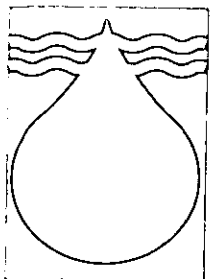




**PLANT COMMUNITY RATING
AND ITS RELATIONSHIP WITH
FRESHWATER SUPPLY - SOUTH
AFRICAN ESTUARIES**

JB Adams • JC Coetzee • GC Bate

WRC Report No. 601/1/00



Water
Research
Commission

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PLANT COMMUNITY RATING AND ITS RELATIONSHIP WITH
FRESHWATER SUPPLY - SOUTH AFRICAN ESTUARIES

BY

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EXECUTIVE SUMMARY

MOTIVATION AND BACKGROUND

The continued supply of freshwater to estuaries is very important in South Africa where much of the country is arid. The construction of impoundments and the resultant decrease in freshwater flowing into estuaries will have far-reaching consequences to their biological and physical functioning (Reddering 1988, Allanson 1992, and Adams *et al.* 1992). The construction of dams appears, at present, to be the only way that the freshwater demand of the people can be satisfied. If this trend continues it will mean that not all estuaries will be able to be conserved, even in their present condition, with respect to required freshwater. Important estuaries should be earmarked for conservation but first must be identified.

An estuary can be identified as important for a number of different reasons. It may have a rare bird species present. Another may have unique hydrological features; it might be an important recreational estuary or it may have especially large saltmarsh areas. These botanical, zoological, physical and socio-economic factors all contribute to the overall importance of an estuary. This project aimed to determine only the botanical importance of a number of individual estuaries.

PROJECT OBJECTIVES

The original project objective was to identify estuarine plant communities and their freshwater requirements in different types of South African estuaries. The freshwater requirements of the plant communities can only be determined once the communities within the estuary have been identified. Project objectives were revised to:

- * A classification of estuarine plant communities in different types of estuaries to establish whether all estuaries might be considered botanically the same.
- * In order to retain a complete range of South African estuarine types, the project aimed to identify those estuaries which have a high conservation status in terms of their botanical communities (botanical importance rating).
- * Compile a comprehensive list, as well as develop an identification key of the diatom species present in Cape estuaries.

BRIEF SUMMARY OF MAJOR RESULTS AND CONCLUSIONS

Literature review

An extensive review was completed of the following topics;

- (1) Classification of South African estuaries,
- (2) Estuarine plant communities related to their importance, and
- (3) Importance Rating Indices.

Classification of South African estuaries based on plant communities in relation to freshwater management

The initial classification of estuarine plants in the five different estuarine types as proposed by Whitfield (1992) showed that most species occurred in all the different types of estuaries. However, Natal estuaries were separated from Cape systems based on floristic differences i.e. mangrove swamps versus saltmarshes. Ordination of the area covered by the four different plant communities in temporarily and permanently open Cape estuaries, showed that the estuaries flowing into False Bay were reed dominated, and could be separated from the remaining estuaries which were dominated by saltmarshes. The estuaries with large saltmarsh areas could be further divided into those dominated by either intertidal (eg. Swartkops, Kromme) or supratidal saltmarshes (eg. Gamtoos, Gouritz).

From knowledge of the different plant communities in an estuary, general comments can be made about the management of freshwater flows into the estuary in order to maintain these plant communities. For example if one considered the freshwater management of the Swartkops estuary, a permanently open system that has extensive intertidal saltmarshes, it would be important to;

- i) maintain salinity between 10-35 ppt, as this is the optimal salinity range for the growth of intertidal saltmarsh plants,
- ii) ensure daily tidal flushing, because the salinity must be maintained and should not drop to zero,
- iii) prevent prolonged inundation during the growing season, because if the plants are submerged they do not flower and set seed, and
- iv) prevent prolonged dry sediment conditions as the plants require waterlogged conditions for optimal growth.

The development of a botanical importance rating system for estuaries

A system has been developed which rates estuaries according to their botanical importance. Botanical importance is defined as the contribution of the plant communities to the overall conservation status of an estuary. The formula derived to calculate a numerical importance value allows a single value to be calculated. The area covered by each estuarine plant community type (i.e. supratidal saltmarsh, intertidal saltmarsh, submerged macrophytes and reed/sedge swamps) and its importance in the estuary forms the basis of the score. The condition of the plant community and the community richness within the estuary were also used in the formula.

The botanical importance rating system was presented to a panel of experts (Appendix 1) at a workshop in December 1994. A number of improvements to the importance rating were suggested. These included:

- (1) Separate the permanently and temporarily open estuaries and show their scores separately,
- (2) The four different estuarine plant communities should be assigned importance values based on the closeness of their association with the estuary,
- (3) The area impacted in the different plant community types should be included instead of only the number of impacts, and
- (4) A plant species richness component was to be included.

The first two suggestions were incorporated into the final botanical importance rating system. The area of plant community impacted was not included, as this was very difficult to quantify. A plant species richness component was not feasible because monospecific communities such as *Zostera capensis* or *Phragmites australis* beds are common in estuaries.

The botanical importance of selected Cape estuaries

This study focused on temporarily and permanently open estuaries only along the Cape coast. For convenience the whole region was sub-divided into four regions: namely, western Cape; south-western Cape; southern Cape and south-eastern Cape. These sub-regions were included as they correspond to regionally discrete rainfall areas.

Thirty three estuaries were studied and rated according to:

- (1) Their importance along the whole Cape coast,
- (2) Their sub-regional importance (i.e. southern Cape versus south-eastern Cape, etc),
- (3) Their rating compared to other estuaries of their type (i.e. temporarily or permanently open).

The Olifants estuary on the west coast received the highest importance score for the whole Cape coast. It has extensive marshes in its lower reaches that are in good condition. Reed and submerged macrophyte beds are also a feature of this estuary. Two False Bay estuaries, the Lourens and Sir Lowry's Pass, had the lowest scores. These two estuaries are severely impacted as a result of residential and industrial proximity, and rehabilitation would be necessary to restore any botanical significance to them.

Not all estuaries were used to obtain these scores and more need to be included to make the importance rating relative to all estuaries along the whole South African coast. This rating can be used to identify estuaries that should receive a high conservation status. The freshwater requirements of important estuaries should be managed accordingly and the development of impoundments on them curtailed.

The importance rating formula is effective in determining the botanical importance of estuaries. Further methods to determine the zoological, physical and socio-economic importance of estuaries need to be developed to allow the overall importance of estuaries to be determined. However we feel that the condition and extent of the plant communities can to a large extent determine the overall ecological condition of an estuary.

Distribution and identification of estuarine microalgae

We have found 78 diatom genera to be present in nine estuaries that have been sampled. A catalogue of scanning electron microscope photographs of estuarine diatom species has been prepared which relates each species to its position in a specific estuary and to the salinity of the water. Species associated with marine, brackish and freshwater conditions have been identified. Digital images of the diatom taxa have been captured and will be available for incorporation into a World Wide Web site on the Internet.

The multivariate technique, ordination was used to determine whether diatom species could be associated with specific estuaries or salinity conditions. Ordination of the estuaries according to the water column diatoms showed no apparent clustering. Too many species were considered and it is recommended that future studies only consider the dominant 1 to 3 species at a particular site. For the benthic diatoms fewer species were considered. Ordination of the benthic diatoms showed that species and sites could be associated with specific salinity conditions. In particular, the Gamtoos, Palmiet and Berg sites were grouped together probably because of their brackish conditions.

A computerised key for the identification of estuarine diatoms to the level of genus has been developed. Further identification to the level of species remains a problem and requires to be addressed. The identification system makes use of a database, customised to the interests of the user, which is capable of interrogation using simple database programs.

Although this key was developed for the estuarine diatoms of the Cape coast, it is a customized

system that will allow water scientists to compile a system to identify the species which are important in the aquatic systems in which they are working.

OVERALL CONCLUSIONS

Objective 1

Classification of estuarine plant communities in different types of estuaries to establish whether all estuaries might be considered botanically the same.

Result

The classification of specific Cape estuaries according to their plant communities showed that they can be sub-divided into two groups based on their botanical features:

- Group 1: Estuaries dominated by brackish species
(reed and sedge communities)
- Group 2: Estuaries dominated by halophytic species
(saltmarsh communities)
 - 2.1 Estuaries dominated by intertidal saltmarshes
 - 2.2 Estuaries dominated by supratidal saltmarshes.

From knowledge of the different plant communities in an estuary general recommendations can be made concerning the management of freshwater flows into the estuary in order to maintain the plant communities in good condition.

Objective 2

In order to retain a complete range of South African estuarine types, the project aimed to identify those estuaries which have a high conservation status in terms of their botanical communities (botanical importance rating).

Result

A system has been developed which rates estuaries according to their botanical importance. The area covered by each estuarine plant community type, its importance in the estuary, the condition of the plant community and the community richness within the estuary form the basis of the formula. Thirty-three temporarily and permanently open estuaries were studied and scores allocated according to their importance along the whole Cape coast. A regional importance was also determined. Using the calculated score, estuaries can be compared with others of their type (i.e. temporarily or permanently open estuaries).

When each estuary is classified with respect to its botanical importance, we believe that the data set will be extremely important to the Department of Water Affairs and Forestry. It will assist them to allocate water impoundment schemes to river systems. Other management bodies such as the Department of Environmental Affairs and Tourism and Cape Nature Conservation to rank estuaries according to their botanical importance can also use the rating system. Because of the nature of the scoring system, each rating can be analysed with respect to the plant communities and ameliorating actions devised to reduce adverse impacts. If the plant communities are in good condition then other conditions (i.e. faunal, socio-economic etc.) will also be optimal or near optimal.

Objective 3

Compile a comprehensive list, as well as develop an identification key of the diatom species present in Cape estuaries.

Result

A list of 78 diatom genera has been compiled. These are listed by the estuary and salinity conditions in which they were found. Digital images of these species have been captured and will be available for incorporation into a World Wide Web site on the Internet. Research workers or personnel of the Department of Water Affairs and Forestry would be able to consult such a reference site should they find diatom species identification a necessity.

A computer-based program has been devised which provides an identification system for South African estuarine diatom species. The system is believed to be relatively simple so that untrained staff should be able to identify species after a short training period. This is a customised diatom identification system that will allow water scientists to compile a system to identify the species that are important in the aquatic systems in which they are working. This identification key has great potential if further developed for use as a water management tool. This is because diatoms respond rapidly to changes in water chemistry.

RECOMMENDATIONS FOR FUTURE RESEARCH

- (1) The botanical importance rating should be extended to include all South African estuaries.
- (2) Rehabilitation plans must be formulated to restore botanical importance to those estuaries that were identified as degraded.
- (3) The diatom identification key should be extended to include species names. Visual material should be made available to water managers.
- (4) Studies on estuarine microalgae should continue in order to include them at a later stage into the botanical importance rating of estuaries.

PUBLICATIONS AND SYMPOSIA PRESENTATIONS

Miss J. Coetzee completed a MSc as part of this project. It was entitled "Classification of South African estuaries based on plant communities". Three other student projects were completed on topics related to the objectives of the project. Chapter 3 and 4 were published in journals. The paper "The identification of diatom genera for ecological studies, G.C. Bate and F.E. Round" which is a component of Chapter 5 was also prepared. Seven presentations were made at local symposia and one overseas conference (25th Annual Symposium of the Estuarine and Coastal Sciences Association. Trinity College, Dublin, Ireland).

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Dr PC Reid was chairman of this project for the first year, his enthusiasm and contribution was appreciated.

The Steering Committee responsible for this project, consisted of the following persons:

Dr S. Mitchell	:	Water Research Commission (Chairman)
Mr HC Chapman	:	Water Research Commission
Mr D Huyser	:	Water Research Commission (Secretary)
Prof CM Breen	:	University of Natal
Prof OAM Lewis	:	University of Cape Town
Prof TH Wooldridge	:	University of Port Elizabeth
Dr AK Whitfield	:	JLB Smith Institute
Dr MMB Talbot	:	Talbot & Talbot
Mr C Archibald	:	CSIR/Natal
Mr P Huizinga	:	Environmentek/CSIR
Dr JR Pretorius	:	Department of Environmental Affairs
Mr JLJ vd Westhuizen	:	Department of Water Affairs & Forestry

A workshop was held in December 1994, Steering Committee participants and others, Mr P. Morant and Mr P. Raal (Environmentek, CSIR) are thanked for their valuable contribution.

The Department of Botany, University of Port Elizabeth is thanked for providing facilities and equipment. Mrs J. Henegan provided excellent secretarial assistance and Mr B. Colloty helped with the preparation of the final report.

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Diatom specialist, Prof F.E. Round of the University of Bristol, U.K. visited our Department in November 1995 and is thanked for his valuable input to the development of the diatom identification key. He assisted with the identification of our estuarine diatom species and provided a method for separation of benthic diatoms from sediment particles.

This project would not have possible without the initial botanical information on estuaries provided in the ECRU reports "*Estuaries of the Cape, Part II*". ECRU has since been incorporated into EMATEK (Division of Earth, Marine and Atmospheric Science and Technology) and that subsequently into Environmentek, CSIR.

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LIST OF ABBREVIATIONS

BHI	-	Biological Health Index
CDI	-	Community Degradation Index
CERM	-	Consortium for Estuarine Research and Management
CSIR	-	Council for Scientific and Industrial Research
DCA	-	Detrended Correspondence Analysis
DSS	-	Decision Support System
DWAF	-	Department of Water Affairs and Forestry
ECRU	-	Estuarine and Coastal Research Unit
EDSSys	-	Estuarine Decision Support System
EHI	-	Estuarine Health Index
EMATEK	-	Division of Earth, Marine and Atmospheric Science and Technology
FRD	-	Foundation for Research Development
MF	-	Multiplication factor
NRIO	-	National Research Institute for Oceanology
ppt	-	part per thousand
SEM	-	Scanning Electron Microscopy
WRC	-	Water Research Commission

GLOSSARY OF TERMS USED IN THE REPORT

BOTANICAL IMPORTANCE

Contribution of the plant communities to the overall conservation status of an estuary.

CLASSIFICATION

Attempts to reorganise grouping in the vegetation dataset as mathematically as possible.

CONSERVATION STATUS

The amount of the present vegetation that is conserved.

ORDINATION

Organises community data on species abundance exclusively.

ALLOCHTHONOUS

Not made *in situ* (i.e. not made in the estuary but imported from outside the system)

BRACKISH

Water within the salinity range of 5 - 15 ppt (seawater = 35 ppt)

HABITAT

Area or natural environment in which the requirements of a specific plant or animal are met.

HALOPHYTE

A plant that is tolerant of high concentrations of salinity.

HYPERSALINE

Salinity greater than 40 ppt

IN SITU

In the natural habitat or within the organism

PHYTOPLANKTON BLOOM

Dense growth of algae or phytoplankton.

PRIMARY PRODUCTION

Fixation of inorganic carbon etc. into organic matter by autotrophs, which are referred to as primary producers.

RETENTION TIME

This is an estimate of the average length of time that a water/solute concentration remains at a particular level in an estuary. Other terms commonly used are flushing time or mean detention time.

SALINITY

The proportion of salts in pure water, in parts per thousand by mass. Units expressed as ppt, g l⁻¹, g kg⁻¹. In this report ppt was used.

INTRODUCTION

The initial project title was "The freshwater requirements of plant communities in different types of estuaries". The objective was to identify the various estuarine plant communities and their freshwater requirements in South African estuaries. The freshwater requirements of the plant communities could only be determined after the communities within the different estuaries had been identified. The first section of the study, was an attempt to classify South African estuaries based on the plant communities present. A botanical importance rating system for estuaries was subsequently developed and applied to Cape estuaries. Another component of the study was the identification of estuarine microalgae and the relationship between these species and freshwater input.

As the project developed emphasis was placed on the botanical importance of South African estuaries and the title of the project was changed to "Botanical importance and its relationship with freshwater supply - South African estuaries."

The project objectives were:

- * A classification of estuarine plant communities in different types of estuaries to establish whether all estuaries might be considered botanically the same.
- * In order to retain a complete range of South African estuarine types, the project aimed to identify those estuaries that have a high conservation status in terms of their botanical communities (botanical importance rating).
- * Compile a comprehensive list, as well as develop an identification key of the diatom species present in Cape estuaries.

The study used multivariate analysis (ordination) to determine similarities or dissimilarities between estuaries and establish whether all estuaries could be considered botanically similar.

An individual estuary can be identified as being important for a number of reasons. It may have especially large saltmarsh areas; it may have a rare bird species present; another might have unique hydrological features or it might be an important recreational estuary. These botanical, zoological, physical and socio-economic factors all contribute towards the importance of an estuary and the Consortium for Estuarine Research and Management (CERM) is working towards incorporating all these attributes into an overall importance rating for South African estuaries (CERM 1994).

This study focused on the botanical importance of Cape estuaries from the Quko (Double mouth) estuary on the southeast coast, to the Olifants estuary on the west coast (Figures 1-3). Only temporarily and permanently open estuaries were considered. The estuaries were rated according to their importance within the Cape region, their regional importance as well as against other estuaries of their type (i.e. temporarily or permanently open).

The index developed in this project is effective at summarising botanical information into a single score. Using this index planners, developers, managers and conservationists can see at a glance which estuaries are considered the more botanically important and which, therefore, require careful consideration, management and conservation in an environment which is increasingly being utilised solely for the supply of a single commodity, water.

A catalogue of estuarine diatom species was made which relates each species to its position in specific estuaries, salinity value of the water and time of year at which the collection was made. The multivariate technique, ordination was used to determine whether specific species could be associated with specific estuaries or salinity conditions. A computerised key for the identification of estuarine diatoms was developed. Although this key was developed for the estuarine diatoms of the Cape coast, it is a customized system that will allow water scientists to compile a system to identify the species that are important in the aquatic systems in which they are working.

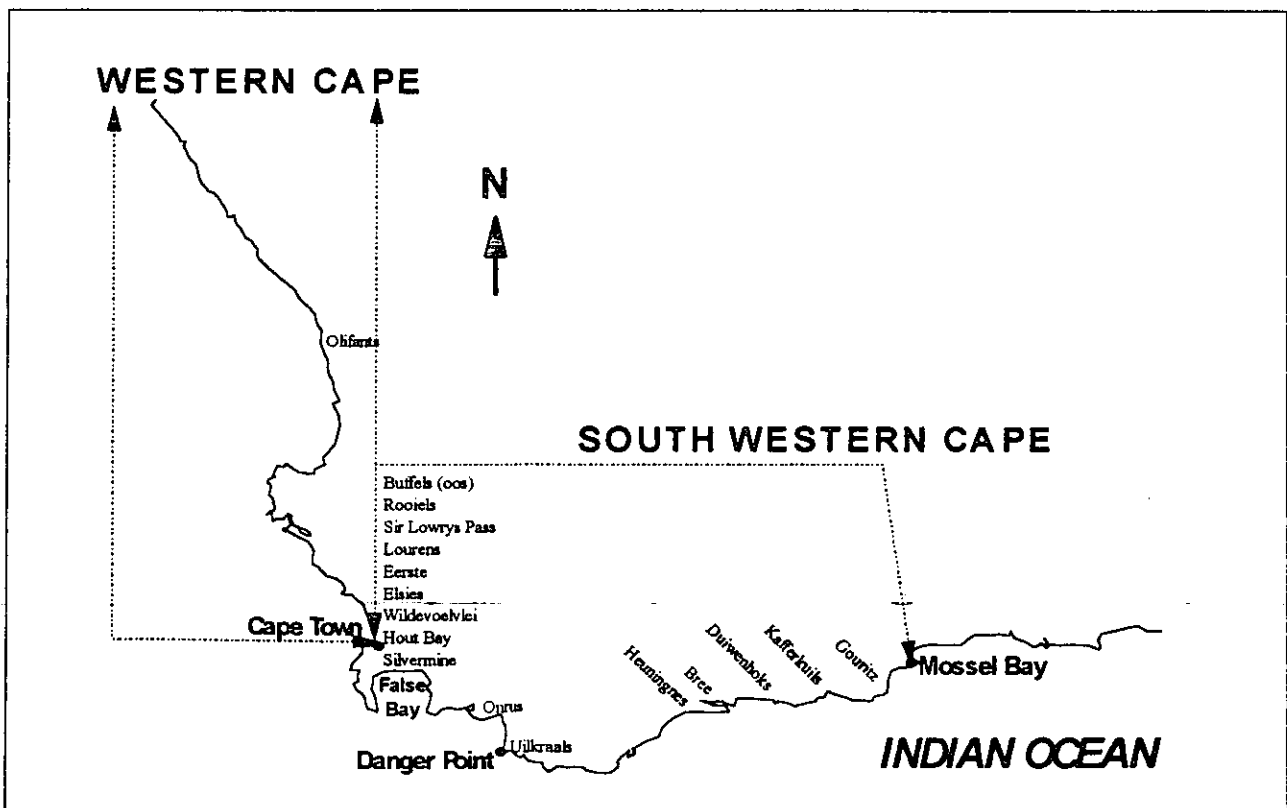


FIGURE 1. Diagrammatic representation of the west and south western Cape. The approximate location of the estuaries used in the scoring system are shown.

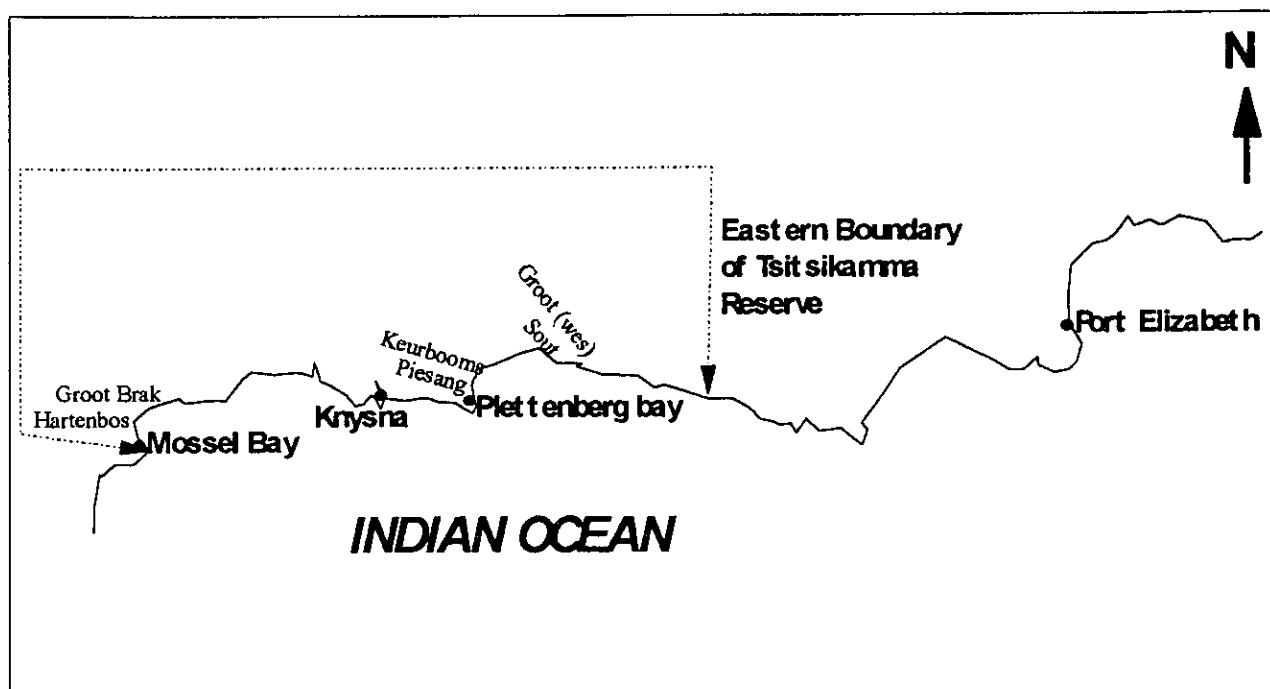


FIGURE 2. Diagrammatic representation of the southern Cape region. The approximate location of the estuaries used in the scoring system are shown.

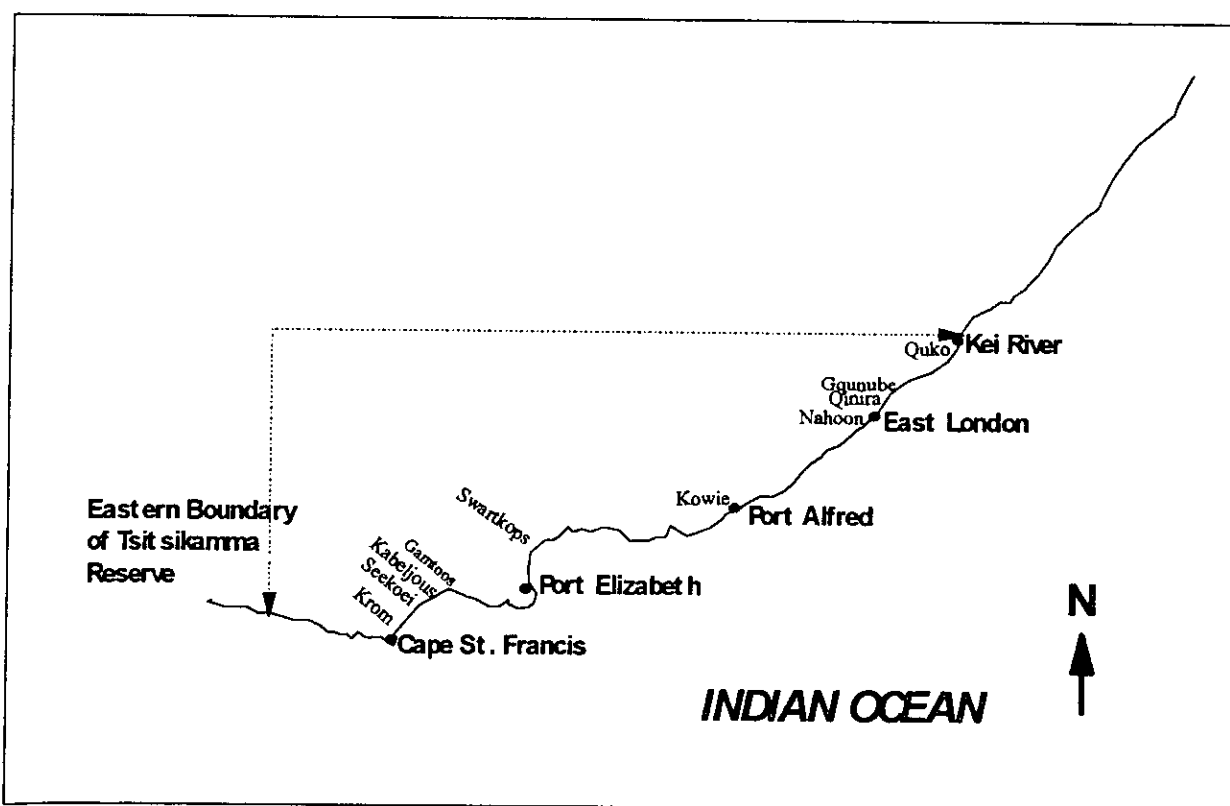


FIGURE 3. Diagrammatic representation of the south eastern Cape region. The approximate location of the estuaries used in the scoring system are shown.

1. LITERATURE REVIEW

1.1 CLASSIFICATION OF SOUTH AFRICAN ESTUARIES

Classification schemes for the estuaries along the South African coastline have used a number of different parameters. These include the general morphology of the estuary, the mixing processes involved, salinity stratification, circulation patterns, tidal range and salinity regime. None, however, have used biological parameters to group similar estuaries. This section presents the different classification schemes proposed for South African estuaries. South African estuaries are generally small and their inlets are often restricted by sandspits (Day 1981, Reddering 1988). Sea water intrusion is influenced strongly by the strength of the inflowing freshwater and the estuaries can have varying periods of salinity in their lower reaches which vary from strongly saline to freshwater conditions, depending on the rainfall in the catchment (Day 1981, Adams *et al.* 1992). South African estuaries can be regarded as unique and for this reason classification schemes which deal exclusively with South African estuaries are described. The classification scheme at the end of this section (Whitfield 1992), is the scheme which was accepted and used for the initiation of this study.

1.1.1 Begg (1978)

Begg's (1978) report presented the morphology, geology, mouth condition, physico-chemical conditions and hydrology on 73 of Natal's estuaries. Also given are general descriptions of the fauna and flora in each estuary. Before describing each of the estuaries however, he gave a general classification of the estuaries along the Natal coast (Table 1).

Begg's (1978) estuary classification and descriptions are very similar to those of Whitfield (1992). The descriptive names are easy to understand and it is easy to place a estuary into any one of the classes on the basis of what the estuary looks like. Begg (1978) however, make the distinction between a "true" estuary and the others, whereas Whitfield (1992) does not. Begg (1978) used the term "true estuaries", to describe permanently open estuaries. This is misleading, as the reader/user is led to believe that an estuary in this class is more important than one in the closed or blind estuary class. Day (1981) described an estuary as ".. a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with freshwater...." This definition includes those estuaries that are always open or occasionally open to the sea and does not imply that the one is better than the other in terms of their estuarine function.

TABLE 1. The five estuary types described by Begg (1978) for only Natal Estuaries.

ESTUARY TYPE	DESCRIPTION
TRUE ESTUARY	Free access to the sea and under tidal influences. Salinity should be measurably diluted by freshwater inflow.
LAGOON	Separated from sea by a sand bar. Dominated by freshwater. Generally wind mixed.
EMBAYMENTS	Salinity, as a result of tidal influence, not markedly reduced by freshwater inflow. Generally tranquil environments with nutrient rich bottom sediments.
ESTUARY LINKED LAKE SYSTEM	Largely fluctuating environment – from hypersaline to fresh water conditions depending on climate.
RIVER MOUTH	Freshwater dominated system, no tidal mixing of sea and freshwater.

1.1.2 Heydorn and Tinley (1980)

Heydorn and Tinley (1980) presented a classification of South African estuaries. This classification described Cape estuarine systems exclusively and not those found in Natal. As in some of the other classification schemes (Day, 1981; Whitfield, 1992), Heydorn and Tinley divided the coast into different regions. The basis of those divisions was the major changes in the coastal environment along the coast to which the estuaries would be subject, eg. wave or wind exposure. The four regions recognised are listed below:

<u>West Coast:</u>	Orange River mouth to Stompneuspunt .
<u>South West Coast:</u>	Stompneuspunt to Cape Agulhas.
<u>South Coast:</u>	Cape Agulhas to Cape Padrone (east of Algoa Bay)
<u>South East Coast:</u>	Cape Padrone to Kei River mouth

The classification scheme used the general morphology of the estuary's mouth to divide them into four types (Table 2). This scheme used easily recognisable physical features of estuaries to place them into similar classes, in this case, mouth structure. It does not give any indication of whether estuaries are perennially open to the sea, what their salinity range would be or the freshwater inflow, it only considered the lower reaches of the estuary. The scheme was aimed at managers and planners. It gave an indication of the sensitivity of the different areas in the lower reaches, to recreational activities and developments.

TABLE 2. The four different estuary types described by Heydorn and Tinley (1980) for only Cape estuaries.

ESTUARY TYPE	DESCRIPTION
SINGLE SAND SPIT	A single sand spit on one side of the mouth with a rocky platform on the other.
DOUBLE SAND SPIT	No rocky platform in the vicinity of the mouth – only sand.
ROCKY HEADLANDS	No sand in the vicinity of the mouth – only rocks.
VLEI COAST	A double sand spit, but backed by extensive wetland and floodplain areas. Long beaches and foredunes are not uncommon along the surrounding coastline.

1.1.3 Day (1981)

Day (1981) described three broad estuary types along the South African coast. He also divided the coastline into, what he termed, biotic provinces, i.e. cold temperate, warm-temperate and subtropical. These divisions were based on water temperatures in the estuaries, which are indirectly determined by rainfall and river flow in the area. The estuaries occurring in these provinces would, on the basis of the water temperature, rainfall and river flow, have their own distinctive characteristics. The three provinces recognised were:

SUBTROPICAL estuaries of southern Mozambique to the Transkei - minimum water temperatures of 16°C, good summer rainfall and strong river discharge.

WARM-TEMPERATE estuaries of the eastern and southern Cape - minimum water temperatures between 12-14°C, variable rainfall. According to Day (1981) the estuaries along the Tsitsikamma coast form a special subgroup, as the rainfall is higher and more consistent through the year.

COLD-TEMPERATE estuaries of the Atlantic coast - few estuaries are found here due to the low rainfall and high evaporation, the Berg and Olifants are the only two permanently open estuaries and are characterised by strong freshwater inflow in winter.

The different types of estuaries that Day (1981) recognised in his general classification are described in Table 3. In order to use Day's classification, measurements would have to be taken to determine whether vertical or horizontal salinity gradients are present and also what mixing patterns were involved. An estuary cannot be classified simply on its appearance as with the system of Heydorn and Tinley (1980).

TABLE 3. The estuary described by Day (1981).

ESTUARY TYPE	SUB-TYPE	DESCRIPTION
1. NORMAL		Increase in the salinity from the head of estuary to the mouth. Net flow seaward.
	<i>1a. Saltwedge</i>	Wedge of sea water along the bottom and a layer of freshwater at the top with no mixing between the two.
	<i>1b. Highly stratified</i>	Layer of seawater along bottom with freshwater at the surface with some mixing between the two.
	<i>1c. Partially stratified</i>	Vary degrees of mixing stratification between inward and outward flowing water, vertical salinity gradient often present.
	<i>1d. Vertically homogenous</i>	Salinity decreases from the mouth to the head of the estuary, strong mixing and turbulent waters mean no vertical salinity gradient is present.
2. HYPERSALINE		Reversed salinity gradients that increase in salinity from the mouth to the head. Conditions often hypersaline in times of drought.
3. CLOSED BLIND		Temporarily closed by a sandbar across the mouth resulting in no tidal range or currents. Only freshwater enters. Hyper- or hyposaline conditions can prevail.

1.1.4 Harrison, Cooper, Ramm and Singh (1994)

Harrison *et al.* (1994) used the community degradation index (CDI) (Ramm 1990) to calculate the estuarine health index (EHI) of west and south-western Cape estuaries (Orange river to Buffels (Oos) in False Bay). In the calculation of the EHI the physical nature of all the estuaries was assessed and each was placed into groups with similar characteristics (Table 4). The parameters considered in this classification included catchment size, salinity, channel width, mouth condition and floodplain width. Multivariate analysis techniques were used to determine which estuaries form similar groups according to those parameters. In total, nine different groups were recognised (Table 4).

This scheme uses a large number of different classes to describe essentially similar systems. There are five groups which all describe ephemeral pans, differing mainly with respect to their size. This large number of different groups makes the placing of estuaries into these groups difficult and time consuming. Only someone who is familiar with the scheme and who knows the various descriptions would be proficient at using it. Descriptive names were not given to the different classes, only numbers, making it difficult to distinguish from one another in the system.

TABLE 4. The nine different estuary types recognised by Harrison *et al.* (1994) for the west and south western Cape estuaries.

TYPE	DESCRIPTION	ESTUARIES
1	Large estuaries with near permanent mouth, tidally mediated salinities, permanent surface water.	Orange, Olifants, Groot Berg.
2	Large estuary/coastal lagoon with long coastal barrier, permanent surface water and can become hypersaline.	Diep River/Rietvlei.
3A	Large ephemeral coastal pans. High proportion of freshwater and hypersalinity uncommon.	Buffels, Verlore, Papkuils, Wadrif, Jakkals.
3B	Small ephemeral coastal pans either dry or hypersaline. Not estuaries as they are prone to dryness, hypersalinity and lack contact with the sea, little or no habitation by marine, estuarine or freshwater organisms.	Spoeg, Holgat, Groen, Sout (noord), Swartlintjies, Bitter, Brak.
4	Freshwater dominated (groundwater) ephemeral coastal pan.	Dwars (suid).
5	Tiny semi-arid systems seasonally dry also termed small ephemeral coastal stream (wadi) termination's with infrequent connection with the sea.	Jacobsbaai, Dwars (noord) and Lêerbaai.
6	Very small ephemeral coastal wadi termination's with periodic connection with the sea – small catchments, seasonally dry beds fed by periodic rivers.	Sout (suid), Bok, Silverstroom, Modder.
7A	Moderately large perennial hyposaline estuaries with good salinity variation (all in False Bay).	Buffels (Oos), Lourens, Sand/Sandvlei, Eerste, Elsie, Rooiels.
7B	Small/tiny perennial estuaries dominated by freshwater with minimal marine influence.	Houtbaai, Schuster, Bokramspruit, Boiskraal, Krom, Wildevoëlvlei, Buffels (Wes), Silvermyn, Sir Lowry's Pass.
8	Moderately large coastal lake dominated by freshwater inflow and open to the sea.	Zeekoei.
9	Pock bounded estuary without a sandy barrier.	Steenbras.

1.1.5 Whitfield (1992) : Physical classification

This last classification scheme to be described is the one that was accepted for use in this study. Whitfield (1992) used the physical aspects such as the salinity, mouth characteristics, tidal prism and mixing processes present in estuaries to categorise them into five types. It is easy to determine into which class an estuary would fall with only a small amount of information on the tidal influence, catchment and general estuary morphology. Because this scheme was used for the rest of the study a detailed description of the different estuarine types is provided.

(a) Permanently open estuaries:

As the name suggests these estuaries are permanently open to the sea. Vertical and horizontal salinity gradients are present and are modified by the river flow, tidal range and mouth condition. Wetlands, as well as submerged macrophyte beds are common and the fauna are predominantly marine and estuarine. Hypersaline conditions in the upper reaches can occur during times of severe drought. The sea during normal conditions and the river input during flood conditions controls water temperatures in this estuary type.

(b) Temporarily open estuaries:

Sandbars often form in the mouths of these estuaries blocking off connection with the sea. Sand bars form as a result of a combination of low river flow conditions and longshore sand movement on the adjacent coast. Flooding is frequently the cause of mouth opening, which also results in large amounts of sediment removal. However, infilling from marine and fluvial sediment can be rapid. Hypersaline conditions occur in these estuaries during times of drought. Tidal and riverine inputs control the water temperature in these systems when the mouth is open, but is independent of them when the mouth is closed. Marine, estuarine and freshwater life forms are all found in these systems, depending on the state of the mouth.

(c) River mouths:

Riverine influences dominate the physical processes in these estuaries. Oligohaline conditions are often found. The mouth is generally permanently open but the tidal prism is small and strong riverine outflow prevents marine intrusion. During strong flood conditions the outflow of these mouths can influence the sea salinity for many kilometres. Heavy silt loads are frequent in these estuaries often resulting in shallow mouths (<2m). Water temperatures are strongly influenced by river inflow although the sea can influence bottom waters.

(d) Estuarine lakes:

To be considered within this type the water area has to exceed 1 200 ha. These systems are usually drowned river valleys filled in by reworked sediments and separated from the sea by vegetated sand dune systems. The dune can result in complete separation of the lake from the sea that then results in a loss of estuarine characteristics and the system can be referred to as a coastal lake. Estuarine lakes can be either permanently or temporarily linked to the sea and salinities within them are highly variable. Freshwater input, evaporation and the magnitude of the marine connection are the main causes of this large salinity fluctuation. The tidal prism is small, and marine and river input have little influence on water temperatures which are directly related to solar heating and radiation. Estuarine, marine and freshwater organisms all occur depending on the salinity condition of the system.

(e) Estuarine bays:

Here too the water area must exceed 1 200 ha for a system to be considered within this type. Natural bays (Knysna) and artificially formed bays (Durban Bay) are permanently linked to the

sea and the salinities within them reflect this. Hypersaline conditions are not common and water temperatures are strongly influenced by the sea. Marine and estuarine organisms dominate these systems and extensive wetland/mangrove swamps occur (Whitfield 1992).

Whitfield (1992) also divided the coast into three biogeographic zones they were:

Subtropical - Kosi Bay (Natal) to Mbashe estuary (Transkei)
Warm Temperate - Mendu estuary (Transkei) to Buffels (Wes) estuary (False Bay)
Cool Temperate - Booiskraal estuary (Cape Peninsula) to Orange river mouth
 (Cape west coast)

Whitfield's (1992) classification is easily understandable, it does not make use of numerous subgroups which make the placing of estuaries into classes confusing. The descriptive names given for each group are concise and effective at conjuring up the correct image of the estuary. For these reasons, it is the scheme that was accepted and used for this study. CERM's Decision Support System will also use this classification in the determination of overall estuary importance ratings (CERM Progress Report 1994).

All the estuaries along the South African coastline are assigned to one of the different estuary types in Whitfield's (1994) synopses of available information. This report lists all the publications that deal with individual estuaries. Included in this report is a rough estimation of the ecological condition of each of the estuaries by classifying it as either poor, fair, good or excellent. The description gives an indication of the degree to which human interference has affected the functioning and viability of the system (Whitfield 1994).

TABLE 5. Physical classification for all South African estuaries (Whitfield 1992).

TYPE	TIDAL PRISM	MIXING PROCESS	AVERAGE SALINITY
ESTUARINE BAY	Large ($>10 \times 10^6 \text{ m}^3$)	Tidal	20 – 35 ‰
PERMANENTLY OPEN	Moderate ($1-10 \times 10^6 \text{ m}^3$)	Tidal/riverine	10 - >35 ‰
RIVER MOUTH	Small ($<1 \times 10^6 \text{ m}^3$)	Riverine	< 10 ‰
ESTUARINE LAKE	Negligible ($<0.1 \times 10^6 \text{ m}^3$)	Wind	1 - > 35 ‰
TEMPORARILY OPEN	Absent	Wind	1 - > 35 ‰

1.2 ESTUARINE PLANT COMMUNITIES AND THEIR IMPORTANCE

A wide range of flora may be found within individual estuaries. These plant communities have an *ecological as well as economic importance within the estuary* (Vernberg 1993). Ecologically they are a source of primary production and provide habitat and food for a large variety of faunal species. The economic importance of estuarine plant communities relates to their effectiveness in flood, erosion and stormwater surge control (Vernberg 1993). Their ability to improve water quality by retaining pollutants and excess nutrients can also have important economic implications.

The various plant communities associated with estuaries include; phytoplankton (microscopic unicellular or chain forming algae) which occur in the water column and benthic microalgae found associated with the bottom sediments and macrophytic plants. The larger macrophytic plants occur in *distinct communities of submerged macrophyte beds, inter- and supratidal saltmarshes as well as reed, rush and sedge areas.*

1.2.1 Phytoplankton

Phytoplankton are microalgae suspended in the water column. In southern Africa phytoplankton are dominant in large channel-like estuaries (e.g., Sundays and Gamtoos) that have a high freshwater input. The nutrients derived from freshwater support the high phytoplankton biomass (Adams and Bate 1994a). Phytoplankton support a pelagic or water-column based food-chain. Small zooplankton, such as mysid shrimps in the Sundays River (Jerling and Wooldridge 1994) and larval fish feed on these microalgae which are in turn eaten by larger fish and invertebrates.

The destruction or alteration of the phytoplankton community has been shown to have serious consequences. The full impact may occur years after the community has been changed and will come in the form of depleted stocks of commercial fish, gamefish, crustaceans and molluscs (Odum 1970). An example of this has been reported for the dominant pelagic catfish *Barbus holubi*, whose juvenile stages are predominantly planktivorous. According to Allanson (1982), any factor that causes a decrease in primary production of phytoplankton has an effect on these juvenile fish, and materially influences the contribution they would make to the later biomass of harvestable fish.

1.2.2 Benthic microalgae

In shallow estuaries or those with large intertidal regions, benthic microalgae are often important contributors to primary production. A survey of Cape estuaries showed that in most systems benthic microalgal biomass was two or three orders of magnitude higher than the phytoplankton (Adams and Bate 1994a). Under calm conditions and low wave heights diatoms accumulate on the sediment surface. In the Langebaan lagoon and in the Swartkops estuary the highest microalgal biomass occurred in the top 1 mm of sediment (Fielding *et al.* 1988, Rodriguez 1993). Increased water currents and sedimentary movements easily disturb Benthic microalgal communities. They bind to sediments with mucilage threads and can contribute to sediment stabilisation.

Benthic microalgae are grazed directly by some invertebrates (Whitfield 1989a) and fish species. In the Swartkops and Swartvlei estuaries benthic diatoms are important food items of the mullet species (Masson and Marais 1975, Whitfield 1988a).

1.2.3 Submerged macrophytes

Dense eelgrass (*Zostera capensis*) beds occupy the mudflats of the intertidal and shallow subtidal zone in permanently open South African estuaries. *Ruppia cirrhosa*, another submerged macrophyte, is common in periodically open estuaries characterised by fluctuating salinities, but can also be found in the calm brackish upper reaches of permanently open estuaries (Adams *et al.* 1992, Adams and Bate 1994b). *Potamogeton pectinatus* is commonly associated with lower salinity waters in estuaries (Day 1981).

Submerged macrophytes are an essential biotic component responsible for the maintenance of good quality water. They play an essential role in nutrient trapping and recycling. Some submerged macrophytes such as *Zostera capensis*, are thought to assist in the deposition of sediment carried under load, and act as a sediment binding agent (Edgcumbe 1980). Submerged macrophytes provide an important habitat for fish and invertebrates. Wildfowl numbers have also been shown to be closely related with the occurrence of these plants (Blindow *et al.* 1993, cited in Quick and Harding 1994).

Submerged macrophyte beds have been shown to support more diverse and abundant invertebrate and juvenile fish communities than bare soft-bottomed habitats and marshes (Fredette *et al.* 1990, Connolly 1994). Whitfield (1989a) found that the biomass and diversity of macroinvertebrates at eelgrass sites in the Swartvlei estuary were higher than adjacent sandy sites. Similarly, the abundance of dominant benthic invertebrate species, in the Berg River estuary, have also been reported to fluctuate in response to seasonal growth of *Zostera* (Kalejta and Hockey 1991). These submerged macrophyte beds provide shelter for the invertebrates from predators and strong water currents (Whitfield 1988a and Whitfield 1989a) while also providing a substratum for the attachment of suspension feeders (Davies 1982). In addition they provide food for epifaunal and benthic invertebrate species, in the form of detritus (and associated micro-organisms), diatoms and filamentous algae that are trapped in the beds (Whitfield 1989a).

Submerged macrophyte beds form nursery areas for juvenile fish by providing shelter and protection from predators (Whitfield 1984), while also providing them with a food supply. Branch and Grindley (1979) showed that juvenile fish in the Mngazana estuary had strong preference for submerged macrophyte beds. Hanekom and Baird (1984) reported for the Kromme estuary, that significantly higher numbers of *Monodactylus falciformis* and *Rhabdosargus holubi* were recorded in *Zostera* beds. In the Swartkops River, the *Zostera* beds were found to form an integral part of the nursery function, for the ichthyofauna, of the estuary (Beckley 1983), as was the case with *Potamogeton* in the Sundays estuary (Beckley 1984).

Although submerged macrophytes can be grazed directly for food, it is more common that consumption of plant material is centred around filamentous algae and diatoms growing on the consumer organisms (Thayer *et al.* 1975, Larkum and West 1990, Walker and McComb 1992). This is supported with findings from a number of South African estuaries, including Swartvlei (Whitfield 1988a); Kromme and Swartkops (Hanekom and Baird 1984); Klein River (Talbot

1955); West Kleinmond and Kasouga (Blaber 1974). The plants also provide food indirectly through their diverse and abundant invertebrate faunas consumed by carnivorous fish species (Whitfield 1984, Connolly 1994).

The collapse of the submerged macrophyte community in the South African Swartvlei estuary, resulted in a major decline in total invertebrate standing stocks as well as a simultaneous change in species composition (Davies 1982). This regression phase lasted three years, and the prolonged senescence of *Potamogeton pectinatus* and charophyte beds in the estuary, resulted in a 60% decline in primary production, a 74% slump in littoral invertebrate biomass and a 54% decline in the abundance of fish species (*Monodactylus falciformis* and *Rhabdosargus holubi*) associated with the macrophytes (Whitfield 1984). The effect on the decline in fish numbers was indirect and related mainly to the collapse of the invertebrate stocks associated with the plants. Similar effects would be expected to spread through the herbivorous and invertebrate-feeding avifaunal community of the lake (Davies 1982). Studies on the effect of macrophyte harvesting on invertebrates associated with *P. pectinatus*, in the Zandvlei estuary, also showed higher invertebrate standing stocks at unharvested sites (Stewart and Davies 1986).

The importance of the movement of *Zostera* debris from the site of production to outside areas where beds are absent, has been documented as an important source of food for fishes occurring in the macrophyte free areas (Bach *et al.* 1986, and Whitfield 1988a, 1988b). Whitfield (1988b) reported a total export, of *Zostera* and associated algae, of 0.87 g ash-free dry mass m⁻²d⁻¹, which represented a monthly export of 18 % of the *Zostera* bed biomass in the Swartvlei estuary. Allanson (1982) reported on the overwhelming importance of the littoral plant community, during the *Potamogeton* climax phase, as a source of net organic carbon production (Allanson 1982). There was a reduction of 60% in daily littoral production, after a major regression of *Potamogeton* in the Swartvlei estuary.

Whether the submerged macrophytes are used primarily as protection from predators or as a food source is difficult to determine (Connolly 1994), but the fact that numerous species utilise these areas is proof enough of their importance in an estuary. Submerged macrophytes are also important for primary and secondary production within estuaries.

1.2.4 Saltmarsh community

Saltmarsh communities occur in protected estuaries and embayments along the southeastern, southern and western coasts of South Africa. North of the Kei River the subtropical climate favours the development of mangrove swamps.

Saltmarsh plants are zoned according to their water requirements and tolerance of salinity. The grass *Spartina maritima* is commonly found near the low water level. Higher up the shore, succulents such as *Salicornia* and *Sarcocornia*, and sedges and rushes, such as *Scirpus* and *Juncus*, are common. This leads to the division of this vegetation into either intertidal or supratidal saltmarshes. Other saltmarsh species include the small shrubs *Chenolea diffusa* and *Limonium scabrum*, as well as *Triglochin bulbosa* and *Cotula coronopifolia* (Day 1981 and O'Callaghan 1994). In the supratidal saltmarsh areas, which are only occasionally inundated, one finds the grasses, *Sporobolus virginicus*, *Stenotaphrum secundatum* and *Cynodon dactylum*, as well as the rush *Juncus kraussii* and the succulents, *Disphyma crassifolium* and *Carpobrotus edulis* (Day 1981, Adams *et al.* 1992 and O'Callaghan 1994).

Marsh plants are important inorganic and organic nutrient sources for estuarine ecosystems (Childers and Day 1990). However, the estuarine water levels and the degree of flushing are important in determining how much of the nutrient is released into the water column. If a marsh is rarely flooded, its importance in the ecosystem decreases (Childers and Day 1990). A supratidal marsh, therefore, with little tidal flooding, will be less important with respect to nutrient exchange than an intertidal marsh or submerged macrophyte bed. The marsh's importance as a habitat for invertebrate and bird species, however, does not increase. From work done in the Kariega estuary, Taylor and Allanson (1995) demonstrated the significance of high saltmarshes in the functioning of estuarine ecosystems. Although they are rarely inundated by the tide, during high spring tides, detrital plant material originating from the low saltmarsh areas is deposited on the high salt marsh areas, whose structure serves to act as a detrital sink. Long periods of exposure allow heterotrophic breakdown and decomposition in an environment where available oxygen is not limiting. Carbon dioxide produced by respiration is released to the atmosphere. By this natural process, high saltmarshes act as carbon "sink" for the estuary and consequently play an integral part in the carbon budget of the estuarine ecosystem.

Kokkin and Allanson (1985) stated that a marked variation in river inflow, influenced by the rainfall regime and an increase in dam construction, reduced the import of carbon from terrestrial sources. Estuaries have therefore, become reliant on autochthonous (plant material) sources and marine imports. The primary production of *Spartina maritima*, in the Swartkops estuary, has been estimated at over $10\,000\text{kJ}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ($602\text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$) (Day 1981). Only half of this is estimated to accumulate in the detritus chain and the remainder is either deposited in the estuary or washed out to sea (Day 1981). Kokkin and Allanson (1985) further showed that the important organic carbon produced by the marshes remains in the estuary and is utilised by the organisms that live there or alternatively it remains bound in the food chain.

Saltmarshes provide a unique niche for some crustacean and mollusc invertebrates that are

specifically adapted to marshes, and which do not occur elsewhere in the estuary. During flood tides many fish species enter the marsh creeks where they feed off the substrate, or prey on mudprawn that occurs there in high abundance. Bacteria and other micro-organisms break down the plant material from marsh plants, and "filter-feeders" sieve out the fine organic particles as a food source. Other plant fragments sink to the bottom and are eaten by "deposit-feeders" such as worms. In this way these plants offer feeding opportunities to a broad spectrum of animal life, thus playing an essential role in the functioning of the estuarine foodweb (Cape Nature Conservation).

Costa *et al.* (1994), showed that in the Mira estuary, Portugal, the saltmarsh-border-zone was more important for juvenile fish species than the seagrass beds in the estuary. Estuarine saltmarshes also support large numbers of avifauna, such as those of the Swartkops estuary, which not only provide a valuable breeding locality for many bird species, but also provides a year-round feeding area for shorebirds (Martin 1991).

The ecological function and physical stability of marshes are easily disrupted by, for example, interference with the tidal exchange of water, reclamation or infilling, pollution, dredging, or trampling by vehicles or animals (Baird *et al.* 1992).

1.2.5 Reed/rush/sedge communities

In freshwater and brackish zones reed, rush and sedge communities are common. These communities serve the valuable ecological function of protecting banks from erosion. Destruction of *Phragmites australis* (common reed) stands by recreational activities in Europe have been shown to require costly shore rehabilitation programmes (Weisser and Howard-Williams 1982). Reedbeds have been shown to function as effective silt traps by reducing the turbulence and therefore, the silt carrying capacity of water flowing through them (Weisser 1978, cited in Benfield 1984). According to Weisser and Parsons (1981, cited in Benfield 1984), such accumulation of sediments in the upper reedbeds of the Siyaya Lagoon, South Africa, may protect the lower sections of the lagoon from sedimentation, but at the same time may seriously impede the flow of water through these sections.

Phragmites-dominated marshes provide a habitat for many birds, invertebrate and fish species (Haslam 1971). Whitfield (1980) has shown that, within the Mhlanga estuary north of Durban, the detrital aggregate, with a standing stock of 161 KJ.m⁻² and arising from the fringing *Phragmites* swamps, was the most important food resource of 90% of the fish community of the estuary. According to Benfield (1984), production by *P. australis* is high. He cites various authors that have reported reedswamp communities of temperate regions to have the highest productivity of any plant community.

Wetlands, and particularly reedswamps, are capable of removing large amounts of nutrients from the water column. They act as nutrient sinks in the natural environment and are so effective that they are used as water purification systems in artificial wastewater treatment

systems (Brix 1993, Martin and Fernandez 1992). Taylor (1983) showed that *Phragmites australis* contributed about 90 % of Swartvlei's littoral primary production after the *Potamogeton pectinatus* beds had diminished. This indicates that reed beds can act as either nutrient sources or sinks depending on the status of the other plant community types present in the estuary.

In addition, reed and rush communities have an important utilitarian value, particularly in rural areas of Natal (Begg 1986). The rush, *Juncus kraussii* is used for the construction of sleeping mats and numerous craftwork products (Heinsohn and Cunningham 1991). Hut-building and thatching material is obtained from *Phragmites*.

In summary, the plant communities associated with estuaries are important as:

- nursery areas for juvenile fish
- food sources for fish and invertebrate species
- habitat for a large number of invertebrate species
- providers of nutrient input into the water column
- uptakers of excess nutrients from the water column
- detritus sources for food chain, and
- stabilisers of sediment.

1.3 IMPORTANCE RATING INDICES

Due to the increasing number of people utilising the coastline (Allanson 1992, Begg 1978), there is now a need to evaluate estuarine and coastal resources and to determine sensitive areas where careful planning and management must take place. Biological and physical information needs to be presented in an easily readable and understandable format. Lengthy reports summarising the information, like the ECRU reports and Begg's (1984) reports, are likely to be ignored as too much reading and interpretation of the information is required to determine the sensitivity of an estuary. A simple way to summarise biological information is to develop an index that gives an indication of the status of certain aspects of the area or community in question (Ramm 1988). Planners, developers, managers and conservationists can then see at a glance which areas are sensitive and require more attention and which have a high conservation priority.

One way to achieve this is to develop a method that summarises the biological information into one index or score for the estuary. In most cases, however, an index takes into consideration only one species, or aspect of the estuary. When such an index is used for management, or planning purposes, it is important that there are a number of other factors that are also important in the estuary, not just the factor used to obtain the index. Ramm (1988) mentioned that in the use of indices, "detail" is sacrificed for "perspective" as no index can summarise all the aspects important in an estuary. The use of a number of indices in conjunction with each other is a way to achieve a more holistic impression of the condition of an estuary. Also,

provided the details are available showing how an index is obtained, specific management options can be determined. This is the concept behind the development of CERM's (Consortium for Estuarine Research and Management) Decision Support System, where the physical, biological and socio-economic factors of the estuary are taken into consideration to achieve a final importance rating (CERM Progress Report, 1994).

1.3.1 CSIR 1989

The CSIR report "The Mapping and Conservation Importance Rating of the Cape Coastal Vegetation as an Aid to Development Planning" was reviewed. A number of sensitivity maps have been provided for the Cape coastal region with the aim of providing development planners with a guideline to floristically sensitive areas. All vegetation types were considered, i.e. terrestrial, dune and estuarine flora.

This report used the following criteria to allocate importance values to each mapping unit:

- (1) whether they have high concentrations and numbers of endemic species,
- (2) whether they form a concentration of biogeographic outliers,
- (3) whether they form examples of important natural processes,
- (4) the existence of aesthetic landforms and ecosystem diversity,
- (5) the ecological quality of the sites (the state of intactness /disturbance), and
- (6) the degree of threat from human activities.

An arithmetic formula was developed to provide a consistent ranking of all vegetation types. The components included in the formula were: vegetation type rarity factor, level of endemism, plant species richness, presence of threatened species, extent to which each vegetation type has been abused by land-use activities, and extent to which vegetation type is invaded by alien vegetation.

A vegetation importance hierarchy was established and used to identify areas with high biotic significance. The vegetation maps were prepared using a colour code to indicate the different conservation categories i.e. purple represented the most important vegetation types and brown those of low conservation importance. The study recommended that where future developments are planned areas of high biotic importance are avoided.

1.3.2 O'Callaghan (1990)

O'Callaghan (1990) made use of past and present aerial photographs to observe the changes in the vegetation as a result of industrial or residential action, around the False Bay estuaries. The increase or decrease in key vegetation types (wetlands, riverine shrub, dune vegetation) and water surface area were used to calculate the relative environmental importance (I), the

relative environmental state (E), the coefficient of change (A) and the conservability (C) of each of the False Bay estuaries. The conservability of an estuary was then calculated by determining how much the estuary had changed as a result of the surrounding development. No change, or an increase in wetland or water area, was seen as a positive effect and such an estuary would receive a high conservability rating (O'Callaghan 1990). A decrease in overall wetland or water area was regarded as negative and such an estuary would receive a low conservability rating.

Estuaries with the highest conservability were Rooiels, Steenbras and Buffels (Oos), due to very little residential and industrial development around them. The Zeekoei obtained the lowest conservability rating due to the presence of sewage ponds and encroaching alien vegetation. Residential, recreational and industrial development as well as alien vegetation encroachment, were all given as the major factors causing changes to the vegetation observed in the estuaries flowing into False Bay (O'Callaghan 1990).

The evaluation technique of examining past and present aerial photographs can be valuable in determining the effects of development on the estuarine environment. O'Callaghan's (1990) study, however, was restricted to False Bay estuaries only and to extend such a study to cover the entire coastline would be an expensive, time-consuming project. The interpretation of the aerial photographs can be subjective, as it is necessary to determine the extent to which a development has had either a positive or negative influence on the vegetation or estuary. For O'Callaghan's study (1990), an expert panel was used to provide their opinions on both negative and positive impacts.

1.3.3 Harrison et al. 1994

Ramm (1988) developed the community degradation index (CDI) to compare "...the present biological community to the community that would exist in the absence of (or prior to) degradation....". In the implementation of his CDI no subjective decisions are made with respect to the sensitivity of particular species to a pollutant or mix of pollutants. The subjectivity is in the interpretation and in the use of the index for planning purposes. Cooper *et al.* (1993) and Harrison *et al.* (1994) used the CDI (Ramm 1988) to calculate the estuarine health of Natal estuaries and west and south western Cape estuaries respectively. The report for the southern and eastern Cape estuaries will be available in early 1996 (Harrison pers. comm.). The biological health, water quality and aesthetic conditions of the estuaries were used to compile a final estuarine health index (EHI) for different estuaries.

a) Biological Health Index (BHI)

This index was calculated after surveying the existing fish communities and comparing them to historical data on the same systems. The CDI (Ramm 1988) was adapted to measure the

degree of similarity between the historical (potential) community and the actual community found in a survey.

b) Water Quality Index

Selected chemical and bacteriological parameters were used to obtain an index number for the water quality of an estuary. The parameters used were: dissolved oxygen, oxygen absorbed, ammonia, *Escherichia coli* counts, nitrate, phosphate and chlorophyll-a concentration.

c) Aesthetic Health Index

This aspect took into account the appearance of an estuary by comparison with its pristine state. Parameters taken into account to determine the differences were floodplain landuse, degree to which the channel margins were natural, persistent odours, presence of exotic vegetation, oil sheen, mouth stabilisation, presence of bridges and degree of visual impact from industrial or residential buildings.

An Estuarine Health Index is derived from the three components, namely, a biological health, water quality and aesthetics indices. The final value obtained, for the EHI, is more representative of the overall condition of the estuary than if only one of the indices had been used. If an index is used that considers historical data, the data has to exist in fairly extensive format and in such a format that adequate comparisons can be made with present-day information. Should changes have occurred in the data being used to develop the index, it must be clear such changes were as a result of anthropogenic habitat degradation and not natural causes (Ramm 1988).

1.3.4 CERM 1994

The Consortium for Estuarine Research and Management is developing a computer based Decision Support System (DSS) to establish an importance and present status rating for South African estuaries. This DSS will ultimately be made up of a number of modules, namely: biological and physical importance, socio-economic importance, current status, potential for rehabilitation and lastly the consequences of catchment development. The biological importance in the DSS is made up of the following criteria:

- CLASSIFICATION: the rareness, uniqueness on a national or regional scale.
 HABITAT: the amount and diversity of habitat available to organisms
 SPECIES: species diversity and species richness
 UTILIZATION: extent to which estuarine-dependent species utilize the estuaries.

As part of the CERM importance-rating sub-project Turpie (1994) developed a method for prioritizing South African estuaries for waterbird conservation. A variety of techniques were used and compared to determine the most effective method of identifying important conservation sites. The criteria used for each site evaluation are given below, as well as the different techniques used in each.

1. Diversity

Species richness: the total number of species

Shannon's index of species diversity

2. Abundance

Total number of birds

An index of abundance - assigned abundance scores for common, rare and abundant species.

3. Rarity and conservation status

Conservation Value (CV) index

An index of coastal population size

Site endemism index

Conservation Status score - taking into account the species rarity

4. Multiple criteria indices (MCI)

Two different multiple criteria indices were used, one incorporated the conservation status score and the site endemism as well as the proportion of coastal population. The other incorporated the conservation status score, site endemism score and abundance score.

Turpie (1994) mentioned that one of the problems with multivariate indices is that the cause of the site (estuaries) position in the hierarchy is hidden in a complex formula. The factors indicating the importance rating of the estuary need to be clearly indicated to the decision-makers. A number of criteria were thought to be the most relevant when evaluating sites for waterbird conservation. Species richness was recommended as a better indication of diversity than the Shannon-Weaver diversity index. All species should be given weighting according to their level of national abundance, endemism and Red Data book status. Each bird species should be given some measure of abundance in the estuary, i.e. rare, common, very common or abundant. Rarity is an important descriptor as species restricted in their distribution need more attention devoted to their conservation status.

A number of importance rating indices were reviewed in order to provide a background for the development of the botanical importance rating.

2. CLASSIFICATION OF SOUTH AFRICAN ESTUARIES BASED ON PLANT COMMUNITIES IN RELATION TO FRESHWATER MANAGEMENT

2.1 INTRODUCTION

One of the objectives of the study was to determine whether each of the physical estuary types as classified by Whitfield (1992) had their own unique botanical features and whether those botanical features could be used to divide the estuaries into similar classes. The study used multivariate analysis (ordination) to determine similarities or dissimilarities between estuaries.

2.2 METHODS

Information was obtained from the CSIR, ECRU "Estuaries of the Cape" reports (Table 6) and Begg's reports "The estuaries of Natal" (Table 7). An attempt was made to classify South African estuaries according to their botanical features into the five estuary types as identified by Whitfield (1992). This was done using the multivariate technique, detrended correspondence analysis (DCA) with the aid of the computer programme, CANOCO. Multivariate analysis is a statistical technique adapted by ecologists to determine primary gradients in large data sets. DCA techniques were used on data organised in a number of different ways, namely; individual plant species cover presence/absence of species, and the area cover of plant communities.

2.2.1 Individual species cover

Species data in the ECRU reports are presented in the form of Braun Blanquet cover classes (Table 8). Begg (1978), however, provided diagrammatic vegetation maps, showing the location of the communities, as well as a description of the plant species composition. Braun Blanquet scores were subjectively assigned to the species present in the Natal systems with the aid of Begg's (1978) maps and descriptions.

A Braun Blanquet class is a cover score that gives an indication of the percentage cover of the individual plant species in the different estuarine communities. Each class has a percentage cover range associated with it (Table 8). The Braun Blanquet classes i.e. numbers from 1-5, were used in the DCA multivariate technique. This ordination technique is used to find similarities and dissimilarities between samples, (estuaries in this case), on the basis of the cover of plant species summarised into a matrix. The end result is presented as an ordination diagram that illustrates the similarity, or dissimilarity, by placing dissimilar estuaries further apart along an axis and more similar estuaries closer together.

TABLE 6. The Cape estuaries used for the classification and botanical importance rating. The estuaries of the Cape report numbers, CSIR report numbers, index numbers and the author and the year of the publication are provided.

ESTUARY REPORT #	CSIR REPORT #	ESTUARY	CSIR INDEX #	AUTHOR(S) & YEAR
7*	406	Gamtoos	CMS 48	Heinecken (1981)
8*	407	Rooiels	CSW 10	Heinecken (1982)
9*	408	Uilkraals	CSW 17	Heydorn & Bickerton (1982)
10*	409	Kowie	CSE 10	Heinecken & Grindley (1982)
11*	410	Hartenbos	CMS 1	Bickerton (1982)
12*	411	Buffels (wes), Elsies, Sir Lowrys	CSW 1,2	Heinecken (1982)
13*	412	Silvermine	CSW 3	Heinecken (1982)
16*	415	Eerste	CSW 6	Grindley (1982)
17*	416	Lourens	CSW 7	Cliff & Grindley (1982)
19*	418	Groot (wes) & Sout	CSW 23	Morant & Bickerton (1983)
20*	419	Groot Brak	CMS 3	Morant (1983)
21*	420	Breë	CSW 22	Carter (1983)
23*	422	Swartkops	CSE 3	Baird, Hanekom & Grindley
24*	423	Onrus	CSW 14	Heinecken & Damstra (1983)
25*	424	Heuningnes	CSW 19	Bickerton (1984)
26*	425	Olifants	CW 10	Morant (1984)
27*	426	Wildevölvlei/Noordhoek	Cw 28	Heinecken (1985)
29*	428	Hout Bay	CW 27	Grindley (1988)
31*	430	Keurbooms/Bitou & Piesang	CMS 19	Duvenage & Morant (1984)
33*	432	Krom, Seekoei & Kabeljous	CMS 45, 46	Bickerton & Pierce (1988)
34*	433	Kafferkuils & Duiwenhoks	CSW 24	Carter, Brownlie (1990)
38*	437	Gourits	CSW 25	Heydorn (1989)
39*	438	Quko	CSE 56	Burns, du Plessis, Verwoerd
42*	441	Nahoon, Qinira, Gqunube	CSE 44, 45	Wiseman, Burns, Vernon

TABLE 7. The Natal estuaries used in the Natal and Cape DCA analysis.

NATAL ESTUARIES	
Damba	Msimbazi
Fafa	Mtamvuna
iNtshambili	Mtwalume
Koshwana	Mzimkulu
Kosi	Mzinto
Ku-boboyi	Mzumbe
Lovu	Nagane
Mahlongwa	Nhlabane
Mahlongwana	Nonoti
Matigulu	Nyoni
Mbokodweni	Richards Bay
Mdloti	Seteni
Mfolozi	Sipingo
Mgeni	Siyai
Mgobezeleni	St. Lucia
Mhlabatshane	Tugela
Mhlali	Tongati
Mhlanga	Tongazi
Mhlugwa	uMgababa
Mkomazi	Zinkwasi
Mlalazi	Zolwane
Mpenjati	Zotsha

TABLE 8. The Braun Blanquet classes and the associated cover percentages.

Braun Blanquet	% Cover range
5	75 – 100
4	50 – 75
3	25 – 50
2	5 – 25
1	1 – 5
+	<1*
r	<<1**

- * Plants that occur occasionally
- ** Plants that occur only once; cover is ignored and assumed insignificant

2.2.2 Presence/absence data

A presence/absence matrix was compiled using the dominant estuarine species observed in the field (Table 9). Further DCA analysis was performed on these data and the clustering with respect to Whitfield's (1992) estuary types was again investigated.

TABLE 9. The dominant species used for presence / absence DCA ordination run.

Plant communities	Dominant species
Supratidal saltmarsh	<i>Sarcocornia pillansii</i>
Intertidal saltmarsh	<i>Sarcocornia spp.</i> <i>Spartina maritima</i> <i>Triglochin spp.</i> <i>Salicornia spp.</i>
Submerged macrophytes	<i>Zostera capensis</i> <i>Ruppia spp.</i> <i>Potamogeton spp.</i>
Reed and sedge communities	<i>Phragmites australis</i> <i>Scirpus spp.</i> <i>Typha spp.</i> <i>Juncus spp.</i>

2.2.3 Community area cover

The ECRU reports provide the cover (in ha) of the plant community types present in the estuary. Four communities were considered:

- supratidal saltmarsh,
- intertidal saltmarsh,
- submerged macrophytes, and
- reed and sedge swamps.

Using the area values given, the percentage area cover of each of the communities in the estuary was calculated relative to the other estuarine communities and the water surface area (see example A). If the plant community area values were not provided in the ECRU reports, then the areas of the community types were calculated using the diagrammatic vegetation maps. The mapping programme, MapInfo, was used to digitise the boundaries of each of the communities present as well as the water surface area.

Example A

Consider an estuary which has three plant communities present: an intertidal marsh with an area of 4 ha, a submerged macrophyte bed with an area of 0.5 ha, and a reedswamp with an area of 1.5 ha. The water surface area, up to the head of the estuary is 10 ha.

The calculation would look as follows:

<u>COMMUNITY TYPE</u>	<u>AREA (ha)</u>	<u>% AREA CALCULATED</u>
Submerged macrophytes	0.5	$0.5/16 * 100 = 3.12 \%$
Intertidal saltmarsh	4	$4/16 * 100 = 25\%$
Reedswamp	1.5	$1.5/16 * 100 = 9.38\%$
Water surface area	10	$10/16 * 100 = 62.5\%$
Total	16	100%

Blaun Blanquet scores were allocated to each of these communities and water surface area, based on the percentage cover value obtained in the calculation above:

<u>COMMUNITY</u>	<u>BRAUN BLANQUET SCORES</u>
Submerged macrophytes	2
Intertidal saltmarsh	1
Reedswamp	2
Water surface area	4

These numbers were then used in the matrix for DCA analysis.

2.3 RESULTS

2.3.1 Individual species cover

The separation of Natal and Cape estuaries into two distinct groups can be clearly seen in Figure 4. The estuaries were separated according to species differences i.e. the presence of mangrove swamps in the Natal estuaries and saltmarsh species in the Cape estuaries. On the basis of the separation of the Natal and Cape estuaries, the decision was taken to exclude the Natal estuaries from further examination and to concentrate only on the Cape estuaries that had ECRU reports available. Also the locality of the Natal estuaries would have made field observations and ground truthing of the data time consuming and expensive.

When only Cape species data were used for DCA analysis there was weak clustering of permanently open estuaries (indicated by the crosses) and estuarine lakes and bays (solid triangles). Temporarily open estuaries (open circles), however, did not display any clustering. This indicates that temporarily open estuaries do not have specific plant species associated with them as do permanently open estuaries and estuarine lakes and bays. The latter estuaries, when compared to temporarily open estuaries, are fairly stable with respect to mouth dynamics i.e. opening and closing. Within these three estuarine types, therefore, the plant species have ample opportunity to establish specific community types. The dynamic nature of temporarily open estuaries is probably the reason why these systems have a wide representation of plant species.

2.3.2 Presence/absence

Estuarine lakes, estuarine bays and river mouths were excluded from further analysis. Only a small number of these systems occur along the Cape coastline and are unique with respect to their physical, morphological and biological features. For this reason these estuaries already enjoy a high conservation status. The presence or absence of the dominant estuarine macrophytes was considered for temporarily and permanently open estuaries only. A distinctive clustering of permanently and temporarily open estuaries was evident (Figure 6). The estuaries were grouped according to the estuarine plant species present that were distributed along a salinity gradient. False Bay and surrounding estuaries (i.e. Elsies, Eerste, Lourens, Hout Bay, Wildevoelvlie and Onrus) occurred on the top left hand side of the ordination diagram. These temporarily closed systems are dominated by freshwater through most of the year (O' Callaghan 1990) and are characterized by brackish reed and sedge species i.e. *Typha*, *Cyperus* and *Scirpus* (Figure 7). The species ordination diagram (Figure 7) shows that the species changed along a salinity gradient from freshwater to brackish (*Potamogeton*, *Phragmites*, *Juncus* and *Ruppia*) and then to saltmarsh species (*Triglochin*, *Salicornia*, *Sarcocornia*, *Sporobolus*, *Zostera* and *Spartina*). *Spartina* is a grass species which is only found in permanently open estuaries (Adams and Bate 1995) such as the Duiwenhoks, Kafferkuils, Keurbooms and Kowie.

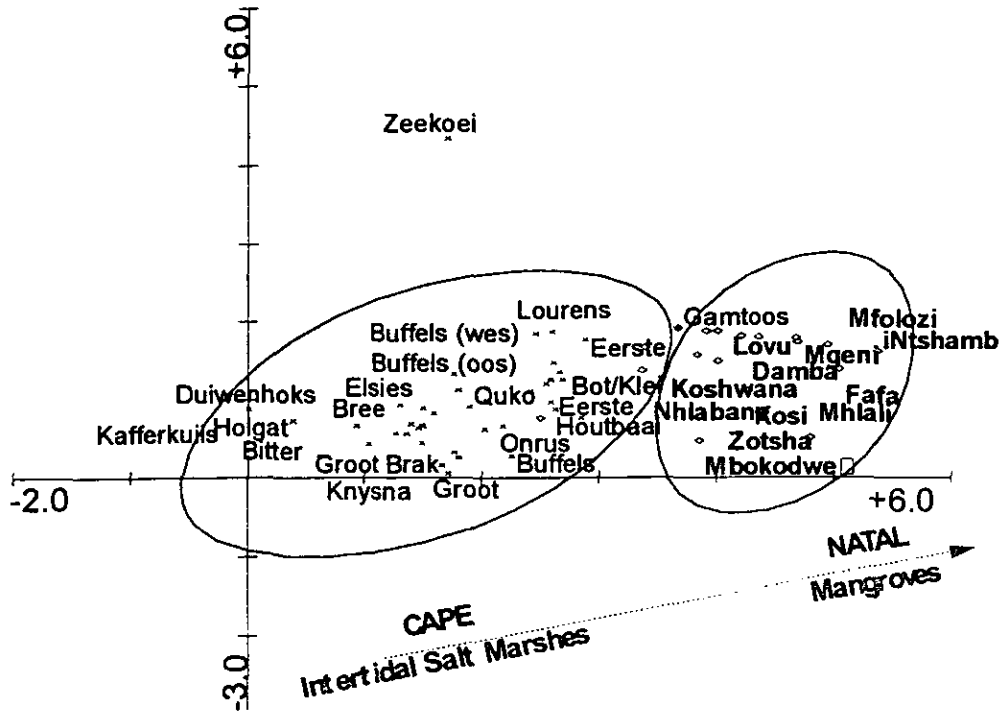


FIGURE 4. The ordination diagram for Cape and Natal estuaries using Braun Blanquet scores for individual species. The arrow indicates the gradient referred to in the text.

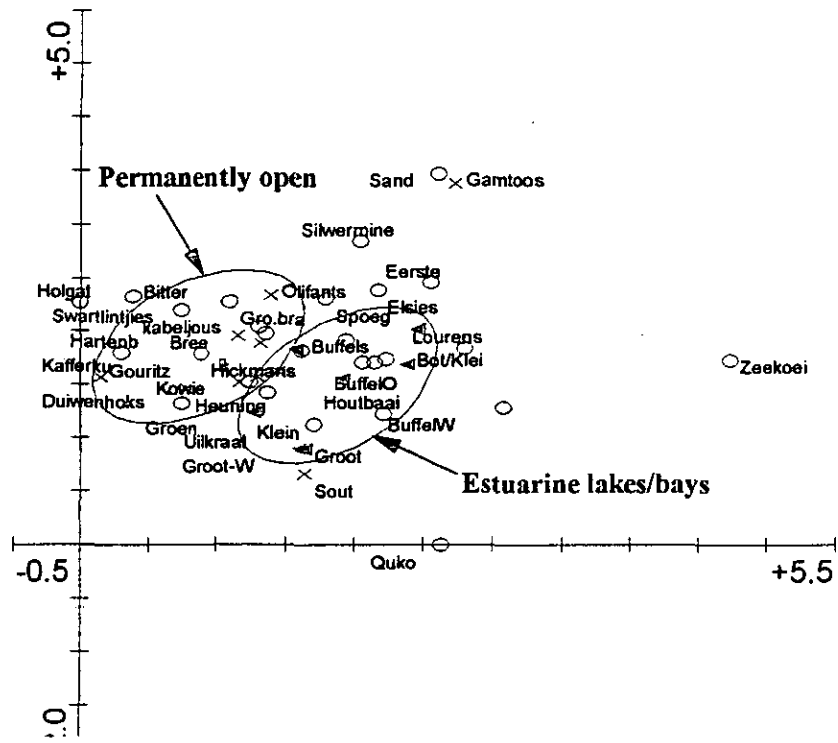


FIGURE 5. The ordination diagram for all Cape estuaries. groupings of permanently open estuaries (x), estuarine lakes and estuarine bays (<) is indicated. The temporally open estuaries did not show any clustering.

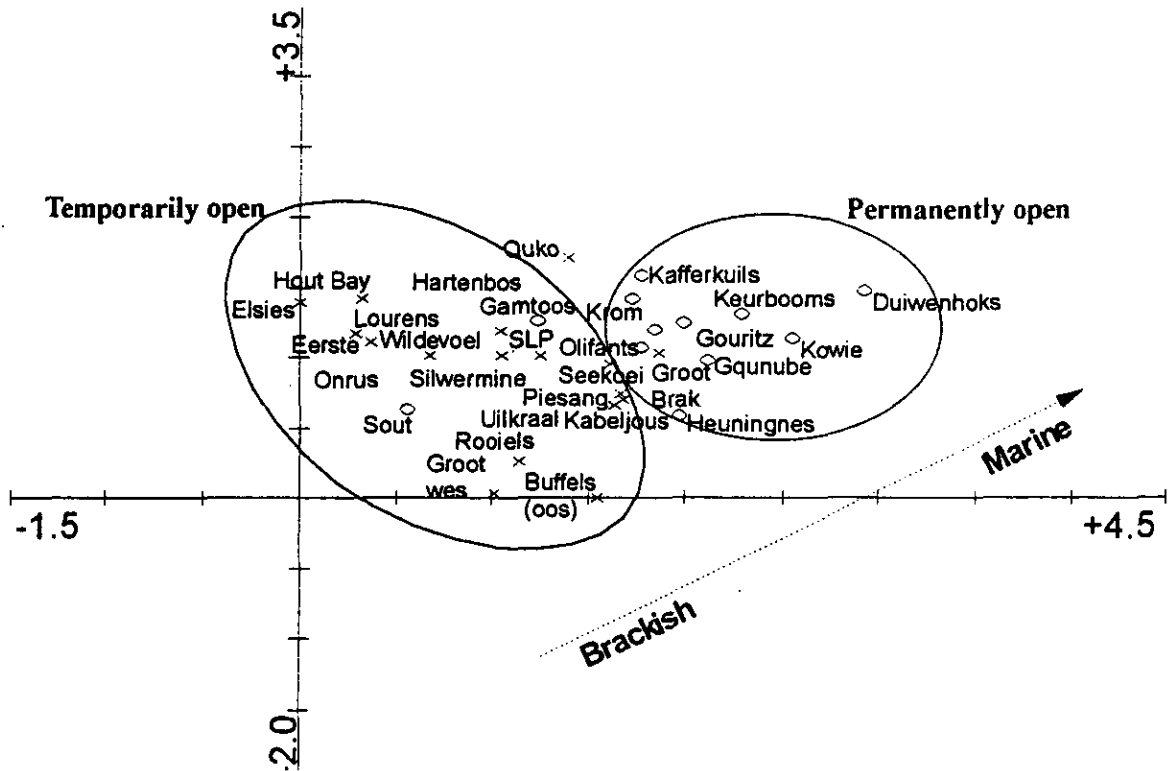


FIGURE 6. The estuary presence or absence ordination diagram obtained for permanently open (o) and temporarily open estuaries (x).

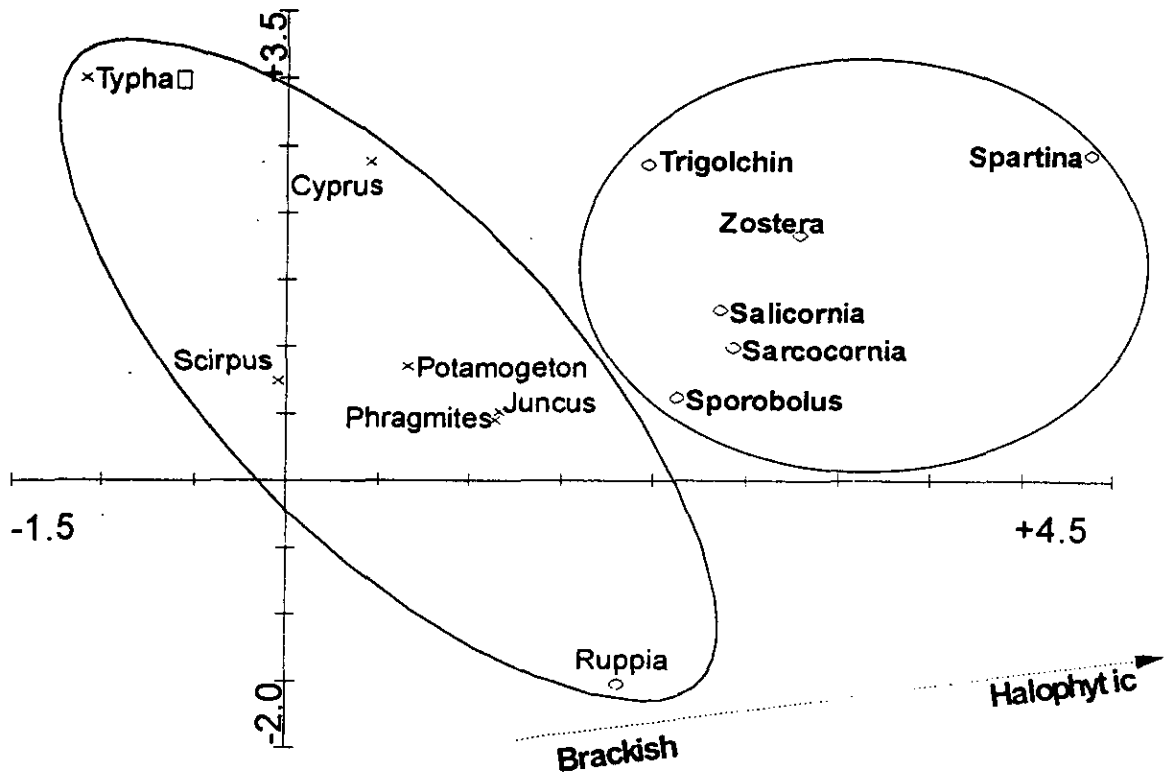


FIGURE 7. The species presence/absence ordination diagram obtained for estuary ordination above. The arrow indicates the gradient referred to in text.

2.3.3 Plant community area cover

Tables 10-13 presents the percentage area cover values calculated and the associated Braun Blanquet scores used for the DCA analysis. Figure 8 is the ordination diagram obtained using these Braun Blanquet scores. From the values obtained in the Tables, observations can be made regarding the dominance of certain community types in the different regions. For example every estuary in the False Bay and surrounding region has a reed/sedge community and very few other communities. The remaining estuaries have high percentage covers of both supra- and intertidal marshes. It is important to note that these percentage cover values are only for those plant community types for which an area value was provided in the ECRU reports. Community types that were present in the estuary, but for which area values were not provided, did not receive a percentage area cover value and are not represented in these tables. These communities are only taken into account in the scoring (botanical importance rating) section of this study.

The estuary ordination diagram (Figure 8) for the plant community area cover shows two gradients. The first gradient is from reed/sedge communities to halophytic communities. The False Bay and surrounding estuaries grade into permanently open estuaries with saltmarsh communities present. The second gradient from the bottom to the top of the ordination diagram indicates estuaries dominated by supratidal marshes. These estuaries included the Uilkraals, Gamtoos, Heuningnes and Gourtiz estuaries that changed to a group of estuaries with intertidal saltmarshes (Swartkops, Duiwenhoks, Kafferkuils, Nahoon, Kowie and Gqunube). The estuaries appeared to be grouped according to their geographical location rather than because they are either temporarily or permanently open.

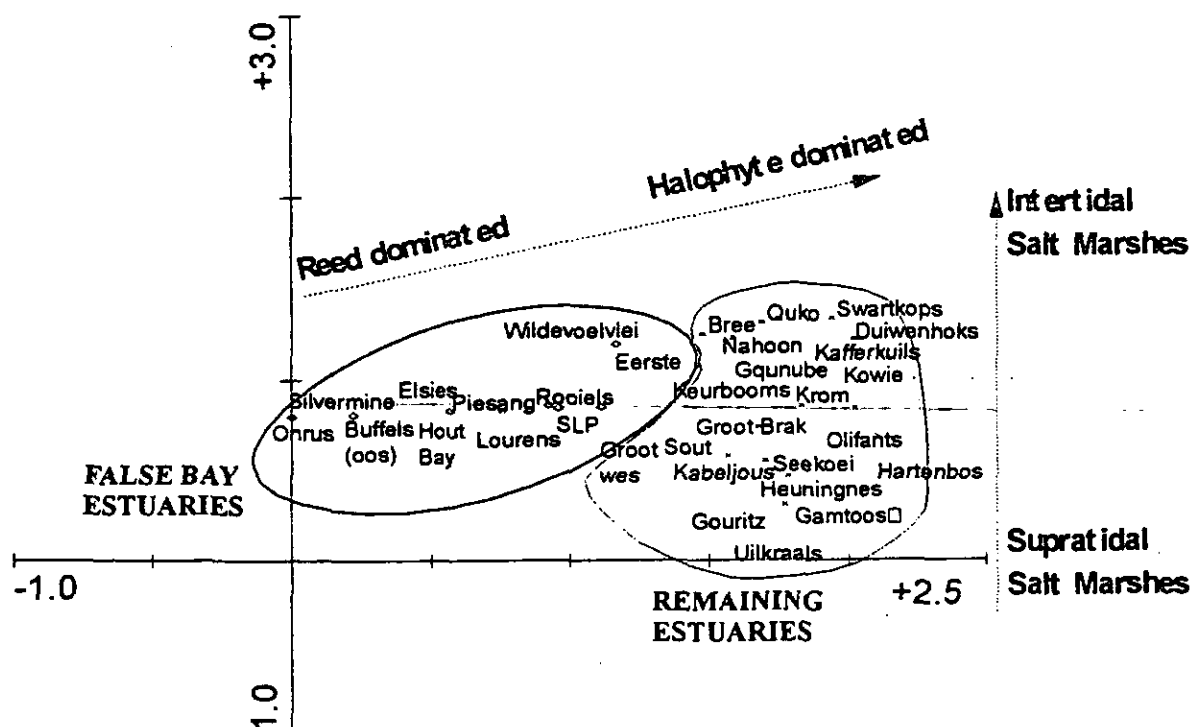


FIGURE 8. The estuary ordination diagram obtained using the area cover of the plant communities (Tables 10-13). Arrows indicate the gradients referred to in the text.

TABLE 11. Area values (in ha) and the subsequent percentage area cover of each community type in the estuaries of south western Cape coast. The Braun Blanquet class to which each community is assigned is indicated in brackets after the percentage area values.

	AREA							
	Olifants	Uilkraals	Onrus	Heuningnes	Bree	Duiwenhoks	Kafferkuils	Gouritz
Water (Ha)	164.08	21		39.37	370.74	72.91	47.78	91.51
Supratidal (Ha)	284.9	37.7		28.15				
Intertidal (Ha)	196.79				41.08	50.78	44.2	21.07
Submerged macrophytes (Ha)								
Reedswamp/Sedgeland (Ha)			41.08	3.13				
TOTAL AREA (Ha)	645.77	58.7	41.08	70.65	411.82	123.69	91.98	112.58
PERCENTAGE AREA								
WATER	25.41 (3)	35.78 (3)		55.73 (4)	90.02 (5)	58.95 (4)	51.95 (4)	81.28 (5)
SUPRATIDAL	44.12 (3)	64.22 (4)		39.84 (3)				
INTERTIDAL	30.47 (3)				9.98 (2)	41.05 (3)	48.05 (3)	18.72 (2)
REEDSWAMP			100 (5)	4.43 (1)				
SUBMERGED MACRO								

TABLE 12. Area values (in ha) and the subsequent percentage area cover of each community type in the estuaries of the south Cape coast. The Braun Blanquet class to which each community is assigned is indicated in brackets after the percentage area values.

	AREA						
	Groot (Wes)	Groot Brak	Hartenbos	Sout	Piesang	Keurbooms	
Water (Ha)	27.86	38.46	15.72	42.43	8.5	192.07	
Supratidal (Ha)	0.76	34.83	13.62	0.49			
Intertidal (Ha)		5.36	2.04			42.9	
Submerged macrophytes (Ha)							
Reedswamp/Sedgeland (Ha)	2.54	4.34			3.14		
TOTAL AREA (Ha)	31.16	82.99	31.38	42.92	11.64	234.97	
PERCENTAGE AREA							
% WATER	89.41 (5)	46.34 (3)	50.1 (4)	98.86 (5)	73.02 (4)	81.74 (5)	
% SUPRATIDAL	2.44 (1)	41.97 (3)	43.4 (2)	1.14 (1)		18.26 (2)	
% INTERTIDAL		6.46 (2)	6.5 (2)				
% REEDSWAMP	8.15 (2)	5.23 (2)			26.98 (3)		
% SUBMERGED MACRO							

TABLE 13. Area values (in ha) and the subsequent percentage area cover of each community type in the estuaries of the southeastern Cape coast. The Braun Blanquet class to which each community is assigned is indicated in brackets after the percentage area values.

	AREA									
	Gamtoos	Seekoel	Kabeljous	Quko	Qinira	Kowie	Swartkops	Krom	Gqunube	Nahoon
Water (Ha)	175	87.6	226.47	31	38.2	43.08	142	262.68	74.21	56.55
Supratidal (Ha)	62	1.2	35.83					68.55		
Intertidal (Ha)				3.9		35.2	360	104.93	7.62	6.88
Submerged macrophyte (Ha)		43.41	58.03				13.7	15.81		
Reedswamp/Sedgeland (Ha)	4.18	0.18	3.78		16.83	6.36		18.91		
TOTAL AREA (Ha)	241.18	132.39	324.11	34.9	55.03	84.64	515.7	470.88	81.83	63.43
PERCENTAGE AREA										
WATER	72.56 (4)	66.17(4)	69.87 (4)	88.83 (5)	69.42 (4)	50.9 (4)	27.54 (3)	55.78 (3)	90.69 (5)	89.15 (5)
SUPRATIDAL	25.71 (3)	0.91(1)	11.05 (2)					14.56 (2)		
INTERTIDAL				11.17 (2)		41.59 (3)	69.81 (4)	22.28 (2)	9.31 (2)	10.85 (2)
REEDSWAMP	1.73 (1)	0.14 (1)	1.17 (1)		30.58 (3)	7.51 (2)		4.02 (1)		
SUBMERGED MACRO		32.79 (3)	17.9 (2)				2.66 (1)	3.36 (1)		

2.4 DISCUSSION

Multivariate analysis techniques were used to establish whether plant species were associated with specific types of estuaries (Whitfield 1992). The estuaries were separated according to species differences i.e. the presence of mangrove swamps in the Natal estuaries and saltmarsh species in the Cape estuaries. When the Natal estuaries were removed from the analysis the results showed that the remaining estuaries could not be grouped according to species cover. Presence/absence of dominant species and plant community cover was more useful in determining estuary groupings. The presence/absence

ordination diagram indicated that estuaries could be grouped into clusters representing permanently and temporarily open estuaries. In particular, the temporarily open estuaries flowing into False Bay were separated from the remaining estuaries on the basis of their brackish plant communities. Classification of the estuaries according to their plant communities showed that estuaries can be divided into two groups based on their botanical features:

- Group 1: Estuaries dominated by brackish species
(reed and sedge communities)
- Group 2: Estuaries dominated by halophytic species
(saltmarsh communities)
 - 2.1 Estuaries dominated by intertidal saltmarshes
 - 2.2 Estuaries dominated by supratidal saltmarshes.

Group 1 is dominated by temporarily open estuaries in south western and southern Cape (False Bay), where freshwater conditions and brackish wetlands are common (O'Callaghan 1990). Group 2 describes all the remaining permanently and temporarily open estuaries along the Cape coast. These estuaries, especially the permanently open, have greater tidal exchange and more marine influence and halophytic species are therefore common. The Swartkops, Kromme and Olifants estuaries have extensive intertidal marshes and therefore fit the description for group 2.1. The Gamtoos and Gouritz estuaries have large supratidal saltmarshes and fit into group 2.2.

From knowledge of the different plant communities in the estuary general comments can be made about the management of freshwater flows into the estuary in order to maintain the plant communities. For example if one considered the freshwater management of the Swartkops estuary (i.e. a permanently open system) which has extensive intertidal saltmarshes it would be important to;

- : maintain salinity between 10-35 ppt, as this is the optimal salinity range for the growth of intertidal saltmarsh plants,
- : ensure daily tidal flushing, because the salinity must be maintained and should not drop to zero,
- : prevent prolonged inundation during the growing season, because if they are submerged they do not flower and set seed, and
- : prevent prolonged dry sediment conditions as the plants require waterlogged conditions for optimal growth.

Freshwater input thus effects a number of physical factors to which the plants respond, these include salinity, water level, water velocity and turbidity. Freshwater input is important in maintaining salinity at optimal conditions for plant growth. Species that comprise the reed and sedge communities (i.e. *Phragmites* spp, *Scirpus* spp) grow optimally at a salinity of less than 5 ppt, but can survive between 5 and 15 ppt. Intertidal and supratidal saltmarsh plants predominate at salinities between 10-35 ppt, at salinities outside this range growth and productivity are reduced. The reedswamp communities and the saltmarsh plants require waterlogged conditions. The degree of tidal flushing determines whether the marsh is intertidal or supratidal. Prolonged inundation can have a detrimental effect on plant growth and supratidal marsh plants are more sensitive to submergence than intertidal plant. Submerged macrophytes are sensitive to water velocity and water clarity. The physical conditions that need to be maintained in order to ensure the growth and survival of estuarine plants is summarized in Table 14.

TABLE 14. Physical conditions that need to be maintained in order to ensure the growth and survival of estuarine plants.

Supratidal saltmarsh

- : salinity between 10-35 ppt
- : tidal flushing once/twice a year

Intertidal saltmarsh

- : salinity between 10-35 ppt
- : daily tidal flushing
- : prevent prolonged inundation during growing season
- : prevent prolonged dry sediment conditions

Submerged macrophytes

- : salinity varies depending on dominant submerged macrophyte
- : prevent prolonged exposure
- : prevent turbid conditions
- : water velocity < 1 m.s⁻¹
- : periodic flooding

Reeds and sedges

- : salinity less than 15 ppt
- : periodic flooding and water level fluctuation to prevent encroachment of the water body
- : prevent prolonged dry sediment conditions

3. THE DEVELOPMENT OF A BOTANICAL IMPORTANCE RATING SYSTEM FOR ESTUARIES

3.1 INTRODUCTION

Encroaching industrial and residential development, recreational activities as well as an increasing demand for freshwater from a rapidly expanding population threaten estuaries in South Africa. The construction of dams appears, at present, to be the only way that the freshwater demand of the population can be satisfied. This implies that not all estuaries will be able to be conserved with respect to their freshwater requirements. Estuaries with a high conservation priority need to be identified and their freshwater requirements met in order to ensure their continued functioning. All that remains is to identify estuaries with a high conservation value.

Any individual estuary can be identified as important for a number of different reasons. It may have a rare bird species present; another may have unique hydrological features and another may have especially large saltmarsh areas or it might be an important estuary for recreation. These zoological, physical, socio-economic and botanical factors all contribute towards the overall importance of an estuary. The Consortium for Estuarine Research and Management (CERM) is working towards incorporating all these attributes and developing an overall importance value for South African estuaries (CERM 1994). This project, however, deals with only the botanical importance of estuaries. Botanical importance is defined as the contribution of the plant communities to the overall conservation status of an estuary.

Plant communities in estuaries have ecological as well as economic importance within the estuary (Vernberg 1993). Ecologically, saltmarshes are a source of primary production and they provide habitat and food for a large variety of faunal species (Childers and Day 1990, Kolkkin and Allanson 1985, Taylor and Allanson 1995). Reedswamps, are capable of removing large amounts of nutrients from the water column and act as nutrient sinks in the natural environment (Martin and Fernandez 1992, Brix 1993, Vernberg 1993). The economic importance of estuarine plant communities relates to their effectiveness in flood, erosion and stormwater surge control (Vernberg 1993). The ability of estuarine plant communities to improve water quality by retaining pollutants and excess nutrients can also have important economic implications.

Any method that aims to determine the botanical-importance-of-estuaries-must take these properties into account. A larger salt marsh will be more effective at performing the functions mentioned above, than a small one and should therefore be considered more important for the estuary. Also, the greater the number of different plant community types in the estuary the greater the variety of habitat types. Maintenance of habitat has long been recognized as the key issue in conservation and environmental management.

This chapter will describe the development of a scoring system that was effective at

summarising botanical importance into a single score. With this information planners, developers, managers and conservationists can see at a glance which estuaries are botanically more important and require careful consideration, management and conservation.

3.2 DEVELOPMENT OF A BOTANICAL IMPORTANCE SCORE

The factors used in the botanical scoring of estuaries were:

- Plant community area covered,
- Plant community condition (degree of impact),
- Plant community importance within the estuary and,
- Plant community richness.

Species were not considered separately because, unlike in most terrestrial environments, most estuarine plant communities consist of either one or very few dominant species (O'Callaghan 1994). For example monospecific stands of the reed *Phragmites australis* are common in brackish estuaries.

Each estuary score is the arithmetic sum of each of the four factors listed above. The principle behind the scoring was, the greater the area covered by a plant community, the fewer impacts associated with it, and the greater the number of communities (i.e. community richness) in an estuary - the higher the final score. The four plant communities considered and their main species are listed in Table 15.

The formula developed for the calculation of the final botanical score for each estuary was as follows:

Where:

$$1(A_{\text{supra}} \times \text{MF}) + 1.75(A_{\text{inter}} \times \text{MF}) + 2(A_{\text{subm}} \times \text{MF}) + 1.5(A_{\text{reed}} \times \text{MF})$$

Where:

- A_{supra} = Area covered by supratidal saltmarsh.
- A_{inter} = Area covered by intertidal saltmarsh.
- A_{subm} = Area covered by submerged macrophytes.
- A_{reed} = Area covered by the reed-sedge community.

MF = Multiplication Factor (plant community condition)

2, 1.75, 1.5, 1 = community importance values based on the association of the plant community with the estuary.

Each of the components of the formula are discussed below and an example is given of how this scoring system would be used for a hypothetical estuary.

3.2.1 COMMUNITY AREA COVERED (A_x)

First the areas covered by the different plant communities and the water surface area in the estuary were summed. Then the percentage area covered by each plant community and the percentage water surface area were calculated from this total. To incorporate the area cover of the plant communities into the formula, cover scores were transformed as follows: first the percentage estimates were transformed into Braun-Blanquet cover scale values (Table 16) as used in phytosociology (Mueller-Dombois and Ellenberg 1974) and then these values were replaced by equally spaced figures between 20 and 100 (Table 16). This large range of values was chosen to enable a more distinct comparison between community types as to the area covered by them.

A major limitation to any project that looks at a number of different areas, is data availability and uniformity. Information on the area covered by different plant communities might be available for one estuary, but not for another; or for one estuary many historical data may be available, whereas for other estuaries only one recent description is known. This means that the same sort of data is not always available for all estuaries. Using percentage range classes means that estimations can be made of the area covered by different plant communities with some degree of accuracy. Each plant community in the estuary was allocated a cover score in this manner and is represented in the formula as A_x .

Example A:

An estuary has three plant communities: An intertidal marsh with 34 % area cover, a reedswamp with 3 % area cover and a submerged macrophyte community with 8 % area cover. The scores for each of these communities, would be:

	% COVER	B-B CLASS	SCORE (From Table 15)
Intertidal marsh	34	25-50%	60
Reed swamp	3	< 5 %	20
Submerged macrophytes	8	5-25%	40

These values are then used as the cover score in the formula i.e.

$$A_{\text{inter}} = 60, A_{\text{reed}} = 20, A_{\text{subm}} = 40.$$

TABLE 15. Plant communities used for botanical scoring of estuaries.

Plant communities	Dominant species (for South African estuaries)
Supratidal salt marshes	<i>Suaeda fruticosa</i> , <i>Sarcocornia pillansii</i> , <i>Atriplex vestita</i> , <i>Disphyma crassifolium</i>
Intertidal salt marshes	<i>Sarcocornia perennis</i> , <i>S. decumbans</i> , <i>Triglochin bulbosa</i> , <i>T. maritima</i> , <i>Spartina maritima</i> , <i>Chenolea diffusa</i> , <i>Cotula coronifolia</i>
Submerged macrophyte beds	<i>Zostera capensis</i> , <i>Ruppia cirrhosa</i>
Reed and sedge communities	<i>Phragmites australis</i> , <i>Juncus kraussii</i> , <i>Scirpus littoralis</i>

TABLE 16. Braun – Blanquet (B-B) percentage classes and associated scores.

B-B class	Customary B-B score	Score allocated for use in formula
0.01 – 5 %	1	20
5.01 – 25 %	2	40
25.01 – 50 %	3	60
50.01 – 75 %	4	80
> 75 %	5	100

3.2.2 PLANT COMMUNITY CONDITION (MF)

The ecological condition of the plant communities was incorporated into the formula using a multiplication step. Multiplication was used instead of addition, as an addition step would always result in an increase in the score, even if the condition of the plant community was poor. A high score indicates a plant community in good condition.

Looking at the number of impacts affecting it assessed the condition of the community. The impacts (Table 17) included were chosen after reviewing the literature and from local experience of estuarine systems and the factors affecting them. The impacts were grouped into five categories, namely;

- hard engineering structures,
- anthropogenic impacts,
- alien plant invasion status,
- water quality and
- sedimentation.

Within each category a number of impacts were listed which affect plant communities (Table 17). Each estuarine community needs to be checked and the number of impacts affecting the community noted. In this way the total number of impacts for each community type can be determined. Four different condition classes (Class 1 - 4) were subjectively determined, based on the number of impacts (Table 18). Multiplication factors were assigned to these classes. Class 1 "pristine" indicates an estuary in a natural condition with no major impacts. Class 2 "under impact", indicates an estuary under some impact, but no rehabilitation is required. It includes estuaries where, for example, the saltmarsh communities undergo some impacts, but the marsh as a whole is not in an ecologically poor condition. Class 3 "degraded" refers to those estuaries that have been changed to the extent that the plant communities involved are in a degraded state. Rehabilitation measures are necessary to restore significant botanical importance potentially attached to them. These measures may include the removal of a weir, managing the water quality or removal of invasive plants species. Class 4 "disturbed", indicates estuaries that are under severe anthropogenic impact and have little remaining botanical significance.

The multiplication factors assigned to the community condition classes were used to modify the cover score to give a final number which incorporated the community area cover and community condition (see example C). If the plant community has a large area and is in a pristine condition (class 1) then the score is doubled. If, however, the marsh is impacted and in poor condition (class 3), the score is divided by a factor of 2. If the community is disturbed and of little botanical significance, the cover score is multiplied by 0.1, which decreases the score considerably. Such a reduction in importance score may appear if a large salt marsh area has been degraded.

Example B:

The impacts affecting each of the hypothetical communities were determined using the impact Table shown in Table 17. If, for example, the intertidal marsh has eight impacts affecting it, the reedswamp one impact and the submerged macrophyte community three impacts, multiplication factors could then be assigned using Table 18. The condition score then changes the cover scores (A_x) in the following manner:

	Percentage cover (%)	Cover score (A_x)	Multiplication factor (MF)	Cover x condition ($A_x \times MF$)
Intertidal marsh	34	60	0.5	30
Reedswamp	3	20	2	40
Submerged macrophytes	8	40	1	40

With 30, 40 and 40 being the adjusted scores for each community type.

3.2.3 PLANT COMMUNITY IMPORTANCE

Each plant community was assigned an importance value according to its association with the estuary, particularly the water column. Because of their close association with the water, submerged macrophytes (eg. *Zostera* and *Ruppia* beds) were regarded as the most important plant community (importance value = 2). They support more diverse and abundant invertebrate and juvenile fish communities than soft-bottomed habitats and marshes (Whitfield 1984, Whitfield 1989a, Fredette *et al.* 1990 and Connolly 1994). Primary productivity of submerged macrophyte beds is also very high and on par with the most productive plant habitats in marine and terrestrial ecosystems (Day 1981, Fredette *et al.* 1990). Intertidal saltmarshes were regarded as the second most important plant community (importance value = 1.75). Although they also perform most of the functions associated with submerged macrophytes, they do not support as wide a variety of faunal species (Fredette *et al.* 1990). Both the submerged macrophyte and intertidal saltmarsh communities are important with respect to water column processes and produce considerable amounts of plant detrital matter (Allanson 1982, Whitfield 1988b).

TABLE 17. The impact checklist against which each plant community type in the estuary was checked.

HARD ENGINEERING STRUCTURES
Bridge, weir through habitat, rubble obstructing flow
Retaining walls, canalisation of estuary course, canalisation of the mouth
Jetties through the community
Major dam or numerous farm dams in catchment affecting FW flow
ANTHROPOGENIC IMPACTS
Littering
Trampling and foot paths
Bait digging
Overgrazing
Boats mooring in the plant community
ALIEN PLANT INVASION STATUS
Presence of invasive plants
WATER QUALITY
Effluent discharge upstream negatively affecting plant community
Storm water discharge into estuary negatively affecting plant community
SEDIMENTATION
Erosion from catchment increasing siltation in plant community
Marine sediment intrusion into plant communities

TABLE 18. Impact classes and multiplication factors assigned to them.

Class #	# of impacts	Community quality description	Multiplication factor
1	< 2	Pristine	x 2
2	3 – 6	Impacted but no rehabilitation required	x 1
3	7 – 10	Impacted to the extent that some rehabilitatory steps are required	x 0.5
4	> 10	Severely degraded community – of little botanical significance	x 0.1

Saltmarshes are important inorganic and organic nutrient sources for estuaries but the degree of tidal flushing is important in determining how much of the nutrient is released into the water column (Childers and Day 1990). A supratidal marsh with little tidal flooding would be less important with respect to nutrient exchange than an intertidal marsh or submerged macrophyte bed. For this reason supratidal saltmarshes were given the lowest importance value (importance value = 1) as they are rarely flooded and in contact with the water column. Reed swamps and sedge communities were assigned an importance value of 1.5. These wetlands act as natural biological filters (Weisser and Parsons 1981, Brix 1993), they are important for bank stabilization and contribute to the diversity of aquatic life (particularly avifauna) (Haslam 1971).

Example C:

The hypothetical estuary has three communities, an intertidal marsh, a reedswamp and a submerged macrophyte bed. The scores determined according to the cover and condition components were 30, 40 and 40 respectively. After incorporating the importance values for each community the scores are adjusted in the following way:

	Cover x condition ($A_y \times MF$)	Importance value (n)	Importance score $n(A_y \times MF)$
Intertidal marsh	30	1.75	53
Reedswamp	40	1.5	60
Submerged macrophyte	40	2	80

The values used in the following step would be 53, 60 and 80.

3.2.4 PLANT COMMUNITY RICHNESS

The scores calculated for each individual community i.e. the product of the cover, condition and importance values are added together to obtain an overall score for the estuary. The addition step incorporates the community richness aspect of the importance rating i.e. the greater number of plant communities in the estuary the higher the score.

Example D:

Using the same example, the three final scores for each community are added together:

$$53 + 60 + 80 = 193$$

The score of 193 is the final botanical importance score for the estuary that includes the area covered by the three plant communities present in the estuary, condition, importance and richness of all the different plant communities. In multiple estuary comparisons the estuary which obtained the highest score after this step would be regarded as the most important estuary botanically. The estuaries were then be rated from highest to lowest to achieve a

botanical importance rating.

3.3 WORKSHOP-IMPROVEMENTS TO SCORING SYSTEM

The initial scoring system developed in 1994 was presented to a panel of experts (Appendix one) at a workshop in December 1994. A number of improvements to the botanical importance rating were suggested and are summarized below;

1. The permanently and temporarily open estuaries be separated and their scores presented separately,
2. The four different estuarine plant communities be assigned importance values based on their association with the estuary,
3. The area impacted in the different plant community types be included instead of just the number of impacts, and
4. The final score be downgraded according to the number of species one would expect to find in each plant community (i.e. n/N_{max}).

The first two suggestions by workshop participants were included in the final botanical importance rating system. This inclusion of a modification factor that would take into account the area impacted in the different plant community types was investigated. Because the area impacted needs to be quantified, impacts would have to be restricted to those that result in the destruction of the plant community, i.e. impacts would be restricted to; hard engineering structures, anthropogenic impacts, and invasion status.

Quantification of the area impacted proved problematic. Impacts such as littering, grazing and canalisation of the estuary mouth can be observed but to quantify the area impacted is difficult. It was also found that in estimating the area impacted, these areas fell into the lowest Braun Blanquet cover classes of < 5% and 5-25%. It was felt that the secondary impacts might have a far greater effect on the estuarine plant communities, but could not be accurately quantified. For example, a footpath may result in destruction of a certain area of marsh that can be directly quantified. However, the footpath could have a number of secondary impacts such as restricting tidal flushing of the marsh. This could be a far greater impact resulting in dry sediment conditions and increased sediment salinity.

The final suggestion from the workshop was to include a plant species richness component for *each of the different plant communities*. The suggestion was to determine the maximum potential number of species for each plant community (N_{max}) and then determine the actual number of species (n). n/N_{max} would then give a species richness component. This was not practical as most estuarine plant communities consist of monospecific stands (eg. *Zostera* beds and *Phragmites* stands).

3.4 DISCUSSION

The botanical scoring system was successful in condensing the botanical significance data for the estuaries to a single number. Because the formula is made up of a number of different components (i.e. area, condition, importance and richness) an estuary can achieve a high or low score for different reasons. The presentation of tables showing the allocation of points is therefore essential.

In the present scoring system all impacts were considered to have an equal effect on the plants, e.g. the presence of invasive plants is comparable to the negative effect of bait digging or the construction of a road through a plant community. The scoring system could be improved by including the degree of impact on a plant community, i.e. determining the area of the plant community disturbed by the impact. This information is not readily available for South African estuaries but can be obtained from aerial photographs. This would be a time consuming process and is probably only justified when comparing two estuaries rather than for the overall importance rating of numerous estuaries. In many cases aerial photographs are not available for the estuary before an impact occurred, e.g. in the Kowie estuary the mouth was canalised in 1836 (Heinecken and Grindley 1982). An extensive knowledge of the history of the estuary would be necessary to determine the extent of different impacts.

Other impacts that are not readily quantifiable are those that result in a change in species composition. For example, an increase in salinity as a result of decreased freshwater inflow from the catchment, might cause the disappearance of *Potamogeton* (a brackish submerged macrophyte) and an increase in *Zostera* (a marine submerged macrophyte) (Adams *et al.* 1992). Decreased tidal flushing as a result of a weir or bridge may change the species composition of an intertidal saltmarsh to a more supratidal or freshwater type. It is difficult to calculate the area of plant community affected by these impacts. For these reasons the degree of impact is not included in the present botanical scoring system. Only the numbers of impacts are included. This is advantageous as the condition of the plant community can be rapidly assessed with an impact checklist after a single visit to the estuary. In the development of any index, detail is often sacrificed for perspective (Ramm 1988). In the case of this botanical scoring system, detail on the degree of impact on a plant community is omitted in preference to a perspective on the number of impacts affecting the community.

The importance rating does not incorporate the dynamic nature of estuarine plant communities. Periodically open estuaries, and some permanently open estuaries are characterised by fluctuating biomass of submerged macrophytes (Talbot and Bate 1987, Talbot *et al.* 1990, Adams *et al.* 1992). The formula does not take this into account as it only considers optimal areal cover and the potential of the estuary to support a high plant biomass.

In South Africa, narrow channel-like estuaries that have a large freshwater input support rich phytoplankton communities. Alterations in the freshwater input and the associated nutrients can impact these communities. Phytoplankton communities are excluded from the botanical scoring system due to lack of knowledge. They should be included at some stage because in certain

estuaries phytoplankton are the dominant primary producers.

The conservation status or importance of a system is often determined using species richness or diversity. Turpie (1995) successfully used the diversity of bird species as a component of an index that rated the importance of South African estuaries based on avifauna. This botanical scoring system does not include species richness. Monospecific communities such as *Zostera capensis* or *Phragmites australis* beds are common in estuaries. In the saltmarsh habitat, diversity is influenced by the degree of elevation above the high water mark or the salinity gradient. Saltmarsh plants occur in distinct zones along this gradient. If the gradient is absent then fewer species occur. It is for these reasons that plant community richness was included instead of species richness.

The botanical scoring system developed in this project can be used to identify estuaries that have a high botanical conservation status. The freshwater input into these estuaries should be managed accordingly. From knowledge of the dominant plant communities in the estuary, general comments can be made about the management of freshwater flow into the estuary in order to maintain the plant communities. For example, an estuary that has extensive brackish plant communities needs freshwater to maintain the environment in that condition rather than allow it to become more saline.

The botanical importance rating score can be effectively used in an environmental or impact assessment when a dam is to be built in a region. The score will indicate estuaries which are botanically unique and whose freshwater requirements need to be maintained. Dam construction in their catchments should then be discouraged. If construction is unavoidable, stringent management policies need to be enforced to fulfil the requirements of the estuary.

4. THE BOTANICAL IMPORTANCE OF SELECTED CAPE ESTUARIES

4.1 INTRODUCTION

This study focused on the botanical importance of Cape estuaries from the Quko (Double mouth) estuary on the south-east coast, to the Olifants estuary on the west coast (Figures 1-3). The estuaries were rated according to their importance within the Cape region, their regional importance as well as against other estuaries of their type (i.e. temporarily or permanently open). Only temporarily and permanently open estuaries were considered. Estuarine lakes and estuarine bays (e.g. Knysna and Wilderness, Whitfield 1992) were excluded from the study. Estuarine lakes and bays are unique with respect to their physical, morphological and biological features and should in any event enjoy a high conservation status arising out of an importance system. Temporarily and permanently open estuaries on the other hand, have a large diversity of form and structure. The extent and type of plant communities present differ and therefore, the botanical importance and conservation status of these estuaries will also differ.

The morphology of an estuary can restrict the establishment of estuarine plant communities resulting in an estuary receiving a low botanical importance score. Whitfield (1995) classified the condition of the Quko and Sout estuaries as excellent i.e. the estuaries are in a near pristine condition with negligible human impact on either the estuary or catchment. These estuaries should therefore receive a high conservation status. However these estuaries received low botanical importance scores as steep banks surround them and the estuarine vegetation is sparse. For this reason it is important that not only the final score be considered but also the components from which it is derived.

4.2 METHODS

The botanical importance rating of estuaries was determined using the scoring system described in Chapter 3. This system indicates which estuaries are botanically important and the reasons for their importance. Factors used in the botanical scoring of estuaries were; plant community area covered, condition (degree of impact), association with the estuary (plant community importance within the estuary) and plant community richness.

The information required for the importance scores, i.e. area cover of plant communities and the impacts affecting plant communities, was obtained from the Estuarine and Coastal Research Unit's (ECRU) "*Estuaries of the Cape, Part I*" reports and from field visits. ECRU was subsequently incorporated into EMATEK (Division of Earth, Marine and Atmospheric Science and Technology) (Wiseman *et al.* 1993) and is now known as Environmentek, CSIR. Although these reports are generally descriptive and aim to be understood by non-scientists (Wiseman *et al.* 1993), they provide the most coherent form of information available on individual Cape estuaries. The estuaries for which scores were calculated are listed in Table 6.

The formula developed for the calculation of the final botanical score for each estuary was as follows:

$$1(A_{\text{supra}} \times \text{MF}) + 1.75(A_{\text{inter}} \times \text{MF}) + 2(A_{\text{subm}} \times \text{MF}) + 1.5 (A_{\text{reed}} \times \text{MF})$$

Where:

A_{supra} = Area covered by supratidal saltmarsh.

A_{inter} = Area covered by intertidal saltmarsh.

A_{subm} = Area covered by submerged macrophytes.

A_{reed} = Area covered by the reed-sedge community.

MF = Multiplication Factor (plant community condition)

2, 1.75, 1.5, 1 = community importance values based on association with the estuary.

A cover score of either 20, 40, 60, 80 or 100 was assigned to each plant community. The higher the area covered by the plant community the higher the score. If a site visit to the estuary confirmed the presence of a plant community for which an area was not provided in the ECRU reports then the community was allocated a cover score of 20.

The multiplication factor (MF) was determined from the number of impacts affecting each community, the greater the number of impacts the lower the multiplication factor. Each community in the estuary was checked against the impact table. The numbers of impacts affecting the community were noted and the total number of impacts for each community type determined (Tables 20-22). The total number of impacts is indicated as well as the multiplication factor subsequently assigned to the plant community (Tables 20-22).

The cover score was multiplied by the multiplication factor to obtain a single score for each plant community. This number was then multiplied by the community importance value. Plant communities were assigned an importance value according to its association with the estuary, particularly the water column.

The botanical importance scores for the different estuaries were calculated using the formula described. Because a wide range of scores was obtained, the scores were normalized to make the differences easier to conceptualise. The estuary with the highest score was regarded as having a score of 100 and the rest were ranked as a percentage of the highest score. The botanical importance rating is presented according to the three categories "all Cape", "regional" and "estuary type" (i.e. temporarily and permanently open estuaries). The regional importance rated the estuaries within four climatic and rainfall regions (Table 19 and Figures 1-3).

TABLE 19. Regional climatic divisions along the Cape coast.

REGION	BOUNDRIES	CLIMATE
Western Cape	Orange River to Cape Town	dry
South western Cape	Cape Town to Mossel Bay	winter rainfall
Southern Cape	Mossel Bay to Tsitsikamma	all year rainfall
South eastern Cape	Tsitsikamma to Kei mouth	bimodal rainfall

TABLE 20. Impacts affecting the estuaries along the south eastern Cape coast. An impact is indicated by an "X" and the communities impacted are shown in brackets. The number of impacts were totalled and a multiplication factor was assigned (in brackets). FW = Fresh water, S = Supratidal marsh, I = Intertidal marsh, s = Submerged macrophytes, R = Reedswamps and sedges.

	Olifants	Heuningnes	Hout Bay	Rooiels	Wildevoel	Silvermine	Elsies	S.L.Pass	Uilkraal	Lourens	Eerste	Onrus	Buffels Oos
HARD ENGINEERING STRUCTURES													
Bridge, weir through habitat			X(R)	X(s,R)		X(R)	X(R)	X(R)	X(S,R)	X(R)	X(R)		
Retaining walls, canalisation of estuary course		X(S)	X(R)			X(R)	X(R)	X(R)		X(R)	X(R)		
Jetties													
Rubble obstructing flow			X(R)			X(R)	X(R)						
Farm dams in catchment affecting FW inflow													
Dam in catchment affecting FW inflow		X(R)										X(R)	
Canalisation of mouth													
ANTHROPOGENIC IMPACTS													
Littering	X(S,I)		X(R)		X(I)	X(R)				X(R)	X(R)		
Trampling and foot paths	X(S,I)	X(S,R)	X(R)		X(I)				X(S,R)	X(R)	X(I,R)		
Bait digging													
Grazing	X(S)	X(S)	X(R)						X(S)		X(I,R)	X(R)	
Mooring in habitat													
High speed boating													
INVASION STATUS													
Presence of invasive plants			X(R)		X(I,R)	X(R)	X(R)	X(R)	X(S)	X(R)	X(I,R)	X(R)	
Vegetation encroachment		X(S)				X(R)		X(R)					
WATER QUALITY													
Effluent discharge upstream							X(R)	X(R)		X(R)	X(R)	X(R)	X(I)
Storm water discharge into estuary			X(R)		X(R)	X(R)	X(R)	X(R)		X(R)	X(R)	X(R)	X(I)
SEDIMENTATION													
Erosion from catchment increasing siltation			X(R)									X(R)	
Marine sediment intrusion													
TOTAL # OF IMPACTS:													
Supratidal	3(1)	4(1)							4(1)				
Intertidal marsh	2(2)				3(1)						3(1)		2(2)
Submerged macrophytes	0(2)	0(2)		1(2)									
Reedswamps and sedges	0(2)	2(2)	9(0.5)	1(2)	2(2)	7(0.5)	6(1)	6(1)	2(2)	7(0.5)	8(0.5)	6(1)	

TABLE 21. Impacts affecting the estuarine plant communities along the southern Cape coast. An impact is indicated by an "X" and the communities impacted are shown in brackets. The number of impacts were totalled and a multiplication factor was assigned (in brackets). Abbreviations described in Table 20.

	Sout	Groot-wes	Groot Brak	Hartenbos	Breë	Duiwenhoks	Kafferkuils	Gouritz	Piesang	Keurbooms
HARD ENGINEERING STRUCTURES										
Bridge, weir through habitat			X(I)	X(S)						
Retaining walls, canalisation of estuary course			X(s)	X(S,I,s)					X(R)	X(I)
Jetties										
Rubble obstructing flow										
Farm dams in catchment affecting FW inflow							X(I)			
Dam in catchment affecting FW inflow			X(I,S)							
Canalisation of mouth										
ANTHROPOGENIC IMPACTS										
Littering				X(s)						
Trampling and foot paths			X(S,I,R)	X(S,I)	X(I,R)		X(S,I,R)	X(S)	X(R)	X(I)
Bait digging			X(s)				X(s)			X(s)
Grazing				X(S,I)		X(S,I)	X(S,I)	X(S)		
Mooring in habitat										
High speed boating										
INVASION STATUS										
Presence of invasive plants		X(S,R)	X(S,R)	X(S,I)	X(I)		X(S,I)	X(S)	X(R)	X(S,I)
Vegetation encroachment										
WATER QUALITY										
Effluent discharge upstream			X(I,s)	X(I,s)					X(R)	
Storm water discharge into estuary										
SEDIMENTATION										
Erosion from catchment increasing siltation									X(R)	
Marine sediment intrusion										
TOTAL # OF IMPACTS:										
Supratidal	0(2)	1(2)	3(1)	5(1)		1(2)	3(1)	3(1)		1(2)
Intertidal marsh			4(1)	5(1)	2(2)	1(2)	4(1)			3(1)
Submerged macrophytes			3(1)	3(1)		0(2)	1(2)	0(2)		1(2)
Reedswamps and sedges		1(2)	2(2)		1(2)		1(2)	0(2)	5(1)	0(2)

TABLE 22. Impacts affecting the estuarine plant communities along the southern eastern Cape coast. An impact is indicated by an "X" and the communities impacted are shown in brackets. The number of impacts were totalled and a multiplication factor was assigned (in brackets). Abbreviations described in Table 20.

	Krom	Seekoei	Kabeljous	Gamtoos	Swartkops	Kowie	Nahoon	Quinira	Gqunube	Quko
HARD ENGINEERING STRUCTURES										
Bridge, weir through habitat	X(S,I)	X(S,s)	X(R)		X(S,I,s)	X(I,s)				
Retaining walls, canalisation of estuary course										
Jetties	X(I,s,R)				X(I,s)		X(I,s)			
Rubble obstructing flow		X(S,s)								
Farm dams in catchment affecting FW inflow		X(s,R)	X(s,R)							
Dam in catchment affecting FW inflow	X(I,s,R)						X(I)			
Canalisation of mouth		X(S)				X(s)				
ANTHROPOGENIC IMPACTS										
Littering					X(R)	X(I,s)				
Trampling and foot paths	X(S,I,s)		X(S)		X(S,I,s)	X(S,I,s)	X(I,s,R)	X(R)	X(I,s)	
Bait digging	X(s)				X(I,s)	X(I,s)	X(s)		X(s)	
Grazing	X(S,I)			X(S)	X(S)	X(I)				
Mooring in habitat	X(I,s)				X(s)					
High speed boating	X(s)				X(I,s,R)	X(I)	X(I,s)			
INVASION STATUS										
Presence of invasive plants	X(S)	X(S)		X(S)	X(S)	X(S)	X(I,R)		X(I)	
Vegetation encroachment							X(I)	X(R)		
WATER QUALITY										
Effluent discharge upstream					X(I)					
Storm water discharge into estuary					X(s)					
SEDIMENTATION										
Erosion from catchment increasing siltation	X(I)				X(I)			X(R)		X(I)
Marine sediment intrusion							X(I)			
TOTAL # OF IMPACTS:										
Supratidal marsh	4(1)	4(1)	1(2)	2(2)	3(1)	2(2)				
Intertidal marsh	7(0.5)			0(2)	7(0.5)	6(1)	6(1)		2(1)	1(2)
Submerged macrophytes	6(1)	3(1)	1(2)		7(0.5)	5(1)	4(1)		2(1)	
Reedswamps and sedges	2(2)	1(2)	2(2)	0(2)	2(2)		2(2)	3(1)	0(2)	

4.3 RESULTS

Tables 23-26 show the final formula scores and the breakdown of the scoring components for each estuary. The presentation of tables showing the allocation of points is essential as an estuary can achieve a score for different reasons. The final score should therefore be considered in relation to its component scores.

4.3.1 Importance rating for all Cape estuaries

In the following text the estuary score is presented in brackets after the name of the estuary. The actual formula score is given first, followed by the normalised score. Table 27 shows the importance rating for all the estuaries considered and the condition of each estuary as described by Whitfield (1994). The estuary with the highest score was the Olifants (410, 100), a permanently open estuary on the west coast. The estuaries with the lowest scores were two temporarily open False Bay estuaries, Lourens and Sir Lowry's Pass (30, 7; Plate 1). The Olifants obtained a high score as it has extensive marshes in the lower reaches that are in good condition. Community diversity was also high, as all four estuarine plant communities were present. The Duiwenhoks (330, 80) a permanently open estuary had the second highest score. Three plant communities were represented which had few impacts associated with them.

Eleven estuaries had normalised scores above 50. Within these eleven estuaries there was good representation of both temporarily and permanently open estuaries. The Kabeljous (300, 73) a small temporarily open estuary had the third highest score. It is a dynamic system often open or closed depending on the rainfall of the region. It has extensive submerged macrophyte beds when water levels are high, as well as intertidal saltmarshes and reedbeds (Adams *et al.* 1992).

The Groot Brak (290, 71) estuary is perceived to have a number of impacts associated with it, mostly related to effluent seepage into the estuary (Morant 1983, Slinger *et al.* 1994). Despite this it received a high botanical importance score. The high score can be attributed to the large marsh areas in the lower reaches which have few visible impacts associated with them. All four estuarine plant communities were also present. Blooms of filamentous green macroalgae have long been associated with eutrophic conditions (Josselyn and West 1985). Such blooms occur in the Groot Brak estuary and have been shown to adversely impact the social acceptability of water (Huizinga, Environmentek, CSIR, pers. comm.).

The condition of the Quko (140, 34) and Sout (40, 10) estuaries was rated as excellent by Whitfield (1994). Although these estuaries are in a botanically pristine undisturbed state they did not receive a high botanical score as the estuarine vegetation is sparse and only one estuarine plant community is represented. Steep banks surround these systems with thick terrestrial coastal thicket vegetation up to the water's edge. The morphology of an estuary can therefore limit botanical diversity of an estuary. The two estuaries with the lowest score, the Lourens and Sir Lowry's Pass (30,7) flow into False Bay. These estuaries are in poor condition and rehabilitatory steps would be necessary to restore any botanical significance to them.

TABLE 23. The scoring components used to obtain the final score for each estuary for the False Bay and surrounding areas. The cover score is given for each community. The multiplication factor (MF) indicates the condition of the community. Each community is allocated an importance value. The final score is obtained from the addition of each plant community's score after multiplication with the importance value.

	Hout Bay	Rooiels	Wildevool	Silvermine	Elsies	Sir Lowrys Pass	Lourens Eerste	Buffels Oos	
SUPRATIDAL									
< 5 %									
5 - 25 %									
25 - 50 %									
50 - 75 %									
>75 %									
MF									
INTERTIDAL									
< 5 %									
5 - 25 %			40					40	
25 - 50 %									
50 - 75 %									
>75 %									
MF			1					1	
REEDSWAMPS									
< 5 %						20			
5 - 25 %							40		
25 - 50 %	60	60	60		80			60	
50 - 75 %								80	
>75 %				100					
MF	0.5	2	2	0.5	1	1	0.5	0.5	2
SUBMERGED MACROPHYTES									
< 5 %		20							
5 - 25 %									
25 - 50 %									
50 - 75 %									
>75 %									
MF		2							
Cover score X importance value									
Supratidal Importance value									
Intertidal Importance value									
			40					40	
			1.75					1.75	
			70					70	
Reedswamps Importance value									
	30	120	120	50	80	20	20	30	160
	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	45	180	180	75	120	30	30	45	240
Submerged macrophytes Importance value									
		40							
		2							
		80							
FINAL SCORE									
	45	260	250	75	120	30	30	115	240

TABLE 24. The scoring components used to obtain the final score for each estuary for the south western Cape region. The cover score is given for each community. The multiplication factor (MF) indicates the condition of the community. Each community is allocated an importance value. The final score is obtained from the addition of each plant community's score after multiplication with the importance value. The final score is obtained from the addition of each plant community score after multiplication with the importance value. "20*" indicates the communities for which area cover was not available, these communities were allocated to the lowest cover class.

	Olifants	Heuningnes	Uilkraal	Onrus	Bree	Duiwenhoks	Kafferkuils	Gourits
SUPRATIDAL								
< 5 %						20*	20*	
5 - 25 %								40
25 - 50 %	60	60						
50 - 75 %			80					
>75 %								
MF	1	1	1			2	1	1
INTERTIDAL								
< 5 %								
5 - 25 %					40			
25 - 50 %	60					60	60	
50 - 75 %								
>75 %								
MF	2				2	2	1	
REEDSWAMPS								
< 5 %		20	20*		20*		20*	20*
5 - 25 %	20*							
25 - 50 %								
50 - 75 %								
>75 %				100				
MF	2	2	2	1	2		2	2
SUBMERGED MACROPHYTES								
< 5 %	20*	20*				20*	20*	20*
5 - 25 %								
25 - 50 %								
50 - 75 %								
>75 %								
MF	2	2				2	2	2
Cover score x importance value								
Supratidal	60	60	80			40	20	40
Importance value	1	1	1			1	1	1
	60	60	80			40	20	40
Intertidal	120				80	120	60	
Importance value	1.75				1.75	1.75	1.75	
	210				140	210	105	
Reedswamps	40	40	40	100	40		40	40
Importance value	1.5	1.5	1.5	1.5	1.5		1.5	1.5
	60	60	60	150	60		60	60
Submerged macrophytes	40	40				40	40	40
Importance value	2	2				2	2	2
	80	80				80	80	80
FINAL SCORE	410	200	140	150	200	330	265	180

TABLE 25. The scoring components used to obtain the final score for each estuary for the southern Cape region. The cover score is given for each community. The multiplication factor (MF) indicates the condition of the community. Each community is allocated an importance value. The final score is obtained from the addition of each plant community score after multiplication with the importance value. "20*" indicates the communities for which area cover was not available, these communities were allocated to the lowest cover class.

	Groot Brak	Hartenbos	Sout	Groot Wes	Piesang	Keurbooms	Krom	Gamtoos
SUPRATIDAL								
< 5 %			20	20		20*		
5 - 25 %							40	
25 - 50 %	60	60						60
50 - 75 %								
>75 %								
MF	1	1	2	2		2	1	2
INTERTIDAL								
< 5 %								20*
5 - 25 %	40	40				40	40	
25 - 50 %								
50 - 75 %								
>75 %								
MF	1	1				1	0.5	2
REEDSWAMPS								
< 5 %						20*	20	20
5 - 25 %	40			40				
25 - 50 %					60			
50 - 75 %								
>75 %								
MF	2			2	1	2	2	2
SUBMERGED MACROPHYTES								
< 5 %	20*	20*				20*	20	
5 - 25 %								
25 - 50 %								
50 - 75 %								
>75 %								
MF	1	1				2	1	
Cover score x importance value								
Supratidal	60	60	40	40		40	40	120
Importance value	1	1	1	1		1	1	1
	60	60	40	40		40	40	120
Intertidal	40	40				40	20	40
Importance value	1.75	1.75				1.75	1.75	1.75
	70	70				70	35	70
Reedswamps	80			80	60	40	40	40
Importance value	1.5			1.5	1.5	1.5	1.5	1.5
	120			120	90	60	60	60
Submerged macrophytes	20	20				40	20	
Importance value	2	2				2	2	
	40	40				80	40	
FINAL SCORE	290	170	40	160	90	250	175	250

TABLE 26. The scoring components used to obtain the final score for each estuary for the south eastern Cape region. The cover score is given for each community. The multiplication factor (MF) indicates the condition of the community. Each community is allocated an importance value. The final score is obtained from the addition of each plant community's score after multiplication with the importance value. "20*" indicates those communities for which areas were not available and therefore allocated to the lowest class.

	Seekoei	Kabeljous	Swartkops	Kowie	Nahoon	Qinira	Gqunube	Quko
SUPRATIDAL								
< 5 %	20		20*	20*				
5 - 25 %		40						
25 - 50 %								
50 - 75 %								
>75 %								
MF	1	2	1	2				
INTERTIDAL								
< 5 %								
5 - 25 %					40		40	40
25 - 50 %				60				
50 - 75 %			80					
>75 %								
MF			0.5	1	1		2	2
REEDSWAMPS								
< 5 %	20	20	20*		20*		20*	
5 - 25 %								
25 - 50 %						60		
50 - 75 %								
>75 %								
MF	2	2	2		2	1	2	
SUBMERGED MACROPHYTES								
< 5 %			20	20*	20*		20*	
5 - 25 %		40						
25 - 50 %	60							
50 - 75 %								
>75 %								
MF	1	2	0.5	1	1		2	
Cover score X importance value								
Supratidal	20	80	20	40				
Importance value	1	1	1	1				
	20	80	20	40				
Intertidal			40	60	40		80	80
Importance value			1.75	1.75	1.75		1.75	1.75
			70	105	70		140	140
Reedswamps	40	40	40		40	60	40	
Importance value	1.5	1.5	1.5		1.5	1.5	1.5	
	60	60	60		60	90	60	
Submerged macrophytes	60	80	10	20	20		40	
Importance value	2	2	2	2	2		2	
	120	160	20	40	40		80	
FINAL SCORE	200	300	170	185	170	90	280	140

TABLE 27. Botanical importance rating for all Cape estuaries. The formula scores are followed by the normalised scores. The ecological condition of each community (Whitfield 1994) is given in the last column.

	Formula Score	Normalised Score	Whitfield rating
Olifants	410	100	Good
Duiwenhoks	330	80	Excellent
Kabeljous	300	73	Good
Groot Brak	290	71	Fair
Gqunube	280	68	Good
Kafferkuils	265	65	Good
Rooiels	260	63	Good
Keurbooms	250	61	Good
Gamtoos	250	61	Fair
Wildevölvlei	250	61	Good
Buffels Oos	240	59	Good
Seekoei	200	49	Poor
Breë	200	49	Good
Heuningnes	200	49	Good
Kowie	185	45	Fair
Gouritz	180	44	Good
Krom	175	43	Fair
Swartkops	170	41	Fair
Nahoon	170	41	Fair
Hartenbos	170	41	Poor
Groot Wes	160	39	Good
Onrus	150	37	Poor
Quko	140	34	Excellent
Uilkraal	140	34	Fair
Elsies	120	29	Poor
Eerste	115	28	Poor
Piesang	90	22	Fair
Qinira	90	22	Good
Silvermine	75	18	Poor
Hout Bay	45	11	Poor
Sout	40	10	Excellent
Sir Lowry's Pass	30	7	Poor
Lourens	30	7	Poor

4.3.2 Regional importance rating

Table 28 lists the botanical importance scores for the different regions. The Olifants estuary (410, 100) received the highest score in the western Cape as it was the only estuary considered in this region. The estuary with the highest score in the south western Cape was the Duiwenhoks (330, 100). In the southern Cape, the Groot Brak estuary (290, 100) had the highest score. The estuary with the second highest score, the Keurbooms (250, 86), is an important recreational estuary near Plettenberg Bay.

In the southeastern Cape, the Kabeljous estuary had the highest score. Two of the larger estuaries in this region, the Krom (175, 58) and Swartkops (170, 57) had lower scores than other smaller systems along the coast. Although extensive intertidal saltmarshes and *Zostera capensis* beds characterize these estuaries, their botanical importance is decreased by numerous residential and industrial impacts that are associated with them. A low condition score therefore decreases the significance of their large estuarine plant areas.

4.3.3 Estuary-type score

The permanently open estuary with the highest score was the Olifants (410, 100) and the Sout near Natures Valley had the lowest score (40, 10) (Table 29). Examples of heavily impacted permanently open estuaries include the Kowie (185, 45) and Nahoon (170, 41) estuaries. Impacts in the Kowie estuary include hard engineering structures such as the marina on a wetland area near the mouth and the canalisation of the estuary course in the lower reaches. Trampling, as a result of bait digging and livestock grazing, has severely impacted the largest marsh in this estuary. The Nahoon estuary in East London on the south east Cape coast, is impacted as a result of close residential proximity, decreased freshwater inflow and effluent discharge. The estuarine plant communities cover small areas and consequently receive low cover scores that were further decreased by the low condition score.

The two temporarily open estuaries with the highest scores were the Kabeljous (300, 100) and Groot Brak (290, 97). As already mentioned two False Bay estuaries, Lourens and Sir Lowry's Pass (30, 10) received the lowest score (Table 28). The estuaries in the False Bay area generally obtained low scores, with the exception of the Rooiels (260, 87), Wildevoëllei (250, 83) and Buffels (Oos) (240, 80). These three estuaries are located away from the dense residential areas that surround the other estuaries. Although these estuaries are small with low community richness and low community area cover, the absence of impacts affecting the communities increased the cover score and improved the final score. Of the 10 temporarily open estuaries with scores below 50, seven occur in the area of False Bay and surroundings. These estuaries are severely impacted as a result of residential and industrial proximity. Rehabilitatory steps would be necessary to restore any botanical significance to them.

TABLE 28. The estuary type botanical importance rating. The formula score is followed by the normalised score.

PERMANENTLY OPEN			TEMPORARILY OPEN		
Olifants	410	100	Kabeljous	300	100
Duiwenhoks	330	80	Groot Brak	290	97
Gqunube	280	68	Rooiels	260	87
Kafferkuils	265	65	Wildevoeëlvlei	250	83
Keurbooms	250	61	Buffels Oos	240	80
Gamtoos	250	61	Seekoei	200	67
Breë	200	49	Hartenbos	170	57
Heuningnes	200	49	Groot Wes	160	53
Kowie	185	45	Onrus	150	50
Gouritz	180	44	Quko	140	47
Krom	175	43	Uilkraal	140	47
Swartkops	170	41	Elsies	120	40
Nahoon	170	41	Eerste	115	38
Sout	40	10	Piesang	90	30
			Qinira	90	30
			Silvermine	75	25
			Hout Bay	45	15
			S.L. Pass	30	10
			Lourens	30	10

TABLE 28. Regional botanical importance rating. The formula score is followed by the normalised score.

Region 1			Region 2			Region 3			Region 4		
Olifants	410	100	Duiwenhoks	330	100	Groot Brak	290	100	Kabeljous	300	100
			Kafferkuils	265	80	Keurbooms	250	86	Gqunube	280	93
			Rooiels	260	79	Hartenbos	170	59	Gamtoos	250	83
			Wildevoeël	250	76	Groot Wes	160	55	Seekoei	200	67
			Buffels Oos	240	73	Piesang	90	31	Kowie	185	62
			Breë	200	61	Sout	40	14	Gouritz	180	60
			Heuningnes	200	61				Krom	175	58
			Onrus	150	45				Swartkops	170	57
			Uilkraal	140	42				Nahoon	170	57
			Elsies	120	36				Quko	140	47
			Eerste	115	35				Qinira	90	30
			Silvermine	75	23						
			Hout Bay	45	14						
			S.L. Pass	30	9						
			Lourens	30	9						

4.4 DISCUSSION

The botanical importance scores highlighted estuaries with important botanical features e.g. the Kabeljous. The importance of the Kabeljous estuary could be overlooked because it is not very large nor important from a recreational point of view. However, it is a good example of a dynamic temporarily open estuary and the condition of its plant communities is reflected in its high score. The Rooiels and Wildevoëlvele were two other small estuaries that obtained high botanical importance values. In a separate study by O'Callaghan (1990), the Rooiels received the highest conservability rating, because there has been little human impact on this system.

The Olifants achieved the highest botanical importance score in this study. Two other studies have also indicated its importance (Turpie 1994, Harrison *et al.* 1994a and b). Turpie (1994) ranked the Olifants amongst the top 10 estuaries important for waterbird conservation in South Africa. In Harrison *et al.* (1994a,b) it achieved the highest score in their estuarine health index (EHI) survey of the west coast. The estuarine health index is based on biological health (assessment of fish community), water quality and aesthetic condition of an estuary (Harrison *et al.* 1994a). The Olifants is an example where three indices, looking at different parameters, can be combined to decide the importance of the estuary.

Management of estuaries inevitably requires trade-offs and it is recognized that not all estuaries are equally important. Certain estuaries have little ecological value and enjoy low priority when water is scarce, whilst others would be regarded as being so important that they would be allocated water in almost any circumstances. The botanical importance rating indicates which estuaries need existing freshwater flows in order to maintain their importance. A management plan for these estuaries should then be developed. The scoring method helps in this management plan by indicating which botanical communities are present. Different plant communities will have different freshwater requirements. A permanently open estuary which has large brackish communities, needs freshwater to maintain the brackish environment. In other estuaries freshwater is needed to keep the mouth of the estuary open and intertidal marsh areas tidally flushed (Adams and Bate 1995).

Estuarine microalgal communities were not considered in the botanical importance rating. Estuaries that have a strong freshwater inflow and a pronounced salinity gradient up the length of the estuary, e.g. the Gamtoos are capable of supporting a rich phytoplankton community (Adams and Bate 1994a). Lack of knowledge on the phytoplankton communities, however, is a major limiting factor to their inclusion into a botanical importance rating at this stage. Mangroves were also excluded from the botanical importance rating, as subtropical estuaries where mangroves occur were not considered. It is recommended that the botanical importance rating is revised to include estuaries north of the Kei River and a fifth estuarine plant community i.e. mangroves. The botanical importance rating does not extract the socio-economic importance of an estuary. For example in the Groot Brak estuary, effluent discharge creates adverse socio-economic impacts as unsightly macroalgal blooms form when the mouth is closed. The Groot Brak estuary still received a high botanical importance score as all four estuarine plant communities considered were present and in fair condition.

Only a small number of estuaries were used in this botanical importance rating. There are 127 permanently and temporarily open Cape estuaries. Thirty-three estuaries were used in this study, as these were the only systems that had consistent botanical data available. There is an urgent need to extend this botanical importance rating by including further estuaries as this method can be successfully used by water planning managers, scientists and conservationists to determine the overall importance of individual estuaries. In addition, a clear statement regarding the condition of any estuary may result in local residents pushing for improvements.

5. MICROALGAE IN CAPE ESTUARIES

5.1 RESEARCH APPROACH

In an earlier report to the Water Research Commission on the freshwater requirements of South African estuaries (Adams and Bate 1994a), the work of Hilmer (1990) showed that the amount of chlorophyll present in estuaries was dependent on the input of nutrients into the system via river flow. The work that led to these conclusions was undertaken in the Swartkops and Sundays estuaries. The physical conditions responsible for high phytoplankton biomass were identified and incorporated as rules into the Estuarine Decision Support System (EDSSys). This Decision Support or expert system was designed to predict the response of estuarine flora to alterations in freshwater input (Adams and Bate 1994a). When, at the request of the project steering committee, the examination of microalgae and freshwater input, was extended to south coast estuaries, the rules were shown to not be universal but confined to the eutrophied Swartkops and Sundays estuaries. Other systems which did not have high levels of nutrient input but which did have a relatively high flow of freshwater, did not exhibit the same increase in phytoplankton biomass.

The original EDSSys model incorporated a factor of 'residence time' into the rule base. This was to allow the phytoplankton time to develop after the entry of water and nutrients into the estuary. When this was tested in other south coast estuaries, it was found that the water was not in the estuary sufficiently long for a high biomass to develop. At the same time, it was possible to understand that the dynamic nature of phytoplankton meant that they were not a time-integrated measure of the quality of water entering the estuary.

With this in mind, Dr. Gerald Boalch from the Marine Biological Association, Plymouth, England, was invited to South Africa to advise us on how to proceed with the study of the influence of freshwater on the microalgal flora. Dr Boalch is the Chief Editor of the prestigious journal *Botanica Marina* and was therefore in a position to know what research was being undertaken around the world. As a result of his visit, the approach was altered from biomass and primary productivity to species ecology. The basis of this latter approach was that the species present would indicate habitats. Because diatoms were the first organisms to respond to habitat change, they would have to become the focus of the research.

Diatom taxonomy is in some disarray because of the proliferation of electron microscopes at research institutes. This meant that diatom taxonomy would be an important aspect in the understanding of freshwater effects in the estuarine environment. The work undertaken in the study included an examination of the diatom flora, and especially the static (benthic, epilithic and epipelagic) flora. However, the phytoplankton was also included.

The distribution of microalgae in Cape estuaries was therefore studied with respect to the general diatom flora. This produced problems related to species identification and, to solve those problems a visit was made to Professor F.E. Round at the Botany Department, University of Bristol, England. Professor Round is a co-author of a revision of diatom taxa (Round *et al.*

1990). He was extremely helpful in naming taxa that we were unable to identify. During the visit to Bristol it became apparent that Professor Round's main interests were in river ecology and the use of diatoms as indicators of water quality. For this reason he was invited to Port Elizabeth to advise us on how to proceed. He arrived in Port Elizabeth in November 1995 and spent some time in the field examining rivers and estuaries. As a result of that visit he recommended that the sampling strategy then in use be altered to include only epipelagic diatoms, in estuaries, and epilithic diatoms in rivers as indicators of water quality. Furthermore, he demonstrated that an examination of the full diatom flora was unnecessary. Only the dominant species or dominant 2-3 taxa are important in describing the habitat (water quality). However, the physical habitat, stones, mud or plant material is equally important. For this latter reason, the physical habitat sampled must be kept constant up the length of the water body, i.e. only one physical habitat can be used for comparative purposes.

Prior to the visit of Professor Round the method of identifying and counting benthic diatoms was very unsatisfactory. Correspondence by e-mail with other workers around the world indicated that they were experiencing the same problems of separating diatom frustules from sediment particles. Professor Round demonstrated a method of overcoming all the problems previously encountered. The result is that an easy method of separating diatoms is now available. This method is now in use both by the Port Elizabeth team and the Durban team (Dr. Derek Watt, UDW) both of whom are working on the water quality of Eastern Cape and Natal estuaries.

Professor Round was instrumental in pointing out that each of the diatom genera has a number of distinctive characteristics. He listed a few of these characteristics and this led to the analysis of the work by Round *et al.* (1990), from which the computerised identification system evolved.

5.2 THE DISTRIBUTION OF MICROALGAE IN CAPE ESTUARIES

5.2.1 INTRODUCTION

In order to establish the relationship between freshwater input and phytoplankton and benthic microalgae the identification of microalgal species became necessary. Diatoms were the dominant benthic microalgal component whereas higher numbers of flagellates occurred in the phytoplankton. Although the microflora comprises diatoms, dinoflagellates and other microalgal groups, we believe that the diatoms are the most important because they respond more quickly to changes in water quality. There have been a few diatom taxonomic studies in the past (e.g. Archibald 1983), but none have related diatom species composition to physical characteristics of the estuaries. A catalogue of estuarine diatom species has been made which relates each species to its position in specific estuaries, salinity value of the water and time of year at which the collection was made. Data matrices were drawn up for the presence /absence of diatom species in the seven estuaries sampled. The multivariate technique, ordination was then used to determine whether there was any pattern in the data i.e. whether specific species could be associated with specific estuaries or salinity conditions.

5.2.2 METHODS

Two field trips were undertaken to study diatom populations in different estuaries. Four stations were sampled in each estuary in order to obtain samples along a gradient from marine to freshwater conditions. Phytoplankton and benthic diatoms were identified in the field and in the laboratory using light microscopy to a magnification of approximately 1000. Scanning electron microscopy (S.E.M.) was used to identify microalgae to species level. Light and scanning electron microscope photographs of the different diatom species were catalogued according to estuary and position in the estuary.

A note was made of the salinity value of the water and time of year at which the collection was made. Species lists were compiled for:

- (1) Phytoplankton (diatom) species found in Cape estuaries sampled,
- (2) Benthic microalgae (diatom) species found in Cape estuaries sampled, and
- (3) Species associated with marine (20-35 ppt), brackish (5-20 ppt) and freshwater (< 5 ppt) regions of the estuary.

A presence/absence data matrix was drawn up for water column (Table 30) and benthic diatoms (Table 31) in the seven estuaries sampled (Berg, Palmiet, Kafferkuils, Gouritz, Great Brak, Keurbooms and Gamtoos.). Ordination (Detrended correspondence analysis, DCA) was used to determine whether estuaries and sites within the estuaries, could be grouped according to similarities in diatom composition. Ordination is the collective term for multivariate techniques that arrange sites along axes on the basis of species composition (Gauch 1982).

The result of ordination is the arrangement of species and samples in low-dimensional space such that similar entities are close by and dissimilar entities far apart. The species and site (estuary) ordination diagrams obtained from the presence/absence DCA analysis are presented in the Results section.

5.2.3 RESULTS

A catalogue of photographs of estuarine diatom species has been made which relates each species to its position in specific estuaries, salinity value of the water and time of year at which the collection was made. So far, we have shown that there are 195 diatom taxa and 78 genera present in the nine Cape estuaries studied (Berg, Palmiet, Kafferkuils, Gouritz, Groot Brak, Keurbooms, Gamtoos, Sundays and Great Fish). Digital images of these species have been captured and will be available for incorporation into a World Wide Web site on the Internet. Research workers or personnel of the Department of Water Affairs and Forestry would be able to consult such a reference site should they find species identification a necessity.

Certain diatom species were found to occur over a wide salinity range from freshwater (0 ppt) to marine (35 ppt) conditions. These species included *Amphora coffeaformis*, *Aulacoseira* sp., *Campylodiscus* sp., *Cocconeis* sp., *Coscinodiscus* sp., *Cylindrotheca closterium*, *Entomeis* sp., *Extubocellulus spinifer*, *Haemiaulus* sp., *Leptocylindrus* sp.1., *Melosira* sp.2., *Navicula tripunctata*, *Nitzchia* sp., *Tabularia* sp. and *Thalassiosira decipiens*. Of the taxa listed, more species (29) were found in only saline water (35 ppt) than freshwater (10). Sixteen taxa were only associated with brackish water (5-20 ppt) and not marine or freshwater conditions.

DCA analysis provides two ordination diagrams i.e. the species and estuary ordinations. These diagrams must be looked at in association with each other. This is because the species ordination indicates the cause of the clustering observed in the estuary ordination and visa versa. The principle behind DCA is that the points closer together are more similar than points which are further apart. In this way it was possible to see which estuaries and sites within the estuaries or species were similar to each other.

Table 30. Presence/absence data matrix for the water column diatom species in the Cape estuaries sampled.

	Berg				Gamtoos				Gouritz				Great Brak				Kafferkuijs				Keurbooms				Palmiet			
	B1	B2	B3	B4	Ga1	Ga2	Ga3	Ga4	G1	G2	G3	G4	GB1	GB2	GB3	GB4	KF1	KF2	KF3	KF4	KB1	KB2	KB3	KB4	P1	P2	P3	
<i>Achnanthes amoena</i>																												
<i>Achnanthes brevipes</i>																												
<i>Achnanthidium dekaduta</i>																												
<i>Actinoptylchus senarius</i>																												
<i>Actinoptylchus splendens</i>																												
<i>Actinoptylchus undulatus</i>																												
<i>Amphipropra</i> sp.																												
<i>Amphitetras</i> sp.																												
<i>Amphora aculeiscuda</i>																												
<i>Amphora coffeaefomis</i>																												
<i>Amphora</i> sp.																												
<i>Amphora</i> sp1																												
<i>Amphora</i> sp2																												
<i>Amphora</i> sp3																												
<i>Amphora</i> sp4																												
<i>Amphora</i> sp5																												
<i>Amphora</i> sp6																												
<i>Anaulus</i> sp.1																												
<i>Anaulus</i> sp.2																												
<i>Ardissonia</i> sp.																												
<i>Asterionophalus</i> sp.																												
<i>Asterionella glacialis</i>																												
<i>Autacodiscus johnsonii</i>																												
<i>Autacodiscus granulata</i>																												
<i>Auricula</i> sp.																												
<i>Bacillaria</i> sp.																												
<i>Biddulphia alternans</i>																												
<i>Biddulphia luomeyi</i>																												
<i>Biremis</i> sp.																												
<i>Campylodiscus</i> sp.																												
<i>Campyloneis</i> sp.																												
<i>Catacombas</i> sp.																												
<i>Chaetoceros curvisetus</i>																												
<i>Chaetoceros protuberans</i>																												
<i>Chaetoceros</i> sp.1																												
<i>Chaetoceros</i> sp.2																												
<i>Chaetoceros tripes</i>																												
<i>Climacospheria</i> sp.																												
<i>Cocconeis arenicola</i>																												
<i>Cocconeis costata</i>																												
<i>Cocconeis</i> sp.1																												
<i>Cocconeis</i> sp.2																												
<i>Cocconeis</i> sp.3																												
<i>Cocconeis</i> sp.4																												
<i>Cocconeis</i> sp.5																												
<i>Cocconeis</i> sp.6																												
<i>Coscinodiscus nodulifer</i>																												
<i>Coscinodiscus radiatus</i>																												
<i>Coscinodiscus</i> sp.1																												
<i>Coscinodiscus</i> sp.2																												
<i>Coscinodiscus</i> sp.3																												
<i>Craticula</i> sp.																												
<i>Cyclotella atomus</i>																												
<i>Cyclotella menighiana</i>																												
<i>Cyclotella ocellata</i>																												
<i>Cyclotella pseudostelligera</i>																												
<i>Cyclotella</i> sp.																												
<i>Cyandrotheca closterium</i>																												
<i>Delphineis angustata</i>																												
<i>Delphineis</i> sp.																												
<i>Diploneis didyma</i>																												
<i>Diploneis</i> sp.																												
<i>Ditylum brightwellii</i>																												
<i>Eritomoneis alata</i>																												
<i>Eritomoneis</i> sp.																												
<i>Eucocconeis</i> sp.																												
<i>Eupodiscus oculatus</i>																												
<i>Exlibocephalus spinifera</i>																												
<i>Falscia</i> sp.																												
<i>Fragilaria elliptica</i>																												
<i>Fragilaria</i> sp1																												
<i>Fragilaria</i> sp2																												
<i>Gomphonemopsis</i> sp.																												
<i>Gomphonemopsis</i> sp.																												
<i>Grammatophora</i> sp.																												
<i>Guinardia flaccida</i>																												
<i>Haemaulus</i> sp.																												
<i>Hantzschia</i> sp.																												
<i>Haslea</i> sp.																												
<i>Lauderia</i> sp.																												
<i>Leptocylindrus</i> sp.1																												
<i>Leptocylindrus</i> sp.2																												
<i>Licmophora</i> sp.																												

Table 30. cont.

Stations	Berg				Gamtoos				Gouritz				Great Brak				Kafferkuils				Keurbooms				Palmiet				
	B1	B2	B3	B4	Ga1	Ga2	Ga3	Ga4	G1	G2	G3	G4	GB1	GB2	GB3	GB4	KF1	KF2	KF3	KF4	KB1	KB2	KB3	KB4	P1	P2	P3		
<i>Lulicola</i> sp.			1																										
<i>Lyrella</i> sp.																													
<i>Mastogloia</i> sp.			1																										
<i>Melosira moniliformis</i>																													
<i>Melosira nummuloides</i>																													
<i>Melosira</i> sp.1		1																											
<i>Melosira</i> sp.2					1	1																							
<i>Navicula</i> sp.1			1		1	1	1																						
<i>Navicula</i> sp.2			1																										
<i>Navicula</i> sp.4			1																										
<i>Navicula</i> sp.5			1																										
<i>Navicula</i> sp.6		1	1		1	1	1																						
<i>Navicula</i> sp.7			1																										
<i>Navicula</i> sp.8		1	1		1	1	1																						
<i>Navicula</i> sp.9		1	1		1	1	1																						
<i>Navicula</i> sp.10		1	1		1	1	1																						
<i>Navicula</i> sp.11																													
<i>Navicula</i> sp.12		1																											
<i>Navicula</i> sp.13																													
<i>Navicula</i> sp.14		1			1	1																							
<i>Navicula</i> sp.15			1																										
<i>Navicula</i> sp.16																													
<i>Navicula</i> sp.17																													
<i>Navicula</i> spC																													
<i>Navicula</i> spK			1																										
<i>Navicula joharrossii</i>																													
<i>Navicula lineata</i>																													
<i>Navicula perminuta</i>																													
<i>Navicula tenelloides</i>																													
<i>Navicula truncata</i>		1																											
<i>Nitzschia closterium</i>		1	1		1	1																							
<i>Nitzschia constricta</i>		1	1		1	1																							
<i>Nitzschia delicatissima</i>			1																										
<i>Nitzschia dissipata</i>																													
<i>Nitzschia frustulum</i>		1																											
<i>Nitzschia longissima</i>			1																										
<i>Nitzschia obtusa</i>		1																											
<i>Nitzschia ovalis</i>																													
<i>Nitzschia pacifica</i>																													
<i>Nitzschia seriala</i>																													
<i>Nitzschia</i> sp.1		1	1		1	1	1																						
<i>Nitzschia</i> sp.2																													
<i>Nitzschia</i> sp.3																													
<i>Opephora pacifera</i>																													
<i>Opephora</i> sp.																													
<i>Paralia</i> sp.																													
<i>Petrodictyon</i> sp.																													
<i>Petrodictyon</i> sp.																													
<i>Pleurosigma</i> sp.																													
<i>Prokoekea</i> sp.																													
<i>Parammodictyon</i> sp.		1																											
<i>Pteroncola</i> sp.																													
<i>Rhabdonema</i> sp.																													
<i>Rhizosolenia</i> sp.																													
<i>Rhizosolenia stoff</i>																													
<i>Roperia</i> sp.																													
<i>Semnavis</i> sp.																													
<i>Skeletonema</i> sp.																													
<i>Stephanodiscus binatus</i>																													
<i>Surirella</i> sp1		1																											
<i>Surirella</i> sp2																													
<i>Surirella</i> sp3		1																											
<i>Synedra</i> sp.																													
<i>Tabularia</i> sp.																													
<i>Terpsinoe</i> sp.																													
<i>Thalassionema nitzschoides</i>																													
<i>Thalassiosira decipiens</i>		1																											
<i>Thalassiosira levanderi</i>																													
<i>Thalassiosira rotula</i>																													
<i>Thalassiosira</i> sp.																													
<i>Thalassiosira subtilis</i>		1																											
<i>Thalassiosira weissflogii</i>																													
<i>Thalassiothrix</i> sp.																													
<i>Tryblionella</i> sp.																													

TABLE 31: Presence/absence data matrix for the benthic diatoms in the Cape estuaries sampled.

	Berg				Gamtoos				Gouritz				Groot Brak				Kafferkuils				Keurbooms			Palmiet	
	B1	B2	B3	B4	Ga1	Ga2	Ga3	Ga4	G1	G3	G4	GB1	GB2	KF1	KF2	KF3	KF4	KB1	KB2	P1	P2				
Amphipropra sp.																									
Amphora coffeaeformis	1																								
Amphora sp.	1																								
Amphora sp3				1																					
Ardissonia sp.								1																	
Bacillaria sp.		1																							
Biddulphia pulchella															1	1									
Biddulphia tuomeyi															1	1		1							
Campylodiscus sp				1																					
Cocconeis sp1		1																							
Cocconeis sp4																					1	1			
Cocconeis sp5																					1				
Coscinodiscus rad																1									
Coscinodiscus sp3			1	1																	1	1			
Cylindrotheca closterium															1										
Diploneis didyma							1																		
Diploneis sp.																						1			
Entomoneis sp.													1								1	1			
Extubocellulus spinifera																			1						
Fragilaria sp1																					1				
Fragilaria sp2															1										
Gyrosigma sp.								1		1															
Leptocylindrus sp1				1																					
Licmophora sp.		1																							
Melosira lineata		1																							
Melosira moniliformis		1																							
Melosira sp2	1	1	1	1																		1			
Navicula sp1		1						1	1								1					1			
Navicula sp3	1		1																		1				
Navicula sp6		1		1																					
Navicula sp7	1	1	1	1																					
Navicula sp9	1	1	1																		1	1			
Navicula sp10	1	1	1	1																	1	1			
Navicula sp17																						1			
Navicula spC														1							1				
Navicula spK										1															
Navicula Linulate							1								1		1	1							
Navicula perminuta															1						1				
Navicula tenelloides															1										
Navicula tripunctata	1	1		1												1									
Nitzschia closterium		1																			1	1			
Nitzschia constricta	1	1	1													1	1	1							
Nitzschia elegantula																						1			
Nitzschia frustulum																					1				
Nitzschia obtusa	1							1																	
Nitzschia sp1			1					1	1												1	1			
Nitzschia sp2	1																								
Odontella rostrata																					1				
Odontella sp.																					1				
Opephria sp.		1																							
Paralia sp.				1																					
pleurasigma sp.																									
Psammodyctyon sp.								1													1	1			
Seminavis sp.																									
Skeletonema potamus																									
Surirella sp3		1																				1			
Thalassiosira allenii																									
Thalassiosira decipiens																						1			
Thalassiosira rotula																						1			

Figure 9 the ordination diagram for the estuaries based on the phytoplankton species composition, shows that Gamtoos, Palmiet and Berg sites can be grouped together. These estuaries are similar because of their brackish conditions. Diatom species (Figure 10) do not show any distinct grouping. The species presented on the lower left corner of the ordination diagram are those that would be more abundant in the Gamtoos, Palmiet and Berg estuaries and are therefore probably associated with brackish conditions.

The estuary ordination diagram for the benthic diatoms (Figure 11) indicates four distinct groups. Site 2 in the Groot Brak estuary (GB2) a group on its own. Certain species only occur in this site (Figure 12). These species are listed in Table 32.

Group 2 includes sites from the Berg, Gamtoos and Palmiet estuaries that would indicate brackish conditions. All the stations in the Kafferkuils estuary form group 3 (Figure 11) while group 4 is made of sites that would indicate saline conditions. The diatom species associated with these saline sites are listed as group 4 in Table 32. At site 1 (mouth) in the Keurbooms estuary two different *Odontella* spp were found. These species are usually associated with sandy conditions (Round, pers. comm.). This indicates the habitat preference of diatoms.

5.2.4 DISCUSSION

Ordination of the estuaries according to the phytoplankton (diatom) species showed no apparent clustering. This illustrates the problem of considering all diatoms as opposed to the dominant three or four species. Despite the lack of clustering in the species ordination diagram, the diagram of the estuaries showed that the Gamtoos, Palmiet and Berg appeared to form a distinct group. This is possibly as a result of the predominance of brackish stations in these systems. Both the Gamtoos and Berg estuaries have strong salinity gradients between the mouth and head of the estuary. However, in winter the Berg functions as a river mouth, as does the temporarily open Palmiet estuary (Slinger *et al.* 1995, Taljaard and Largier 1989).

DCA analysis of the benthic diatom species occurring in the different estuaries showed that species and sites could be associated with specific salinity conditions. Fewer benthic (60) than phytoplankton (161) diatom species were identified in the estuaries. This is possibly a reason why clustering or grouping of sites and species was evident for the benthic diatom ordinations and not the phytoplankton ordination. It is recommended that future studies only consider the dominant 1 to 3 species at a particular site.

It is important that the habitat preference be taken into account when sampling benthic diatoms i.e. certain species are associated with mud particles while others occur attached to sand grains. Five benthic diatom species were dominant at site 2 of the Great Brak estuary. These species included *Cylindrotheca closterium* which occurs in the epipelon of marine habitats (Round *et al.* 1990) and *Navicula tenelloides* which according to van Dam *et al.* (1994) can be associated with specific water quality conditions. These conditions include high O₂ saturation, low organic nitrogen concentrations, low salinity (< 1 ppt) and wet, moist habitats that occasionally dry out.

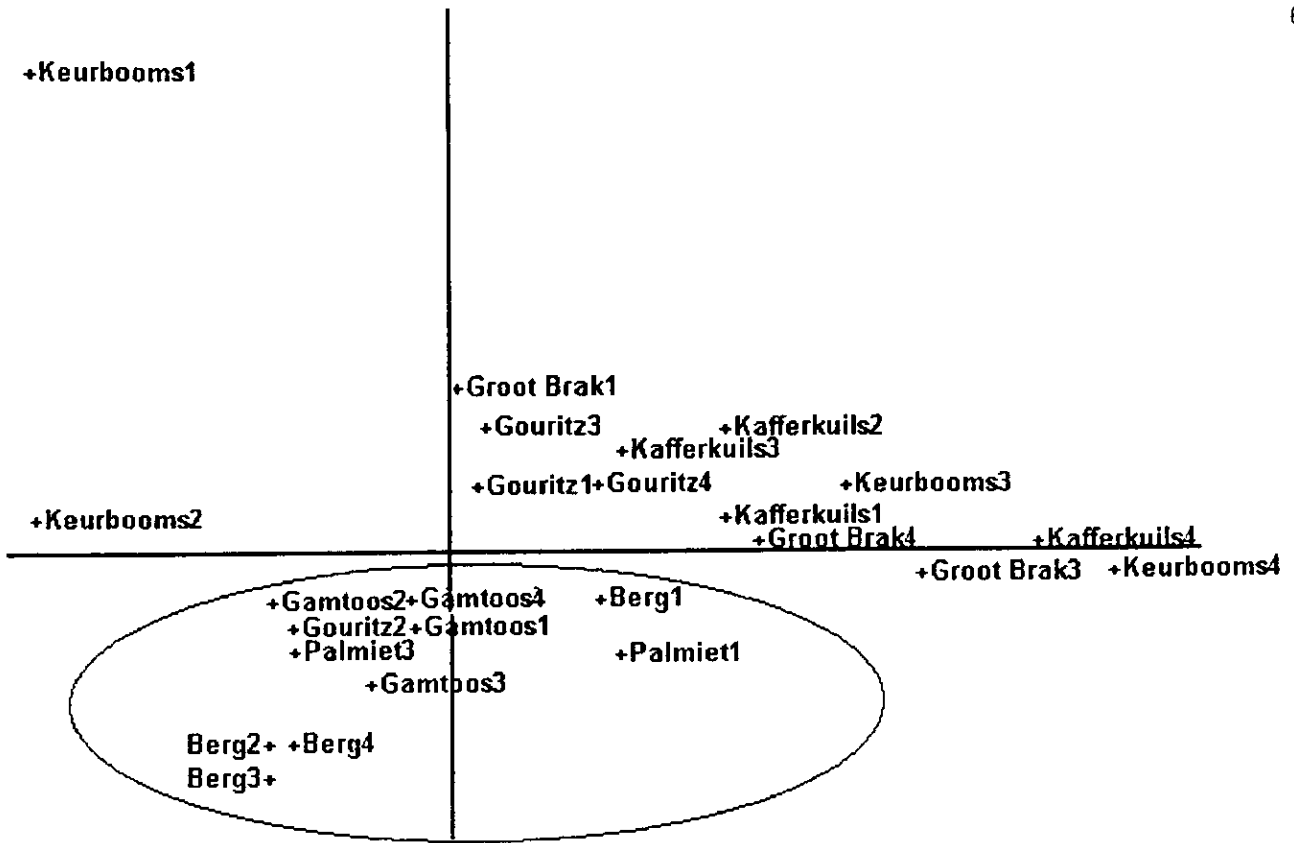


FIGURE 9: The ordination diagram for the estuaries based on water column diatoms.

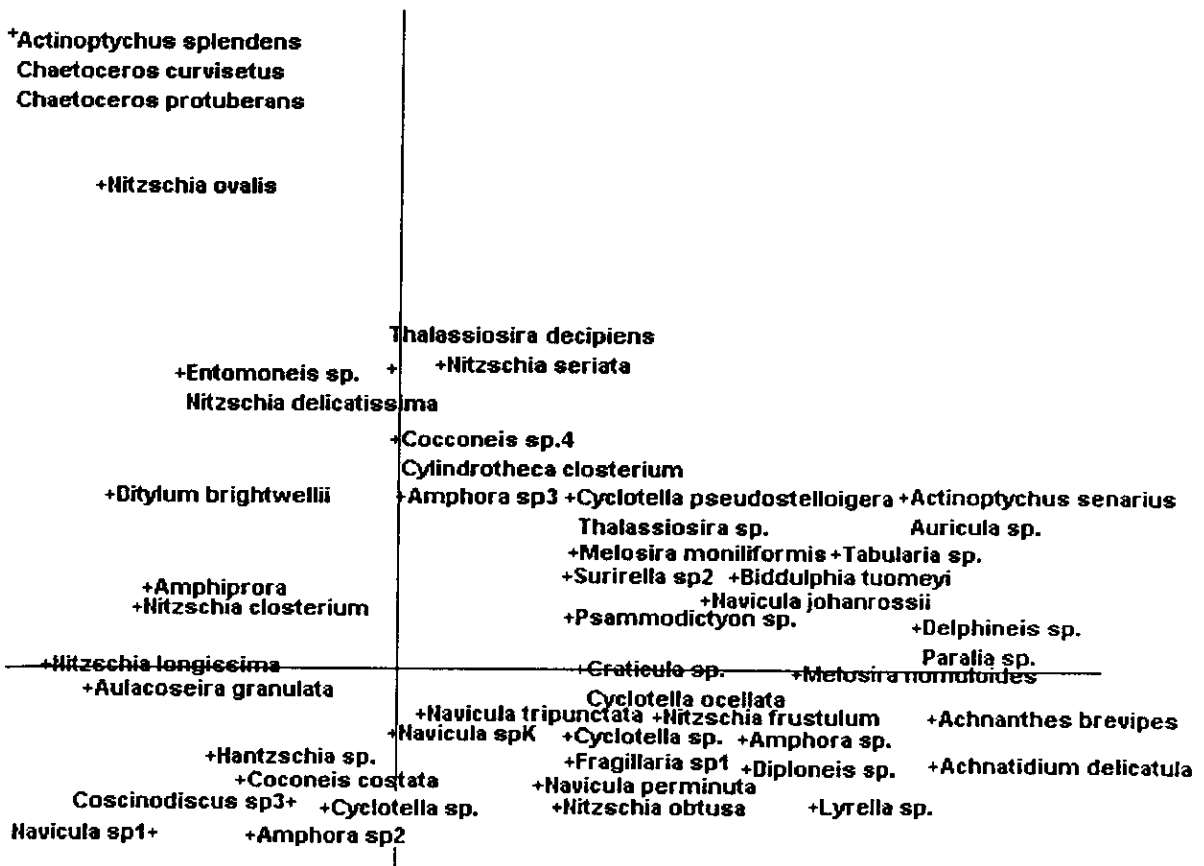


FIGURE 10: The ordination diagram for the water column diatom species based on estuary sites.

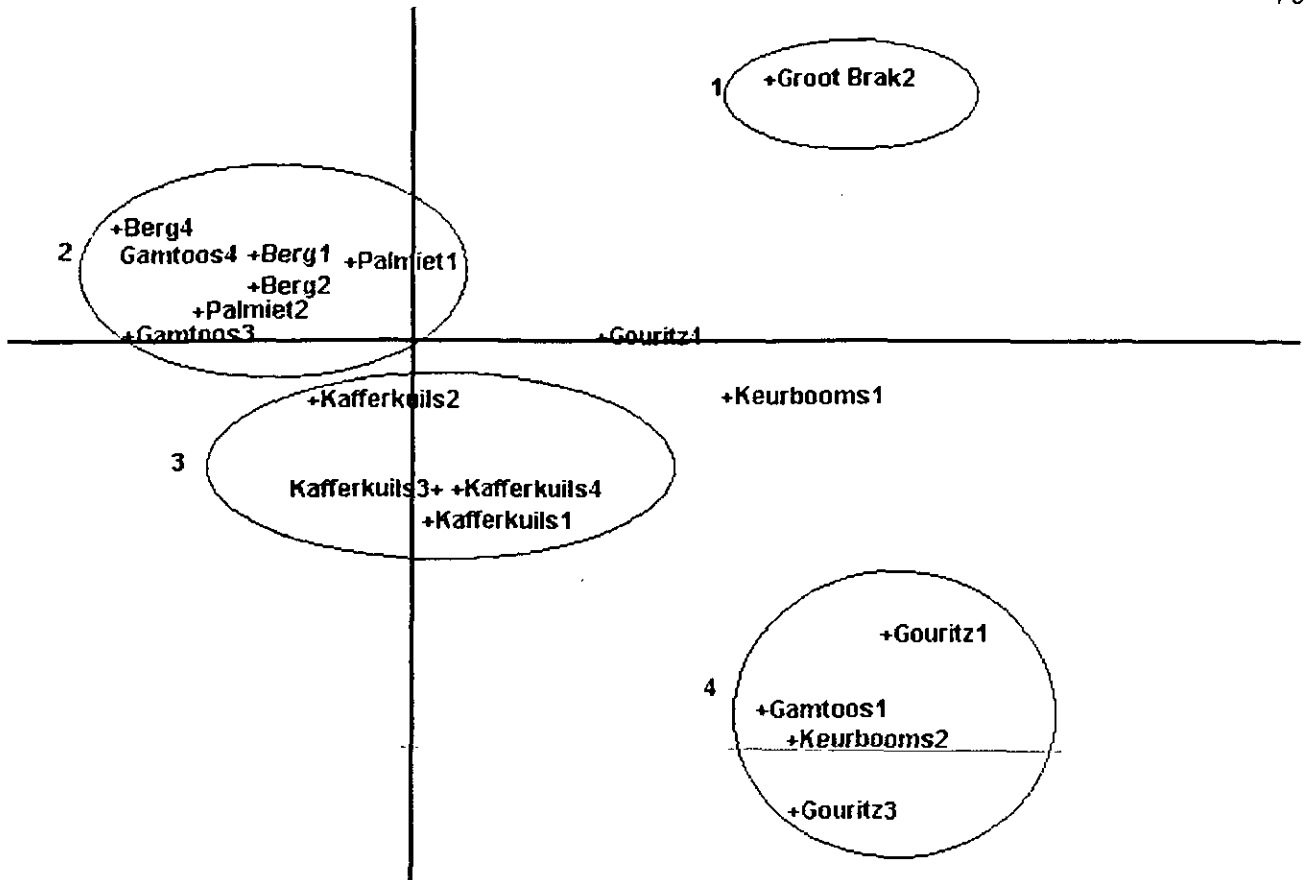


FIGURE 11: The ordination diagram for the estuaries based on benthic diatom species.

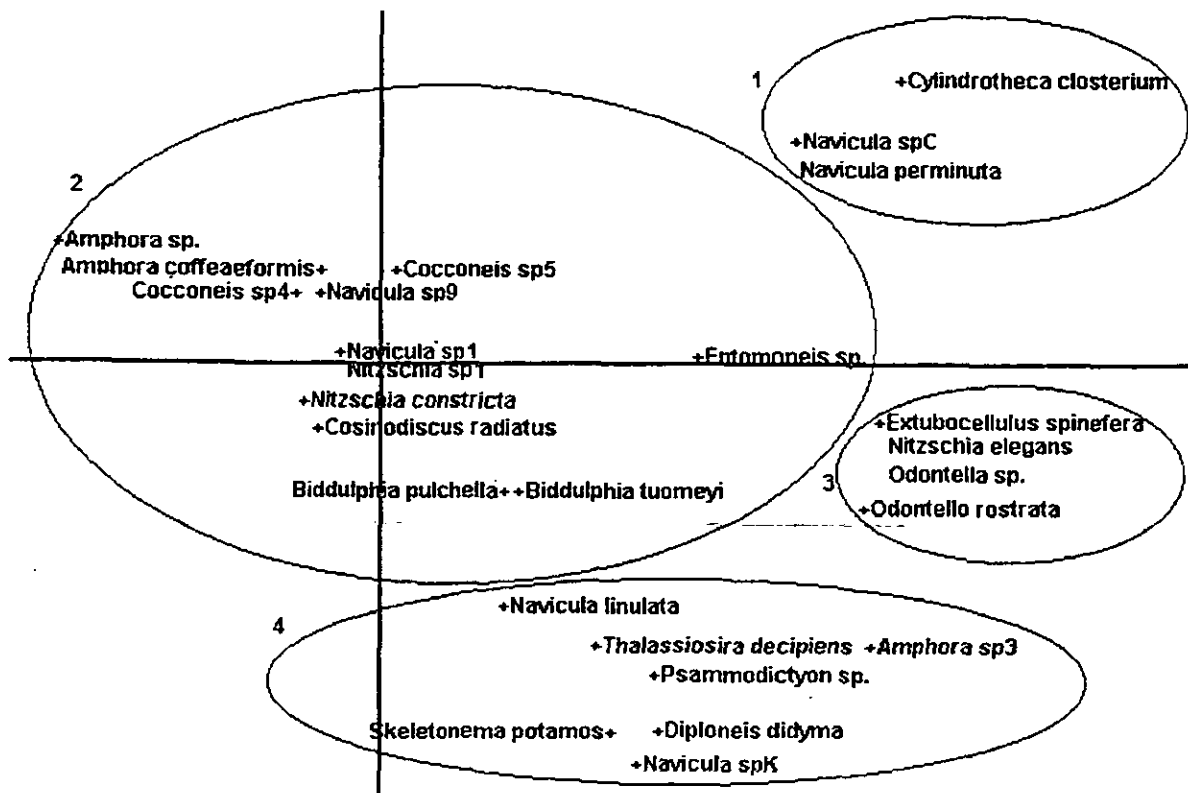


FIGURE 12: The ordination diagram for the benthic diatom species based on estuary sites. Species occurring in the four different groups are listed in Table 32.

TABLE 32. Benthic diatom species for the four groups identified in the ordination diagram, Figure 12.

GROUP 1	GROUP 2	GROUP 3	GROUP 4
Cylindrotheca closterium	Amphora sp.	Extubocellulus spinifera	Amphora sp3
Fragilaria sp 2	Amphora coffeaeformis	Nitzschia elegantula	Diploneis didyma
Navicula spC	Bacillaria sp.	Nitzschia frustulum	Navicula spK
Navicula tenelloides	Biddulphia tuomeyi	Odontella sp.	Navicula linulate
Navicula perminuta	Biddulphia pulchella	Odontella rostrata	Psammodictylon sp.
	Campylodiscus sp.	Thalassiosira rotula	Skeletonema potamos
	Cocconeis sp4		Thalassiosira allenii
	Cocconeis sp1		Thalassiosira decipiens
	Cocconeis sp5		
	Coscinodiscus radiatus		
	Diploneis sp.		
	Entomoneis sp.		
	Fragilaria sp 1		
	Gyrosigma sp.		
	Leptocylindrus sp 1		
	Licomorpha sp.		
	Melosira lineata		
	Melosira moniliformis		
	Navicula sp9		
	Navicula sp6		
	Navicula sp7		
	Navicula sp1		
	Navicula sp17		
	Nitzschia sp1		
	Nitzschia constricta		
	Nitzschia sp2		
	Opephria sp.		
	Paralia sp.		
	Pleurasigma sp.		

5.3 AN IDENTIFICATION KEY FOR ESTUARINE DIATOMS

5.3.1 INTRODUCTION

Diatoms are especially useful in studies on the ecology of freshwater, estuarine and marine systems (Round 1990, Round 1991 and van Dam *et al.* 1994). The diatoms are particularly important because they respond to changes in water chemistry. These include changes in species and cell numbers. To use them, however, it is necessary to have some understanding of the taxonomy of this group of microalgae.

A great number of texts are available on the genera of diatoms, some having been written as long ago as 1853 (Smith 1853). From the point of view of water ecology, such texts are not helpful to the pure ecologist because they are too voluminous, they may not be easily available, or they lack a systems approach to establishing the name of a particular taxon. In addition, many of the early taxa have been renamed in recent times (Round *et al.* 1990). This is partly as a result of using scanning electron microscopy where fine anatomy is revealed in a manner that is not possible with the light microscope.

Difficulties with diatom identification have reduced their potential for useful work in water research. A computerised key for the identification of estuarine diatoms was developed. Although this key was developed for the estuarine diatoms of the Cape coast, it is a customized system that will allow water scientists to compile a system to identify the species which are important in the aquatic systems in which they are working. The principle behind the scheme is that only the dominant "indicator" species are important. This greatly reduces the total number of species that require to be identified. When a "new" species is found it can easily be added to the system. This work is a collaborative effort with Professor Frank Round, Bristol University, U.K. He provided the basis of the identification scheme by correlating the most important features on which the taxonomy of each genus is based.

5.3.2 METHODS

To identify a diatom genus, it is first necessary to know its diagnostic characteristics that are identified using microscopic techniques. To obtain a sample of epipelagic diatoms almost free of sediment, the upper layers of the silt, sand and mud is drawn up using a glass tube. The sample is allowed to settle overnight before the excess liquid is removed from the surface downwards. Coverslips are placed carefully on the wet surface of the sediments and left in place for a further day. During this time, the benthic diatoms rise to the surface and attach to the glass coverslips. The coverslips are carefully removed with only very small amounts of the sediment.

In our laboratory, a permanent microscope slide of cleaned frustules is prepared by placing the diatom-encrusted coverslips into a mixture of saturated potassium permanganate and concentrated hydrochloric acid. This mixture of live diatoms and digestion mixture is heated at 60°C until the solution turns clear. The coverslips are removed and the frustules centrifuged at

2000 rpm for 10 minutes after which the supernatant is drawn off and distilled water added. The tube is well mixed and the process of centrifugation repeated five times to remove all the acid. On the last occasion distilled water is not added and a concentrated digest remains. A few drops of the mixed diatom "digest" is spotted onto a coverslip and allowed to dry naturally. When completely dry, a small amount of Naphrax[®] is dotted onto a slide and warmed on a hot plate. This is placed over the coverslip and the whole warmed to about 60°C to disperse the Naphrax. When the surplus Naphrax[®] has solidified, the excess is removed with a blade and the coverslip sealed with Bioseal[®]

The slide is viewed on a computer screen using a Zeis Axioplan microscope with differential interference contrast optics. The image is digitised using a JVC KY-F3 television camera and visualised using a Vidas image analysis program (Kontron Elektronik GMBH).

Using a computer the names of the 78 diatom genera, already identified in our studies in Cape estuaries, were entered into a Lotus 1-2-3 spreadsheet in the first column. Forty-six diagnostic features were selected from Barber and Haworth (1981). These diagnostic features were entered as a single word descriptor as the top row in the spreadsheet. Appendix 2 shows the spreadsheet with the 78 diatom genera and associated diagnostic features.

From Round *et al.* (1990), each of the included genera was added to the database by entering a 1 into the appropriate column where the diagnostic characteristic applied, or leaving it blank if it did not apply. In this way, between 2 and 13 characters were provided for each genus. Once the Lotus 1-2-3 database was complete, it was taken into a Lotus Approach DBase IV file.

The Lotus Approach database is used in Forms Mode (Figure 13). Using "Find", characteristics of the visualised diatoms are entered into the blank form. When all recognisable attributes have been entered, the "Find" is activated. The Lotus Approach program matches the attributes entered into the "Find" form and compares them with the database. It then produces an output indicating the number of "hits" in which all the characteristics entered match the database.

Lotus Approach - [DESTUAR.APR:Form 1]

File Edit View Create Browse Tools Window Help

Form 1 : Worksheet 1

OK Cancel Clear Find Find More

Genus Round Araphid Raphe Assymetrical Hapolar Clavate Circle Sigmoid

Linear Lanceolate Square Elliptic Reniform Cruciform Oblong Ovate Oval Rectangle

Triangular Arcuate Undulate Capitata Stellate Str II Str rad Str Str Str Cur Spines

N stern W stern Centre Spokes FW Brak Marine Plank Epibiotic Epipsammic Epipelagic

Epiphy Colonial Str. Filam Zig-zag fil Filament Ribs Processes Photograph

Comments

Form 1 Find Records Found 78 of 78

FIGURE 13. Computer screen showing the Forms Mode of the Lotus Approach database for estuarine species.

5.3.3 RESULTS: IDENTIFICATION OF A DIATOM GENUS

EXAMPLE 1

The diatom shown in Figure 14 is used as an example. All that an amateur might be able to recognise was that the specimen was linear or lanceolate, possessed a raphe and parallel striae which were straight. These diagnostic characteristics were entered. "OK" was pressed and 8 "records" or possible genera were registered (Figure 15). The first was *Achnanthes*, but the data in the Lotus Approach file indicated that the specimen should have been assymetrical, therefore *Achnanthes* was incorrect. All the other records could similarly be rejected except for *Navicula*. Hence from the available evidence it is possible to conclude that the most likely identification is *Navicula*.

Navicula manifesta Hust.



FIGURE 14. Example of a light micrograph of a diatom taken from Cholnoky (1962) to illustrate the type of information that a researcher might have available for use in the identification of a species.

Lotus Approach - [DESTUAR.APP:Form 1]

File Edit View Create Browse Tools Window Help

Form 1 Worksheet 1

Genus	Round	Araphid	Raphe	Assymetrical	Hipolar	Clavate	Circle	Sigmoid		
Achnanthes	502	1	1	1						
Linear	Lanceolate	Square	Elliptic	Reniform	Cruciform	Oblong	Ovate	Oval	Rectangle	
1	1			1						
Triangular	Arcuate	Undulate	Capitate	Stellate	Str II	Str red	Str Str	Str Cur	Spines	
		1			1	1	1	1		
N stern	W stern	Centre	Spokes	FW	Brak	Merine	Plank	Epilithic	Epipsammic	Epipelic
		1		1		1				
Epiphy	Colonial	Str. Filam	Zig-zag fil	Filament	Ribs	Processes	Photograph			
		1			1					

Comments

Form 1 Browse Record 1 Found 8 of 78

FIGURE 15. The first of eight records located by Lotus Approach in the search mode. These eight records contain the identified species. The correct species is determined using Round et al. 1990.

EXAMPLE 2

The diatom shown in Figure 16 is used as an example. We might only be able to recognise that the specimen was lanceolate and sigmoid. These attributes were entered. "OK" was pressed and two "hits" were registered. The first was *Gyrosigma*. The form showed that further information on the genus could be found on page 586 of Round *et al.* (1990). Visual examination showed that the specimen in question could well be *Gyrosigma*. The second possibility was *Pleurosigma* that could be found on page 580 of Round *et al.* 1990. An examination of the differences between these two genera in that text showed that the striae in *Pleurosigma* run at an angle of $> 90^\circ$ to each other whereas in *Gyrosigma* they run at an angle of 90° to each other. With this information we were able to choose *Gyrosigma* as the most likely genus.

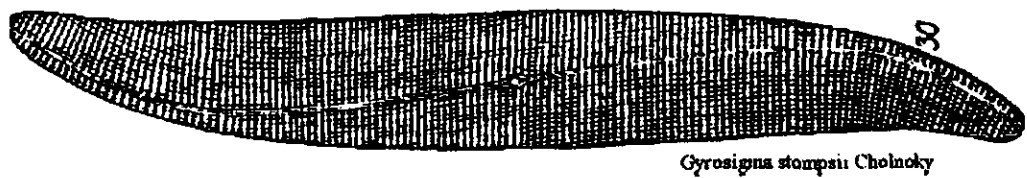


FIGURE 16. Example of the *Gyrosigma stompsii* diatom from Cholnoky (1962) to illustrate the type of information that a researcher might have available for use in the identification of a species.

5.3.4 DISCUSSION

We believe that an important feature of the method devised is that it provides a system which can be used by an amateur, but, more importantly, it provides the basis of a teaching tool so that the user quickly becomes reasonably proficient at recognising details of diatom morphology. We recommend the system to students and to researchers who wish to embark on a programme of water research.

Within this identification system, only data that is relevant to a particular system need be included. It is possible to include the data for all known taxa, but if marine systems are the focus of the research effort, it may be possible to exclude all freshwater taxa. Likewise, if rivers are being studied, all the marine taxa may be excluded.

In many countries, lists of diatom species are easily found in the literature. Many of the names may have been changed but these features can be entered into the database. Hence, it is easy for a scientist setting out on a programme of research to quickly create a database of all the species likely to be found. This will greatly ease the problem of identification.

The key developed for identification of estuarine diatoms has great potential if further developed for use as a water management tool. This is because diatoms respond rapidly to changes in water chemistry. A catalogue of epipelagic diatom species should be compiled which indicates the water quality characteristics in which they are commonly found. Lists of this type are currently being compiled in the European Economic Community for use in their systems to monitor the inorganic conditions of their rivers and estuaries.

6. GENERAL CONCLUSIONS AND RECOMMENDATIONS

This study has successfully developed a botanical importance rating system for South African estuaries. This importance rating must now be extended to other estuaries in order to make it applicable on a national basis and on a full regional basis. We believe that the importance rating must be extended to Natal estuaries. When each estuary is classified with respect to its botanical importance, we believe that the data set will be extremely important to the Department of Water Affairs in assisting them to allocate water impoundment schemes to river systems. Because of the nature of the scoring system, each rating can be analysed with respect to the plant communities and ameliorating actions devised to reduce adverse impacts. We further believe that the botanical importance rating is of greater significance than other possible ratings (faunal, socio-economic, etc.) because if the plant communities are in good condition then other conditions will also be optimal or near optimal.

The European Economic Community are undertaking extensive research into the diatom communities in their rivers. These organisms are able to register the integrated water quality flowing in a system. A similar study is under way in Britain and the indications are that this type of system is very important. For the foregoing reasons, we recommend that research on the attached diatom flora of South African rivers and estuaries be extended. Associated with this research, emphasis is required on the identification of South African diatoms.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

The most important recommendations for future research include:

1. The botanical importance rating should be extended to include all South African estuaries.
2. Rehabilitation plans must be formulated to restore botanical importance to those estuaries that were identified as degraded.
3. The diatom identification key should be extended to include species names. Visual material should be made available to water managers.

These data would be most conveniently placed on compact disks. A catalogue of epipelagic diatom species should be compiled which indicates the water quality characteristics in which they are commonly found. Lists of this type are currently being compiled in the European Economic Community for use in their systems to monitor the inorganic conditions of their rivers and estuaries.

4. Studies on estuarine microalgae should continue in order to include them at a later stage into the botanical importance rating of estuaries.

28. PUBLICATIONS AND SYMPOSIA PRESENTATIONS

8.1 Reports and theses

Adams, J.B. 1996. Estuarine Botanical Communities. In: (T.H. Wooldridge and L. McGwynne, eds) *The Estuarine Environment*. SAB Institute for Coastal Research Report No. C.31). pp 34-42.

Coetzee, J.C. 1995. Classification of South African estuaries based on plant communities. Unpublished MSc dissertation, Department of Botany, University of Port Elizabeth. 117 pp.

Home, I.F. 1995. The use of microalgae as indicators of eutrophication by urban runoff at the Motherwell canal on the Swartkops estuary. Unpublished third year project, Department of Botany, University of Port Elizabeth. 34 pp.

Snow, G. 1994. Biomass and distribution of benthic microalgae and phytoplankton in the Kromme estuary, eastern Cape. Unpublished third year project, Department of Botany, University of Port Elizabeth. 48 pp.

Van Wyk, U.P. 1994. Biomass and distribution of phytoplankton and benthic microalgae in the Gamtoos estuary. Unpublished Honours project, Department of Botany, University of Port Elizabeth. 76 pp.

8.2 Refereed publications

Adams, J.B. and G.C. Bate. 1994. The effect of salinity and inundation on the estuarine macrophyte *Sarcocornia perennis* (Mill.) A.J. Scott. *Aquatic Botany* 47: 341-348.

Adams, J.B. and G.C. Bate. 1994. The ecological implications of tolerance to salinity by *Ruppia cirrhosa* (Petagna) Grande and *Zostera capensis* Setchell. *Botanica Marina* 37: 449-456.

Adams, J.B. and G.C. Bate. 1994. The tolerance to desiccation of the submerged macrophytes *Ruppia cirrhosa* Petagna (Grande) and *Zostera capensis* Setchell. *Journal of Experimental Marine Biology and Ecology* 183: 53-62.

Adams, J.B. and G.C. Bate. 1995. Ecological implications of salinity and inundation tolerance in the estuarine halophyte, *Spartina maritima* (Curtis) Fernald. *Aquatic Botany* 52: 183-191.

Adams, J.B. and G.C. Bate. 1996. Understanding the freshwater requirements of estuarine plants. In: (A.H.P.M. Salman, M.J. Langeveld and M. Bonazountas, eds) *Coastal Management and Habitat Conservation*. EUCC, Leiden, The Netherlands. pp. 181-192.

Bate, G.C., F.G. Rodriguez and J.B. Adams. 1996. The influence of freshwater management on estuarine microalgae in semi-arid areas. In: (A.H.P.M. Salman, M.J. Langeveld and M. Coetzee, J.C., J.B. Adams and G.C. Bate. 1996. A Botanical Importance Rating System for

Estuaries. *Journal of Coastal Conservation* (Accepted for publication).

Coetzee, J.C., J.B. Adams and G.C. Bate. 1997. A botanical importance rating of selected Cape estuaries. *Water SA* 23: 81-93.

Bate, G.C. and F.E. Round. In Prep. The identification of diatom genera for ecological stu

8.3 Symposia presentations

Adams, J.B. and G.C. Bate. 1996. Are microalgae important in marine dominated estuaries ? Oral presentation at the 13 th Congress of the Phycological Society of Southern Africa, Meerensee, Hermanus. 21-24 January 1996.

Adams, J.B., J.C. Coetzee and G.C. Bate. 1996. Saltmarshes - a threatened habitat. Poster presentation at the ECSA 26 and ERF 96 Symposium, Middelburg, The Netherlands.

Adams, J.B., G.C. Bate, J. Slinger and P. Huizinga. 1996. Predicting the response of estuarine macrophytes to changes in freshwater input. Oral presentation at the ECSA 26 and ERF 96 Symposium, Middelburg, The Netherlands.

Bate, G.C., Coetzee, J.C. and J.B. Adams. 1995. A Botanical Importance Rating System for Estuaries. Oral presentation at the 25th Annual Symposium of the Estuarine and Coastal Sciences Association. Trinity College, Dublin, Ireland.

Bate, G.C. and J.B. Adams. 1996. The interpretation of microalgal distribution in Cape estuaries. Oral presentation at the 13 th Congress of the Phycological Society of Southern Africa, Meerensee, Hermanus. 21-24 January 1996.

Coetzee, J.C., J.B. Adams and G.C. Bate. 1994. A botanical categorization of South African estuaries. Oral presentation at the South African Society of Aquatic Sciences conference, University of Port Elizabeth, Port Elizabeth.

Coetzee, J.C., J.B. Adams and G.C. Bate. 1995. A botanical importance rating system for Cape estuaries. Oral presentation at the ZSSA & SASAQS symposium, Rhodes University, Grahamstown.

Suiro, V.I., G.C. Bate and G. Boalch. 1994. The distribution of microalgae in Cape estuaries. Oral presentation at the Phycological Society of Southern Africa conference, University of Witwatersrand, Johannesburg.

Suiro, V.I., J.B. Adams and G.C. Bate. 1994. The distribution of microalgae in Cape estuaries. Poster presentation at the South African Society of Aquatic Sciences conference, University of Port Elizabeth, Port Elizabeth.

van der Molen, J., J.B. Adams and G.C. Bate. 1996. Diatoms as indicators of water quality in a riverine/estuarine system. Poster presentation at the 13 th Congress of the Phycological Society of Southern Africa, Meerensee, Hermanus. 21-24 January 1996.

9. REFERENCES

- ADAMS, J.B. AND M.M.B. TALBOT. 1992. The influence of river impoundment on the estuarine seagrass *Zostera capensis* Setchell. *Botanica Marina* 35: 69-75.
- ADAMS, J.B., W.T. KNOOP AND G.C. BATE. 1992. The distribution of estuarine macrophytes in relation to freshwater. *Botanica Marina* 35: 215-226.
- ADAMS, J.B. AND G.C. BATE. 1994a. The freshwater requirements of estuarine plants incorporating the development of an estuarine decision support system. Water Research Commission Report No. 292/2/94.
- ADAMS, J.B. AND G.C. BATE. 1994b. The ecological implications of tolerance to salinity by *Ruppia cirrhosa* (Petagna) Grande and *Zostera capensis* Setchell. *Botanica Marina* 37: 449-456.
- ADAMS, J.B. AND G.C. BATE. 1995. Ecological implications of salinity and inundation tolerance in the estuarine halophyte, *Spartina maritima* (Curtis) Fernald. *Aquatic Botany* 52: 183-191.
- ALLANSON, B.R. 1992. *An Assessment of the SANCOR Estuaries Research Programme from 1980 to 1989*. Committee for Marine Science Occasional Report No 1. pp. 72.
- ALLANSON, B.R. 1982. The energy base of aquatic systems in South Africa. *Journal of the Limnological Society of southern Africa* 8: 47-53.
- ARCHIBALD, R.E.M. 1983. *The diatoms of the Sundays and Great Fish Rivers in the Eastern Cape Province of South Africa* (J. Cramer, ed). A.R. Ganter, K.G. Verlag, Germany. 431 pp.
- BACH, S.D., G.W. THAYER AND M.W. LACROIX. 1986. Export of detritus from eelgrass (*Zostera marina*) beds near Beaufort, North Carolina, USA. *Marine Ecological Progress Series* 28:265-278.
- BAIRD, D., N.M. HANEKOM AND J.R. GRINDLEY. 1986. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 23 Swartkops (CSE 3)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 422, pp. 82.
- BAIRD, D, J.F.K. MARAIS AND G.C. BATE. 1992. *An environmental analysis for the Kromme River area to assist in the preparation of a structure plan*. Institute for Coastal Research Report Number 16. 49 pp.
- BARBER, H.G. AND E.Y. HAWORTH. 1981. *A guide to the morphology of The Diatom Frustule*. Freshwater Biological Association. Scientific Publications No. 44. 112 pp.
- BECKLEY, L.E. 1983. The ichthyofauna associated with *Zostera capensis* Setchell in the Swartkops estuary, South Africa. *South African Journal of Zoology* 18: 15-24.

- BECKLEY, L.E. 1984. The ichthyofauna of the Sundays estuary, South Africa, with particular reference to the juvenile marine component. *Estuaries* 7: 248-258.
- BEGG, G.W. 1984. *The Estuaries of Natal (Part II)*. Natal Town and Regional Planning Report: Vol. 55. Teeanem Printers, Pietermaritzburg, pp. 631.
- BEGG, G.W. 1979. *Policy proposals for the estuaries of Natal*. Natal Town and Regional Planning Reports. Volume 43. 39 pp.
- BEGG, G.W. 1978. *The Estuaries of Natal*. Natal Town and Regional Planning Report. Volume 41. Blackhouse, Pietermaritzburg. 657 pp.
- BEGG, G.W. 1986. *The wetlands of Natal (Part 1)*. An overview of their extent, role and present status. Natal Town and Regional Planning Report. Volume 68. 114 pp.
- BENFIELD, M.C., 1984. *Some factors influencing the growth of Phragmites australis (Cav.) Trin ex Steudel*. Unpublished MSc thesis, Department of Biological Sciences, University of Natal.
- BICKERTON, I.B. 1982. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 11 Hartenbos (CMS 1)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 410, pp. 54.
- BICKERTON, I.B. 1982. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 15 Zeekoei (CSW 5)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 414.
- BICKERTON, I.B. 1984. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 25 Heuningnes (CSW 19)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 424, pp. 64.
- BICKERTON, I.B. AND PIERCE, S.M. 1988. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 33 Krom (CMS 45), Seekoei (CMS 46) and Kabeljous (CMS 47)*. Heydorn, A.E.F. & Morant, P.D. (Ed). Stellenbosch, CSIR Research Report 432, pp. 109.
- BLABER, S.J.M. 1974. Field studies of the diet of *Rhabdosargus holubi* (Pisces: Teleostei: Sparidae). *Journal of Zoology, London* 173: 407-417.
- BRANCH, G.M. AND J.R. GRINDLEY. 1979. Ecology of southern African estuaries Part XI. Mngazana: A mangrove estuary in the Transkei. *South African Journal of Zoology* 14: 149-170.
- BRIX, H. 1993. Wastewater treatment in constructed wetlands: system design, removal processes and treatment performances. In: (Moshiri, ed) *Constructed Wetlands for Water Quality Improvement*. G.A. Lewis Publishers, Florida. pp: 9-22.
- BURNS, M.E.R., DU PLESSIS, M.A. AND VERWOERD, D.J. 1988. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 39 Quko (CSE*

56). Heydorn, A.E.F. & Morant, P.D. (Ed). Stellenbosch, CSIR Research Report 238, pp. 62.

CARTER, R.A. 1983. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 21: Bree (CSW 22)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 420, pp. 58.

CARTER, R.A. AND S. BROWNLIE. 1990. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 34 Kafferkuils (CSW 24) and Duiwenhoks (CSW 23)*. Heydorn, A.E.F. & Morant, P.D. (Ed). Stellenbosch, CSIR Research Report 433, pp. 86.

CERM. Consortium for Estuarine Research and Management Progress Report. 1994. *A Co-ordinated Research Programme on Decision Support for the Conservation and Management of Estuaries*. The Consortium for Estuarine Research and Management (CERM), Progress Report for Importance Rating Sub-project. April 1993 - March 1994. pp. ~24.

CHILDERS. D.L. AND J.W. DAY. 1990. Marsh-water column interactions in two Louisiana estuaries. II Nutrient dynamics. *Estuaries* 13: 404-417.

CLARKE, B.C. 1989. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 37 Palmiet (CSW 12)*. Heydorn, A.E.F. & Morant, P.D. (Ed). Stellenbosch, CSIR Research Report 436, pp. 82.

CLIFF, S. AND GRINDLEY, J.R. 1982. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 17 Lourens (CSW 7)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 416, pp. 39.

CONNOLLY, R.M. 1994. The role of seagrass as preferred habitat for juvenile *Sillaginades punctata* (Cuv. & Val.) (Sillaginidae, Pisces): habitat selection or feeding? *J. Exp. Mar. Bio. Ecol.* 180: 39-47.

COSTA, M.J., J.L. COSTA, P.D. DE ALMEIDEA AND C.A. ASSIS. 1994. Do eelgrass beds and salt marsh borders act as preferential nurseries and spawning grounds of fish? An example of the Mira estuary in Portugal. *Ecological Engineering* 3: 187-195.

CSIR REPORT. 1989. *The mapping and conservation importance rating of the Cape coastal vegetation as an aid to development planning*. Report reference: EMA - C 89153.

DAVIES, B.R. 1982. Studies on the zoobenthos of some southern Cape coastal lakes. Spatial and temporal changes in the benthos of Swartvlei, South Africa, in relation to changes in the submerged littoral macrophyte community. *Journal of the Limnological Society of Southern Africa.* 8:33-45.

DAY, J.H. 1981. *Estuarine Ecology with Particular Reference to Southern Africa*. A.A. Balkema, Cape Town.

DUVENAGE, I.R. AND P.D. MORANT. 1984. *Estuaries of the Cape: Part II: Synopses of*

- available information on individual systems. Report No. 31 Keurbooms/Bitou (CMS 19) and Piesang (CMS 18). Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 430, pp. 64.
- EDGECEMBE, D.J. 1980. Some preliminary observations on the submerged aquatic *Zostera capensis* Setchell. *Journal of South African Botany* 46: 53-66.
- FIELDING, P.J., K.St.J. DAMSTRA AND G.M. BRANCH. 1988. Benthic diatom biomass, production and sediment chlorophyll in Langebaan Lagoon, South Africa. *Estuarine Coastal Shelf Science* 27: 413-426.
- FREDETTE, T.J., R.J. DIAZ, J. VON MONTFRANS AND R.J. ORTH. 1990. Secondary production within a seagrass bed (*Zostera marina* and *Ruppia maritima*) in lower Chesapeake Bay. *Estuaries* 13: 431-440.
- GAUCH, H.G. 1982. *Multivariate Analysis in Community Ecology*. Cambridge University Press, London. 298 pp.
- GRINDLEY, J.R. 1982. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 16 Eerste (CSW 6)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 415, pp. 51.
- GRINDLEY, S.A. 1988. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 29 Hout Bay (CW 27)*. Heydorn, A.E.F. & Morant, P.D. (Ed). Stellenbosch, CSIR Research Report 428, pp. 76.
- HANEKOM, N. AND D. BAIRD. 1984. Fish community structures in *Zostera* and non-*Zostera* regions of the Kromme estuary, St. Francis Bay. *South African Journal of Zoology* 19: 295 - 301.
- HARRISON, T.D., J.A.G. COOPER, A.E.L. RAMM AND R.A. SINGH. 1994a. *Health of South African Estuaries, Orange river - Buffels (oos)*. Department of Environmental Affairs - Executive Report. pp. ~90.
- HARRISON, T.D., J.A.G. COOPER, A.E.L. RAMM, AND R.A. SINGH. 1994b. *Health of South African Estuaries, Orange river - Buffels (oos)*. Department of Environmental Affairs - Technical Report.
- HASLAM, S.M. 1971. Biological flora of the British Isles *Phragmites communis* Trin. *Journal of Ecology* 59: 585-609.
- HEINECKEN, T.J.E. 1982. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 8 Rooiels (CSW 10)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 407, pp. 35.
- HEINECKEN, T.J.E. 1985. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 27. Wildevoelwei/Noordhoek (CW 28)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 426, pp. 58.

- HEINECKEN, T.J.E. 1992. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 13 Silvermine (CSE 3)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 412, pp. 43.
- HEINECKEN, T.J.E., I.B. BICKERTON AND P.D. MORANT. 1982. *Estuaries of the Cape: Part II: Synopsis of available information on individual systems. Rep. No. 12 Buffels (wes) (CSW 1), Elsies (CSW 2), Sir Lowry's Pass (CSW 8), Steenbras (CSW 9), Buffels (oos) (CSW 11)*. Stellenbosch, CSIR Research Report 411, pp. 72.
- HEINECKEN, T.J.E. AND K.St.J. DAMSTRA. 1983. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 24 Onrus (CSW 14)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 423, pp. 37.
- HEINECKEN, T.J.E. AND J.R. GRINDLEY. 1982. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 10 Kowie (CSE 10)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 409, pp. 58.
- HEINSOHN, R-D. AND A.B. CUNNINGHAM. 1991. Utilization and potential cultivation of the saltmarsh rush *Juncus kraussii*. *South African Journal of Botany* 57: 1-5.
- HEYDORN, A.E.F. AND I.B. BICKERTON. 1982. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 9 Uilkraals (CSW 17)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 408, pp. 37.
- HEYDORN, A.E.F. AND K.L. TINLEY. 1980. *Estuaries of the Cape, Part I: Synopsis of the Cape Coast - Natural Features, Dynamics, Utilisation*. National Research Institute for Oceanology, Stellenbosch. 97 pp.
- HEYDORN, H.J. 1989. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 38 Gourits (CSW 25)*. Heydorn, A.E.F. & Morant, P.D. (Ed). Stellenbosch, CSIR Research Report 437, pp. 66.
- HILMER, T. 1990. *Factors influencing the estimation of primary production in small estuaries*. Unpublished PhD thesis. Botany Department, University of Port Elizabeth, South Africa. 154 pp.
- HUIZINGA, P. 1994. Personal communication. EMATEK, CSIR, Stellenbosch.
- JERLING, H.L. AND T.H. WOOLDRIDGE. 1994. Feeding of two mysid species on plankton in a temperate South African estuary. *Journal of Experimental Marine Biology and Ecology*. 188: 243-259.
- JOSELYN, M.N. AND J.A. WEST. 1985. The distribution and temporal dynamics of the estuarine macroalgal community of San Francisco Bay. *Hydrobiologia* 129: 139-152.
- KALEJTA, B. AND P.A.R. HOCKEY. 1991. Distribution, abundance and productivity of benthic invertebrates at the Berg River estuary, South Africa. *Estuarine, Coastal and Shelf Science* 33:

175-191

KOKKIN, M.J. AND B.R. ALLANSON. 1985. On the flux of organic carbon in a tidal salt marsh, Kowie River estuary, Port Alfred, South Africa. *South African Journal of Science* 81: 613-617.

LARKUM, A.W.D. AND R.J. WEST. 1990. Long-term changes of seagrass meadows in Botany Bay, Australia. *Aquatic Botany* 37: 55-70.

MARTIN, I. AND J. FERNANDEZ. 1992. Nutrient dynamics and growth of Cattail crop (*Typha latifolia* L.). Developed in an effluent with high eutrophic potential - application to wastewater purification systems. *Bioresource Technology* 42: 7-12.

MARTIN, A.P. 1991. *Feeding ecology of birds on the Swartkops estuary, South Africa*. Ph.D. thesis, University of Port Elizabeth, Port Elizabeth.

MASSON, H. AND J.F.K. MARAIS. 1975. Stomach content analyses of mullet from the Swartkops estuary. *Zoologica Africana* 10: 193-207.

MORANT, P.D. 1983. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 20 Groot Brak (CMS 3)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 419, pp. 52.

MORANT, P.D. 1984. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 26 Olifants (CW 10)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 425, pp. 54.

MORANT, P.D. AND I.B. BICKERTON. 1983. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 19 Groot (Wes) (CMS 23) and Sout (CMS 22)*. Heydorn, A.E.F. & Grindley, J.R. (Ed). Stellenbosch, CSIR Research Report 418, pp. 54.

MUELLER-DOMBOIS, D. AND H. ELLENBERG. 1974. *Aims and Methods of Vegetation Ecology*. Wiley, New York, NY.

O'CALLAGHAN, M. 1990. The ecology of the False Bay estuarine environments, Cape, South Africa. 2. Changes during the last fifty years. *Bothalia* 20: 113-121.

O'CALLAGHAN, M. 1994. *Saltmarshes of the Cape (South Africa) : Vegetation Dynamics and Interactions*. PhD Thesis. University of Stellenbosch.

ODUM, W.E. 1970. Insidious alteration of the estuarine environment. *Transactions American Fisheries Society* 4: 836-847.

QUICK, A.J.R., AND W.R HARDING. 1994. Management of a shallow estuarine lake for recreation and as a fish nursery: Zandvlei, Cape Town, South Africa. *Water South Africa* 20(4): 289-297.

- RAMM, A.E.L. 1988. The community degradation index: A method for assessing the deterioration of aquatic habitats. *Water Research* 22: 293-301
- RAMM, A.E.L. 1990. Application of the community degradation index to South African estuaries. *Water Research* 24: 383-389.
- REDDERING, J.S.V. 1988. Catchment and catchment basin controls on estuary morphology of the south-eastern Cape coast. *South African Journal of Science* 84: 154-157.
- RODRIGUEZ, F.D.G. 1993. *The determination and distribution of microbenthic chlorophyll-a in selected south Cape estuaries*. Unpublished MSc dissertation. Botany Department, University of Port Elizabeth, Port Elizabeth, South Africa. 134 pp.
- ROUND, F.E. 1990. The effect of liming on the benthic diatom populations in three upland lakes. *Diatom Research* 5: 129-140.
- ROUND, F.E. 1991. Epilithic diatoms in acid water streams flowing into the reservoir Llyn Brianne. *Diatom Research* 6: 137-145.
- ROUND, F.E., R.M. CRAWFORD AND D.G. MANN. 1990. *The Diatoms. Biology and Morphology of the Genera*. Cambridge University Press, Cambridge. 747 pp.
- SLINGER, J.H., S. TALJAARD AND J.L. LARGIER. 1994. Changes in estuarine water quality in response to a freshwater flow event. In: (Dyer, K.R. and R.J. Orth, eds) *Changes In Fluxes in Estuaries*. Olsen and Olsen. Denmark. pp: 51-56.
- SMITH, W. 1853. *A synopsis of the British Diatomaceae; with remarks etc*. London Volume 1.
- STEWART, B.A. AND B.R. DAVIES. 1986. Effects of harvesting on invertebrates associated with *Potamogeton pectinatus* L. in the Marina da Gama, Zandvlei, Western Cape. *Transactions of the Royal Society of South Africa* 46: 35-50.
- TALBOT, F.H. 1955. Notes on the biology of the white stumpnose, *Rhabdosargus globiceps* (Cuvier), and on the fish fauna of the Klein River Estuary. *Transactions of the Royal Society of South Africa* 34:387-407.
- TALBOT, M.M.B. AND G.C. BATE. 1987. The distribution and biomass of the seagrass *Zostera capensis* in a warm-temperate estuary. *Botanica Marina* 30: 91-99.
- TALBOT, M.M.B. AND G.C. BATE. 1990. The dynamics of estuarine macrophytes in relation to flood/siltation cycles. *Botanica Marina* 33: 159-164.
- TALJAARD, S. AND J.L. LARGIER. 1989. *Water circulation and nutrient distribution patterns in the Palmiet river estuary: a winter study*. CSIR Research Report 680. CSIR, Stellenbosch, South Africa. pp. 38 + appendices.
- TAYLOR, D.I. 1983. The effects of a major macrophyte regression upon primary production in

the littoral of Swartvlei. *Archiv für Hydrobiologie* 96: 345-353.

TAYLOR, D.I. AND B.R. ALLANSON. 1995. Organic carbon fluxes between a high marsh and estuary, and the inapplicability of the Outwelling Hypothesis. *Marine Ecology Progress Series* 120: 263-270.

THAYER, G.W., D.A. WOLFE AND R.B. WILLIAMS. 1975. The impact of man on seagrass systems. *American Scientist* 63: 288-296.

TURPIE, J.K. 1994. A Methodology for prioritising South African estuaries for conservation. In: *A Co-ordinated Research Programme on Decision Support for the Conservation and Management of Estuaries*. The Consortium for Estuarine Research and Management, Progress Report of the Importance Rating Sub-Project April 1993 to March 1994. pp. 27.

TURPIE, J.K. 1995. Prioritizing South African estuaries for conservation: A practical example using waterbirds. *Biological Conservation* 74: 175-185.

VAN DAM, H., A. MARTENS AND J. SINKELDAM. 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Netherlands Journal of Aquatic Ecology* 28: 117-133.

WALKER, D.I. AND A.J. McCOMB. 1992. Seagrass degradation in Australian coastal waters. *Marine Pollution Bulletin* 25: 191-195.

WEISSER, P.J. AND C. HOWARD-WILLIAMS. 1982. The vegetation of the Wilderness Lakes system and the macrophyte encroachment problem. *Bontebok* 2: 19-40.

WHITFIELD, A.K. 1980. A quantitative study of the trophic relationships within the fish community of the Mhlanga estuary, South Africa. *Estuarine and Coastal Marine Science* 10: 417-435.

WHITFIELD, A.K. 1984. The effects of prolonged aquatic macrophyte senescence on the biology of the dominant fish species in a southern African coastal lake. *Estuarine and Coastal Shelf Science* 18: 315-329.

WHITFIELD, A.K. 1988a. The fish community of the Swartvlei estuary and the influence of food availability on resource utilization. *Estuaries* 11: 160-170.

WHITFIELD, A.K. 1988b. The role of tides in redistributing macrodetrital aggregates within the Swartvlei estuary. *Estuaries* 11: 152-159.

WHITFIELD, A.K. 1989a. The benthic invertebrate community of a southern Cape estuary: structure and possible food sources. *Transactions of the Royal Society of South Africa* 47: 159-179.

WHITFIELD, A.K. 1989b. Ichthyoplankton in a southern African surf zone: nursery area for the postlarvae of estuarine associated fish species? *Estuarine, Coastal and Shelf Science* 29: 533-547.

WHITFIELD, A.K., L.E BECKLEY, B. BENNET, G.M. BRANCH, H.M. KOK, I.C. PATTTER, AND R.P. VAN DER ELST. 1989. Composition, species richness and similarity of ichthyofaunas in eelgrass *Zostera capensis* beds of southern africa. *South African Journal of Marine Science* 8: 251 - 159.

WHITFIELD, A.K. 1992. A characterisation of Southern African estuarine systems. *South African Journal of Aquatic Science* 18 (1/2): 89-103.

WHITFIELD, A.K. 1994. *Available Scientific Information on Individual Southern African Estuarine Systems*. The Consortium for Estuarine Research and Management (Draft Copy). pp. 184.

WISEMAN, K.A., M.E.R. BURNS AND C.J. VERNON. 1993. *Estuaries of the Cape: Part II: Synopses of available information on individual systems. Report No. 42. Nahoon (CSE 44), Qinira (CSE 45) and Gqunube (CSE 46)*. Morant, P.D. (Ed). Stellenbosch, CSIR Research Report 441, pp. 136

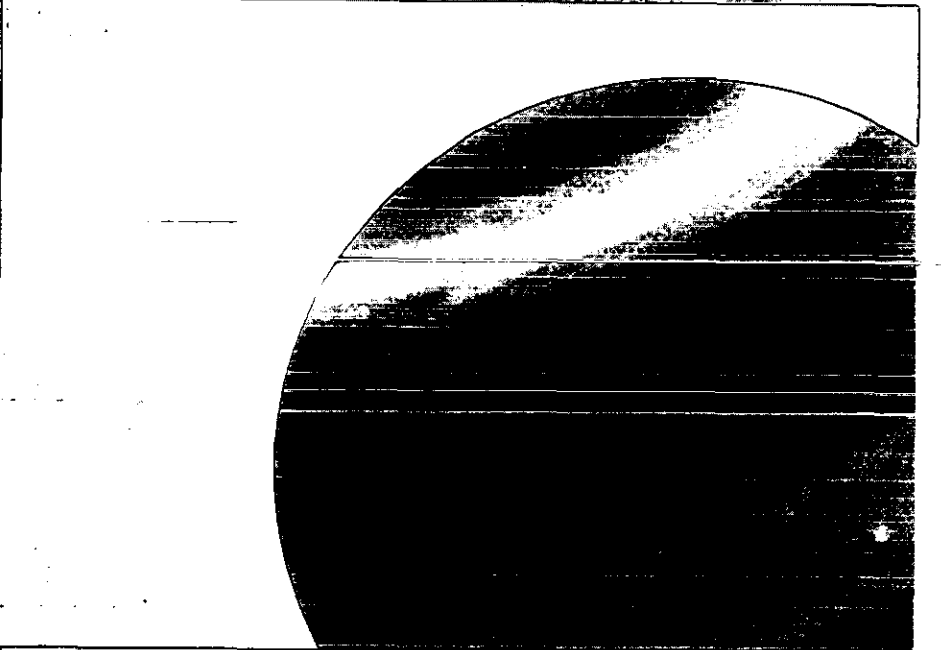
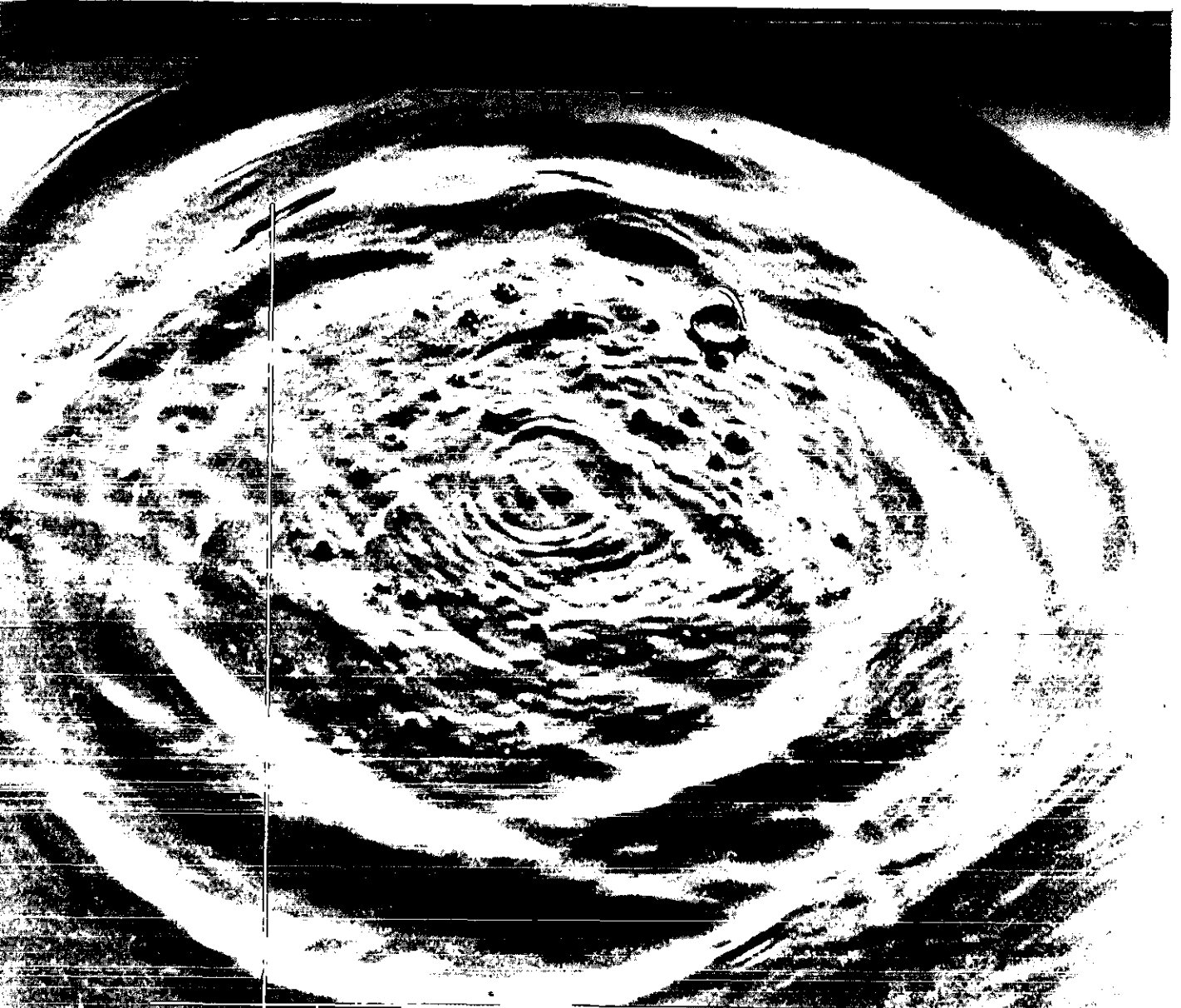
10. APPENDIX

WORKSHOP DELEGATES

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