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**AN ASSESSMENT OF THE SANCOR ESTUARIES
RESEARCH PROGRAMME FROM 1980 TO 1989**

BY

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COMMITTEE FOR MARINE SCIENCE OCCASIONAL REPORT NO 1

MARCH 1992

Issued by

Committee for Marine Science

Foundation for Research Development (FRD)

P O Box 2600

PRETORIA

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From whom copies of this report are available on request.

Printed in 1992 in the Republic of South Africa by the University of Cape Town Printing Service.

ISBN 0 7992 1401 9

Cover photograph by courtesy of EMATEK, CSIR. The Knysna Heads from the sea.

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ACKNOWLEDGEMENTS

This assessment would not have been possible without the cooperation of many colleagues who generously gave of their time to discuss many of the issues raised in the text, and contributed to the bibliography. Naturally their opinions and comments influenced my interpretation of my responsibilities in terms of the mandate from the Foundation for Research Development (FRD), but the biases are my own.

My thanks are due to Prof G M Branch of the University of Cape Town and Mr N D Geldenhuys of the National Parks Board who gave generously of their time to review the Assessment and make suggestions for its summary.

My thanks are also due to:

- Mr O A van der Westhuysen and Miss A Schnetler of FRD who provided unlimited access to the reports in their office, and Miss Schnetler contributed further by arranging meetings and air travel;
- Dr A T Forbes of the Department of Biology and Dr T R Mason of the Department of Geology, University of Natal;
- Prof A J de Freitas, Dr M H Schleyer and Miss W D Robertson of the Oceanographic Research Institute (ORI);
- Dr A E L Ramm of the Division of Water Technology (WATERTEK) of the CSIR;
- Dr R Hart and Prof J Heeg of the Department of Zoology and Entomology, University of Natal;
- Mr J Mitchie, Mr A Hansen and Mr B Martin of the Natal Town and Regional Planning Commission, Natal Provincial Administration
- Prof D Baird and Dr T Wooldridge of the Department of Zoology; Prof I C Rust of the Department of Geology, University of Port Elizabeth and Mr J S V Reddering of the Geological Survey;
- Dr A K Whitfield of the JLB Smith Institute of Ichthyology (JLBSII);
- Prof T Hecht of the Department of Ichthyology and Fisheries Science, Rhodes University;
- Dr D I Taylor, Mr C de Villiers and Mr N Grange of the Estuarine Group within the Institute of Freshwater Studies, Rhodes University;
- Dr J R Cooper of the Percy FitzPatrick Institute of African Ornithology, University of Cape Town;
- Dr R A Bally of the Department of Zoology, University of Cape Town;
- Prof J R Grindley and Ms M Sowman of the Environmental Evaluation Unit, University of Cape Town;
- Prof G de F Retief, University of Stellenbosch;
- Dr D H Swart, Mr P Huizinga, Mr P Morant and Mrs H Heydorn of the Division of Earth, Marine and Atmospheric Science and Technology (EMATEK) of the CSIR;
- Mrs S Allanson compiled the bibliography

EXECUTIVE SUMMARY

1. THE IMPORTANCE OF THE SCIENTIFIC FINDINGS

1.1 The rich data source, its analysis and the interpretation of the physical, chemical and biological structure of the **microtidal** estuaries of Southern Africa are represented in the extensive bibliography presented in the **Assessment**. These sources have accumulated since 1980 and have materially increased our understanding of how these ecosystems function. Reference to papers in support of particular points (where relevant) are given in italics after each paragraph. Bold capitals refer to the sections of the bibliography which supports the **Assessment**.

1.2 **Classification**: There are three principal groups of microtidal estuaries:

OPEN : those that are permanently open to the sea, eg Tugela, Breede, Great Fish, Kariega

CLOSED : those which are cut off from the sea for some time during the year. Two principal divisions can be recognised:

- those with varying river input normally low in suspended solids, and which either open naturally or are assisted during the spring by man. eg Swartvlei, Bot River, Palmiet;
- those with wide variation in river inflows and summer flooding with which is associated large quantities of terrigenous sands and silts as a consequence of the relative youth of the river catchments exacerbated by weak catchment management. These are characteristic of Natal.

COASTAL LAKES : extensive wetland systems variously connected to the sea and as a result their physical, chemical and biological characteristics are largely determined by the degree to which they are isolated from the sea and their depth.

1.3 **Sedimentology** : These divisions illustrate the general pattern of estuarine evolution through the Holocene within which there was considerable variation, and about which good core and sedimentological data and interpretation are available. **Increases in the rate of sedimentation over the last 60-80 years and decreases in river inflows are principally of anthropogenic origin.**

Of paramount importance has been the resolution of a number of sedimentological "myths" which have materially influenced our earlier management of estuaries. In so doing it has been unequivocally established that the majority of Cape estuaries are flood tide dominated systems. **In the absence of river floods or more commonly, their attenuation, channel volume is reduced by the accumulation of marine sands. If unalleviated by scour this leads to a reduction in tidal prism volume until the estuary mouth closes. (Reddering 1988 A)**

THIS IS THE FIRST EFFECT OF RIVER FLOW REDUCTION.

While this feature is also characteristic of Natal estuaries, it has a different origin. Terrigenous sediments brought down by the rivers fill the estuarine basin rapidly raising the floor above sea level. Lagoons form in conjunction with sand bars, and where siltation is severe hydrosere succession to dryland is common. **The consequences of drought, water abstraction and gross interference in the hydraulic structure of estuaries over the past 60 years have resulted in some instances in the destruction of the ecosystem. The extremes available are;**

- The Seekoei estuary near Jeffreys Bay which has become a dry sand basin, and

- the Mtwalume estuary in Natal in which sedimentation has become so severe that it is represented by a small lagoon. The elevated floodplain is then exploited by man. (*Whitfield & Bruton 1989 A; Begg 1984 B*)

It is clear from the findings reported and their careful interpretation that sedimentologists can now properly interpret the changes observed in estuaries and predict their consequences. A very valuable example is the pattern of mouth migration of the Keurbooms River estuary as defined by the oscillation of this migration during the past 100 years. **The management implications are immediately obvious, although they are often not accepted by the relevant local authority who try desperately to reverse the phase of oscillation.** (*Reddering 1983 A*)

1.4 **Hydrodynamics:** The microtidal estuaries of South Africa are defined hydrodynamically as:

- well mixed,
- partially mixed and
- highly stratified.

This dynamic classification depends largely upon the discharge volume relative to the tidal prism volume and is illustrated in Figure 1. (*Huizinga 1985 B; Allanson & Read 1987 B; Largier 1986 A; Branch & Day 1987 A*)

All transitions between these conditions can and do occur both seasonally and during tidal cycles. Figure 2 summarises this feature.

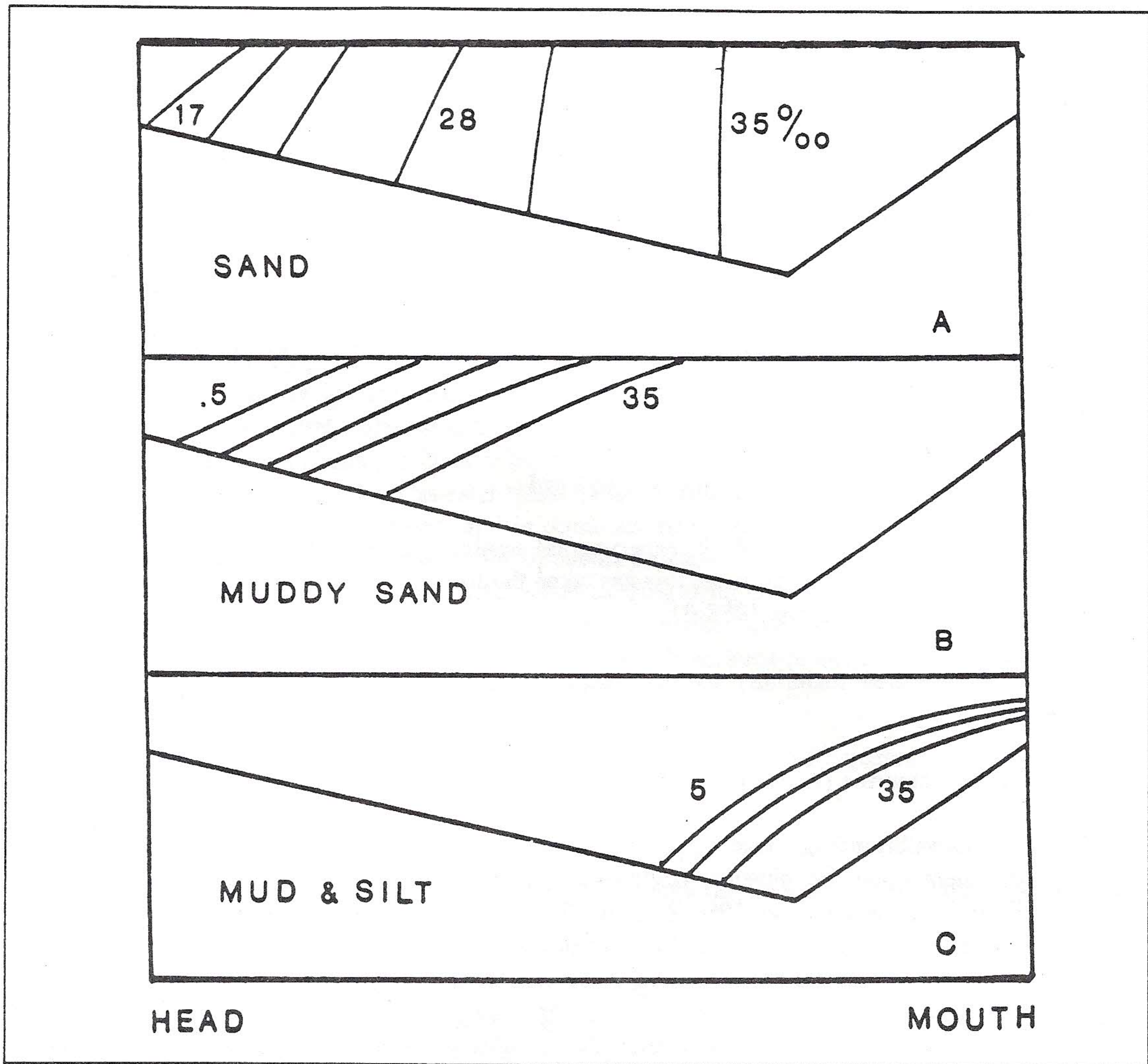
Recognition of these hydrodynamic properties has determined the approach adopted in research but to a lesser degree, management.

Where river inflow is sustained or increases seasonally or demands for freshwater permanently reduce, or seasonally attenuate, the supply to the estuary, its hydrodynamic behaviour can be predicted from Figure 2.

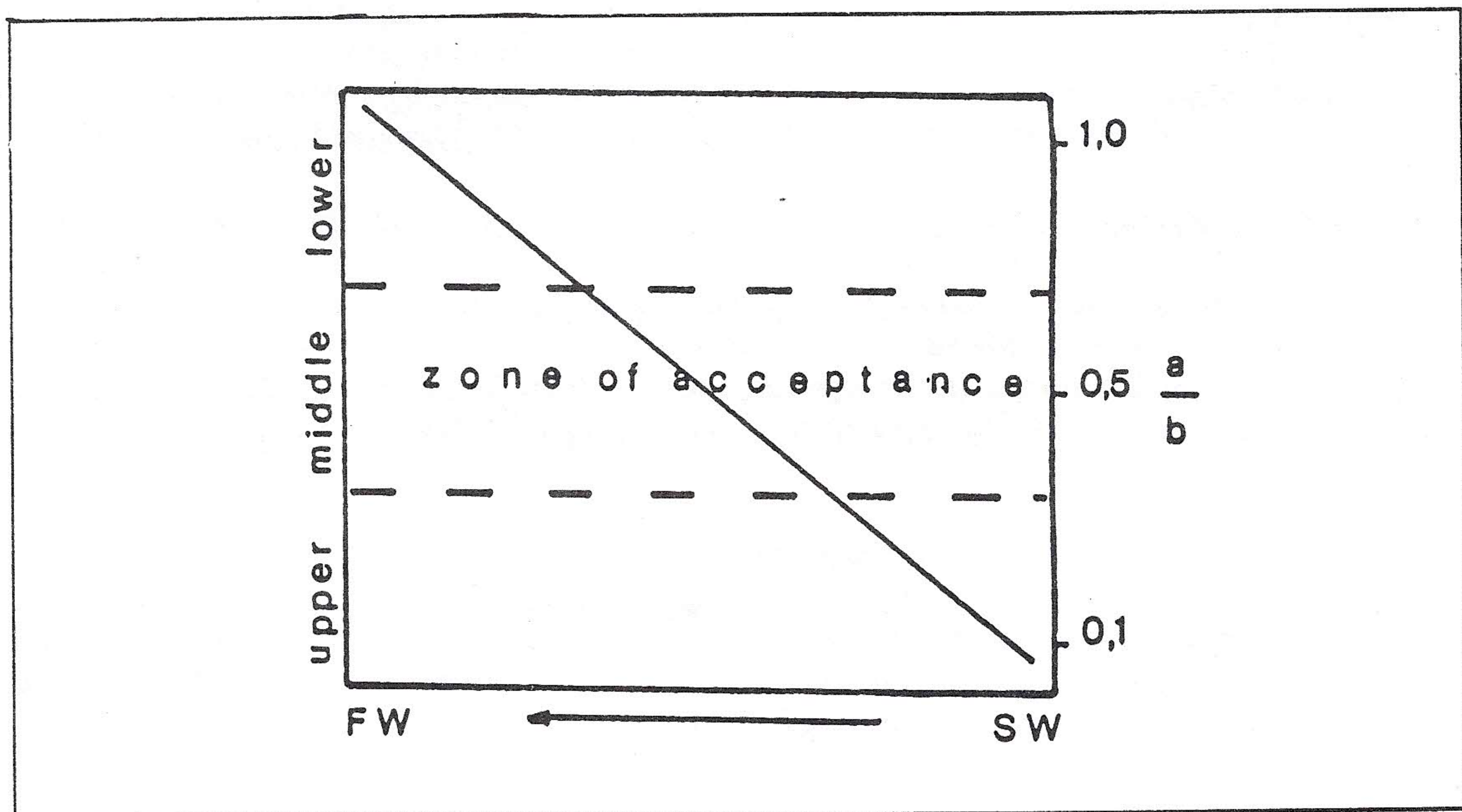
Linked to this model are changes in the sedimentary character of the estuary (see 1.2 & 1.3 above). Thus:

- Where high river inflows occur in association with high silt loads, sand and mud accumulate in the lower estuary;
- conversely where the reduction in river flow is sustained flood tide deltas expand within the lower estuary causing shallowing and channel narrowing; and
- both cause shallowing of the basin of the estuary leading to lagoon formation unless removed by scouring floods.

1.5 **Chemistry:** The chemical structure of the estuaries is moderately well known. Some estuaries such as the Swartkops and Berg River are better known and exhibit elevations of nutrients such as P and N either through sewage effluent access or agricultural runoff. Where this anthropogenic feature is absent, such as in the Swartvlei, Kariega and to a lesser degree the Palmiet, these estuaries depend upon tidal exchange to supply N and P. More recent studies have demonstrated the role of saltmarshes in recycling and generating nitrogen and phosphorus. These studies confirm the earlier work on North American and European systems. **However, no fixed pattern of nutrient export has been established. Some systems are sinks of nutrients (Kariega) while others are net exporters**



- A Well mixed with stratification in upper reaches. [Discharge volume over tidal cycle (a)/volume tidal prism at Spring tide(b)] $a/b = 0.01-0.09$. Kariega River.
- B Partially mixed with stratification in middle reaches (ideal): $a/b = 0.1-0.5$. Kieskamma River.
- C Highly stratified with small tidal incursion in lower reach: $a/b = 0.6- > 1$. Palmiet, Mgeni, Tugela. All become river mouths during floods.



A two-dimensional model of estuarine reaction to changes in the ratio a/b where a = discharge volume over tidal cycle and b = volume of tidal prism at spring tide

(Swartkops). The natural estuaries in the Cape rarely exhibit severe pollution. Those which have been canalised are not included. (*Eagle & Bartlett 1984 B; Emmerson 1985 A; Taylor 1987 D; Baird et al 1987 A*)

Only in a very few systems are heavy metal concentrations in the bottom sediments indicative of such pollution. The Buffalo River estuary is the most contaminated between East London and Mossel Bay. (*Watling et al 1985 A*)

1.6 **Biology:** The biological analysis of estuarine structure and function has been carried out at three levels:

- (a) Single species ecology;
- (b) faunal and or floral community ecology; and
- (c) system description in which experimental analysis is performed to establish the principal interactions. In some instances this has taken the form of quantitative measures of energy transfer and efficiencies. (*Baird 1988 B*)

Each has contributed materially to the present holistic view of our estuarine systems. They have established:

- (d) that the estuarine plants and animals are ecologically robust.
- (e) But, notwithstanding, research has also established the degree to which the estuarine ecosystem is dependent upon the physical environment, (although some biological modulation is evident). (*Wooldridge & Erasmus 1980 A; Hill 1981 A; Blaber et al 1983 A; Achituv & Cook 1984 A; Wooldridge 1986 A; Hodgson 1987 A; Branch & Pringle 1987 A*)

This is particularly evident in the change from macrophytes to phytoplankton communities when turbidity increases occur in the estuary. As turbidity is invariably associated with decreased salinity, those members of the benthos intolerant of sustained low salinities die out. This is followed by an increase in zooplankton abundance as phytoplankton production rises. This community "switching" is common in many south east coast estuaries.

- (f) Of immediate relevance is the role of estuaries in the life cycle of a number of important marine fish. The interaction between the estuary and surf zone has been unequivocally established (see pages 6 and 7 of the Assessment). This imposes a clear management strategy to re-establish tidal exchange during early summer in those systems normally closed by sandbars during the winter if stocks of estuarine dependent species are to be maintained. (*Whitfield 1989 a & b A*)

In this regard it is important to recognise that in contrast to the shallow turbid coastal seas of the Indo-Pacific, the coastal zone around the South African coast is deep and turbulent. Only the estuaries provide the shallow turbid conditions required by many of the juvenile stages of fish and other invertebrate taxa. This is particularly true in Natal estuaries and underlines the urgent need to introduce strategies to maintain tidal flux and re-establish it where realistic to do so in degraded systems. (*Blaber 1981 A; Blaber & Blaber 1980 A; Cyrus & Blaber 1987 a, b & c A*)

- (g) Of equal importance in estuaries is the diversity of benthic animals. While on the one hand the research has established through careful population analysis the effects of bait digging upon the maintenance of viable populations, it has established on the other, the role they play in biological modulation of the physical environment of the sediments through the transfer of oxygen into sediment structure. (*Branch & Pringle 1987 A*)

Thus bait digging has two principal effects:

- to reduce the viability of the population and
 - impair the transfer of oxygen through the sediments with consequent decrease in redox potential leading to anaerobiosis. (Day & Grindley 1981 A)
- (h) The recognition that estuarine ecosystems are detritus based, which in essence means that a very large proportion of the primary production particularly of the intertidal flats and saltmarshes is not directly utilized by grazing herbivores but is degraded bacteriologically, has been responsible for a rather lax attitude towards determination of the precise nature of this detritus, its origin and utilization. Fortunately new investigations have shown that the detritus derived from the most abundant estuarine plants, eg *Zostera capensis* is not a major component (if used at all) in the diet of burrowing animals. This was established by the examination of stable isotopic ratios $^{13}\text{C} : ^{12}\text{C}$ in an array of C3 and C4 plants and in dominant filter feeding animals such as the razor clam, *Solen cylindraceus* and the mud prawn *Upogebia africana*. Plants possessing the C4 photosynthetic pathway such as *Z. capensis* have ^{13}C values ranging from -9 to -19‰. Those with C3 pathways such as the saltmarsh plants, *Sarcocornia* and *Chenolea* have values of -24 to -34‰. What is important to remember is that the detritus derived from such plants retains the same negativity. (Day & Grindley 1981 A; de Villiers 1989 D)

The results show that there are at least three principal sources of depleted ^{13}C . They are

- saltmarsh vegetation,
- terrestrial detritus via flooding and
- riparian litter from vegetation which overhangs the intertidal zone, and to a lesser extent phytoplankton.

The significance of this important work lies in what it tells us about the role of saltmarsh and riparian plants, and floods in the trophic dynamics of the estuary. Remove the saltmarshes, destroy the riparian vegetation and attenuate the floods, and the faunal diversity of the estuary will collapse!

THIS WOULD BE THE SECOND EFFECT OF RIVER FLOW REDUCTION.

- (a) Returning to the array of coastal wetlands reported on page (1), the application of rigorous observation and experiment has established the criteria by which the evolutionary state of the wetland may be judged, and as a consequence its wise management. A particularly good example of this is provided by the investigation of the Bot River lagoon. (Branch et al 1985 A & associated papers)

This system is essentially an estuary in transition to a coastal lake of which Swartvlei and Lake Sibaya are good examples. Management strategies which require the maintenance of strictly estuarine conditions in the lagoon as opposed to simply the reduction in water level will be difficult to achieve. Breaching of the mouth will always result in rapid lowering of water levels in the lagoon and the elimination of water plants, loss of water birds and the wholesale destruction of a complex of invertebrate fauna which use the macrophytes as substrata.

Clearly from a human ecological viewpoint, a strategy of controlled breaching as recommended by the investigation would be preferred. This should happen not more frequently than once every three to four years. By so doing salinities will remain within the tolerance of marine fish species which use the lagoon, although the estuarine and marine representatives of the benthic fauna will gradually die out.

In effect this strategy is attempting to maximise the lagoon environment for man. If his wants could be ignored then the viable option will be to allow the system to evolve naturally to a coastal lake.

The scientific findings outlined in this section of this commentary have been directed uncompromisingly towards exposing the structural and operational parameters of the microtidal estuarine ecosystem so as to advise upon the proper integration and, where necessary, the restriction of human ecological demands.

2. HOW CAN THE SCIENTIFIC FINDINGS BE USED, AND HOW ARE THEY PRESENTLY APPLIED, IF AT ALL?

The human link with aquatic systems is ancient, but it is only in very recent times in South Africa that the impact of man has become retrogressive. The sensitivity of the estuarine environment to human activity both directly and indirectly through developments of river catchments and estuarine flood plains has been unequivocally demonstrated through the scientific findings.

The prime question arising from this activity is: "What are the freshwater requirements of estuaries". As it is the responsibility of the estuarine ecologist (*sensu latu*) to set these requirements, the following guidelines are proposed: (*Jezewski & Roberts 1986 B*)

- (a) While each estuarine system has specific requirements, the model shown in Figure 2 suggests that, ideally, the zone of stratification should occur in the middle reaches of those estuaries which tend towards partial or complete mixing.
- (b) This will have the effect of increasing the biotic diversity by maintaining a rich array of wetland plant communities ranging from the salt intolerant *Phragmites* association of the upper estuarine flood plain to the salt tolerant *Zostera* beds and salt marshes of the lower tidal flats. The complex of C-3 plants among this community, including the riverine riparian, generate particles upon which many of the suspension feeding animals depend. These animals play a pivotal role in the trophic requirements of fish and birds.
- (c) Annual floods to scour the estuarine channel are not always essential, but flooding of sufficient magnitude to scour the mouth should occur every three years. If such a flood regime cannot be accommodated within the hydrological development of the catchment, dredging of the sand bar or the flood-tide delta may be necessary. **Evidence exists which demonstrates the absolute necessity of tidal exchange if the dominant marine component of estuarine plants and animals is to be maintained. Where this exchange is attenuated or stops, the biotic diversity falls as salinity increases through evaporation or decreases through dilution.**
- (d) The gradual attenuation of river flow during the hydrological year is acceptable as the salinity tolerances of the plants and animals have been shown to be wide enough to tolerate such seasonal or annual variation. What is important is to ensure that the condition is not sustained for long periods of time, eg 3-6 years otherwise the brackish water plants and animal associations regress and die out.

During the period under review (see the Assessment), a total of 309 reports were prepared which had as their consumer market, government departments, regional services councils, local authorities, developers and consulting engineers. The extent to which the findings and recommendations contained in these reports have been applied is uncertain. **In many instances the human disregard of the ecological sensitivity of the estuarine ecosystem has been so severe that it required separate description and analysis.** The Reports of the Town and Regional Planning Commission of Natal

prepared by Dr Begg, and more recently those of Ms Sowman from the Environmental Research Unit at the University of Cape Town examine such conditions for the Natal and Cape coasts.

Fortunately we are aware, of the close collaboration developing between EMATEK in Stellenbosch and Provincial authorities. More recently the Department of Water Affairs has made extensive use of the combined knowledge of groups of specialists in preparing recommendations for the Orange River Mouth system.

It would appear that current practice is to involve environmentalists and ecologists directly in the decision making process. This has much to commend it, but its success will depend on how up to date they are with the current literature. To this end I would recommend that the Assessment with its bibliography, highlighting those papers and reports which are of particular relevance be made available to all practising estuarine scientists and coastal environmentalists.

We must at the same time recognise that Act 73 of 1989 known as the Environment Conservation Act, while constituting an advance in our environmental legislation, falls short of insisting upon a proper code of public accountability for development programmes. There is no obligation on the part of third tier government to call for specialist ecological or environmental opinion.

This makes effective application of the rich resources of knowledge about estuarine systems difficult. We depend entirely upon the recognition by the public authority or developer that an environmental problem may arise before interaction occurs. It is at this grass roots level where the most serious lack of understanding occurs. With the present confusion over legislation covering the coastal zone, development in ecologically sensitive areas is a real and constant threat.

3. WHAT OTHER FINDINGS COULD BE APPLIED?

- 3.1 With the extensive and intensive planning and development of marinas, the need to apply the principles of microtidal estuarine physics and chemistry to the design of such marinas is paramount. Failure to do so will result in serious and sustained environmental deterioration of the marina canals and adjacent tidal channels.
- (a) The stratification in microtidal estuaries is dominated by salinity, and to a lesser degree by temperature. Design features must optimise wind driven circulation where tidal exchange is likely to be materially attenuated so as to reduce the likelihood of deoxygenation of the water column with all its unpleasant consequences. (*Huizinga 1987, 1988 B*)
 - (b) Surface runoff will contribute materially to the phosphorus and nitrogen loading which if retention is high will contribute to nuisance algal and macrophyte growths.
 - (c) Where tidal exchange with effectively full seawater is efficient as in the Cape St Francis canals, such growths are minimal and the canals have become a refuge for a rich array of bottom animals. (*Baird et al 1981 B*)
 - (d) Demonstration of the positive role macrophytes such as the ecological equivalent *Potamogeton* and *Ruppia* play in the sequestration of phosphorus and as substrata for an array of filter feeding animals responsible for phytoplankton control. (*Howard-Williams & Allanson 1981 b A; Stewart & Davies 1986 A*)

- (e) Where salinities are expected to fall to between 13‰ and 4 ‰ predominance of *Potamogeton pectinatus* is assured. The subsequent rapid growth of this macrophyte will present management problems. The scientific findings from the studies of the Zandvlei marina, Cape should be carefully examined.

3.2 The dependence of the estuary upon saltmarshes, riparian vegetation and river flow to sustain its particulate food resources needs strong emphasis. In effect what this means is that the components of the estuarine ecosystem and their functional integrity must be preserved. It is repeatedly asked "What is the value of intertidal marshes and contiguous wetlands? Surely they can and should be drained?" The answer is now unequivocal.

4. FUTURE NEEDS

4.1 With the changing social structure of South Africa the demand upon the coastal region will (indeed is) increase(ing) at a rate apparently in excess of the ability of local authorities to handle efficiently. Developers are in demand to create the much needed accommodation and services. The needs are totally anthropocentric.

If this is allowed to continue the accumulated knowledge embodied in the literature will be of archival value only. What is required, therefore, is an aggressive sales campaign in which the needs of the estuary *per se* are spelt out. The consequences of anthropocentric thinking are numerous: the Seekoei and Knysna Lagoon in the eastern and southern Cape, and twenty one estuaries in Natal of which the Sezela lagoon is the most extreme are pertinent examples.

The implication of such a campaign would be that in human ecological terms, Man must be seen as part of these sensitive coastal wetlands. His present overwhelming dominance is leading to their destruction.

4.2 In view of the rich resources of information currently available, the need now is for less fundamental work and a greater application of this knowledge to the solution of specific estuarine problems. Three areas are immediately relevant:

- (a) The origin, identification and utilization of food particles by estuarine suspensoid feeders, and
- (b) The chemical composition and properties of estuarine water. No substantial body of data exists. There is a real need to properly evaluate existing conditions during spring and neap tide cycles. The role of the Continuous Low-level Environmental Observations (CLEO) programme in this regard needs careful examination.
- (c) The creation of a more sensible management policy for the maintenance of tidal conditions in estuaries during the most critical period of fish migration, namely early summer. The effect of this will be, in many instances, that the estuary will remain tidal for a long period during summer, notwithstanding the reduction of river flow due to drought or catchment development. If this could have happened in the case of the Seekoei estuary, the ecosystem would not have collapsed.

INTRODUCTION

South Africa has a coastline of some 3100 km (Figure 3) and has seen, during the decade, an increasing awareness of its value as a focus of human settlement. This, coupled with the severe drought which has existed or still exists in the catchments of the major river systems which open along this coastline, has resulted in the inflow of freshwater being severely reduced. This condition has been further exacerbated by the need to impound much of the flow upstream of the estuaries.

The impact of these and other anthropogenic activities have caused or are causing material and often irreversible changes in the structure and function of the estuarine ecosystem. While there has been an awareness of these changes, particularly in Natal where their effects are immediately obvious in gross estuarine degradation, the research emphasis generally prior to 1982 was largely biological.

In 1976 Dr G W Begg was appointed by the Natal Town and Regional Planning Commission as co-ordinator of their estuarine research programme with the objectives:

- to assemble existing information on Natal estuaries
- to describe and examine the parameters which define the equilibrium state of Natal's estuaries, so as to clearly understand the natural forces which govern their existence and form, and to ensure that these factors can be taken into account in developmental planning.

In 1979, the National Research Institute for Oceanology (NRIO) (now EMATEK) was commissioned by the Department of Environmental Planning and Forestry (now the Department of Environment Affairs) to put together all available knowledge on the 167 estuaries of the Cape Province between the Kei River in the northeast and the Orange River in the northwest.

This request resulted in the establishment of the Estuarine and Coastal Research Unit (ECRU) under the direction of Dr A E F Heydorn within the Institute, which has resulted in a remarkable series of synopses of information on 41 of the major estuarine systems in the Province.

While these developments were in direct response to central or provincial government's appreciation of the need to control the development of these sensitive environmental areas along the coastline, there was an equal need to assemble what had been learnt about South Africa's estuaries, since the inception in 1947 of the studies of Knysna, Hermanus and Lake St Lucia by Prof J H Day and his colleagues at the University of Cape Town. The South African National Committee for Oceanographic Research (SANCOR) was instrumental in getting this done by inviting Prof Day to take on the task with the principal term of reference "the review was to be based on international researches so as to reveal the gaps in our knowledge" (Day 1981). The success in attainment of this goal may be judged from Hedgpeth's (1983) review in the Quarterly Review of Biology: "in all respects this book deserves to be a classic work available in every estuarine and coastal research laboratory."

This synthesis is sufficiently well known not to require any further commentary except to emphasize that it laid the foundation for a more holistic approach to estuarine work. This was deemed essential for any significant advance in our understanding of these ecosystems beyond the descriptive and ecophysiological ecology of earlier years. This approach was further assisted by the review by Nixon (1981) in which he examined twenty years of speculation and research on the role of saltmarshes in estuarine productivity and water chemistry. The purpose of this review was to examine the validity of a number of well known, but not necessarily very critical hypotheses about the way estuaries worked. Thus the concept, for example, of "outwelling" in marsh-estuarine fluxes had become sufficiently embedded in how we think about estuaries, that it had reached paradigm status. There was clearly a need to re-examine the validity of these ideas in the light of what was already known about estuarine function which, in quantitative terms, was minimal (Day 1981), for estuaries of the geomorphological and hydrodynamic character of the South African coastline.

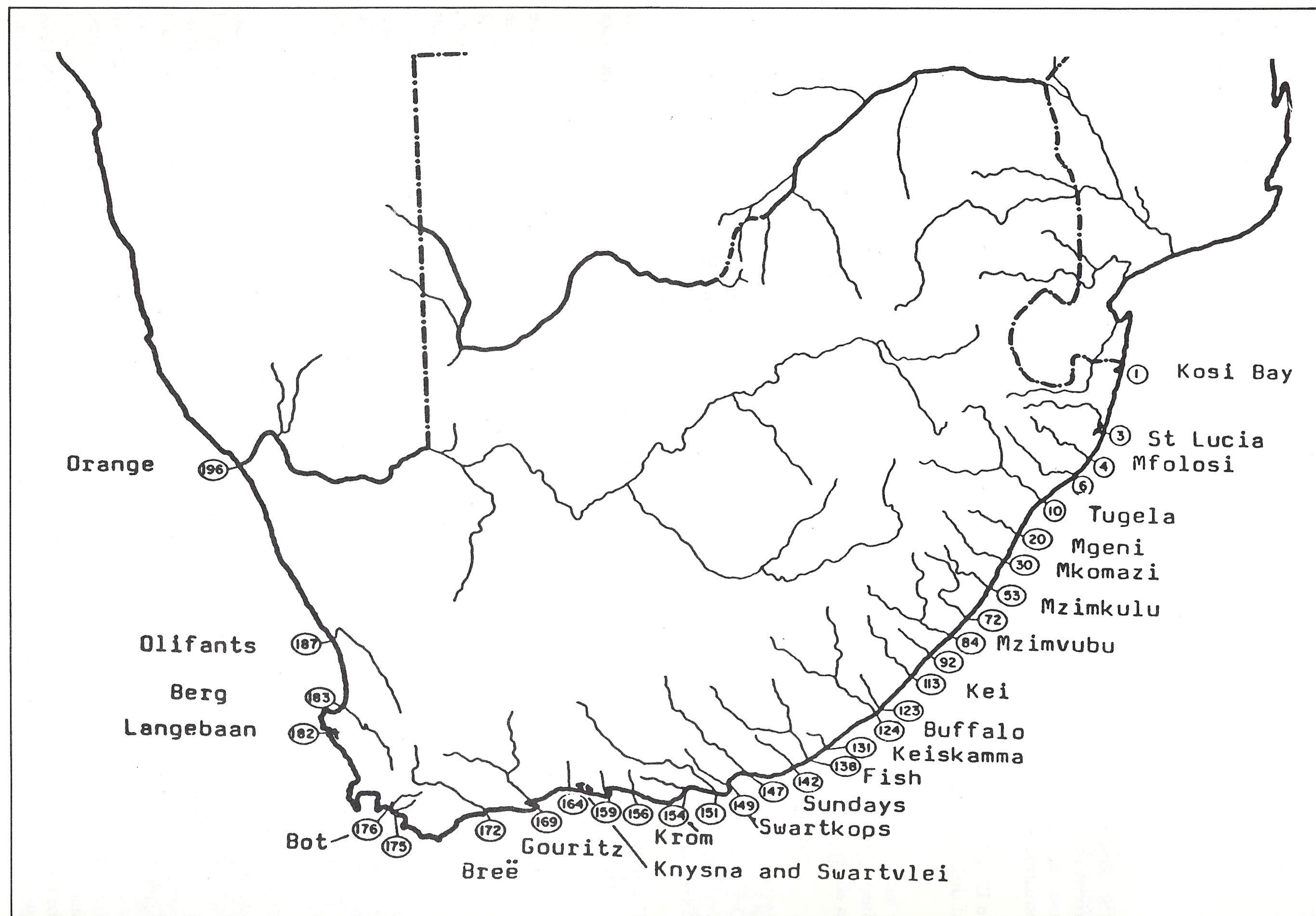


FIGURE 3

The position of some of the estuaries referred to in the report and bibliography.
From Noble and Hemens (1978) : Figure 9 and Table 8

By 1982 the support for estuarine research had been placed under the control of a National Programme, with the objective 'to provide a scientific understanding of estuaries - in particular of the interactive physical, chemical and biological processes within them, of their interactions with fringe areas and with their adjacent marine and terrestrial environments and finally of human impact upon them - thereby contributing information required for their wise management' (SANCOR 1983).

The assessment at the request of the SANCOR Estuaries Committee, which follows, examines in how far the research and management community have realized the goals of the National Programme, through which the research has been funded. I have been guided less by the structure of the published programme than by the annual reports which reflect the interpretation adopted by the research community.

PRINCIPAL FINDINGS

GEOMORPHOLOGY AND HYDRODYNAMICS OF SOUTH AFRICAN ESTUARIES

The geomorphological structure of the coastal rimland of South Africa is dominated by the presence of four major lineaments and fault patterns. These have been neatly summarized by Heydorn and Tinley (1980). Along the west coast the Namib monocline results in the coastal margins being tilted seawards, but differentially in the southern and northern sectors. The Natal monocline has resulted in a similar tilting of the coastline of Natal; while along the south coast the eastward-trending axis of the Cape Fold Belt of great antiquity has resulted in steeply flowing rivers as well as large embayments formed in the troughs of the seaward terminations of the fold valleys of the Cape Rocks.

The overall effect is an upwardly warped coastline upon which have been superimposed cycles of erosion and sedimentation. Much of the present estuarine scenery is the result of river rejuvenation during the last glacial period and reworking of the eroded sediments as the sea returned and transported the reworked material by coastal hydraulic processes filling them to depths of 35 m or greater.

The estuaries are small in area and together cover some 600 km² or 0.2 km² per km of coastline, compared with the USA with approximately 10 000 km of coastline in which estuaries cover an area of 107 722 km² (Begg 1984), or some 11 km² per km of coastline.

Reddering (1988) has determined the characteristics of the estuaries of the south east coast between Knysna and East London as small Ria-type with tidal prisms usually 10⁶ m³ or less. The channels are narrow, occupying drowned, incised river valleys. The tidal inlets are often restricted or blocked, and whereas the ebb-tide deltas are poorly developed, flood-tidal deltas are well developed, indicating that the estuaries are wave-dominated.

Many of these facies are to be found in the estuaries of Natal, a well watered area of the Republic lying to the east of the massive Drakensberg erosion scarp. The differences in estuarine scenery which do exist are entirely due to the remarkable geological paroxysms which the region has experienced since Pliocene times, resulting in a principal axis of uplift, the Natal Monocline. The subsequent huge valley excavations (King 1972) which fashioned the scenery of Natal during the Quaternary were subject to repeated inundation as the coastline increased in height with rising sea level. Marine and fluvial debris filled the drowned valleys.

In the Mfoloze River valley 16 km from the sea >67 m of alluvium were penetrated before bedrock was reached (Hobday 1979). Thus there has been an estuarine history of sedimentation in which fluvial inputs appear to play a more prominent role than in the more arid southern and western coastal systems.

It is against this background of geomorphology that the multidisciplinary investigation of the estuaries has developed.

SEDIMENTOLOGY

The development of Research on Sedimentation in Estuaries (ROSIE) and Sedimentation in Estuaries and Lagoons (SEAL) are major programmes supported by SANCOR through the initiatives of Prof I C Rust at the University of Port Elizabeth and Prof T R Mason at the University of Natal. Both programmes have precisely described the sedimentary structure of a number of estuaries and the relative contribution of fluvial and marine sediments. Together these programmes, in association with the Geological Survey, NRIO and the University of Cape Town have established the facts as opposed to the myths of sedimentation processes and rates of accumulation.

The contribution of these groups to the primary literature and the supply of technical reports of direct and immediate value to environmentally concerned groups satisfy the requirements of SANCOR.

As so many of the ecological processes within this particular aquatic environment are written in their sediments, a continuing and penetrating research programme which incorporates the estuaries of the south and east coast is required.

HYDRODYNAMICS

The spring tide tidal range along the coast increases from microtidal (1.6 m) in the west to the transition between micro and mesotidal (2.4 m) at Durban. This tidal range coupled with the shallowness of the estuary results in the small tidal prisms of all but one or two estuarine systems, eg Knysna and St Lucia. In such estuaries surface salinities increase steadily down the estuary and undiluted fresh water only occurs near the head of the estuary. There is also a longitudinal gradient of salinity in the bottom water, and a zone occurs some distance from the mouth where vertical salinity gradients are marked. Such estuaries are known as "partially mixed". Where freshwater inflow is reduced or falls to zero during severe droughts the estuary is rapidly mixed and negative salinity gradients develop.

Because of these features the tidal and seasonal density structure of the water column is particularly sensitive to short-term changing patterns of river and tidal inflow and ephemeral changes in sea temperature.

The development of a one-dimensional hydrodynamic and transport-dispersion model by Mr P Huizinga's group at NRIO has materially assisted in the design of properly constructed investigations of water level and flow variations, and the influence of freshwater flows upon horizontal salinity distribution. It is now possible to measure quantitatively the distribution of pollutants, the flux of nutrients through various cross-sections and the influence of the diverse man-made structures such as rail and road bridges upon flow patterns and sedimentation. As yet it does not allow modelling of the internal vertical density structure of the estuary.

An impression remains, however, that the real significance of these studies and the value of the one-dimensional model will only become apparent when current studies on nutrient flux, the distribution of pollutants and the role of tidal flow in the transport and distribution of fish larvae are complete.

CHEMISTRY

It is but a small step from the definition of the hydrodynamic properties of an estuary to a consideration of their nutrient status, the flux of nutrients and their determinants.

The overall impression gained from the reported literature (Appendix A) is that the chemical structure and the dynamics of particular chemical substances is poorly recorded for the majority of South African estuaries. The chemical structure is usually described from spot samples taken at various points along the estuary often separated by long periods of time and with little reference to tidal state! The work of

Dr R J Watling on metal cation levels in estuarine surface sediments, cores and the water column has provided an excellent framework of reference for unpolluted river catchments, such as the Fish, Bushmans and Kariega. Comparable studies on the estuaries of Natal appear not to be available for the period of this assessment, although Mr W D Oliff during the 1970's in a series of reports on the pollution of Natal estuaries recorded the concentrations of heavy metals. These data have been incorporated in Begg's (1978) assessment of Natal's major estuaries.

The concentration and distribution of the nutrient anions of nitrate and phosphate are usually presented as an adjunct to primary production studies, and rarely studied for their own sake. However, the recent work of Dr G A Eagle and his team at NRIO is a useful assembly of such data from four winter rainfall systems.

Recent studies at the University of Port Elizabeth have applied correctly designed sampling programmes to the measurement of the flux of nitrogen and phosphorus through given cross-sections. Only in this way will it be possible to properly interpret the relative contributions of river and tidal inflows and tidal saltmarshes to the total flux of ions in the estuarine ecosystem.

While there exist in the literature reported in Appendix A numerous records of the chemical quality of estuaries, their meaningful integration into the proper study of ecological processes is difficult, and cautions against this persistent anecdotal sampling. Fortunately, the data reported indicate that, with quite rare exceptions, the chemical quality of the tidal reaches is good. Much of this is a consequence of the daily exchange of the intertidal volume of the estuary with fresh seawater, a hydrodynamic characteristic which gives an apparent tolerance of an estuary (eg Swartkops) to potentially polluting freshwater inflows.

BIOLOGY

In common with all estuarine or coastal wetland studies worldwide, there is a marked emphasis upon the biological structure of these systems in South Africa. The reason for this is the comparative ease of sampling and the powerful integrative properties of plant and animal associations. Thus provided that the diversity of taxa and community structure is recognised as unexceptional, the ecological or environmental health of the system is assured. While there is a good deal of ecological sense in this approach, it has perforce limited, somewhat, the scope of ecological thinking and practise during the years of the review.

Few groups have broken out of this mould, but the fact that some have will encourage the wider and hopefully more productive interdisciplinary process approach.

MACROPHYTES AND PHYTOPLANKTON

The most significant work since the publication of Prof Day's detailed review of the composition and distribution of estuarine plants is the detailed study by Pierce (1982, 1983) of the rice grass, *Spartina maritima*. Her sensible and timely ecological interpretation of the role of *S maritima* in the estuaries to the east and west of Algoa Bay, a likely site of introduction between 1829 - 1830, seems **not** to have received the attention it deserves.

Largely contemporaneous with this work were the detailed investigations of the macrophyte community of the Swartvlei ecosystem (Howard-Williams & Liptrot, 1980). An array of dominant taxa from the freshwater-brackish tolerant *Potamogeton pectinata* through *Ruppia cirrhosa* to *Zostera capensis* were studied in considerable ecological detail, particularly as regards the role they play in phosphorus mobilisation in the estuary. Although this work was not directly funded by SANCOR, it laid the foundation for similar work in other systems, eg the Bot River Lagoon system, and the Kromme River Estuary. Comparable studies in Natal are sparse, although the work on mangroves continues to be important.

The predominance of macrophytes in the estuaries of South Africa has tended to draw attention from the structure and productivity of their phytoplankton. The taxonomic studies of Prof R N Pienaar in Natal have described eight algal families found in the Mhanga River estuary. Biological studies on *Pyramimonas pseudoparkae* have shown dependence upon extra-cellular products of bacterial metabolism and that the genus *Prymnesium* is euryhaline. *P. parvum* appears to be the commonest of the likely nuisance or toxic taxa. This work seems not to be continued after 1981. The Bacillariophyceae are the most diverse taxon present with *Coscinodiscus* spp and *Bacillaria paxillifer* common at all salinity fluctuations.

ZOOPLANKTON

One of four faunal groups in estuaries which are very well known; the second, third and fourth are the benthos, fish and birds, respectively. Fortunately, Grindley (1981) is an effective synthesis of work on this heterogeneous group up until that time. Subsequently, the synthesis has provided the foundation for more detailed and specific studies in the coastal lakes and lagoons of the south coast and the estuaries of the south east coastal region. The emphasis in this later work, particularly at Rhodes University and the University of Port Elizabeth, was to inject a much needed quantitative approach, in which the structure and the behavioural and trophic responses of the estuarine zooplankton are examined in relation to salinity and temperature and their interaction. From this work we begin to see with greater clarity the mechanisms which play a definitive role in the retention of zooplankton within an estuary. The innovative studies of Whitfield (1989 a, b) on the ichthyoplankton of Swartvlei and its estuary have given firm data on recruitment into an estuary of particular fish taxa and emigration from the estuary. The further significance of this study is commented upon on pages 6 and 7.

BENTHOS

The structure of the benthos of the estuaries is well known from the earlier work of Prof J H Day and his colleagues. It comes as a somewhat refreshing surprise to see that this rich field of investigation has not been entirely forgotten in the changing emphasis given to ecological research by, for example, the systems approach.

In the Kariega estuary, reduced freshwater inflow increased transparency with consequential expansion of the *Zostera* beds. The stable physical conditions allowed the development of a rich macrobenthos Hodgson (1987). For Langebaan lagoon a University of Cape Town project under the direction of Prof G M Branch was designed to investigate the ecological roles which five key species, *Callinassa kraussi*, *Assiminea globosus*, *Arenicola loveni*, and *Patriella exigua*, play in the economy of the tidal lagoon.

In general these species enhance bacterial numbers and biomass, and reduce the density of diatoms and meiofauna. Sand prawns are prodigious burrowers, oxygenating the sediments through this activity. They are the only abundant animal which subserves this function in the lagoon. The research has demonstrated the importance of biological modulation in such ecosystems which are generally thought to be under the control of physical forces. Thus exploitation by Man through bait digging is seen as a negative factor due to the gross disturbance of the sediments, and the time it takes for the recovery of the macrofauna.

The 1980's saw the end of a productive period of ecophysiological work on the macrofauna of estuaries. The studies at Rhodes University on the feeding biology of the portunid crab, *Scylla serrata* and on the respiratory adaptations of three species of the thalassinid genus *Upogebia* are particularly valuable examples of the important contribution such work can make to understanding the structure of the multidimensional niche of a given species. Fortunately this approach has been extended more recently to other benthic invertebrates, notably the razor clam, *Solen cylindraceus*, about which we now know a good deal regarding the factors in control of filtration efficiency and osmotic tolerance.

The high quality of the journals in which much of this work has been or is being published should be noted from the record in Appendix A.

NEKTON

Moving from the largely benthic to the nektonic estuarine component among the invertebrates, the studies by diverse groups of the penaeid prawn assemblage which are seasonally common in the estuaries of the east and south east coast require specific mention, if only to highlight the fragmentary nature of our knowledge and understanding of the ecology of this complex. At least three taxa are recorded in commercial catches: *Penaeus indicus*, *P monodon* and *Metapenaeus monoceros*. *P japonicus* is apparently not important in the fishery.

The investigation at the University of Port Elizabeth of the carid shrimp *Palaemon pacificus* by Dr W D Emmerson, which includes its exchange between the sea and the estuary, and its seasonal abundance and production, could contribute to a redefinition of the penaeid studies in St Lucia, as they are characterised by rigorous field and laboratory experimental design.

The second component of the nekton is fish, and this group has been extensively studied. At least 22% of the contributions to the primary literature have dealt specifically with this fauna. Three major research sites are apparent:

- In Lake St Lucia during Dr S J Blaber's period at the University of Natal;
- the Swartkops estuary under the direction of Dr J F K Marais at the University of Port Elizabeth; and
- at Swartvlei, Sedgefield during Dr A K Whitfield's appointment in the Institute for Freshwater Studies at Rhodes University. New foci have developed as the originators moved away or were replaced.

Apart from the more general descriptive studies of diversity and distribution, these investigators examined the nature of the competitive or predator-prey interspecific reactions, the structure of estuarine food webs and the degree of estuarine dependence. This latter has received wide attention and in so doing has removed many of the uncertain and previously poorly argued hypotheses upon which management proposals could have been based.

The results and interpretations of the diverse array of projects have been brought together in the broader context of zoogeography, specifically the Indo-Pacific region. Blaber (1981) has argued convincingly that the remarkably close affinity of the fish of the south east coast of Africa (63% of the species in St Lucia have been recorded in south east Asian waters) is due very largely to the properties which the estuaries share with extensive seas of the Indo-Pacific. They are shallow, turbid, warm systems with varying salinities. As the coastal seas of Southern Africa are far removed from this characterization, the estuaries offer environmental conditions suitable for the juveniles of many species and as feeding grounds for adults.

Obviously there is subtraction as these estuarine qualities are replaced southwards and westward. Nevertheless, the quantitative approach adopted in the Swartkops estuary and adjacent seas and further developed in the Swartvlei system have provided unequivocal support (Whitfield 1989 a, b) that:

- Most fish found in estuaries are dependent upon a link between the estuary and the sea to complete their life cycle.
- This link is particularly important during early summer when most ichthyoplankton interchange takes place. Thus barriers to this migration such as sand bars will prevent larvae of estuarine spawners from reaching the sea, and conversely the larvae and post larvae of marine species from entering the estuary.

- For those species which live in estuaries and which breed in the sea (eg *Monodactylus falciformis*) the surf zone is an important transitional environment for the metamorphic larvae before they pass into the estuary. It appears that this zone is used as an interim nursery area before the quiet, productive waters of the estuary are invaded.

The implications for the wise management of a spectrum of estuaries are obvious.

The diversity of the research projects has firmly established the structure of the estuarine fish community, and its tolerance of and preference for a variety of environmental conditions. A number of "trophic interactions" has been worked out within the estuarine food web, but the plasticity of the dominant predators in being able to adjust to substantial change in, for example, turbidity further emphasises the familiarity with such varying conditions. Studies on the food accepted by the spotted grunter, *Pomadasys commersoni* in south coast estuaries of contrasting turbidity by students in the Department of Ichthyology and Fisheries Science at Rhodes University has provided useful input in this field.

The fact that so much of this work has been published in widely read, high level scientific journals attests its high quality at an international level.

BIRDS

The diversity of birdlife found on the estuarine floodplains and associated wetlands is related to the high productivity of the community of invertebrates. While this may seem axiomatic, what was less clear in 1981 when Prof W R Siegfried reviewed the estuarine avifauna of Southern Africa was the interaction between the bird species and their prey. This review did, however, make considerable advances in the analysis of the geographical distribution of the resident species and resulted in the definition of two biotic provinces : a west coast province extending southwards from southern Angola, and a tropical avifaunal province along the east coast of Africa with a zone of overlap between the provinces stretching from Cape Point to the Transkei. Within these provinces, the proportion of migrant and resident species which feed mainly on invertebrate food stocks is 54% of the total number of species known to occur in the estuaries during the austral summer.

One of the principal foci of feeding studies during the period under consideration was the Swartkops estuary. The majority of the birds (92%) were recorded on the intertidal mud and sandflats where densities ranged from 12 - 38 birds per hectare, which is high compared with other sites in South Africa and abroad. A positive correlation was established between bird density and the biomass of the principal invertebrate prey, *U africana* in the lower reaches of the estuary.

Piscivores on the other hand tended to be distributed throughout the estuary. These studies coupled with the searching review by Baird *et al* (1985) on the utilisation by shorebirds of benthic invertebrate production have provided useful estimates of consumption. Thus at Langebaan these authors report that invertebrate feeders consume 20% of the total invertebrate production of 705 KJ m² y. Preliminary estimates for the common tern in Swartkops indicate that some 56% of their daily ration is made up of *U africana*. The remainder is made good from the intertidal of Algoa Bay. I have cited these data to impress upon my readers that quite considerable advances in the predator-prey interaction in the estuarine ecosystem have developed since 1981. Taken together with similar studies in the rocky intertidal zone, a reasonable body of quantitative information is available. This should allow the inclusion of shore birds in models of energy and nutrient transfer in these systems.

PROCESS ORIENTATED STUDIES

This more holistic attitude to the study of estuarine function developed contemporaneously with the reductionist research approach. In my view the rich resources of data and interpretation which are available

from the reductionist have increased the overall success of the projects which have chosen the more integrative method.

One of the earliest programmes to adopt this method was developed in the Swartkops and Kromme River estuaries by Prof D Baird and his colleagues at the University of Port Elizabeth. The currency chosen was energy (KJ). The principal conclusions draw attention to the key positions of *Gilchristella aestuarius* and *U. africana* in the food web. *G. aestuarius* because of its permanence in the water column "forges a strong link" (Baird 1988) between the zooplankton, bird and fish predators, while the burrowing prawn is a major prey species of a diverse avifauna and fish. It contributes some 55% of the total benthic invertebrate production in the Swartkops estuary.

This research group has also provided measurements of the magnitude of the flux of an array of particulate and soluble materials through the mouth of the estuary. They have established that the Swartkops system is a net exporter of energy and nutrients to the coastal zone of Algoa Bay, giving support to the "outwelling" hypothesis of E P Odum. These investigations are complemented by a number of other flux studies. Examples are the saltmarsh studies of Dr D I Taylor in the Kariega estuary and that of Prof G M Branch, Prof J A Day, Dr J Largier and Ms S Taljaard on the Palmiet estuary. Apart from the detailed information which these particular sites have respectively provided on the flux of nutrients from a saltmarsh *per se*, and the transport of particulate and soluble materials in a strongly stratified estuary, they also point to the variation in the net direction of such fluxes from one estuary to another.

The integrative nature of these studies is an important characteristic if the systems approach is to be successfully applied to any study site. However, it remains essential that ecological paradigms be subject to wise scrutiny. Thus while recognising that much of the primary fixation of energy as reduced carbon makes its way via the detritus pathway, it is unwise to argue that such material, particularly if internally generated from *Zostera* and *Spartina*, is used as the food of suspensoid feeders, tempting though it might be.

The as yet unpublished studies, by Mr C J de Villiers at Rhodes University, on the $^{13}\text{C} : ^{12}\text{C}$ isotope ratio in *Solen cylindraceus* and *Upogebia africana* and of the particulate material in the size range normally utilized by these filter feeders, have shown the somewhat unexpected $\delta^{13}\text{C}$ ratio of *Solen* to be $> -24\text{‰}$ in the region where the bivalve is abundant in the Kariega estuary. This value matches very closely the $\delta^{13}\text{C}$ ratio for the terrestrial plants which border or overhang the estuary in this region. Granted, where more than one source of food is likely, conclusions drawn from too rigid an application of this ratio could be ambiguous (Mann 1988). Nevertheless, this and complementary studies elsewhere caution against the uncritical acceptance of autochthonous derived detritus as a significant food source in food web studies.

ENVIRONMENTAL INVESTIGATIONS AND THEIR SOCIO-ECONOMIC CONSIDERATIONS

I am impressed by the remarkable fitness of the environmental investigations which have been either completed or initiated during the last 10 years. They are strongly biased towards understanding the impact of Man in one or other specific way upon this sensitive environment. In so doing they have focused attention initially upon one of the four main areas of human ecology (Erlach 1985), namely the impact of human beings upon their environment.

Within the array of environmental studies, those of the ECRU series "Estuaries of the Cape", and the Town and Regional Planning Commission reports, "Estuaries of Natal", Begg (1978, 1984) are of major importance. These remarkable works are encyclopedic in concept, and together with "The Comparative Ecology of Natal's Smaller Estuaries", published in 1984, are rich sources of biological and environmental information and interpretation, about a diverse and sensitive coastline.

It is essential that local authorities and in particular Regional Services Councils make themselves familiar with the extent of the information these reports provide.

The numerical analytical techniques which are applied in Dr G W Begg's work have materially reduced an extensive data set to a level where sensible interpretations become possible. Wise use has been made of the "indicator community" concept, and while the conclusions drawn are unexceptional, they are by their very simplicity capable of rapid assimilation by management systems.

It points unerringly to the principal agents of environmental degradation which are made that much more urgent because of the landscaping processes which have characterised the Quaternary, and more specifically the Holocene in Natal. Such an agent is the increased rate of soil erosion by agricultural developments during the past 80 years.

While there appears to be some disagreement that the sediments of the estuaries of Natal are directly the result of this activity, the fact is inescapable that many of the estuaries are rich in recent sediments. This coupled with the construction of dams in the mainstem rivers now decreases the eroding effects of moderate floods. Those of cataclysmic proportions such as DEMOINA erode the rivers almost down to base levels. But even the scouring of the Mgeni estuary was rapidly made good by sedimentary infill after the flood peaks had passed.

But perhaps the most lasting contribution these investigations have made is the clear identification of three stadia in the contemporary evolution of an estuary in Natal. The stadia are

- the open tidal system, generally partially mixed with a horizontal salinity gradient;
- the lagoon stadium which implies a largely permanent closure of the mouth resulting in decreased salinities; and
- a river mouth in which the river flow is displaced vertically above sea level so that no salinity gradients occur. This last stadium is directly the result of increased sedimentation rates.

Furthermore, this is one of the patterns of serious degradation which has contributed to the declining CPUE for those marine line fish which are associated with or dependent upon estuaries during their life cycle.

Just as these studies were extensive in their treatment of estuarine conditions, those of Prof G M Branch and his colleagues in the Bot River Estuary were intensive. The symposium held under the auspices of the Royal Society of South Africa and published in 1985 brought together a variety of disciplines including sedimentology, hydrology, history, botany, invertebrate and vertebrate zoology and chemistry to describe the recent and geological history of the lagoon and its bio-physical and chemical structure under lagoon and tidal conditions. The resultant management options derive from a wise fusion of results from a directed research programme. The question arises : who can, or will, sensibly implement them?

Another area of environmental concern relates to the freshwater requirement of estuaries, Jezewski and Roberts (1986). This vexed question has been partly addressed by the work of Dr G H L Read on the Kariaga River. While the maintenance of the tidal prism ensures the diversity of the estuarine fauna, Reddering (1988) has established that reduction in river discharge, by for example dam construction on the main stem river, lengthens the periods between river floods. The severity of this effect will depend upon the capacity of the reservoirs relative to the mean annual runoff. His paper is important for the further good reason that it describes the sedimentological processes which are emphasized, such as shoaling and the compaction of mud which makes it more resistant to erosion. As sediment under these conditions is mostly accumulated in the subtidal zone, the tidal prism is little reduced which is reflected in the sustained diversity of intertidal benthic biota as observed by Hodgson (1987) and Allanson & Read (1987).

It must be recognised that none of the estuarine systems (with the possible exception of Knysna) has any commercially viable fin or shell fisheries. Thus the economics of estuarine dependence, other than for Man are unimpressive (Begg 1984). The dependence, however, of Man is paramount and in each of the environmental studies undertaken, the implication that his best interests must be served is unequivocal!

The cavalier disregard which we have given to the other bio-physical components of these systems continues at our peril.

In this regard the recently revised "Policy for the Estuaries of Natal" (Begg 1985) is a valuable statement of the constraints which should be exercised when developments in the estuarine environment are considered. A deeper analysis of the attitudes of Man when involved in such developments is to be found in the recently published report edited by Ms M R Sowman (1988) of the Environmental Evaluation Unit of the University of Cape Town. The report deals with the socio-economic features affecting estuarine degradation : A case study of the Kafferkuils estuary. It is a brilliant analysis of exactly those socio-economic factors responsible for the decrease in quality of the estuarine and coastal environment over the past 50 years. **These reports should become compulsory reading for all estuarine scientists!**

I have drawn specific attention to Ms Sowman's report because of the clarity it introduces into an otherwise murky environmental picture. Fortunately, decisions at Council for the Habitat level will, hopefully, provide for a realistic and attainable policy of "Integrated Environmental Management". Unless it does so, the role of estuarine ecological research as currently exists in SANCOR will have little proper impact upon the environmental crisis developing in the estuarine environment.

PUBLICATIONS

The bibliography (Appendix A) has been divided into four sections.

- A: The primary literature;
- B: Reports to a variety of agencies;
- C: Symposia and conferences;
- D: Theses accepted for higher degrees.

We have tried to be as exhaustive as possible in our search, and hope that those who have found the funds for the programme will feel that the resultant products are worthwhile. Authors will, we hope, forgive incorrect categorisations. Their work is often so recent that the final form of publication has still to be decided upon!

A total of 841 formal communications have been prepared during the period 1980 - to the present. They are distributed as follows:

Total	Primary	Reports	Symposia	Theses			
				Hons	MSc	PhD	DSc
841	397	309	73	13	35	11	1
	(47,4%)	(36,7%)	(8,6%)	(7.1%)			

Of the primary literature, 123 (30,9%) have been published in international journals or books of wide readership. The balance is published in South African peer reviewed journals, of which the *SA Journal of Zoology*, *SA Journal of Science* and the *Journal of the Limnological Society of Southern Africa* have been the most popular.

Of the reports, by far the majority has been directly concerned with providing information about specific estuaries or regions to local, provincial and government agencies.

The contribution to post-graduate training has been considerable. Fortunately many of the masters and doctoral graduates have remained in the research field.

HAVE THE GOALS BEEN REALISED?

- The quality of the scientific understanding of these interfaces between the river and the sea has increased as a consequence of the work the programme has supported. This is attested by the high quality of the journals in which much of the work is published.
- Because the research product is of high quality, the analysis of environmental issues is at once available to planners and decision-makers at all levels of government.
- The excuse that the research findings are published in communications not normally available to management is not acceptable. Informed summaries and advice are readily available or can be prepared or provided on request.
- The definition of human impact through a diverse complex web of socio-economic and socio-political attitudes requires increased attention. The studies referred to have examined and begun to expose the complexities of the components of this impact.
- The effect of agricultural and chemical changes in river catchments is recognised, but their description in quantitative terms is only weakly developed. Consequently only limited effective amelioration is possible.
- Similarly, the magnitude and quality of the contribution estuaries make to the resources of the coastal seas is recognised, but poorly understood.

COSTS

The total grants awarded to the various researchers and groups by SANCOR for the assessed period amounted to R3 027 485. This represents a direct cost. There are, however, many hidden costs by virtue of the support provided to the programme by the Universities through their provision of laboratories and services to them. It is thus impossible to provide a reasonable figure of the overall costs.

RECOMMENDATIONS

SCIENTIFIC

The importance of the inter-disciplinary approach to the development of estuarine studies has been shown by the more recent work within the programme. The SANCOR Estuaries Programme (1983) remains an excellent statement of research needs. It is the execution of this research which I understand is under review by FRD. But above all things we must be careful not to throw out the baby with the bathwater in our haste to restructure the programme. The following questions are, I believe, embedded in the SANCOR programme. Their enumeration may help the decision makers in FRD in their task.

- Is the rate of sedimentation increasing as a result of anthropogenic activities in the catchments of the influent rivers, and the spread of *Spartina maritima* in the estuarine flood plain?
- Other than changes in sedimentation rates and distribution, what direct effect has the construction of dams, particularly in the mainstem rivers, upon the diversity of the biota and its production? Of reference is the reduction in the number and quality of particles which are used by suspensoid feeders.
- The above requires the careful expansion of a proper understanding of the origins of the particles used by suspensoid feeders. The development of $\delta^{13}\text{C}$ studies of both suspensoid material, and

of the filter feeding benthos in particular, is urgent, and notwithstanding the costs it seems to be the only reasonable way in which trophic structure can be accurately worked out.

- Notwithstanding the magnitude of the tidal prism in relation to river inflow, or because of it, there is a need to examine the chemical structure of the estuaries and tidal basins, such as Langebaan, Knysna and St Lucia, in a more effective and critical manner than hitherto. This is perhaps one of the most serious of the gaps I have noticed. I have already referred to this. As far as I am aware the Continuous Low-level Environmental Observations (CLEO) programme does not address this area except in the broadest terms. What I am suggesting goes beyond the level of monitoring by seeking answers to questions such as "With the very likely decrease in river inflows, what is the quality of the marine input and what is, or are the processes of chemical change in the estuary which are material to its sustained biological functioning? I am concerned here that we may be overlooking insidious changes in water column or sediment chemistry which are slowly changing the metabolic functioning of estuarine biocoenoses.
- What is the role of saltmarshes in the generation of nutrients such as nitrogen and phosphorus compounds as well as the effect of the benthic and epibenthic fauna upon nutrient and trace element cycling? Do they, as Dr D I Taylor has suggested, provide an "alternative" source when river inflows are greatly reduced?
- Is *Spartina maritima* an exotic which is invading the estuaries as Ms S M Pierce believes? We should take careful note of her proposals. None has been developed following her pioneering work.

MANAGEMENT

- There is not the slightest doubt that as a result of the SANCOR programme and the rich resources of data and understanding which it has generated, there is more than enough information upon which to assess the ecological state of an estuary and the likely impact upon its viability of development in its catchment and floodplain.
- We may argue, therefore, the time for data collection for its own sake has passed and orientate our efforts towards the solution of particular environmental issues, and implicit in this are the needs of Man. As stressed earlier, the inability of the estuarine scientist to have any significant impact upon decisions taken at administrative or quasi-political level is due to the lack of public accountability. This has been marked in the application of socio-economic parameters to coastal development during the time of the SANCOR programme.
- While our understanding of estuarine systems has increased, their socio-economic development has gone on unheeding the rich resource of knowledge and understanding which could materially increase the environmental quality of these developments. It could be argued that this is because the level of "technology transfer" is still too esoteric. If this is indeed the case it can be very easily corrected. In my view, this is an excuse which transfers the responsibility of accountability. But once planners and developers are required by law to incorporate such knowledge it will become "suddenly" that much more understandable.
- Nevertheless, it is clear that there are enough areas of potential understanding between the research groups at present, and in this regard I consider attention must be given to a closer association between the research specialist, be he a sedimentologist or a chemist or a biologist, and those groups such as the Environmental Evaluation Unit at the University of Cape Town who have to deal with specific socio-economic issues in relation to what they perceive as the correct ecological or environmental data set. I have already referred to Ms Sowman's excellent report on Kafferkuils and would propose that meetings between this group and the diversity of estuarine scientists be set up to explore new avenues of real cooperation. This I see as the most important task within the family of environmentalists. Unless we understand each other's viewpoint we can never speak with unity.

- There is a real need to direct reports about what is being degraded and why? This implies less attention be given to "description" and more to establishing "causes." In this way you will be able to direct the attention of the authorities to where or upon whom to act.
- Please try and adopt a more uniform system of report presentation and citation. It is often difficult to assess the nature of the problem(s) being addressed because of the variation in presentation. Attention to this would go a long way towards making your work more acceptable to government and their consultants.

GENERAL

- A problem of major concern, and one which the programme participants perceive as being central to the success of any future programmes, is the very vexed question of tenure. It is unfortunate in the extreme, that so many of our young and bright scientists should find it necessary to leave South Africa, and not all on political grounds, because of the very simple human need to ensure a career and provide for one's family. I have repeatedly stressed that this issue should be addressed at the highest level between FRD and the Universities, Museums and other research groups. I recommend that this be seriously considered.
- In view of the considerable advance in our understanding of the ecology of estuarine biocoenoses since 1981, the FRD may wish to consider inviting a review of the rich literature which has accumulated during the decade. A division of such a review into Science and Management would seem a possibility.

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SECTION B : REPORTS TO NATIONAL SCIENTIFIC PROGRAMMES; GOVERNMENT, PROVINCIAL AND LOCAL AUTHORITIES; SOCIETIES AND INSTITUTIONS, FROM 1980 TO 1989

Please note that as far as possible this list contains reports not normally subject to peer review before publication.

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