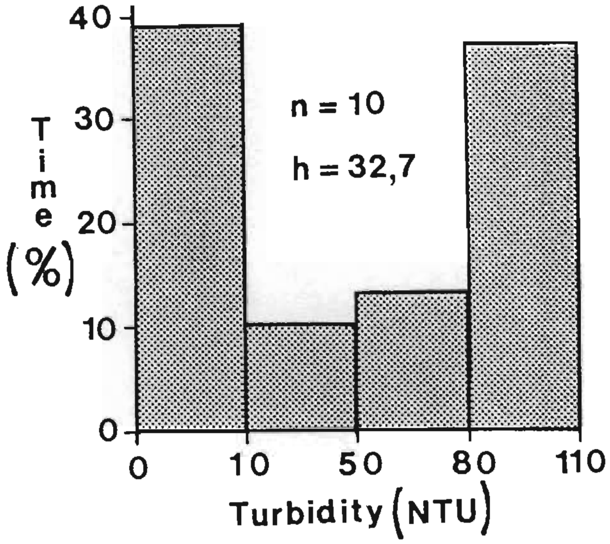

Figure 60: Turbidity preference of Terapon jarbua; percentage time spent in four turbidity ranges of a choice chamber tank (n = number of test runs, h = number of hours under test conditions).

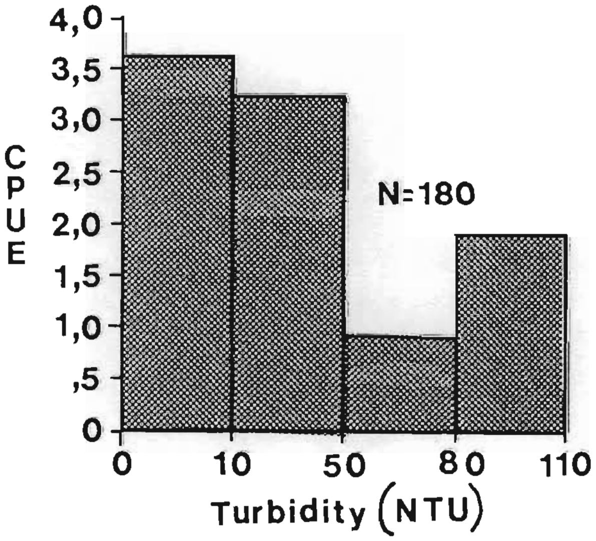

Figure 61: Catch per unit effort (CPUE) of Terapon jarbua in four turbidity ranges (n = number caught).

7.3 Statistical analysis of data.

7.3.1 Closeness of fit of data.

Results of a similarity matrix calculated from the principal co-ordinate analysis of the field and laboratory data combined, are listed in Table 54. From this (most similar = 1,0) it can be seen that laboratory results for all except one species showed agreement with the field data. The low closeness of fit value for M.argenteus is considered to be due to this species entering the lowest available turbidities which would provide it with concealment (see 7.2 above).

The comparatively low similarity value for L.dumerili (0,709) is due to the fact that laboratory data showed a high percentage of time spent in <10 NTU, whilst field results showed an almost equal occurrence in <10 and 10-50 NTU. The laboratory data indicate that given the choice, this species will always move into the very clear water (<10 NTU).

Table 54: Closeness of fit of field and laboratory data from a similarity matrix derived from a principle co-ordinate analysis (1,0 = most similar, 0 = no similarity).

Species	Similarity
Gerres filamentosus	0,946
Rhabdosargus sarba	0,821
Rhabdosargus holubi	0,820
Valamugil buchanani	0,810
Pomadasys commersonni	0,802
Acanthopagrus berda	0,802
Liza macrolepis	0,760
Terapon jarbua	0,750
Liza dumerili	0,709
Monodactylus argenteus	0,370

7.3.2 Kolmogorov-Smirnov two sample test for goodness of fit.

The field and laboratory data for the ten species were tested for agreement using the Kolmogorov-Smirnov two sample test for non-parametric data. As with the testing for significance of the replicate runs, data obtained in the laboratory for each species which showed preferences for two of the four turbidity groups ('clear to partially turbid', <10 & 10 - 50 NTU) were tested a second time with the data placed into three groups.

The results are given in Table 55, from which it can be seen that, apart from the three species whose results were not significantly different when in three groups, significant differences between laboratory and field data occurred for only two species.

Table 55: The Goodness of Fit of laboratory and field data as determined by the Kolmogorov-Smirnov two sample test (Ds [max] = largest cumulative difference, D.S. = Difference between field and laboratory sample significant & # = tested with three groups).

Species	Ds [max]	D.S.	Probability
<u>M</u>.<u>argenteus</u>	0,53	YES	<0,01
<u>R</u>.<u>holubi</u>	0,11	NO	-
<u>L</u>.<u>dumerili</u>	0,24	YES	<0,01
<u>L</u>.<u>dumerili</u> #	0,05	NO	-
<u>L</u>.<u>macrolepis</u>	0,19	YES	<0,05
<u>L</u>.<u>macrolepis</u> #	0,08	NO	-
<u>R</u>.<u>sarba</u>	0,09	NO	-
<u>G</u>.<u>filamentosus</u>	0,06	NO	-
<u>V</u>.<u>buchanani</u>	0,25	YES	<0,01
<u>V</u>.<u>buchanani</u> #	0,06	NO	-
<u>A</u>.<u>berda</u>	0,18	NO	-
<u>P</u>.<u>commersonni</u>	0,10	NO	-
<u>I</u>.<u>jarbua</u>	0,19	YES	<0,05

7.3.3 Ranking test.

Both Roscoe (1975) and Lee and Lee (1983), in their descriptions and uses of Spearmann's Rank Correlation Coefficient, point out that coefficient values for this test, when only four ranks are used, can only be calculated exactly to probabilities of 10% and p values below this are not given. Ranking tests comparing the laboratory and field results, in four turbidity groups, could therefore only be correlated to a significance level of p<0,10. Roscoe (1975) gives the critical value for the 10% level as 0,8000. The results from this test are given in Table 56, which shows that significant agreement between field data and laboratory test results was present in six of the ten species studied.

Table 56: Degree of agreement and significance levels between turbidity data from the field and laboratory as determined by Spearmann's Rank Correlation Coefficient (R = Rank Correlation Coefficient, - = no agreement).

Species	R	Probability
Monodactylus argenteus	-0,6	-
Rhabdosargus holubi	0,8	<0,10
Liza dumerili	1,0	<0,10
Liza macrolepis	0,6	-
Rhabdosargus sarba	0,8	<0,10
Gerres filamentosus	1,0	<0,10
Valamugil buchanani	0,8	<0,10
Acanthopagrus berda	0,6	-
Pomadasys commersonni	0,8	<0,10
Terapon jarbua	0,4	-

7.4 Discussion.

7.4.1 Field and laboratory results.

Table 57 summarizes the results of the four methods of analysis used to determine whether the species studied could be considered as showing agreement between the field and laboratory results. The initial interpretation of the data (7.2) indicated possible agreement between the two sets of results for at least eight out of the ten species. Added weight was given to this by the results of the similarity matrix from the principal co-ordinate analysis which also indicated good agreement between the results for the same eight species. However, this test did not allow determination of significance levels for the results obtained. Using the Kolmogorov-Smirnov two sample test it was established that significant differences between the field and laboratory results occurred only in two species, *M.argenteus* and *T.jarbua*, these being the two which were initially considered as not showing much agreement.

Table 57: Summary of agreement between field and laboratory data, for ten species, as indicated by four methods (I.I. = Initial Interpretation, S.M. = Similarity Matrix, K-S = Kolmogorov Smirnov, ^{1} = Partial, ^{2} = Marginal & ^{3} = with three categories).

Species	I.I.	S.M.	K-S	Rank
Monodactylus argenteus	NO	NO	NO	NO
Rhabdosargus holubi	YES	YES	YES	YES
Liza dumerili	YES^1	YES^2	YES^3	YES
Liza macrolepis	YES	YES	YES^3	NO
Rhabdosargus sarba	YES^1	YES	YES	YES
Gerres filamentosus	YES	YES	YES	YES
Valamugil buchanani	YES	YES	YES^3	YES
Acanthopagrus berda	YES	YES	YES	NO
Pomadasys commersonni	YES	YES	YES	YES
Terapon jarbua	NO	NO	NO	NO

Spearmann's Rank Correlation test were used to provide added confirmation of the results of the Kolmogorov-Smirnov test. Although similarity between the data sets could only be tested to a probability level of 10%, due to there only being four data pairs, the results were similar to those obtained from the previous test, the only difference being that two more species, *L.macrolepis* and *A.berda*, were found not to show significant agreement within their rankings between the field and laboratory results. In the case of *L.macrolepis* this can be attributed to the species favouring two of the four test turbidity test ranges (<10 & 10 - 50 NTU), which led to the order of preference shown for these two turbidities in the laboratory results, as well as for the two groups not favoured, to be opposite to those shown in the field. Figures 48 and 49 show that, although the ranking is reversed, a distinct preference for the two lower turbidity groups exists. In *A.berda*, the fact that the ranking results for the two data sets did not agree may be attributed to the species being indifferent to turbidity. As a result its occurrence in each compartment would be random and therefore one would not necessarily expect a significant level of agreement between the two.

As far as the two other species which showed no agreement are concerned, *T.jarbua* is also indifferent to turbidity as discussed above, while *M.argenteus* appears to have shown a different turbidity preference in the laboratory as a result of its using the turbidity in which to hide (see 7.2).

By comparing the results from field and laboratory data it has been found that a significant level of agreement exists between the two for most species. These results therefore add further weight to the assumption that turbidity is an important factor in determining the distribution of juvenile fish in South Lake. Analysis of the field data on twenty species has shown that of the major physical factors within the system, turbidity is of overall importance and exerts the major influence on the distribution of the fish.

The fact that results from the laboratory tests, where all variables except turbidity were eliminated, have shown significant agreement with the field data, has provided conclusive evidence that turbidity influences fish distribution in South Lake. Added to this, it has been shown that the species present can be divided into five distinct groups according to their turbidity preferences as follows: clear (<10 NTU), ´clear to partially turbid´ (<50), intermediate (10 - 80), turbid (>50) and indifferent.

The question of whether it is the particulate concentration of turbid waters or the fact that turbidity limits light penetration, which influences the fish has not been investigated. However, results from a limited number of night-time laboratory tests on turbidity preference, not included in this study, suggest that the clear and ´clear to partially turbid´ water species are indifferent to turbidity at night. Also, turbidity indifferent species showed similar pattern to those observed during daytime tests. Added to this preliminary results from shading tests on two species has shown that light penetration is an important factor.

Gradall and Swenson (1982) have postulated that the responses to greater visual isolation, brought about by reduced light penetration due to high turbidities, lead to increased activity, a decrease in the use of fixed overhead cover and a reduced association with the substratum. Laboratory results from daylight runs and a limited number of night runs, indicate that the responses found by Gradall and Swenson (1982) could occur equally under increased turbidity attraction of some species to turbid waters could be related to the fact that turbidity may promote spatial and visual isolation of the species from their predators.

It would thus seem that light penetration, which is greatly affected by turbidity, may be a major factor influencing the presence or absence of different fish species in any area.

7.4.2 Conclusion.

Although it has been shown that turbidities need to increase substantially above natural levels before lethal limits are reached, increases of much lower orders also have profound effects on fish. Both laboratory studies and fieldwork on the juveniles of marine fish common in estuaries have confirmed the existence of fish distribution patterns related to turbidity. Although little other work has been done in this field, results from this study have been found to conform with the basic patterns of fish distribution and turbidity found in Moreton Bay, Australia by Blaber and Blaber (1980). Their work is one of the only investigations available on the distribution of juvenile estuarine fish in relation to turbidity. The ranges of turbidity recorded during this study have necessitated the establishment of additional turbidity preference groups to accommodate the ranges occupied by juvenile fish in South Lake. However, the basic patterns are the same as those found in Moreton Bay by Blaber and Blaber (1980). The effects of turbidity on the distribution/occurrence of species studied in South Lake in other Natal estuaries, are discussed in Chapter 8.

8. TURBIDITY AND FISH DISTRIBUTION IN NATAL ESTUARIES.

8.1 Introduction.

Although fieldwork for this study concentrated on South Lake, St.Lucia a number of other estuaries were also sampled. This work was done in order to obtain data on fish distribution and turbidity, which, together with those from South Lake, could be used to establish the overall influence of turbidity in Natal estuaries. As these estuaries were not sampled as intensively and because the full turbidity range (<10 to >80 NTU) was not present in every one of these systems, it has not been possible to determine the similarities of the results to within statistically acceptable limits. However, the data obtained do provide additional insight into the influence of turbidity on fish distribution in Natal estuaries.

8.2 Results.

8.2.1 Turbidity and other physical factors in Natal estuaries.

(a) Turbidity.

The turbidity ranges recorded in the seven systems studied are given in Table 58. This Table also gives turbidity figures recorded in the marine offshore environment, up to 5km off the Kosi and Mlalazi Estuary mouths and off Durban Bay, for comparison. The turbidity data for St.Lucia and Kosi have been divided into Estuary and Lake so that results from the different parts may be compared.

(b) Temperature.

Although temperatures were measured during all visits, a full 12 months of data were only collected from South Lake, Tongati and Mdloti. The ranges of temperatures recorded in all estuaries is given in Table 59, which also includes, where available, temperatures recorded in the other systems by other workers.

Table 58: Turbidity ranges recorded in Natal estuaries and the offshore marine environment (n = number of samples; $\overline{x}$ = mean; S.E.= Standard Error; (L) = Lake & (E) = Estuary).

System	Range NTU	Data sets	n	$\overline{x}$	S.E.
Estuaries					
St.Lucia (E)	2,0 - 568,0	51	1662	84,2	1,57
St.Lucia (L)	2,0 - 1472,0	57	1310	51,4	1,42
Tongati	5,0 - 464,0	12	92	46,3	8,92
Mdloti	3,5 - 232,0	12	91	50,9	5,35
Mtamvuna	1,6 - 86,0	2	31	30,0	4,74
Mlalazi	4,4 - 65,0	7	88	25,2	1,56
Fafa	10,0 - 29,5	1	26	17,3	0,96
Kosi (E)	0,5 - 2,6	8	110	1,2	0,05
Kosi (L)	0,5 - 9,7	5	58	3,5	0,32
Marine					
5km offshore	1,5 - 2,8	5	10	2,1	0,13

(c) Salinity.

The ranges of salinity recorded in the seven systems sampled are given on Table 59.

(d) Wave Action.

It was found that wave action of any significance was only present in the estuarine lakes and that only in St.Lucia did it have any real effect. In the latter it was responsible, with wind, for causing increases in turbidity where wave action was directly onshore (see 4.4.1). In the Kosi Lakes the mean sand grain particle size was large (see below) and as a result wave action had no effect on turbidities in the system (Table 58).

(e) Wind.

The only detailed wind data gathered was at St.Lucia (see 4.2.5). However, Begg (1978) has given a generalized Wind Rose for coastal Natal which shows that the predominant winds are from the S.W. (26%), N.E. (22%) and E. (10%).

(f) Water Levels.

The very fact that estuaries are connected to the sea (unless the mouth is closed) means that there are level changes on a twice daily basis according to the state of the tide. This means that any influence water levels may have on fish will be temporal rather than spatial. The effects of level fluctuation at St.Lucia has been discussed in Chapter 4. No fluctuations occurred in the levels of the Kosi Lakes during this study.

Table 59: Summary of some physical factors measured in seven Natal estuaries (Temperature in °C, Salinity in °/oo, Substratum = ´predominant´ type, Benthos in mean biomass - # = g/m^2 dry mass * = J/m^2, Depth in metres, [1] = East & [2] = West).

System	Temperature	Salinity	Substratum	Benthos	Depth
South Lake[1]	16,0-30,5	32,0-42,0	Sandy	1,07#	2,0
South Lake[2]	16,0-31,5	33,0-44,5	Muddy	4,19#	2,0
Tongati	15,9-29,0	0-35,0	Sandy	15712*	2,7
Mdloti	13,0-26,5	0-35,0	Sandy	1925*	2,5
Mtamvuna	18,1-29,8	1,0-34,5	Muddy	-	10,0
Mlalazi	15,0-27,9	7,0-35,0	Muddy	-	3,2
Fafa	14,0-29,0	0- 1,0	Sandy	-	1,4
Kosi	17,0-28,0	0,5-35,0	Sandy	269732*	31,0

(g) <u>Substratum Particle Size</u>.

Mean particle sizes of the substrata of St.Lucia and Kosi were measured (see below), while details on the different types of substrata present in all other systems investigated were determined during field sampling and from published sources. The data are summarized on Table 59.

The approximate particle sizes of each substratum category referred to are given in Table 60. St.Lucia Estuary substrata are essentially composed of clean sand from the mouth to the N.P.B. jetty (Site 2 - Fig. 8), from there to Honeymoon Bend a layer of mud covers the sandy substratum. The remainder of the estuary consists of fine silt and thick mud. The substrata of South Lake constitute two basic types, ´sandy´ and ´muddy´ (Boltt, 1975). The western shores are ´muddy´ and have a mean particle size of 150µm while the eastern shores are ´sandy´ with a particle size of 350µm predominating (see 4.2.7).

For its entire length, the substratum of the Kosi Estuary consists of white sands. Particle size composition is very uniform, with over 80% of the particles of the estuary and the three saline lakes being between 250 and 500µm. Details of substrata of Mlalazi Estuary are taken from Hill (1966) who found the substratum around the mouth consisted of clean sand; from there to the N.P.B. Jetty (Site 7 - Fig. 4) sandy mud predominated. The area from the jetty to the rail bridge consists of sandy silt which is replaced by a covering of glutinous mud for the next 2km, after which substrata consist essentially of very coarse river sand.

Table 60: Terminology of particle sizes based on the Wentworth Scale as modified from Green (1968).

Name	Particle size
Very coarse sand	1000 - 2000µ
Coarse sand	500 - 1000µ
Medium sand	250 - 500µ
Fine sand	125 - 250µ
Very fine sand/mud	62 - 125µ
Silt	<62µ

Information on substrata of the Tongati and Mdloti Estuaries comes from Blaber <u>et</u> <u>al</u>. (1984) who analysed particle size composition in the two estuaries. The former had lower reaches consisting of medium/coarse sand, the middle reaches of medium/fine sand and the upper reaches of fine sand. A slight increase in the amount of silt present and a decrease in coarse sand occurred towards the upper reaches, but otherwise the substrata appeared relatively uniform. In the Mdloti the lower reaches consisted of medium/coarse sand with medium sand on the 'mudflats' area. The middle and upper reaches were of medium sand. Somewhat more silt was present in the middle and upper reaches but in general the substratum throughout was uniform.

Fafa Lagoon substrata have been listed as consisting of undifferentiated river sand (Orme, 1974) with the fine silt content present making up <18% (Hemens et al., 1971). The Mtamvuna Estuary is considered by Hemens et al.(1973) to consist of fairly homogeneous silt, with a change to marine sand in the immediate vicinity of the mouth.

(h) Food available in the Benthos.

Detailed investigation into food availability in the benthos was only carried out in South Lake (see 4.2.8). However, details are available for an additional three systems, Kosi (Cyrus & Blaber, 1983) and Tongati and Mdloti (Blaber et al., 1984). Unfortunately the mean standing stock of benthos for these systems is expressed in J/m² while that from South Lake (this study) is in g/m²). These figures have however been included in Table 59.

(i) Water Depth.

Table 59 gives the maximum depth of each system sampled. In the case of Kosi, sampling concentrated on the estuary and the broad shelf areas of the lakes which were no deeper than 3,0m. At Mtamvuna sampling was undertaken along the shoreline areas where the depth was less than 3,0m.

8.2.2 Turbidity and fish distribution in Natal estuaries.

As mentioned in 8.1 above, due to only South Lake being sampled intensively, the results obtained from the other systems do not allow for statistical comparison and determination of levels of significance. Table 61 lists the number of large seine samples collected in each of the four categories from the seven systems investigated. The CPUE for the common species caught during these hauls are given in Tables 62 to 81 below, which, for each turbidity class, provide the CPUE in each system, the 'overall' CPUE as well as the actual number of fish caught.

Table 61: Distribution of large seine hauls according to turbidity and system (NA = Turbidity Not Available ; NS = No Sample).

Locality / Turbidity	<10	10-50	51-80	>80	n
South Lake - St.Lucia	28	15	8	10	61
Kosi System	11	NA	NA	NA	11
Mlalazi Estuary	9	17	2	NA	28
Tongati Lagoon	NS	10	3	3	16
Mdloti Lagoon	NS	11	3	3	17
Mtamvuna Estuary	3	5	1	NA	9
Fafa Lagoon	NA	3	NA	NA	3
Total	51	61	17	16	145

Table 62: The CPUE of Gerres acinaces in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	14,5	1,7	0	0	430
Kosi System	27,5	*	*	*	303
Mlalazi Estuary	0	0,1	0	*	1
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0	0	0	*	0
Fafa Lagoon	*	0,3	*	*	1
'Overall' CPUE	10,5	0,4	0	0	735

Table 63: The CPUE of Gerres rappi in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	4,9	2,9	0,4	0	177
Kosi System	28,4	*	*	*	312
Mlalazi Estuary	1,2	1,8	0	*	42
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0,4	0	4
Mtamvuna Estuary	2,3	2,4	0	*	19
Fafa Lagoon	*	0,3	*	*	1
'Overall' CPUE	9,2	1,2	0,2	0	555

Table 64: The CPUE of Monodactylus argenteus in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	4,0	0,5	0,8	0,9	134
Kosi System	8,2	*	*	*	90
Mlalazi Estuary	0,2	1,1	0	*	21
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0	0	0	*	0
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	3,1	0,3	0,2	0,2	245

Table 65: The CPUE of <u>Rhabdosargus</u> <u>holubi</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	6,8	2,3	0,6	0,7	237
Kosi System	8,7	*	*	*	96
Mlalazi Estuary	2,3	2,1	0	*	58
Tongati Lagoon	*	0,1	0,3	0	2
Mdloti Lagoon	*	1,1	0,7	0,7	15
Mtamvuna Estuary	2,0	0,8	0	*	10
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	4,8	1,1	0,3	0,5	418

Table 66: The CPUE of <u>Caranx</u> <u>sexfasciatus</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	0,6	0,4	0,1	0	24
Kosi System	1,1	*	*	*	12
Mlalazi Estuary	2,6	1,7	0	*	53
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	1,1	0	0	12
Mtamvuna Estuary	0	1,2	0	*	6
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	1,1	0,7	0,02	0	107

Table 67: The CPUE of <u>Liza</u> <u>dumerili</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	5,5	4,6	0,8	0	231
Kosi System	5,1	*	*	*	56
Mlalazi Estuary	9,1	8,0	0	*	219
Tongati Lagoon	*	3,8	0	0	38
Mdloti Lagoon	*	0,5	0	0	5
Mtamvuna Estuary	34,0	13,2	0	*	168
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	10,7	5,0	0,2	0	717

Table 68: The CPUE of <u>Liza macrolepis</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	 10-50	 51-80	 >80	n
South Lake - St.Lucia	18,9	10,6	5,2	3,6	767
Kosi System	9,9	*	*	*	109
Mlalazi Estuary	24,8	22,7	6,5	*	623
Tongati Lagoon	*	0,3	0,3	0,3	5
Mdloti Lagoon	*	2,9	2,6	0	40
Mtamvuna Estuary	5,3	4,6	0	*	31
Fafa Lagoon	*	0,3	*	*	1
'Overall' CPUE	14,7	6,9	2,9	1,3	1576

Table 69: The CPUE of <u>Rhabdosargus sarba</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	 10-50	 51-80	 >80	n
South Lake - St.Lucia	25,8	19,3	13,9	2,1	1143
Kosi System	36,4	*	*	*	401
Mlalazi Estuary	3,6	1,7	0	*	62
Tongati Lagoon	*	0,4	0	0,3	5
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0,3	0,2	0	*	2
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	16,5	3,6	2,8	0,8	1613

Table 70: The CPUE of <u>Gerres filamentosus</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	 10-50	 51-80	 >80	n
South Lake - St.Lucia	0,5	1,7	0	0	40
Kosi System	10,6	*	*	*	117
Mlalazi Estuary	12,1	22,6	0	*	494
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0,3	0,2	0	*	2
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	5,9	4,1	0	0	653

Table 71: The CPUE of Valamugil buchanani in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity				n
	<10	10-50	51-80	>80	
South Lake - St.Lucia	0,2	0,7	0,1	0	16
Kosi System	3,2	*	*	*	36
Mlalazi Estuary	2,3	1,2	0	*	43
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0,3	0,8	0	*	5
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	1,5	0,5	0,002	0	100

Table 72: The CPUE of Leiognathus equulus in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity				n
	<10	10-50	51-80	>80	
South Lake - St.Lucia	0	4,9	7,6	1,1	145
Kosi System	0	*	*	*	0
Mlalazi Estuary	30,0	79,0	9,5	*	1633
Tongati Lagoon	*	0,1	0	0	1
Mdloti Lagoon	*	0	0,3	0	3
Mtamvuna Estuary	0,7	3,2	0	*	18
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	7,7	14,5	3,5	0,4	1800

Table 73: The CPUE of Mugil cephalus in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity				n
	<10	10-50	51-80	>80	
South Lake - St.Lucia	0,1	0,4	1,1	0,2	20
Kosi System	0,5	*	*	*	2
Mlalazi Estuary	3,8	1,6	0	*	63
Tongati Lagoon	*	8,8	3,0	0	97
Mdloti Lagoon	*	8,6	3,3	0,7	107
Mtamvuna Estuary	2,6	3,0	0	*	23
Fafa Lagoon	*	4,0	*	*	12
'Overall' CPUE	1,8	4,4	1,5	0,3	324

Table 74: The CPUE of Valamugil cunnesius in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	0,1	0,1	2,8	0,3	28
Kosi System	0,5	*	*	*	2
Mlalazi Estuary	0,2	33,1	0	*	567
Tongati Lagoon	*	20,9	0,3	0,3	211
Mdloti Lagoon	*	23,6	2,3	0,7	269
Mtamvuna Estuary	17,6	42,8	2,0	*	269
Fafa Lagoon	*	25,6	*	*	77
'Overall' CPUE	4,6	24,4	1,5	0,4	1423

Table 75: The CPUE of Acanthopagrus berda in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	1,0	5,1	6,9	1,5	174
Kosi System	0,1	*	*	*	1
Mlalazi Estuary	0,2	1,4	11,5	*	49
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0,1	0	0	1
Mtamvuna Estuary	0	6,8	3,0	*	37
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	0,3	2,2	4,3	0,5	262

Table 76: The CPUE of Pomadasys commersonni in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	2,8	3,7	5,5	4,4	222
Kosi System	0,8	*	*	*	9
Mlalazi Estuary	0,5	1,2	7,5	*	40
Tongati Lagoon	*	0,3	0	0	3
Mdloti Lagoon	*	0,7	0	0	8
Mtamvuna Estuary	2,3	3,8	2,0	*	28
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	1,6	1,6	3,0	1,5	310

Table 77: The CPUE of <u>Terapon jarbua</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	3,6	3,3	1,0	2,1	180
Kosi System	1,0	*	*	*	11
Mlalazi Estuary	1,4	0,9	1,5	*	32
Tongati Lagoon	*	1,1	0	0	11
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	1,0	0,6	0	*	6
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	1,8	1,0	0,5	0,7	229

Table 78: The CPUE of <u>Elops machnata</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	0,1	0,7	2,6	0,6	39
Kosi System	0	*	*	*	0
Mlalazi Estuary	0	0	0	*	0
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0	0	0	*	0
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	0,03	0,1	0,5	0,2	39

Table 79: The CPUE of <u>Solea bleekeri</u> in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	0,4	6,6	17,8	29,9	552
Kosi System	0	*	*	*	0
Mlalazi Estuary	0	0,1	0,5	*	3
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0	0	0	*	0
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	0,1	1,1	3,7	10,0	555

Table 80: The CPUE of Johnius belengerii in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	0	0	1,6	3,4	47
Kosi System	0	*	*	*	0
Mlalazi Estuary	0	0	0	*	0
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0	0	0	*	0
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	0	0	0,3	1,1	47

Table 81: The CPUF of Thryssa vitrirostris in four turbidity classes from seven estuarine systems (* = Turbidity not available/not sampled, n = number of fish caught).

Locality	Turbidity <10	10-50	51-80	>80	n
South Lake - St.Lucia	0,1	0,1	8,9	7,5	148
Kosi System	0	*	*	*	0
Mlalazi Estuary	0	0	2,5	*	5
Tongati Lagoon	*	0	0	0	0
Mdloti Lagoon	*	0	0	0	0
Mtamvuna Estuary	0	0	0	*	0
Fafa Lagoon	*	0	*	*	0
'Overall' CPUE	0,03	0,02	2,3	2,5	153

8.3 Discussion.

8.3.1 Physical factors influencing fish distribution.

Results from South Lake, St.Lucia (Chapter 4) have indicated that of all the physical factors investigated only temperature, turbidity and the amount of food available in the benthos may have been influencing fish distribution. However, it was found (Chap. 5) that only the latter two actually influenced distributions, temperature having a temporal rather than spatial effect, and that, of these two, turbidity is the most important.

Measurement of physical parameters in seven Natal estuaries showed a number of similarities. The turbidity ranges present in most systems covered all four or at least three of the classes considered to be important to fish (<10 to >80 NTU). The exceptions were Kosi (<10 NTU) and Fafa (10 to 50 NTU) where only one class was present. Temperatures recorded showed that all systems experienced similar seasonal fluctuations with only minor variations occurring.

Apart from South Lake, where salinity variation was minimal, and Fafa, which was almost fresh, a wide range was recorded in all other estuaries. The effects of wind, wave action and water levels appear to be similar in all estuaries. As has been shown for St.Lucia, the former two have no direct influence on the fish but they are closely related to water turbidity.

Substratum type and mean particle size showed considerable variations between systems. When classed as either ´sandy´ or ´muddy´ substrata (Table 59), South Lake was found to have both, five were sandy and three muddy. Information on the availability of food in the benthos is limited, but it is known that Kosi and St.Lucia are rich when compared with the other systems studied. The maximum depth of all system, except Kosi and Mtamvuna, is under 3,0m. In the latter two sampling was restricted to areas corresponding to the depth of the other systems.

Although there are insufficient data to be able to statistically compare the physical parameters of the different systems, those which are available indicate that they are, to a large extent, comparable. The main differences were; the upper turbidity levels, basic substratum type and food available in the benthos. All these differences were found to exist between the eastern and western sides of South Lake, the main study site. Results from analysis of those data have shown that the factors of potential importance in determining fish distribution are turbidity and benthos.

The relative importance of the environmental variables considered above are likely to be similar for other estuaries, except that they have a far wider range of salinity than South Lake. However, as shown by laboratory studies and discussed in Chapter 6, the effects of salinity can therefore also be excluded as having an effect on fish distribution in Natal estuaries.

As data necessary to determine the extent of effect available benthos has on fish distribution in other estuaries is lacking, it is again necessary to draw on the results from South Lake. Here it was found that although benthos was possibly affecting some species, turbidity was the major factor which determined distribution of the common marine fish species in the lake. One can therefore tentatively assume that the prevailing turbidities, which are largely determined by the type of substratum present, would to a large extent determine which species would be present in the systems sampled and in what densities.

8.3.2 Factors contributing to the turbidity regimes of estuaries.

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

Results from turbidity sampling in the estuaries studied show that a range of regimes are present (Table 58). The points listed by Carriker (1967), coupled with field observations made during this study, indicate that there are four major factors contributing towards the setting up of estuarine turbidity regimes in Natal estuaries. The four factors, river inflow, substrata, tides and wind are all interlinked. The first two exert the greatest influence in the long term, while rising and falling tides may have opposing affects and winds may cause seasonal variation in turbidity. These factors influencing turbidity in Natal estuaries have also been shown to affect estuarine turbidities elsewhere in the world. Shideler (1980), who 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.

The influence of river inflow acts in the following ways: it increases turbidity during high water inflow when much sediment is brought down, this in turn increases the substratum sediment load as deposition occurs, and 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 are clearly shown by comparison of the turbidity regimes of St.Lucia Estuary (´muddy´ substrata) with Kosi Estuary (´sandy´).

Since turbidity is not static, and can be viewed as existing in a continuum from clear to turbid, the mean turbidity merely gives an indication of the turbidity regime dominating in a particular system. This in turn allows the determination of the probable fish species composition which may be present. However, as turbidity plays a major role in influencing fish distribution, the species may change in response to changing turbidities. This was seen at Mlalazi Estuary ($\overline{x}$ = 25,2 NTU), where an increase of turbidity to over 50 NTU led to species common in turbid waters, such as I.vitrirostris, being present (Table 82).

8.3.3 Fish distribution related to turbidity.

While it is possible that some factors, including the environmental state of the estuaries sampled, may contribute to the absence of some species, the combined results from all study sites has shown that in general the fish distribution trends related to turbidity, as found to be significant in South Lake, St.Lucia, still hold.

The combined data show that even though the CPUE is low in some systems, the relative densities of certain species are still related to turbidity. This trend is particularly evident in the clear water species such as G.rappi (Table 63) which in Mlalazi and Mtamvuna were only and T.vitrirostris showed similar trends in that they were only caught in the more turbid waters present (Tables 79 & 81).

Those species such as L.dumerili and L.macrolepis which had shown a preference for 'clear to partially turbid' waters (<50 NTU), showed similar preferences in the other systems (Table 67 & 68). This is particularly evident in the data from Mlalazi Estuary. The 'overall' (combined) CPUE data tend to mask those 'clear to partially turbid' species by indicating that they have a greater preference for clear water (<10 NTU). This had also been the case with the South Lake data until the results had been statistically tested, and following laboratory tests, it had been clearly shown that the group of species with a preference for 'clear to partially turbid' waters does exist.

CPUE for species which had in South Lake shown a preference for intermediate turbidities showed similar trends in other estuaries, except that the species were only dominant in one of the two intermediate turbidity classes. With all three intermediate species, L.equulus, M.cephalus and V.cunnesius, the preference shown was for 10 to 50 rather than 50 to 80 NTU (Tables 72, 73 & 74).

The three species, A.berda, P.commersonni and T.jarbua, which had not shown any definite turbidity preference in South Lake, showed similar trends in the other estuaries (Table 75, 76 & 77). With A.berda it was again found that there was an apparent preference for intermediate turbidities. However, as no significant differences were found between the four classes of the South Lake data, it is probable that the same holds for the data from the other estuaries.

8.3.4 Conclusion.

The results obtained from the six systems, investigated as a secondary part of this study, have shown that, although the intensity of sampling was not as high as in South Lake, the same general influences of turbidity over turbidity is important to juvenile marine fish in estuaries, and also suggests that the four turbidity classes identified at the begining of this study apply to fish in a wide range of Natal estuaries.

9. GENERAL DISCUSSION.

9.1 Importance of turbidity to juvenile fish.

Fieldwork carried out in South Lake, St.Lucia and six other estuarine systems in Natal has shown that turbidity, which is influenced by wind speed, substratum particle size and wave action, is the dominant physical factor influencing fish distribution. It has been found that the fish fauna shows preferences for waters of various turbidities and that levels of 10, 50 and 80 NTU appear to be the significant values above or below which certain species are either absent or occur in greatly reduced numbers. By dividing the fish fauna into groups according to the turbidity ranges in which they occur: <10, 10-50, 51-80 and >80 NTU it is found that waters of <50 NTU hold the highest species richness, while highest fish densities are present in waters of <10 NTU.

However, analysis of the catch data showed that an overlap between turbidity classes occurred and that this was due to the existence of five rather than four distinct species groups related to turbidity. These are Clear water species (highest densities in <10 NTU), 'Clear to partially turbid' (<50 NTU), Intermediate (10 to 80 NTU), Turbid (>50 NTU) and species indifferent to turbidity (common throughout the range).

The preferences for the different turbidity classes as mentioned above have led to the juveniles of marine species common in estuaries, showing different distribution patterns. This is well illustrated in a large estuarine system such as St.Lucia, where it is found that certain species may only be located in areas of the system which are consistently clear (<10 NTU). In small estuarine systems it has been found that the turbidity regimes present determine, to a large extent, the species composition of any individual estuary. However, as the turbidity ranges in these small systems overlap with more than one of the recognized turbidity classes it has been found that species preferring turbidities other than the estuaries' dominant class do occur occasionally.

individuals of ten common estuarine species, using choice chamber tanks with gradients, revealed similar patterns of turbidity preference to those shown by the species in the field. Thus indicating that the distribution of juveniles of the common estuarine species is strongly linked with turbidity.

The results from the laboratory tests were found to be statistically significant, while tests for each species, on the goodness of fit of the laboratory data with that from the field, were significant for eight out of the ten species. The laboratory studies, which provided tests for turbidity preferences to the exclusion of all other physical variables, have helped to prove conclusively that turbidity plays a major role in determining the distribution of juveniles of marine species which are common in estuaries.

The question as to what turbidity values represent clear, intermediate or turbid-waters appears largely dependent on the range of readings obtained by different workers in their study area. The range recorded for the estuaries in this study was from 0,5 to 1472,0 NTU (Table 58), which is far greater than that recorded by workers in other parts of the world. Blaber and Blaber (1980), working in north eastern Australia, considered values >10 NTU as highly turbid (recorded range 1,0 - 60,0). Similar ranges were recorded by Shideler (1980) in a Texas estuary and by Swenson (1978), who worked in a freshwater lake in the U.S.A..

Dyer (1972), considers that a natural background of about 15mg/l of suspended matter (±20 NTU) is present in most estuarine waters during any stage of tidal flow. Other workers in estuaries have recorded much higher turbidities: Settlemyre and Gardner (1977) in South Carolina, U.S.A. and Poore (1982) in Victoria, Australia both obtained readings up to 124 NTU (130mg/l), while D'Anglejan (1981) recorded approximately 266 NTU (250mg/l) in the Saint Lawrence Estuary, Canada. In freshwater Gray and Ward (1982) obtained readings of 268 NTU (300mg/l), while Brabben (1981) recorded turbidities up to 4256 NTU (5000mg/l). The latter figure, however, was from the totally fresh portion of a river system

NTU figures given above are approximations derived by converting silt concentrations using Figure 12.

Although there is no standardization of the NTU levels at which water should be classed as turbid, many workers have indicated that values above 10 NTU should be considered as such (Swenson, 1978 ; Blaber & Blaber, 1980). Assuming this to be an acceptable figure, it is apparent that the majority of estuaries, particularly in Natal, are turbid water systems. By dividing all species according to their turbidity preferences into either clear (<10 NTU) or turbid water groups (>10 NTU), the species listed in Chapter 5.2.2b as 'Clear to Partially Turbid' species (<50 NTU), would then be classed as either indifferent to turbidity (equally common in waters above and below 10 NTU) or as turbid water species (those predominant in waters with turbidities >10 NTU). If this method of grouping is followed then only four species, Gerres rappi, G.acinaces, Rhabdosargus holubi and Monodactylus argenteus would be classed as truly clear-water species, while the remaining 16 (Table 30) are either indifferent to turbidity or prefer turbid waters.

The importance of turbidity to juvenile fish may be directly related to turbidity, or be due to some factor associated with it. In the former case turbidity may be acting as an isolating mechanism which provides the juveniles with a form of cover through a reduction in light intensity, which acts physically to visually isolate prey species from their predators. In the case of predatory fish species such as Caranx sexfasciatus, whose juveniles are known to inhabit waters which are more turbid than those in which the adults occur, the isolation and protection provided by turbidity may not only help to prevent interspecific, but also intraspecific predation. In this way potential effects of intraspecific predation on the population of the species may be limited. Blaber (1979) found that, once larger than 10cm, Thryssa vitrirostris switched from filter feeding to taking small fish up to 3cm, and that intraspecific predation occurred. It is possible that the latter form of predation is much reduced due to the juveniles of the species inhabiting turbid estuarine waters. When the availability of their main estuary (Blaber, 1979), thus further reducing the possibilities of intraspecific predation.

Vinyard and O'Brien (1976) have shown that the distance at which Bluegill, *Lepomis macrochirus*, reacted to their prey, in this case 2,5mm *Daphnia pulex*, decreased from 27cm at 6,25 NTU to 5cm at 30 NTU. This gives some idea of how effective turbidity may be in protecting juvenile fish from piscivorous fish predators. They also calculated that a 50% reduction in reactive distance reduced the volume searched by the fish by a factor of 4 if the fish was considered to be searching a cylinder, or a factor of 8 if searching a hemisphere or sphere. They further found that decreased light intensity at low turbidities led to a similar effect in reducing the reactive distance in Bluegills. Predators in turbid waters thus need to get much closer to their prey before a catch attempt is executed. At the same time, the prey, when it becomes aware of the impending attack, can effectively disappear into the turbidity through making only the slightest move. This advantage is not available in clear waters, where the predator would still be in visual contact with the prey and the attack could be followed through. This form of protection provided by turbidity could, in addition, reduce the effectiveness of non visual predators in that chemical and mechanical senses used by the predators may be affected by particulate matter concentrations of the water.

A number of authors (Lenanton, 1977; Whitfield & Blaber, 1978b) have indicated that predation pressure in estuaries as a whole may already be reduced due to the shallow nature of the systems, which causes larger predators such as sharks, carangids and sciaenids to be absent.

Protection provided by turbidity would isolate the juveniles, not only from fish predators, but also from piscivorous birds. At Lake St.Lucia, densities of wading birds such as Little Egret *Egretta garzetta*, Great White Egret *Egretta alba*, Grey Heron *Ardea cinerea* and Goliath Heron *Ardea goliath* are greater on the 'clear' eastern shores than the 'turbid' west (pers. obs.). Whitfield and Blaber (1979a) have shown that mullet species such as *Liza dumerili* and L.macrolepis made up 19, 31 and 33% in terms of frequency of occurrence in the diet of the latter three bird species. Both mullet are, in this work, classified as 'clear to partially turbid' water species in terms of turbidity preference, occurring predominantly in waters <50 NTU, and are common on the 'clear' eastern shores of Lake St.Lucia.

Turbidity also provides some protection from diving and swimming piscivorous birds, as Whitfield and Blaber (1978c & 1979b) found that clear water species such as mullet had a 58% frequency of occurrence in the diet of Fish Eagle _Haliaeetus_ _vocifer_ and that mullet and _Rhabdosargus_ _sarba_ had frequencies of occurrence of 22% and 27% respectively in the diet of the Whitebreasted Cormorant _Phalacrocorax_ _carbo_.

Of the factors associated with turbidity which could attract large numbers of juvenile fish, the availability of food in these areas may well be the most important. Studies on the benthos of South Lake, St.Lucia (Blaber _et_ _al_., 1983), under conditions of stable salinities, have shown that the mean annual dry biomass was 4,19g/m^2 for turbid areas with 'muddy' substrata and only 1,07g/m^2 for clear water areas with 'sandy' substrata. The turbid water benthos was dominated by the bivalve _Solen_ _cylindraceus_, indicating that particulate concentrations (turbidity levels) in these areas seldom reach lethal limits, as it is usually the filter feeders, such as _Solen_, which are the first benthic animals to be affected by excessive levels of turbidity (Morton, 1977).

The substratum of clear water areas such as those in the Kosi system also have high invertebrate densities, with values of 173054J/m^2 at the Estuary and 255807J/m^2 in Lake Makawulani (Fig. 3) (Cyrus & Blaber, 1983). Results from Lake St.Lucia appear to indicate that food availability in turbid waters may be important in attracting some species to these areas, but the fact that high benthic densities also occur in very clear waters such as the Kosi System tend to indicate that food availability, although important, is not an overriding factor attracting juvenile fish to turbid waters.

Zooplankton densities vary considerably between estuaries (Blaber _et_ _al_., 1981) with no clear pattern relating to turbidity of the systems other than that the system. These are more than 25x greater than any other estuary sampled (Blaber _et al_., 1981). In the American Great Lakes, Swenson (1978) showed that high turbidities stimulate high zooplankton densities in surface waters, which in turn cause an increase in the number of filter feeding fish in turbid waters. During this study highest densities of the filter feeder _Thryssa vitrirostris_ were recorded in the turbid waters of the St.Lucia system. As there appears to be no difference in the plankton densities in the clear and turbid areas of St.Lucia (S.J.M.Blaber, pers comm.), it is likely that _T.vitrirostris_, which is a rather slow moving and thus vulnerable species, may be taking advantage of turbidity for the protection it provides by isolating the fish from its predators.

Wallace _et al_. (1984) have pointed out that estuaries are important to many species because they act as nursery grounds for the juveniles, while Blaber and Blaber (1980) have shown that it is not estuaries as such which are important, but the features occurring within them. Previously the attraction of juvenile fish to the estuaries of the Indo Pacific, and particularly South East Africa, has been linked to calm waters and shelter (Day, 1951 ; Blaber, 1974), reduced predation pressure (Whitfield & Blaber, 1978b ; Blaber, 1980) and food availability (Talbot, 1955 ; Blaber & Whitfield 1977). Recently, Blaber and Blaber (1980) have shown that these factors do not satisfactorily explain the presence of juvenile fish in estuaries. They therefore considered three additional factors which may be attracting juveniles into estuaries, salinity, temperature and turbidity, and came to the conclusion that the former two had little influence on fish distribution, while the latter appeared to be the single most important factor determining the distribution of juvenile fish in estuaries.

Results from this study have shown that the juveniles of most species present in estuaries are found in a wide range of salinities, and that they are also able to tolerate the range of temperatures which occur seasonally in Natal estuaries. Turbidity, however, has been found to be important in determining the distribution of juvenile fish in estuaries waters. This assuming that, as suggested by other workers, waters of >10 NTU be considered as turbid.

Although turbidity may be important in attracting juvenile fish into and determining their distribution within estuaries, it undoubtedly acts in combination with other factors in providing the requirements of the juveniles. The protective isolation created by turbidity, coupled with the low number of predators in calm, sheltered and shallow waters and the abundance of food in estuaries, produce conditions which are advantageous to the survival and growth of juvenile fish. Blaber and Blaber (1980) have shown that where these conditions exist outside estuaries in the Indo Pacific region, the same juvenile fish are also present. The importance of these factors is further enhanced, because there are no shallow turbid areas in the marine environment off South East Africa (Blaber, 1981).

Few data are available on turbidity preferences of the adults whose juveniles occur in estuaries. In a number of instances it is known that once maturity is reached the fish leave the estuary to spawn at sea and do not return. This occurs with Gerres acinaces, G.rappi and G.filamentosus (Cyrus & Blaber, 1984), but the adults of Caranx ignobilis and C.sexfasciatus, whose juveniles are found in turbid waters, occur in clear waters within estuaries (Blaber & Cyrus, 1983). The adults of species such as Mugil cephalus and Pomadasys commersonni, which return to estuaries after spawning, appear to be indifferent to turbidity. From the limited amount of information available, it appears that turbidity may have some influence on the distribution of adult fish in estuaries but this may not be as marked as it is in the case of juveniles.

9.2 Effects of increased turbidity on juvenile fish.

While it has been established that the juveniles of the majority of species present in estuaries show a preference for turbid waters (>10 NTU), the field results show that very few are commonly found in turbidities above

above 500 NTU are exceptional and seldom occur for more than a few hours. Such high levels may exist for longer periods in association with dredging (depending on substratum) and could also occur at St.Lucia as a result of the proposed St.Lucia/Mfolozi River link canal (based on data in Lund, 1976).

The effects of increased turbidity have been considered by Swenson & Matson (1976) to be indirect, resulting essentially in behavioural changes such as demonstrated by Herbert & Merkens (1961), who studied the effects of different volumes of suspended solids on the rainbow trout _Salmo gairdnerii_. Increases in turbidity cause some species to be driven away while others are attracted (Hollis _et al_., 1964). In many cases changes in turbidity may lead to changes in species composition, as shown by Swenson _et al_. (1977) in Western Lake Superiour, U.S.A.

Prior to behavioural and species composition changes occurring, increased turbidity may cause increased rates of ventilation and oxygen consumption in some species such as those recorded by Horkel & Pearson (1976) for the green sunfish _Lepomis cyamellus_ or it may affect behaviour, leading to reduced activity as occurs with large mouth bass _Micropterus salmoides_ when they are placed in turbid water (Heimstra _et al_., 1969). Increased turbidities affect feeding rates and alter the effective distances at which bluegills _L.macrochirus_ react to their prey (Gardner, 1981; Vinyard & O´Brien, 1976) and can be lethal to fish eggs and larvae according to Auld & Schubel (1978) who studied six estuarine fish species in Chesapeake Bay, U.S.A.

Although the juveniles of most estuarine species show a preference for turbid waters, very high levels caused by dredging or the input of silt laden water (above 1500 NTU) could seriously influence fish populations and make an estuary such as St.Lucia, the largest estuarine system in Natal, unsuitable as a nursery area. This, in turn, might seriously affect adult populations of the 30 species listed by Wallace _et al_. (1984) as dependent on estuaries for all or part of their life cycle.

Turbidity at tolerable levels affects fish by limiting physical presence of particles but their ability to restrict the light. Gradall and Swenson (1982) have also suggested that it is the limiting of light penetration which exerts the major effect on fish. The turbidity levels at which those test species which showed turbidity preferences showed orientation reactions, were at particulate concentrations well below those which have been shown by various workers to have lethal or even sublethal effects on fish (O'Connor *et al*., 1976 & 1977).

The importance of Natal estuaries for the continued existence of certain marine species has been stressed by other workers (Day, 1967 ; Blaber, 1974 ; Wallace *et al*., 1984) and it is important that estuarine degradation is curbed and appropriate impact studies undertaken prior to any manipulations of estuaries is initiated. Many such manipulations associated with development must inevitably lead to abnormal increases in turbidity resulting in a decrease in species diversity and change in species composition of the fish fauna.

9.3 Turbidity, fish and estuaries in the southern third of Africa.

While 201 (16%) of the 1198 marine fishes occurring in northern Natal waters (Smith, 1980) have been recorded as entering estuaries (Whitfield, 1980b), less than 5% are considered by Whitfield (1982) to occur commonly. That so few are able to enter estuaries is related to the need to be physiologicaly adapted to fit the new environment. In this respect Panikkar (1960) considers the ability to adjust to changing salinities as the most important, while Wallace and van der Elst (1975) indicate that marine species may have benefited from this adaptation by being able to utilize a new resource area. The success in this direction of certain species is to some extent dependent on the degree of specialization, and this has probably resulted in 8 species becoming totally dependent on estuaries and a further 22 being partially dependent (in the juvenile phase) (Wallace *et al*., 1984).

Whitfield (1982) has shown that estuaries, whether permanently or seasonally open, act as detritus traps and that this detritus forms the food base of South African estuaries. While it is known that both clear and turbid estuarine waters may be rich in available food (Blaber et al., 1983 ; Cyrus & Blaber, 1983), this study has shown that the fish component of turbid waters (>10 NTU), based on results for twenty marine species common in estuaries, has 20% more species than the clear water component (<10 NTU). Sixteen common estuarine species occur in the former group and only 13 in the latter. Of the thirteen occurring in clear waters nine also occur in waters with turbidities >10 NTU. However, fish densities in clear waters (<10 NTU) and those with turbidities between 10 and 50 NTU were similar.

Equal densities but greater species richness indicate that a greater degree of niche utilization may be taking place in turbid waters. Natal estuaries are mostly turbid in nature. At the same time they offer calm waters, with an abundant food supply, and, due to their shallowness, reduced predation by larger predators. Water turbidity further enhances the importance of these systems to a large proportion of the fauna; protection is provided by creating visual isolation which eliminates interspecific as well as intraspecific predation within estuaries. While all the features mentioned above may collectively attract juvenile fish into estuaries, it is apparent from this study that turbidity may be the single most important feature in this regard.

Having established that turbidity preferences exist amongst the juvenile estuarine fish fauna of Natal, and that the species richness in turbid waters (>10 NTU) is greater than in clear water (<10 NTU), these results should be considered in relation to other estuaries and coastal areas of South East Africa and of the world. Of the species in the turbid waters group (>10 NTU) the majority are tropical in origin (Day et al., 1981), their distributions extending down the South East coast of Africa barely reaching the South coast of South Africa. It has been suggested by Blaber (1981) that the evolutionary development of the preference for species, probably arose in such areas as the Bay of Bengal and in the waters of South East Asia. It is thus probably an extension of this behaviour pattern which has led juvenile fish to enter the estuarine environment of South East Africa.

Although there is a general decrease in species richness as one moves southward down the East coast of Africa and then around to the West coast, it appears that there may also be a general decrease in juvenile estuarine dependence although data are not available. There may also be a tendency for the southern estuaries, with the exception of those of very large rivers such as the Orange which always carries a high silt load, to be less turbid, except during flooding.

Blaber (1981) has mentioned that estuaries on the South coast of Africa have highest turbidities during winter, which is the rainy season in the South, and that this may restrict the penetration of these estuaries by turbid tropical species which spawn during summer, as their juveniles would not find suitable habitat. Added to this, as one moves southwards and around onto the West coast, it is possible that the productivity of estuaries decreases while that of the sea increases. On the South East coast, estuaries act as detritus traps (Whitfield, 1982) and are highly productive, while in the South and West the nearshore marine environment is greatly influenced by upwellings of deep oceanic waters rich in plant nutrients. Added to this, there are few estuaries along the West coast. These factors all probably contribute to juvenile fish of the South and West coasts being primarily present in the nearshore environment.

Results from studies in the nearshore and estuarine environments of south-western Australia (Lenanton, 1982 ; Lenanton <u>et al</u>., 1982) have shown that juveniles of a number of species are present in estuaries of the area and that they are equally abundant in the nearshore areas of the coast. Lenanton (1982) found that the juveniles of only 3 out of 16 species studied could be considered to be estuarine dependent, while juveniles of the other 13 species were also found in the inshore environment, with many utilizing accumulations of detached macrophytes as nursery areas

Although the situation on the south-western Australian coast is not identical to that of the South and West coasts of South Africa, the fact that juvenile fish were present in both estuarine and nearshore environments tends to indicate the they are less dependent on estuaries in south-western Australia than juvenile fish of the South East coast of Africa. These results lend further weight to the suggestion that the preference for turbid waters, such as is shown in Natal estuaries by the juveniles of many species, is essentially related to tropical and subtropical systems. The turbid food rich waters of these estuaries are attractive to juveniles and this has led to increased species richness and resource utilization within the estuaries.

9.4 Conclusion.

The main aim of this study was to establish to what extent turbidity influences the distribution of juvenile marine fish occurring in Natal estuaries. In order to determine this the research effort followed three directions. The first was to establish the patterns and levels of turbidity occurring in estuaries, what factors influence turbidity and what relationships exist between it and the other physical factors present.

On the physical side it has been established that a wide range of turbidities occur and that the majority of Natal estuaries may be classed as being turbid. Close relationships were found to exist between turbidity, substratum particle size, wind speed and wave action. It was also established that the turbidity regimes within estuaries are largely determined by the dominant substratum type and the direction and strength of the wind. No direct relationships were found between turbidity and the other major physical factors, salinity and temperature.

Examination of the ranges and possible influences which all physical factors may exert on juvenile fish distribution led to the conclusion that only three were of any real and direct importance. These were turbidity, The second line of research was to determine whether the common estuarine species were found in all turbidities. Here field sampling, with South Lake - St.Lucia being used as the main study site, revealed that there were certain levels above or below which certain species were either absent or occurred in greatly reduced numbers. Analysis of the data showed that five distinct species groups are present, clear water species (<10 NTU), 'clear to partially turbid' (<50 NTU), intermediate (10 to 80 NTU), turbid (>50 NTU) and turbidity indifferent species.

Comparison of the catch data with the physical factors identified as being potentially important in influencing fish distribution showed that turbidity was the most important. This fact was also shown by the results of a number of statistical tests carried out on the data which were found to be significant.

While all the field data indicated the importance of turbidity, the question of whether a combination of factors or some unknown factor was determining fish distribution, needed to be established. This led to the third part of the investigation, laboratory studies, which allowed the exclusion of all factors except turbidity. These provided significant results for eight of the ten species tested, and the comparison of the field and laboratory results using the Kolmogorov-Smirnov two sample test showed that there was a good fit between the two data sets.

The laboratory results have provided substantiation of the field results and it has been concluded that turbidity significantly affects the distribution of juveniles of the marine species commonly occurring in estuaries. As most species prefer waters >10 NTU, levels above which are considered by most workers to be turbid, it is proposed that turbidity is very important in terms of the protection which it offers the fish. This factor, coupled with an abundance of food and calm shallow waters free of large predators, has led to the estuaries of South East Africa becoming significant nursery areas for a number of marine species.

This study has shown what levels of turbidity exist in a number of estuaries, as well as their influence on juvenile workers have found that increases in turbidity level, brought about by man's activities, could not only alter the species composition within an estuary but could also have detrimental effects on the whole fish fauna present. These facts should all be considered before any manipulatory activities, which could potentially alter the turbidity regime, are undertaken in an estuary. Anything affecting the juvenile populations in the nursery areas would undoubtedly affect recruitment into the population of adults and could thereby cause a radical reduction in the standing stocks of particular species.

10. REFERENCES

AMERICAN WATER WORKS ASSOCIATION. 1975. *Standard methods for the examination of water and waste water*. Washington : American Public Health Association.

ANDERSON, T.R. & ZELDITCH, M. 1975. *A basic course in statistics with social science implications*. New York : Holt, Rinehart & Winston.

AULD, A.H. & SCHUBEL, J.R. 1978. Effects of suspended sediment on fish eggs and larvae; a laboratory assessment. *Estuar. Coast. Mar. Sci.* (*London*), 6: 153 - 164.

BEGG, G. 1978. The Estuaries of Natal. *Natal Town and Regional Planning Report*, 41: 1 - 657.

BEGG, G. 1983. The comparative ecology of Natal´s smaller estuaries. Ph.D. Thesis : University of Natal, Pietermaritzburg.

BLABER, S.J.M. 1974. Field studies of the diet of *Rhabdosargus holubi* (Pisces : Teleostei : Sparidae). *J. Zool. Lond.*, 173: 407 - 417.

BLABER, S.J.M. 1976. The food and feeding ecology of Mugilidae in the St.Lucia Lake system. *Biol. J. Linn. Soc.*, 8(3): 267 - 277.

BLABER, S.J.M. 1978. Fishes of the Kosi system. *Lammergeyer*, 24: 28 - 41.

BLABER, S.J.M. 1979. The biology of filter feeding teleosts in Lake St.Lucia, Zululand. *J. Fish Biol.*, 15: 37 - 59.

BLABER, S.J.M. 1980. Fish of the Trinity Inlet system of Northern Queensland with notes on the ecology of fish faunas of Tropical Indo-Pacific estuaries. *Aust. J. Mar. Freshwater. Res.*, 31: 137 - 146.

BLABER, S.J.M. 1981. The zoogeographic affinities of estuarine fishes in South-East Africa. *S. Afr. J. Sci.*, 77: 305 - 307.

BLABER, S.J.M. 1982. The ecology of *Sphyraena barracuda* (Osteichthyes : Perciformes) in the Kosi system with notes on the Sphyraenidae of other Natal estuaries. *S.*

BLABER, S.J.M. 1984. The diet, food selectivity and niche of Rhabdosargus sarba (Teleostei : Sparidae) in Natal estuaries. S. Afr. J. Zool., 19: 241 - 246.

BLABER, S.J.M. & BLABER, T.G. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. J. Fish Biol., 17(2): 143 - 162.

BLABER, S.J.M. & CYRUS, D.P. 1981. A revised checklist and further notes on the fishes of the Kosi System. Lammergeyer, 31: 5 - 14.

BLABER, S.J.M. & CYRUS, D.P. 1983. The biology of Carangidae (Teleostei) in Natal estuaries. J. Fish Biol., 22: 173 - 188.

BLABER, S.J.M. & WHITFIELD, A.K. 1977. The feeding ecology of juvenile mullet (Mugilidae) in south-east Africa. Biol. J. Linn. Soc., 9(3): 277 - 284.

BLABER, S.J.M., CYRUS, D.P. & WHITFIELD, A.K. 1981. The influence of zooplankton food resources on the morphology of the estuarine clupeid Gilchristella aestuarius. Env. Biol. Fish., 6: 351 - 355.

BLABER, S.J.M., KURE, N.F., JACKSON, S. & CYRUS, D.P. 1983. The benthos of South Lake, St.Lucia following a period of stable salinities. S. Afr. J. Zool., 18: 311 - 319.

BLABER, S.J.M., HAY, D.G., CYRUS, D.P. & MARTIN, T.J. 1984. The ecology of two degraded estuaries on the North Coast of Natal. S. Afr. J. Zool., 19: 224 - 240.

BOLTT, R.E. 1975. The benthos of some southern African lakes. Part V: The recovery of the benthic fauna of St.Lucia Lake following a period of excessively high salinity. Trans. roy. Soc. S. Afr., 41(3): 295 - 323.

BRABBEN, T.E. 1981. Use of turbidity monitors to assess sediment yield in east Java, Indonesia. Proc. Erosion Sediment Transport Measurement Symp., 113: 105 - 113.

CARRIKER, M.R. 1967. Ecology of estuarine benthic invertebrates : A perspective. In Estuaries pp 442 - 487. G.H. Lauf. (Ed.). Washington : American Association for the Advancement of Science - Publication No. 83.

CORDONE, A.J. & KELLY, D.W. 1961. The influences of inorganic sediment on the aquatic life of streams. Calif. Fish & Game, 47: 189 - 228.

CYRUS, D.P. 1980. The biology of Gerreidae Bleeker, 1859 (Teleostei) in Natal estuaries. M.Sc. Thesis : University of Natal, Pietermaritzburg.

CYRUS, D.P. & BLABER, S.J.M. 1982. Species identification, distribution and abundance of Gerreidae (Teleostei) Bleeker, 1859 in the estuaries of Natal. S. Afr. J. Zool., 17: 105 - 116.

CYRUS, D.P. & BLABER, S.J.M. 1983. The feeding ecology of Gerreidae, Bleeker 1859, in the estuaries of Natal. J. Fish Biol., 22: 373 - 393.

CYRUS, D.P. & BLABER, S.J.M. 1984. The reproductive biology of Gerres in Natal estuaries. J. Fish Biol., 24: 491 - 504.

D'ANGLEJAN, B. 1981. On the advection of turbidity in the Saint Lawrence middle estuary. Estuaries, 4(1): 2 - 15.

DAY. J.H. 1950. Unpublished field notes on the Mtamvuna Estuary.

DAY. J.H. 1951. The ecology of South African estuaries. I : A review of estuarine conditions in general. Trans. roy. Soc. S. Afr., 33(1): 53 - 91.

DAY, J.H. 1967. The biology of Knysna Estuary, South Africa. In Estuaries G.H.Lauff (Ed.). Washington : American Association for the Advancement of Science - Publication No. 83.

DAY, J.H. 1974. A guide to marine life on South African shores. Cape Town : A.A.Balkema.

DAY, J.H., BLABER, S.J.M. & WALLACE, J.H. 1981. Estuarine Fishes. In Estuarine ecology with particular reference to South Africa. pp 197 - 221. J.H. Day (Ed.). Cape Town : A.A.Balkema.

DOAN, K.H. 1941. Relation of sauger catch to turbidity in Lake Erie. Ohio Sci., 41: 449 - 452.

DOAN, K.H. 1942. Some meteorological and limnological conditions as factors in the abundance of certain fishes in Lake Eire. Ecol. Monographs, 12: 293 - 314.

DYER, K.R. 1972. Sedimentation in Estuaries. In The Estuarine Environment pp 12 - 32. R.S.K. Barnes & J. Green (Eds.). London : Applied Science Publishers Ltd.

EATON, A., GRANT, V., BRICKER, O. & WELLS, D. 1981. On the use of the Nephelometer in Estuarine waters. Estuaries, 4(4): 379 - 384.

ELLIOTT, J.M. 1977. Some methods for the statistical analysis of samples of Benthic Invertebrates. Ambleside, U.K. : Freshwater Biological Association.

ELLIS, M.M. 1931. A survey of the conditions affecting fisheries in the upper Mississippi River. U.S. Bur. Fish. Fishery Circular, 5; 1 - 18.

ELLIS, M.M. 1936. Erosion silt as a factor in aquatic environments. Ecology, 17: 29 - 42.

GARDNER, M.B. 1981. Effects of turbidity on feeding rates and selectivity of Blue Gills. Trans. Am. Fish. Soc., 110(3): 446 - 450.

GRADALL, K.S. & SWENSON, W.A. 1982. Responses of Brook Trout and Creek Chubs to turbidity. Trans. Am. Fish. Soc., 111: 392 - 395.

GRAY, L.J. & WARD, J.V. 1982. Effects of sedimentation releases from a reservoir on stream macroinvertebrates. Hydrobiologia, 96(2): 177 - 184.

GREEN, J. 1968. The biology of estuarine animals. London : Sidgwick and Jackson.

HEIMSTRA, N.W., DAMKOT, D.K. & BENSON, N.G. 1969. Some effects of silt turbidity on behaviour of juvenile largemouth bass and green sunfish. Bur. Sport Fish. Wildl. Tech. Pap., 20: 3 - 9.

HEMENS, J. et al. 1971. The Ifafa estuary. C.S.I.R. Natal Rivers Project, 36: 29 - 45.

HEMENS, J., METZ, H., SIMPSON, D.E. & WARWICK, R.J. 1973. Natal Coastal Estuaries Environmental Survey, 6 : The Umtamvuna estuary. Prog. Rep. C.S.I.R./N.I.W.R. 26th sterring committee meeting : Marine disposal & effluent., 25: 1 - 10.

HERBERT, D.W.M. & MERKENS, J.C. 1961. The effects of suspended mineral solids on the survival of trout. Int. J. Air Wat. Poll., 5(1): 46 - 55.

HILL, B.J. 1966. A contribution to the ecology of the Mlalazi estuary. Zool. Afr., 2(1): 1 - 24.

HOLLIS, E.S., BOONE, J.G., DE ROSE, C.R. & MURPHY, G.J. 1964. A literature review of the effects of turbidity on aquatic life. Staff report, Department of Chesapeake Bay Affairs, Annapolis, 26 pages.

HORKEL, J.D. & PEARSON, W.D. 1976. Effects of turbidity on ventilation rates and oxygen consumption of green sunfish, Lepomis cyanellus. Trans. Am. Fish. Soc., 105(1): 107 - 113.

HUTCHISON, I.P.G. & PITMAN, W.V. 1973. St.Lucia Lake Research Report Volume 1 : Climatology and hydrology of the St.Lucia Lake system. Pietermaritzburg : Natal Provincial Administration.

HUTCHISON, I.P.G. & PITMAN, W.V. 1977. Lake St.Lucia : Mathmatical modeling and evaluation of ameliorative measures. Civ. Engr. S. Afr., 19(4): 75 - 82.

JOHNSON, I.M. 1977. A study of the phytoplankton of the St.Lucia System. M.Sc. Thesis : University of Natal, Pietermaritzburg.

KRIEL, J.P. 1967. Report of the commision of inquiry into the alleged threat to animal and plant life at St.Lucia Lake, 1964 - 1966. Pretoria : Government Printer.

LANGLOIS, T.H. 1941. Two processes operating for the reduction in abundance or elimination of fish species from certain types of water. Trans. Sixth North. Am. Wildlife Conf., pages 189 - 201.

LEE, J.D. & LEE, T.D. 1982. Statistics and numerical mehtods in basic for biologists. New York : Van Nostrand Rheinhold Company.

LENANTON, R.C.J. 1977. Aspects of the ecology of fish and commercial crustaceans of the Blackwood River Estuary, Western Australia. West. Aust. Fish. Bull., 19: 1 - 72.

LENANTON, R.C.J. 1982. Alternative Non-estuarine habitats for some commercially and recreationally important fish species of south-western Australia. Aust. J. Mar. Freshw. Res., 33: 881 - 900.

LENANTON, R.C.J, ROBERTSON, A.I. & HANSEN, J.A. 1982. Nearshore accumulations of detached Macrophytes as nursery areas for fish. Marine Ecology, 9: 51 - 57.

LUND, G.B.A. 1976. *The propcsed Umfolozi - St.Lucia link canal*. Pietermaritzburg : N.P.A. Building Services Department.

MATHEWS, W.J. & HILL, L.G. 1979. Age-specific differences in the distribution of red shiners, *Notropis lutrensis*, over physicochemical ranges. *Am. Midland Nat.*, 101(2): 366 - 372.

McCLUNEY, W.R. 1975. Radiometry of water turbidity measurements. *J. Water Poll. Contr. Fed.*, 47(2): 252 - 266.

MOORE, P.G. 1973. The kelp fauna of northeast Britian. II. Multivariate classification : Turbidity as an ecological factor. *J. Exp. Mar. Biol. Ecol.*, 13: 127 - 163.

MORONEY, M.J. 1965. *Facts from figures*. Harmondsworth, U.K. : Penguin Books Ltd.

MORTON, J.W. 1977. Ecological effects of dredging and dredge spoil disposal : A literature review. *U.S. Fish Wildlife Ser. Tech. Pap.*, 94: 1 - 33.

NEUMANN, D.A., O'CONNOR, J.M., SHERK, J.A. & WOOD, K.V. 1975. Respiratory and haematological responces of oyster toad (*Opsanus tau*) to suspended solids. *Trans Am. Fish. Soc.*, 104(4): 775 - 781.

O'CONNOR, J.M., NEUMANN, D.A. & SHERK, J.A. 1976. Lethal affects of suspended sediments on estuarine fish. *U.S. Coast. Eng. Res. Tech. Pap.*, 76(20): 1 - 38.

O'CONNOR, J.M., NEUMANN, D.A. & SHERK, J.A. 1977. Sublethal effects of suspended sediments on estuarine fish. *U.S. Coast. Eng. Res. Tech. Pap.*, 77(3): 1 - 90.

ORME, A.R. 1974. Estuarine sedimentation along the Natal coast, South Africa. *Tech. Rep. Office of Naval Research*, 5: 1 - 53.

PANIKKAR, N.K. 1960. Physiological aspects of adaptation to estuarine conditions. *Aust. Fish. Coun. Proc.*, 32: 168 - 175.

POORE, G.C. 1982. Benthic communities of the Gippsland Lakes, Victoria. *Aust. J. Mar. Freshw. Res.*, 33(5): 901 - 915.

RAY, A.A. 1982. *S.A.S. User's Guide : Statistics*. Cary, N.C., U.S.A. : S.A.S. Institute Inc.

ROSCOE, J.T. 1975. Fundamental research statistics for the behavioural sciences. New York : Holt, Rinehart and Winston Inc.

SETTLEMYRE, J.L. & GARDNER, L.R. 1977. Suspended sediment flux through a salt marsh drainage basin. Estuar. Coast. Mar. Sci. (London), 5(5): 653 - 663.

SHIDELER, G.L. 1980. Reconnaissance observations of some factors influencing the turbidity structure of a restricted estuary : Corpus Christi Bay, Texas. Texas J. Sci., 32: 59 - 71.

SORENSON, D.L., McCARTHY, M.W., MIDDLEBROOKS, E.J. & PORCELLA, D.B. 1977. Suspended and dissolved solids effects on freshwater biota : a review. U.S. Env. Protection Agency Report No.EPA-600/3-77-042.

SMITH, J.L.B. 1972. The sea fishes of southern Africa. Cape Town : Central News Agency.

SMITH, M.M. 1980. Marine fishes of Maputaland. In Studies on the ecology of Maputaland. M.N.Bruton & K.H.Cooper (Eds.). Grahamstown : Rhodes University.

SWENSON, W.A. 1978. Influence of turbidity on fish abundance in western Lake Superior. Res. Rep. U.S. Env. Protection Agency Duluth, pp 1 - 84.

SWENSON, W.A. & MATSON, M.L. 1976. Influence of turbidity on survival, growth and distribution of larval lake herring (Coregonus artedii). Trans. Am. Fish. Soc., 105: 542 - 546.

SWENSON, W.A., BROOKE, L.T. & DE VORE, R.W. 1977. Effects of red clay turbidity on the aquatic environment. Center for Lake Superior Environmental Studies, Periodic Contribution, 21: 1 - 24.

TALBOT, F.H. 1955. Notes on the biology of the white stumpnose, Rhabdosargus globiceps (Cuvier), and notes on the fish fauna of the Klein River Estuary. Trans. roy. Soc. S. Afr., 34: 387 - 407.

TAYLOR, R. 1980. A land capability study for Hippopotomuses at Lake St.Lucia, Zululand. M.Sc. Thesis : University of Natal, Pietermaritzburg.

TAYLOR, R.H. (Ed.). 1982. St.Lucia Research Review. Pietermaritzburg : Natal Parks Game and Fish

UNITED STATES GEOLOGICAL SURVEY. 1964. Quality of surface water of the United States. Washington : Government Printing Office.

VAN OOSTEN, J. 1945. Turbidity as a factor in the decline of Great Lakes fishes with special reference to Lake Erie. Trans. Am. Fish. Soc., 75: 281 - 322.

VINYARD, G.L. & O'BRIEN, W.J. 1976. Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). J. Fish. Res. Bd. Can., 33: 2845 - 2849.

WALLACE, J.H. 1974. Aspects of the biology and ecology of the estuarine fishes of the east coast of South Africa. Ph.D. Thesis : University of Natal, Pietermaritzburg.

WALLACE, J.H. & VAN DER ELST, R. 1975. The estuarine fishes of the east coast of South Africa. IV. Occurrence of juveniles in estuaries. V. Ecology, Estuarine dependence and status. Invest. Rep. Oceanog. Res. Inst., 42: 1 - 63.

WALLACE, J.H., KOK, H.M., BECKLEY, L.E., BENNETT, B., BLABER, S.J.M. & WHITFIELD, A.K. 1984. South African estauries and their importance to fishes. S. Afr. J. Sci., 80 (5): 203 - 207.

WALLEN, I.E. 1951. The direct effect of turbidity on fishes. Oklahoma Ag. Mech. College Bull., 48(2): 1 - 27.

WALMSLEY, R.D. 1978. Factors governing turbidity in a South African reservoir. Verh. Int. Verein Limnol., 20: 1684 - 1689.

WALMSLEY, R.D., BUTTY, M., VAN DER PIEPEN, H. & GROBLER, D. 1980. Light penetration and the interrelationships between optical parameters in a turbid subtropical impoundment. Hydrobiologia, 70: 145 - 157.

WHITFIELD, A.K. 1977. Predation of fish in Lake St.Lucia, Zululand. M.Sc. Thesis : University of Natal, Pietermaritzburg.

WHITFIELD, A.K. 1979. Field observations on the lepidophagous teleost *Terapon jarbua* (Forskal). Env. Biol. Fish., 4(2): 171 - 172.

WHITFIELD, A.K. 1980a. A quantitative study of the trophic relationships within the fish community of the Mhlanga Estuary, South Africa. Estuar. Coastal Mar. Sci., 10:

WHITFIELD, A.K. 1980b. A checklist of fish species recorded from Maputaland estuarine systems. In Studies on the ecology of Maputaland. M.N.Bruton & K.H.Cooper (Eds.). Grahamstown : Rhodes University.

WHITFIELD, A.K. 1982. Trophic relationships and resource utilization within the fish communities of the Mhlanga and Swartvlei estuarine systems. Ph.D. thesis : University of Natal, Pietermaritzburg.

WHITFIELD, A.K. & BLABER, S.J.M. 1978a. Scale-eating habits of the marine teleost *Terapon jarbua* (Forskal) J. Fish Biol., 12: 61 - 70.

WHITFIELD, A.K. & BLABER, S.J.M. 1978b. Food and feeding ecology of piscivorous fishes at Lake St.Lucia, Zululand. J. Fish Biol., 13: 675 - 691.

WHITFIELD, A.K. & BLABER, S.J.M. 1978c. Feeding ecology of piscivorous birds at Lake St.Lucia. Part 1 : Diving birds. Ostrich, 49: 185 -198.

WHITFIELD, A.K. & BLABER, S.J.M. 1979a. Feeding ecology of piscivorous birds at Lake St.Lucia. Part 2 : Wading birds. Ostrich, 50: 1 - 9.

WHITFIELD, A.K. & BLABER, S.J.M. 1979b. Feeding ecology of piscivorous birds at Lake St.Lucia. Part 3 : Swimming birds. Ostrich, 50: 10 -20.

WHITFIELD, A.K., BLABER, S.J.M. & CYRUS, D.P. 1981. Salinity ranges of some southern African fish species occurring in estuaries. S. Afr. J. Zool., 16: 151 - 155.