THE BENTHOS OF THE SIYAYA ESTUARY: SPECIES COMPOSITION, DENSITY AND DISTRIBUTION

By

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Supervisor: **Professor D P Cyrus**
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NATURE

For I have learned

To look on nature, not as the hour

Of thoughtless youth, but hearing oftentimes

The still, sad music of humanity.

WILLIAM WORDSWORTH (1770-1850). *LINES WRITTEN A FEW MILES ABOVE TINTERN ABBEY.*

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PREFACE

The work described in this thesis was carried out in the Department of Zoology, University of Zululand from February 1993 to December 1994, under the supervision of Professor D. P. Cyrus.

This study represents original work by the author unless specifically stated to the contrary in the text, and has not been submitted in any form to another university.

Christine Fiona MacKay

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ABSTRACT

This study describing the zoobenthos of the Siyaya Estuary is the result of data collection spanning three consecutive years (1992 - 1994). The investigation of the zoobenthic component of the estuary, forms part of a multidisciplinary study to monitor the effects of catchment rehabilitation. The abiotic and biotic characteristics of the estuary have been used as a tool to determine the effectiveness of improved management practices in the catchment. The response of the zoobenthos was first examined in 1983, and this showed 37 zoobenthic taxa with a strong marine/estuarine component.

From 1992 to 1994, the zoobenthos was sampled on a seasonal basis at each of five sites along the length of the estuary. A total of 88 taxa representing four phyla were collected over three years. During 1992, 50 taxa were recorded in samples and the impression was of a wide faunal assemblage, with representatives from Nematoda, Annelida, Crustacea, Insecta, and Gastropoda. Five less taxa were recorded during 1993, although the faunal assemblage was still fairly wide with the inclusion of several more insect taxa. The greatest number of taxa were recorded during 1994. Of the 59 zoobenthic taxa, 40 represented the freshwater component. Over the three year period, few decapod invertebrates were sampled, the majority were primarily post prawn larvae. Results of this study have therefore shown that the number of taxa have increased. However, the majority of new taxa added to the total species list belong to the freshwater component of the zoobenthos. This is due to prolonged closure of the estuary mouth as a result of the prevailing drought conditions.

A comparison of zoobenthic densities from the estuarine and freshwater components revealed that the estuarine component still dominated the benthos, and that this dominance decreased from 1992 to 1994. During 1992, the estuarine component constituted 97.2% of the total zoobenthos, while this decreased to 84.6% and 54.4% in 1993 and 1994, respectively. Of the overall mean density of 29 623 invertebrates m^{-2} calculated from the sum of five sites, on a seasonal basis over three years, 48.7% (14 433 m^{-2}) of the total was from 1992. Zoobenthic densities declined in 1993 and 1994, to

28.2% (8 340 m^{-2}) and 23.1% (6 850 m^{-2}) of the total for the three years. Zoobenthic densities were generally highest in winter, and lowest in autumn. However, a multifactor ANOVA showed that season alone was not a significant factor governing the increase or decrease of zoobenthic densities. The relict estuarine amphipods *Grandidierella lignorum* and *Corophium triaenonyx*, and the tanaid *Apseudes digitalis* were among the taxa dominating the benthos in all seasons.

Various parameters were used to determine the physico-chemical condition of the estuary, and several were used as an input matrix to determine their effects on the distribution and abundance of the zoobenthos. Salinity, temperature, dissolved oxygen concentration, depth and turbidity were measured each year. In 1994, a more detailed water quality and sediment analysis was performed. A gradient of turbidity, salinity and oxygen existed from the upper to lower reaches of the estuary, and the substratum constituted medium sands in the lower reaches to detrital muds with silt patches in the upper reaches. The estuary became increasingly fresh over the study period, as salinity declined in the upper reaches from 6‰ in 1992 to 0‰ at the end of 1994. A suite of multivariate techniques involving classification and ordination methods revealed that sediment particle size was not the most important environmental factor determining species distributions. A combination of turbidity, dissolved oxygen, pH and the percentage organic content proved to be the most important effect of the environment, accounting for most of the variability in the distribution and abundance of the zoobenthos.

On the basis of the results obtained, it is concluded that the effects of improved catchment management practices have had a positive effect on the ecology of the estuary, and particularly on the state of the zoobenthos. However, the prevailing drought conditions also had an effect on the benthos, in terms of a change in species composition from 1992 to 1994. Despite this, the estuarine taxa still dominate the estuarine benthic fauna.

OPSOMMING

Hierdie studie is gebaseer op data versamel oor 'n tydperk van drie jaar (1992 - 1994), en beskryf die soöbentos van die Siyaya estuarium. Die ondersoek na die biotiese komponent van die estuarium vorm die basis van 'n multidisiplinêre studie, waarin die effek van rehabilitasie op opvanggebiede gemoniteer word. Die biotiese en abiotiese eienskappe van die estuarium is gebruik ten einde die effektiwiteit van verbeterde bestuurspraktyke in die opvanggebied te bepaal. Gedurende 1983 is die reaksie van die soöbentos op hierdie praktyke vir die eerste keer ondersoek en 39 soöbentiese taksa van die mariene/estuarium komponent is aangeteken.

Vanaf 1992 tot en met 1994 is soöbentos seisoenliks by vyf verskillende versamelpunte, versprei oor die lengte van die estuarium, versamel. 'n Totaal van 88 taksa, wat verteenwoordigend is van vier filums, is gedurende die drie jaar versamel. Gedurende 1992 is 50 taksa, met verteenwoordigers van die Nematoda, Annelida, Crustacea, Insecta en Gastropoda aangeteken en dit het die indruk geskep dat daar groot variasie in die fauna was. Alhoewel die getal taksa in 1993 met vyf gedaal het, was die variasie in fauna egter nog steeds betreklik groot en het dit verskeie ander insek-taksa ingesluit. Die grootste aantal taksa (59) is gedurende 1994 aangeteken en 40 daarvan was deel van die varswater komponent. Min dekapoda invertebrate is gedurende hierdie tydperk versamel en postlarwale steurgarnale het die grootste gedeelte hiervan beslaan. Resultate dui dus daarop dat die aantal taksa met verloop van tyd toegeneem het. Daar moet egter in aanmerking geneem word dat die oorgrote meerderheid van die taksa wat tot die spesielys toegevoeg is, aan die varswater komponent behoort. Dit word toegeskryf daaraan dat die mond van die estuarium weens die voortdurende droogtetoestand gesluit het.

'n Vergelyking van soöbentiese digthede tussen die varswater en estuarium komponente toon dat die estuariene komponent egter steeds die bentos oorheers en dat hierdie dominansie met verloop van tyd toegeneem het. Gedurende 1992 het die estuariene komponent 97.2% van die totale soöbentos beslaan. Dit het in 1993 en 1994 afgeneem

tot 84.6% en 54.4% onderskeidelik. Die gemiddelde digtheid van die invertebrate is 29 623 m^{-2} (*bereken as die som van die seisoenlikse opnames by al die versamelpunte oor die hele tydperk*), waarvan 48.7% (14 433 m^{-2}) van die totaal, in 1992 verkry is. Die soöbentiese digthede het in 1993 afgeneem tot 28.2% (8 340 m^{-2}) en in 1994 tot 23.1% (6 850 m^{-2}). Oor die algemeen was die soöbentiese digthede hoër in die winter en die laagste soöbentiese digthede is gedurende die herfs aangeteken. Volgens 'n multifaktor ANOVA, was seisoene op sigself egter nie 'n beduidende faktor in die toename of afname in soöbentiese digthede nie. *Grandidierella lignorum*, *Corophium triaenonyx* (Amfipoda) en *Apseudes digitalis* (Tanaidae) is van die taksa wat, elke seisoen, die bentos oorheers het.

Met behulp van verskeie parameters is die fisies-chemiese kondisie van die estuarium beskryf. Etlike van hierdie parameters is gebruik as matriks om die effekte daarvan op die verspreiding en volopheid van die soöbentos te bepaal. Saliniteit, temperatuur, opgeloste suurstofkonsentrasie, diepte en turbiditeit is elke jaar bepaal. Gedurende 1994 is 'n meer gedetaileerde waterkwaliteit- en sedimentanalise uitgevoer. Vanaf die boonste deel tot by onderste punt van die estuarium is daar 'n duidelike gradiënt in turbiditeit, saliniteit en suurstofkonsentrasie. Die substraat in die estuarium varieër van medium partikelgrootte sand in die onderste gedeelte tot detritus-modder met slik kolle in die bolope. Gedurende die studieperiode, het die estuarium toenemend vars geword en die saliniteit het van 6‰ in 1992 tot 0‰ aan die einde van 1994 afgeneem. 'n Reeks multivariansie tegnieke, waar klassifikasie- en ordineringsmetodes gebruik is, het aangedui dat sedimentpartikelgrootte nie die bepalende omgewingsfaktor ten opsigte van spesieverspreiding is nie. 'n Kombinasie van turbiditeit, opgeloste suurstof, pH en persentasie organiese inhoud het die grootste effek op variasie in die bentos gehad.

Hieruit kan afgelei word dat verbeterde bestuurspraktyke in die opvanggebied 'n positiewe invloed op die ekologie van die estuarium, en veral op die soöbentos gehad het. Die voortdurende droogtetoestande het egter ook 'n invloed gehad op die spesiesamestelling van die bentos. Die taksa van die estuariene komponent het, nieteenstaande, die estuariene bentiese fauna oorheers.

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1.0 GENERAL INTRODUCTION

In its broadest sense, an estuary is a place where a river meets the sea and forms a transition zone between freshwater and seawater (Pritchard, 1967; Day, 1981a). As estuaries include a wide variety of systems from small to large, and those that are either periodically or permanently open to the sea, much deliberation has gone towards defining them (Pritchard, 1967; Reid and Wood, 1976; Begg, 1978 and Day, 1981a) A generally accepted definition in the South African context is that an estuary is a 'partially enclosed body of water, 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 fresh water derived from land drainage' (Day, 1980). This definition is particularly descriptive of many estuaries in KwaZulu-Natal, which partly through modifications to their catchments, are subject to reduced marine influence through repeated closure of their mouths. The salinity of freshwater is less than 0.5‰ (McLusky, 1974). Thus, in an estuary the salinity range is potentially 0.5-35‰. Characteristically, an estuary is defined as a body of water in which river water mixes with, and measurably dilutes sea water (Ketchum, 1983) to a greater or lesser extent. Those waters that have a greater dilution of fresh water are termed 'brackish' (McLusky, 1974).

KwaZulu-Natal has a fairly small share of South Africa's 2900 km of coast line. Nevertheless, the 540 km stretch from Port Edward (31°04.5'S/30°12'E) to Kosi Bay (26°47'S/32°47'E) supports 73 estuaries, and on average, is fairly intensely developed (Little, 1984). The coastal zone is more intensely utilised than any other region in KwaZulu-Natal, and no other part of the South African coastline is as degraded, resulting in a threatened status due to human impact (Begg, 1984). There is evidence to suggest that over 90% of the coastal lowland forest in the province has been lost as a result of sugarcane cultivation, and that large areas of riverine and swamp forest have suffered the same fate (Cooper, 1985).

1.1 Historical Aspects

The Siyaya estuary is situated on the east coast of South Africa, at the town of Mtunzini, 140 km north of Durban (Begg, 1978) (Figure 1.1). Using a combination of physiographic, hydrographic and salinity features, Whitfield (1992) classified the Siyaya Estuary into one of five categories used for the characterisation of southern African estuaries. The Siyaya Estuary was described as a temporarily open/closed estuary, behaving as a typical estuary when open. Day's (1981a) classification of estuaries places the Siyaya Estuary into the 'Closed or Blind estuary' category. That is, it is temporarily closed by a sandbar across the sea mouth, causing the salinity to vary from hypo- to hypersaline conditions depending on seepage at the mouth, freshwater inflow and precipitation. This also agrees with Ketchum's (1983) definition of a bar-built estuary, in that it is generally part of a flat coastal plain, has a bar enclosing a shallow body of water, with limited exchange with the sea. Hence, the circulation pattern is more dependent upon wind, than it is upon tidal ebb and flow. Despite the Siyaya Estuary fitting into the above categories, there has been no record of it becoming hypersaline.

The Siyaya was a deep (2 m), clear stream until 1946 when farmers cleared the surrounding vegetation to replant sugarcane (Oceanographic Research Institute, 1991). Most of the wetlands in the catchment were drained during the following decade and replaced with sugarcane. Furthermore, indigenous riverine swamp forests were felled to provide additional farming area for cane crops. Factors such as cultivation of crops on the edge of the Siyaya's banks and canalisation of drainage lines in fields, contributed to the accelerating degradation of the estuary (Benfield, 1984). Erosion as a consequence of these farming practices reduced the depth of the estuary, especially during 1971, when high catchment rainfall figures marked the end of a previously dry period (Siyaya Project Newsletter No.1, 1981). Since bank stabilising vegetation had been removed, large areas of river bank collapsed and silt was transported downstream into the estuary.

This issue was compounded by the encroachment of the swamp reed *Phragmites australis* into the stream bed and adjoining estuary. It was suggested by Benfield (1984) that, as agricultural run-off was allowed to flow more freely into the water courses in the

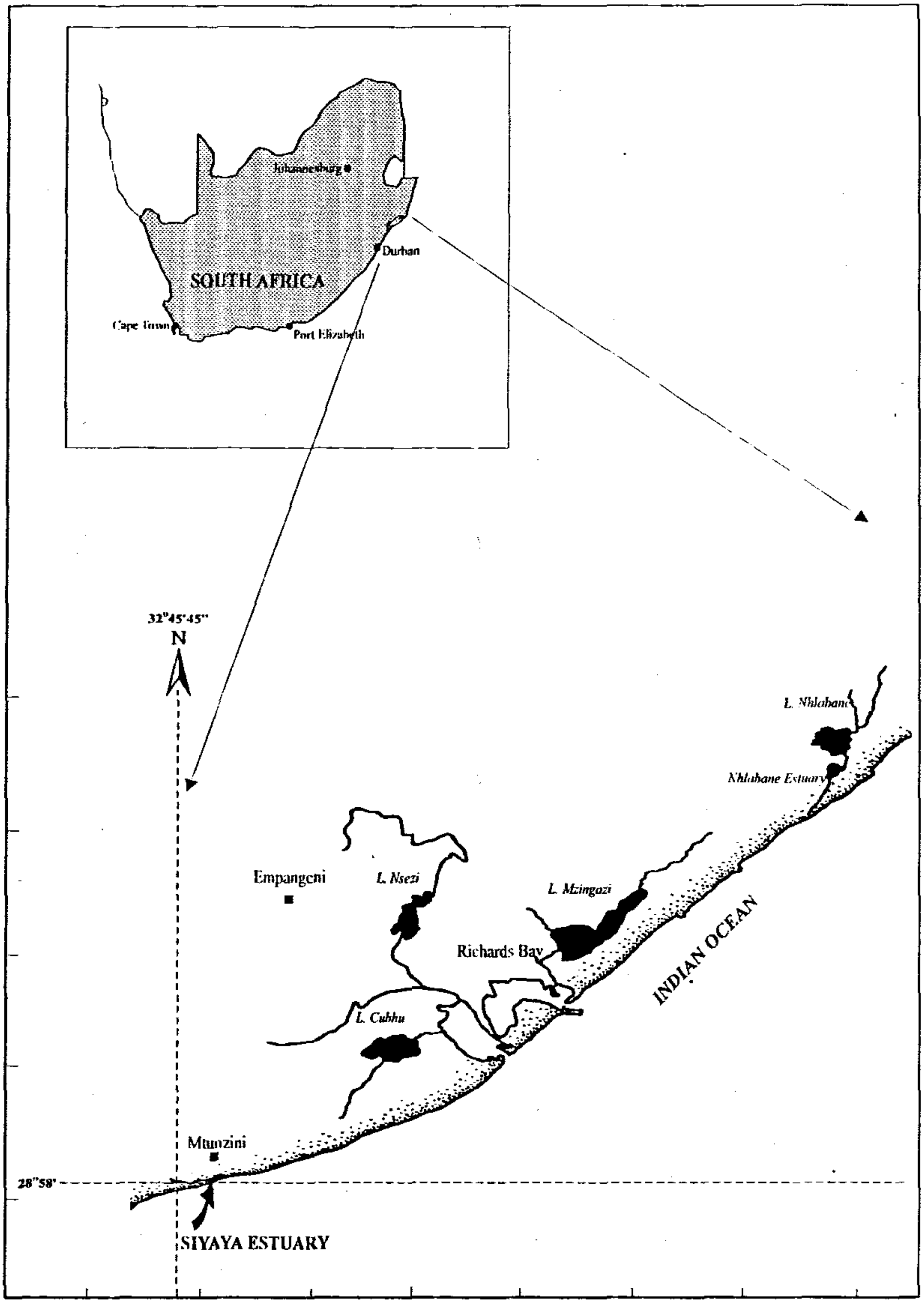


Figure 1.1: Map of Zululand showing location of coastal lakes and nearby towns in relation to the Siyaya Estuary

absence of marginal vegetation, leached fertilisers resulted in the proliferation of aquatic macrophytes. The vigorous growth that followed was caused by nitrate and phosphate nutrients being taken up by these plants (Begg, in Siyaya Project Newsletter No. 3, 1981). Runoff from crop-producing systems carries pollutants of many different forms into watercourses, to the detriment of water quality (Siyaya Project Newsletter No. 3, 1981). During the 1950's, there were very few reeds growing in the system. However, since 1957, the accelerated expansion of the reedbeds and deposition of silt have both contributed to a reduction in the depth of the estuary (Begg, 1978). Colonisation by this aquatic macrophyte reduced the depth of the estuary by reducing current velocity, creating a sediment trap and increasing the deposition of silt (Oceanographic Research Institute, 1991). Increased reedbed expansion in several regions of the estuary was observed during a study conducted between 1981 and 1983 (Benfield, 1984). At present (1992 to 1994), it appears that *P. australis* is indeed expanding to occupy much of the available habitat in the estuary. Active removal of the reeds is an essential part of any attempt to restore the estuary to its pre-1957 condition, when *P. australis* occupied less than 12% of the estuary's surface area (Begg, 1978). From personal observation of the Siyaya Estuary and aerial photographs taken at the beginning of 1994, *P. australis* now appears to occupy more than half of the surface area of the estuary.

Any estuary must have a supply of organic detritus that forms the basic ingredient upon which energy flow through the food web depends (Begg, 1978). *P. australis* is one of the major suppliers of detritus to the Siyaya system. Second to this are *Saccharum officinarum* (sugarcane), *Barringtonia racemosa, Hibiscus tiliaceous* and *Ipomea brasiliensus* (Schleyer, 1984). Despite this being a useful supply of detritus, the decomposing leaf litter accounts for low oxygen tensions in water. This is especially true in the upper reaches of the estuary where a thick riparian belt on exists on each bank. Excessive yields of silt have contributed greatly to the general degradation of the Siyaya Estuary, by modification of habitats within the estuary, with some species being totally excluded (Begg, 1978; Oceanographic Research Institute, 1991).

In the catchment, the cultivation of sugarcane up to stream banks, the removal of riverine vegetation and the drainage of wetlands resulted in a mass movement of soil from croplands into streams, and this was eventually deposited in the estuary. Denuded of natural barriers, the increased water velocities into the estuary carried a harmful combination of silt, soil fertilisers and herbicides. Changes in the morphology of river channels and adjacent flood plains due to removal of vegetation are major causes of sedimentation of river estuaries (Siyaya Project Newsletter No. 2, 1981). The role that vegetation plays is not so much the physical protection of soil on which it grows, but the resistance it offers to the flow of water.

1.2 Land Management and Ownership

Six years ago, land ownership in the Siyaya Catchment changed, with an accompanying conversion of landuse to timber cultivation. The 1602 hectares of catchment (excluding the 198 ha owned and occupied by the Natal Parks Board) are at present, 61% (978 hectares) the responsibility of Mondi Forests, Mtunzini. Of this portion, 16.3% (261 hectares) has been set aside for conservation, which includes replanting indigenous vegetation (Table 1.1).

Exactly half of the catchment area (801 hectares) is presently devoted to timber cultivation followed by 410 hectares of cane (25.6% of the catchment area). All remaining cane has currently been abandoned to be used as drought-relief fodder, and harvesting of forest areas is to be on a block or panel-felling basis to reduce erosion (Siyaya Research Working Group minutes, 1992 and 1993). The principal local authorities are the Natal Parks Board in the lower reaches, and Mondi Forests in the upper reaches of the Siyaya Catchment.

Table 1.1: Hectares and percentage of total area devoted to various landuses and landownership in the Siyaya Catchment, as at 1994

Land Uses:	Hectares	% Total Area
cane	410.0	25.6
timber	801.0	50.0
conservation	261.0	16.3
residential	128.0	8.0
other	2.0	0.1
	*1602	100
Land Owners:		
Mondi Forests	978.0	61.0
Mtunzini Sands	248.0	15.5
Mtunzini Town Board	128.0	7.9
Thevenau	124.0	7.7
J. Murray	121.0	7.7
A. Kirkland	1.5	0.1
D. Nel	1.5	0.1
	*1602	100
Mondi Forests:		
cane	0.0	0.0
timber	713.0	72.9
conservation	240.0	24.5
residential	25.0	2.6
	978	100

***1602** = total catchment excluding Natal Parks Board area.

1.3 Reclamation Management in the Siyaya Catchment

Concern was expressed as to the state of the catchment from the commencement of heavy silt deposition into the estuary in 1971, until the beginning of the last decade. At this time a local farmer Mr Ian Garland, initiated restoration of the Siyaya Catchment through bank stabilisation and re-establishment of riverine and swamp communities, of that area running through his farm 'Twinstreams'. This he achieved, by using the properties of several tree species, to bind soil to their root systems and others that functioned as 'plugs' to raise water table levels. The farm has subsequently been purchased by Mondi Forests, but Mr Garland continues to replant indigenous swamp forest communities in areas around the Siyaya stream banks. To date Mr Garland has been responsible for the rehabilitation of 55-60% of the streams and conservation areas of the current land owner's property. Natural rehabilitation of the estuary by fringing wetland vegetation has proved to be important, as these floral components serve as cleansers of ecosystems, by reducing water velocity, absorbing and then releasing it slowly, thereby reducing siltation (Oceanographic Research Institute, 1991).

1.4 The Siyaya Catchment Demonstration Project (SCDP)

One of the most progressive developments in the field of estuarine rehabilitation is the Siyaya Catchment Project. The Siyaya was originally chosen because it was influenced by a single form of landuse (sugarcane cultivation), and because it was small enough (18 km^2) to bring the task within the realms of being practically achievable (Begg, 1984).

Twenty years ago, the degraded state of the catchment necessitated the implementation of a catchment study, adhering to the conservation ethic involving a reduction of soil loss through agricultural processes. The Siyaya Estuary forms part of a much broader catchment restoration project, which was initiated in the late 1970's, and formally launched in April 1980, under the leadership of Dr G W Begg[1]. The restoration of the catchment to a state of balance, and rehabilitation of the Siyaya Estuary would hopefully open the way for similar projects in other degraded estuaries, as sand and silt have

[1] Senior Staff and Executive Member of the Oceanographic Research Institute from 1970's to 1980's

already disturbed 45 of KwaZulu-Natal's 73 estuaries (Siyaya Project Newsletter No. 1, 1981). At present, the SCDP is being co-ordinated by the multidisciplinary Siyaya Catchment Research Working Group, under the chairmanship of Dr R McC Pott, Manager of Environmental Conservation, Mondi Forests. To date a research programme has been effected to monitor catchment restoration in terms of biotic and abiotic responses of the estuary. To identify research needs, monitoring projects were divided into three categories:

1. **total catchment**
2. **wetlands and watercourses**
3. **the estuary**

Each is to provide a database against which changes in the catchment can be measured. Ideally, results of a study of this kind may predict what changes to management practices need to take place. In the case of the estuary, its state is considered to reflect the condition of the catchment. Davies and Day (1986), maintain that the physical, chemical and biological characteristics of any watercourse are almost entirely determined by the nature of their catchments and the activities that take place in it.

Rehabilitation of the Siyaya Estuary would require that silt deposition be reduced through an integrated landuse plan. Furthermore, eight farmers in the area had to agree to re-plan their farms by replanting stream banks with natural indigenous vegetation, and filling unnecessary drainage channels. Replanting riparian vegetation, using inherent conservation qualities of the cane crop, minimum tillage and crop re-establishment on a strip system combined with trashing, will greatly reduce the amount of silt deposited in the estuary. This is because riparian vegetation along the stream banks encourages the deposition of sediment. In stream bank ecology, trees are used to consolidate stream banks as their combined root systems are robust and dense and are able to stabilise the soil during flooding. Silt deposition is reversible, but if left to itself would take decades, and in the interim floods would still cause damage. Therefore intervention is necessary through bank stabilisation. The expertise and manpower of Government departments, various associations (the World Wide Fund for Nature, SA for example), research bodies and individuals were enlisted to monitor the effects of the SCDP on soils, vegetation, the river and the estuary. The primary motivating factor was the establishment of a conservation ethic. The resulting programme to restore the catchment to a more natural condition was launched in April 1980 and the example drawn of the SCDP may serve as a blueprint for other degraded KwaZulu-Natal estuaries.

1.5 Objectives of the Siyaya Catchment Demonstration Project

At the inception of the catchment restoration project in April 1980, the principal objectives were to prove that effective catchment management can retard estuarine degeneration (Bowmaker, van der Zee and Ridder, 1987), and that if the programme was successful, it would provide the basis for the rehabilitation of other degraded catchments in the province. Whilst under the authority of the KwaZulu-Natal Town and Regional Planning Commission, the primary aim of the Demonstration Project was formally set out on 27 May 1980. It was to determine the effectiveness of integrated resource management in estuarine restoration (Benfield, 1984) and to upgrade the poor state of knowledge of the system by establishing its physical, chemical and biological characteristics. In summary, the principle philosophy behind the project is to develop a comprehensive picture of the rehabilitation process and to pinpoint the major responses of the estuary with regards to the three categories of monitoring projects (Section 1.4).

1.6 Comparability of the Siyaya Estuary to other KwaZulu-Natal estuarine systems

If the Siyaya Demonstration Project is ever completed, it would be ideal if the results obtained could be applied to other catchments in the province, and the principles applied to catchments in South Africa. In order to perform comparability studies on other estuarine systems, it had to be established whether the Siyaya was representative in some manner of other systems. For this purpose a detrended correspondence statistical analysis was performed on some characteristics of each catchment by the originators of the SCDP (Oceanographic Research Institute, 1991). This involved comparing aspects such as catchment size, river length and whether coastal plains were absent or not. The result was that, based on these characteristics, the Siyaya Estuary was atypical of any other system in the province. Further analysis was conducted to include the hydrological features and physical conditions of the estuary, which enabled these results to be more broadly applicable to a wide variety of estuaries in KwaZulu-Natal (Oceanographic Research Institute, 1991).

1.7 Previous research on the Siyaya Estuary

Without a detailed baseline study, the extent of change that has, or is taking place in the estuary may be difficult to determine in the future. Since the inception of the SCDP, fifteen years ago, no long term monitoring effects on the estuarine benthos have been conducted. During September 1979, dredged samples of benthic fauna were analysed by the National Institute for Water Research, Durban. A second, more detailed survey was conducted by the South African National Committee for Oceanographic Research (SANCOR) on four occasions during the period 1983 to 1984. Here, an attempt was made to obtain more quantitative results using a corer, and to evaluate seasonal variations. These initial surveys established that there was low benthic diversity and abundance in the central and upper reaches of the estuary. This was attributed to low oxygen tensions in the bottom waters of these regions, with species occurrences being related to the physico-chemical conditions of an estuary characteristic of little marine influence (Connell, Mc Clurg, Stanton, Engelbrecht, Stone and Pearce, 1981). The recommendation of the Oceanographic Research Institute (Oceanographic Research Institute, 1991), was that any significant changes in the general character of the fauna, which may have arisen from catchment restoration should be clearly distinguishable against these study backgrounds in the future.

Examination of the insect fauna of the Siyaya River in the early 1980's suggested that habitat destruction had resulted in low numbers and poor diversity. At that time, zoological studies of the benthic fauna confirmed that they were part of a stressed environment as reflected by taxa present and their relative abundance (Siyaya Project Newsletter No. 2, 1981).

1.8 Current Project Objectives

The seven objectives of this project, arose out of a need expressed by the requirement for a medium to long-term data base against which comparable future studies could be measured, using standardised techniques and samples.

- To determine the physico-chemical characteristics of the estuary.
- To determine the spatial and temporal nature of the substrate.
- To identify the benthic components and classify them to species level or as far as possible.
- To determine spatial and temporal differences and changes in the benthic community.
- To relate benthic distributions to physico-chemical parameters.
- To establish, as far as possible, the present state of the catchment.
- To compare the state of the Siyaya Estuary with other estuarine systems in KwaZulu-Natal.

1.9 Outline of Thesis

Chapters 2 deals with a general description of the Siyaya Catchment and the possible factors that may affect it, with a view to eventually influencing the estuary and ultimately the zoobenthos within it. Chapter 3 describes firstly the estuary in terms of sampling sites selected for the collection of biotic and abiotic samples and secondly, the general methods of sample collection and laboratory analysis. A detailed account of the equipment used and type of analysis employed for the physico-chemical and zoobenthic data is set out in the respective chapters (Chapters 4 and 5). Upon commencement of this study, the scope of the physico-chemical variables that could affect the benthos in terms of abundance and distribution was unknown. It was felt, that a detailed account of the water quality of the system would provide some assessment of the current situation within the estuary. That is, in terms of its prolonged isolation from the sea, and the additional effect of the prevailing drought. Chapter 5 is exclusively devoted to dealing with a description of the benthos within the estuary in terms of spatial and temporal abundance. A combination of univariate and multivariate analyses were employed to qualify and quantify the aforementioned descriptions. On the basis of their contribution to overall abundance each sampling year, dominant taxa were selected and described. The main objective of Chapter 6 is to provide some explanation for the spatial and temporal differences in species assemblages, by looking at the effects of various physical and chemical parameters. Parameters chosen include those that have previously been identified in other studies as affecting benthos, as well as some additional water quality variables that may be used to describe benthic community patterns. Chapter 7 discusses how results obtained in this study could be used in the context of other monitoring programs, incorporated into health indices or geographical information systems. Conclusions drawn from the findings of this study are also set out in this final chapter.

2.0 STUDY SITE

2.1 Catchment Location and Morphology

The Siyaya Estuary (28°58'S; 31°45'45''E) is part of an 18 km^2 catchment, lying on the east coast of South Africa in the province of KwaZulu-Natal (Figure 1.1). Since 1960, the estuary has been periodically cut off from the ocean by a sandbar across the mouth (Oceanographic Research Institute, 1991), with the longest recorded period of isolation from the marine environment being November 1991 to April 1995. During these periods, no flushing of the estuary took place, only occasional overtopping occurred on spring tides, and breaching during floods (Oceanographic Research Institute, 1991). According to this report, no breaching took place between April 1981 and February 1984, but cyclonic events of 1984 removed the sandbar but not the accumulation of silt. An explanation might be, that due to the shallow gradient of the estuary no scouring of the bed occurred. Low salinities and fresh water conditions are expected in the Siyaya Estuary, due to the lack of tidal influences.

The Siyaya catchment consists of two main subcatchments around the Siyaya and Amanzimnyama streams (Figure 2.1). The flow of the Amanzimnyama Stream through stable wetlands, well-wooded swamp forests, reed and papyrus beds ensures that there is a low silt load in it, compared with that of the Siyaya Stream. The Siyaya Stream travels through fewer patches of swamp forest, less riverine vegetation and has a steeper gradient. This combination creates a less stable situation and water from the Siyaya is often discoloured by silt (Siyaya Project Newsletter No.1, 1981).

The catchment has a typical sand dune topography with short, but steep slopes and well defined valleys (Oceanographic Research Institute, 1991). The stability that existed in the past with the effectiveness of the wetlands and swamp forests, in maintaining a high water table ensured minimum silt levels in the estuary. Consequently, the Siyaya Estuary was described as a 'paradise of undisturbed beauty' before 1950 and even as late as 1960 (Siyaya Project Newsletter No.1, 1981). With time, the number of farmers in the catchment doubled, and wetlands were drained to provide a larger area to cultivate

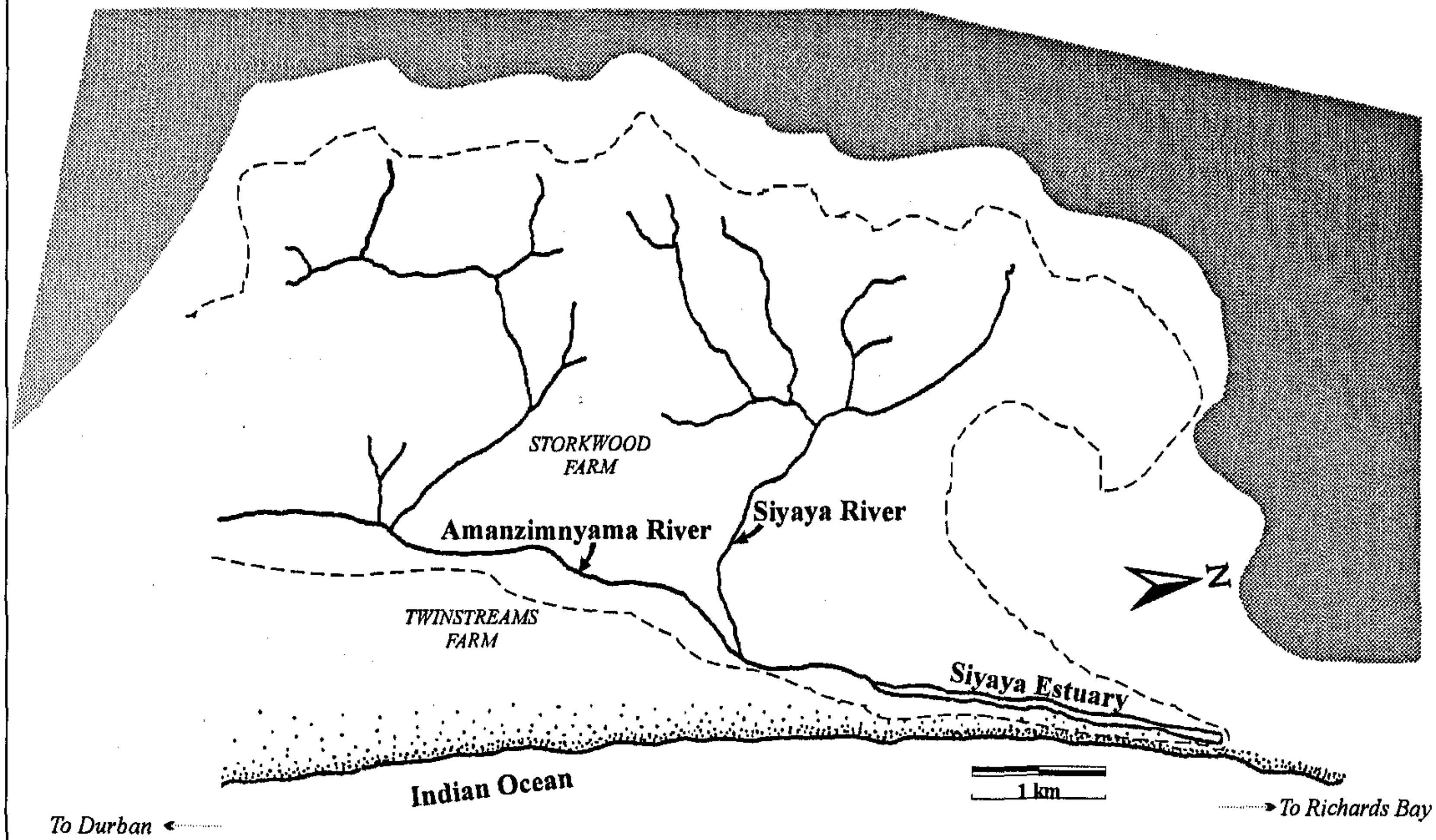


Figure 2.1: The Siyaya Catchment indicating the location of the Siyaya and Amanzimnyama Streams, in relation to the Siyaya Estuary

sugarcane. This subsequently resulted in a lowering of the water table. As 1959-1969 was a comparatively dry decade, no visible effect of the drainage was observed as increased silt load into the estuary, although papyrus and riverine swamps were eliminated (Siyaya Project Newsletter No.1, 1981). During the 1970's, a wet cycle altered estuarine dynamics. The absence of wetlands, swamp forests and riparian trees to reduce the velocity of flow, caused a deposition of soil into the estuary which altered the bathymetry and water quality. As a consequence, the Siyaya Estuary became a body of muddy water, a few inches deep (Siyaya Project Newsletter No. 1, 1981).

2.2 Climate

2.2.1 Temperature

The area has a typically subtropical climate that is usually humid and warm to hot. Absolute maximum and minimum temperatures for Mtunzini are 39.0 ^{O}C and 5.7 ^{O}C (Tinley, 1985).

2.2.2 Rainfall

Figure 2.2 represents the typical rainfall distribution in KwaZulu-Natal. The area around the study site (Mtunzini), has an average rainfall of >1280 mm per annum, which is the highest in the province. The mean annual rainfall at Storkwood Farm in the catchment is 1215 mm (Oceanographic Research Institute, 1991). The period of this study (1992-1994), was characterised by severe drought conditions with mean annual rainfalls of 675 mm, 1019 mm and 898 mm on Twinstreams Farm (Table 2.1). These were drier than previously experienced. Other dry years were 1937 and 1950 with rainfall figures of 748.3 mm and 710.7 mm, respectively (Siyaya Research Working Group minutes, 1993).

Heavy cyclonic rainfall during January and February of 1984 (Cyclones Domoina and Imboa), as well as heavy March rainfall together produced more rain than the previous hydrological year (Oceanographic Research Institute, 1991). Rain recorded during Imboa was >300 mm and during Domoina was >400 mm in the Richards Bay area

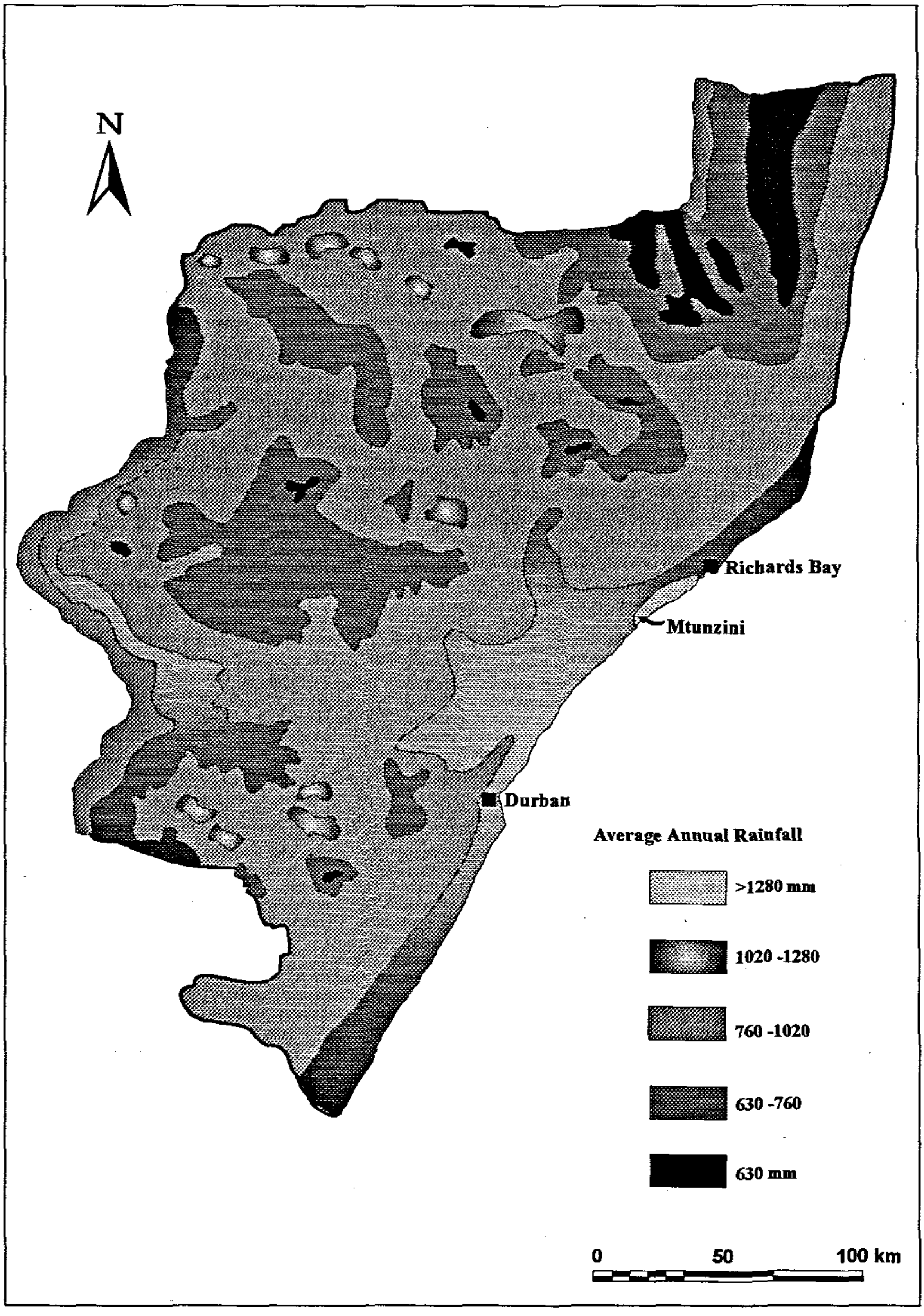


Figure 2.2: Average annual rainfall distribution in KwaZulu-Natal (Based on Orme, 1974; Cyrus and Robson, 1980; Harrison, 1993)

(Hunter, 1988). These events may not be representative of the catchments responses to management practices over the long term.

The 1970's to 1980's were one of the wettest decades this century, whilst the 1980's were comparatively dry (Siyaya Project Newsletter, No.1, 1981). Evidence suggests that a climatic cycle does exist, apparently operating on a ten year time span (Dyer and Tyson, 1977; Siyaya Project Newsletter, No.1, 1981). According to these cycles, the current decade (1990-2000) should be 'wet' following the dry spell 1980-1990 (Figure 2.3). This has considerable relevance to the Siyaya Catchment Demonstration Project, as the farming community will have endeavoured to implement farm management plans through both drought and flood cycles.

2.3 Geological, Geomorphological and Soil Type features of the Siyaya Catchment.

The bedrock under the catchment is comprised of shales and sandstones of the Vryheid formation, with minor intrusions, mainly in the form of sheets of Karoo dolerite. Red sands of the Berea Formation overlie the bedrock (Siyaya Project Newsletter No. 4, 1981). This configuration of the Siyaya Catchment area has been determined by sea level and climatic changes in the Quaternary period over the past two million years. The four ice ages during this period saw cooler climates and lower sea levels (Siyaya Project Newsletter No. 4, 1981), it is now in the inter glacial period that the climate is warmer, the sea level has risen, and major dunes have built up along the KwaZulu-Natal coastline. During the present age, the natural determinants along this stretch of the coastline are similar to those operative throughout the rest of South Africa (Tinley, 1985). They are:

- \- the configuration and trend of the coastline
- \- marine influences (wave action and longshore drift)
- \- sediment sources
- \- the wind regime
- \- fluvial influences and
- \- plant colonisation (Tinley, 1985)

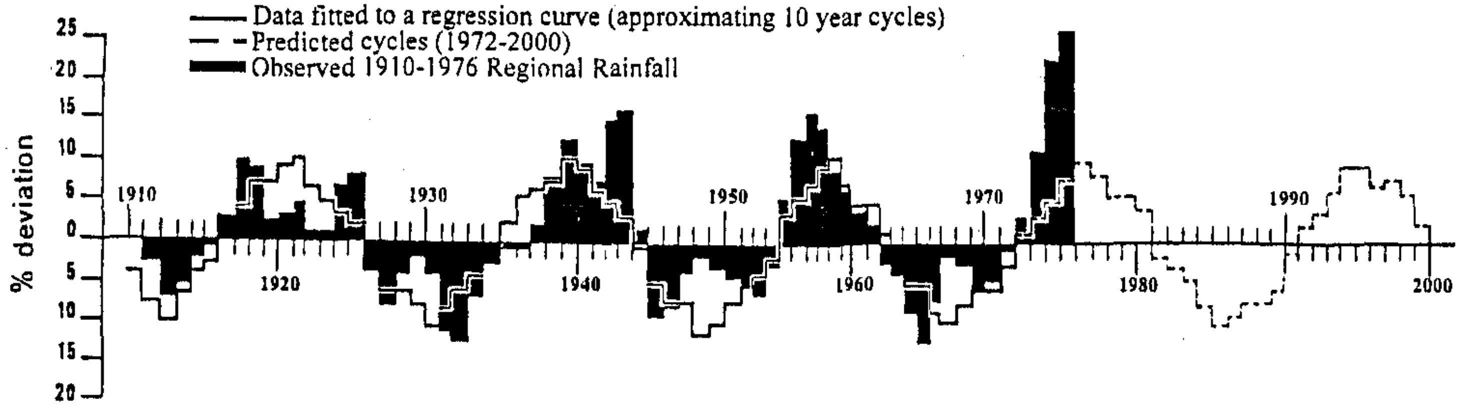


Figure 2.3: Rainfall Deviation above and below the mean annual (1910-2000), showing wet and dry cycles (After Dyer and Tyson, 1977)

Table 2.1: Table of monthly rainfall in the Siyaya Catchment (1987-1994) and comparison of total rainfall (mm) each year.

	January	February	March	April	May	June	July	August	September	October	November	December	Total
1987	230	20	186	68	41	233	54	168	471	135	146	156	1881
1988	36	282	296	17	59	96	33	39	62	125	224	202	1471
1989	95	206	69	70	121	34	85	19	109	106	432	181	1527
1990	98	79	280	109	75	13	9	151	56	149	71	188	1278
1991	144	161	373	23	141	51	62	33	106	108	116	68	1386
1992	53	14	81	39	0	0	34	33	70	58	231	62	675
1993	160	65	105	46	34	12	7	80	97	163	57	193	1019
1994	89	101	72	34	9	33	36	140	47	158	78	101	898

(rainfall measurements taken on the farm "Twinsteams", and obtained courtesy of Ian Garland)

However, basic differences are that most of the coast is south-east facing, thus it is a high energy environment dominated by south-easterly swells, and the two opposing NE and SW prevailing winds blow parallel to the coast. The beaches are thus dynamically unstable areas, with their shapes constantly changing due to alterations in wave climate and local weather patterns (Begg, 1991). Besides the tilted topography of KwaZulu-Natal and the high incidence of relatively short rivers, factors such as the incapacity of runoff to prevent sand movement in the littoral zone from sealing river mouths, lead to the closure of estuaries. This temporary impoundment behind a sandbar means that contact with the sea is discontinued and the estuary becomes dominated by fauna and flora characteristic of freshwater environments (Begg, 1991). The effect of Tinley's (1985) first two determinants, that is the configuration of the coastline and the marine influence on this, may be too broad a generalisation for the Siyaya and neighbouring Mlalazi Estuary, which are both in the greater Mtunzini Catchment Area. This stretch of coast is the only prograding beach in the country, contrary to all others which are all retrograde (Begg, 1978).

The soils of The Siyaya Catchment are young, and strongly reflect the influence of parent material. The soils of Zululand's coastal lowlands largely comprise arenosols, which are sands derived from aeolian and alluvial deposits (Brink, 1985). Eleven soil types are derived from five parent materials (Table 2.2 and Figure 2.4).

They are: Fernwood soils from Grey Recent Sands, Hutton and Shepstone from Red Recent Sands, Swartland, Kroonstad, Glenrosa, Clovelly and Cartref from Middle Ecca sediments, Dundee and Champagne from alluvium and Shortlands-type soils from Dolerite parent materials. Red recent sands contribute most (714 hectares) to the geology of the catchment (Oceanographic Research Institute, 1991).

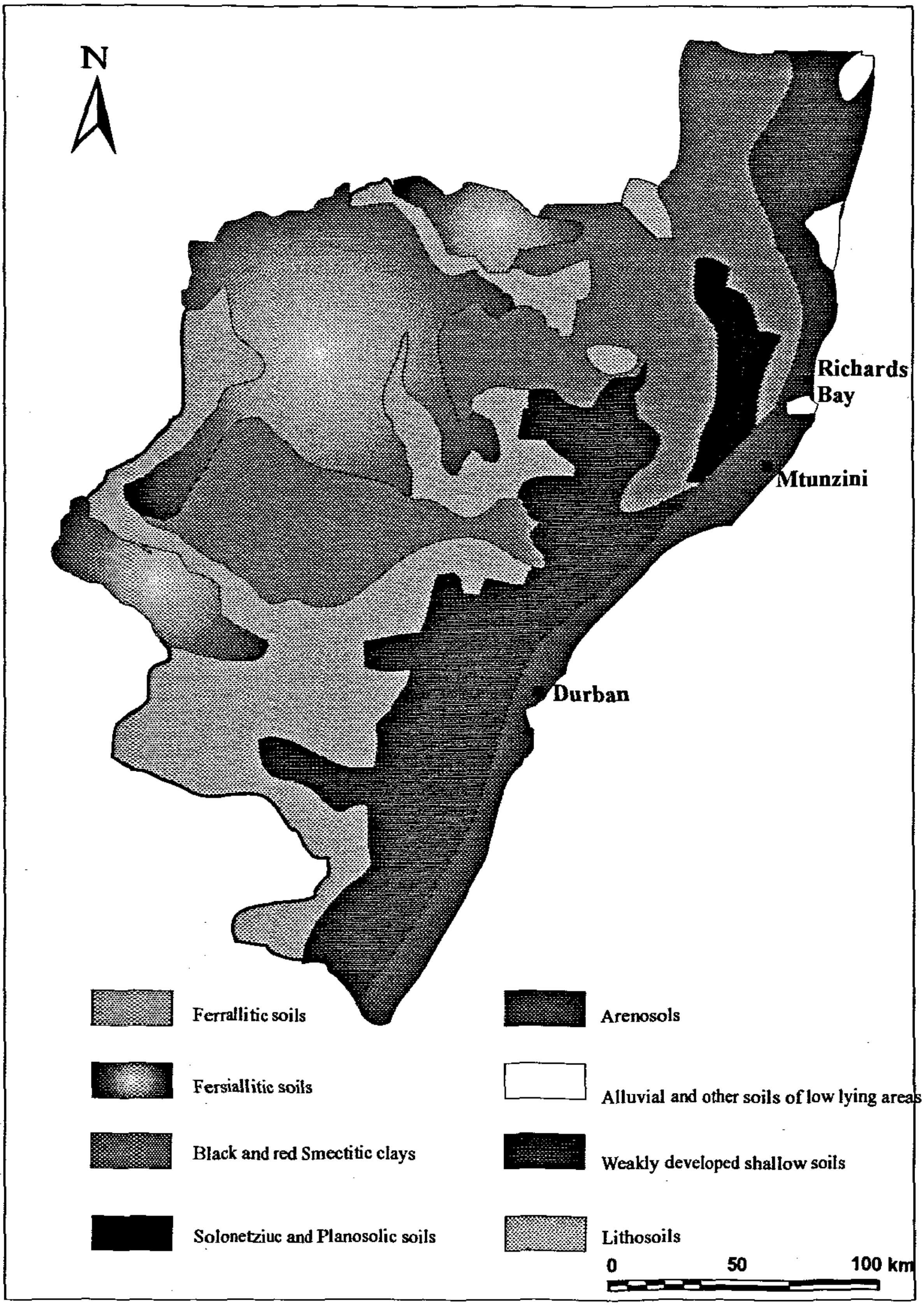


Figure 2.4: Distribution of eight main Soil Types in KwaZulu-Natal (After Harrison, 1993)

Table 2.2: Table of Soil Types derived from the five parent materials present in the Siyaya Catchment and the area (ha) they cover. (Based on Siyaya Project Newsletter No. 3; Oceanographic Research Institute, 1991).

Parent Material	Soil Form	Area of catchment
•Grey Recent Sands	<Fernwood	323 ha
•Red Recent Sands	<Hutton <Shepstone	714 ha
•Middle Ecca	<Swartland <Kroonstad <Glenrosa <Clovelly <Cartref	301 ha
•Alluvium (peat)	<Dundee <Champagne	5 ha
•Dolerite	<Shortlands	7 ha

(note that hectares were measured in early 1980's when the total catchment area was 1350 ha)

Table 2.3 shows that the estimated annual soil yield is high in both catchments: (Siyaya Project Newsletter No. 3, 1981).

Table 2.3: Estimated annual Soil Yield (kg/ha) for the Siyaya and Amanzimnyama Catchments.

	Amanzimnyama	Siyaya
Yield (kg/ha)	**392 194.0**	**1 019 754.0**
Catchment export (kg/ha)	**408.5**	**1 603.4**

This clearly reflects the activities that have dominated the catchment over the past several decades, as well as the erodibility of the catchment soils.

2.4 Vegetational Characteristics

The present vegetation of the area, is typical coastal forest with species such as *Barringtonia racemosa* and *Hibiscus tiliaceous* fringing the riverine channels and estuary. This does not differ from other larger estuarine systems in the area such as Richards Bay and St Lucia, although mangrove species are absent from the Siyaya Estuary due to the lack of constant water interchange with the marine environment (Begg, 1991; Harrison, 1993). Prior to the felling and clearing of indigenous trees and vegetation to make room for cane (the period between the 1960's and 1980's), the wetlands adjacent to the swamp forests, the swamp forests themselves, as well as papyrus swamps were effective in establishing a permanently high water table (Siyaya Project Newsletter No.3, 1981).

2.5 Ocean Currents

The most important large-scale oceanographic feature off the KwaZulu-Natal continental shelf, is the Agulhas Current (Schumann, 1988). Figure 2.5 depicts the major oceanic currents of the south-west Indian Ocean around southern Africa and those passing the study area. These are the Mozambique and warm water Agulhas Currents. The latter is formed off the northern KwaZulu-Natal/Mozambique coast and has its core generally off the shelf break (Schumann, 1988).

Along the Zululand coast, the continental shelf tends to be narrow (<10 km in places) until South of port Durnford (28°55'S; 31°50'E), where the shelf widens out to its maximum of 45 km (Schumann, 1988; Harrison, 1993). Pearce (1977), stated that salinities of inshore waters particularly around estuary mouths may be reduced due to land runoff. For the same reason, silty areas of ocean water may be seen during the rainy season.

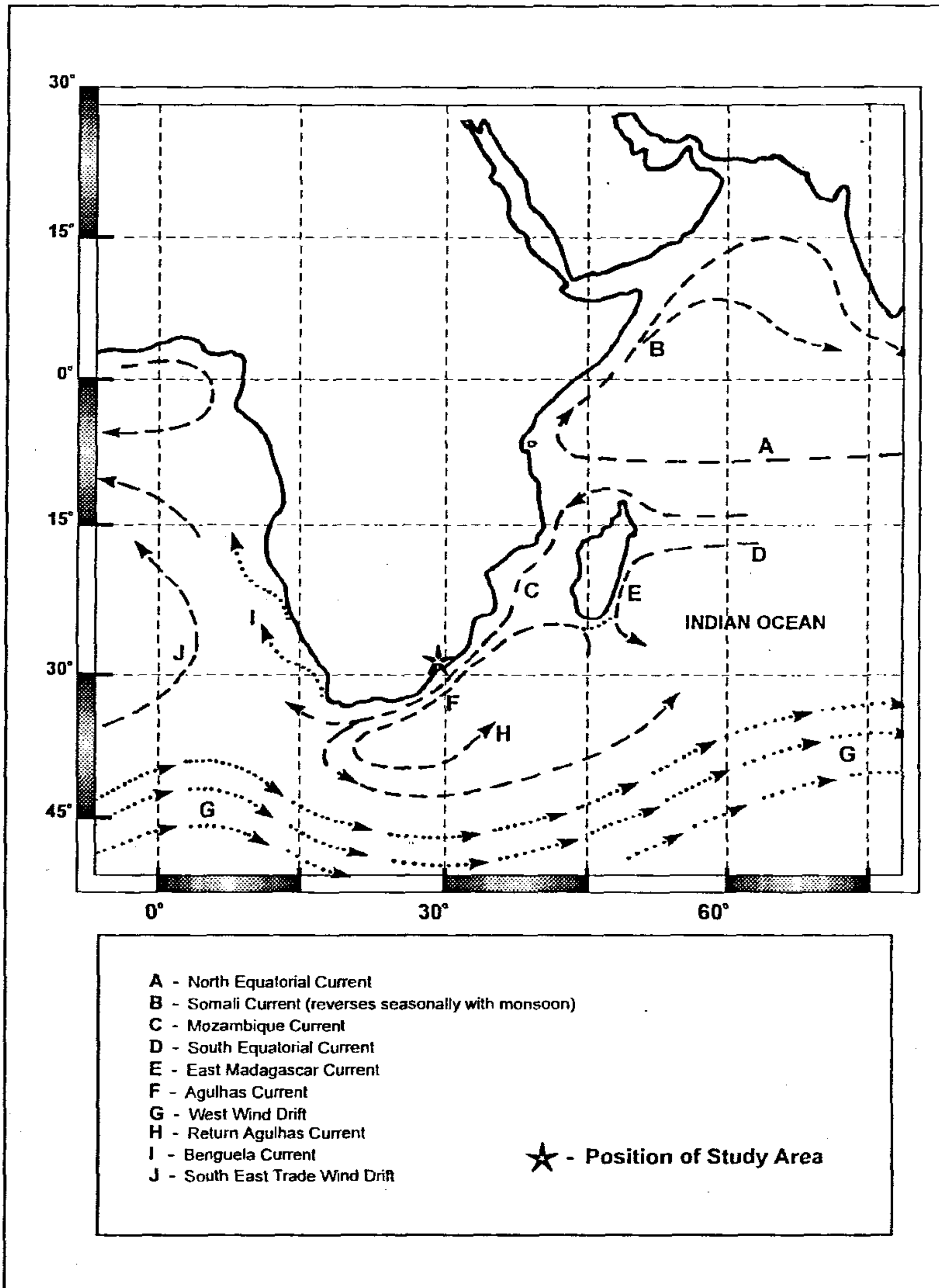


Figure 2.5: Schemtaic indication of the major currents in the west Indian Ocean region (After Heydorn, 1978)

2.6 Morphology and Characteristics of the Siyaya Estuary

From the confluence of the Siyaya and Amanzimnyama Rivers, the estuary has an axial length of 2.6 km, and a surface area approximate to 8 hectares (Begg, 1978), and has its mouth situated in a north east direction and runs parallel to the shore (Figure 1.1). Between 1937 and 1977 the estuary mouth moved a distance of 740 m north eastwards at a rate of 17.4 $m.yr^{-1}$ (Begg, 1978). The shoreline length is approximately 5.2 km with a width that was 45 m in 1978, but from personal observation is now much less than half of this. The nature of the sediments during the 1950's were described as being sand of marine origin (Begg, 1978). From the upper to the lower reaches of the Siyaya Estuary the substrata range from detrital-rich mud to coarse, marine sand at the mouth.

3.0 GENERAL METHODS AND MATERIALS

3.1 Selection and Characteristics of Zoobenthic and Physico-Chemical sampling sites

The Siyaya Estuary was divided into five areas for the purpose of sampling the zoobenthos and measurement of physico-chemical parameters (Figure 3.1). A site was chosen in each area to represent a progression from the upper to the lower reaches of the estuary, thus producing a gradient of quantifiable characteristics. This was especially so of substrate type, where there was a trend for detrital muds to occur in the upper reaches, with a gradient of silt and fine to coarse-grained marine sands occurring in the lower reaches (Begg, 1978) (Figure 3.2). A description of each of the five sampling sites and surrounding riparian vegetation, as well as their distances apart is presented in Table 3.1:

Table 3.1: Physico-chemical and zoobenthic sampling site characteristics of the Siyaya Estuary, summer 1993 - spring 1994.

• **Site 1:**	north of the bridge from Mtunzini Chalets, at the seaward end near the mouth of the estuary. This site was characterised by coarse, fluvial, clean sands.
• **Site 2:**	north of the bridge from Mtunzini Chalets, adjacent to the first dune hill on the east bank, and approximately 350 m upstream from Site 1. This site had a substratum comprising a mixture of sand and mud (Begg, 1978), with the aquatic macrophyte *Potamogeton pectinatus* present in the water. This site had surrounding riparian vegetation dominated by *Phragmites australis*, *Hibiscus tiliaceous*, *Imperata cylindrica* and *Juncus kraussi*.
• **Site 3:**	within the bay area, under the bridge and situated 1.2 km upstream from the mouth. The substrate was fine-grained sandy mud, with a fairly thick layer of organic matter. *Barringtonia racemosa*, *H. tiliaceous*, *Tricalysia sonderana* and *Phoenix reclinata* surrounded the bay. *Phragmites australis* encroached thickly towards the open water areas, and had entirely blocked off the channel between Sites 2 and 3. *Potamogeton pectinatus* formed dense mats within the water column and occurred in noticeably denser aggregations during the summer months, especially when little or no overtopping of the sand bar at the mouth had taken place. **cont.**

• **Site 4**	located 500 m south of the bridge, this site was characterised by the same surrounding vegetation and substratum as Site 3, but had less *P. australis* encroaching towards the centre of the channel. In the open water, *P. pectinatus* formed dense mats in certain areas, with filaments extending from the water to substratum surfaces.
• **Site 5:**	at the head of the estuary (400 m upstream from Site 4), near the confluence of the two rivers. The detrital-rich substrate supporting *P. australis* provided a good organic nutrient source resulting in the reed encroaching across the channel both to the north and south of the sampling site. *Potamogeton pectinatus* colonised during 1993, and grew steadily thicker during the entire sampling period (1992-1994).

Due to the lack of precipitation during this period, no flushing of the estuary occurred, thereby allowing aquatic plant invaders like the duckweed *Lemna minor* to proliferate. *Lemna minor*, was present in small aggregations among the reeds at Site 3. Towards the end of the project sampling period (winter 1994), *L. minor* had spread reaching Sites 2 and 5, and by spring 1994, had grown denser at Site 3.

3.2 Zoobenthos

3.2.1 Fieldwork

Samples were collected on a seasonal basis, and an attempt was made to sample at intervals of three months from 1992 to 1994 (Table 3.2):

Table 3.2: Zoobenthic and physico-chemical parameter sampling dates from the Siyaya Estuary, 1992-1994

	summer	autumn	winter	spring
1992	28/02/92	24/04/92	30/06/92	16/10/92
1993	02/02/93	19/04/93	09/06/93	13/09/93
1994	11/02/94	19/04/94	2/08/94	1/11/94

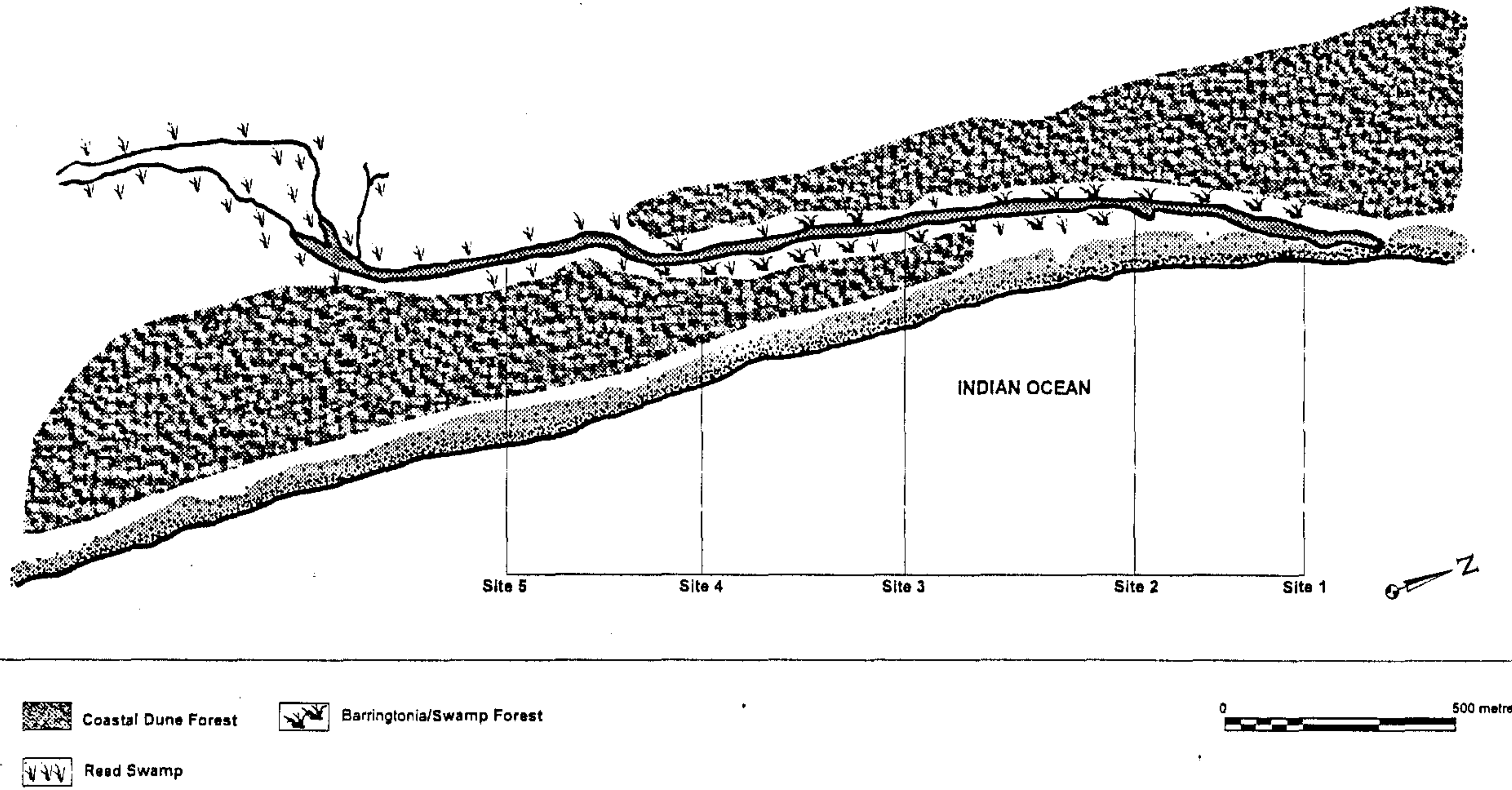


Figure 3.1: The Siyaya Estuary showing position of Zoobenthic and Physico-chemical Sampling Sites

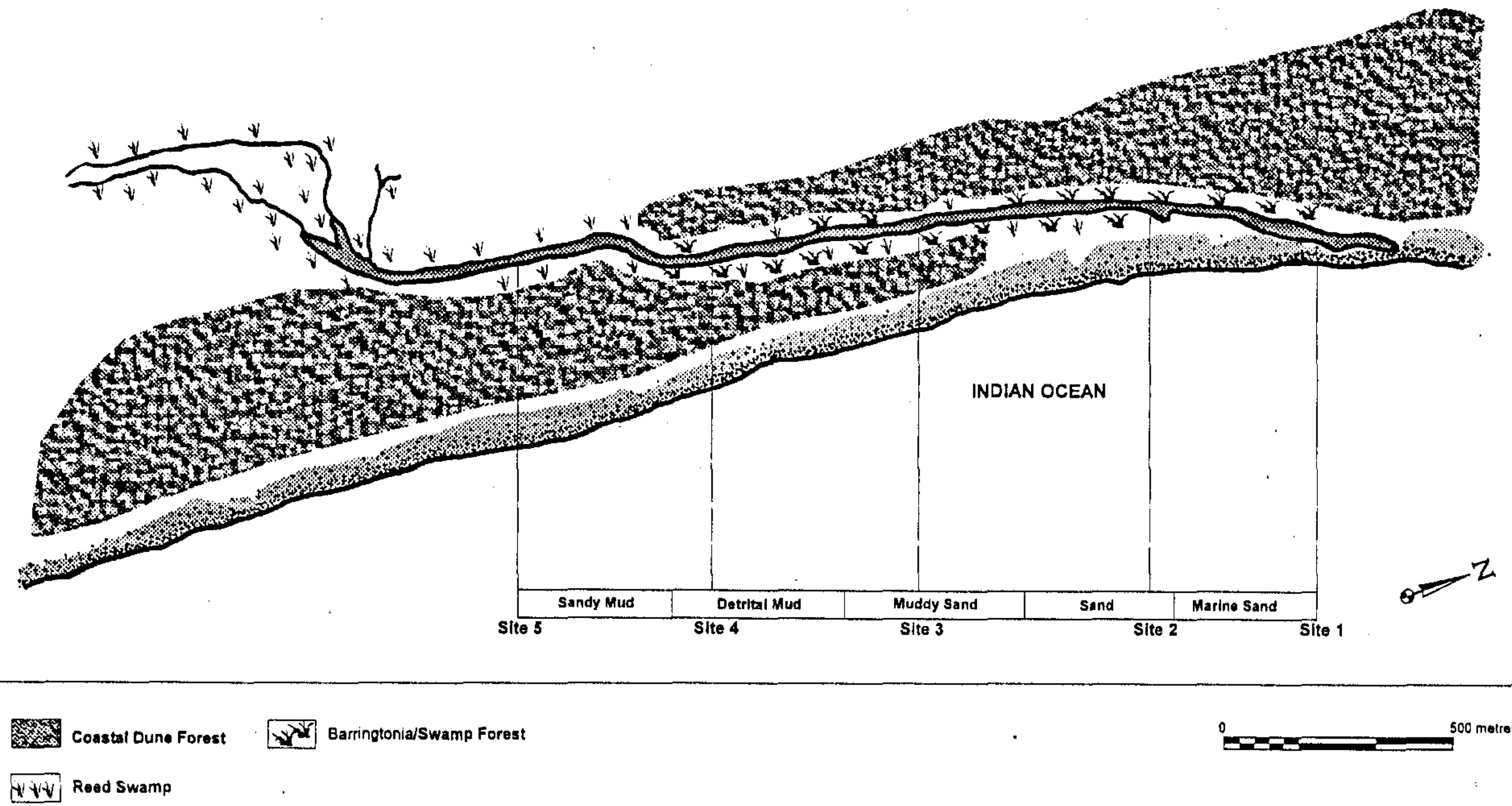


Figure 3.2: The Siyaya Estuary showing location and type of substrate in relation to Sampling Sites

During each fieldtrip, five random grab samples were taken at each of the five sites. This method previously used by other workers (Cyrus and Martin, 1988; Reavell and Cyrus, 1989) is known to provide a good species representation of an area. Each sample was collected using standardised techniques and equipment so that results were comparable.

3.2.2 Laboratory Analysis

Preserved samples were sorted, counted and identified to species level as far as possible using a Leica Wild stereo microscope (model M3Z) with 1.0 and 1.5 objectives together with 10X and 40X eyepieces. A Kyowa compound microscope (model Medilux 12) was used to identify parapodia on polychaetes, and count cilia and setae on all annelids. Taxon densities for each site were expressed as the number of individuals per square metre. Statistical and other analyses of zoobenthic samples are discussed in Chapter 5 (Zoobenthos of the Siyaya Estuary).

3.3 Physico-chemical Characteristics

3.3.1 Fieldwork

Each fieldtrip, 10 water samples were collected, two per sampling site (top and bottom) and put on ice for transportation to the laboratory, where turbidity levels were later determined. Other measurements, namely dissolved oxygen, depth, pH, total dissolved solids, conductivity temperature and salinity were obtained in the field. Additional water samples (in 1l plastic containers) were collected in the field at Sites 1, 3 and 5 for analysis (see Section 3.3.2) by Mhlatuze Water Board laboratories. The recommended container for all water samples was a 1l plastic bottle (polyethylene or equivalent), (Standard Methods, 1985).

One sediment sample was taken per site during the summer of 1992. A more detailed sediment study was conducted during 1994, whereby sediment samples were taken at each site, every season (at the same time as benthic samples).

3.3.2 Laboratory Analysis

These techniques, and a description of equipment used are set out in the Methods and Materials section of Chapter 4 (Physico-chemical Parameters of the Siyaya Estuary).

The three samples, collected for the purpose of measuring all other water chemistry parameters (ions and nutrients) were refrigerated (for short term preservation) and transported within 24 hours to the Mhlatuze Water laboratory where they were immediately analysed. Refrigeration is the recommended preservation technique, and 24 hours is the maximum time approved for storage in a refrigerator (Standard Methods, 1985). Samples collected for analysis in the department, were used to determine the top and bottom turbidity (NTU) from each sampling site.

All sediment samples were prepared for analysis of grain size properties and percentage organic content. The aim was to compare the differences of sediment properties at each site, over four consecutive seasons, and to determine if sediment samples collected during 1994 differed from the original samples collected during February (1992). All water and sediment samples were collected using standardised techniques and equipment so that results were comparable, and that statistical techniques could be applied.

A database of zoobenthos of the Siyaya Estuary on a seasonal and yearly basis was constructed to examine the effects (if any) of the appropriate physico-chemical characteristics, sampled within an identical spatial and temporal background.

4.0 PHYSICO-CHEMICAL PARAMETERS OF THE SIYAYA ESTUARY

4.1 Introduction

This section, is an introduction to all physico-chemical parameters measured in the Siyaya Estuary. The aim is to provide an outline of the current state of the water quality of the system, and the potential effect it has on the zoobenthos is presented in Chapter 6.

4.1.1 The Water

The composition of river water varies, and is dependent on the main source of dissolved salts derived from two main areas: sea salts added with precipitation, and weathering of rock by rain containing carbon dioxide (Dryssen and Wedborg, 1980). Dissolved constituents and particulate matter are then brought to the estuary where the river mixes (to a greater or lesser extent) with sea water. Generally, the major constituents of river water are calcium and carbonate, while sodium, magnesium, chloride and sulphate form the major part of dissolved sea water constituents (Dryssen and Wedborg, 1980).

4.1.1.1 Ionic Composition

There are eight ions present in large quantities in most fresh waters and sea water. These are divided into the cations: Na^+, K^+, Ca^{2+} and Mg^{2+}, and anions: Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-}. Na^+ and Cl^- predominate in sea water while Ca^{2+} and HCO_3^- predominate in most fresh waters (Day and King, 1995). The ionic composition of estuarine water generally reflects the ionic composition of diluted seawater, being dominated by sodium and chloride. Nitrate and Phosphate (even in clean estuaries) may be present in large concentrations from land run-off and can play a part in controlling plant growth. In dilute salinities, the supply of calcium increases (McLusky, 1974). Of the 35‰ salt content in seawater, about 29‰ is NaCl, the rest is mostly Mg, Ca and K salts. Seawater chemistry may be summarised as follows in Table 4.1:

Table 4.1: Proportions of anions and cations (‰) constituting seawater. (After Odum, 1971; Head, 1985).

Positive Ions:		Negative Ions:	
Sodium	10.8	Chloride	19.4
Magnesium	1.3	Sulphate	2.7
Calcium	0.4	Bicarbonate	0.140
Potassium	0.4	Carbonate	0.007
		Bromide	0.07
		Total	35.21

pH= 8.12

The main constituents of river water are sodium, potassium, magnesium, calcium, chloride, sulphate, hydrogen carbonate and silicon (Table 4.2). A distinction is made between waters of high and low alkalinity, as the formation of hydroxide and carbonate complexes is dependent upon these (Morris, 1985). Thus, the dominant feature controlling the distribution, speciation and reactivity of chemical components within estuaries is the mixing of fresh and saline waters (Morris, 1985).

Table 4.2: Concentrations of the main ionic constituents of standard low and high alkalinity river water (‰). (After Dryssen and Wedborg, 1980)

Positive Ions:			Negative Ions		
	Low	*High*		*Low*	*High*
Sodium	0.0069	0.0069	Chloride	0.0071	0.0071
Magnesium	0.0049	0.0007	Sulphate	0.0144	0.0144
Calcium	0.0228	0.0035	Bicarbonate		
Potassium	0.0025	0.0025	Carbonate		
pH	8.43	7.30			

4.1.1.2 Total Dissolved Solids (TDS), Salinity and Conductivity

The amount of dissolved material a sample of water contains is expressed as total dissolved solids (TDS), salinity or electrical conductivity (Day, 1990). At any point in an estuary, the salinity (measure of inorganic salts) is dependent on the topography of the system, the tide, the time of year (season, controlling rainfall etc.) and the extent of freshwater inflow (Day, 1990). Infaunal benthic animals spend most of their time in burrows, and are thus effectively sealed off from the overlying water. The range of interstitial salinity is considerably reduced in comparison with the range of salinity in the overlying water (Reid, 1930; McLusky, 1974). TDS (expressed as mg/l or g/l) is a measure of organic and inorganic dissolved salts and is affected by dissolved organic material (DOM) (Day, 1990). In fresh and brackish waters, measures of salinity and TDS may be used interchangeably. Conductivity (µS or mS/l @ 25 ^{o}C) is a measure of the concentration of ions and changes with changing pH (Day, 1990). Seawater has a salinity of about 35 g/kg or ‰.

4.1.1.3 Nutrients (P and N) in Estuaries

In shallow water systems, the internal nutrient loading from the sediment is often an important factor in eutrophication processes (van Raaphorst, Ruardij, and Brinkman, 1988). Exchange mechanisms exist between the sedimentary environment and overlying water in any aquatic system, and these are dependant on whether or not the sediments are disturbed (Vidal, 1994). The main nutrients in estuaries, have been identified as phosphates and nitrates. Nowicki and Nixon (1985) found that the release of nitrate and phosphate takes place from muddy sediments, while sandy sediments take up these nutrients. As temperature increases, the movement from muddy substrates increase, but not into sandy substrates. By calculating water column N/P ratios, it is possible to show which nutrient is limiting (Nowicki and Nixon, 1985). Nitrogen limitation is commonly associated with marine systems (Nowicki and Nixon 1985; van Raaphorst *et al.*, 1988). High levels of nitrogen and phosphorus encourage dense growth of microplankton, causing decreased light levels, death of plankton, decay and thereby depleting oxygen supply (Kunishi and Glotfelty, 1985).

4.1.1.3.1 Phosphorus

Phosphorus is transported to estuaries as minerals in suspended detritus and dissolved phosphate in river water. Phosphorus is released through weathering of the Earth's crust, domestic sewage and detergents, fertilisers and industrial effluent disposal (Head, 1985). Essentially, all phosphorus present in the aquatic environment is in the +5 oxidation state, as various forms of phosphate (Head, 1985). Studies have shown that phosphate buffering by solution-mineral reaction also occurs in estuarine environments (Aston, 1980). Depending on the phosphate concentration and the mineral surface area available (for adsorption), adsorption decreases with an increasing salinity. Phosphate removal from suspension will be greater in fresh and brackish waters (pH=3-8), than in sea water (pH=8.1) (Aston, 1980). In the course of incorporation into biological tissue, much phosphorus is incorporated into poly- and organophosphates (Head, 1985). Thus, for the purposes of this study, orthophosphates (inorganic) and total phosphates (including organic states) were measured. The natural biogeochemical cycle of phosphorus in estuaries is summarised in Figure 4.1.

It is expected that the contribution of phosphate from sewage is more important in the estuarine environment than in the open sea, and that the rate of biological cycling is dependent on environmental factors which can change in a short time compared with the open oceans (Aston, 1980). Dissolved phosphate concentrations in many estuaries are maintained within a narrow range by adsorption/desorption reactions involving particles (the 'buffering effect'). The capacity of sediment surfaces to adsorb phosphate leads to short term competition between sediment particles and the availability of this nutrient to bacteria and algae, and may supply a significant fraction of the nutrients required by these primary producers (Callender, 1982; Vidal, 1994). This in turn may develop into circumstances where benthic community structure may change due to the availability of food. This is particularly true of phosphate dynamics tied to sediment disturbances elucidated in a study conducted by Vidal (1994).

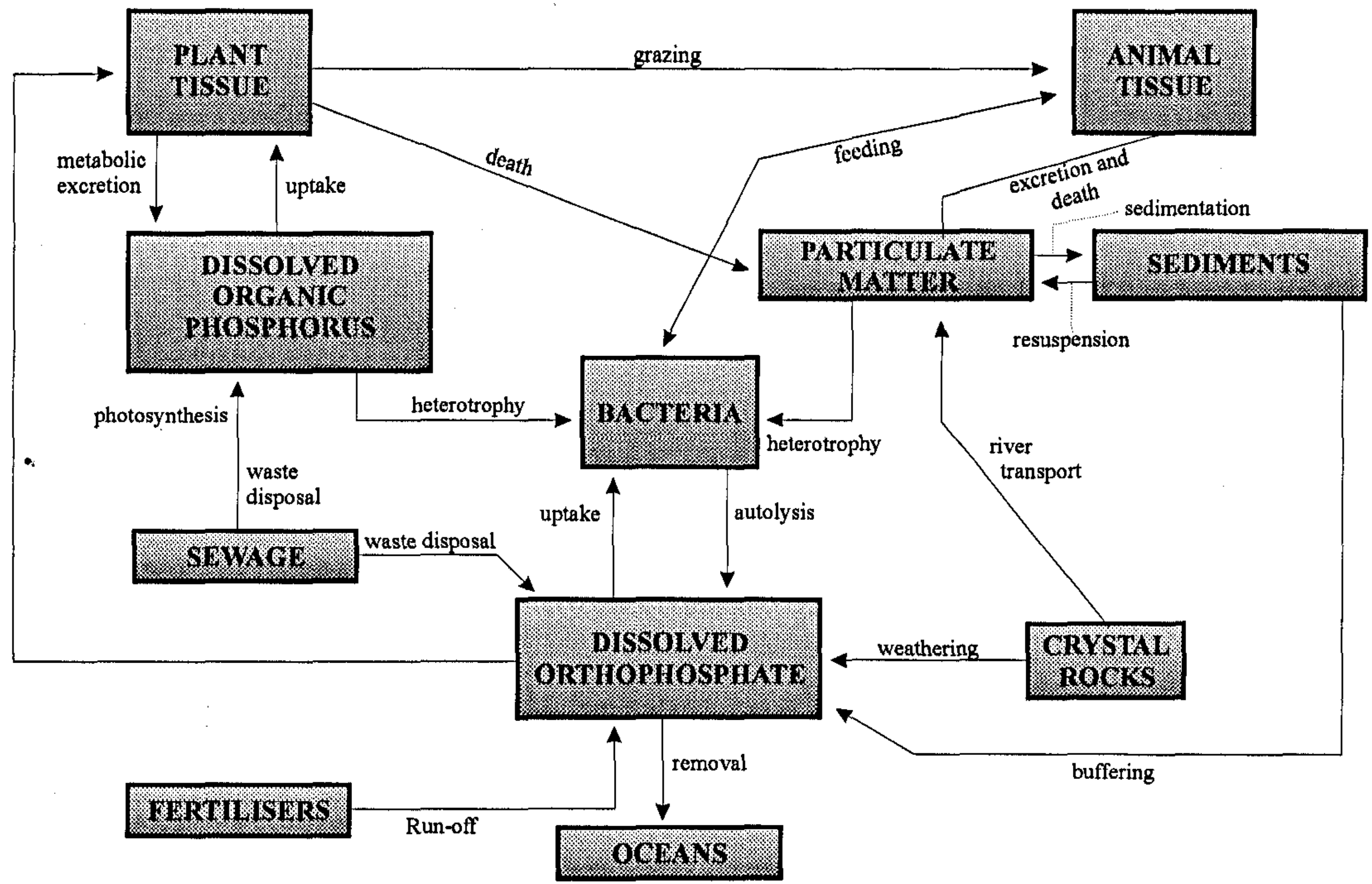


Figure 4.1: The phosphorus cycle in the estuarine environment. (After Aston, 1980)

4.1.1.3.2 Nitrogen

Nitrogen is supplied in both molecular and combined forms to estuaries. The main form of combined nitrogen is dissolved nitrate, derived from rock weathering and pollution sources such as the application of nitrogenous fertilisers to agricultural land (Aston, 1980). Inorganic controls of nitrogen seem to be restricted by physical processes occurring in estuaries. Figure 4.2 represents the biological cycling of nitrogen in estuaries.

The most abundant form of nitrogen in estuaries is as the elemental gas, derived from the atmosphere (Aston, 1980). Other forms are nitrates, nitrites, ammonia and organic nitrogen compounds. It is these latter forms that are involved to any extent in biological processes (Head, 1985). Furnas, Hitchcock and Smayda (1976) have shown that nitrogen supply to estuaries is important for primary production. They investigated the nutrient-phytoplankton relationships in Narragansett Bay and found that high levels of production require frequent replenishment of nitrogen both *in situ,* and from external sources. As primary production is often limited by nitrogen, the availability of nitrogen supply to aquatic coastal systems is important (Forès, Christian, Comín and Menendez, 1994). The rate of exchange or benthic flux of inorganic nitrogen species in shallow water plays a major role in controlling their concentrations, and release of NO_3^- and NH_4^+ from sediments can thus potentially supply from 30-100% of the annual nitrogen requirement for primary producers in coastal areas (Jensen, Lomstein and Sørensen, 1990). Benthic nutrient exchange is largely determined by the rate of detritus sedimentation and decomposition in the sediment and the rate at which the nutrients are transported to or from the overlying water by diffusion and bioturbating infauna (Jensen, *et al.*, 1990).

4.1.1.4 Chlorophyll 'a'

The photosynthetic production of organic matter by phytoplankton is made possible by the assimilation of inorganic nutrients (P and N) from surrounding water (Ryther and Dunstan, 1971). Mazumder (1994a) discussed the direct relationship between chlorophyll '*a*' (Chl) concentrations and densities of *Daphnia* in north and south

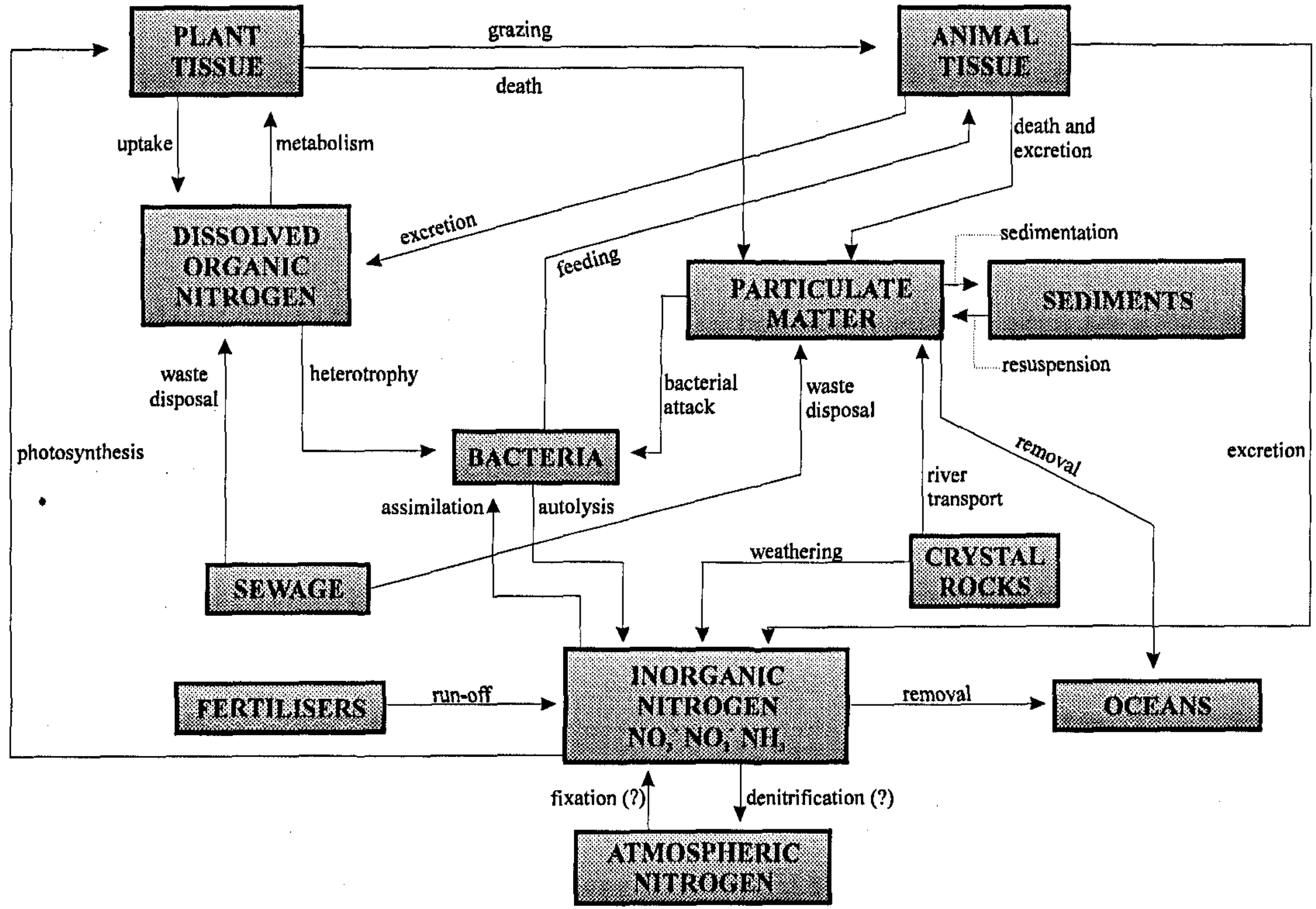


Figure 4.2: The nitrogen cycle in the estuarine environment. (After Aston, 1980)

temperate, and Antarctic zones as compared to systems without herbivorous grazers such as cladocerans. In experimental situations, it was found that in enclosures where *Daphnia* was eliminated by planktivorous fish, additions of nutrients (1 g $P \cdot m^{-2} \cdot yr^{-1}$, 13 g $N \cdot m^{-2} \cdot yr^{-1}$) produce higher Chl yields than in enclosures where *Daphnia* are abundant (Mazumder, 1994a). As expected, there is a strong relationship between total phosphorus levels and Chl. Mazumder, (1994b) related experimental work to the strong interaction that may exist between nutrients and herbivory, in controlling algal biomass.

4.1.1.5 Dissolved Oxygen and Chemical Oxygen Demand (COD)

Ample supplies of oxygen enter estuaries (that are connected to the sea) through both freshwater and saltwater. The precise concentration of the supply depends on temperature, salinity and the amount of evapotranspiration at the water surface (McLusky, 1974). Oxygen concentrations in estuaries are strongly influenced by biological cycles, namely natural biological consumption and oxidation of pollutant organic matter, if any (Aston, 1980). The oxygen resources of a body of water are usually taken as a critical indicator of the quality of that water body. A discharge of material with an oxygen demand, may be damaging to the oxygen resources of the receiving water body (Benedict, 1977). The typical oxygen content of natural waters is equivalent to 11 mg/l, and it is recommended that levels should not fall below 4 mg/l in estuaries for the protection of biological resources (Benedict, 1977). The standing crop of aerobic and heterotrophic bacteria within estuarine sediments, is also important in terms of the oxygen demand of the entire system (Aston, 1980). In general, the upper portion of the water column is dominated by photosynthetic, oxygen-producing activities and those at the bottom by oxygen-consuming, respiratory processes. There is an important influence of both biological and physical factors on dissolved oxygen (DO). The level of DO in a closed system is a suitable way of monitoring the effect of biological (chemical) processes. That is, in closed bottles under experimental situations, any fluctuations in levels observed would then be attributable to the biological effect. (Kemp and Boynton, 1980).

Seasonal depletion of oxygen or anoxic/hypoxic conditions (O_2<2 mg/l) have been reported for a number of estuarine and coastal systems, particularly during the summer months (Diaz, Neubauer, Schaffner, Pihl and Baden, 1992; Kemp, Sampou, Garber, Tuttle and Boynton, 1992). Diaz, *et al.* (1992), studied the prolonged effects of hypoxia in terms of it posing a threat to the ecological balance of these ecosystems, as well as short term effects on macrobenthic behaviour. Kemp *et al.* (1992), suggested that it is the combined effects of spring increases in both biological (respiration) and physical (stratification) processes which lead to summer depletion of bottom water O_2 in partially-stratified, temperate coastal systems. This, in many cases, is also coupled with the anthropogenic inputs of nutrients into coastal waters (Kemp *et al.*, 1992). Nutrients are primarily borne in coastal runoff, and have a direct relationship with the increase in phytoplankton and algal growth which in turn causes a rapid depletion of bottom water O_2 (Kemp *et al.*, 1992).

4.1.1.6 Temperature

Sub-tropical conditions enhance the growth rate of many organisms, since metabolism and growth rate are typically temperature regulated (McLusky, 1974). Due to its effects on the density of water, temperature plays an important role in the mixing processes between seawater and freshwater that occur in estuaries (Blaber, 1980). Many animals are also sensitive to the temperature fluctuations that take place in shallow estuaries (Blaber, 1980).

4.1.1.7 Turbidity

The turbidity of water, is largely determined by the nature of the substrate, depth and flow rate (Blaber, 1980). Surveys of waterbodies around South Africa have revealed that turbidity levels are high and play a major role in determining the nature of ecological interactions in these systems (Bruton, 1988; Cyrus, 1988). Increased turbidity levels are a conspicuous result of alteration to landscape, with soil erosion being the major cause - a reason for integrated catchment management (Bruton, 1988). Invertebrate fauna are sensitive to different turbidity levels and systems may constitute species that are either sensitive or unresponsive to high numbers of suspended particles (Cyrus, 1988). Cyrus

(1988) discussed the connection between river inflow, substrata, tides and wind in affecting turbidity. The four turbidity regimes reported by Cyrus (1988) are as follows:

1. **Clear systems**: Mean turbidities <10 NTU. Substratum variable, but predominantly 'sandy'.
2. **Semi turbid systems:** Mean turbidities 10-50 NTU. Substratum variable, but usually of both 'sandy' and 'muddy' components.
3. **Predominantly turbid systems**: Mean turbidities 51-80 NTU. Substratum predominantly 'muddy' with 'sandy' components.
4. **Very turbid systems:** Mean turbidities >80 NTU. Substratum generally 'muddy'.

Cyrus (1988) stated that some systems falling into regimes **2** and **3** close for periods during each year thereby commonly displaying reduced turbidity levels, but these rise again as these systems open during times of flood.

4.1.2 Biotic Aspects of Estuarine Chemistry

The generally higher densities of benthic organisms in estuaries compared with the sea has an effect on estuarine chemistry, through their role as consumers and by reworking the sediment. These activities have an effect on the chemistry of the overlying water, as well as on the turbidity of the bottom waters, as mud becomes suspended (Wolff, 1980). In response to a severe lowering of oxygen levels, a situation where there is a reduction in faunal numbers and mortality can be expected. Wolff (1980), reported this only taking place under persistent hypoxia at high summer temperatures. Behaviour of invertebrates might also be modified by moving to the sediment surface where they are more vulnerable to predation (Diaz *et al.*, 1992). Rosenberg, Loo, and Möller (1992), have shown that some infaunal benthic species are able to tolerate O_2 concentrations between 0.5-1.0 mg/l for a period of weeks in undisturbed sediments. However, once having reached a threshold concentration (the concentration depending on the species studied), these animals migrated to the sediment surface where they remained exposed. In several studies, workers have agreed that the critical lower O_2 concentration for survival of most benthic macroinfauna species is around 2 mg/l (Rosenberg *et. al.*, 1992)

4.1.3 Sediments

Geologically, estuaries are temporary structures with the history of each system being largely determined by its sediment supply (Postma, 1980). The primary sources of sediments deposited into estuaries are through land runoff, coastal erosion, and small amounts are transported through the atmosphere (Postma, 1980). Long-term changes in sediment supply can be attributed to deforestation or reforestation of the river drainage area, and by soil erosion through urban development plans (Roberts and Pierce, 1976). As sediment deposition is controlled by the speed of currents and the sediment particle size more is deposited in estuaries than is carried out to the open sea. This is because small particles sink slower than coarse particles, thus as a tidal current enters an estuary and slackens speed, it will first deposit gravel, then sand and silt. Similarly, this happens in the upper reaches of the estuary, with the inflow of river water, and the deposition of silt to form muds (McLusky, 1974).

4.1.3.1 Modification of sedimentation properties

Sizes of particles introduced into an estuary may vary considerably, and in general those in suspension are within the 1 to 10 micron size range (Postma, 1980). Residence time of these particles within estuaries is generally long (Postma, 1980). That is, longer than the water mass that changes with the tides in an open estuary and in the case of the Siyaya, will remain there for extended periods, until the mouth opens and there is scouring of the estuary bed (during severe flooding). During this period within the estuary, sediment particles are subject to processes of flocculation and biological grain size changes. The process of flocculation may briefly be described as follows: Clay particles and hydroxides are flocculated by inorganic salts of sea water and these increase to sizes of several hundred microns in quiet water (Gray, 1981). Although the Siyaya Estuary is at present a fairly fresh system, it is subject to slight variations in salinity, depending on season, and whether overtopping of the sand bar at the mouth takes place. Depending on the salinity in the mid to upper reaches, flocculation of bottom sediments may be an important consideration when determining particle sizes of sediments in a particular sampling site by grain size analysis.

4.1.3.2 Detritus as an organic source in sediments

Simply defined, detritus is all particulate dead organic matter still containing chemical energy which may be used by organisms. Origins are dead animals, exoskeletons, faecal matter and dead plants (especially macrophytes) (Wolff, 1980). As previously mentioned, this becomes important in the case of the Siyaya with vast reedbeds, and the colonisation of other aquatic macrophytes such as *P. pectinalis* and *L. minor*. Detritus feeders are found amongst all invertebrate and vertebrate groups and detritus serves as a constant and stable food source comparative to the seasonal dependence of primary productivity (Wolff, 1980).

4.2 Methods and Materials

4.2.1 Water Physico-chemical Variables: 1992 - 1994

4.2.1.1 Fieldwork

4.2.1.1.1 Depth

The depth at each sampling site was measured (m) using a graduated plumbline, with intervals every 20 cm.

Top and bottom measurements were made of the following variables: temperature, oxygen, salinity and turbidity. Top measurements were taken approximately 10 cm below the estuary surface, and bottom measurements were taken just above the sediment boundary layer.

4.2.1.1.2 Temperature

The water temperature (°C) at each sampling site was recorded to the nearest 0.5 °C, using a WTW Microprocessor Oximeter (Model OXI96), with a detachable probe.

4.2.1.1.3 Dissolved Oxygen

Dissolved oxygen levels (mg/l) were recorded at each sampling site with a WTW Microprocessor Oximeter (Model OXI96), with a detachable probe.

4.2.1.1.4 Salinity

Salinity (‰) was recorded at every sampling site using an American Optics, temperature-compensated Optical Refractometer, accurate to 0.5‰.

4.2.1.2 Laboratory Analysis

4.2.1.2.1 Turbidity

Top and bottom turbidity measurements were obtained in the laboratory using water samples collected at sampling Sites 1-5 during each season (Section 3.3.1: General Methods and Materials). Equipment used was a Hellige Digital Direct Reading Turbidimeter (1992-1993) and a Hach Turbidimeter (Model 2100A) during 1994. Both measured turbidity in Nephelometric Turbidity Units (NTU).

4.2.2 Seasonal Water Quality: autumn 1994 - winter 1995

4.2.2.1 Fieldwork

pH, total dissolved solids and conductivity were measured in the field together with the other physico-chemical variables (4.2.1). These were measured at each sampling site every season, from autumn 1994 to winter 1995.

4.2.2.1.1 pH

pH was measured using a hand-held Mettler Toledo Microcep microprocessor with interchangeable probes for pH, dissolved oxygen, conductivity and total dissolved solids.

4.2.2.1.2 Total Dissolved Solids (TDS)

TDS (mg/l) was measured using a hand-held Mettler Toledo Microcep microprocessor with interchangeable probes for pH, dissolved oxygen, conductivity and total dissolved solids.

4.2.2.1.3 Conductivity

The conductivity at each sampling site was recorded in µS (units of micro siemens), using the microprocessor employed for measuring pH levels (4.2.2.1.1) and TDS (4.2.2.1.2), in the Siyaya Estuary.

4.2.2.2 Laboratory Analysis

4.2.2.2.1 Chemical Oxygen Demand (COD) as O_2 (mg/l)
4.2.2.2.2 Total Alkalinity as CaCO3 (mg/l)
4.2.2.2.3 Chlorophyll 'a' (µg/l)
4.2.2.2.4 Phosphates (mg/l)
4.2.2.2.5 Nitrates (mg/l)
4.2.2.2.6 Calcium as Ca (mg/l)
4.2.2.2.7 Chloride as Cl (mg/l)
4.2.2.2.8 Sodium as Na (mg/l)
4.2.2.2.9 Potassium as K (mg/l)
4.2.2.2.10 Magnesium as Mg (mg/l)

4.2.2.2.1 - 4.2.2.2.10 were measured from 1l water samples collected at Sites 1, 3 and 5 (Section 3.3.1: General Methods and Materials) and analysed by an independent laboratory (Section 3.3.2: General Methods and Materials).

Water quality sampling commenced in autumn 1994 and was originally to continue for the duration of one sampling year (four seasons). However, the sandbar at the mouth of the Siyaya Estuary was breached on 12/04/1995, and samples were collected the following day at points 5 m, 75 m and 150 m from the open mouth. Subsequent sampling trips were carried out to compare the estuarine water quality parameters in both mouth closed and open phases, using identical sampling sites, equipment and methods as those used for the measurement of the water quality characteristics during the first part of the study (1994). For the purposes of this study, only samples up to winter 1995 (excluding autumn 1995) are considered.

4.2.3 Statistical Methods used in the Analyses of water samples

Since top and bottom measurements were taken for several physico-chemical parameters, these were put through a Two Sample Analysis (*t*-test), using the statistical programme

STATGRAPHICS, version 6 (Statistical Graphics Corporation). The resultant *t*-statistic estimated whether the H_o (null Hypothesis) that the means (at the 99% confidence interval), and the variances (at the 95% confidence interval) of the two samples (top and bottom) were the same.

Maucha's (1922) technique for the graphical representation of the water quality data was used on data from the Siyaya Estuary. This was used to compare ionic, pH, TDS and conductivity levels at the different sites for each season including those samples taken on 13/04/95 during the mouth open phase. The program for transforming the raw data was supplied by M. J. Silberbauer[2], and the final product of the program produces a radial graph of the relative ionic concentration of each water sample. Essentially, these diagrams are graphical representations of the proportional concentrations of the major ions (Day and King, 1995). A diagram consists of a circle divided into eight equal sectors, each representing a major ion. Each sector may or may not bear a quadrilateral, whose area is proportional to the molar concentration of that particular ion (Day and King, 1995). Each ionic diagram is then comparable to the 'global mean' freshwater and seawater values as given by Silberbauer and King (1991). The chemical composition of surface water may be divided into three groups according to the mechanisms controlling ionic dominance (Silberbauer and King, 1991). These processes are rainfall, geological processes and evaporation, and crystallisation, with dominant Na^+ and Cl^- concentrations being characteristic of evaporation or rainfall. Where geological processes are the controlling factor, HCO_3^- is the dominant ion (Silberbauer and King, 1991).

Simple line graphs were constructed to show turbidity, depth, salinity, temperature and dissolved oxygen levels, to compare them at different sampling sites, seasons and years during the mouth open and mouth closed phases. In addition, box and whisker plots of the results of multiple analyses of variance (Multifactor ANOVAs) of each of the abovementioned variables were constructed to compare the spread of data. The spread was taken as those measurements during three consecutive years (1992-1994), over each season at every sampling site (1-5). This was to provide some indication of how the

[2] Hydrological Research Institute, Department of Water Affairs, Private Bag X313, Pretoria, 0001 South Africa

medians of the physico-chemical samples differed according to the three factors (site, season and year), as well as to determine the position of outliers within the data.

The physico-chemical data from the Siyaya Estuary were also suitable for non-parametric analyses. Multivariate Spearman's rank correlation coefficients were calculated for each variable, to determine the effects (if any) of variables on each other. To represent this graphically, the data were grouped according to physico-chemical samples. That is 20 per year (1992-1994), separated according to five per season (one per sampling site). The same data were then grouped according to a particular physico-chemical variable. Hierarchical Agglomerative Clustering was then applied to these two data sets, using Normalised Ranked Euclidean Distance through the programme *PRIMER* (Clarke and Warwick, 1994). Refer to Chapter 5: Results, for details on the programme. Similar distances of '10' and '5' were marked off as lines running across both the sample cluster, and the variable cluster dendrograms. Normalised Euclidean Distance is the similarity measure recommended by Clarke and Warwick (1994) for environmental data on physical and chemical variables, as normalisation gives each variable equal importance (Clarke and Warwick, 1994). This suited the physico-chemical data from the Siyaya Estuary, as variables were measured on different scales and in different units, as well as having differing ranges.

To show that the clusters calculated and drawn in each dendrogram were true, non-metric Multidimensional scaling (MDS) using *PRIMER* (Clarke and Warwick, 1994) was performed on the data. Dissimilarity distance lines were drawn around groups with dissimilarities of '10' and '5', respectively. The resultant MDS graphic is a 2D representation of multiple random generations through multidimensional space. The techniques and background theory of this are explained in Chapter 5 (Zoobenthos of the Siyaya Estuary). MDS was used to analyse the environmental data in place of Principal Components Analysis (PCA), which has previously been used to describe environmental data (Pearson, 1975). The reason being that the abiotic data were later used to describe the biotic data in terms of spatial and temporal differences in distribution (Chapter 6), and this required that the data had been pre-analysed in a similar manner.

4.2.4 Sediment Analysis

4.2.4.1 Fieldwork

All sediment samples were collected from the Siyaya Estuary during each scheduled zoobenthic sampling trip (Section 3.3.1: General Methods and Materials). Samples were collected at each of the five sites during summer 1992. A comparative sediment study was conducted during 1994, to examine if sediment composition of sampling sites had altered, and if the grain size characteristics were different for each site, over a two year period. The study was subsequently lengthened to include sediment samples taken over different seasons. Therefore sediment samples available for analysis were collected during autumn, winter and spring of 1994 and summer 1995, to represent one full year of study. Each sediment sample was collected by means of a Zabalocki-type Eckman grab, which uniformly samples 0.0236 m^2 of the substratum to a depth of 4.5 cm. Subsequent to the collection of each sample in the field, 10% formalin was added to the sample, so benthic animals ceased to consume any detritus and other organic matter that may have been present in any of the samples, and also to prevent organic decomposition before they were analysed.

4.2.4.2 Laboratory Analysis

Grain size analyses and content of organic matter were carried out on all sediments collected from the Siyaya Estuary, as these are the most important characteristics of substrata as far as the biota are concerned (Morgans, 1956).

4.2.4.2.1 Grain Size Analysis

Sieving is the simplest way of separating medium-sized particles (Morgans, 1956), and as the sediments of the Siyaya Estuary had previously been reported as having a substrate of sandy/muddy origin this was the method employed (Oceanographic Research Institute, 1991).

Gray (1981), suggested that with macrofaunal studies, a single sample of 50-100g from a grab is widely used for assessing grain size. Therefore, subsamples of the original grab were weighed to approximately 75.00 g using a four digit balance. These samples were presumed large enough to yield statistically meaningful results. That is, they were 'large' relative to the largest particle size present (Lewis, 1984). As the samples were suspected of having a mud fraction, they were analysed according to the 'wet-sieving' method. That is, the subsample (±75.00 g) was placed on top of a series of graded sieves each corresponding to a particular square mesh size. These decreased geometrically according to the Wentworth scale which is described as follows (after Morgans, 1956; McLusky, 1974; Lewis, 1984):

64 - 4 mm	=	pebble
4 - 2 mm	=	granule
2 - 1 mm	=	very coarse sand
1 -0.5 mm	=	coarse sand
0.5 - 0.25 mm	=	medium sand
0.25 - 0.125 mm	=	fine sand
0.125 - 0.0625 mm	=	very fine sand
0.0625 - 0.0039 mm	=	silt
<0.0039 mm	=	clay

Each sediment grain size may be described in either mm or phi units. These scales are related according to the equation: **phi = -log₂ (mm)**, and data are converted to phi units before calculation of grain size parameters (Environmental Protection Agency, 1992). Therefore for the purposes of this study, sieves decreased as follows:

Mesh diameter (mm)	phi value
2.000	-1.00
1.400	-0.49
1.000	0.00
0.500	+1.00
0.250	+2.00
0.125	+3.00
0.063	+3.99
subsieve fraction	+4.00 - ...

The dry weight (80°C, 24 hours) of the sediment fraction retained in each sieve, after gently washing with water was recorded to the nearest 0.0001 g. The dry weight (80°C, 24 hours), of the subsieve fraction was also recorded. The subsieve fraction is a 25 ml aliquot of the sediment/water mixture that passes through the final sieve (0.063 mm) into a 3l container.

4.2.4.2.2 Percentage Organic Content

To determine the organic content of each sediment sample, a subsample of the original grab was oven dried (60°C, 24 hours) to remove any moisture and weighed to the nearest 0.0001 g. Samples were then transferred to crucibles, and incinerated at 600°C for a minimum of 6 hours. The percentage organic content was determined by reweighing samples after incineration. According to the United States Environmental Protection Agency (1991), the percentage organic content of sediment samples may be classified as follows:

Very Low	=	**<0.5%**
Low	=	**0.5 - 1.0%**
Moderately Low	=	**1.0 - 2.0%**
Medium	=	**2.0 - 4.0%**
High	=	**>4.0%**

This classification was adopted for sediment samples collected from the Siyaya Estuary.

4.2.5 Statistical and other methods used in the analysis of sediment Samples

The cumulative dry weights of all sediment fractions were plotted against phi values (Morgans, 1956; Gray, 1981; Lewis, 1984). From this the median phi value (phi at 50%) and sorting co-efficients were determined. Sorting is a measure of the spread of grain distribution (Environmental Protection Agency, 1992) and was calculated according to the preferred method of Gray (1981). This is the Inclusive Graphic Standard Deviation given by:

$$\frac{phi@84\% - phi@16\%}{4} + \frac{phi@95\%-phi@5\%}{6.6}$$

The sorting classes produced by the index are:

Very well sorted	=	**under 0.35 phi**
Well sorted	=	**0.35 - 0.50 phi**
Moderately well sorted	=	**0.50 - 0.71 phi**
Moderately sorted	=	**0.71 - 1.00 phi**
Poorly sorted	=	**1.00 - 2.00 phi**
Very poorly sorted	=	**2.00 - 4.00 phi**
Extremely poorly sorted	=	**Over 4.00 phi**

(After Gray, 1981)

Mean values of the median particle diameter, sorting co-efficient and percentage organic content of the sediment were obtained by combining data. The percentage silt versus the percentage organic content was plotted as a regression curve, to establish whether there was a significant relationship between the two. These data were subsequently analysed using *PRIMER* (Clarke and Warwick, 1994) as described in Section 4.2.3, to obtain a dendrogram and plot of the 2d non-metric multidimensional scaling ordination of the relationship between sediment samples. It was hoped that this would reaffirm the classification of sampling sites in the Siyaya Estuary, according to the different sediment characteristics (median particle diameter, sorting co-efficient and percentage silt).

4.3 Results

4.3.1 Water Physico-chemical variables:

Seasonal measurements of depth (m), temperature (°C), turbidity (NTU), oxygen (mg/l) and salinity (‰) at each sampling site, during mouth open and closed phases are given in Figures 4.3 to 4.7. Although results of a Two Sample Analysis (*t*-test), revealed that top and bottom measurements of salinity and oxygen were not significantly different ($p>0.05$), top and bottom temperatures and turbidities were significantly different during some seasons over the three year period ($p<0.05$). Therefore for the sake of uniformity, values were not collated and the means of these measurements were not used.

The depth of the Siyaya Estuary did not exceed 2.8 m during the study period. The mean depth from 1992 to 1995 was 1.6 m (standard error = 0.06; Figure 4.3). The system was at its deepest during summer 1994, which coincided with rain that fell in the catchment at that time. The estuary was uniformly shallow in it's upper and lower reaches, with the head of the estuary (Site 5) decreasing slightly in depth from summer through to spring. Generally, the trend was a stable average depth for each year, which only slightly fluctuated around the mean, as a result of the prevailing drought conditions in the area. Figure 4.3 shows that the middle reaches (Site 3) were generally more shallow than the other sampling sites. This was an area of increased sediment accumulation (*pers. obs.*), presumably due to the encroachment of thick stands of *P. australis* from both banks. *P. australis* closed off the channels, up- and downstream from the open water area around Site 3. During spring 1992, Site 3 was the deepest area within the Siyaya Estuary (2.7 m). At this time conditions may have been unfavourable for reed growth (usually during the winter months), and accumulated sediments trapped among roots could have been transported downstream to the lower reaches of the estuary (around Site 2), accounting for it's decrease in depth at that time. Depths measured at Sites 2 and 4 during spring 1992, and Site 3 during spring 1993 were below 0.4 m. Opening of the mouth did not significantly change the average depth of the estuary ($p>0.05$).

Water temperature (°C) did not differ greatly among sites or over the study period, but a seasonal effect is evident in Figure 4.4. During winter, temperatures were approximately 10°C - 12°C lower, compared with summer temperatures. The mean annual temperature of the Siyaya Estuary from 1992-1994 fluctuated between 26°C and 29°C. Water temperatures measured during summer 1995 were greater than 30°C (approximately 6°C greater than summer water temperatures measured during previous years), and a temperature of 37.5°C was recorded at Site 5. The air temperature corresponding to this water temperatures was 47°C at the time of sampling.

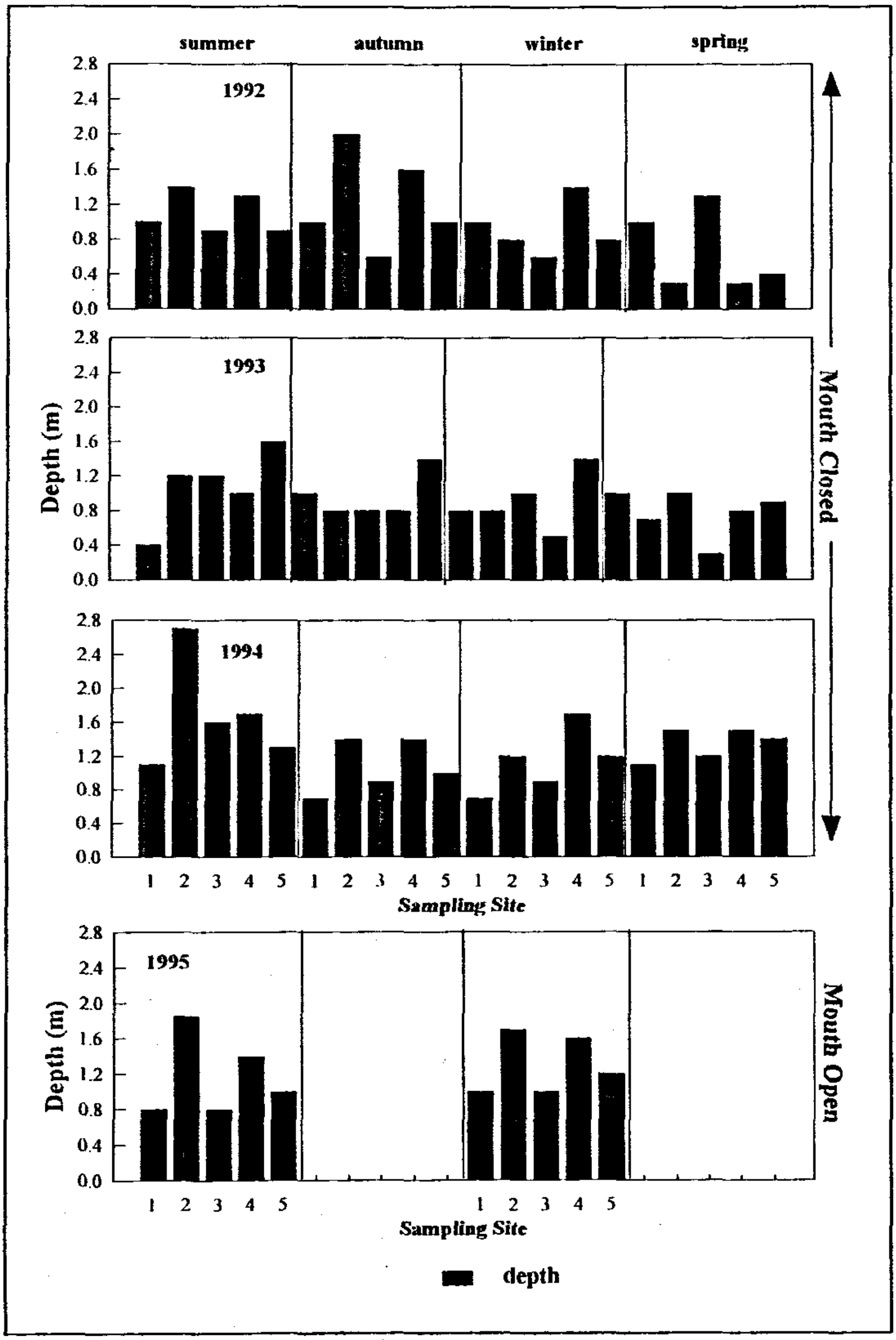


Figure 4.3: Seasonal variation in depth (m) of the Siyaya Estuary at sampling Sites 1-5, from 1992-1995 during mouth open and closed phases

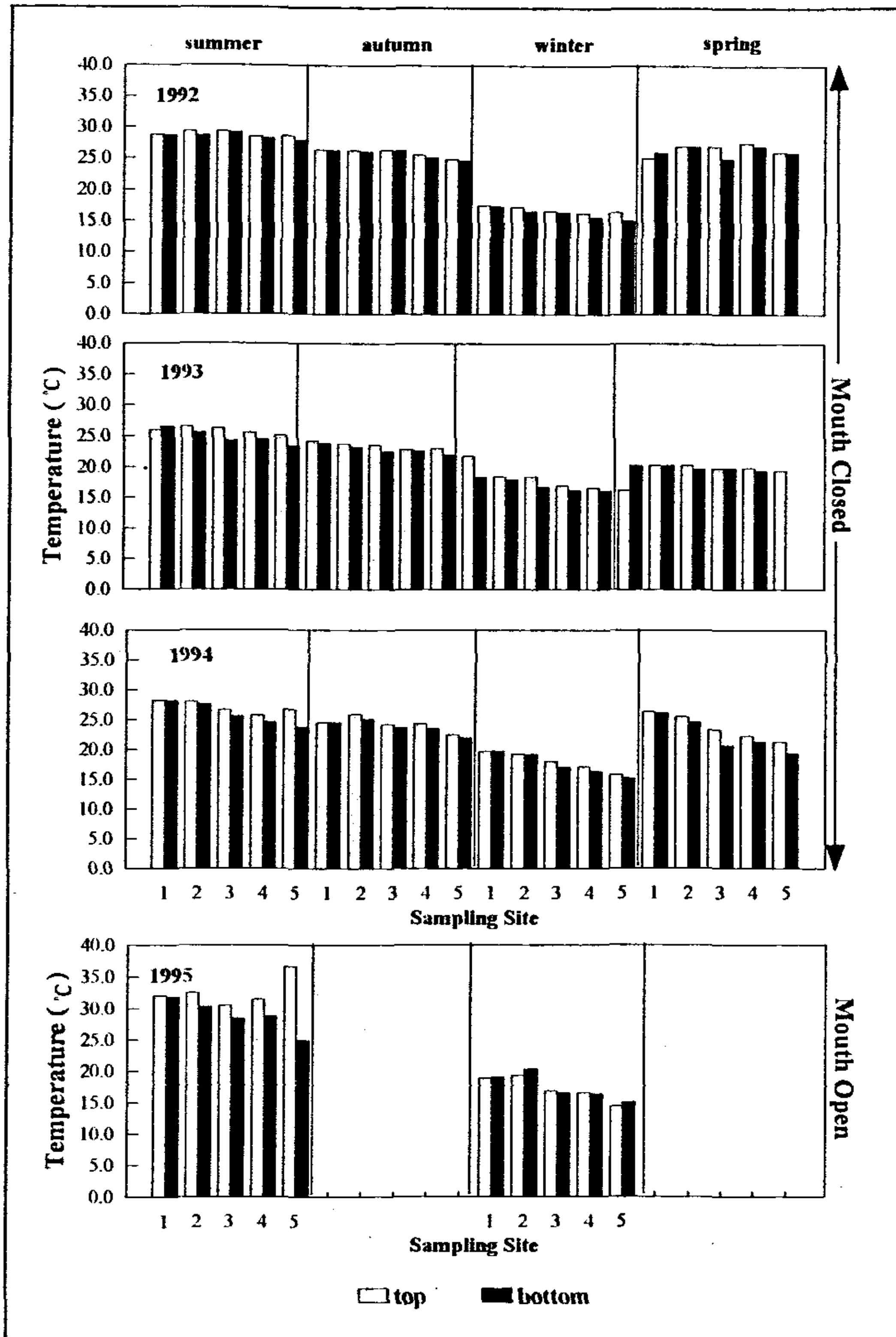


Figure 4.4: Top and bottom temperatures (°C)in the Siyaya Estuary at sampling Sites 1-5, from 1992-1995 during mouth open and closed phases

Top and bottom turbidity measurements (NTU) taken within the Siyaya Estuary decreased from the upper to the lower reaches, due to a decline in the amount of fine silt and debris in suspension from Sites 1-5 (Figure 4.5). The reason lies in the gradient of substrata occurring from head to mouth of the estuary, that ranges from detrital and sandy muds, to coarse-grained sands. *Phragmites* beds decreased the velocity of water entering the system via the upper reaches, and the clear seawater entering the lower reaches during periods of overtopping may also have been responsible for the turbidity gradient. The results obtained tended to support this, however Site 3 during autumn 1992 and 1993 did not conform to this particular pattern, as bottom turbidity measurements were more than 75 NTU. This corresponds well with the shallow nature of the Siyaya Estuary at Site 3, at that time. In terms of turbidity, the water within the Siyaya Estuary is generally well mixed. That is, top and bottom turbidity levels were approximately similar, and in those instances where bottom levels were greater, this was attributed to disturbances created during sampling. The mean turbidity (top and bottom), recorded in the Siyaya Estuary, over the entire sampling period was 12.6 NTU (standard error = 2.22). A range of turbidities existed (from 2-80 NTU) during the mouth open and closed phases.

Figure 4.6 indicates that marked seasonal changes in the dissolved oxygen content of water within the Siyaya Estuary were absent. However, a slight increase in dissolved oxygen levels was observed during winter. The overall increase of average dissolved oxygen for the entire system was >1.5 mg/l, as compared with the increase during other seasons. Over the entire study period, there was a clearly defined gradient of decreasing dissolved oxygen from the mouth to the headwaters. Dissolved oxygen levels were generally higher at Site 1, and decreased towards Site 5 in the upper reaches of the estuary. The causes of these phenomena may lie in the nature of the substrata, the availability of anaerobic bacteria to process detrital matter and the limited turnover of water. Site 5 was characterised by ooze with a sulphurous odour, denotative of anaerobic bacterial processes. Overall, the Siyaya system was not well oxygenated, especially at Sites 4 and 5 where the sediments were anoxic, detrital-rich, fine muds. Top measurements taken just below the water surface were generally slightly higher than those taken at the bottom of the estuary. The highest top measurement of dissolved oxygen was 14.0 mg/l at Site 1 during winter 1992. Bottom oxygen levels were never greater than 9 mg/l, and together both top and bottom measurements never exceeded 14 mg/l from 1992 to winter 1995.

Seasonal salinity values from 1992 to autumn 1995 are given in Figure 4.7. Over the study period, there was generally a gradient from Site 1 to Site 5, although no salinity exceeded 6‰. This was expected, as the influence of overtopping of the sandbar at the mouth during high spring tides, decreased towards the head of the system. During the winter and spring of 1992, spring of 1993 and autumn of 1994, the system was well mixed with uniform salinities of 2‰, 6‰, 0‰ and 0‰, respectively. From 1992 to 1994 (during the mouth closed period) the system became increasingly fresh, with salinity values declining to 0‰ in the upper reaches. The situation changed immediately after the sandbar at the mouth was breached, and salinity increased to over 2‰. The presence of a salt wedge in the estuary is evident from Figure 4.7. Bottom salinity reached 12‰ at Site 2 during autumn 1995, and the salinity at Site 5 increased to 2‰. This was the first instance since autumn 1993 that the salinity at this site rose above 0‰. During the mouth closed phase from 1992 to autumn 1995, the Siyaya Estuary was a well-mixed system with approximately uniform salinities at each sampling site. At this time, the estuary was almost a freshwater system, subject to little or no marine influence.

Draftsman plots were computed in the statistical programme *STATGRAPHICS*, before any univariate and multivariate statistics were performed on the data. These indicated which physical or chemical data transformations (if any) were appropriate. Transformations constitute changing the data to a root-root transformation (most severe), or a log transformation for example. The criteria for transforming data from a draftsman plot are that variables should not show marked skewness across the samples (enabling meaningful normalisation), and that relationships between them should be approximately linear (Manugistics Inc., 1992).

Figures 4.8 - 4.12 are Box and Whisker plots of depth, temperature, turbidity, oxygen and salinity measured in the Siyaya Estuary, 1992-1994. These plot the spread of data

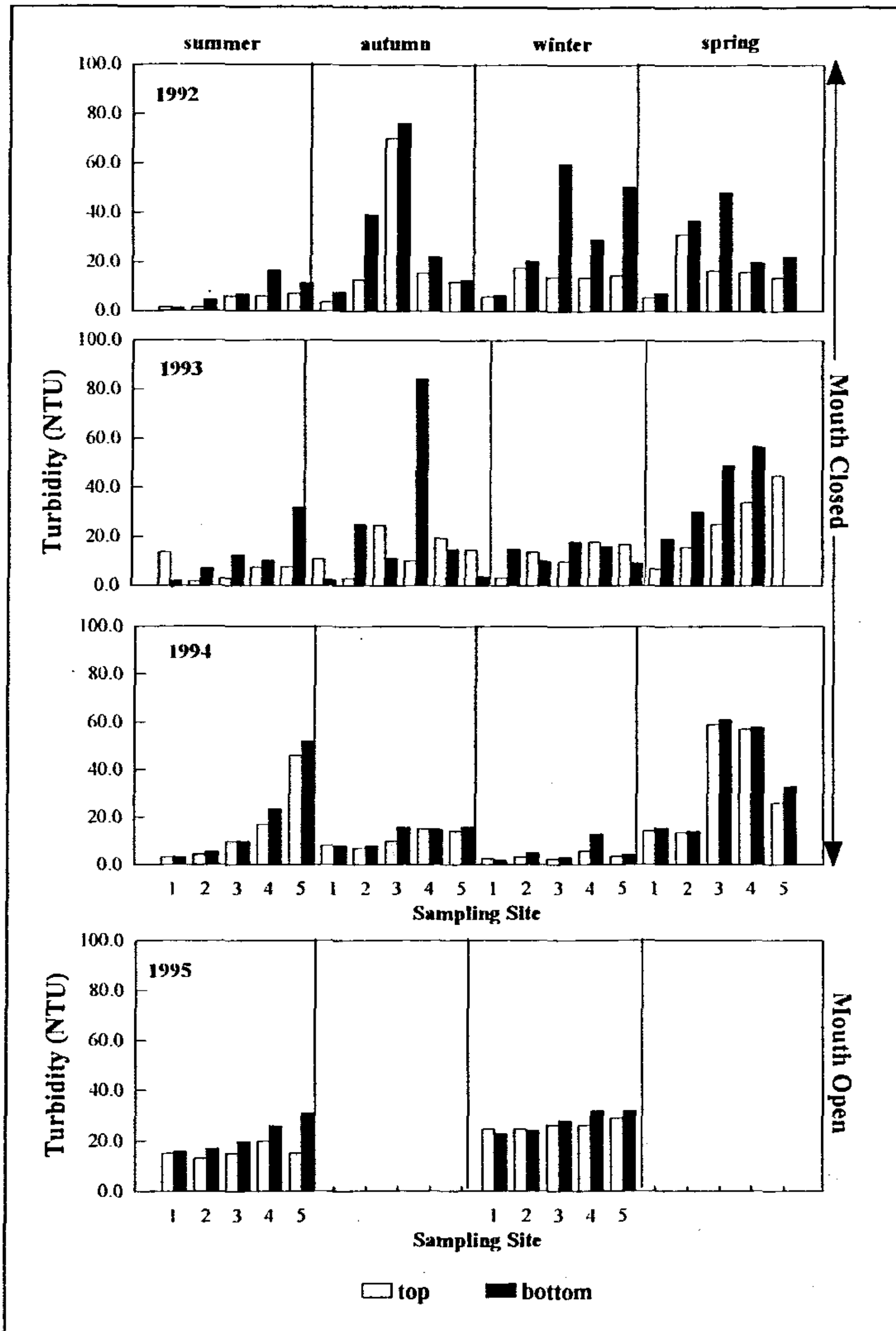


Figure 4.5: Top and bottom turbidity (NTU) of the Siyaya Estuary at sampling Sites 1-5, from 1992-1995 during mouth open and closed phases

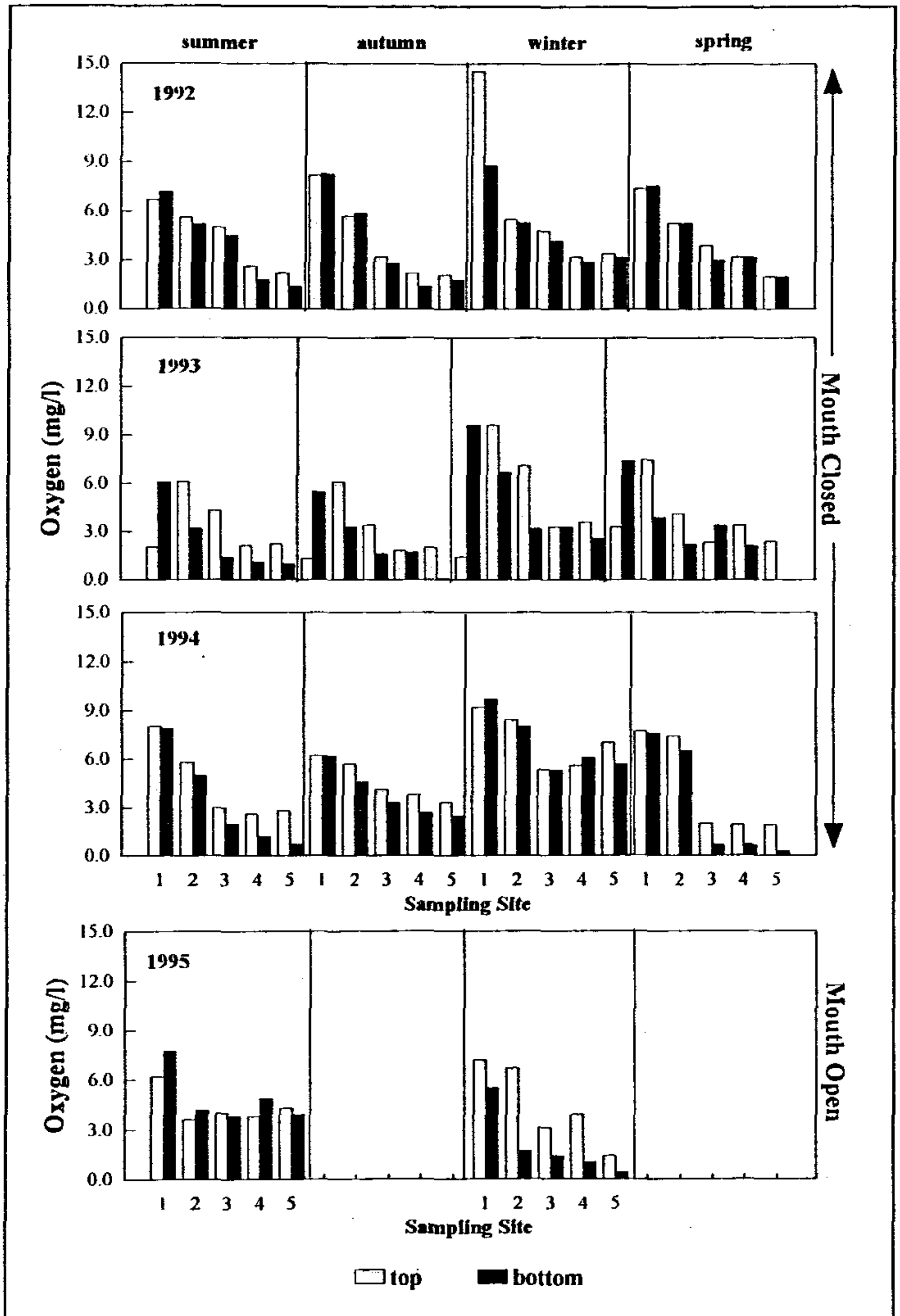


Figure 4.6: Top and bottom oxygen (mg/l) of the Siyaya Estuary at sampling Sites 1-5, from 1992-1995 during mouth open and closed phases

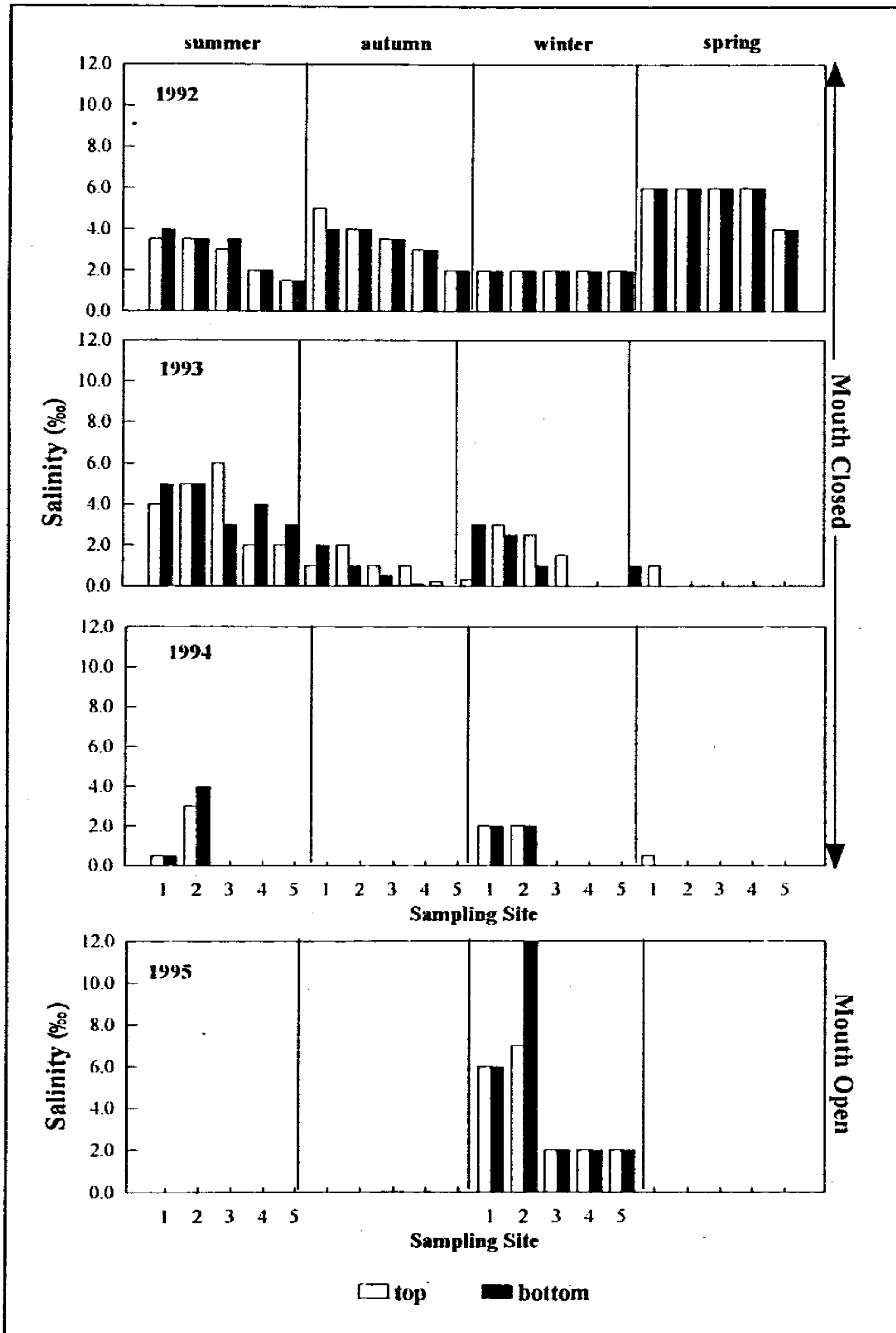


Figure 4.7: Top and bottom salinity (‰) of the Siyaya Estuary at sampling Sites 1-5, from 1992-1995 during mouth open and closed phases

over five sampling sites (1-5), four seasons (summer, autumn, winter and spring) and three years (1992-1994). Each diagram within a figure indicates how a particular variable changed according to a specific sampling site, season or year and identified outliers that were present in the physico-chemical data.

The median depths at Sites 1, 3 and 5 were similar, while those at Sites 2 and 4 were greater, 1992-1994 (Figure 4.8a). The spread of data was greatest at Site 2 (being the most variable) over the three consecutive years. An extreme value (2.7 m) was present above the spread of data at Site 2, while other extreme values occurred below the spread of data at sites 4 and 5. The variation of depth according to season was such that the multiple Box and Whisker plots had medians decreasing in value from summer to winter, and increasing to the highest value during spring (Figure 4.8b). Over three years, the spread of depth data measured in the Siyaya Estuary was such that the median values during 1992 and 1993 were almost identical while that in 1994 was slightly higher (Figure 4.8c). The depth values of the Siyaya Estuary, varied from those measured in either 1993 or 1994. The box and whiskers of 1992 data were also greater than the other two years.

Results of a Multifactor Analysis of Variance (model = season, year and site versus depth) indicated that the effects of season and site on depth were significant ($p<0.05$; 95% confidence for mean). There was also a highly significant relationship between the year and depth ($p<0.01$; 95% confidence for mean). The range of mean depths for season, year and site are shown in Table 4.3:

Table 4.3: Range of mean depths (m) for season, year and site with standard errors given below

DEPTH			
	SEASON	**YEAR**	**SITE**
Range	.92-1.33	.90-1.31	.90-1.30
Standard Error	.13-.09	.61-1.14	1.14-1.56

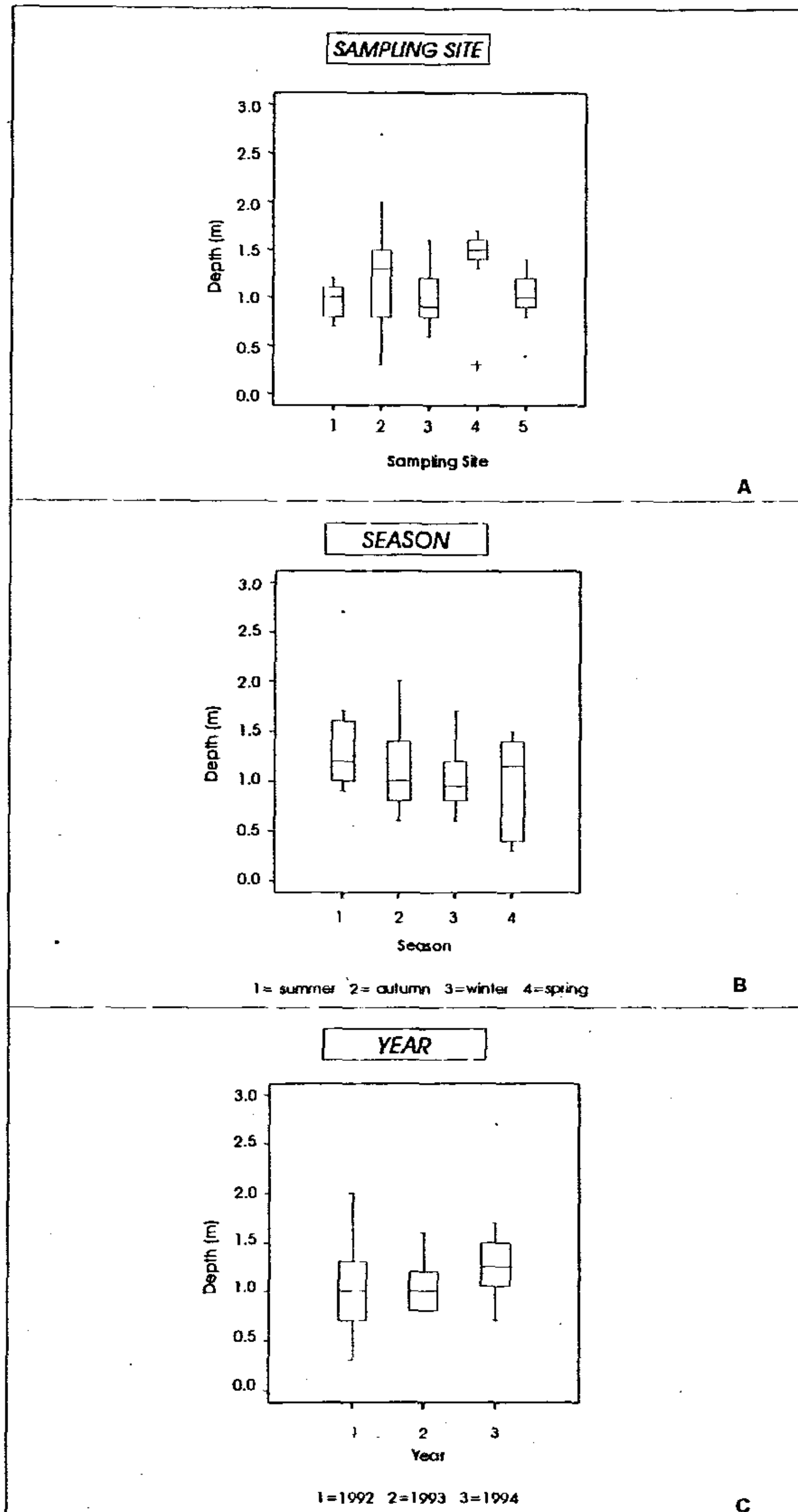


Figure 4.8: Box and Whisker plots of depth (m) measured from 1992 to 1994. **A** represents the range of data over all sampling sites. **B** represents seasonal differences in depth and **C** indicates how the data was spread over three sampling years. Outliers one fifth the distance away from an interquartile range are indicated as '•', and those >3 times the interquartile ranges are drawn as '+'. The line within each box (50th percentile) is the median

Figure 4.9 (A-F) are Box and Whisker Plots of temperature (°C), versus sampling site, season and year. Top and bottom medians over five sampling sites were similar, as were the outliers below the spread of data. Top and bottom temperatures of the Siyaya Estuary were similar during summer, autumn, winter and spring with no outliers. A definite seasonal trend is evident in Figure 4.9 C and D. That is, the medians were not similar for each sampling season. Water temperatures decreased from summer (26 °C) to autumn (25 °C), a marked change in winter (decrease of 9 to 17 °C) and increased again in spring to just above autumn values. Sizes of boxes representing summer and spring data were similar, as were those during autumn and winter. The spread of temperature data (1992 to 1994), was greatest during 1992 (largest box and whiskers), while temperatures during 1993 showed the least amount of variability.

Results of a Multifactor Analysis of Variance (model = season, year and site versus temperature) showed that the effects of the three factors on top and bottom measurements of this physico-chemical parameter were highly significant ($p<0.01$; 95% confidence for mean). Table 4.4 shows the range of mean temperatures on the basis of differences between season, year and site.

Table 4.4: Range of mean temperatures (°C) (top and bottom) for season, year and site with standard errors given below

TEMPERATURE						
	SEASON		YEAR		SITE	
	top	*bottom*	*top*	*bottom*	*top*	*bottom*
Range	16.58-27.15	16.11-26.49	21.51-24.53	20.98-24.19	21.95-23.98	21.03-23.91
Standard Error	.38-.28	.46-.34	.43-.25	.52-.30	.38-.36	.46-.43

Box and Whisker plots of turbidity measured in the Siyaya Estuary, 1992 - 1994 are presented in Figure 4.10. Top and bottom turbidities differed greatly according to sampling site, in that bottom turbidities have larger boxes and whiskers (a larger spread of data). Top measurements of turbidity have several data points that are extreme (outliers). Outliers >3 times the interquartile ranges exist at Sites 3-5. Medians of top and especially

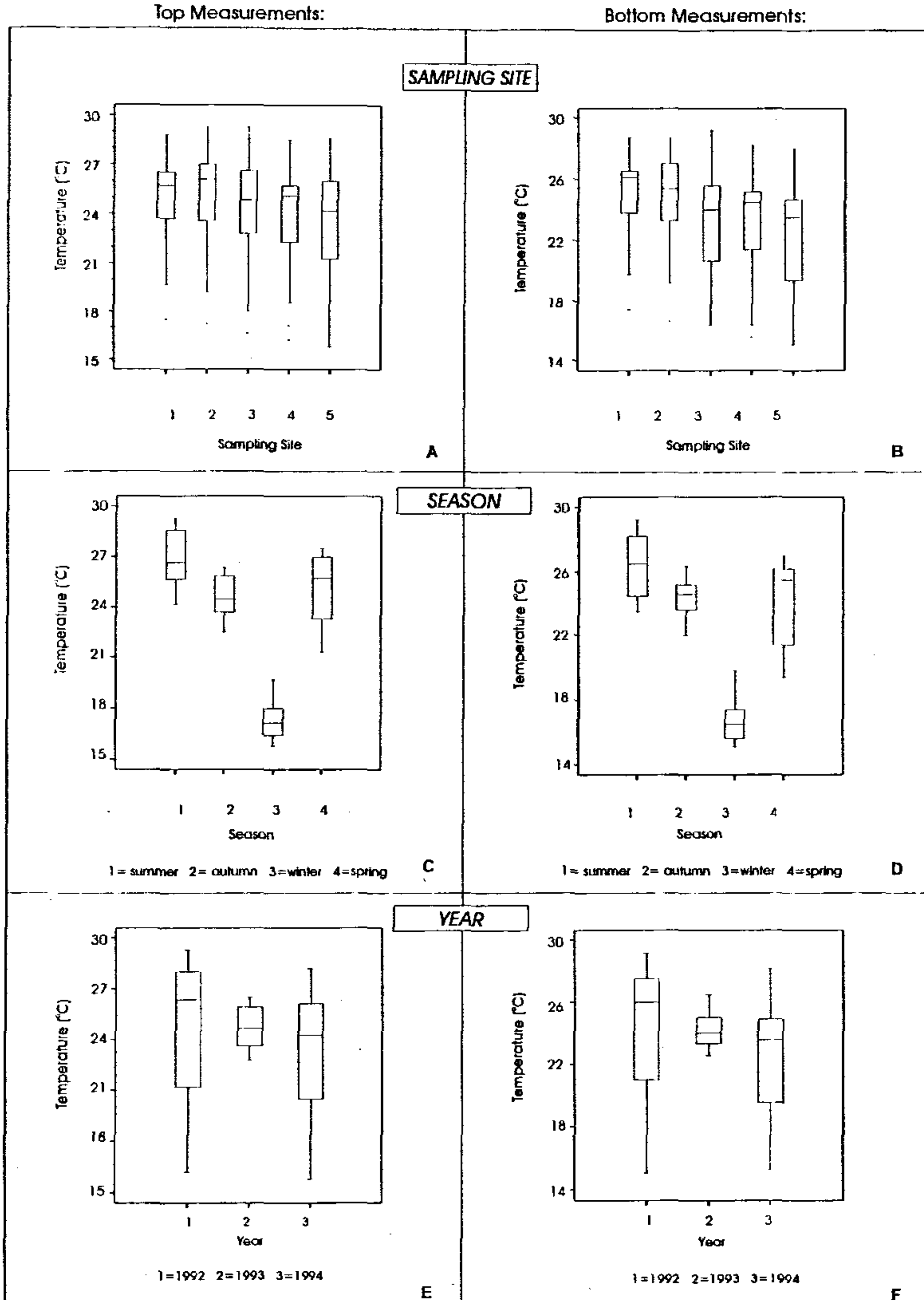


Figure 4.9: Box and Whisker plots of temperature (°C) measured from 1992 to 1994. **A** and **B** represent the range of data over all sampling sites. **C** and **D** represent seasonal differences in temperature and **E** and **F** indicate how the data was spread over three sampling years. **B, D** and **F** are measurements taken at the bottom of the estuary. Outliers one fifth the distance away from an interquartile range are indicated as '•', and those >3 times the interquartile ranges are drawn as '+'. The line within each box (50th percentile) is the median

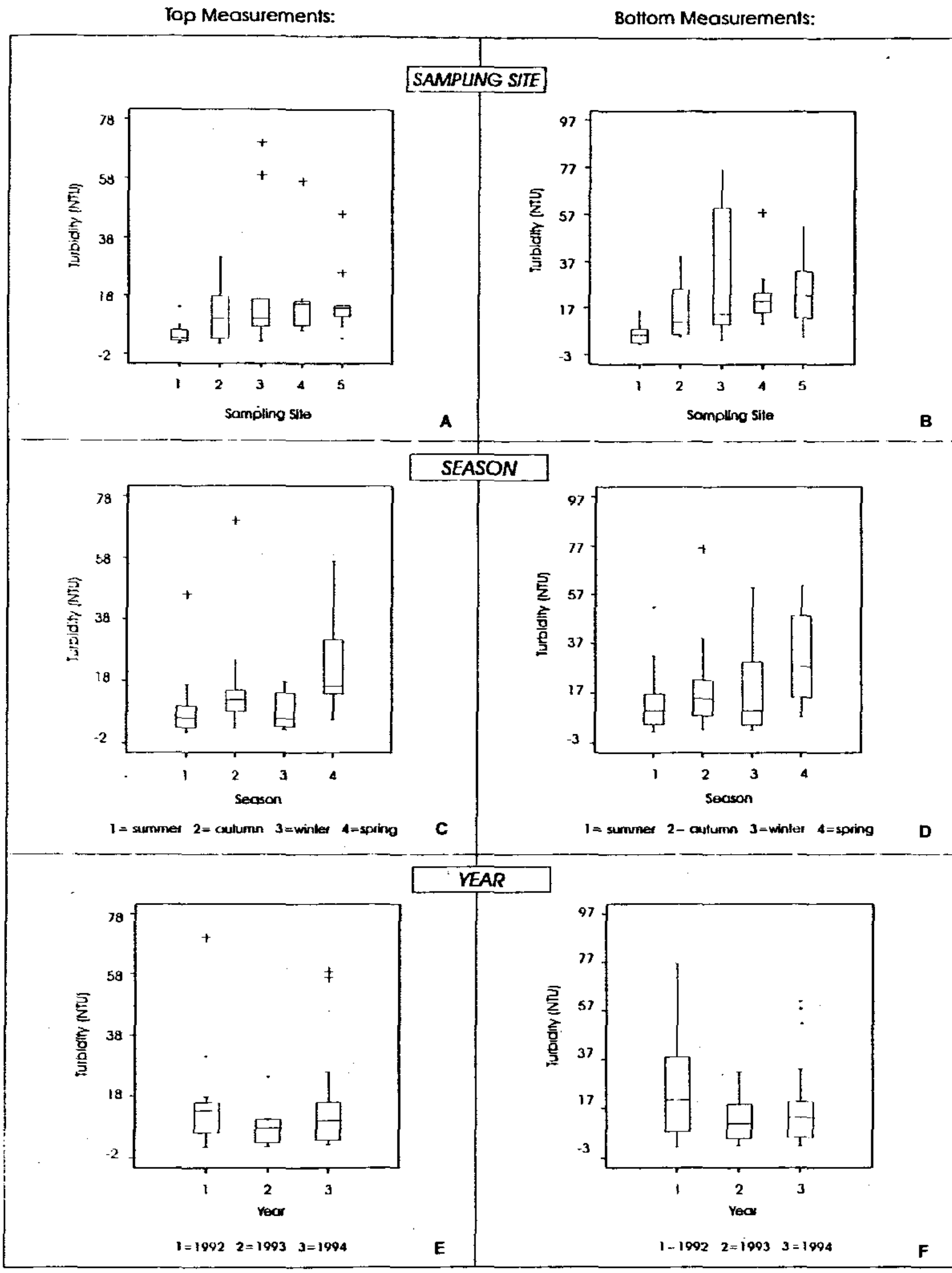


Figure 4.10: Box and Whisker plots of turbidity (NTU) measured from 1992 to 1994. **A** and **B** represent the range of data over all sampling sites. **C** and **D** represent seasonal differences in turbidity and **E** and **F** indicate how the data was spread over three sampling years. **B**, **D** and **F** are measurements taken at the bottom of the estuary Outliers one fifth the distance away from an interquartile range are indicated as '•', and those >3 *times the interquartile ranges are drawn as* '+'. *The line within each box (50th* percentile) is the median

bottom turbidities are greater in the upper reaches of the Siyaya Estuary (Sites 3-5). The *interaction of season and turbidity showed a similar pattern to the top and bottom* measurements. Turbidity levels were lowest during winter and summer and highest in spring (this coincided with rain that fell in the catchment). Turbidities were similar over the entire study period. However, bottom turbidities during 1992 were spread over a larger range, as shown by the larger box and whisker plots compared with the period 1993 and 1994.

Table 4.5 presents the interactions through Multifactor Analysis of Variance (model = season, year and site versus turbidity) and shows that only the effect of season on turbidity was significant ($p<0.05$; 95% confidence for mean).

<u>Table 4.5:</u> Range of mean turbidities (NTU) (top and bottom) for season, year and site with standard errors given below

TURBIDITY						
	SEASON		YEAR		SITE	
	top	*bottom*	*top*	*bottom*	*top*	*bottom*
Range	7.13-24.08	13.31-30.63	11.61-16.04	18.33-25.14	4.71-20.40	6.07-30.89
Standard Error	4.76	4.19-5.63	3.07-5.41	3.63-6.39	4.47-4.47	5.28-5.28

The interaction of dissolved oxygen levels in the Siyaya Estuary with sampling site, season and year is given in Figure 4.11 (A-F). Top and bottom levels were similar in all cases. The median oxygen concentrations were very different in the upper and lower reaches of the estuary. Those in the lower reaches (towards the mouth) were more oxygenated, while the upper reaches of the Siyaya Estuary were not well oxygenated, and anoxic at Site 5. Dissolved oxygen levels differed slightly according to season. Figure 4.11 C and D indicates that the top and bottom medians over three years, were highest in winter and lowest in summer.

Results of a Multifactor Analysis of Variance (model = season, year and site versus dissolved oxygen) revealed that the effects of season, year and site on top and bottom

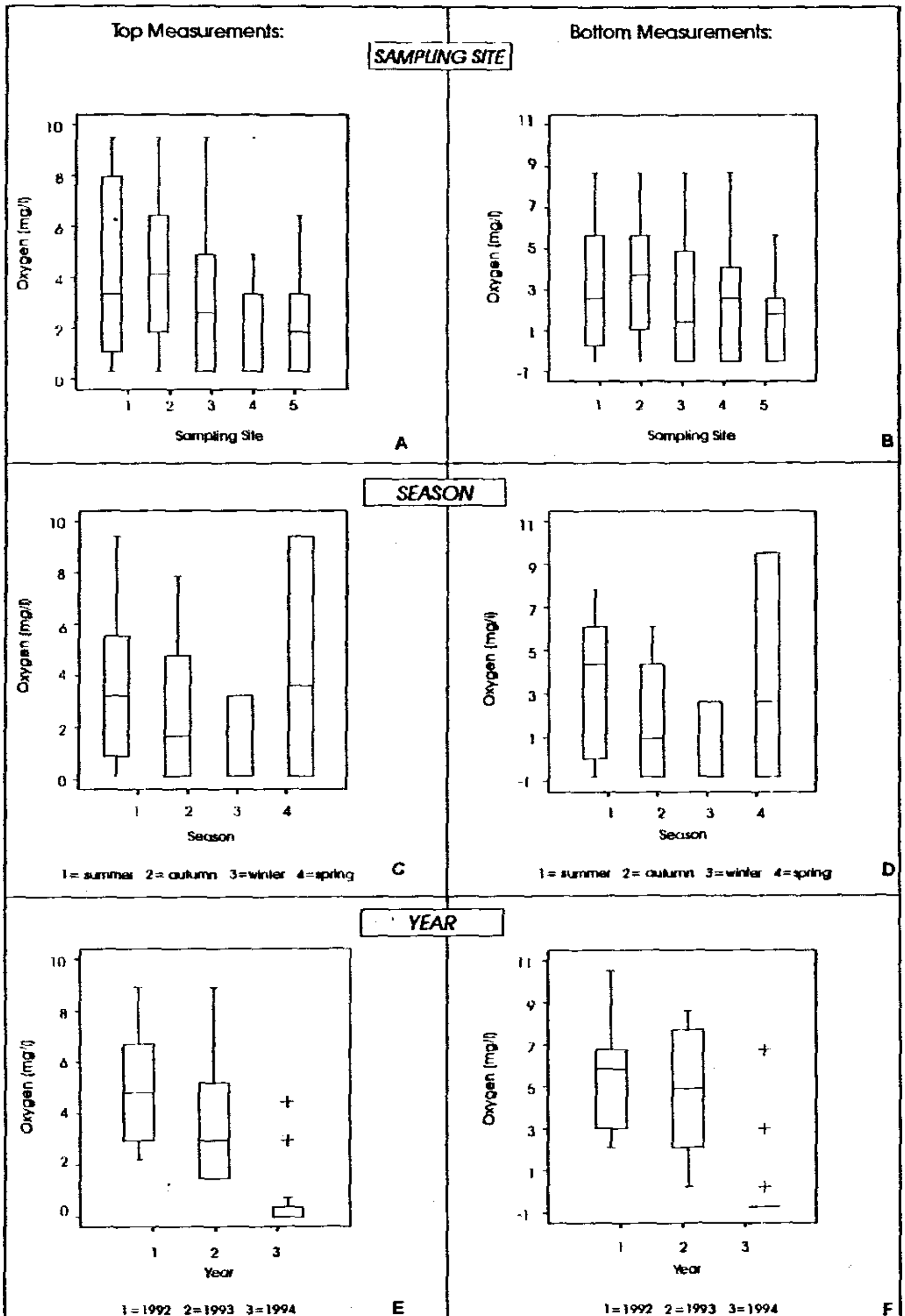


Figure 4.11: Box and Whisker plots of oxygen (mg/l) measured from 1992 to 1994. **A** and **B** represent the range of data over all sampling sites. **C** and **D** represent seasonal differences in oxygen and **E** and **F** indicate how the data was spread over three sampling years. **B**, **D** and **F** are measurements taken at the bottom of the estuary Outliers one fifth the distance away from an interquartile range are indicated as '•', and those >3 times the interquartile ranges are drawn as '+'. The line within each box (50th percentile) is the median

measurements of dissolved oxygen were highly significant ($p<0.01$; 95% confidence for mean). The ranges of mean dissolved oxygen levels on the basis of differences between season, year and site are given in Table 4.6.

Table 4.6: Range of mean oxygen levels (mg/l) (top and bottom) for season, year and site with standard errors given below

OXYGEN						
	SEASON		**YEAR**		**SITE**	
	top	*bottom*	*top*	*bottom*	*top*	*bottom*
Range	3.78-5.69	3.23-5.46	3.37-5.09	2.93-4.34	2.60-7.32	1.82-7.40
Standard Error	.30	.35-.35	.34-.19	.39-.22	.30-.28	.35-.33

The interaction of salinity with sampling site, season and year showed that top and bottom measurements of this variable were generally the same (Figure 4.12 A-F). As with dissolved oxygen levels, the lower reaches had higher values than the upper reaches. This coincided with instances of overtopping of the sandbar at the mouth. Seasonal salinities increased from summer to winter, and decreased again in spring. Spring had the highest median salinity, as well as the largest range (Figure 4.12 C and D) Salinities peaked during 1992, with the lowest salinity values recorded during 1994. The presence of extreme outliers above the box plot in 1994, suggested that overtopping at the mouth still took place at high spring tides (Figure 4.12 A and B).

The model used for a Multifactor Analysis of variance was the interaction of season, year and site versus salinity. All were significant, except the effect of site on bottom salinity ($p>0.05$; 95% confidence for mean). Other interactions were significant, but the manner in which salinity varied according to sampling year was highly significant ($p<0.01$; 95% confidence for mean). The ranges of mean salinity measurements taken within the Siyaya Estuary, 1992 - 1994 are given in Table 4.7.

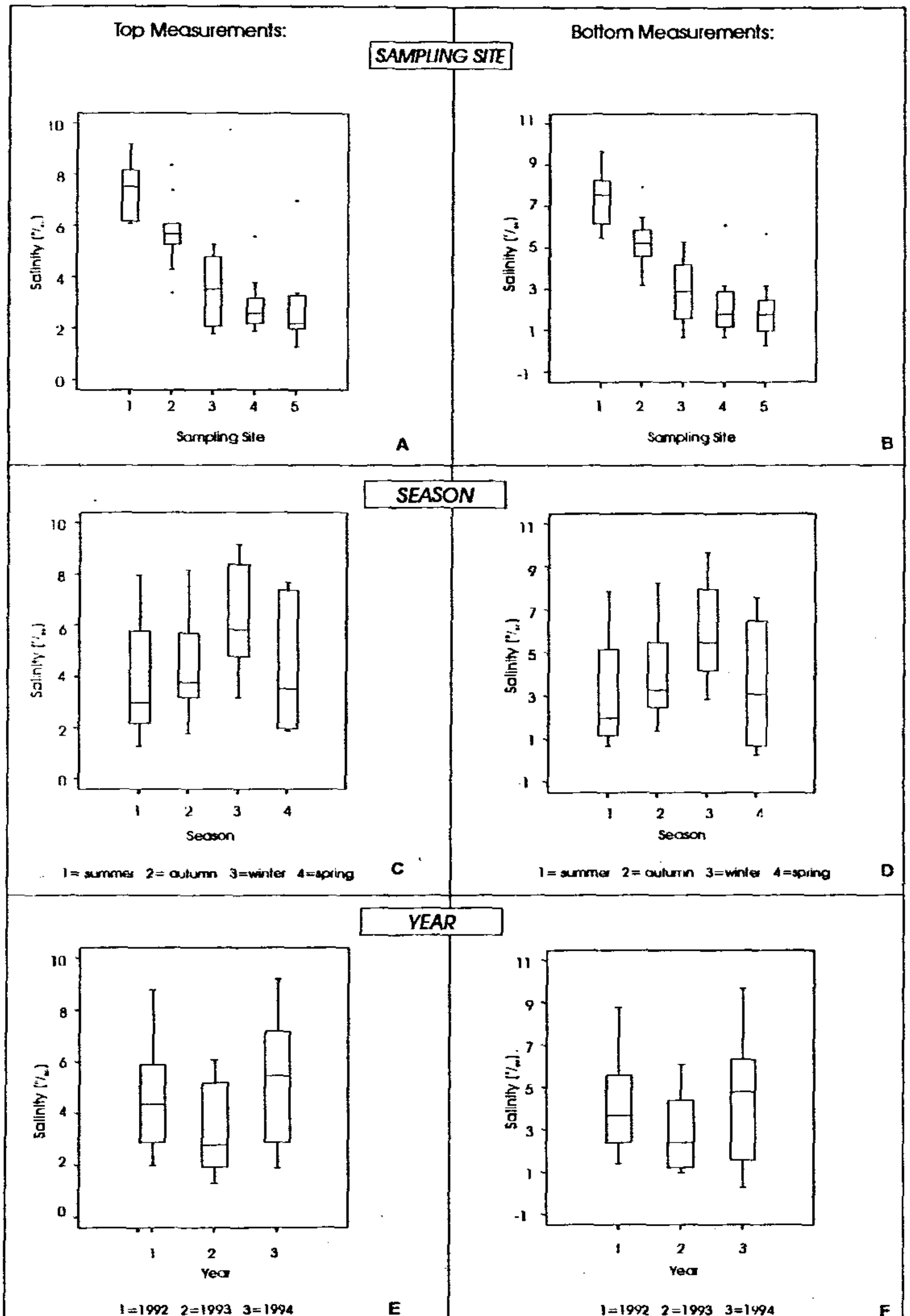


Figure 4.12: Box and Whisker plots of salinity (‰) measured from 1992 to 1994. **A** and **B** represent the range of data over all sampling sites. **C** and **D** represent seasonal differences in salinity and **E** and **F** indicate how the data was spread over three sampling years. **B**, **D** and **F** are measurements taken at the bottom of the estuary Outliers one fifth the distance away from an interquartile range are indicated as '•', and those >3 times the interquartile ranges are drawn as '+'. The line within each box (50th percentile) is the median

Table 4.7: *Range of mean salinities (‰) (top and bottom) for season, year and site with standard errors* given below

SALINITY						
	SEASON		YEAR		SITE	
	top	*bottom*	*top*	*bottom*	*top*	*bottom*
Range	1.59-3.04	1.57-3.11	.40-3.45	.43-3.45	1.28-2.86	1.55-2.91
Standard Error	.42	.35-.43	.27	.28	.43-.40	.43-.40

The Rank Correlation Co-efficient of the physico-chemical parameters were calculated using Spearman's Rank Correlation Co-efficient. The resultant co-efficient falls between -1 (perfect disagreement) and +1 (perfect agreement). This ranked method was employed, as rank-order measures of association are not sensitive to extreme values (such as the occurrence of high turbidity measurements in the Siyaya Estuary, for example) (Manugistics, 1992). The final model used to obtain the correlation co-efficients was a *12 x 12* matrix of:

season *x* year *x* site *x* temperature (T) *x* temperature (B) *x* salinity (T) *x* salinity (B) *x* oxygen (T) *x* oxygen (B) *x* turbidity (T) *x* turbidity (B) *x* depth

This analysis revealed that temperature was correlated to season ($p<0.01$; correlation co-efficients of -.4770 and -.4264 for top and bottom measurements, respectively). Interestingly, turbidity was positively correlated to season ($p<0.01$; correlation co-efficient of .3924 for top measurements, and $p<0.05$; correlation co-efficient of .3372 for bottom turbidity values). The highly significant correlation between salinity and sampling year ($p<0.001$) was expected, as the mouth remained closed from 1992-1994, and conditions within the Siyaya Estuary, became less saline. The variable 'site', was significantly correlated to bottom temperature, top salinity, oxygen and turbidity. The latter two being a highly significant correlation ($p<0.001$ and $p<0.01$). Oxygen was negatively correlated to sampling site, while the opposite was true of the variable, turbidity. An additional motivation for calculating the correlation co-efficients of the variables, was to see what type of relationship each physico-chemical variable had on each other.

Temperature was highly correlated to salinity in the Siyaya Estuary ($p<0.01$; positive correlation co-efficients >.4000). Likewise at each site, oxygen and turbidity exhibited a very significant correlation over the sampling period ($p<0.001$; negative correlation co-efficients >5.000). Depth was positively correlated to sampling year ($p<0.05$; correlation co-efficient of .3492).

Figures 4.13 to 4.20 (A and B) represent the results of the multivariate analyses performed on the water chemistry data between 1992-1994. In all cases, 'A' is a dendrogram of the results of Hierarchical Agglomerative cluster analyses, while '**B**', gives the 2d result of a non-metric multidimensional scaling ordination. Samples and variables were grouped separately during each year to examine the interrelationships amongst the data.

Water samples from 1992 revealed that there were three main groups at a Euclidean distance of 100 (Figure 4.13 A). The first group included all summer, autumn and spring samples taken at each sampling site. However, sampling Site 3 during autumn was not included in this particular group, but separated out into a cluster of its own, forming a second grouping at this similarity (100) because of uncharacteristically high turbidity values (>70 NTU) recorded at this site. The third grouping included all winter samples taken at Sites 1-5, during 1992. Seven groups separated out at a Euclidean distance of 50. The resultant MDS plot (2d minimum stress of .14 after 10 runs) gave a clearer picture of these groupings, in that samples from autumn 1992 (Site 3) were entirely separate from the large cluster (Figure 4.13 B). All winter samples formed a separate group. At a similarity of 50, autumn and summer samples (Sites 4 and 5) separated out, as did those of Site 1 (summer, autumn and spring) together with those from Sites 2 and 3.

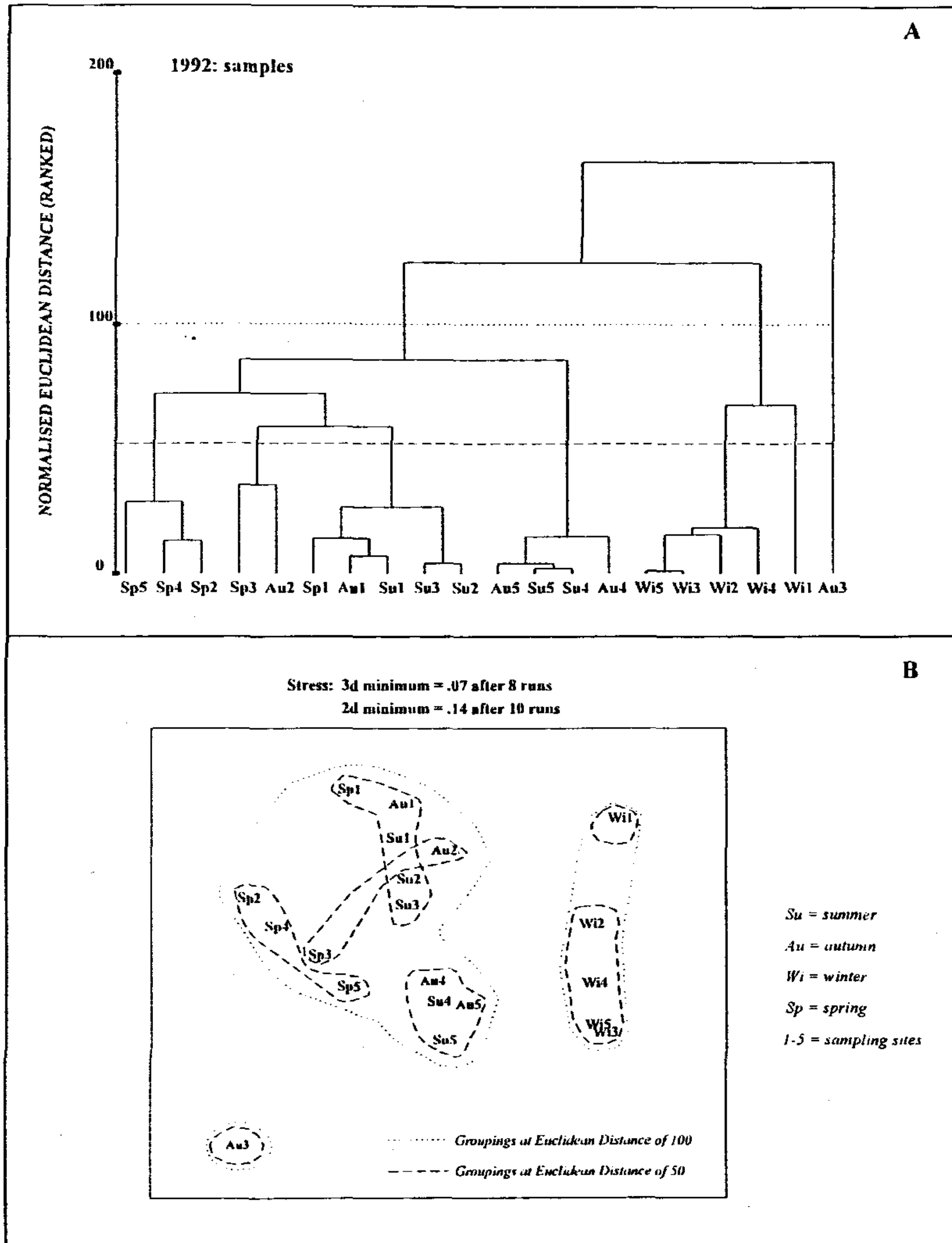


Figure 4.13 A: Ranked cluster analysis of 1992 environmental samples. Each sample is representative of top and bottom measurements for temperature [°C], oxygen [mg/l], turbidity [NTU], salinity [‰] and depth [m] for each sampling site and season. Lines are drawn at normalised Euclidean distances of 100 and 50.

B: 2d result of non-metric multidimensional scaling [MDS] of the above samples, with lines drawn around groups having similarities of 100 and 50. Stress for MDS is .14 after 10 runs

Figure 4.14 A and B are plots of a cluster analysis and MDS ordination on 1992 water physico-chemical variables. At a Euclidean distance of 10, depth, salinity and oxygen (top and bottom), remained together in a cluster as did the variable, temperature. Turbidity (top and bottom), formed clusters on their own. This reinforces the parametric *t*-tests applied to the data, to establish whether top and bottom measurements of the variables could be summed. Top and bottom turbidity measurements were clearly significantly separate from each other while the other variables were not. An interesting cluster combining depth and salinity was discovered in this cluster analysis (Euclidean distance of 5), which was not proved significant in the Spearman's Rank Correlation Co-efficient test. The 2d minimum stress of the MDS was .00 after a single run. Any stress >0.01 gives a perfect representation with no prospect of misinterpretation (Clarke and Warwick, 1994).

Cluster analyses of the 1993 water samples separated four main groups at a Euclidean Distance of 100 (Figure 4.15 A). These were firstly, all summer samples, secondly autumn Site 4, thirdly Site 1 samples for each season except summer and fourthly the balance of the samples. The MDS plot (2d minimum stress = .09 after 19 runs; Figure 4.15 B), gave a clearer indication as to the different groupings at a Euclidean Distance of 50. Only two of the original groups were retained; Site 3, autumn, and Site 1 autumn, winter and spring together with Site 2, winter. The first group (summer samples) separated into the upper and lower reaches of the Siyaya Estuary, as did the largest original group, and reflected the less saline conditions in the upper reaches, the generally low dissolved oxygen levels and the higher turbidity levels.

Multivariate cluster analysis and ordination of 1993 water physico-chemical variables resulted in a dendrogram almost identical to that of 1992 variables (Figure 4.16 A). Although the MDS ordination (stress = .00 after 2 runs) gave slightly different groups, the clustering of variables was the same (Figure 4.16 B). The close relationship between depth and salinity was also evident among 1993 water physico-chemical variables.

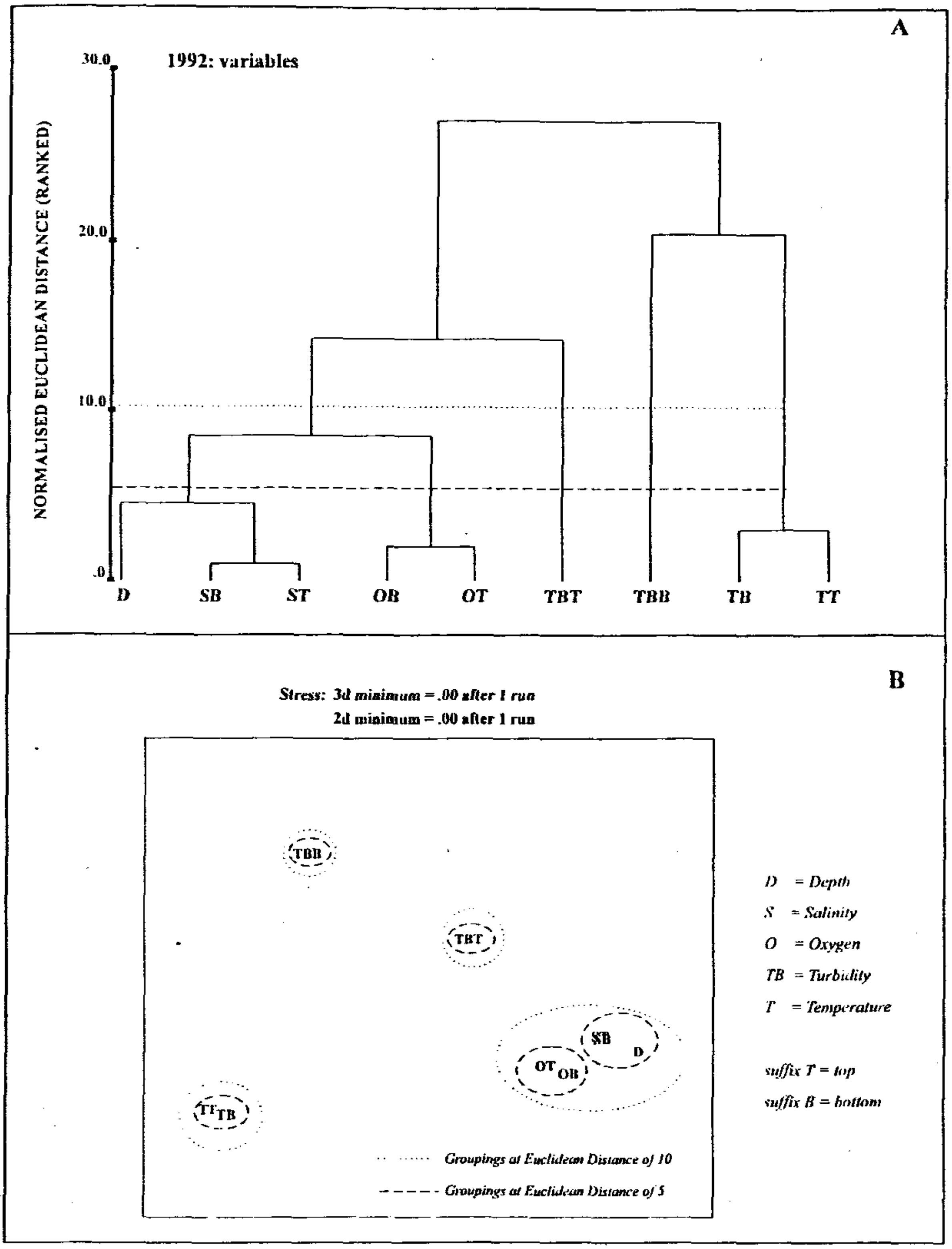


Figure 4.14 A: Ranked cluster analysis of environmental variables measured during 1992. Each variable is representative of top and bottom measurements, and includes every sampling site over four seasons. Lines are drawn at normalised Euclidean distances of 10 and 5.

B: 2d result of non-metric multidimensional scaling [MDS] of the above variables, with lines drawn around groups having similarities of 10 and 5. Stress for MDS is .00 after 1 run

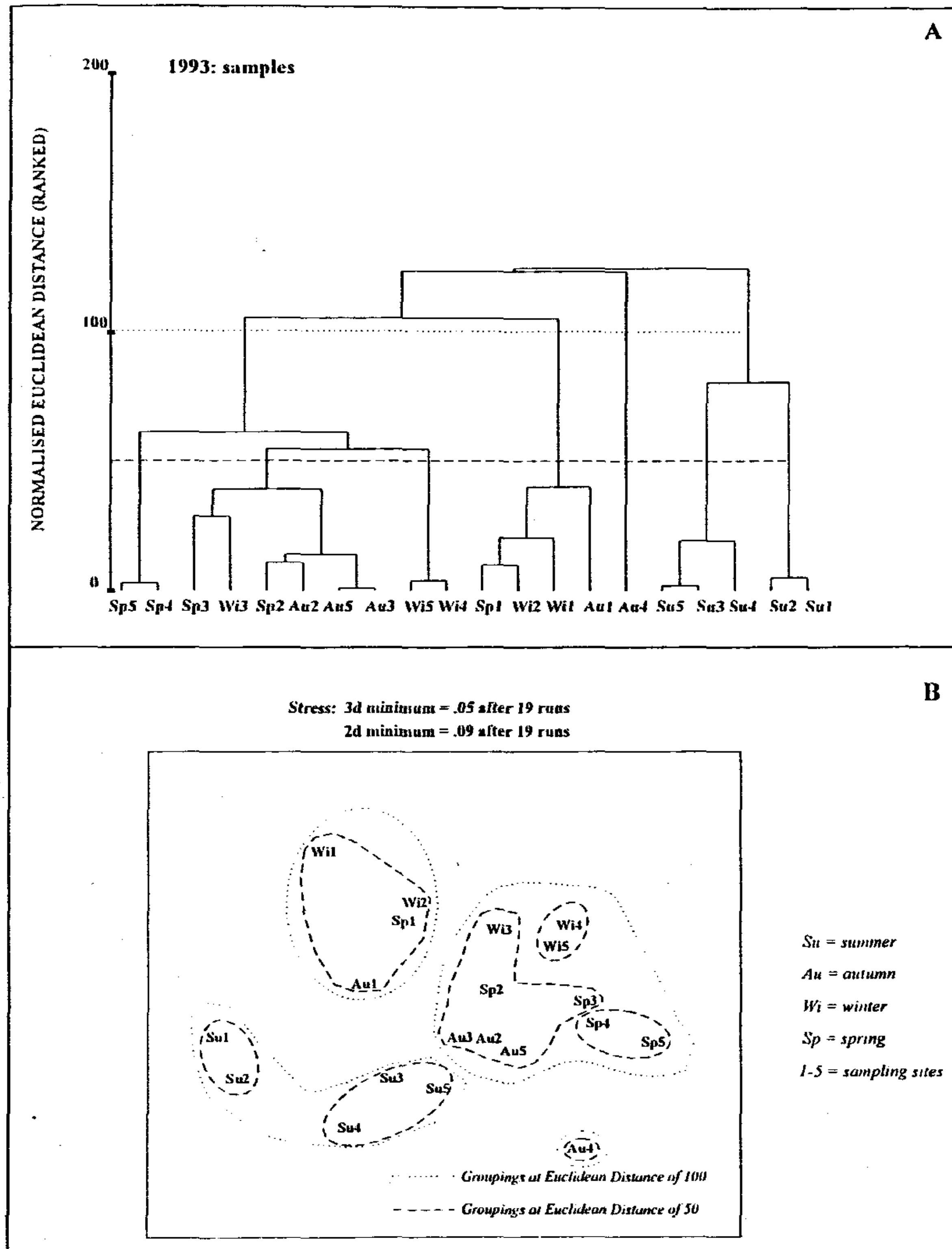


Figure 4.15 A: Ranked cluster analysis of 1993 environmental samples. Each sample is representative of top and bottom measurements for temperature [°C], oxygen [mg/l], turbidity [NTU], salinity [‰] and depth [m] for each sampling site and season. Lines are drawn at normalised Euclidean distances of 100 and 50.

B: 2d result of non-metric multidimensional scaling [MDS] of the above samples, with lines drawn around groups having similarities of 100 and 50. Stress for MDS is .09 after 19 runs

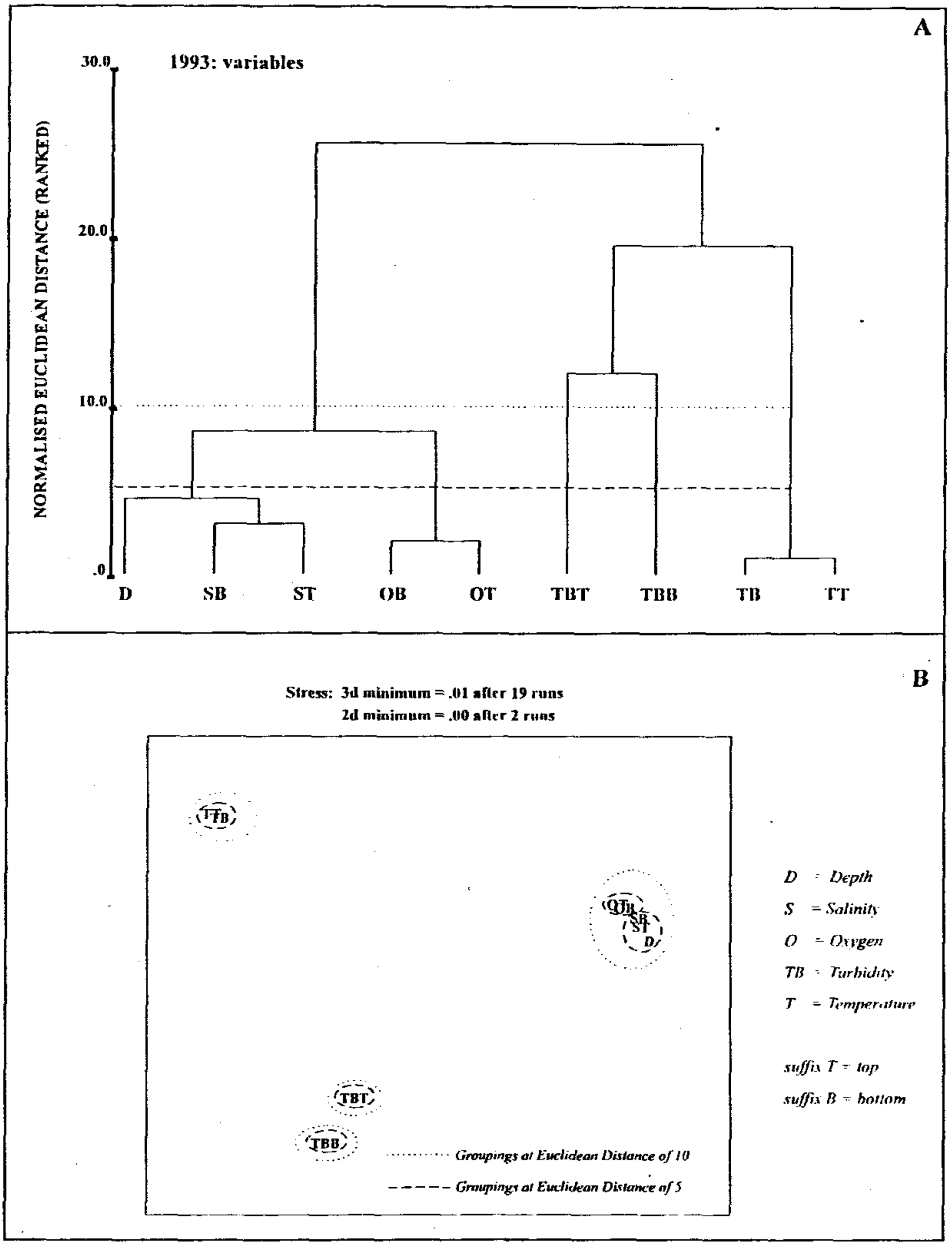


Figure 4.16 A: Ranked cluster analysis of environmental variables measured during 1993. Each variable is representative of top and bottom measurements, and includes every sampling site over four seasons. Lines are drawn at normalised Euclidean distances of 10 and 5.

B: 2d result of non-metric multidimensional scaling [MDS] of the above variables, with lines drawn around groups having similarities of 10 and 5. Stress for MDS is .00 after 2 runs

Figure 4.17 A, represents the results of Hierarchical Agglomerative Clustering using normalised ranked Euclidean distance on 1994 water physico-chemical samples No clear pattern was established at distances of either 100 or 50, thus the MDS plot was used for interpretation (Figure 4.17 B). The 2d plot was a result of 15 runs with a minimum stress of .06. There were six groups at Euclidean distance of 50: the first, Site 2 (summer), the second containing winter samples in the upper reaches of the Siyaya Estuary, while the third grouped all winter samples in the lower reaches. The fourth group separated samples in the upper reaches (Sites 1 and 2) during summer, autumn and spring, and the final two, from the middle to upper reaches of the system, during summer, autumn and spring.

Variables measured during 1994 separated out in a similar manner to those from the previous two years (Figure 4.18 A and B). With the exception of the turbidity variable, which had top and bottom measurements related at a Euclidean distance of 10. The stress of the resultant MDS plot was also a perfect representation of the data, that is .00 after 7 runs.

The final cluster and ordination analyses performed on the water physico-chemical data showed whether each of the sampling years would separate out into different groups. Generally, Figures 4.19 A and B show that while water samples from 1993 and 1994 were similar, those sampled during 1992 tended to separate out at a Euclidean distance of 1000. Upon examination of the MDS plot (stress = .15 after 19 runs), it was found that samples taken in the lower reaches of the estuary were generally separate from those in the middle/upper reaches. As was expected, when all variables were pooled from each of the three sampling years, the resultant plots revealed the same picture as when they were analysed separately. There was a relationship between top and bottom measurements of variables, except for turbidity, and some relationship (not proved significant in a Spearman's Rank correlation test) between depth and salinity (Figures 4.20 A and B).

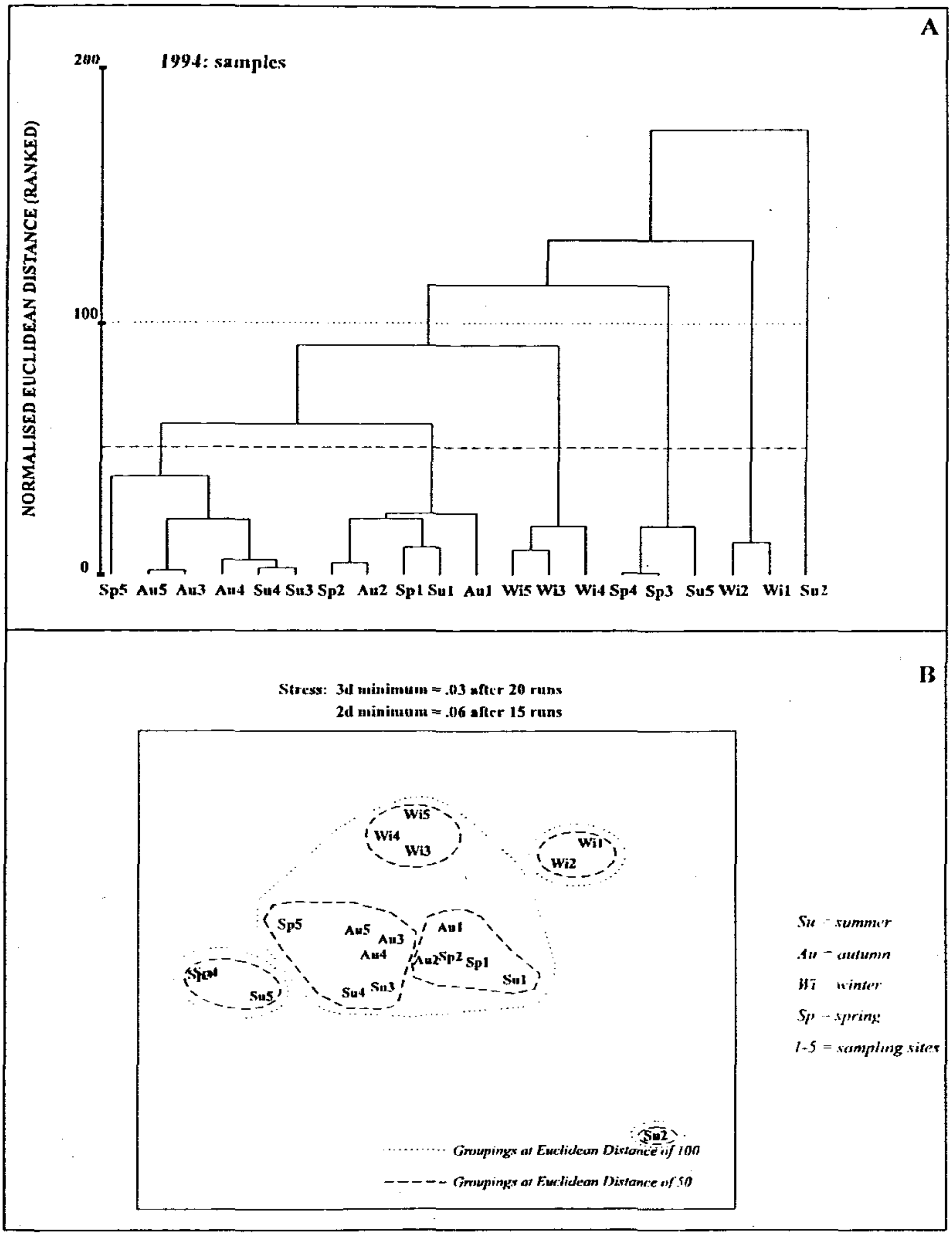


Figure 4.17 A: Ranked cluster analysis of 1994 environmental samples. Each sample is representative of top and bottom measurements for temperature [°C], oxygen [mg/l], turbidity [NTU], salinity [‰] and depth [m] for each sampling site and season. Lines are drawn at normalised Euclidean distances of 100 and 50.

B: 2d result of non-metric multidimensional scaling [MDS] of the above samples, with lines drawn around groups having similarities of 100 and 50. Stress for MDS is .06 after 15 runs

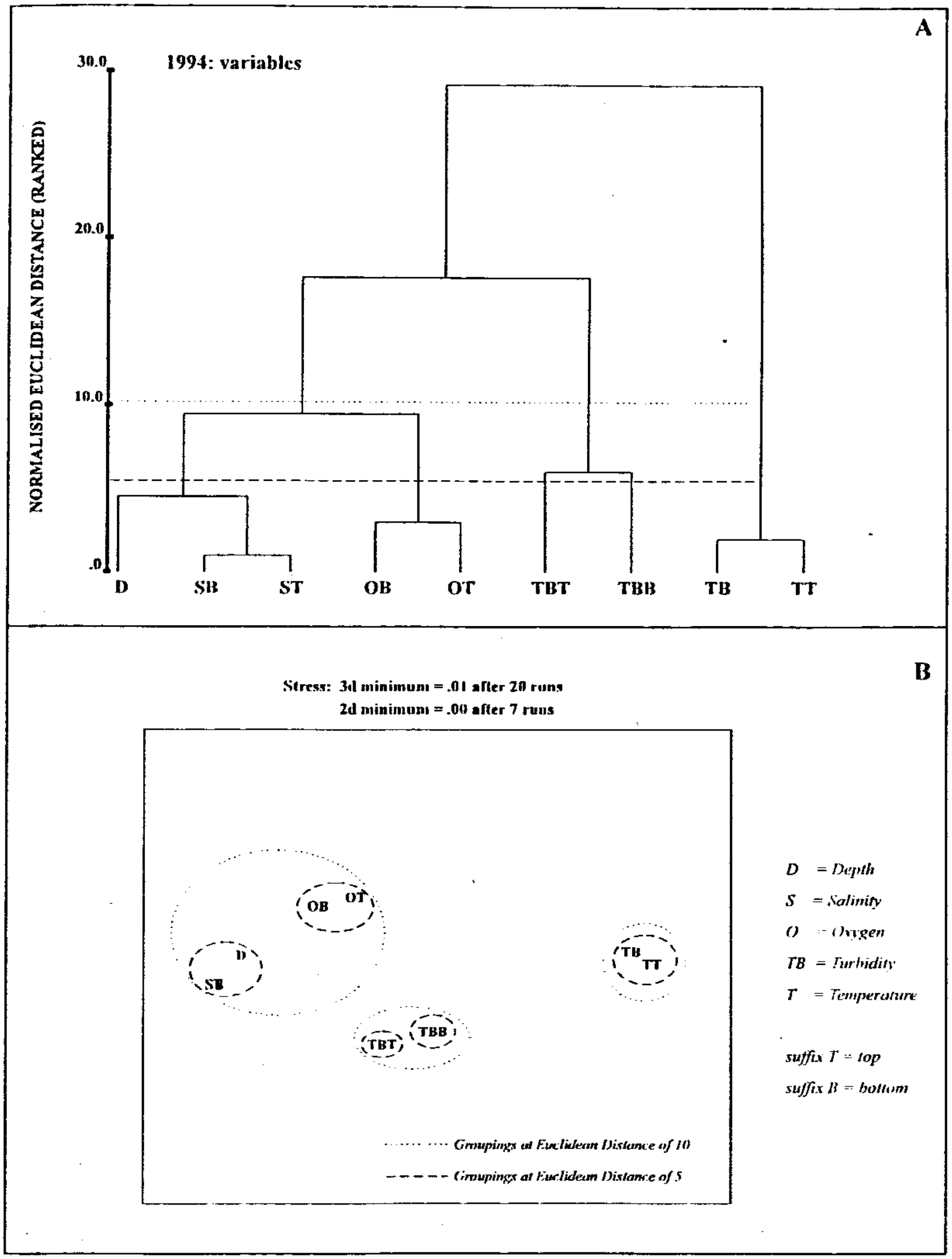


Figure 4.18 A: Ranked cluster analysis of environmental variables measured during 1994. Each variable is representative of top and bottom measurements, and includes every sampling site over four seasons. Lines are drawn at normalised Euclidean distances of 10 and 5.

B: 2d result of non-metric multidimensional scaling [MDS] of the above variables, with lines drawn around groups having similarities of 10 and 5. Stress for MDS is .00 after 7 runs

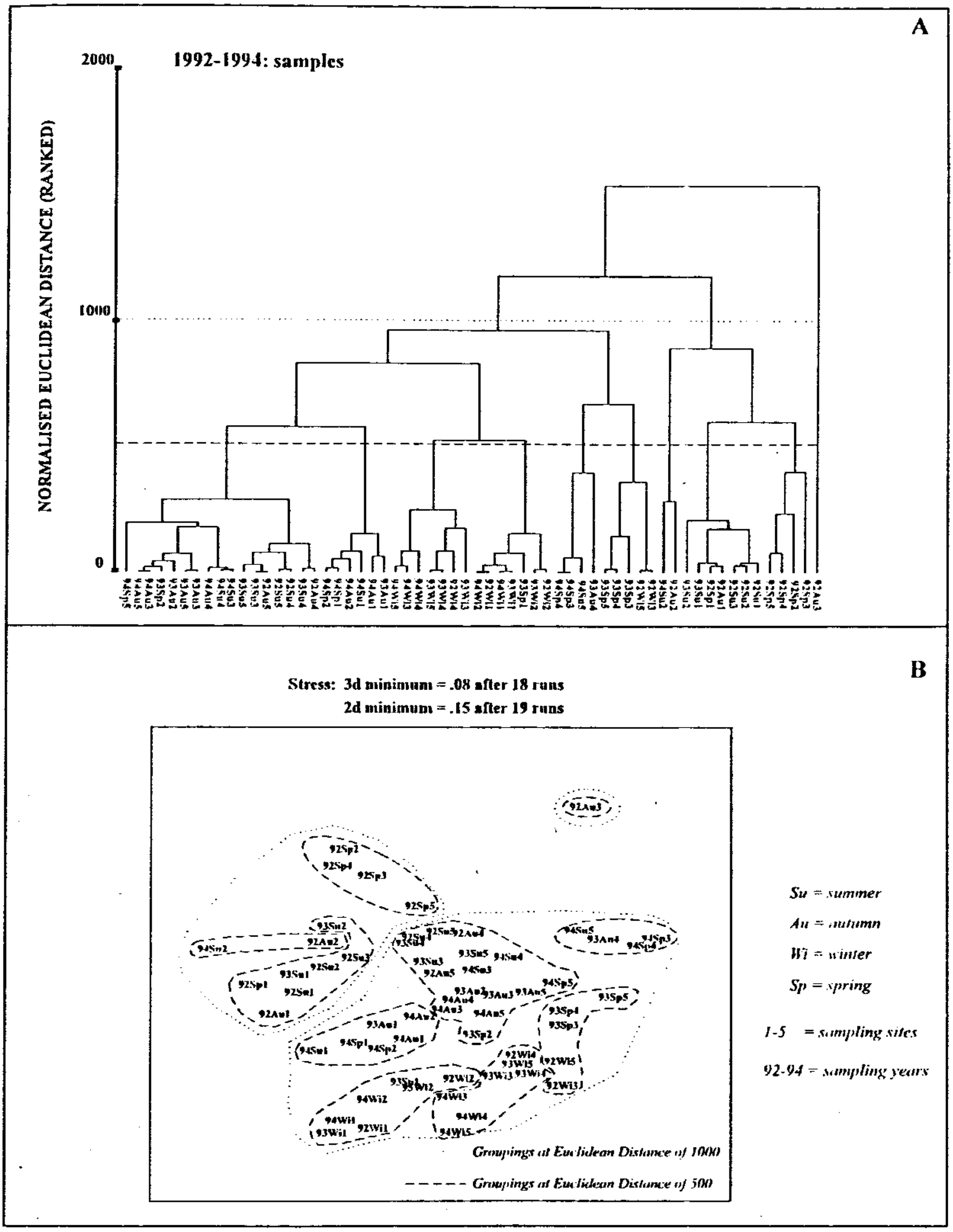


Figure 4.19 A: Ranked cluster analysis of environmental samples taken from 1992 to 1994. Each sample is representative of top and bottom measurements for temperature [°C], oxygen [mg/l], turbidity [NTU], salinity [‰] and depth [m] for each sampling site, season and year. Lines are drawn at normalised Euclidean distances of 1000 and 500.

B: 2d result of non-metric multidimensional scaling [MDS] of the above samples, with lines drawn around groups having similarities of 1000 and 500. Stress for MDS is .15 after 19 runs

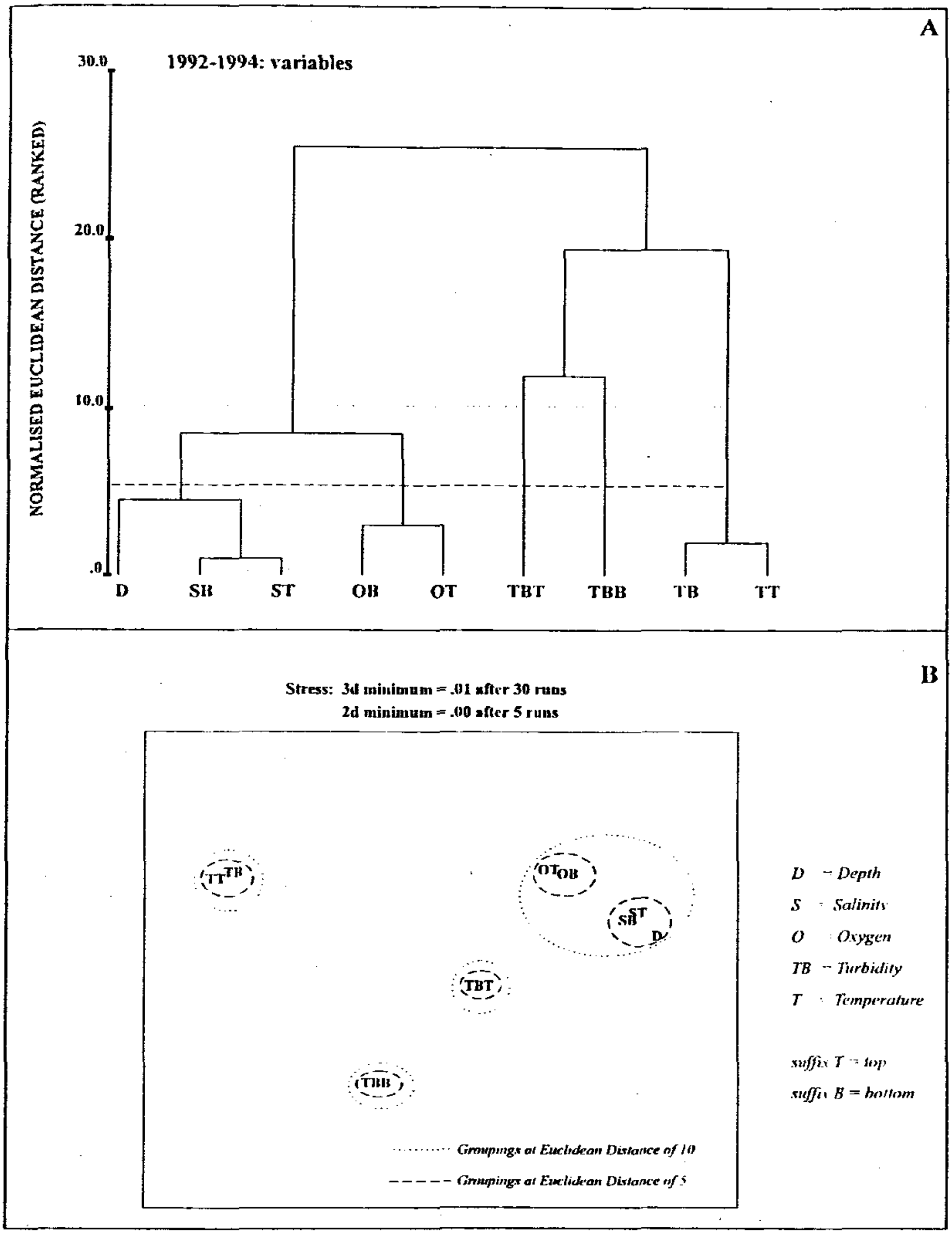


Figure 4.20 A: Ranked cluster analysis of all environmental variables measured from 1992 to 1994. Each variable is representative of top and bottom measurements , and includes every sampling site, season and year. Lines are drawn at normalised Euclidean distances of 10 and 5.

B: 2d result of non-metric multidimensional scaling [MDS] of the above variables, with lines drawn around groups having similarities of 10 and 5. Stress for MDS is .00 after 5 runs

4.3.2 Seasonal Water Quality: Autumn 1994-Summer 1995

Maucha diagrams representative of water sampled from Site 1 during autumn and winter 1994 show that despite continued closure of the mouth, the Siyaya Estuary had a combination of ions similar to the situation found in a seawater dominated system. However, unlike true seawater, calcium (Ca^+) and alkalinity levels (HCO_3^-) were relatively high. Figures 4.21 to 4.28 are Maucha (1922) ionic diagrams and proportional molar concentrations of major ions in the Siyaya Estuary over four seasons (1994-1995) and during the mouth open phase (April and winter 1995), from sampling Sites 1, 3 and 5. Each diagram should be compared to reference Figure 4.21, to ascertain whether the water from a particular sampling site during a season is freshwater or seawater dominated.

Maucha diagrams of water samples taken at Sites 3 and 5 (autumn 1994) and Site 5 (winter 1995) were all similar in construction, which suggested the proportion of ions from both freshwater and seawater systems were similar. The water at Site 3 during winter 1994, had larger proportions of sodium and chloride (Figures 4.22 and 4.23), which coincided with overtopping of the sandbar at the mouth. A large school of postflexion mullet larvae and early juveniles (over 800 individuals, approximately 10 - 20 mm in length) was seined at this time. Mullet are marine spawners, that will only spawn in high salinities and certain species are estuarine-dependant (Whitfield, 1994).

The influence of overtopping was clear during spring of 1994 (Figure 4.24), where diagrams representative of water ionic concentrations at Sites 1, 3 and 5 show that Na^+ and Cl^- proportions were greater in the upper reaches of the estuary than the previous seasons (Figure 4.25). However, the existence of relatively high Ca^+ and alkalinity corroborated the fact that the Siyaya Estuary was still relatively 'fresh' during spring 1994. During summer 1995, just prior to breaching of the mouth, the Siyaya Estuary at Sites 1,3 and 5 was still subject to this dual influence of freshwater and seawater dominated ions.

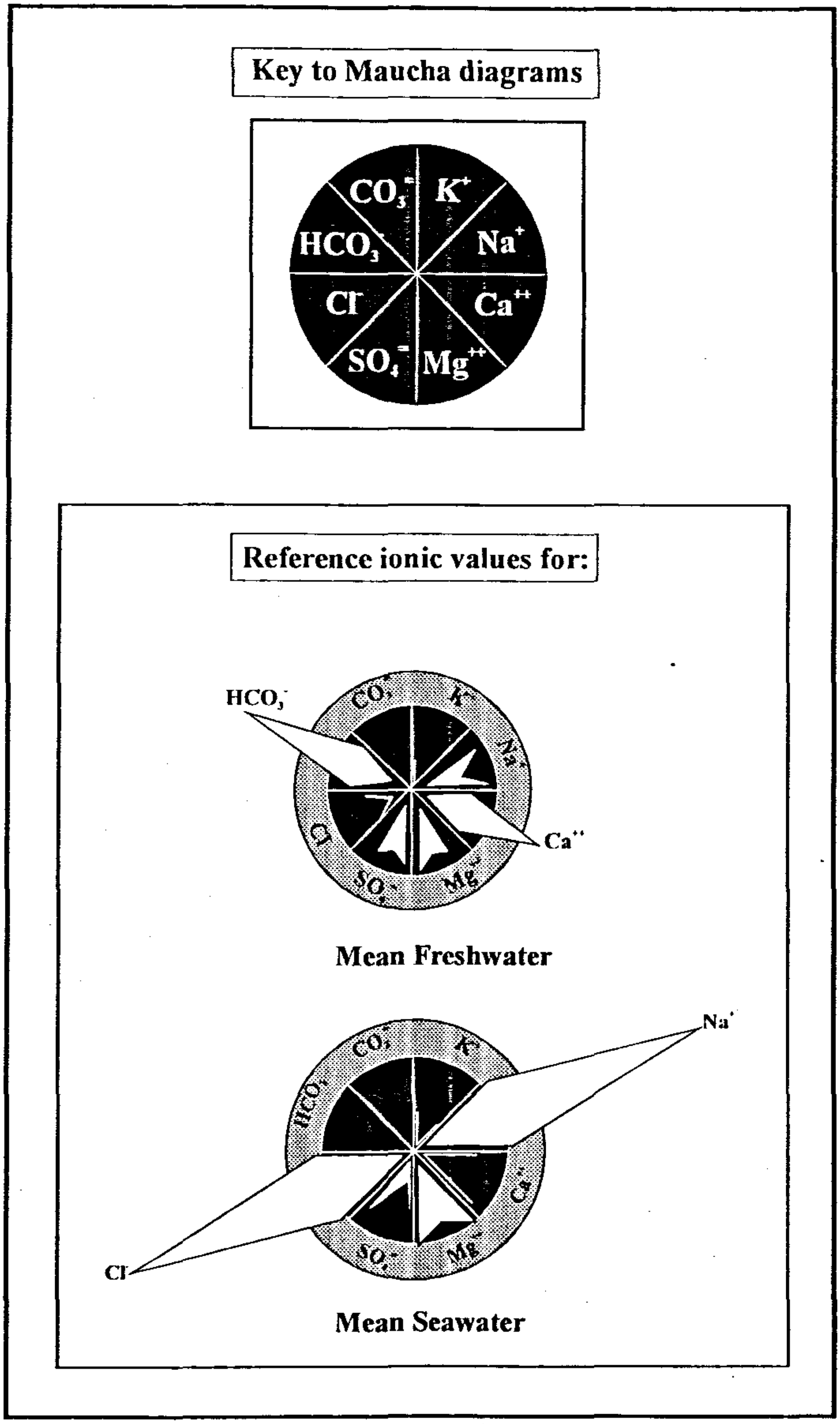


Figure 4.21: Reference ionic values for mean freshwater and seawater, and corresponding key to Maucha diagrams. (After Day and King, 1985)

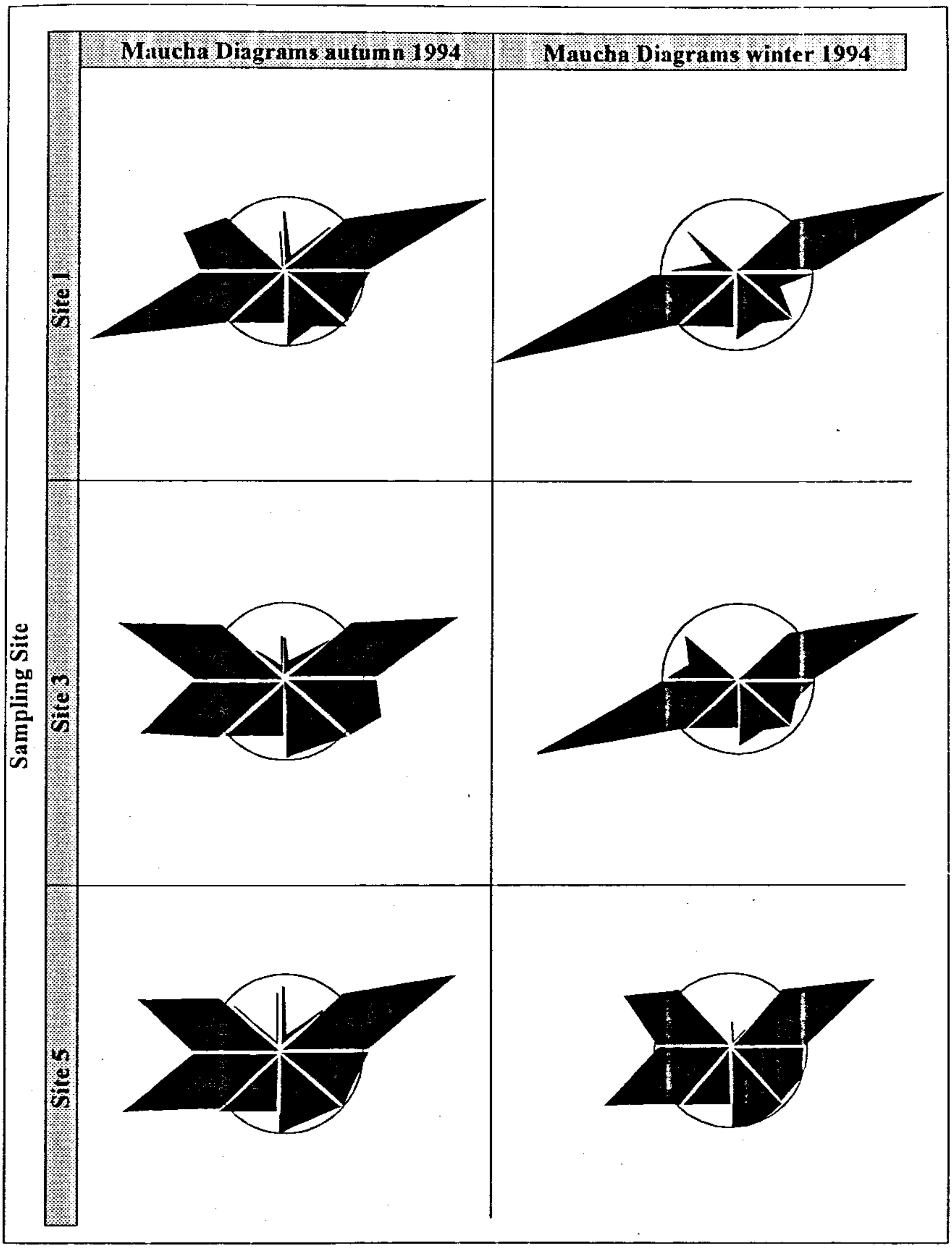


Figure 4.22: Maucha ionic diagrams of the proportional concentrations of major ions during autumn and winter of 1994 (Sites 1,3 and 5). *For reference ionic values see page 81.*

Sampling Site	Site	Proportional molar concentrations autumn 1994		Proportional molar concentrations winter 1994	
	Site 1	Ca^{++}	2.8493	Ca^{++}	5.0399
		Mg^{++}	2.4763	Mg^{++}	7.4866
		$SO_4^{=}$	0.0000	SO_4^{-}	0.0000
		Cl^{-}	7.9549	Cl^{-}	31.6502
		HCO_3^{-}	4.2036	HCO_3^{-}	3.2820
		$CO_3^{=}$	0.0750	$CO_3^{=}$	0.5265
		K^{+}	0.2330	K^{+}	0.4885
		Na^{+}	8.2645	Na^{+}	26.9682
		$H_2CO_3^{+}$	0.0672	$H_2CO_3^{+}$	0.0066
		Total ions	**= 26.1237**	**Total ions**	**= 75.4485**
		Cations	**= 13.8903**	**Cations**	**= 39.9898**
		Anions	**= 12.2334**	**Anions**	**= 35.4586**
	Site 3	Ca^{++}	2.3403	Ca^{++}	4.1168
		Mg^{++}	1.8346	Mg^{++}	4.1711
		$SO_4^{=}$	0.0000	$SO_4^{=}$	0.0000
		Cl^{-}	3.4697	Cl^{-}	15.3456
		HCO_3^{-}	4.1312	HCO_3^{-}	3.4964
		$CO_3^{=}$	0.0281	CO_3^{-}	0.0426
		K^{+}	0.1230	K^{+}	0.3056
		Na^{+}	4.3062	Na^{+}	13.9191
		$H_2CO_3^{+}$	0.1520	$H_2CO_3^{+}$	0.0850
		Total ions	**= 16.3852**	**Total ions**	**= 41.4823**
		Cations	**= 8.7562**	**Cations**	**= 22.5977**
		Anions	**= 7.6290**	**Anions**	**= 18.8846**
	Site 5	Ca^{++}	2.0409	Ca^{++}	2.4202
		Mg^{++}	2.1390	Mg^{++}	2.2789
		$SO_4^{=}$	0.0000	$SO_4^{=}$	0.0000
		Cl^{-}	4.1749	Cl^{-}	4.4288
		HCO_3^{-}	3.7815	HCO_3^{-}	3.7159
		$CO_3^{=}$	0.0181	$CO_3^{=}$	0.0235
		K^{+}	0.1422	K^{+}	0.1962
		Na^{+}	4.7847	Na^{+}	4.9587
		$H_2CO_3^{+}$	0.2002	$H_2CO_3^{+}$	0.1490
		Total ions	**= 17.2815**	**Total ions**	**= 18.1711**
		Cations	**= 9.3070**	**Cations**	**= 10.0029**
		Anions	**= 7.9745**	**Anions**	**= 8.1682**

Figure 4.23: Proportional molar concentrations of major ions during autumn and winter (1994) at Sites 1,3 and 5

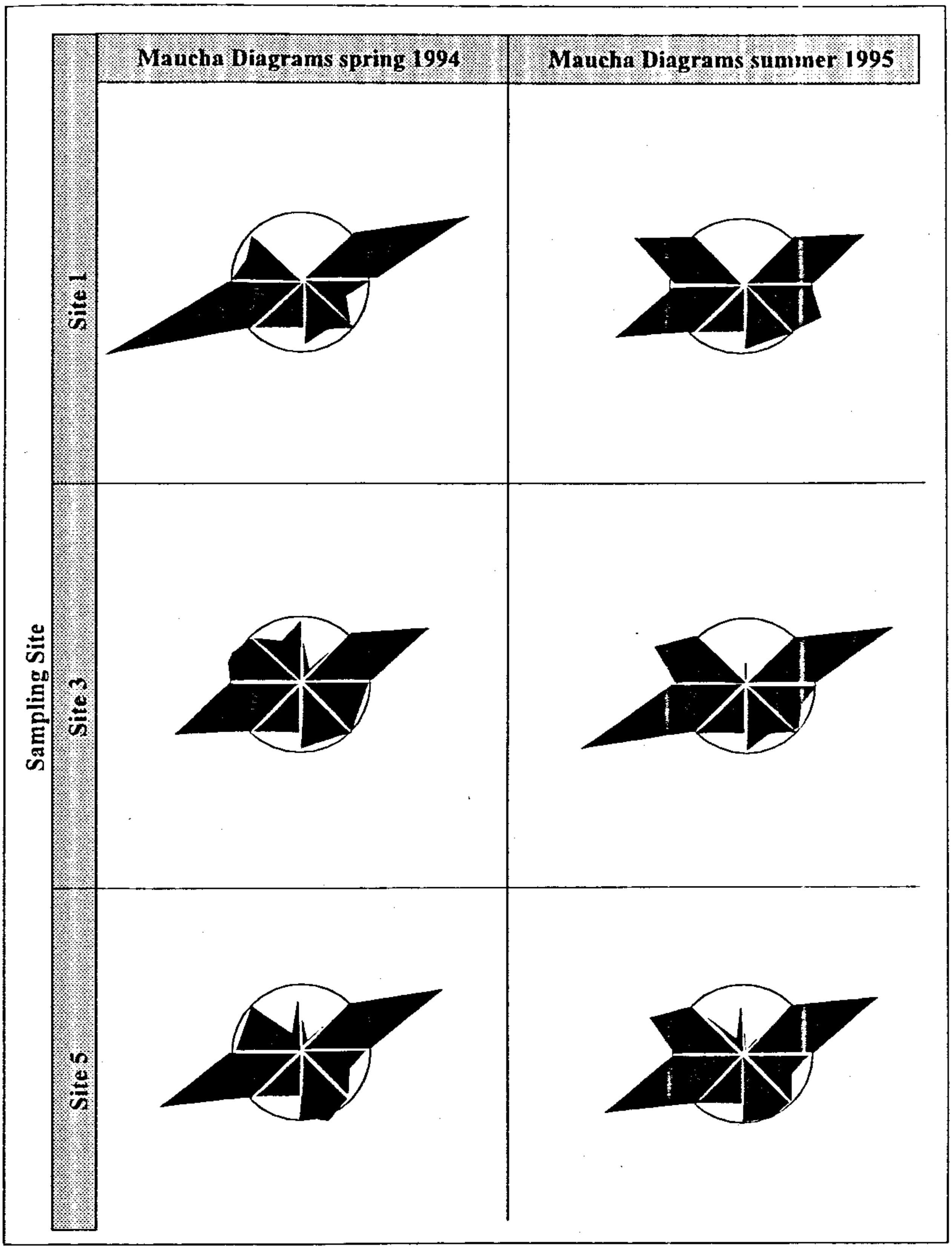


Figure 4.24: Maucha ionic diagrams of the proportional concentrations of major ions during spring (1994) and summer (1995) at Sites 1,3 and 5. *For reference ionic values see page 81.*

Sampling Site	Ion	Proportional molar concentrations spring 1994	Proportional molar concentrations summer 1995
Site 1	Ca^{++}	2.6547	2.3353
	Mg^{++}	3.3896	2.1473
	$SO_4^{=}$	0.0000	0.0000
	Cl^-	12.7504	7.1932
	HCO_3^-	3.5615	3.9879
	$CO_3^{=}$	0.2725	0.0510
	K^+	0.3376	0.1724
	Na^+	10.8743	6.5246
	$H_2CO_3^+$	0.0135	0.0883
	Total ions	**= 33.8539**	**= 22.5000**
	Cations	**= 17.2697**	**= 11.2678**
	Anions	**= 16.5843**	**= 11.2322**
Site 3	Ca^{++}	1.0030	2.2555
	Mg^{++}	1.0037	1.6701
	$SO_4^{=}$	0.0000	0.0000
	Cl^-	2.2285	3.8928
	HCO_3^-	1.2395	3.2942
	$CO_3^{=}$	0.0005	0.0251
	K^+	0.2524	0.0785
	Na^+	2.3054	3.6103
	$H_2CO_3^+$	0.7921	0.1082
	Total ions	**= 8.8250**	**= 14.9346**
	Cations	**= 5.3566**	**= 7.7225**
	Anions	**= 3.4685**	**= 7.2121**
Site 5	Ca^{++}	0.8134	1.6018
	Mg^{++}	1.1682	2.1390
	$SO_4^{=}$	0.0000	0.0000
	Cl^-	2.4542	4.7391
	HCO_3^-	0.9593	3.1033
	$CO_3^{=}$	0.0007	0.5213
	K^+	0.1795	0.1708
	Na^+	2.5228	4.5237
	$H_2CO_3^+$	0.3360	0.0046
	Total ions	**= 8.4340**	**= 16.8037**
	Cations	**= 5.0199**	**= 8.4400**
	Anions	**= 3.4141**	**= 8.3636**

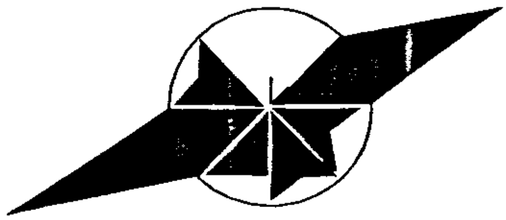
Figure 4.25: Proportional molar concentrations of major ions during spring (1994) and summer (1995) at Sites 1,3 and 5

All data was pooled to establish some idea as to the total concentrations of major ions in the Siyaya Estuary (at Sites 1, 3 and 5) over one sampling year. The resultant Maucha diagrams (one representative of each sampling site) are shown in Figure 4.26. Essentially, the influence of the marine environment was reduced in the upper reaches, while the opposite was true of the influence of freshwater downstream towards the mouth. During April 1995, when the mouth opened, water samples were collected at 5 m, 75 m and 120 m from the estuary/sea interface. The Maucha diagram of proportional ionic concentrations 5 m from the open mouth was the only plot indicative of a seawater dominated system (Figure 4.27). Samples taken at the other two points were similar to diagrams that were constructed for the Siyaya Estuary over the previous year. That is, Na^+ and Cl^- ions were present in only slightly higher concentrations than those indicative of freshening conditions (Ca^+ and HCO_3^-). It must be noted that these samples were taken the day after the mouth opened, and water from the estuary was still flowing out to sea. Figure 4.28 shows that during winter 1995 (three months after breaching of the sandbar at the mouth), the estuary was once again dominated by Na^+ and Cl^- ions. This dominance decreased towards the upper reaches (Site 5), where freshwater ionic conditions predominated.

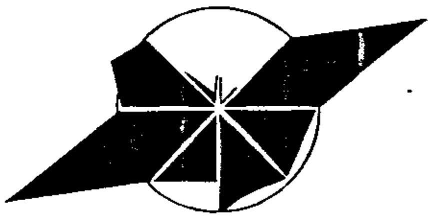
Table 4.8 shows the actual values of ions (mg/l) recorded in the Siyaya Estuary over the study period. Generally all ions, as well as alkalinity measures ($CaCO_3^+$), decreased from the mouth to the head of the estuary. Again, this coincided with the occasional overtopping of the sandbar during high spring tides. Na^+ and Cl^- ions increased dramatically at Site 1 after breaching, in comparison with summer 1995, prior to this event. Na^+ levels in this area were 255 mg/l prior to breaching and 3290 mg/l after, while Cl^- increased from 150 mg/l at Site 1 during summer 1995 to 434 mg/l during winter 1995.

Besides monitoring levels of the major ions constituting the water chemistry of the Siyaya Estuary, additional water quality variables, such as the chemical oxygen demand (COD), pH, total dissolved solids (TDS) and conductivity were also measured for the 1994/1995 period. All except the COD were measured in the field, therefore these parameters were

Proportional molar concentrations of ions:		Maucha Diagrams
		Site 1:
Ca^{++}	3.2186	
Mg^{++}	3.8749	
$SO_4^{=}$	0.0000	
Cl^{-}	14.8886	
HCO_3^{-}	3.8359	
$CO_3^{=}$	0.1569	
K^{+}	0.3069	
Na^{+}	13.1579	
$H_2CO_3^{+}$	0.0276	
Total ions	**= 39.4673**	
Cations	**= 20.5859**	
Anions	**= 18.8814**	



		Site 3:
Ca^{++}	2.4301	
Mg^{++}	2.1719	
$SO_4^{=}$	0.0000	
Cl^{-}	6.2341	
HCO_3^{-}	3.0534	
$CO_3^{=}$	0.0123	
K^{+}	0.1893	
Na^{+}	6.0374	
$H_2CO_3^{+}$	0.1966	
Total ions	**= 20.3251**	
Cations	**= 11.0254**	
Anions	**= 9.2998**	



		Site 5:
Ca^{++}	1.7216	
Mg^{++}	1.9334	
$SO_4^{=}$	0.0000	
Cl^{-}	3.9492	
HCO_3^{-}	3.0124	
$CO_3^{=}$	0.0229	
K^{+}	0.1714	
Na^{+}	4.1975	
$H_2CO_3^{+}$	0.0990	
Total ions	**= 15.1072**	
Cations	**= 8.1227**	
Anions	**= 6.9845**	

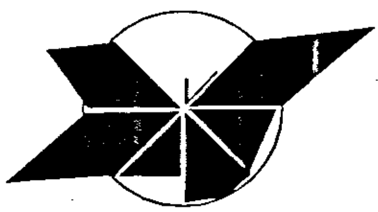
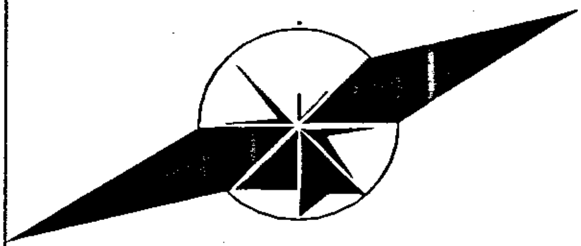


Figure 4.26: Maucha ionic diagrams of the proportional concentrations of major ions over four seasons (mean of Sites 1,3 and 5). Seasons are autumn, winter and spring 1994; summer, 1995. *For reference ionic values see page 81.*

Proportional molar concentrations of ions:		Maucha Diagrams

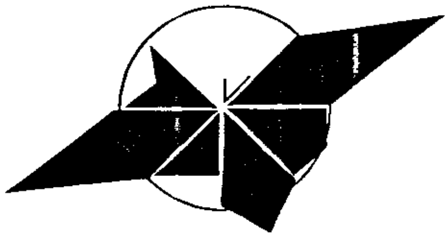
5 m from mouth

Ca^{++}	1.8413
Mg^{++}	4.5742
$SO_4^{=}$	0.0000
Cl^-	19.9718
HCO_3^-	1.2670
$CO_3^{=}$	0.0123
K^+	0.5013
Na^+	18.8778
$H_2CO_3^+$	0.0394
Total ions	**= 47.0851**
Cations	**= 25.8340**
Anions	**= 21.2510**



75 m from mouth

Ca^{++}	1.1128
Mg^{++}	1.4068
$SO_4^{=}$	0.0000
Cl^-	2.4260
HCO_3^-	0.7141
$CO_3^{=}$	0.0052
K^+	0.1020
Na^+	2.5054
$H_2CO_3^+$	0.0234
Total ions	**= 8.2961**
Cations	**= 5.1508**
Anions	**= 3.1453**



120 m from mouth

Ca^{++}	1.1128
Mg^{++}	1.4068
$SO_4^{=}$	0.0000
Cl^-	2.4260
HCO_3^-	0.7141
$CO_3^{=}$	0.0052
K^+	0.1020
Na^+	2.5054
$H_2CO_3^+$	0.0234
Total ions	**= 8.2961**
Cations	**= 5.1508**
Anions	**= 3.1453**

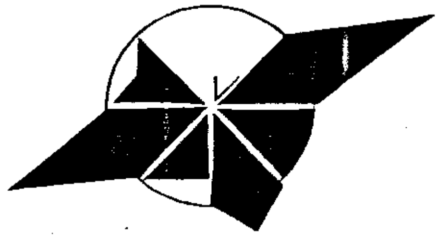
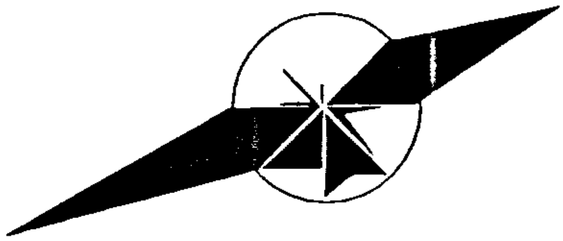


Figure 4.27: Maucha ionic diagrams of the proportional concentrations of major ions during April 1995 (one day after breaching of the sand bar at the mouth). Measurements were taken 5 m, 75 m and120 m upstream from the estuary/sea interface. *For reference ionic values see page 81.*

Proportional molar concentrations of ions:	Maucha Diagrams

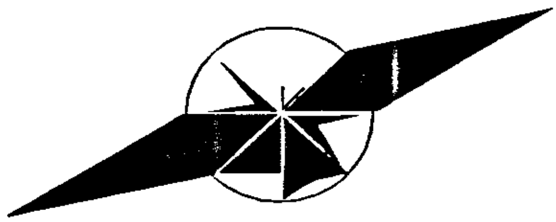
Site 1:

Ca^{++}	6.2874
Mg^{++}	18.6754
$SO_4^{=}$	0.0000
Cl^-	92.8068
HCO_3^-	3.4751
$CO_3^{=}$	0.0442
K^+	1.5601
Na^+	69.1605
$H_2CO_3^+$	0.1108
Total ions	**= 192.1203**
Cations	**= 95.7943**
Anions	**= 96.3260**



Site 3:

Ca^{++}	3.6427
Mg^{++}	7.8157
$SO_4^{=}$	0.0000
Cl^-	30.0423
HCO_3^-	2.7933
$CO_3^{=}$	0.0065
K^+	0.5857
Na^+	29.8826
$H_2CO_3^+$	0.3736
Total ions	**= 75.1424**
Cations	**= 42.3003**
Anions	**= 32.8421**



Site 5:

Ca^{++}	2.0609
Mg^{++}	2.5175
$SO_4^{=}$	0.0000
Cl^-	4.9365
HCO_3^-	1.5984
$CO_3^{=}$	0.0015
K^+	0.1437
Na^+	6.9161
$H_2CO_3^+$	0.4260
Total ions	**= 18.6006**
Cations	**= 12.0641**
Anions	**= 6.5364**

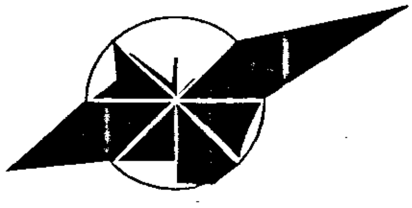


Figure 4.28: Maucha ionic diagrams of the proportional concentrations of major ions during winter, 1995 (Sites 1, 3 and 5). *For reference ionic values see page 81.*

measured at each sampling site (1-5). Results of these analyses are given in Table 4.9. The maximum COD recorded in the Siyaya Estuary over the sampling period, was 38 mg/l at Site 1 during winter 1995. The general pattern was that COD increased from mouth to head of the Siyaya Estuary, except during winter 1994, where the opposite was true. The pH ranged from 6.52 to 9.14 (autumn 1994 to winter 1995), with only a slight decrease in pH in the upper reaches of the estuary, during the open mouth phase. Sites 1 and 2 had slightly higher pH values, relative to those in the middle and upper reaches of the system (Sites 3-5). An exception was during summer 1994, where the pH was fairly stable at Sites 1-4 (mean pH = 7.75), but fairly alkaline at Site 5 (pH = 9.14).

<u>Table 4.8:</u> Concentrations of ions measured at Sites 1, 3 and 5 during autumn, winter, spring (1994), summer and winter (1995). Values in mg/l are compared with those after the mouth open phase (April 1995).

Sampling site		$CaCO_3$	Na	K	Mg	Ca	Cl	Season	Year	Mouth
	1	214	190	9.11	30.10	57.10	282	AUT	1994	Closed
	3	208	99	4.81	22.30	46.90	123			
	5	190	110	5.56	26.00	40.90	148			
	1	191	620	19.10	91.00	101.00	1122	WIN		
	3	177	320	11.95	50.70	82.50	544			
	5	187	114	7.67	27.70	48.50	157			
	1	192	250	13.20	41.20	53.20	452	SPR		
	3	62	53	9.87	12.20	20.10	79			
	5	48	58	7.02	14.20	16.30	87			
	1	202	150	6.74	26.10	46.80	255	SUM	1995	
	3	166	83	3.07	20.30	45.20	138			
	5	182	104	6.68	26.00	32.10	168			
	• 5 m	64	1590	19.60	55.60	36.90	708	*		Open
	• 75 m	36	687	3.99	17.10	22.30	86	*		
	• 120 m	44	159	4.13	17.70	22.40	88	*		
	1	176	434	61.00	227.00	126.00	3290	WIN		
	3	140	57.6	22.90	95.00	73.00	1065			
	5	80	62.3	5.62	30.60	41.30	175			

• refers to distance from estuary/sea interface
* refers to period when mouth was breached (April 1995)

Table 4.9: Table of additional water quality parameters measured in the Siyaya Estuary, autumn 1994 to winter 1995, during mouth open and closed phases.

SAMPLING SITE	COD (mg/l)	pH	TDS (mg/l)	Conductivity (µS)	Season	Year	Mouth
1	15	8.10	702	1400	AUTUMN	1994	
2	*	8.03	593	1179	AUTUMN	1994	
3	25	7.75	399	798	AUTUMN	1994	
4	*	7.76	404	801	AUTUMN	1994	
5	24	7.59	440	867	AUTUMN	1994	
1	22	8.98	2070	4180	WINTER	1994	
2	*	8.68	2010	3910	WINTER	1994	
3	15	7.91	1160	2310	WINTER	1994	
4	*	7.75	604	1169	WINTER	1994	
5	15	7.71	452	817	WINTER	1994	
1	16	8.72	930	1856	SPRING	1994	
2	*	8.52	880	1799	SPRING	1994	
3	34	6.52	204	411	SPRING	1994	
4	*	6.77	187	368	SPRING	1994	
5	32	6.78	228	458	SPRING	1994	
1	16	7.96	619	1233	SUMMER	1994	
2	*	7.77	585	1170	SUMMER	1994	
3	30	7.80	388	777	SUMMER	1994	
4	*	7.60	422	1999	SUMMER	1994	
5	33	9.14	412	829	SUMMER	1994	
• 5 m	33	7.80	1340	2370	♣	1995	MOUTH OPEN
• 75 m	30	7.80	284	561	♣	1995	MOUTH OPEN
•120 m	30	7.80	281	564	♣	1995	MOUTH OPEN
1	38	7.73	4830	9650	WINTER	1995	MOUTH OPEN
2	*	*	4610	9200	WINTER	1995	MOUTH OPEN
3	27	7.16	1730	3500	WINTER	1995	MOUTH OPEN
4	*	*	1130	2280	WINTER	1995	MOUTH OPEN
5	22	6.89	401	8570	WINTER	1995	MOUTH OPEN

• refers to distance from estuary/sea interface
* refers to measurements that were not taken
♣ refers to period when mouth was breached (April 1995)

TDS, conductivity levels, and salinity measurements corroborated the fact that overtopping of the sandbar at the mouth was occasionally taking place. During autumn 1994, when the water quality study commenced, little overtopping had taken place and TDS levels (mg/l) at Sites 1 and 2 were <710 mg/l. However, during the course of the following season, these levels increased to above 2010 mg/l, and TDS at Site 3 increased threefold to 1160 mg/l. It is assumed that little overtopping took place during the course of the following two seasons as TDS levels decreased with time. Subsequent to the opening of the mouth (winter 1995), the TDS levels were >4500 mg/l at Sites 1 and 2, while Sites 3 and 4 also had elevated TDS measurements. For the duration of this study, the TDS at Site 5 never exceeded 450 mg/l, and only fluctuated marginally around this value. The conductivity followed a similar pattern to the TDS. However, where the TDS levels were low and reflected little interchange with the sea, conductivity levels were indicative of the presence of charged ions. This in turn revealed that although salinity levels were close to 0‰ (freshwater), conductivity levels particularly around the mouth of the estuary were elevated. As was expected subsequent to the mouth opening, conductivity around the mouth of the estuary was greater than. 9000 µS. Levels decreased in the middle reaches (3500 and 2280 µS, respectively) and were surprisingly high at Site 5, at the head of the estuary (8570 µS).

Phosphate nutrient levels measured in the Siyaya Estuary were fairly low (generally = 0.05 mg/l for ortho phosphates, and <0.50 for total phosphates (Table 4.10). Nitrates and total nitrogen (nitrates and nitrites) were generally <0.09 mg/l. When the estuary mouth was breached during April 1995, total phosphate and nitrate levels rose markedly (mean values of 1.43 mg/l and 14.48 mg/l, respectively). The heavy rains causing the sandbar to be breached were responsible for transporting large silt loads downstream, and depositing them on the substratum. In turn, nutrients trapped in the sediments may have been released into the water column where they travelled in suspension until they either settled. or were carried out to sea.

Table 4.10: Phosphate and Nitrogen nutrients (mg/l) measured in the Siyaya Estuary over five seasons (autumn 1994 to winter 1995). Ortho and total phosphates were measured, while nitrogen was separated into nitrate and nitrates together with nitrites

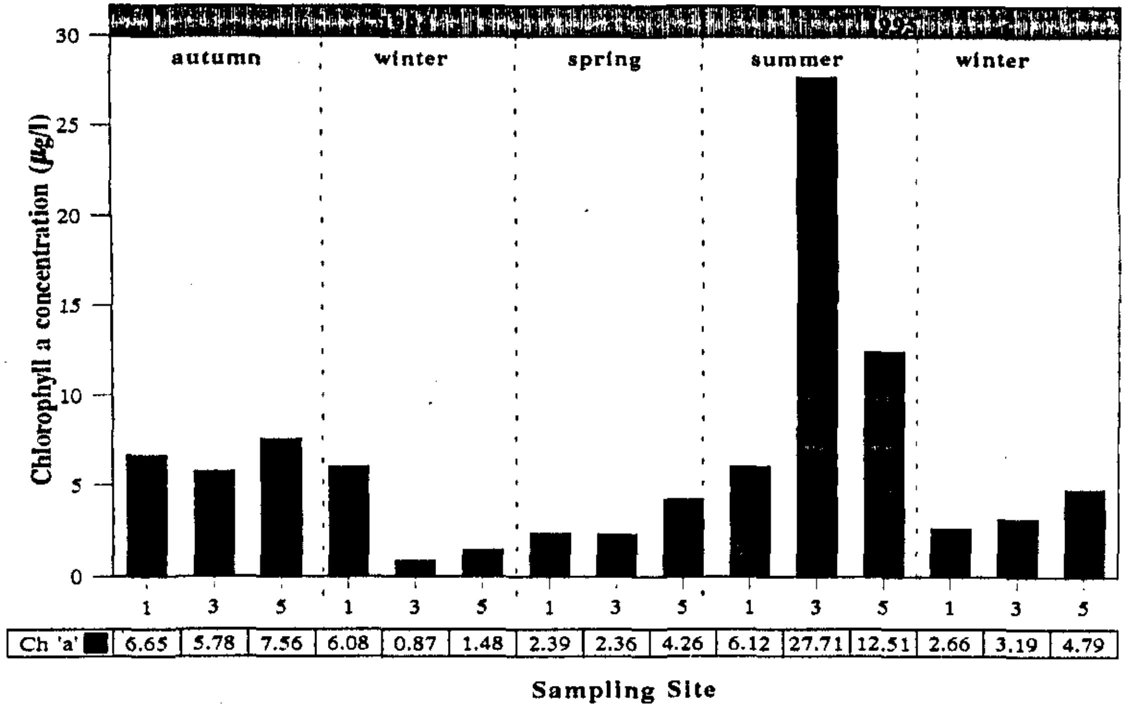
		NUTRIENTS						
		PHOSPHATE (mg/l)		NITROGEN (mg/l)				
		Ortho-	total	Nitrate	Nitrate and Nitrite			
	1	0.03	0.34	0.01	0.06	A		
	3	0.10	0.35	0.01	0.05	U		
	5	0.03	0.24	0.00	0.05	T	1	
S	1	0.23	0.26	0.09	*	W	9	C
A	3	0.09	0.14	0.08	*	I	9	L
M	5	0.16	0.19	0.07	*	N	4	O
P	1	<0.05	0.30	0.09	0.00	S		S
L	3	0.08	0.71	0.08	0.00	P		E
I	5	<0.05	0.46	0.08	0.00	R		D
N	1	0.01	0.69	0.07	0.07	S		
G	3	0.03	0.80	0.08	0.07	U		
	5	0.03	0.14	0.08	0.07	M	1	
S	5 m	<0.05	1.82	13.75	*	♣	9	
I	75 m	0.06	1.28	14.85	*	♣	9	O
T	120 m	<0.05	1.19	14.85	*	♣	5	P
E	1	<0.05	0.25	0.09	0.07	W		E
	3	<0.05	0.42	0.09	0.08	I		N
	5	<0.05	0.46	0.10	0.09	N		

***** - refers to missing values
♣ refers to period when mouth was breached (April 1995)

Chlorophyll '*a*' concentrations in the Siyaya Estuary are given in Figure 4.29. These measurements were <10 µg/l during 1994. But, increased markedly at Site 3 during summer 1995. This measurement coincided with a large presence of floating algae and proliferation of macrophytes, in the area (*pers. obs.*). Low chlorophyll '*a*' concentrations (<5 µg/l) during winter and spring were as a result of decreased phytoplankton production.

4.3.3 Historical ionic levels in the Siyaya Estuary

A summary of the water physico-chemical characteristics measured in the Siyaya Estuary over a decade ago, are presented in Table 4.10. These data may only be compared to



Ch 'a'	6.65	5.78	7.56	6.08	0.87	1.48	2.39	2.36	4.26	6.12	27.71	12.51	2.66	3.19	4.79

Figure 4.29: Graph of Chlorophyll 'a' concentrations (μg/l) in the Siyaya Estuary at Sites 1, 3 and 5 during autumn,winter, spring (1994), summer and winter (1995)

Table 4.11: Summary of Physico-chemical charcteristics of the Siyaya Estuary, taken at quarterly surveys between November 1981 and February 1984. (After Archibald *et. al.*, 1984)

	LAG 1 (*Present Site 4*)			LAG 2 (*Present Site 3*)			LAG 3 (*Present Site 2*)			LAG 4 (*Present Site 1*)		
	Max	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
Maximum Depth (m)	0.95	0.10	0.35	2.20	0.90	1.18	1.98	0.32	0.88	1.52	0.10	0.50
Temperature (°C)	25.2	18.0	22.5	26.2	17.5	22.9	26.5	20.8	23.8	27.0	23.0	25.4
pH	7.43	6.43	-	7.35	6.22	-	7.53	6.32	-	8.20	7.10	-
Conductivity (mS/m @ 20 °C)	53.3	28.0	38.0	93.3	27.9	47.4	439.1	23.9	130.2	990.8	49.4	386
Total Dissolved Solids (mg/l)	355	187	253	622	186	316	2927	159	868	7160	329	2571
Alkalinity (mg $CaCO_3$/l)	42	5	22	83	5	35	166	12	66	225	27	101
Dissolved O_2 (% saturation)	105	37	74	62	36	49	66	18	48	101	36	64
Total soluable P (µg P/l)	55	5	19	70	18	35	156	13	35	148	12	35
Total P (µg P/l)	204	21	84	229	45	136	424	25	99	383	19	75
Ammonia (µgN/l)	162	8	66	475	32	107	872	8	124	821	5	98
Nitrate (µgN/l)	3903	8	1819	2847	62	1553	2886	5	695	2386	11	343
Nitrite (µgN/l)	27	1	9	24	2	12	64	1	14	49	0	8
Chlorophyll "a" (µg/l)	4	1	2	6	1	3	10	2	6	9	1	4
Turbidity (JTU)	126	6	66	58	13	39	33	4	10	3	2	2
Ca (mg/l)	15.7	5.1	9.1	15.6	5.6	12.1	54.6	1.8	24.6	107.0	15.0	47.3
Mg (mg/l)	16.9	6.7	10.9	20.2	5.7	12.1	124.5	1.6	30.8	291.0	13.0	72.7
Na (mg/l)	64.9	35.8	50.9	155.4	33.2	64.1	872.6	25.5	255.9	2181.2	50.5	716.9
K (mg/l)	5.0	2.9	3.1	7.8	2.1	4.1	27.5	0.4	9.1	62.3	3.4	19.8
Cl (mg/l)	139.8	61.4	91.0	255.8	62.3	113.4	1600.0	50.3	396.8	3594.0	100.0	868.8

measurements taken at Sites 1-4 in the present study, as four sites (lags) corresponding to the present sampling sites were used in the first survey. Parameters such as depth and temperature, do not appear to have undergone a marked change through time. However nitrogen nutrient levels during that time were considerably higher (Compare Tables 4.9 and 4.10). That is, nitrate values during the present study were <0.09 mg/l at all sampling sites compared with mean nitrate values of 1.82 mg/l at lag 1 (Site 4), 1.55 mg/l at lag 2 (Site 3), .695 mg/l at lag 3 (Site 2), and .343 mg/l at lag 4 (present Site 1). All the major ions also exhibited a decreasing gradient of concentration from mouth to head of the estuary from each quarterly survey between 1981 and 1984 (lag 4 - lag 1). A decrease in Na^+ and Cl^- concentrations, and declining conductivity and TDS was congruous to a decline in salinity (data not shown on Table 4.11).

4.3.4 Sediment Analysis

Results of analyses on sediments from the Siyaya Estuary, are given in Figures 4.30 to 4.40 and Tables 4.11 and 4.12.

4.3.4.1 Grain Size

The range of sediments from head (Site 5) to mouth (Site 1) of the Siyaya Estuary was, fine sands in the upper reaches, with very coarse sand at Sites 4 and 2. The substratum at Sites 1 and 3 constituted coarse sand. Figures 4.30 to 4.31 are plots of percentage cumulative dry weight against Phi (ø) values of sediments sampled at Sites 1-5. During summer 1992, median ø values fell within the range of ø0.40 - ø3.30 (Figure 4.30). According to the Wentworth Scale (Morgans, 1956; Gray, 1981), the type of sediment associated with these ø values, is very coarse to fine sand. Two years later, during autumn 1994, the median ø value for sediments in the Siyaya Estuary was >1.0 (Figure 4.31). Coarse sand was present along the length of the estuary, except at Site 3. Here sediments had shifted to a category described as very coarse sand, by the Wentworth scale. Sediments at Site 5 continued to constitute fine sand.

The entire estuary constituted sediments comprising coarse sand during winter 1994 (Figure 4.32). A surprising change was at Site 5, where the median ø value was ø0.60,

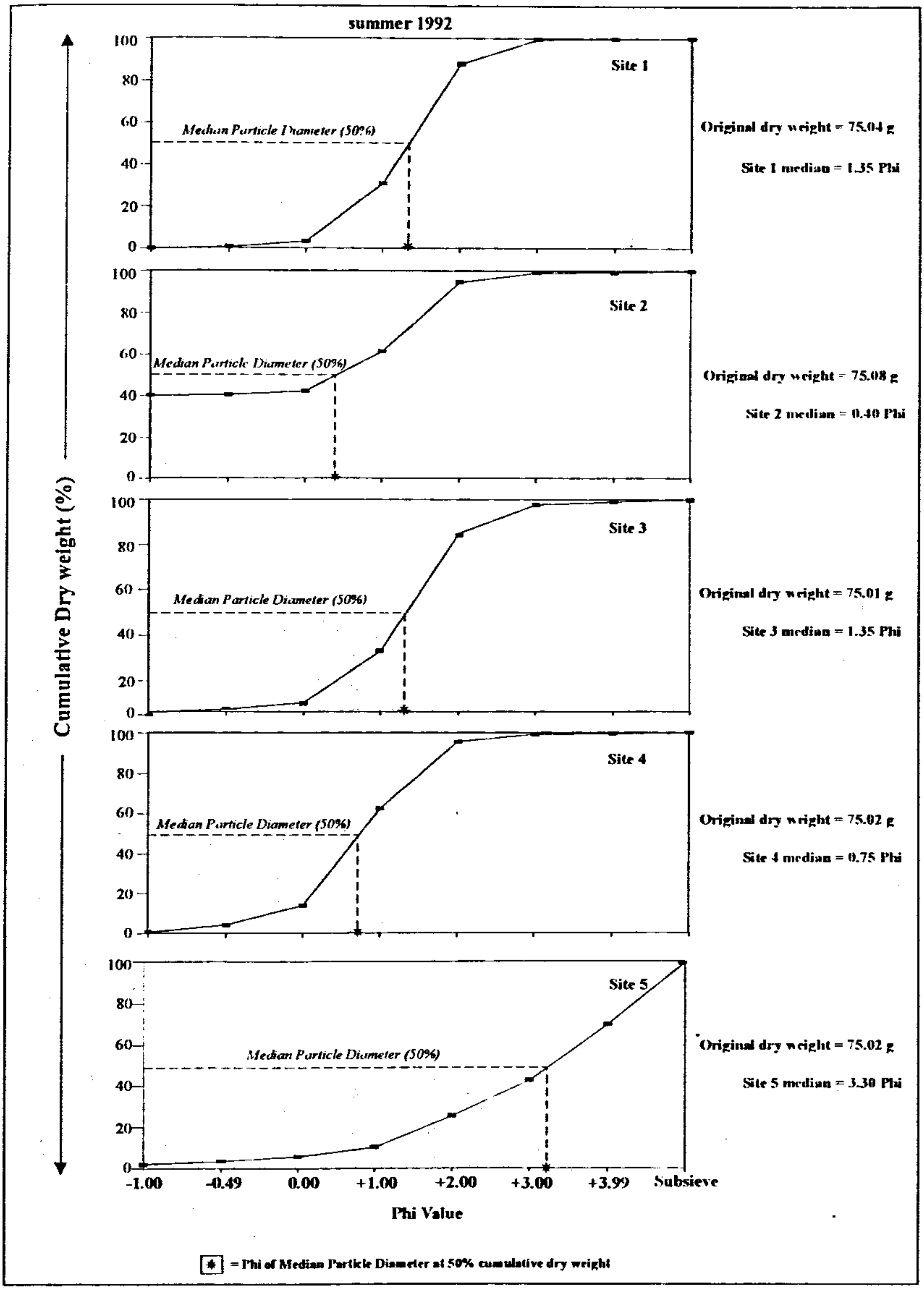


Figure 4.30: Percentage cumulative dry weight against Phi values of sediment samples taken at Sites 1-5 during summer 1992. Lines drawn at 50% cumulative weights represent the median particle diameter for a particular site (in Phi)

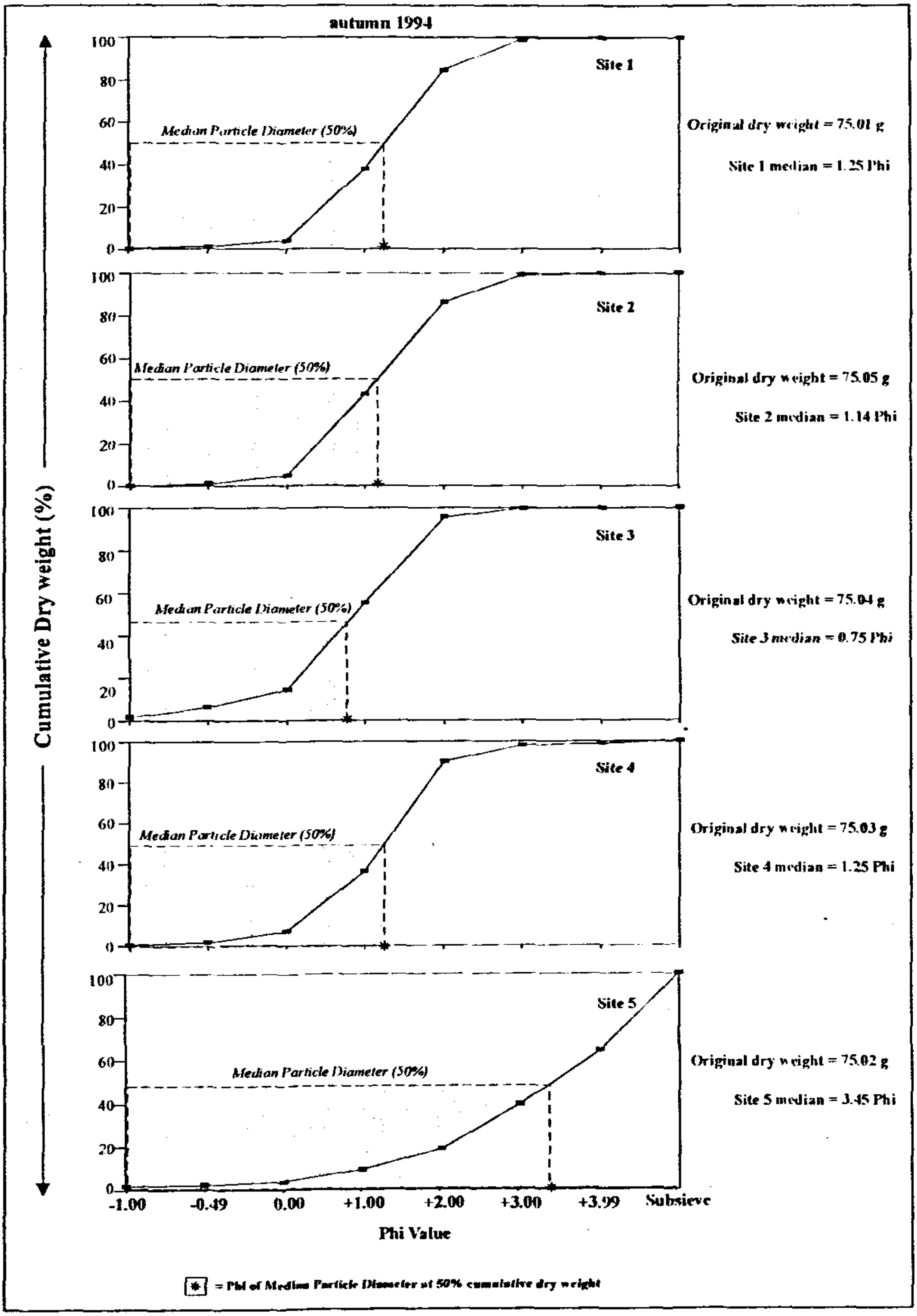


Figure 4.31: Percentage cumulative dry weight against Phi values of sediment samples taken at Sites 1-5 during autumn 1994. Lines drawn at 50% cumulative weights represent the median particle diameter for a particular site (in Phi)

corresponding to very coarse sand. This provided some indication as to the 'patchy' nature of the sediments within the Siyaya Estuary. No heavy rains had fallen between 1992 and 1994, thus scouring of the estuary bed was excluded as being responsible for the change in sediment type. During spring 1994, Site 3 was classified as very coarse sand which was similar to autumn 1994 (Figure 4.33). But for this, the pattern of sediment types was similar to those sampled during winter 1994. The final sampling was conducted during summer 1995 (Figure 4.34). This concluded one full year of study over four different seasons, which was comparable to the original 'once off' sampling performed during summer 1992. Sites 1-4 had substrata of coarse sands, and Site 5 had a median ø =3.99, corresponding to a range of fine to very fine sand.

The coarse nature of the sands at Site 1, increased slightly in coarseness upstream at Sites 2 and 3 (Figure 4.35). At the head of the estuary (Site 5), the sediments constituted medium to fine-grained sands.

The sorting co-efficient was another important character of sediment measured. Results of the mean sorting co-efficients from five sites, 1992-1994 are given in Figure 4.36. Sediments at Site 1 are moderately sorted, moderately well sorted at Site 2, and very poorly sorted at Site 3. Sediments at Sites 4 and 5 fell within the same sorting category. That is, sediments that are poorly sorted. As sorting is a measure of the spread of grain distribution, sediments at Sites 3,4 and 5 were not evenly distributed in terms of grain size.

4.3.4.1 Organic and Silt Content

The results of calculating the percentage organic content of samples from each site revealed that Sites 1-3 were low in organic content (0.5 - 1.0%), and those at Site 4 had a moderately low to medium organic content (1.0 - 4.0%) (Figure 4.37). Sediments at Site 5 had a high organic content (>4.0%), as was expected from the thick layer of detritus on the estuary bed.

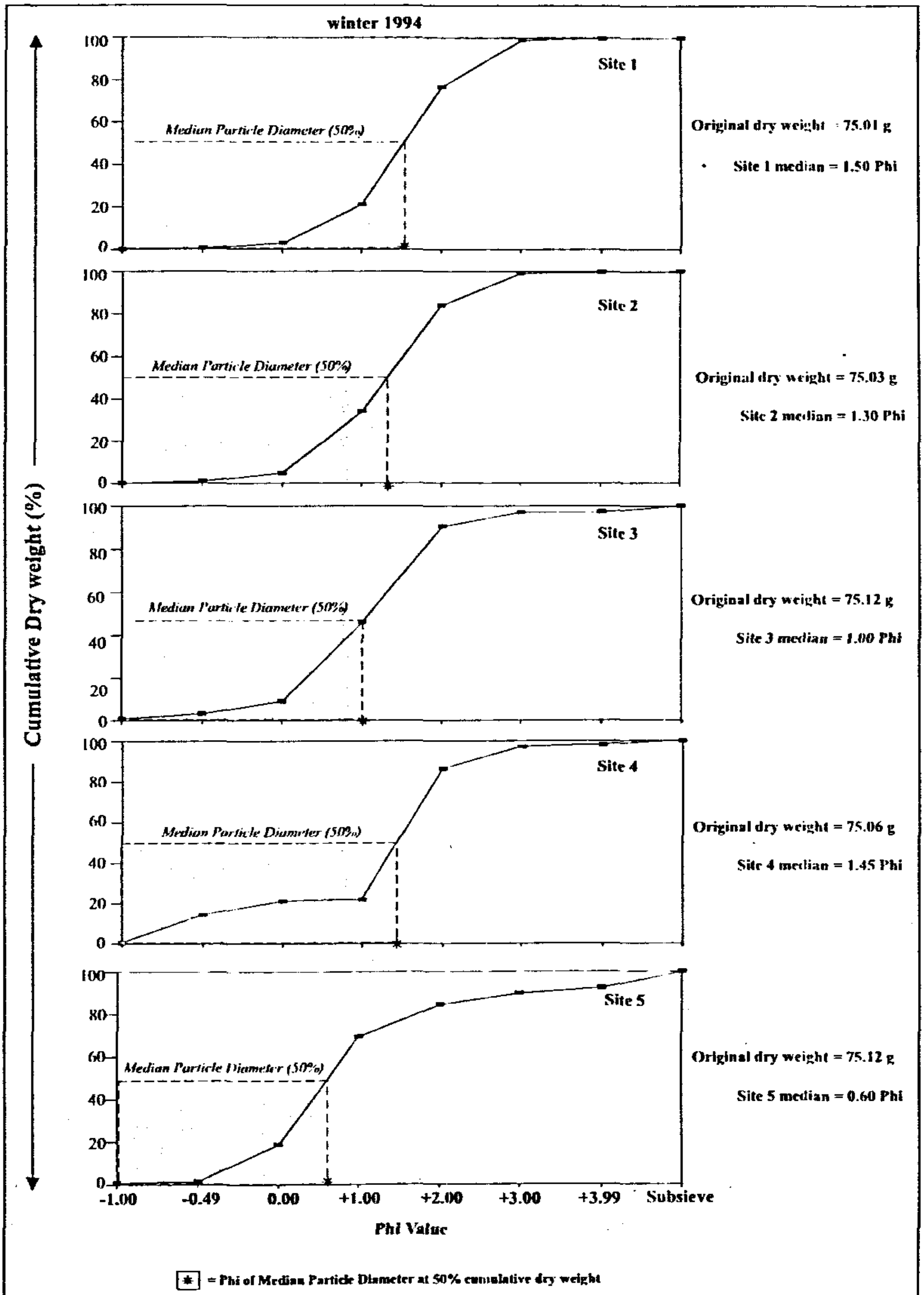


Figure 4.32: Percentage cumulative dry weight against Phi values of sediment samples taken at Sites 1-5 during winter 1994. Lines drawn at 50% cumulative weights represent the median particle diameter for a particular site (in Phi)

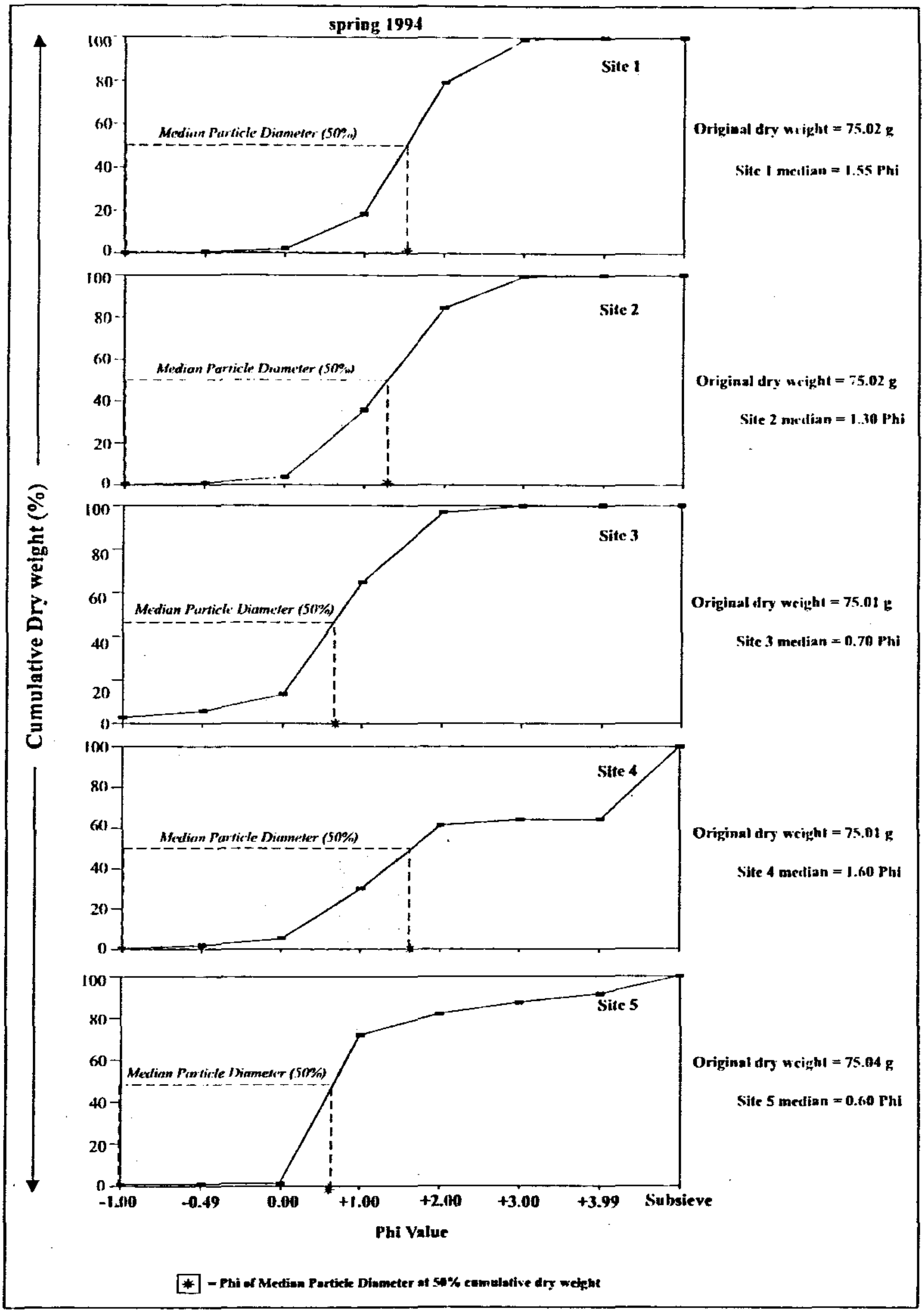


Figure 4.33: Percentage cumulative dry weight against Phi values of sediment samples taken at Sites 1-5 during spring 1994. Lines drawn at 50% cumulative weights represent the median particle diameter for a particular site (in Phi)

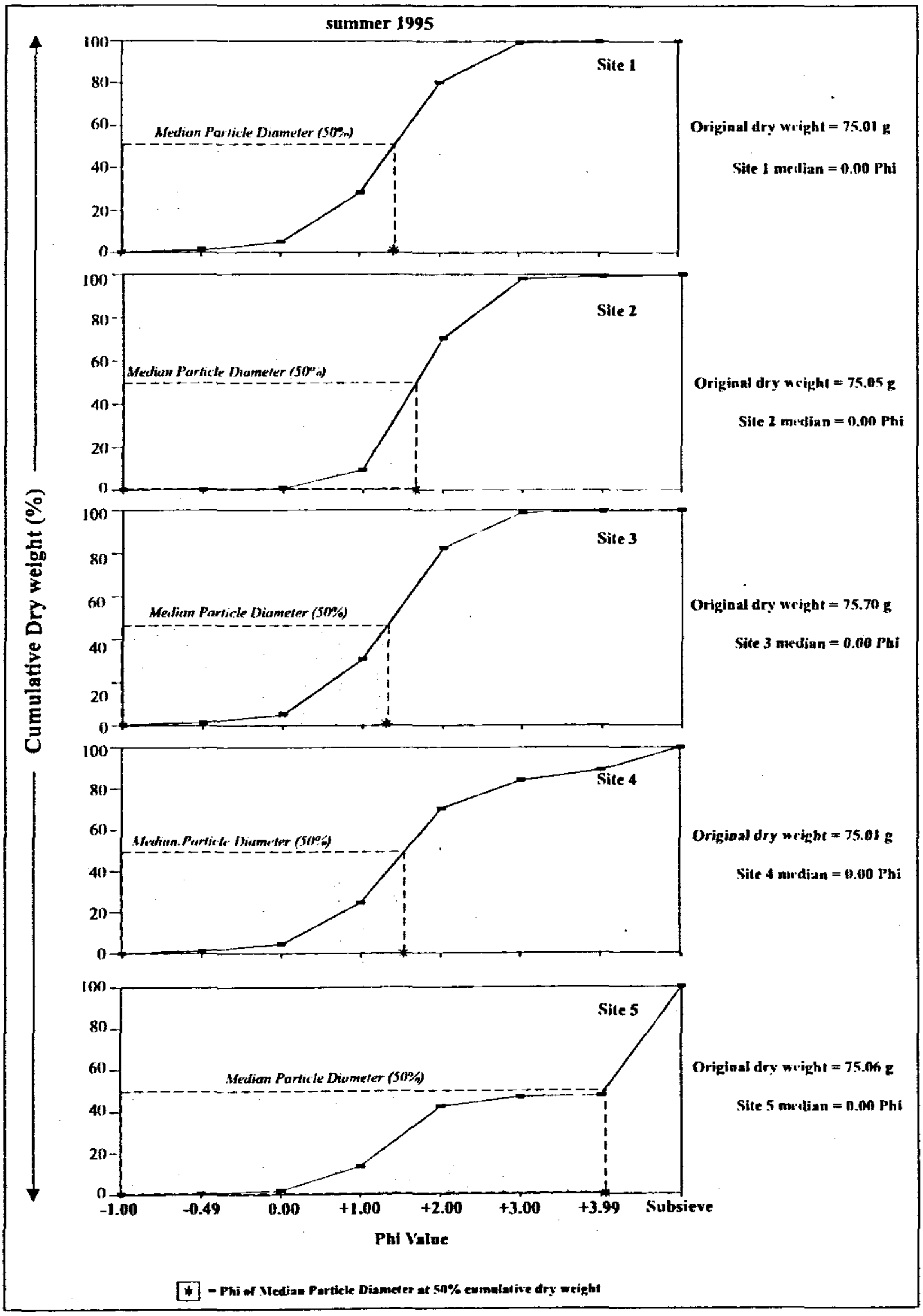


Figure 4.34: Percentage cumulative dry weight against Phi values of sediment samples taken at Sites 1-5 during summer 1995. Lines drawn at 50% cumulative weights represent the median particle diameter for a particular site (in Phi)

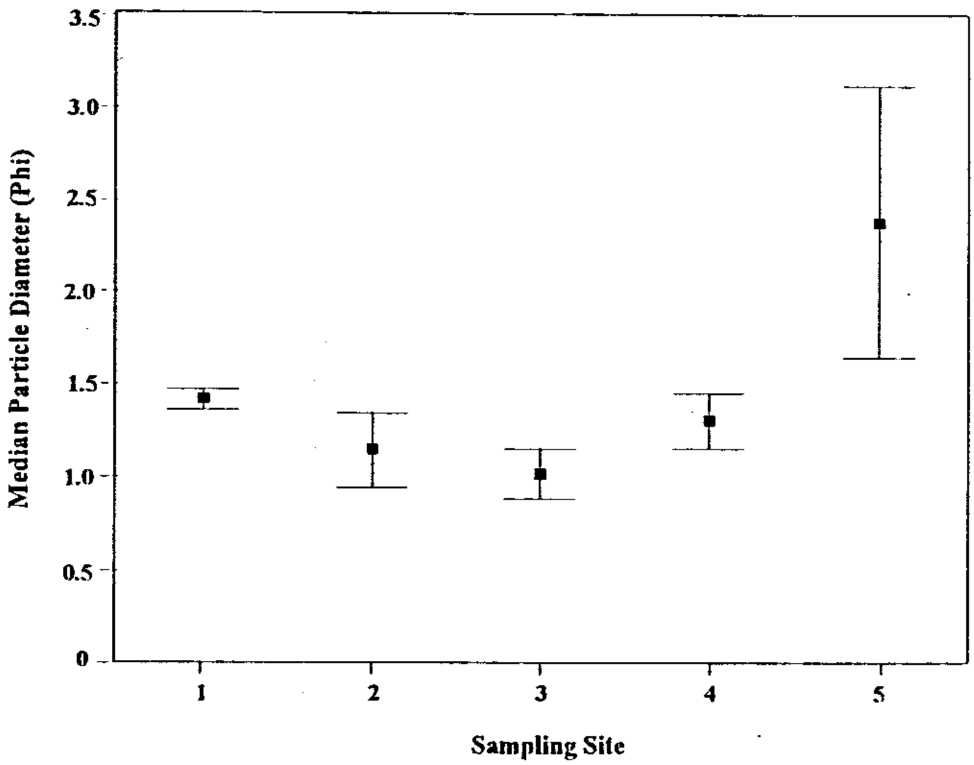


Figure 4.35: Mean median Particle diameter (phi) of sediments from five sites. samples were collected during summer 1992, autumn, winter and spring 1994 and summer 1995. n = 5, and error bars represent one standard error

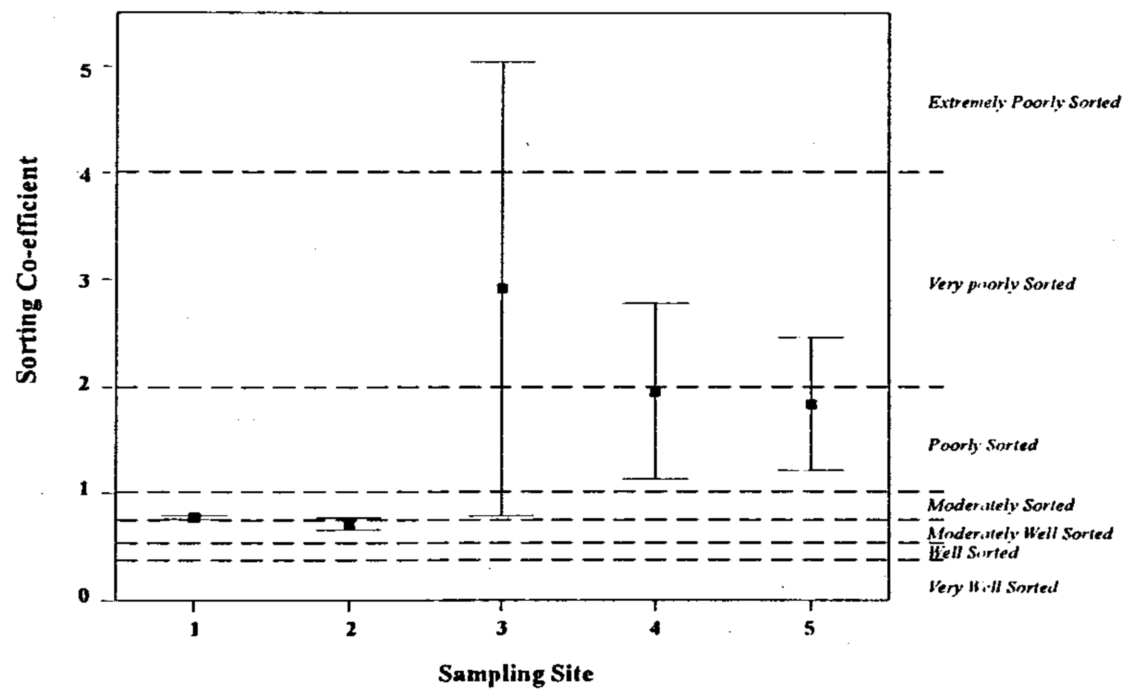


Figure 4.36: Mean sorting co-efficient of sediments from five sites. Samples were collected during summer 1992, autumn, winter and spring 1994 and summer 1995. n = 5, and error bars represent one standard error. Gray's (1981) sorting classes have been used on the Y2 axis

To examine whether there was the expected decreasing gradient of silt from head to of the estuary, the percentage silt content was plotted for each site (Figure 4.38). Sediments at Sites 1-3 had silt contents that were <1.0 %. The percentage silt increased slightly at Site 4 to 3.0 %, and markedly at Site 5 to almost 20%, over the sampling period. This was adequately explained by the past history of the Siyaya Estuary, which is a large runoff, with equally large amounts of silt deposition. It may be concluded that silt was not transported too far downstream. This is subsequent to the occurrence of two major cyclones, which failed to scour the estuary.

To determine if there was a significant relationship between silt and organic content, the regression of mean silt content (%) versus mean organic content (%) was plotted (Figure 4.39). The linear regression yielded a high F - Ratio (389.54), with a corresponding probability level of .0003. That is, it was highly significant ($p<.0001$). R - squared was equal to 99.2%, and was interpreted as: 99.2% of the variability occurring in organic content, could be explained by the percentage silt content.

The actual values of the seasonal differences in sediment characteristics are presented in Table 4.12. A difference in the pattern of a decreasing mean particle diameter of sediments upstream, occurred during winter and spring of 1994. A decrease in Phi value corresponded to a increase in the grain size of sediments sampled. Site 3 (1992), had the highest sorting co-efficient at 11.4303, while Site 2 (1992) had the lowest at 0.7205. The percentage organic content increased slightly during autumn and winter 1994, at all sites and particularly at Site 5. This seemed to correspond to a decrease in production, and dying off of large areas of the swamp reed *P. australis* (*pers. obs.*). As a consequence of these events, large amounts of detrital matter are produced, forming a layer on the substrate, particularly at Site 5.

Over the study period, there was a significant decrease ($p<0.05$) in the amount of silt at Site 5 in the Siyaya Estuary. This decrease occurred in winter 1994, and by summer 1995, was down to 1.12% (as compared with >30.0% during summer 1992). However,

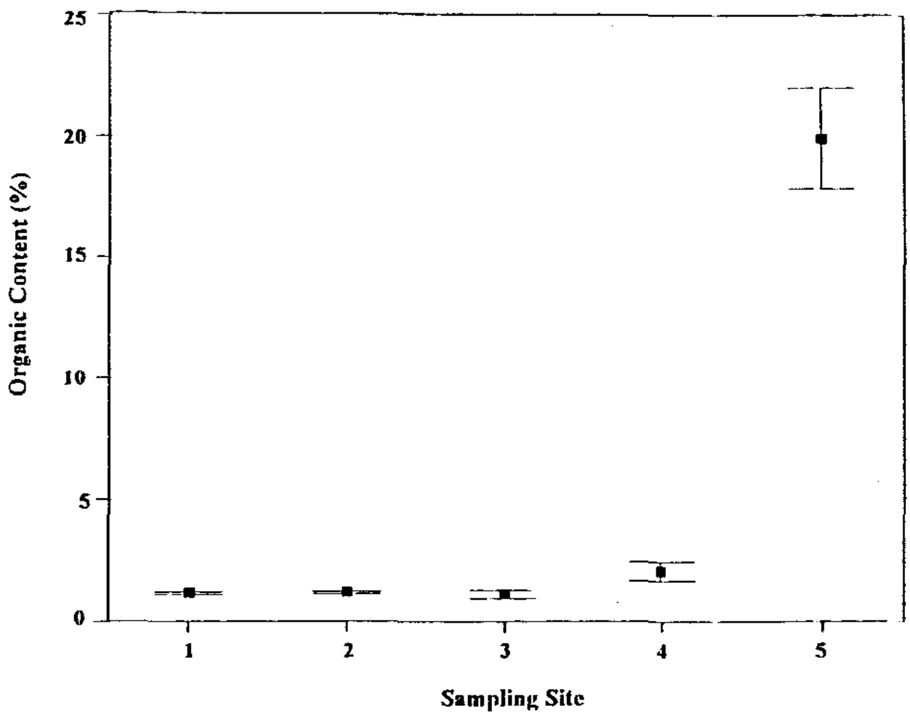


Figure 4.37: Percentage Organic Content of sediments sampled at five sites. Samples were collected during summer 1992, autumn, winter and spring 1994 and summer 1995. n = 5, and error bars represent one standard error.

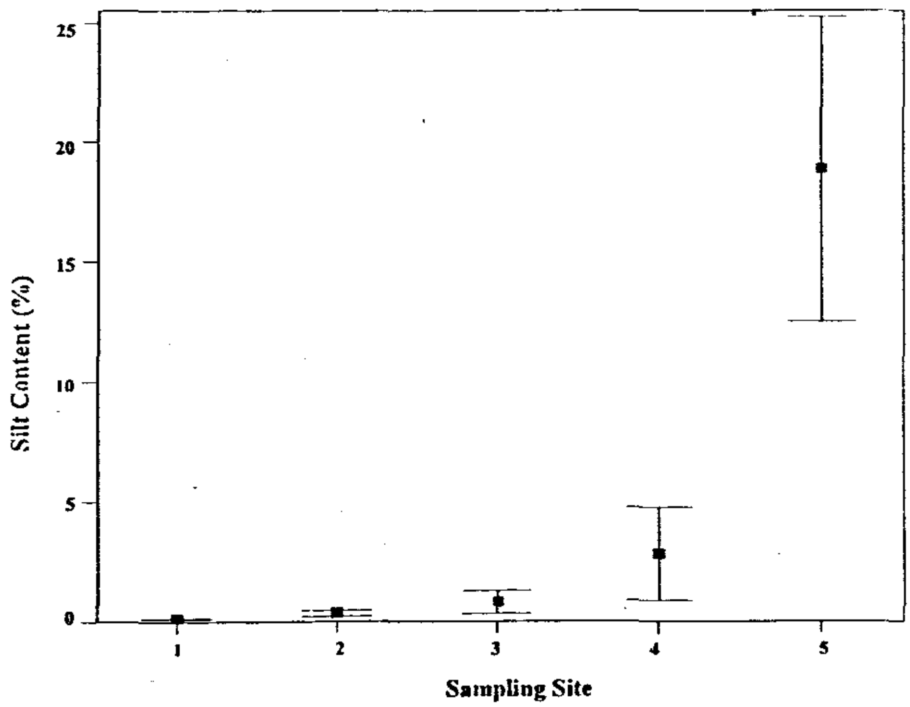


Figure 4.38: Percentage Silt Content of sediments sampled at five sites. Samples were collected during summer 1992, autumn, winter and spring 1994 and summer 1995. n = 5, and error bars represent one standard error.

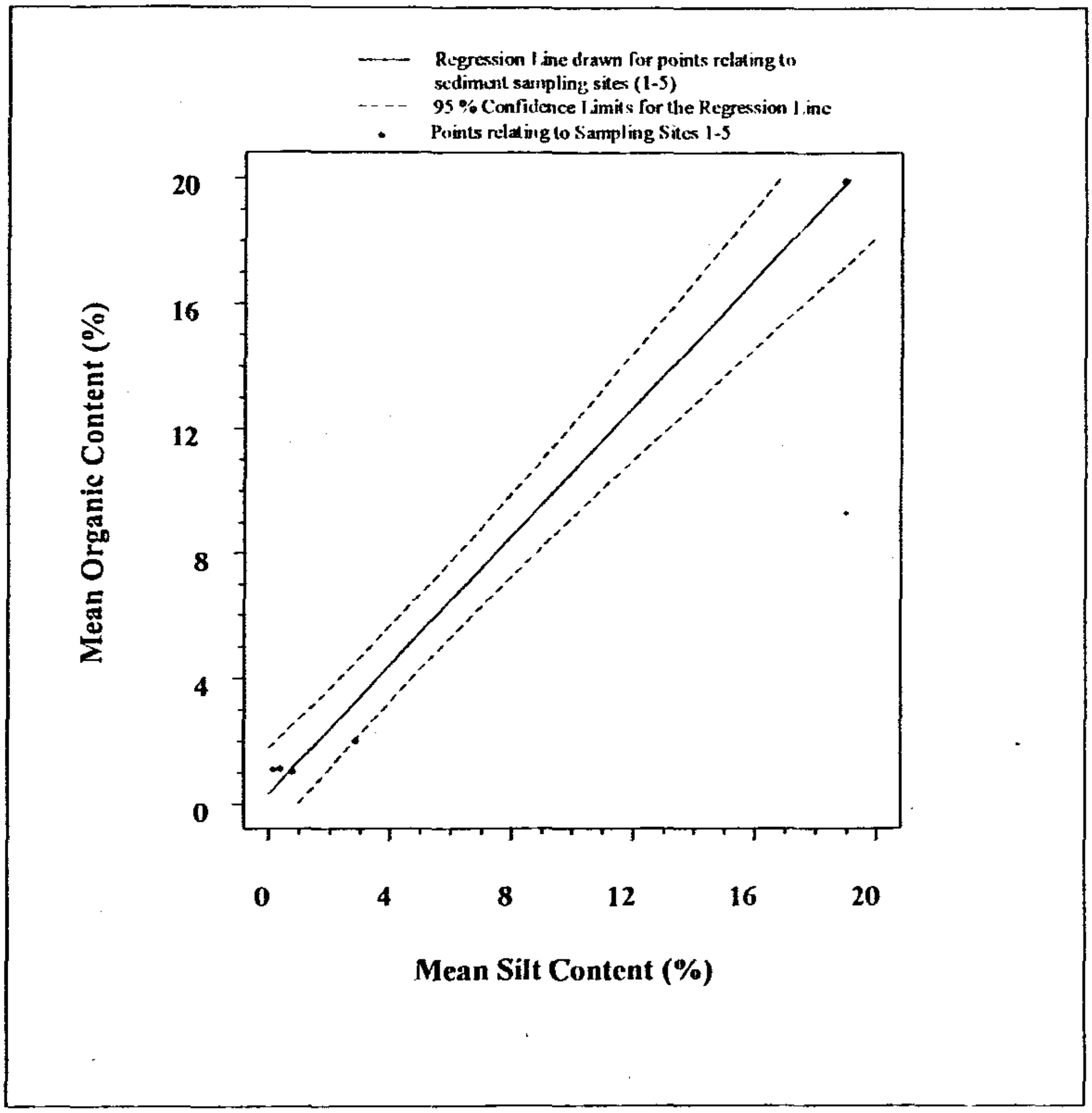


Figure 4.39: Mean Silt content (%) against mean organic content (%) of sediment samples. Straight line is the regression drawn for points relating to sediment sampling sites (1-5). Dashed line is 95% confidence limit for the regression. Points relate to sampling Sites 1-5

during summer 1995 there was a subsequent increase in the percentage silt within the sediments at Site 4 (0.48% during 1992, to 10.54% in 1995).

Table 4.12: Values of Mean Particle Diameter (Phi), Sorting Co-efficient, percentage Organic and Silt content of sediments from the Siyaya Estuary. Sediments were sampled at Sites 1-5, during summer 1992, autumn, winter and spring, 1994, and summer 1995.

Season	Sampling Site	Mean Particle Diameter (Phi)	Sorting Co-efficient	% Organic Content	% Silt
summer 1992	1	1.35	0.7489	1.05	0.11
	2	0.40	0.7205	1.03	0.63
	3	1.35	11.4303	1.75	0.81
	4	0.75	5.2133	1.02	0.48
	5	3.30	4.3073	16.16	30.05
autumn 1994	1	1.25	0.7939	1.15	0.15
	2	1.14	0.7864	1.16	0.15
	3	0.75	0.8189	0.81	0.10
	4	1.25	0.7943	2.67	1.07
	5	3.45	1.1891	27.63	34.86
winter 1994	1	1.50	0.7594	1.24	0.17
	2	1.30	0.8492	1.23	0.16
	3	1.00	0.8117	1.00	2.64
	4	1.45	1.0652	2.71	1.74
	5	0.60	1.1375	21.04	20.35
spring 1994	1	1.55	0.7311	1.02	0.16
	2	1.30	0.5152	1.12	0.111
	3	0.70	0.7345	0.93	0.08
	4	1.60	1.477	1.16	0.28
	5	0.60	1.267	16.65	7.95
summer 1995	1	1.45	0.836	1.24	0.10
	2	1.60	0.7011	1.33	0.72
	3	1.30	0.7939	0.99	0.41
	4	1.50	1.2295	2.69	10.54
	5	3.99	1.2797	18.35	1.12

In the estuary, Site 5 had the highest mean particle diameter (2.39 phi; standard error = 0.74), while Site 3 had the lowest (1.02 phi; standard error = 0.13) (Table 4.13). This was interpreted as: the finest-grained sands occurred at Site 5, while the coarsest sands occurred at Site 3. In terms of mean sorting co-efficient, Site 3 was the most poorly sorted followed by Sites 4 and 5. As the sorting co-efficient is an indication of the spread of grain size, sediments at these sites exhibit a 'patchy' distribution. That is, there is no uniform sediment type in these areas, but rather areas of finer and coarser-grained sands.

The highest mean organic content was at Site 5 (19.97%; standard error = 2.10), and the lowest at Site 3 (1.09%; standard error = 0.17). This was the situation with mean percentage silt, although the least amount of silt within the sediments occurred at Site 1 (0.14%; standard error = 0.01).

Table 4.13: Statistical summary (mean, standard error, minimum and maximum values) of measurements of mean Particle Diameter (Phi), mean Sorting Co-efficient, mean percentage Organic and Silt content of sediments from the Siyaya Estuary. Sediments were sampled at Sites 1-5, over the study period.

Site	Mean Particle Diameter		Mean Sorting Co-efficient	
	mean (s.error)	min-max	mean (s.error)	min-max
1	1.42 (0.05)	1.25-1.55	0.7739 (0.0186)	0.7311-0.8360
2	1.15 (0.20)	0.40-1.60	0.7145 (0.0562)	0.5152-0.8492
3	1.02 (0.13)	0.70-1.35	2.9179 (2.1281)	0.7345-11.4303
4	1.31 (0.15)	0.75-1.60	1.9559 (0.8219)	0.7943-5.2133
5	2.39 (0.74)	0.60-3.99	1.8355 (0.6185)	1.1375-4.3073

Site	Mean % Organic Content		Mean % Silt	
	mean (s.error)	min-max	mean (s.error)	min-max
1	1.14 (0.05)	1.02-1.24	0.14 (0.01)	0.10-0.17
2	1.17 (0.05)	1.03-0.85	0.35 (0.13)	0.11-0.72
3	1.09 (0.17)	0.81-11.43	0.81 (0.48)	0.08-2.65
4	2.05 (0.39)	1.02-5.21	2.82 (1.95)	0.28-10.54
5	19.97 (2.10)	16.61-4.31	18.87 (6.39)	1.12-34.86

Multivariate analyses were conducted on all sediment samples from the Siyaya Estuary. These included a ranked cluster analysis of the samples using Normalised ranked Euclidean Distance (Figure 4.40 A), and a non-metric multidimensional scaling ordination (Figure 4.40 B). Results of the cluster analysis revealed that Site 5 samples (summer, 1992; autumn, winter and spring, 1994; summer 1995), were separate from other sites. At a similarity of 100, winter and spring samples of 1994, and summer 1992 sediment samples were grouped together. The plot of the MDS ordination (2d minimum stress =

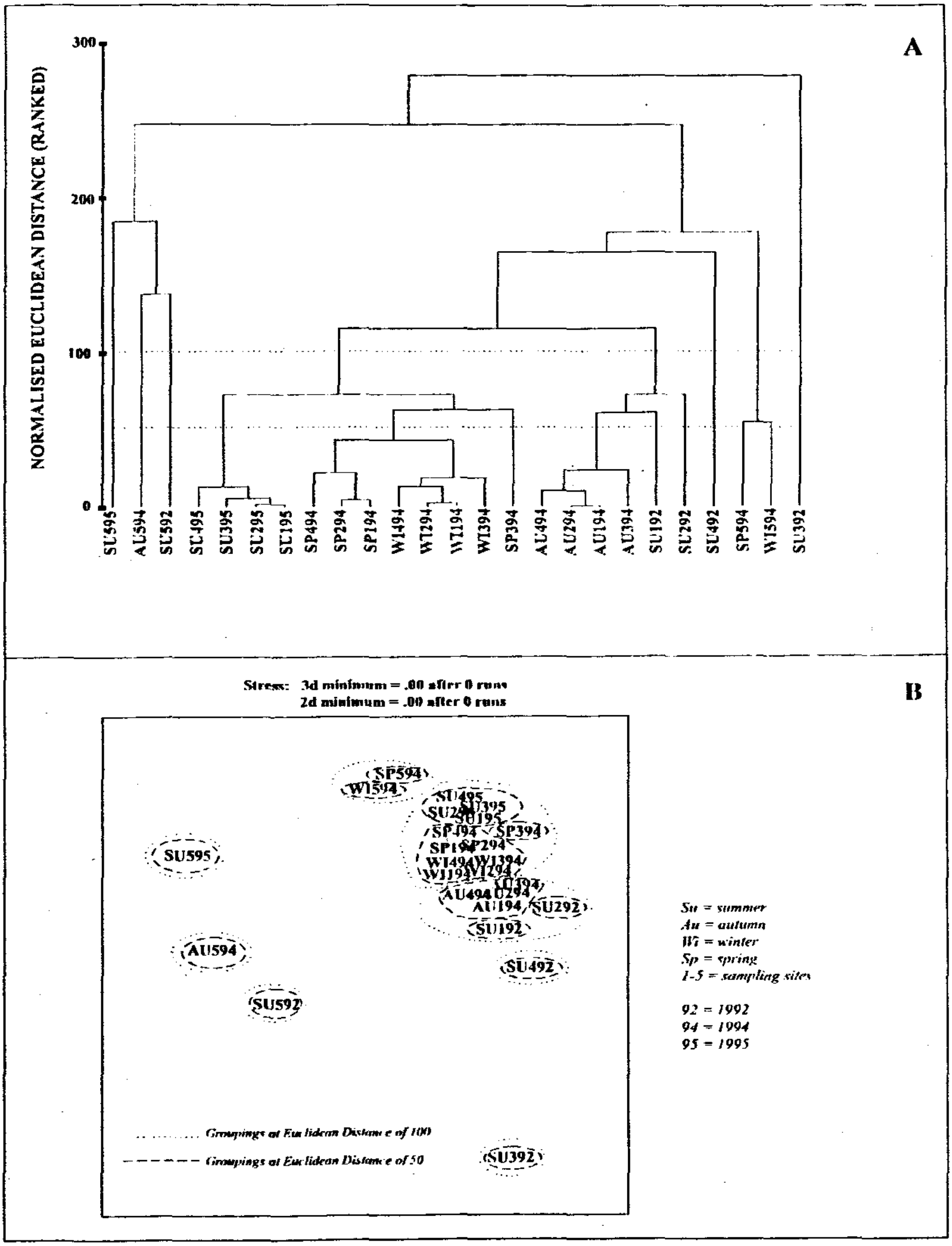


Figure 4.40 A: Ranked cluster analysis of sediment samples. Each is representative of median grain size, percentage organic content, percentage silt and sorting co-efficient for all sampling sites. Lines are drawn at normalised Euclidean distances of 100 and 50.

B: 2d results of MDS of the above samples with lines drawn around groups at distances of 100 and 50. Stress for MDS is .20 after 10 runs

.20 after 10 runs), confirmed this pattern. Sediment characteristics at Site 5 in the Siyaya Estuary were not similar to those at any other site, during any season.

4.4 Discussion

By monitoring the physico-chemical parameters of the Siyaya Estuary over an extended period, it was possible to determine the current state of the water quality of the system. Dallas and Day (1993), define water quality as the combined effect of the physical attributes and chemical constituents of a sample of water for a particular user. The physico-chemical characteristics of the Siyaya Estuary are affected by, and reflect the present phase of the system. That is, it is a river mouth blocked off by a sand bar, with the river water having no free access to the sea, but terminating in a coastal lagoon (Reddering and Rust, 1990). Top and bottom measurements of variables (particularly temperature, salinity and oxygen; Figures 4.3 - 4.12) indicate that it is a well-mixed estuary. This was attributed to its shallow nature (mean depth = 1.6 m; standard error = 0.06), and perhaps also as a result of turbulent mixing from surface to bottom (Day, 1981b).

The physical components of the water quality of the Siyaya Estuary are summarised as follows: The Siyaya Estuary is a relatively shallow system, with the more shallow areas occurring in the upper and lower reaches. The reasons for the shallow nature of the estuary, may be twofold. Several years of continued drought greatly reduced the average depth, particularly on a seasonal basis, and this was exacerbated by silt deposition. Silt deposition is now probably at a minimum, and has been decreasing over the last decade as a result of a change in catchment landuse (sugarcane to forestry). However, the period of silt deposition and accumulation during the 1970's still has an effect on the estuary. The average depth of the estuary did not increase subsequent to opening of the mouth, therefore it is assumed that no scouring took place during the most recent flooding. Multifactor Analysis of Variance indicated that factors of site, sampling season and year of study had a significant effect on depth ($p<0.05$). Briefly, the Siyaya Estuary became increasingly shallower throughout the study period (Figure 4.3). This was especially true at Sites 1 and 5 (the latter having a correlation coefficient = -.3492; $p<0.05$). Results of multivariate cluster analysis and ordination (MDS), showed that when physico-chemical variables were grouped, there was a close relationship between depth and salinity (Euclidean Distance ≤5). *P. australis* is thought to contribute to the reduction in depth, by 'trapping' silt amongst its stems and roots, and by reducing current velocity. The Oceanographic Research Institute (1991) reported that in 1978, the upper zone of the estuary was no more than 0.28 m, while maximum depths of 1.5 m and 2.0 m were measured in the lower zone, during 1980. At some stage during the last decade, a depth of 2.9 m was recorded in the middle section of the Siyaya Estuary, which is the present location of sampling Site 3 (Oceanographic Research Institute, 1991). This is surprising, as Site 3 from 1992 - 1995 was generally <1 m in depth.

Although a significant negative correlation was found between temperature and season, temperature did not appear to affect the oxygen concentration levels in the estuary. This does not support the findings of Dallas and Day (1993) in the western Cape however, who suggested that temperature has a significant effect on the solubility of oxygen and the toxicity of certain chemicals. The only highly significant positive correlation that occurred, was between temperature and salinity. A combination of three major factors taken from those described in Dallas and Day (1993), may be responsible for controlling the temperature regime in the Siyaya Estuary. They are hydrological (flow rate and discharge), climatological (air temperature and precipitation events) and structural factors (water volume and depth, vegetation cover and channel form). Water temperatures of a number of estuaries along the Zululand coast in a study conducted by Cyrus (1988), showed typical seasonal variations within a similar range to those recorded in the Siyaya.

A gradient of decreasing turbidity from head to mouth was sustained for the duration of the project (Figure 4.5). This may be expected in any system with a gradient of finer to coarse-grained substrates from upper to lower reaches, as well as a decrease in water velocity of runoff entering via the head of the system. The shallower the estuary, the greater the increase in turbidity. This was most evident at Site 3, during autumn 1992 and 1993 (dry season), with turbidity >75 NTU. Turbidities varied with season, and top and bottom measurements were significantly different from one another. Bottom measurements had the greatest range of turbidity at every site, during each season of every year. The factor position in the estuary, was significantly positively correlated to turbidity. A positive correlation indicates that the variables vary in the same direction while a negative correlation indicates that the variables vary in the opposite direction. When samples were pooled so that multivariate analysis could establish what relationships existed between top and bottom measurements of variables, the result was that top and bottom turbidity were not related. Samples were clearly separated on the basis of having with high turbidity measurements.

Cyrus (1988), set out mean turbidity values for estuaries both to the north and south of the Siyaya Estuary. The most turbid being St Lucia, with a mean turbidity of 84.2 NTU over the sampling period. The Tongati, Mdloti and Mtamvuna Estuaries (south of the Siyaya Estuary), had mean turbidities within the range 30 - 50 NTU. The Mlalazi, Fafa, Mhlanga and Kosi systems were below 25.5 NTU. The Mlalazi Estuary is the most closely situated to the Siyaya Estuary, with its temporarily open/closed mouth situated approximately 2 km northwards. The Mlalazi drains a much larger catchment than the Siyaya, but is characterised by similar landuse practices. Of the systems mentioned, the Siyaya had relatively low turbidity levels except for seasonally high turbidities in the upper reaches.

The immediate visual effect of a change in turbidity, is a change in water clarity, and may be seasonally controlled in times of normal rainfall. The extent of turbidity in a particular system, is governed by the basic hydrology and geomorphology of a particular region (Dallas and Day, 1993). In the United States, standards for acceptable turbidity levels for rivers are generally defined as increases of not greater than 5-25 NTU above natural (Dallas and Day, 1993). In South Africa, no standards have been set for rivers, but the recommendation of Dallas and Day (1993), is an increase of not more than 5 NTU, depending on the sensitivity of a particular area, for example the south western Cape.

The solubility of oxygen in water is inversely related to temperature and salinity (Dallas and Day, 1993). Thus an increase in either temperature or salinity, results in a corresponding decrease in oxygen. The oxygen levels within the Siyaya Estuary, appeared to be more closely related to the nature of the substrate than either changes in temperature or salinity. Even though salinity levels were higher at the mouth of the Siyaya Estuary (in the area of Sites 1 and 2), a corresponding decrease in oxygen levels did not occur. It may be that salinity changes in the Siyaya Estuary from 1992 to 1995 were too slight to warrant significant changes in the levels of dissolved oxygen. Generally, the presence of detritus, and fine-grained sediments within a sampling site denoted anaerobic conditions. However, on several occasions during the summer season, water temperature was high enough to cause periodic anoxia, particularly in those sampling sites that were shallow. The maximum bottom dissolved oxygen measurement recorded in the estuary over the study period was 9 mg/l, and the minimum <0.5 mg/l, which is highly anoxic and coincided with a particularly warm day. All sampling sites considered, the range of bottom oxygen levels was relatively high (>6 mg/l), as compared with the range of oxygen levels when season and sampling year (>2 mg/l), were considered as factors responsible for the variance in dissolved oxygen.

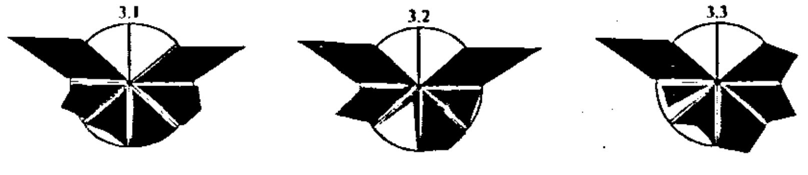
The salinity ranges of the estuaries used in the study conducted by Cyrus (1988), reflected changes in salinity in response to the tidal cycle. Therefore, these results were not comparable to the Siyaya Estuary, as it remained closed for the duration of this project. Over the entire study period, an increasing salinity gradient existed from head to mouth of the Siyaya Estuary, but never exceeded 6‰, in concentration. For all intents and purposes, the estuary was virtually a freshwater system. This situation was alleviated after the mouth opened, and salinity levels were once again 2‰ in the upper reaches, which had been 0‰ for over two years and up to 12‰ in the lower reaches where they had previously been 0‰ to 2‰. From 1992 to 1994, overtopping of the sandbar at the mouth maintained saline conditions. From 1992 to 1994, salinity of the estuary decreased with an increase in the severity of drought conditions. This fact was proved highly significant in correlation test ($p<0.001$). As previously stated, the estuary was well mixed at all times, therefore precluding the existence of a salt wedge. However, Cyrus and Martin (1991), showed that during 1991, there was a well-developed salt wedge starting approximately 0.5 m beneath the estuary surface, and extending the length of the sampling area.

The conductivity levels and total dissolved solids within the Siyaya Estuary showed that despite low salinity levels, the ionic conditions within the system were more indicative of a brackish/marine situation than a freshwater system. The general conductivity and TDS of rivers in the region of the Siyaya Estuary, are taken to be 15-30 mS/m and 100-200 mg/l, respectively, and the natural ground waters of the area are described as highly mineralises chloride sulphate waters (Dallas and Day, 1993). The pH of the Siyaya Estuary was slightly alkaline (±7.75), and these levels did not change significantly from those measurements taken in the past (Archibald *et. al.*, 1984). The pH of aquatic systems is partly determined by alkalinity (Dallas and Day, 1993). The rate of change of pH, is determined by the buffering capacity of a body of water, and in fresh waters pH ranges from 6-8.

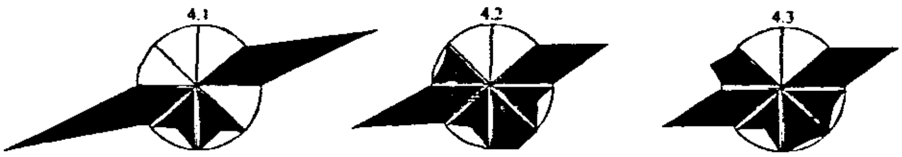
Day and King (1995), reported that in South Africa, there are differences in the dominance of major ions across the country. They attributed ionic dominance to differences in the study area (physiography, geology and climate). From this particular study four categories of ionic dominance arose, which could be geographically distinguished. Samples taken from the Siyaya estuary during 1994 and 1995 fall into the proposed categories 3 and 4 (Figure 4.41). Category 3 has a widespread distribution, and is not restricted to any particular geological formation. Category 4 on the other hand, is confined to three main areas, one being the coastal regions of KwaZulu-Natal on a variety of substrata. When examining the ionic dominance of these categories, Maucha diagrams of the Siyaya Estuary clearly indicate that they are indeed part of these categories (Day and King, 1995). The authors subsequently subcategorised these classifications into three different parts each with a specific proportion of dominant ions.

Day and King (1995), enquired whether the distinctive differences in ionic dominance in waters of South Africa, may have any significance for the distribution of the aquatic biota. However there is little evidence in the literature to support this viewpoint, except where ions act as limiting nutrients and not on the differing ionic proportions on the aquatic biota.

Figure 4.41: Ionic Dominance subcategories 3.1 - 3.3 and 4.1 - 4.3, with corresponding proportions of dominant ions. (After Day and King, 1995). *For reference ionic values see page 81.*



Na^+ within 25% of HCO_3^- *Ca^{2+} & Mg^{2+} both = 25-40%* *$HCO_3^- > Cl^-$* *SO_4^{2-} = 16-35%* *Na^+ = 30-70%*	*Na^+ within 25% of HCO_3* *Ca^{2+} & Mg^{2+} both = 25-40%* *$HCO_3^- > Cl^-$* *$SO_4^{2-} < 15\%$* *Na^+ = 30-70%*	*Ca^{2+}, Mg^{2+}, Na^+:* *All = 25-40%* *$HCO_3^- > Cl^- > SO_4^{2-}$*



Na^+ & Cl^-: > 55% *Others all < 30%*	*Na^+ & Cl^-: > 45-54%* *Others all < 30%*	*$Na^+ > Ca^{2+}$ or Mg^{2+},* *Cl^- > or HCO_3^- or SO_4^{2-}*

In an earlier study by Silberbauer and King (1991), the ionic dominance regions of South Africa, were categorised as follows; a predominance of Na^+ and Cl^- ions in wetlands along the coast and HCO_3^- in wetlands inland. They stressed the importance of chemical variability on the conservation and management of the flora and fauna of wetlands: and stated that "the zoology and botany of wetlands are dependent on the chemistry, and any disruption of the hydrology or water quality, will have an effect on the plants and animals dependent on the wetland system for their survival" (Silberbauer and King, 1991). The major chemical factors affecting the flora and fauna were summarised by these workers as being the TDS, pH, ionic ratio and capacity to buffer changes in pH. Allanson, Hart, O'Keeffe and Robarts (1990), suggested that the region into which the Siyaya Catchment falls may be described a subtropical peneplain with a strong marine influence, resulting in coastal lagoons of varying salinity and elevated salinities in subsoil water.

In the Moresby River Estuary system North Queensland Australia, low dissolved phosphate concentrations (0.02 µmol l^{-1}) are maintained by biological processes, low suspended sediment concentrations and low pH. Low pH favours the adsorption of dissolved phosphate to particulate material, by regulating the isoelectric point of the surface charge (Eyre, 1994). By calculating the P/N ratio of nutrients within the Siyaya Estuary, results show that nitrogen is the primary limiting nutrient within this system. High levels of nutrients encourage dense growth of microflora which results in a decrease in light levels, and the death, submergence and decay of these biota can drastically deplete the oxygen supply (Kunishi and Glotfelty, 1985). The anthropogenic sources of nutrients in the Siyaya Catchment were in the past, and are at present diffuse. That is, in the form of agricultural surface runoff and fertiliser application. Landuse practices such as agriculture and forestry (those important to the Siyaya Catchment) potentially affect the concentrations of suspended and dissolved solids as well as the nutrients, of receiving water bodies (Dallas and Day, 1993). The estimated mean total unfiltered phosphorus and nitrogen entering the system via the catchment with a runoff of 32.4%, and mean annual rainfall of 1299 mm, is 1709 and 14586 $kg.yr^{-1}$, respectively (Oceanographic Research Institute, 1991). As nutrient levels were higher in the Siyaya Estuary from those samples taken during opening of the mouth, it may be concluded that the sediment may be acting as a nutrient sink (Dollar, Smith, Vink, Obrebski and Hollibaugh, 1991). At present, nitrogen and phosphorus nutrient levels entering the Siyaya Estuary are lower than recorded in previous studies (Archibald *et. al.*, 1984; Oceanographic Research Institute, 1991). This decreased with the change in landuse in the catchment. Sugarcane is no longer the principle crop, with a decrease in the use of herbicides, insecticides and fertilisers.

The inclusion of drought and an open mouth phase in this study enabled comparisons to be made both of the physical state of the estuary, as well the accompanying change in water chemistry in the two phases. Archibald *et. al.*, (1984) described three phases of the Siyaya Estuary related to catchment discharge patterns and the status of the mouth over a five year study period. These in turn initiated corresponding physico-chemical responses, which are similar to the present situation, one decade later. This is further evidence of the cyclical nature of rainfall described in Chapter 2. Archibald's *et. al.*, (1984) phases are presented in Table 4.14:

Table 4.14: Phases of the Siyaya Estuary, and corresponding physico-chemical responses. (After Archibald *et. al.*, 1984)

PHASE	RESPONSE OF ESTUARY
Static	Result of severe drought condition. The estuary is a warm, freshwater system with no extremes in temperature or pH. Marked gradation of physico-chemical parameters along length of the estuary, in response to low run-off. TDS, alkalinity, conductivity and major ionic and cationic concentrations increase from head to mouth of the Siyaya.
Flash Flood	Heavy precipitation ultimately leading to breaching of the sandbar at the mouth. Increase of nitrate levels and reduction of ionic concentrations, but uniform conditions from head to mouth.
Sea Breaching	No responses were recorded, as this situation was never observed during the study period. That is the mouth did not remain open for a prolonged period.

(After Archibald *et. al.;* 1984)

In the past, water quality management efforts have focused too strongly on pollutants within the aquatic system, rather than the export of substances from terrestrial ecosystems (Howarth, Fruci and Sherman, 1991). The export of soils from a catchment into an estuary, is a good example of this. The siltation of the Siyaya Estuary, and its causes, are aptly defined by Gardner and Archibald (1992) who stated that: "Silt loads in river systems reflect the runoff from catchment erosion, through poor agricultural practices, natural erodibility of the soils and the destruction of existing vegetation through uncontrolled urbanisation". The input of sediment from non-point source runoff from terrestrial ecosystems is a major source of organic carbon, thus strongly influencing dissolved oxygen concentrations (Howarth, *et al.,* 1991).

By developing a model for the Hudson River estuary, these same workers established that although the Hudson watershed was dominated by forests, the model predicted that a large portion of the sediment and organic carbon inputs were from agricultural fields. They concluded that changes in landuse within a catchment area, may be expected to alter inputs to the estuary. In KwaZulu-Natal, the comparatively high relief of drainage basins, as well as the high discharge of rivers, deliver substantial volumes of sediment to their estuaries (Reddering and Rust, 1990).

The average grain size, and the distribution of particles are of considerable interest as they reflect local conditions, such as changes in current velocity over time (Griffiths, 1967). Griffiths (1967) also points out that the sorting measurement of grain size typifies certain geological process. Aeolian soils are well sorted, whereas glacial sands are poorly sorted. The 18 km^2 catchment of the Siyaya Estuary is estimated at having a sediment yield of 100 tons $km^2.yr^{-1}$ ($M^cCormick$ and Cooper, 1992). This is as much as the neighbouring Mlalazi Estuary, with a catchment 27 times larger. Other catchments within the KwaZulu/Natal province that have catchments that have similar sized catchments, have more than twice the sediment yield of the Siyaya ($M^cCormick$ and Cooper, 1992). With regards to substrate types and the particles sizes of the eight estuaries studied by Cyrus (1988), the Siyaya is most similar to the Mlalazi Estuary. That is, clean sand around the mouth, sandy/silt, mud and coarse river sand in the upper reaches. The Siyaya Estuary is not similar in the latter respect, as the substratum in its upper reaches consists of detrital muds, with silt patches in certain areas. A comparison between sediment analyses of the Siyaya Estuary between 1983 and 1984 and this study showed that there has been a large decrease in the amount of silt in the upper reaches (Table 4.14).

Sediments in the present study were classified as ranging from coarse sand in the lower and middle reaches, to medium and fine-grained sands in the upper reaches. A maximum of 34.86% silt was encountered in the upper reaches, as compared to 100 % encountered during the study conducted by Archibald *et. al.* (1984). The mean silt content of sediments at sampling Site 5 in the Siyaya Estuary was 18.87 % (6.39). Heinis *et al.* (1994), found that at comparable temperatures, the silty sediments of Lake Maarsseveen I (the Netherlands) consume three times as much oxygen as the sediment in the sandy zones. This is comparable with the siltation in the Siyaya Estuary, where sites that were periodically low in dissolved oxygen levels, were sites comprising a fine/silty sediment.

Table 4.15: Results of sediments analysis conducted between 1983 and 1984 on the Siyaya Estuary. (After archibald, *et. al.*, 1984)

Date	Site	% Silt	Description of sediment
19-05-1983	1	22.6	Fine sand
	2	100.0	Silt
	3	3.5	Medium sand
	4	6.1	Medium sand
17-08-1983	1	100.0	Silt
	2	100.0	Silt
	3	7.9	Medium sand
	4	1.1	Medium sand
15-11-1983	1	100.0	Silt
	2	100.0	Silt
	3	0.0	Medium sand
	4	0.0	Medium sand
15-02-1984	1	42.2	Medium sand
	2	100.0	Silt
	3	2.2	Medium sand
	4	0.0	Medium sand

A fact that became increasingly apparent during this study, was the interactive effect that certain parameters had on others, and the so-called 'snowball effect' that transpired once large increases occurred in measurements of certain physico-chemical characteristics. Although other studies must be used as a reference for which parameters should be measured, how often and over what duration, each system and situation is unique. That is, no estuary has experienced an identical past, geomorphological characterisation, geographical situation (in terms of climate, geology, soils and vegetation for example) or physico-chemical input. Therefore, results of any physico-chemical study should not be moulded to a particular model, but rather that the model is utilised as a basic framework for substantiating processes that are taking place in a system. Care should be taken that measurements of a single physico-chemical variable must not be used to characterise a system, or to account for the distribution and abundance of fauna. No variable can 'stand alone' in terms of predictive capabilities and a holistic approach should be adopted. Comprehensive analyses of the water quality should be used to describe the aforementioned biota of a particular system. This is the most suitable method to include all interactive effects of all physical and chemical variables considered.

Each of the variables discussed in this chapter has an effect, either beneficial or detrimental on aquatic organisms in the system. The effect of each variable on individual organisms is also influenced by the tolerance limits of the organism (Dallas and Day, 1993).

5.0 ZOOBENTHOS OF THE SIYAYA ESTUARY

5.1 Introduction

Benthic organisms comprise a broad assemblage of diverse forms that are related by their distribution in space, rather than by phylogeny or exclusive functional attributes. Nevertheless, the fact that they spend part or all of their lives in intimate association with the bottom, results in certain unifying consequences, both for the animals and for the estuary (Day, Hall, Kemp and Yáñez-Arancibia, 1989). Due to the physico-chemical nature and processes taking place in estuaries, benthic organisms are spatially zoned along axial gradients, which link species distribution to the relative inputs of marine and freshwater (Wooldridge, 1995).

Estuarine benthic communities are divided into micro-, meio- and macrofauna, on the basis of size (Kennish, 1986). A mesh of width 0.1 mm allows microfauna to pass through, whilst retaining meiofauna. Meiofauna pass through mesh of width 0.5 mm which retains macrofauna (Kennish, 1986). The latter are the class of benthic fauna that were sampled from the Siyaya Estuary. The type of benthos that can be expected to fall into either of the three categories are firstly microbenthic protozoans living either aerobically or anaerobically in or on the substratum, and secondly meiobenthos that are either temporary (macrobenthic larvae), or permanent members. Meiobenthic fauna may include species of rotifers, nematodes, copepods, ostracods, turbellarians, hydrozoans, gastropods, tunicates, polychaetes and oligochaetes (Day, 1981c). Nematodes dominate this category, and are selective or non-selective deposit feeders or carnivores consuming bacteria and algae (Day, 1981c). The final category is made up of species of crustaceans, larger polychaetes and molluscs. These animals constitute the suspension feeding trophic level, with phytoplankton as a food source (Kennish, 1986).

From descriptions of soft-sediment benthic communities, a condition of static equilibrium can be inferred from factors such as climatic changes, habitat modifications and variations in recruitment and survival (Boesch, Wass and Virnstein, 1976). However, more long-term analyses of zoobenthic communities have revealed that strongly seasonal patterns exist and benthos in some systems exhibit various forms of cyclical dynamics ranging from one year to half a century (Eagle, 1975; Boesch *et. al*, 1976). A range of complex factors are responsible for short and long-term variations in estuarine benthic populations. The nature of variability of environmental factors present major problems to animals from adjacent freshwater or marine conditions colonising estuaries. For this reason, the number of marine species which live in estuaries decline rapidly from the estuary mouth into the middle reaches. Similarly, the number of freshwater species also declines rapidly from the head of the estuary towards the mouth (McLusky, 1974). Kinne (1966) has suggested, that given similar temperature conditions, the degree of dilution of sea water by river water and the resultant physico-chemical mixture, largely determines the performance and distribution of the estuarine organisms. That is, at a particular salinity, it is this and a combination of the accompanying physico-chemical properties that will control the abundance and distribution of estuarine organisms.

5.2 Factors affecting macrobenthic communities

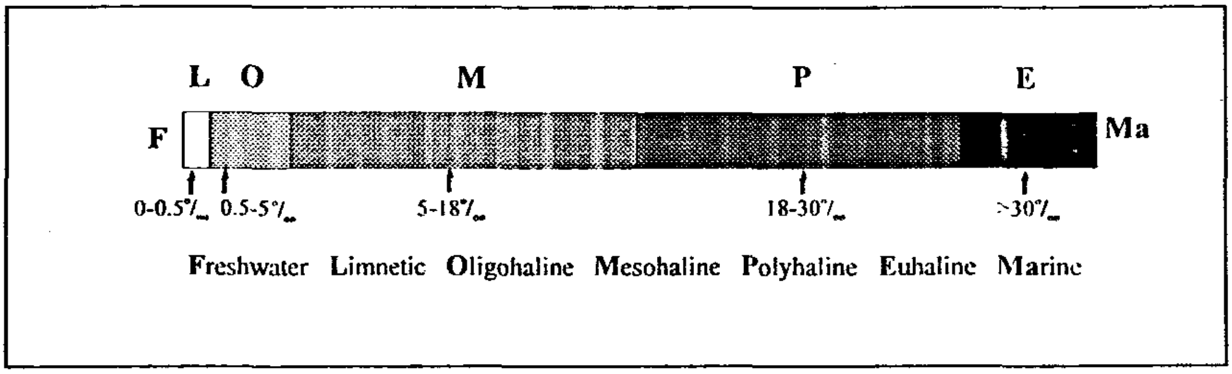
5.2.1 Environmental Factors

A number of physical factors dominate the estuarine environment. For example the substrate, the extent of tidal influence, the size of waves, the strength of currents, the role of these in sedimentation, the pattern of salinity distribution and retention of water by the sediments, the supply of dissolved oxygen, the temperature and the concentration of certain ions (McLusky, 1974).

Physical and chemical environmental factors that affect estuarine benthos are salinity gradients, shelter from wave action, fluctuations in temperature and oxygen levels, the nature of the substratum and the input of detritus (Nichols, 1970; Barnes, 1974; Metzeling, 1993). An estuarine zonation scheme, the 'Venice System' describes patterns of distribution among estuarine organisms in Figure 5.1 (Bulger, Hayden, Monaco, Nelson, and McCormick-Ray, 1993).

By using multivariate techniques involving Principal Components Analysis ordination on 316 species/life stages in the Mid-Atlantic Region, Bulger *et al.* (1993), also derived five salinity zones similar to the Venice System. However, these newly classified zones tend to overlap each other, and accommodate species that occur in both freshwater and brackish systems. Species occurring in estuaries and the truly marine environment also have their position on this scale. The newly classified zones are: freshwater to 4‰, 2-14‰, 11-18‰, 16-27‰ and 24‰ to marine (Bulger *et al.*, 1993).

Figure 5.1: The Venice System of classifying estuarine organisms according to their salinity tolerance, and position along the estuary. (After Bulger *et. al.*, 1993)



Other factors structuring marine benthic communities are food availability, depth, latitude and various biotic interactions (Rosenberg *et. al.*, 1992). Physico-chemical variables are direct factors influencing benthic organisms, in so far as they affect the physiological processes of any life stage of an organism (Boesch *et. al.*, 1976). The components of estuarine fauna are separated by means of their tolerance to salinity, although they are also affected by the aforementioned factors. In tolerable salinity and temperature ranges it is substratum type that becomes the determining factor in benthic distribution (Day, 1981c).

Cooper, Ramm and Harrison (1995), argue that in an estuary, the fauna are influenced by the salinity characteristics, period of connection with the sea, turbidity (controlled by catchment geology and flow), substrate and availability of nutrients (controlled to a large extent by cycles of breaching and flushing). The substrates within estuaries are usually different from adjacent marine coasts, in that they usually have sandy and muddy components. This is typical of most southern African estuaries (Blaber, 1980). Although nutritionally rich, these muds are difficult areas to colonise, as locomotion both through and over the substrate may be difficult. Also, fine silt in suspension can clog the filtering mechanisms of many of the animals who use this as their method of feeding. Muds rich in organic debris play host to a proliferation of microbes, who in turn may consume much of the available oxygen, and even produce large quantities of hydrogen sulphide (McLusky, 1974). In the preceding chapter looking at the physico-chemical aspects of the Siyaya Estuary, this is indeed the case, especially at the top end of the estuary, during the summer months. Gray (1981), maintains that grain size and organic content are important for estuarine benthos. Inhospitable habitats are provided by marine sediments and muds, thus medium and fine sands usually have an abundant benthic faunal assemblage (Gray, 1981). Almost all bottom-dwelling animals will live only on certain specific substrates (McLusky, 1974), and depending on the grain size of the sediment, this may play a role in determining the dominant feeding type (Nichols, 1970). The formation of burrows is dependant on whether the substrate is sand or mud (Blaber, 1980).

The nature of the substrata in any estuary is dependent on:

1. The dominant water mass (fresh or seawater)
2. The nature of offshore deposits
3. The nature of the catchment drained by inflowing rivers (Blaber, 1980).

In addition, man's activities may directly or indirectly affect the distribution of benthos, in that one, more or a combination of the above factors may be altered, through pollution or as is the case in the Siyaya Estuary, through habitat modification by poor agricultural practices.

5.2.2 Non-Environmental Factors

Biological factors affecting the distribution of benthos are food availability, protection from predation and competition (van de Bund and Groenendijk, 1994) or the product of two or more of these processes (Flint and Kalke, 1986). Although long-term environmental fluctuations and spatial heterogeneity in sediment characteristics have been shown to influence estuarine-wide community patterns, subtle biological factors are also thought to significantly affect community organisation changes in soft sediment habitats (Flint and Kalke, 1986).

5.2.2.1 Predation

Predation can prevent competitive exclusion by maintaining competing species at relatively low densities such that interactions are less intense and by periodically providing available free resources (Peterson, 1979). However, this is not always the case and was demonstrated by removing epibenthic predators from soft-sediment marine benthic communities in unvegetated portions of estuaries, and comparing these areas with grassbeds where predators are less effective. In the absence of predation, such communities exhibited increases in total density, species richness and no tendency towards competitive exclusion (Peterson, 1979). A similar experiment in Patos Lagoon, Brazil yielded comparable results. In that, in the absence of epifaunal predators (food and space not being limiting factors), infaunal communities increased in abundance, species richness and diversity while a constant level in epifauna prey was attributed to the protection provided by submerged macrophyte algae (Bemvenuti, 1987). The mechanisms of indirect effects of predation can involve major changes in the abundance, behaviour, habitat utilisation, distribution and even the physiology and morphology of prey and predators (Posey and Hines, 1991).

5.2.2.2 Competition

Competition is defined as "any interaction between two or more species populations which adversely affects their growth and survival" (Odum, 1971). Competition for space or other resources may also affect population fluctuations. Woodin (1974), experimentally showed that densities of burrowing polychaetes were reduced in response to the presence of tube-building polychaetes, indicating competition for space. Wolff (1983) states that many estuarine distribution patterns are ascribed to competition, often of the predator-prey type. By examining the correlation between competition, and the stability of macrobenthic communities, it is found that equilibrial populations in stable habitats gain competitive ability by aggressively defending resources Wolff (1983). This has a great energy cost, which is then denied to reproduction.

Negative interactions in community organisation, like the control of population dynamics by predation, negative adult-postlarvae interactions, recruitment success and disturbance are competitive processes governing population size and the structure of communities (Schaffner, 1990). That is, predation and competitive interactions may also operate to decrease diversity in the same way as environmental stresses like changes in salinity, sediment and temperature, for example (Rainer, 1981).

5.3 The stability, resistance and resilience of macrobenthic communities

Communities are either persistent or cyclic. That is, they maintain constant species compositions and densities over time, or display cyclic changes over varying periods (Gray, 1981). Stability is the property of any community to return to a state of equilibrium after it has been disturbed in some manner. Two models of stability exist for communities; in neighbourhood stability there are many locally stable points, in contrast the unique stable point in global stability. A community which has neighbourhood stability is resistant to small environmental changes, but shifts in species dominance may occur, producing a new state of equilibrium. In global stability, the system returns to the primary state of equilibrium (with the same dominant species and same species composition) no matter how great the extent of environmental change (Gray, 1981). With respect to marine benthic communities, Gray (1981) indicates that over a small spatial scale there is neighbourhood stability with alternate dominant species, shifting to global stability over a larger spatial scale. In summary, the main difference between global and neighbourhood stability, is the scale of disturbance. The two are not mutually exclusive, therefore either one or both apply when describing the state of a community.

In the past, the diversity of a community and its stability were thought to be related. That is, it was thought that the more diverse a community, the more stable it was. However, recent studies have shown that there is not necessarily a link between high diversity and high stability. May (1974), argued that a stable environment would permit the evolution of a complex, but dynamically fragile community. On the other hand, he postulated that an unstable environment would result in a simpler, persistent and dynamically robust community. Benthic communities shift from one stable state to another, as a result of environmental (changes in salinity) and non-environmental (increased predation and competition) changes (Gray, 1981). Marine benthic communities show neighbourhood stability, with a number of alternate dominant species when measured over a small space and time, while over a larger spatial scale global stability is pertinent (May, 1974). Marine populations show cyclical or 'bounce-back' oscillations when disturbed (May, 1974; Gray, 1981).

It is to be expected that less predictable environments favour organisms that are more opportunistic. That is, environments dominated by species that have fluctuating abundances and are short-lived. Estuarine benthic communities seem to have highly variable constituent populations, but more constant species composition. They are therefore viewed as being highly stable in their resistance to and resilience from disturbance, but lack persistence (Boesch *et. al.*, 1976). The changes in a system through time, should be in the direction of increasing constancy in numbers. The constancy may be called stability. In ecology, it is parameters outside as well as inside a system that will determine the ability of such a system to remain similar to itself in spite of changes (Margalef, 1968). A different concept of stability and diversity of communities was presented by Margalef (1968). This concept presupposes the existence of alternative pathways of energy flow, that is, a system has a greater resistance to changes that are external to the system in their origin.

Estuaries are vulnerable ecosystems that have a high tolerance to stress (Wolff, 1983). This 'resistance' is defined by Gray (1981), as the ability of a community to withstand perturbation. Resilience is the ability of a community to rapidly return to the original species composition after being disturbed (depending on the scale and frequency of disturbance (Gray, 1981).

The development of estuarine benthic assemblages after some drastic change in the environment has been described by Wolff (1983) as follows; The first colonisers in northern hemisphere estuaries are usually opportunistic species such as the polychaetes *Capitella capitata* and *Polydora* spp. These species are rapidly followed by a series of other organisms and after three to eight years, these newly colonised areas cannot be distinguished from other areas. Succession is defined as a local progression of species invasion and occupancy following a disturbance (Whitlatch and Zajac, 1985). Zajac and Whitlatch (1982) propose that the portion of a successional sequence during which a species will most likely recolonise and establish a population may be related to its life history characteristics. These authors suggest that species which have *r*-selected (opportunistic) traits will be found during early stages, while species that have *K*-selected traits will be found in those stages closer to recovery.

In recent years, dissatisfaction with explaining a given situation (distribution of benthos for example), in terms of competition, predation, and physical factors has focused attention on recruitment. Giangrande, Geraci and Belmonte (1994), stress the importance of looking at life-cycle patterns and life history diversity, as many benthic organisms spend a certain period of their life history in the plankton as larvae. This leads to a situation where for example, resource partitioning becomes important. That is, the larvae of certain invertebrates will only settle where they may mature without the risk of predation and competition.

5.4 Macrobenthic community diversity and its relationship to stability

The ecosystem may be considered as a 'channel' which projects information into the future. The distribution of individuals into species affords a preliminary measure of the width of the channel of information (Margalef, 1961). Diversity is often seen as a possibility of constructing feedback systems in a given assemblage of species. In an ecosystem, a higher diversity means longer food chains, more cases of parasitism and symbiosis for example. As a measure of organisation, diversity is a parameter that must be qualified that is, to consider the 'spectrum of diversity' (Margalef, 1961). Two populations may have similar diversity indices for a given sample size, but may have completely different diversity spectra (Margalef, 1961). As some samples are enlarged, it may happen that diversity increases therefore spatial configuration of ecosystems is in itself an important factor. Estuarine ecosystems are characterised by low species diversity. The extent to which this low diversity is due to hydrological extremes, pollution effects, or particular sediment characteristics is usually difficult to determine

(Parker, 1975; Rainer and Fitzhardinge, 1981; Kastoro, Aswandy, Hakim, De Wilde and Everaarts, 1989).

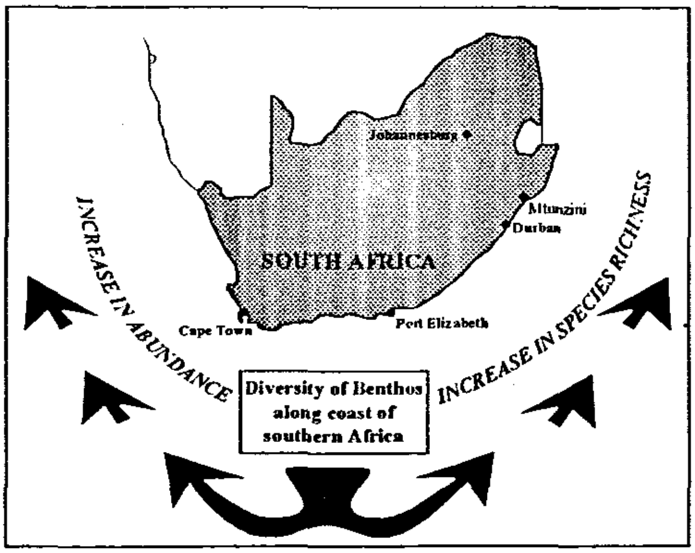
Magurran (1988) states that measures of diversity are important, as they remain a central theme in ecology, and are frequently seen as indicators of the well-being of ecological systems. Diversity is a concept that is difficult to define, because it consists of two components. These are first the variety (species richness), and secondly the relative abundance of species (evenness) (Magurran, 1988). Ecological diversity measurements are often restricted to species richness (a count of the number of species present). However, no community consists of species with equal abundances. Although it is difficult to explain the relative abundances of species within a population, it is a fact that stressed communities are characterised by a change in species abundances (Magurran, 1988). Species diversity measures can be divided into three main categories:

1. species richness indices
2. species abundance models
3. indices based on the proportional abundances of species

5.5 Benthic Macrofaunal Distribution in southern Africa

Day (1981c), produced a concise account of general distributional trends of the various faunal groups around the southern African region. The most abundant faunal group are the polychaetes, which are usually abundant from the west to east coast. This may provide some indication as to this groups tolerance to a wide range of limiting factors. Amphipods increase in abundance from the subtropical region (east coast) to the temperate regions of the eastern and southern Cape (Day, 1981c). In the tropics (Mozambique), there is a greater abundance of bivalves, gastropods, penaeid prawns and crabs (Day, 1981c). Along the Indian Ocean coastline, running from the subtropical (KwaZulu-Natal) to warm temperate zones (eastern Cape Province), there is a tendency for truly estuarine species to be well represented in estuaries. That is, they exhibit a good species richness. Along the west coast of southern Africa, species numbers are impoverished. The climate of the area plays an important role in governing the number and type of species present (Day, 1981c). For example, the west coast has a winter rainfall period, that tends to be erratic in some cases and causes greater geophysical changes to estuaries. Geophysical changes may be in the form of closing of estuary mouths for indefinite periods or the opening of estuary mouths during times of flood. The trend of benthic distribution around the coast is given in Figure 5.2. In summary, regional groups of estuaries show a decrease in diversity between the tropics and cold temperate coasts (Day, 1974).

Figure 5.2. Changes in abundance and species richness of estuarine fauna along the coast of South Africa



5.6 Methods and Materials

The general details pertaining to the sampling sites and sampling dates for the collection of zoobenthos are covered in Chapter 3 (General Methods and Materials). A description of each sampling site, and a diagram of the study area are given in Table 3.1 and Figures 3.1 and 3.2, respectively. The dates for the collection of samples are summarised in Table 3.2, giving details of corresponding seasons from 1992 to 1994.

5.6.1 Field Sampling Strategy

Samples were collected on a seasonal basis (quarterly intervals) over three successive years, from 1992 to 1994. During each fieldtrip, five random samples were collected at each site, in order to obtain a good species representation of each area. A Zabalocki-type Eckman grab which uniformly samples 0.0236 m^2 of the substratum to a depth of 4.5 cm, was used. After the contents of each grab had been emptied into separate buckets, thoroughly stirred and 10% formalin added causing the invertebrates to let go of the sediment, the mixture was decanted through a 0.5 mm mesh. This washing and sieving procedure was repeated five times to obtain invertebrates representative of approximately 95% of those present in the entire sample. Large molluscs were separated from the remaining sediment, and decanted fauna and debris preserved in 10% formalin. The vital dye Phloxine B was added to the preserved material to aid in sorting and counting of the invertebrates in the laboratory (Blaber, Kure, Jackson and Cyrus, 1983). These methods have previously been successfully implemented by other workers (Cyrus and Martin, 1988; Reavell and Cyrus, 1989).

5.6.2 Laboratory Analysis

Preserved samples were sorted, counted and identified to species level as far as possible using the equipment described in Section 3.2.2 of the General Methods and Materials. Each taxon was identified by making use of descriptions and keys by Tattersall (1958), Day (1967a,b), Day (1969), Kensley (1972), Griffiths (1976), Kensley (1978) and Scholtz and Holm (1985). Taxon densities for each site during each season were expressed as the number of individuals per square metre.

5.6.3 Data Analysis

Analysis of benthic data was separated into four stages. Stage one, aimed to describe the benthic community of the Siyaya Estuary, by describing the relationships between the biota in the various samples. The second stage aimed to discriminate between sampling sites on the basis of their biotic composition. Techniques in stage two were used to establish 'before', and 'after' differences at single sites. 'Before' differences were results of a single survey, conducted subsequent to the inception of the Siyaya Catchment Demonstration Project. The penultimate stage used biological measures from the community data to construct biological measures of change (diversity indices, for example). The final stage linked environmental variables to community data. Results of these analyses are dealt with in Chapter 6, which looks at the effects of physico-chemical parameters on the benthos of the Siyaya Estuary. Results of the relevant physico-chemical variables measured in the Siyaya Estuary are presented in Chapter 4 (Physico-chemical Parameters of the Siyaya Estuary). Techniques employed for analyses of each of the four stages were separated into both univariate and multivariate methods. However, Clarke and Warwick (1994), point out that community data is inherently multivariate, and needs to be analysed as a whole, rather than selecting several 'representative species' and analysing their importance in determining the community structure by univariate techniques. For this reason, the majority of the results in this chapter are the outcome of several multivariate methods. Multivariate statistical methods allow the analysis of patterns in biotic data (species attributes/sites/times) and to relate biotic patterns to spatiotemporal environments (Ardisson and Bourget, 1990).

Tables 5.1 and 5.2 summarise the univariate, distributional and multivariate techniques used for stages 1 to 3, in describing the benthos of the Siyaya Estuary. The methodology behind Stage 4 (linking community and environmental data), is fully described in Section 6.2.

Table 5.1: Summary of the Univariate and Distribution techniques used at each of the three stages to describe the benthos of the Siyaya Estuary

	UNIVARIATE METHODS		**DISTRIBUTION METHODS**	
STAGES	**Diversity Indices**	**Indicator Taxa**	**Dominance Curves**	**Abundance Distributions**
1. Representing Communities	Means and 95 % confidence intervals for each site/season/year		Curves for each site/season/year	
2. Discriminating sites/seasons/years	One-way analysis of variance (ANOVA)		ANOVA or analysis of similarity on "distances between curves	
3. Determining stress levels	Reference to Historical Data			
	Decrease in diversity	Initial increase in opportunists		

Table 5.2: Summary of the Multivariate techniques used at each of the three stages to describe the benthos of the Siyaya Estuary.

STAGES	MULTIVARIATE METHODS	
	Hierarchical Clustering	**MDS Ordination**
1. Representing Communities	Dendrogram of samples	Configuration plot of samples
2. Discriminating sites/seasons/years	Analysis of similarity (ANOSIM) on sample similarity matrix	
3. Determining stress levels		

The concept behind studying community data in this manner was obtained from studies previously done by Field, Clarke and Warwick (1982) and Clarke and Warwick (1994). In addition, a synopsis presented in Ludwig and Reynolds (1988), of the stages of the observational ecology approach was used as a framework of how to proceed with the analyses. A brief description of the theory behind each stage of the analysis and the relevancy in using these methods for this study are now presented.

Diversity indices were used to describe species-abundance relations, in place of distribution models, as recommended in Ludwig and Reynolds (1988). The major criticisms of these indices, are that they confound a number of variables (species richness, evenness and the homogeneity of sampling area) and are not easy to interpret, was acknowledged. For this reason, indices of richness and evenness were included in describing the benthos, as well as diversity indices. The indices used were:

A. Richness Index

1. Margalef's (1961) index:

$$D_{Mg} = (S - 1)/\ln N$$

Where S = number of species recorded, and N = total number of individuals summed over all S species.

B. Diversity Indices

2. Shannon's Index - based on theory of Shannon and Weaver (1963)

$$H' = -\sum_{i=1}^{S^*} p_i \ln p_i$$

Where p_i = proportion of individuals found in the *i*th species (N_i/N).

3. Simpson's (1949) Index - a measure of dominance

$$\lambda = \sum_{i=1}^{S^*} p_i^2$$

Where p_i is the proportional abundance of the *i*th species, given by $p_i = n_i/N$. This index varies from 0 to 1, and gives the probability that two individuals drawn from the same population, belong to the same species. That is, if the probability is high, then the diversity of the community sample is low (Ludwig and Reynolds, 1988).

C. Evenness Index

4. Pielou's (1986) Index

$$J' = H'/\ln(S) = \ln(N1)/\ln(N0)$$

Where H' = Shannon's diversity index and S= number of species. **N1** and **N2**, correspond to Hill's family of diversity numbers. The use of **N1** and **N2** are more interpretable than other diversity indices and are in units of species numbers (Ludwig and Reynolds, 1988). This index shows the eveness at which individuals are distributed over the species in a sample (Kastoro *et al.,* 1989). Diversity and other indices were calculated using ***DIVERSE,*** a statistical program incorporated in the statistical package **PRIMER** (Plymouth Routines In Multivariate Ecological Research) **v3.1b** (Clarke and Warwick, 1994).

Gray and Pearson (1982), recommend plotting the number of species in **x2** geometric abundance classes, as a means of detecting environmental stress. In unpolluted situations, the curve is smooth with more rare species in comparison with polluted situations with more abundant and fewer rare species. Species occurring in the intermediate abundance classes 3-5, are most sensitive to environmental change, and are therefore good 'indicators' (Gray and Pearson, 1982).

Dominance curves were also used to represent ranked abundances of the benthic data according to the method of Clarke and Warwick (1994). Species are ranked in decreasing order of abundance, and these (expressed as percentages) are plotted against the relevant species rank.

All other univariate techniques involving the calculation of an information statistic, were performed in the statistical package ***STATGRAPHICS*** (Manugistics Inc., 1992). Multifactor analysis of variance (ANOVA), was used to test whether there were any significant differences between sets of means from sites, seasons and sampling years of the Siyaya benthic data. The main statistical assumptions of the ANOVA are:

1. randomness of replicates
2. independence of errors
3. homogeneity of group variances
4. normality of errors (Fry, 1993)

Spearmans Rank Correlation Co-efficients were used (using ***STATGRAPHICS***) to measure the degree of covariation in abundance data, between the dominant species.

For all of the following multivariate tests, techniques were first applied to matrices of the benthic samples, followed by the benthic species. Tests on groups of species are referred to as inverse analyses for the remainder of this chapter (Field *et al.*, 1982). Hierarchical and agglomerative community classification methods were used on the benthic data. In a hierarchical classification, groups at any lower level of classification are exclusive subgroups of those groups at higher levels (Ludwig and Reynolds, 1988). Individual sampling units are recombined successively, to form larger groups in agglomerative classifications (Ludwig and Reynolds, 1988).

The results classifying samples into similar clusters, were then arranged and presented as a dendrogram. This was used to delimit the different biotic communities. Group averaging was used as a cluster analysis strategy, to 'conserve space', so that little distortion existed between this the cluster matrix and the original matrix distances (Ludwig and Reynolds, 1988). The similarity coefficient used was that of Bray and Curtis (1957). Abundance data (samples) were transformed before computation of Bray-Curtis similarities. The log transform (log[1 + y]) method was used, as this down weights the importance of very abundant species, and always has a positive value (Clifford and Stephenson, 1975). It was felt that as the Siyaya Estuary was influenced by both freshwater conditions and a slight marine input (overtopping of the sandbar at the mouth), even samples containing rare species played some role in determining differences (and similarities) between samples. That is, the rare occurrences of certain marine species may have indicated that overtopping had taken place. Standardisation of the data prior to calculation of similarities was not required, as known sample volumes were taken from 1992 to 1994 (Clarke and Warwick, 1994).

To obtain some idea as to the species differences causing patterns in the sample analyses, inverse analyses were performed on the data. The Bray-Curtis coefficient was used for species similarities. However, data was row-standardised and was left untransformed (opposite of sample analyses) in the input matrix. This is because Clarke and Warwick (1994), recommend that rarer species should first be removed from the matrix. This was not however performed, as rare species sampled in the estuary were often of the estuarine/marine component, and substantiated instances of overtopping. Cluster analyses were used to establish which sites were distinguishable from each other, and to define which species co-occurred in a parallel manner across sites. The method used was Hierarchical agglomerative clustering, with group-average linking. In addition, ranked data was used, as results of clustering were used as an input to non-metric multidimensional scaling (MDS).

The culmination of the above multivariate techniques was to ordinate the benthic data of the Siyaya Estuary. The method used in this study was to ordinate data according to non-metric multidimensional scaling, using the program ***MDS***, in ***PRIMER***. MDS produces an ordination of the stations in a specified number of dimensions. It does this by interpreting some function of the dissimilarity measure between each pair of stations as a distance in Euclidean space. The final stage is to seek the best reconciliation of these interstation distances between points on a 2 (or higher) dimensional map (Field *et al.*, 1982). This method was used in place of other ordination techniques, as it makes few assumptions about the form of the data of the inter-relationships of the samples (Field *et. al.*, 1982). The distances between samples on the ordination attempt to match the corresponding dissimilarities in community structure. Clarke and Warwick (1994) suggest that nearby points have similar communities, samples which are far apart have few species in common or the same species at very different levels of abundance. The calculation of the MDS algorithm is an iterative process, involving a number of random starts (which must be specified), in order to obtain the best 2-dimensional configuration. The adequacy of an MDS representation is given as the 'stress' or 'goodness of fit' (Table 5.3). Generally stress increases with reducing dimensionality and increasing quantity of data.

Table 5.3: Range of stress values used to determine accuracy of 2-dimensional MDS algorithm calculation (Clarke and Warwick, 1994)

STRESS:	*TYPE OF REPRESENTATION*
<0.05	Gives an excellent representation with no misinterpretation
<0.10	Good ordination with no real prospect of misleading interpretation
<0.20	Potentially useful 2d picture (reliance should not be placed on values at the upper end
>0.30	Points are close to being arbitrarily placed in the 2d ordination

5.7 Results

A mean of 9 874 animals m^{-2} per site (1 - 5), and season (summer, autumn, winter and spring) representing 88 taxa were sampled from the Siyaya Estuary from 1992 to 1994.

5.7.1 Species Composition from 1992 to 1994

During 1992, 1993 and 1994 the mean density of benthos sampled over four seasons was 14 433, 8 340 and 6 850 m^{-2} (Tables 5.4, 5.5 and 5.6). The mean density decreased from 1992 to 1994, and during the final year of study, was 7 583 m^{-2} less invertebrates than the number sampled in 1992. That is, a decrease of 52.5% of the number of invertebrates collected in the Siyaya Estuary.

Table 5:4 1992 benthic densities (m^2) recorded each sampling site and season. Mean densities per site and season are given in italics with standard errors in parentheses.

1992 Benthos:	SUMMER	AUTUMN	WINTER	SPRING	*Mean density per site (SE)*
Site 1	21 615	5 198	3 663	16 282	*11 690 (4 341)*
Site 2	21 353	15 766	12 661	13 738	*15 879 (1 935)*
Site 3	33 844	13 636	10 685	23 379	*20 386 (5 242)*
Site 4	17 494	10 939	19 708	13 085	*15 306 (2 003)*
Site 5	2 926	6 428	11 490	14 764	*8 902 (2628)*
Total	**97 232**	**51 967**	**58 207**	**81 247**	
Mean density per season (SE)	*19 446 (4 962)*	*10 394 (2030)*	*11 641 (2 556)*	*16 249 (1 862)*	**14 433 (mean)**

Table 5.5: 1993 benthic densities (m^2) recorded each sampling site and season. Mean densities per site and season are given in italics with standard errors in parentheses.

1993 Benthos:	SUMMER	AUTUMN	WINTER	SPRING	*Mean density per site (SE)*
Site 1	1 929	1 526	1 785	2 350	*1 898 (172)*
Site 2	15 332	8 845	16 093	9 353	*12 406 (1 918)*
Site 3	5 376	10 185	8 395	8 022	*7 995 (992)*
Site 4	5 265	8 311	15 993	14 068	*10 910 (2 491)*
Site 5	4 978	2 748	11 694	14 543	*8 491 (2 772)*
Total	**32 881**	**31 614**	**53 961**	**48 337**	
Mean density per season (SE)	*6 576 (2 280)*	*6 322 (1 747)*	*10 792 (2 672)*	*9 667 (2 230)*	**8 340 (mean)**

Table 5.6: 1994 benthic densities recorded (m^2) each sampling site and season. Mean densities per site and season are given in italics with standard errors in parentheses.

1994 Benthos:	SUMMER	AUTUMN	WINTER	SPRING	*Mean density per site (SE)*
Site 1	2 078	4 333	6 597	18 401	*7852.3 (3635.2)*
Site 2	9 478	6 385	16 451	7 115	*9857.3 (2294.9)*
Site 3	3 638	8 355	13 339	1 594	*6731.4 (2618.1)*
Site 4	1 077	3 545	1 976	4 359	*2739.0 (742.6)*
Site 5	6 140	6 317	11 092	4 740	*7072.3 (1385.5)*
Total	**22 410**	**28 935**	**49 455**	**36 209**	
Mean density per season (SE)	*4 482 (1 513)*	*5 787 (848)*	*9 891 (2 548)*	*7 242 (2 924)*	**6 850 (mean)**

During 1992, 50 taxa were recorded in samples from the Siyaya Estuary during summer, autumn, winter and spring (Table 5.7). The general impression was of a wide faunal assemblage with representatives from Nematoda, Cladocera, Ostracoda, Cumacea, Hirudinea and Oligochaeta. Also present were three species of Gastropoda, eight polychaete taxa of which six were identified to genus level, six genera of Isopoda, seven amphipod and four mysid taxa. Few decapod invertebrates were sampled, the majority were primarily prawn post larvae.

During 1993, 45 taxa were counted and identified (Table 5.7), this was five less taxa than was recorded during 1992. A fairly wide faunal assemblage was sampled during the year, with representatives from the following phyla; Platyhelminthes, Nematoda, Annelida, Arthropoda and Mollusca. With regards to different taxa, Polychaeta, Isopoda and Amphipoda were fairly well represented, with 6, 5, and 4 different taxa respectively. A large number of the remaining taxa collected were within the Insecta, with invertebrates from a wider range of aquatic families than encountered during 1992.

During 1994, 59 taxa were recorded over four seasons (Table 5.7). This was 14 more taxa than 1992, with the majority being freshwater related (40 taxa). Despite large numbers of insect fauna, other faunal groups were also represented, notably, Amphipoda, Isopoda, Polychaeta, Oligochaeta and Nematoda.

Table 5.7: List of species sampled in the Siyaya Estuary from 1992 to 1994

	Species	1992	1993	1994
1	Nematode spp.	X	X	X
2	Platyhelminthes spp.		X	X
3	Oligochaete spp.	X	X	X
4	*Mercierella enigmata*	X		
5	*Ceratonereis keiskamma*	X	X	X
6	*Desdemona ornata*	X	X	X
7	Polydora sp. T1	X	X	
8	Prionospio sp. T1	X	X	
9	*Dendronereis arborifera*	X		
10	Polychaete T1	X		
11	Polychaete T2	X		
12	*Melanoides tuberculatus*	X	X	X
13	*Assiminea bifasciata*	X	X	
14	*Pittaria kochii*		X	
15	*Musculus virgiliae*	X		
16	Cladocera spp.	X	X	X
17	Ostracoda spp.	X	X	X
18	*Dies monodi*	X		X
19	*Leptanthura laevigata*	X	X	X
20	*Munna sheltoni*	X	X	X
21	*Eurydice longicornis*	X	X	
22	*Excirollana natalensis*	X	X	
23	*Corollana africana*		X	
24	*Corophium triaenonyx*	X	X	X
25	*Grandidierella lignorum*	X	X	X
26	Amphipod T1			X
27	*Melita zeylanica*	X		
28	*Orchestia ancheidos*	X	X	X
29	*Bolttsia minuta*	X	X	
30	*Urothoe tumorosa*	X		
31	*Apseudes digitalis*	X	X	X
32	*Iphinoe truncata*	X	X	
33	*Mesopodopsis africanus*	X	X	X
34	*Rhopalophthalmus terrantalis*	X		
35	*Gastrosaccus brevifissura*	X		
36	Mysidopsis sp. T1	X		
37	Branchiura larvae	X		
38	Zoea larvae	X		X
39	Prawn post larvae	X	X	X
40	*Caridina nilotica*	X		X
41	*Lucifer pencillifer*	X		
42	*Callianassa kraussi*	X		
43	*Hymenosoma orbiculaire*		X	X
44	Insecta AT1			X
45	Insecta NT1			X
46	Insecta NT2			X
47	Insecta NT3			X
48	Insecta NT4			X
49	Insecta NT5			X
50	Insecta LT1	X		
51	Tridactylidae LT1		X	
52	Coleoptera NT1	X		X
53	Coleoptera PT1			X
54	Coleoptera AT1			X
55	Coleoptera LT1		X	
56	Hymenoptera NT1			X
57	Hymenoptera NT2			X
58	Hymenoptera NT3			X
59	Corixidae NT1	X	X	X
60	Diptera PT1			X
61	Diptera PT2			X
62	Diptera LT1	X		X
63	Diptera LT2			X
64	Diptera LT3			X
65	Diptera LT4		X	
66	Diptera LT5			X
67	Diptera LT6			X
68	Diptera AT1			X
69	Diptera AT3			X
70	Diptera AT4			X
71	Psychodidae LT1		X	X
72	Ceratopogonidae LT1	X	X	X
73	Chironomid spp. L	X	X	X
74	Chironomid spp. P	X	X	X
75	Chaoborus sp. LT1	X	X	X
76	Chaoborus sp. PT1	X	X	X
77	Trichoptera LT1		X	X
78	Ecnomus sp. LT1			X
79	Odonata NT1			X
80	Zygoptera LT1		X	
81	Gomphid T1	X		
82	Gomphidae NT1		X	X
83	Gomphidae NT2		X	X
84	Corduliidae NT1		X	
85	Baetis LT1	X	X	X
86	Hydrocarina sp. T1		X	X
87	Araneae sp. T1	X	X	X
88	Prosopistoma LT1		X	X

1992 = 50 Taxa
1993 = 45 Taxa
1994 = 59 Taxa

5.7.2 Species Abundance per site and season from 1992 to 1994

Table 5.4 and Figure 5.3 show that a slight seasonal effect was evident in terms of changing abundance with season during 1992. In terms of changing abundance, the benthos at Site 3 (mean density of 20 386 m^{-2}; SE = 5242) was the greatest (Figure 5.3). The upper and lower reaches of the Siyaya Estuary were the least abundant areas (mean density at Site 1 = 11 690 m^{-2}, SE = 4341; Site 5 = 8902 m^{-2}, SE = 2628). The overall trend in abundance was to increase from the upper and lower reaches, towards the middle of the estuary. The most consistent pattern of invertebrate density was that Site 5 had the lowest overall abundance every season except during winter, where Site 1 was the most impoverished area in the Siyaya Estuary. A comparison of the mean number of individuals m^{-2} at Site 5 (fine sand/mud; see Chapter 4) during each season, indicated that there was an increase from 2 926 m^{-2} in summer, peaking at 14 745 m^{-2} in spring. Autumn and winter being periods of population growth. The opposite was generally true at Site 2 (sandy substrate; see Chapter 4), where the highest mean invertebrate density was in summer (21 353 m^{-2}). Sites 1 and 3 showed that invertebrate populations were most abundant in summer, decreased through autumn, were least abundant in winter and again underwent an increase in spring. Table 5.4 shows that the in 1992 the mean density over all five sampling sites was 19 446 m^{-2} (SE = 4 962) in summer, 10 394 m^{-2} (SE = 2 030), 11 641 m^{-2} (SE = 2 556) and 16 249 m^{-2} (SE = 1 862) for autumn, winter and spring, respectively. During 1992, the peak period of production of benthic invertebrates in the Siyaya Estuary, was during summer.

During 1993, within the entire system, total invertebrate densities were highest in winter, followed by spring, summer and autumn (Table 5.5). The mean density during summer was 6 576 m^{-2} (SE = 2280) and decreased slightly to 6 323 m^{-2} (SE = 1747) during autumn. Invertebrate densities decreased slightly between winter and spring to 9667 m^{-2} (SE = 2230). In the Siyaya Estuary, the period of peak abundance of benthic invertebrates was during winter (10 792; SE = 2672 m^{-2}).

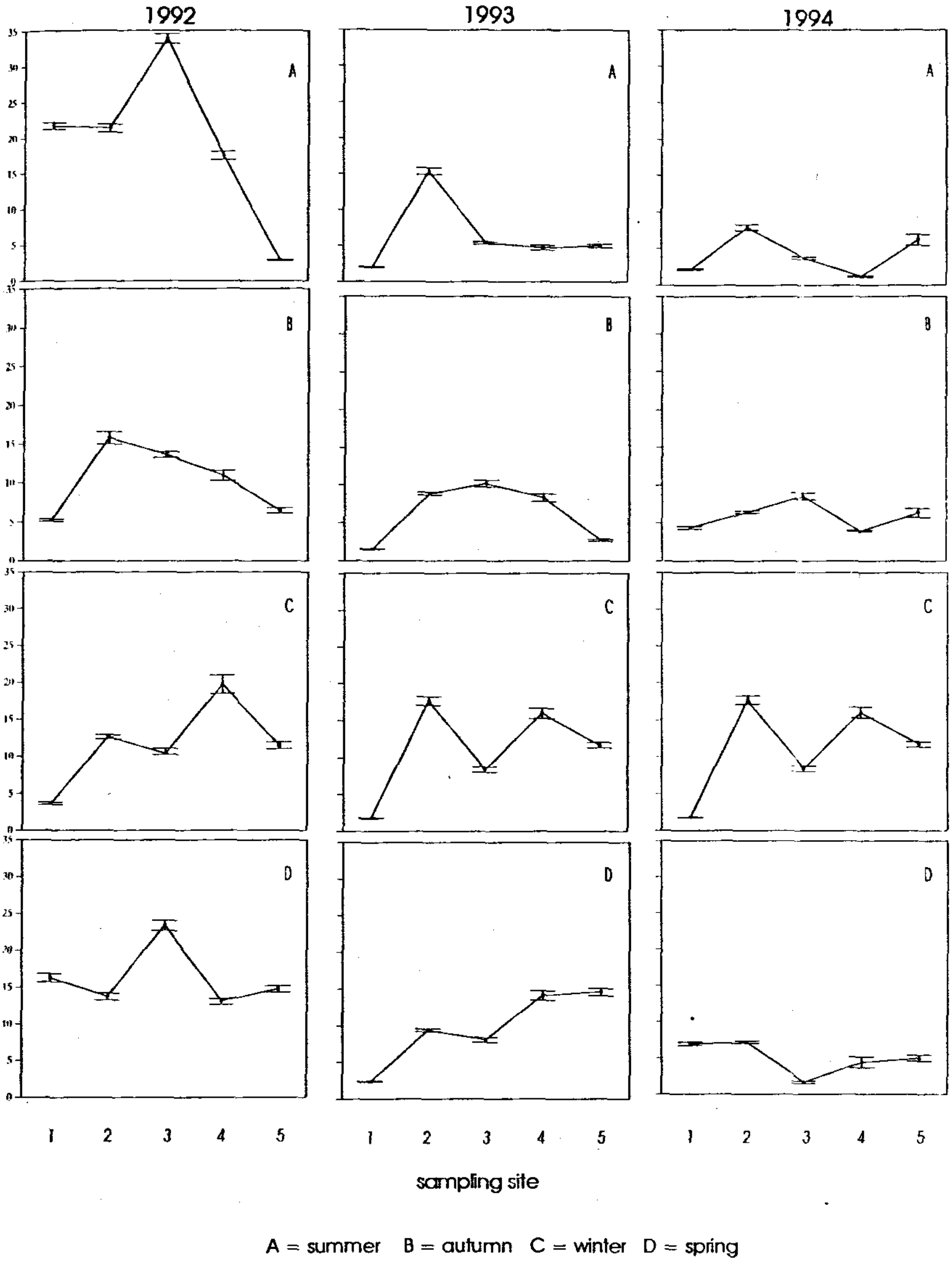


Figure 5.3: Seasonal variation of benthic densities per sampling site, from 1992 - 1994 (± 1 SE).

During the year, Site 1 was the most impoverished area during each season (Figure 5.3). This was in contrast to the situation during 1992, where the least abundant sites fluctuated between Sites 1 and 5. Benthic densities decreased from Site 2 to Site 3, except during autumn, where Site 3 was the most abundant sampling site (10 185 m^{-2}). Site 5 was generally impoverished in terms of density throughout 1993, but during spring Site 5 had densities of 14 543 m^{-2}. That is, more than any other site during that season. Table 5.5 also gives the mean number of invertebrates for all sampling sites during 1993. Site 1 comprised only 4.6 % of the average benthos for the year (1 898 m^{-2}; SE = 172), while Site 2 had the greatest density with an average of 12 406 m^{-2} (SE = 1 918). Sites 3 and 5 were roughly similar with regards to mean faunal densities, ranging from 7 995 m^{-2} (SE = 992) to 8 491 m^{-2} (SE = 2772). During summer, autumn winter and spring of 1992 the mean density per season exceeded those for the same period during 1993 by 12 870 m^{-2}, 4 071 m^{-2}, 849 m^{-2} and 6 582 m^{-2}, respectively. The most marked changes were are Sites 1 and 3. From 1992 to 1993 there was a decrease in the mean density of 9 792 m^{-2} and 12 391 m^{-2} at these sites. The mean benthos over four seasons in 1993 was 6 093 less invertebrates per square metre than 1992.

Table 5.6 and Figure 5.3 indicate the seasonal shift in abundance of benthos sampled during 1994. There was an overall decrease in the mean density (sum of four seasons) by 7 583 m^{-2} compared with 1992 and 1 490 m^{-2} compared with 1993. In terms of the mean density per season, there was an increase in benthic abundance between summer and autumn, and a peak in abundance during winter (peak = 9 891 m^{-2}; SE = 2548). There was also a decline in benthic density between winter and spring. Figure 5.3 shows that throughout the year, Site 2 generally had the highest abundance, while the most impoverished areas fluctuated between Sites 1, 3 and 4. The mean density per site shows that Sites 1, 3 and 5 were similar throughout the year (7 852 m^{-2}, SE = 3 635; 6 731 m^{-2}, SE = 2 618, 7 072 m^{-2}, SE = 1 385, respectively). Sites 2 and 4 had the highest and lowest mean density per site during 1994 (9 857 m^{-2}, SE = 2 294 and 2 739 m^{-2}, SE = 742). The mean density of benthos sampled each season (sum of all sampling sites) was compared to those recorded in 1992, the most abundant sampling year. Decreases during summer, autumn, winter and spring were by 14 964 m^{-2}, 4 607 m^{-2}, 1 750 m^{-2} and 9 007 m^{-2}. The abundance of benthos at Site 1 showed the most important decrease.

Compared to those values recorded during 1993, 1994 benthos showed decreases of 2 094 m^{-2}, 536 m^{-2}, 901 m^{-2} and 2 425 m^{-2}, for summer, autumn, winter and spring.

Table 5.8 indicates the percentage contributions of benthos to each sampling site and season. Overall, autumn contributed the least to total benthic abundance during 1992 and 1993 (18.8 % and 19.0 %), but shifted to summer during 1994 (16.4 %). Note that the percentage contribution of benthos per site and season was calculated using the total abundance for a particular year (Tables 5.4 - 5.6), and not the overall total abundance over three years. The highest contributions made by the total benthos for each year to a particular season were in winter 1993 and 1994 (32.3 % and 36.0 %), and summer 1992 (33.7 %). On a seasonal basis, the highest percentage contribution of the density at a sampling site made to the total density of a particular sampling year was Site 3 in the summer of 1992 (11.7%), Sites 2 and 4 in the winter of 1993 (9.6%) and Site 1 in the spring of 1994 (13.4%).

Table 5.8: Comparison of percentage contributions of benthos to sampling sites (1-5) and seasons (summer, autumn, winter and spring) from 1992 to 1994.

Year	*Season*	Site 1	Site 2	Site 3	Site 4	Site 5	*TOTAL*
1	*S*	7.5	7.4	11.7	6.1	1.0	**33.7 %**
9	*A*	1.8	5.5	4.7	3.8	2.2	**18.0 %**
9	*W*	1.3	4.4	3.7	6.8	4.0	**20.2 %**
2	*Sp*	5.6	4.8	8.1	4.5	5.1	**28.1 %**
						TOTAL	**100 %**
1	*S*	1.2	9.2	3.2	3.2	3.0	**19.8 %**
9	*A*	1.0	5.3	6.1	5.0	1.6	**19.0 %**
9	*W*	1.1	9.6	5.0	9.6	7.0	**32.3 %**
3	*Sp*	1.4	5.6	4.8	8.4	8.7	**28.9 %**
						TOTAL	**100 %**
1	*S*	1.5	6.9	2.7	0.8	4.5	**16.4 %**
9	*A*	3.2	4.7	6.1	2.6	4.6	**21.2 %**
9	*W*	4.8	12.0	9.7	1.4	8.1	**36.0 %**
4	*Sp*	13.4	5.2	1.2	3.2	3.5	**26.5 %**
						TOTAL	**100 %**

S = summer **A** = autumn **W** = winter **Sp** = spring

As the faunal densities varied according to season and site, the differences between each sampling year were subject to a multifactor ANOVA, with the model testing the effect of the variables ***Site***, ***Season*** and ***Sampling Year*** on total benthic density 1992 to 1994 (total density of 59 2455 individuals m^{-2} over all 12 seasons). The results are presented in Table 5.9:

__Table 5.9:__ F-ratios and significance levels for three-way ANOVAs of densities of benthos sample 1992-1994. F-ratios are based on the residual mean square error and DF: degrees of freedom.
S = Site   Se = Season   Y = Year

	Main Effects			2-way interactions			3-way interaction
	Site (S)	*Season (Se)*	*Year (Y)*	*S x Se*	*S x Y*	*Se x Y*	*S x Se x Y*
	(4 DF)	*(3)*	*(2)*	*(12)*	*(10)*	*(7)*	*(22)*
benthic density:	12.8***	1.2	3.0*	0.5	1.2	2.7*	0.6

* = P<0.05   *** = P<0.001

A highly significant relationship existed between benthic density and sampling site ($p<0.001$). Other significant relationships were the effects of year and year versus season on benthic density ($p<0.05$).

5.7.3 Species Abundance Distribution

Figures 5.4 to 5.6 represent the ranking of all taxa sampled in the Siyaya Estuary, in decreasing order of their importance in terms of abundance. The ranked abundances, expressed as a percentage of the total abundance of all species are plotted against the relevant species rank (Clarke and Warwick, 1994). As the Siyaya was characterised by a small number of highly abundant species, and a large number of rare species, partial dominance curves were computed, which shifts the importance from the most abundant species to the second. Figure 5.4 shows that during 1992 at Sites 1, 2, 4 and 5 the percentage partial dominance was elevated between species rank 2 and 4, and decreased at rank order 10. This indicates the presence of a few highly abundant taxa at these sites, with many taxa that were poorly represented. Many taxa were characterised as having a single record of distribution. Site 3 during 1992 had taxa that were generally evenly spread in terms of abundance from the first to the tenth rank. However, ranks at the

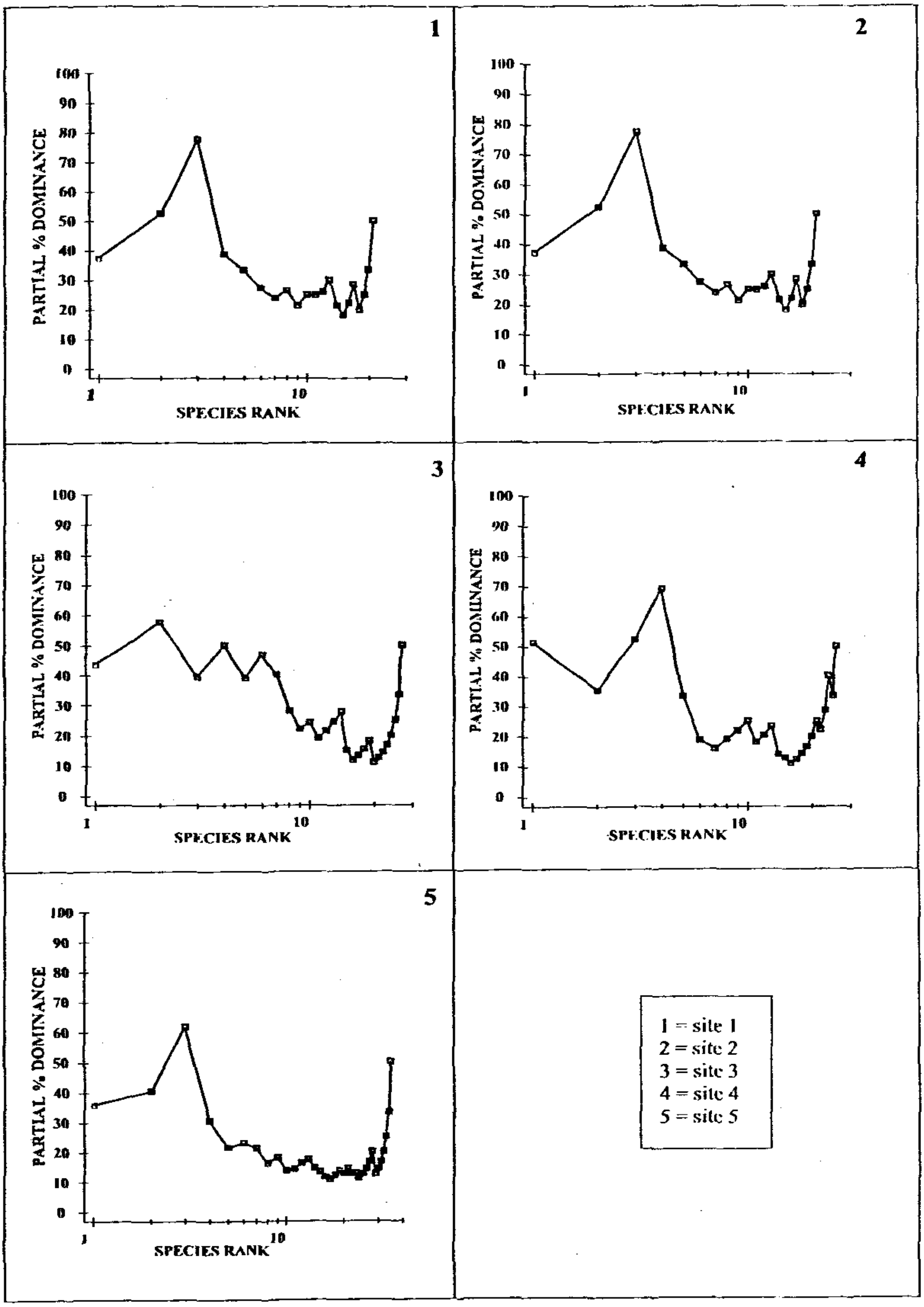


Figure 5.4: Partial dominance curves of benthic species ranked 1 - 10 in abundance, at Sites 1 - 5 during 1992.

furthest end of the scale were indicative of a large number of rare taxa. This pattern of percentage partial dominance according to species rank was also observed at Sites 1, 2, 4 and 5 during 1993 (Figure 5.5). However, the dominance shifted to taxa that were ranked between sixth and eighth in order of importance. Figure 5.6 shows that this type of community structure was disrupted during 1994. Generally, the percentage partial dominance of ranked taxa indicated that there were a fewer number of highly abundant taxa, but more peaks in abundance were observed from taxa at the lower end of the species ranking scale.

Gray and Pearson (1982) recommended plotting the number of species in geometric abundance classes as a means of detecting stress, particularly pollution stress. These authors indicated that in unpolluted situations, a community has many rare species, with a smooth curve having a mode well to the left. Polluted situations are characterised by fewer rare species and a 'jagged' curve. Figures 5.7 to 5.9 are plots of the percentage taxa in each geometric size class at each site, during a particular year. Generally, at all sites in 1992 curves with two peaks were observed (Figure 5.7). This accounted for taxa that either had an intermediate or great number of individuals. Generally, over 25% of the taxa recorded were in the geometric size class range 4 - 8. Over 10% of the taxa in the geometric size class range 10 - 15, accounted for the second peak observed in each of the plots. During 1993 (Figure 5.8), a similar trend was exhibited from Sites 1 to 4. Site 5 was characterised by a greater number of taxa (32% of total), with fewer number of individuals. As was observed in the dominance plots of each sampling site in 1994 (Figure 5.6), 1994 was fairly variable in terms of exhibiting a pattern that was similar to either of the two previous years. The curves representing the percentage taxa in each geometric size class were more irregular, but the highest percentage taxa continued to dominate the smaller size classes (Figure 5.9). This was especially true of geometric size class 4 at Sites 1 to 5, which contained over 25% of the total number of taxa at Sites 1 - 3 and 5.

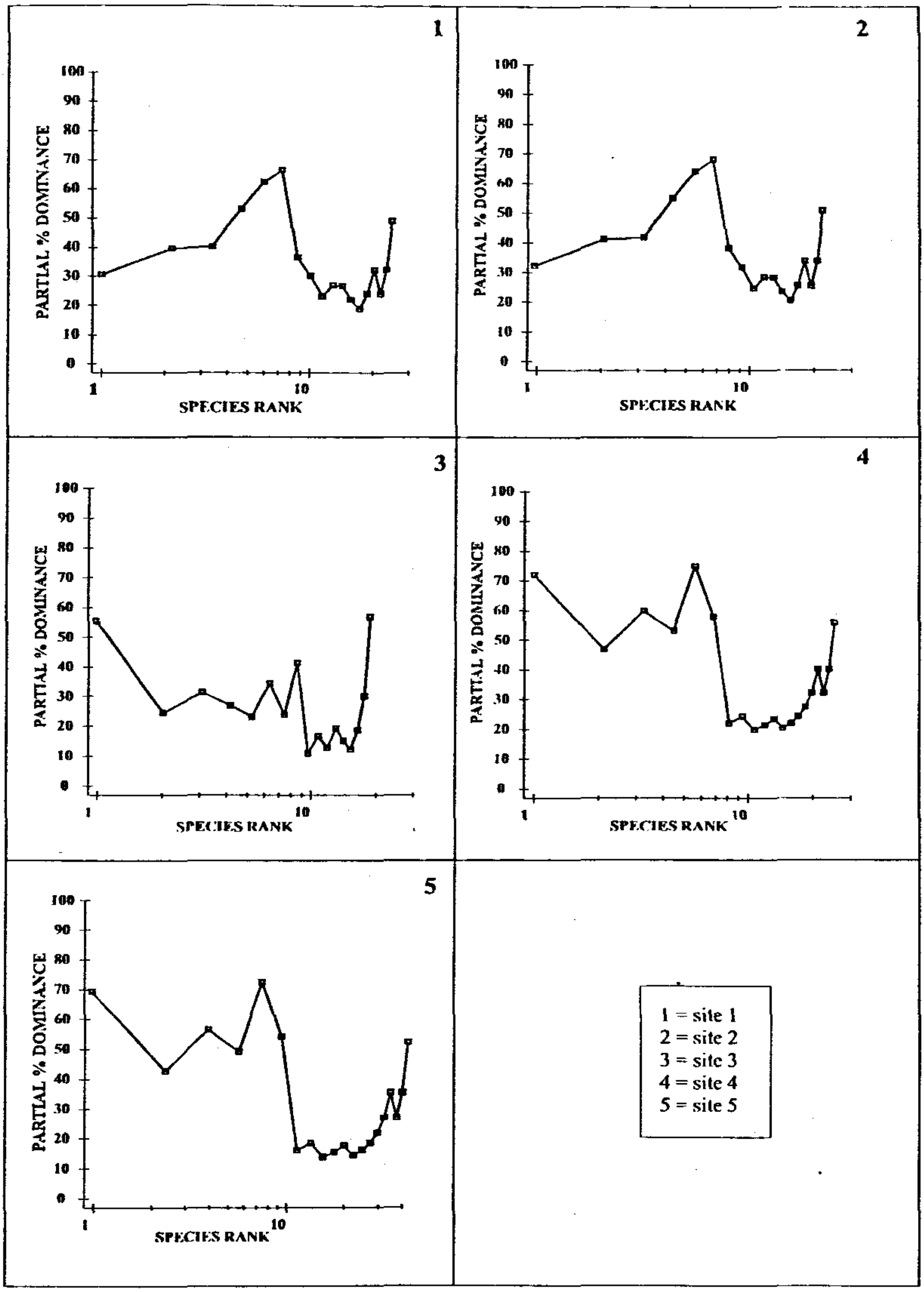


Figure 5.5: Partial dominance curves of benthic species ranked 1 - 10 in abundance, at Sites 1 - 5 during 1993.

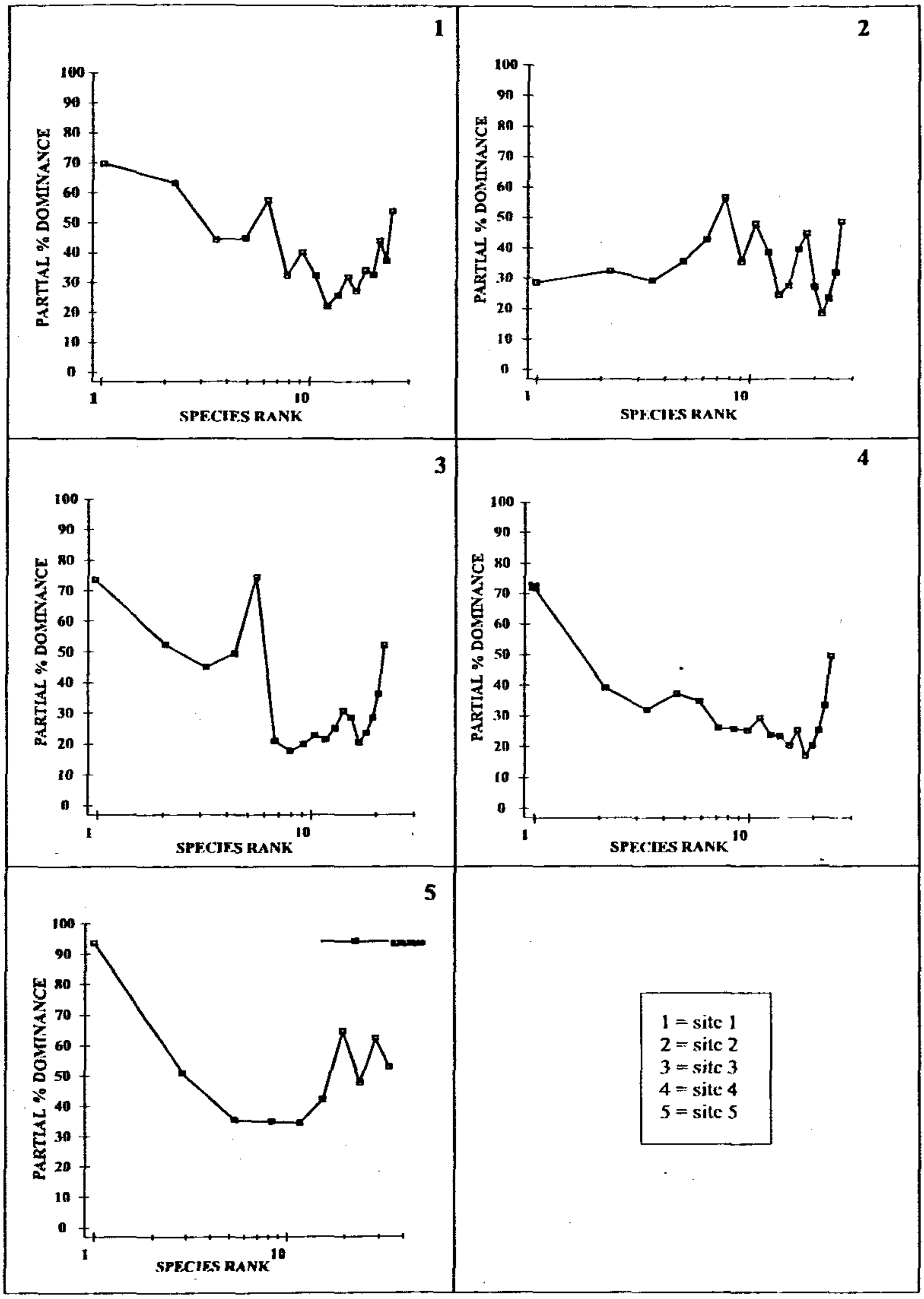


Figure 5.6: Partial dominance curves of benthic species ranked 1 - 10 in abundance, at Sites 1 - 5 during 1994.

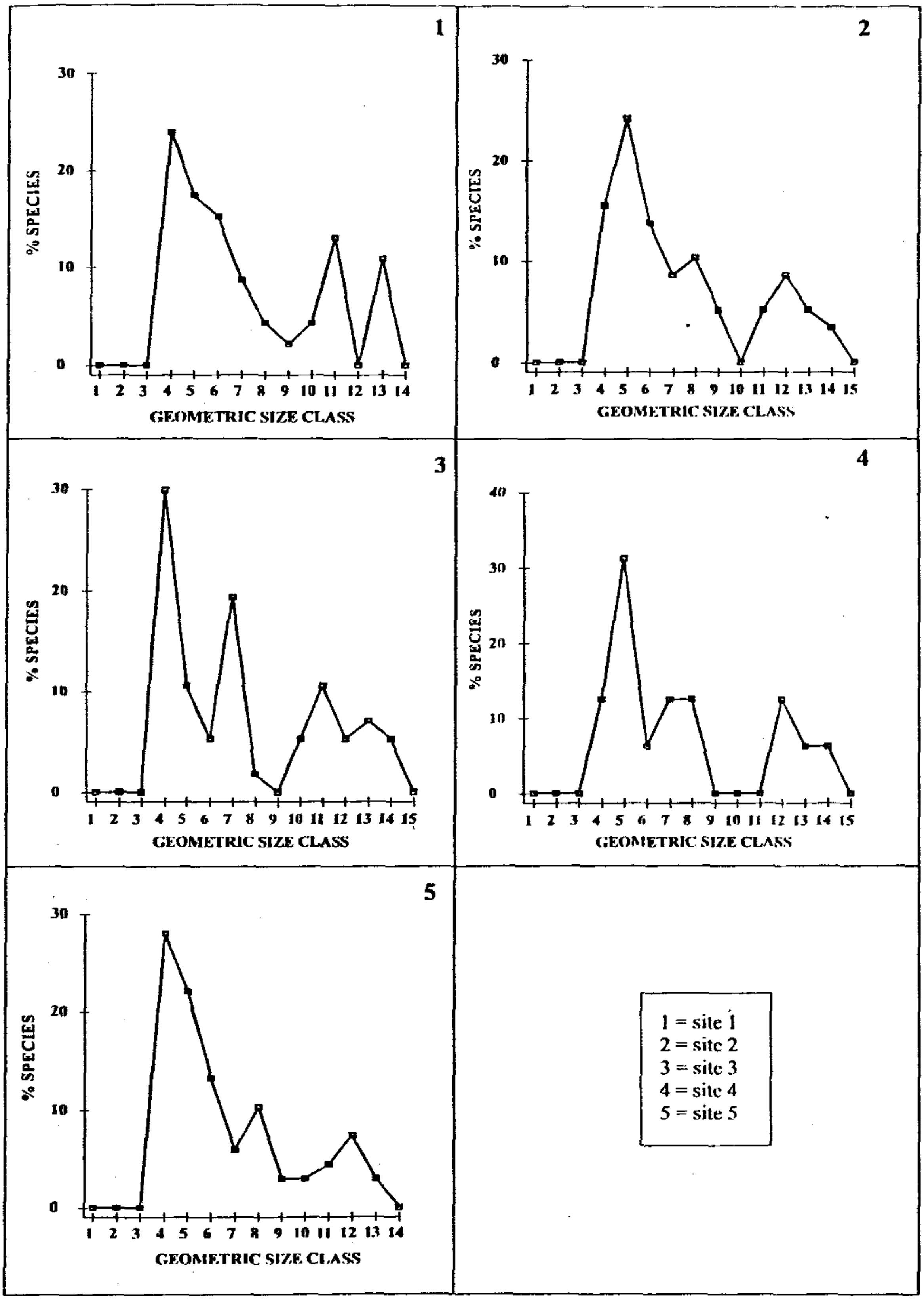


Figure 5.7: Plots of *x2* geometric benthic species abundance classes for Sites 1 - 5, during 1992

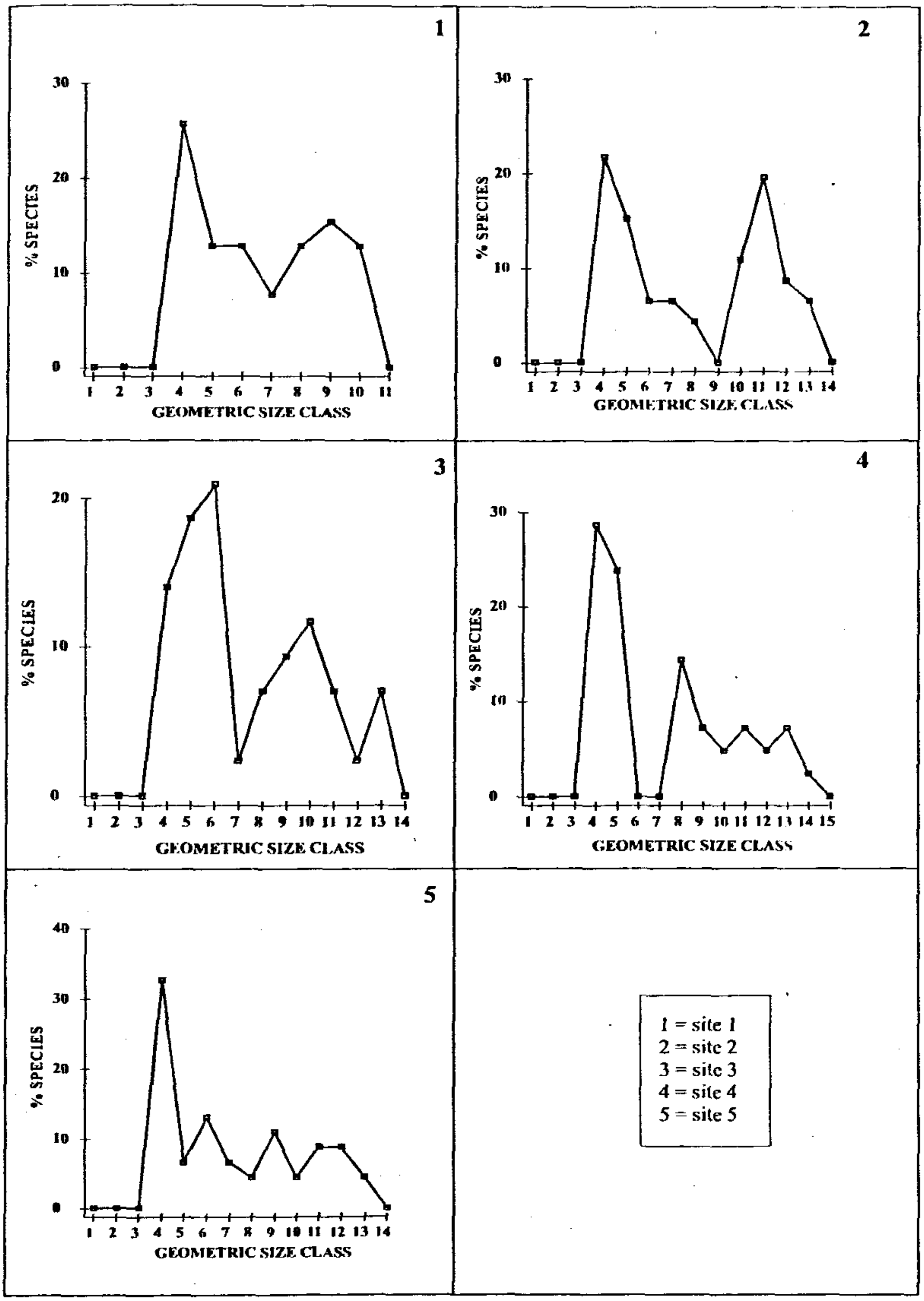


Figure 5.8: Plots of *x2* geometric benthic species abundance classes for Sites 1 - 5, during 1993

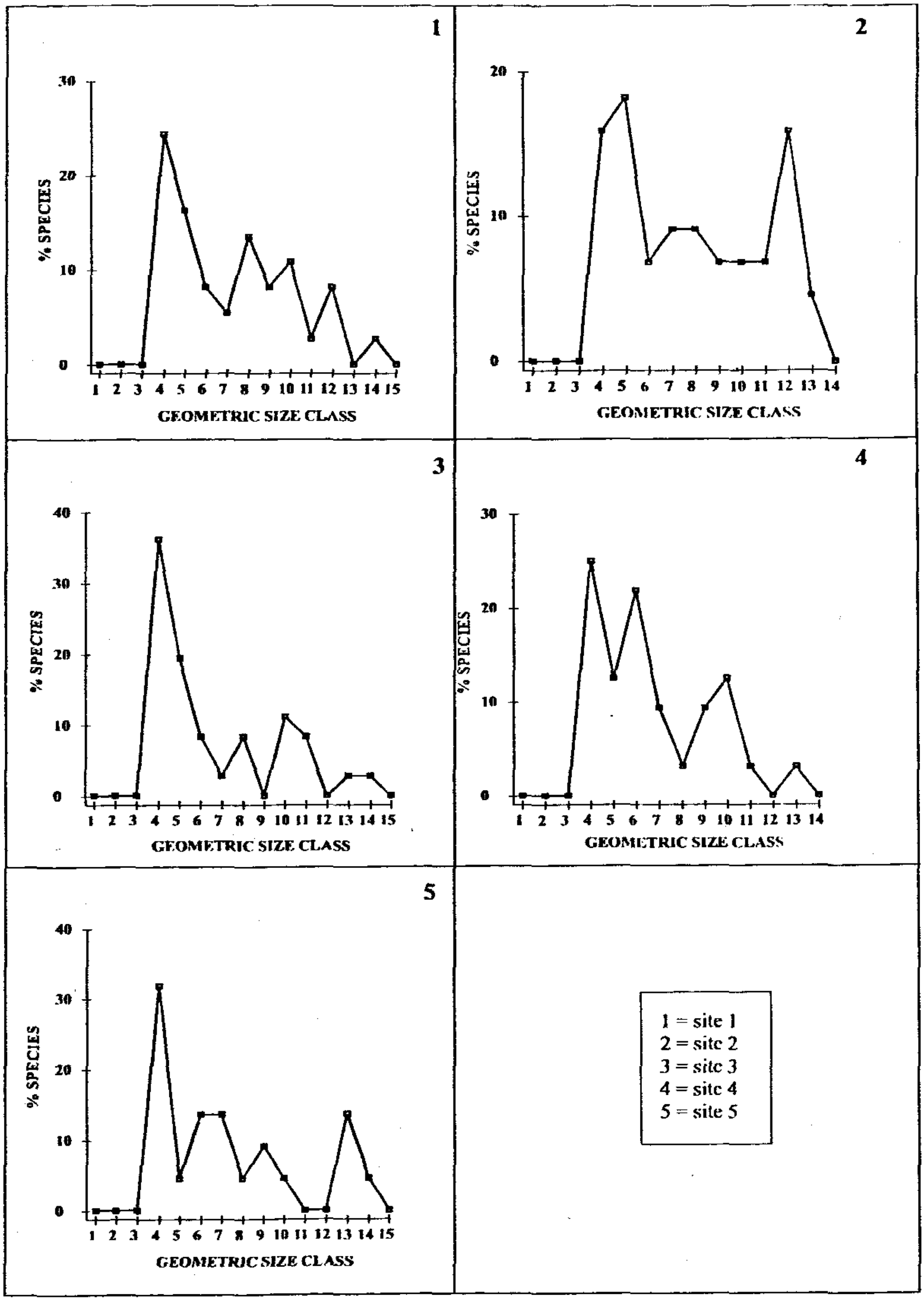


Figure 5.9: Plots of *x2* geometric benthic species abundance classes for Sites 1 - 5, during 1994

5.7.4 Measures of Richness and Diversity

The number of different taxa at each sampling site and season was calculated to establish whether the same pattern as that given by the mean abundance was reflected. That is, a large number of taxa in the lower to middle reaches, and fewer in the upper reaches of the Siyaya estuary. With regards to the seasonal changes in the number of different taxa recorded at each site during 1992, the highest total number were sampled during summer (Figure 5.10). The 36 taxa present in summer declined during autumn and winter, but increased in spring to 31 different taxa. During summer, autumn and spring the number of invertebrate taxa generally increased towards the middle reaches (Site 3). Winter was an exception, as different taxa recorded increased between Sites 1 and 2 (10 to 14 taxa), then declined towards the middle reaches. During 1995, Site 5 was consistently characterised by the highest number of different taxa.

Figure 5.11 shows that during 1993, the highest numbers of different taxa (sum of five sites) were recorded during summer and winter. The 34 different taxa present in summer declined slightly in autumn, increased again in winter and decreased rather rapidly in spring to 26 different invertebrate groups. During summer and autumn the number of invertebrate taxa decreased from headwaters to the mouth of the estuary, while no specific pattern for different number of taxa was evident for either of the other two seasons. In comparison with 1992 taxonomic numbers (Figure 5.11), the number of different invertebrate taxa increased during autumn and winter (26 to 31 and 22 to 34 taxa, respectively). Therefore a slight increase in the number of different taxa per season occurred during 1993.

During 1994, there was an overall decrease in the number of different taxa per season, except in autumn (Figure 5.12). In autumn the number of taxa increased from 31 to 44, and was 18 more taxa than recorded during 1992. During summer, winter and spring, the greatest number of different taxa were concentrated in the middle to upper reaches of the estuary, spread over Sites 3 - 5. Autumn was the exception, and here the greatest number of taxa occurred in the middle to lower reaches (Sites 3 and 2).

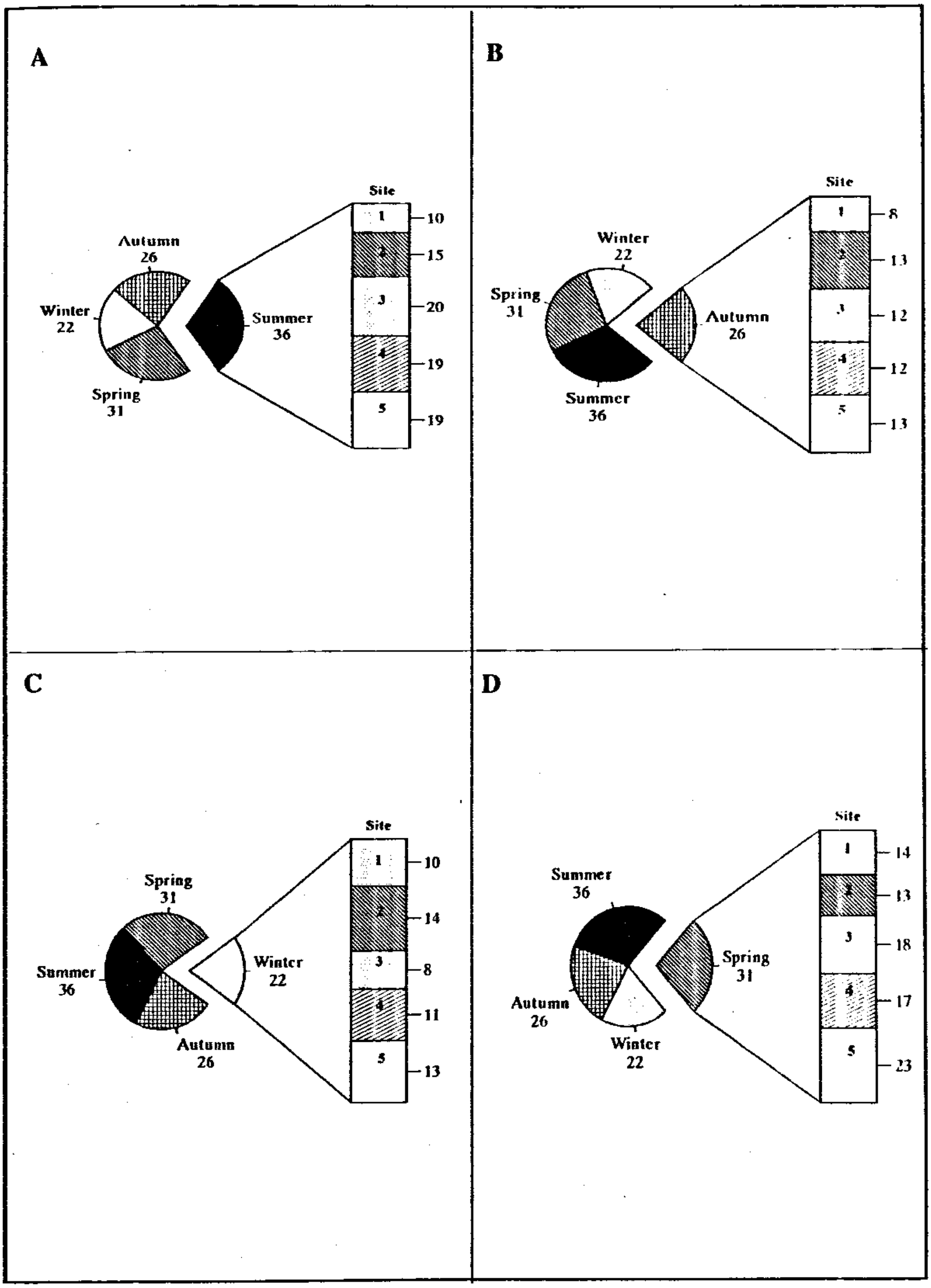


Figure 5.10: The number of different taxa collected at each sampling site and season, during 1992

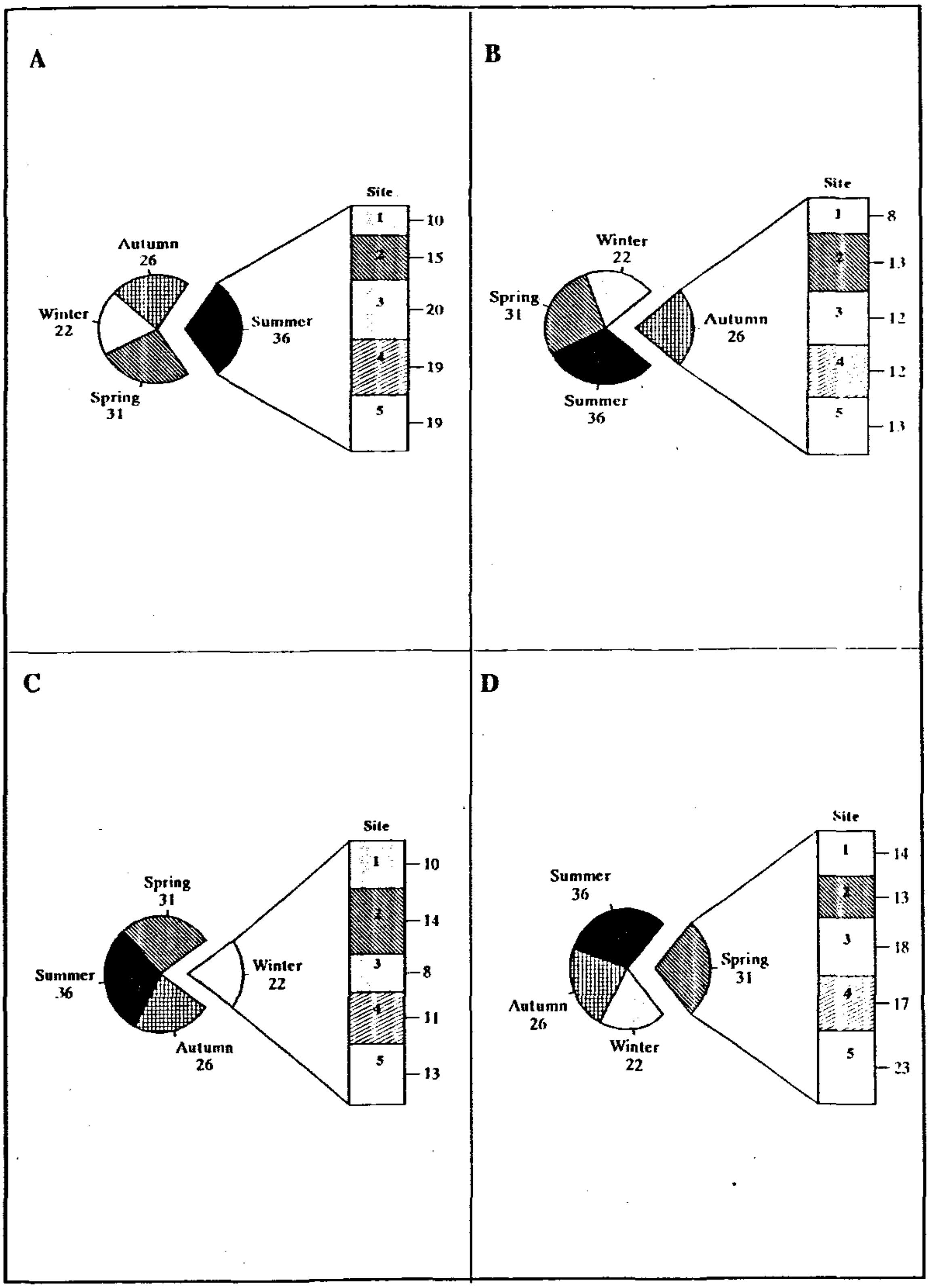


Figure 5.11: The number of different taxa collected at each sampling site and season, during 1993

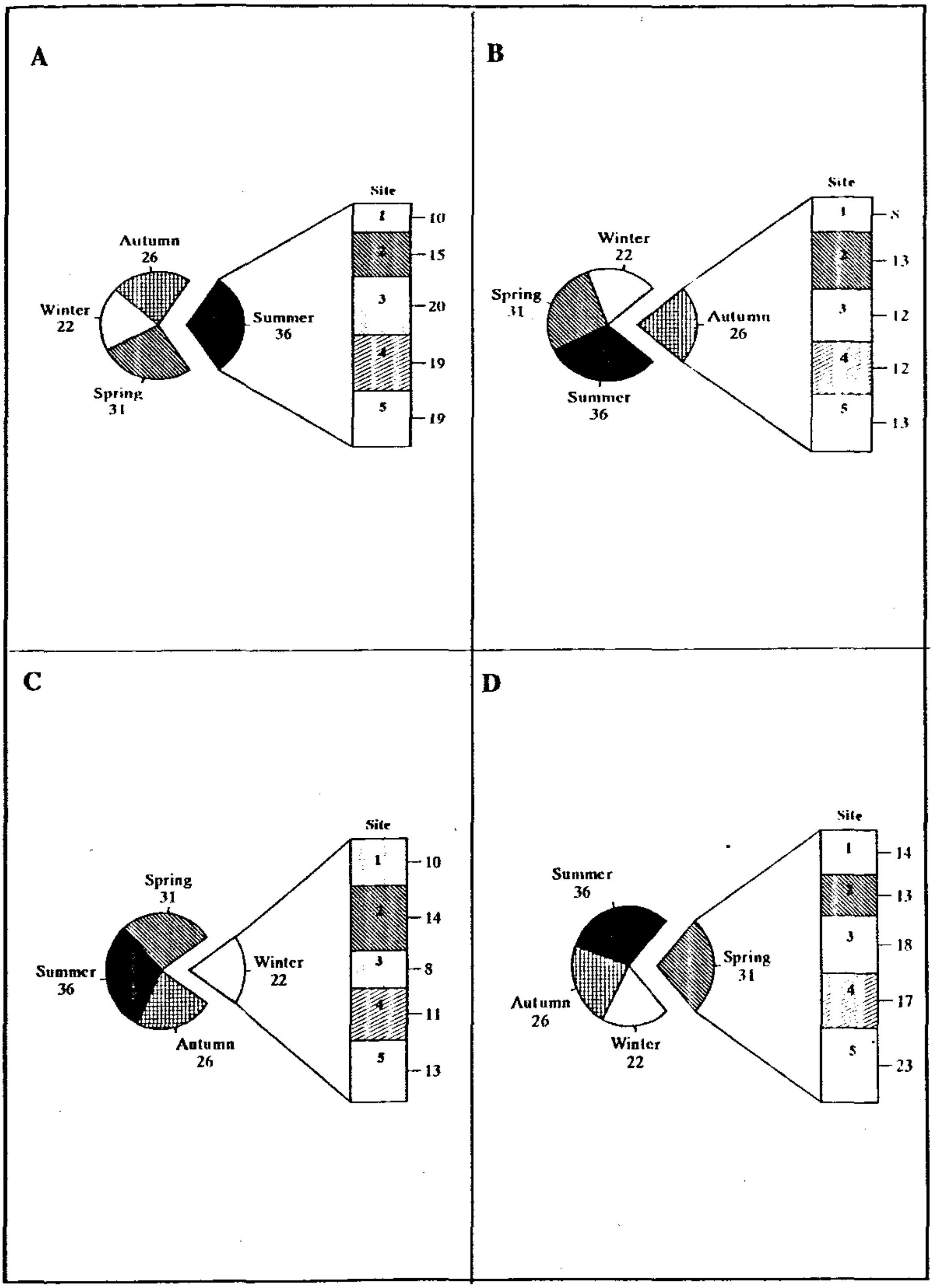


Figure 5.12: The number of different taxa collected at each sampling site and season, during 1994

Four indices were calculated to compare taxonomic dispersion along the length of the Siyaya Estuary. These indices incorporated either taxonomic numbers or abundance or both in their calculations to provide some method to distinguish sampling sites from one another (See Section 5.4). Margalef's (1961), Shannon and Weaver's (1963), Simpson's (1949)and Pielou's (1986) Indices of Richness, Diversity, Dominance and Evenness were calculated and plotted on the same set of axes for each sampling site, over four seasons during each year (Figure 5.13). Margalef's richness index was consistently higher, than either of the others measured. This was attributed to the fact that this index does not incorporate a measure of abundance in its calculation. Three patterns emerge from these plots. The first is that during 1992, species richness was negatively related to abundance. That is, as abundance increased, species richness decreased. Therefore at Site 5 (lowest abundance), the species richness was the highest. The second pattern was a slump in species richness in the middle reaches of the estuary, during winter and spring of 1993. During summer and autumn, the trend was similar to that encountered during 1992, with the greatest species richness occurring in the upper reaches of the estuary. The third pattern of species richness was that the lowest values of species richness occurred in the upper reaches, particularly at Site 5, during 1994. This was the opposite situation to 1992. The range of species richness was 1.88 - 6.06, 1.69 - 3.52 and .275 - 4.23 for 1992, 1993 and 1994, respectively (Appendix I).

The ranges of the other indices calculated (diversity, dominance and evenness) were similar, and values were significantly lower than species richness ($p<0.05$). This was attributed to the fact that these indices incorporate abundance measures to determine results. The highest measures of diversity were observed during summer 1992 (.624, .614, .612 .667 and .882, for Sites 1 - 5, respectively; see Appendix I). The lowest diversity measured during 1992 was .300 at Site 4 during winter. During 1993, diversities were greater at Sites 1 and 2 during each season. The maximum diversity recorded was at Site 2 during spring (.752). Each season, the lowest diversities were recorded at Site 4. As compared to 1992 and 1993, 1994 was characterised by a low species diversity. The lowest diversities over the three successive years were recorded during 1994 (.053, .050 and .024 for Site 5 summer, Site 5 autumn and Site 4 spring, respectively. This was in contrast to the highest values of Simpson's dominance index

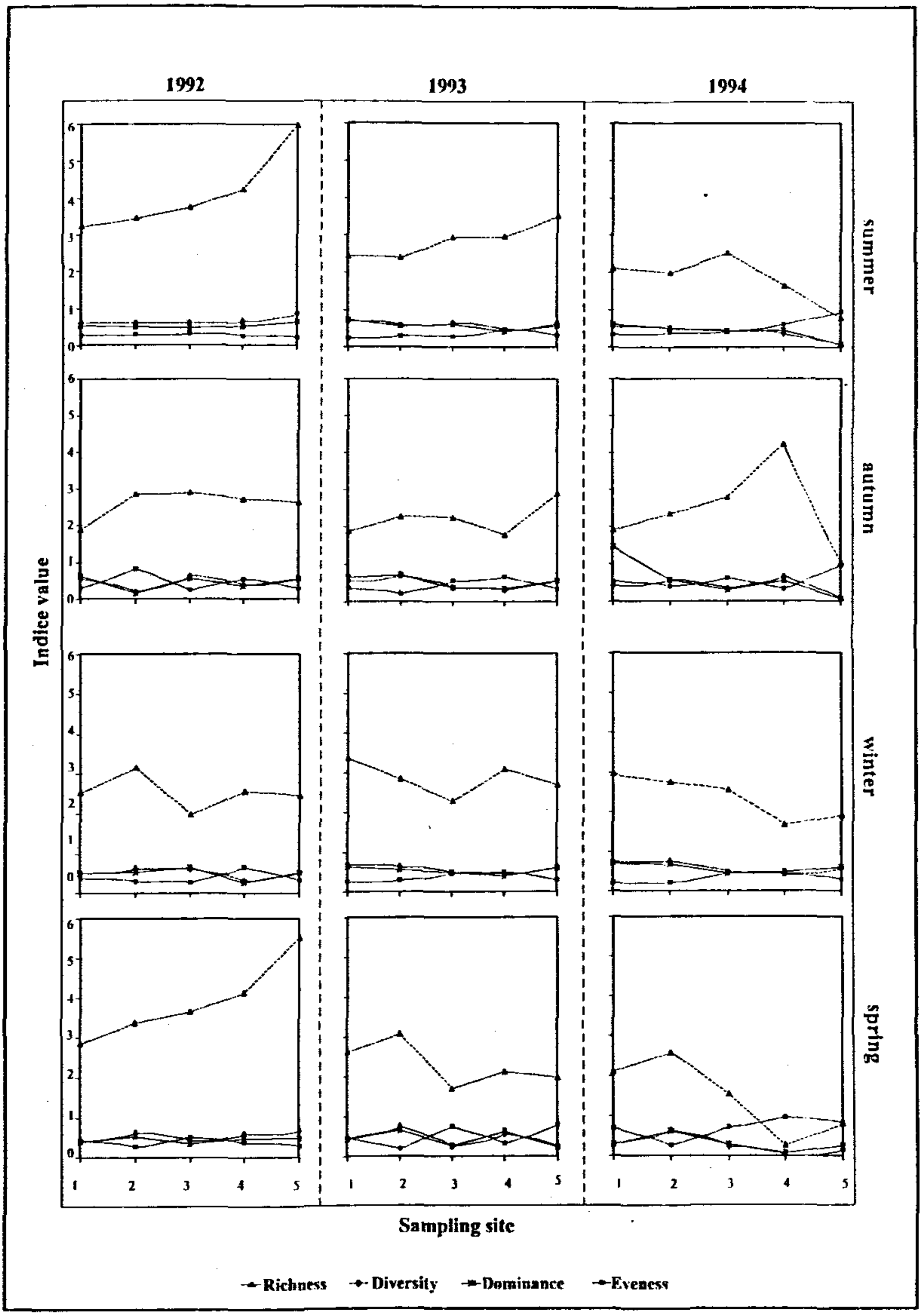


Figure 5.13: Seasonal differences in indices of richness, diversity, dominance and evenness from 1992 to 1994

measured at these sites (.954, .963 and .981). This was so, as this measure gives the probability that two individuals from the same population belong to the same species. If the value is high, the diversity of that sample should be low. When all species are equally abundant, the evenness index should be maximum and decrease toward zero, as relative abundances of species diverge from evenness. Results of Pielou's (1986) index of evenness of benthos, show that in 1992 the greatest evenness was shown at sampling sites situated either end of the Siyaya Estuary (Sites 1 and 5; Appendix 1). This was also the case in winter 1993 (.646 at Site 1, .570 at Site 2, .490 at Site 3, .402 at Site 4 and .600 at Site 5). During the other seasons, the greatest evenness was recorded from samples taken at the lower reaches of the estuary. This pattern was also displayed in 1994, except during winter, where samples from the middle and upper reaches displayed the most evenness. Samples collected at Site 2 during the autumn of 1992 showed the greatest divergence from evenness by the relative abundances of taxa (.179; Appendix I). Maximum evenness was recorded at Site 1 during the summer of 1993 (.735).

5.7.5 Estuarine and Freshwater component of Zoobenthos

The physico-chemical variables measured in Chapter 4 indicated a decline in salinity over the three year period. A subsequent influx of freshwater taxa occurred in the upper reaches, therefore the proportional abundance of estuarine and freshwater taxa were calculated for each site, on a seasonal basis. Figures 5.14 and 5.15 represent the proportion of the freshwater, and estuarine components of taxa at each sampling site within the Siyaya Estuary, from 1992 to 1993. Each chart is a proportion of either the total number of freshwater or estuarine taxa occurring at a particular site. Generally, the greatest proportions of estuarine benthic taxa occurred from Sites 1 to 5 during 1992(Figure 5.14). The highest percentage of estuarine benthos at any site was 69% at Site 4 during summer. This pattern was altered in 1994, when the greatest proportions of estuarine benthos occurred closer to the lower reaches of the estuary. In spring 1994, the highest densities of the estuarine component of the benthos were sampled at Sites 1 and 2 (77 % and 23 %, respectively). This coincides with overtopping of the sandbar at the mouth, and the significant increase in the number of juvenile mullet sampled in the area at this time.

Figure 5.15 clearly indicates that the freshwater taxa sampled in the area were primarily concentrated at Site 5, and from Appendix II that these were mainly oligochaetes and chironmid larvae. Freshwater taxa were represented at all sites except during autumn 1992, where they were absent from Site 2. The highest proportions of freshwater taxa occurring at any site were recorded during summer 1994, autumn 1992 and winter 1994 with proportions equal to 57 %, 52 % and 46 %, respectively.

In terms of actual densities of these two components of the benthos, during 1992 of the mean 14 433 individuals m^{-2} collected, 97% of the total density was contributed by the estuarine component. In 1993, the denisty of the estuarine component was still greater, but contributed slightly less than the previous year to the overall density of freshwater and estuarine components (85%). During 1994 the freshwater component made up 46% of the total density of benthos. Therefore in terms of density, the freshwater component increased steadily from 1992 to 1994, while a subsequent decrease occurred in the density of the estuarine component.

Since the proportional abundance of both estuarine and freshwater taxa per site were calculated, the number of different freshwater and estuarine taxa corresponding to this were also calculated. The aim of this was to show if the number of estuarine taxa in the Siyaya were decreasing in response to the increase in number of freshwater invertebrates. Figure 5.16 are the results of these analyses, and clearly indicate the above fact to be true. A steady increase of the number of freshwater taxa colonising the Siyaya Estuary occurred from 1992 to 1994, while estuarine taxonomic numbers steadily decreased.

5.7.6 Seasonal Dominance of Taxa

During 1992, throughout the estuary the polychaete *Ceratonereis keiskamma*, a cumacean *Iphinoe truncata*, the tanaid *Apseudes digitalis*, and the amphipods *Grandidierella lignorum* and *Corophium triaenonyx* were more abundant in terms of total densities per square metre than any other invertebrate taxon. During summer, of the five dominant taxa, *G. lignorum* and *C. triaenonyx* contributed the most to overall benthic abundance. This is given in Figure 5.17. *I. truncata* and *A. digitalis* were the

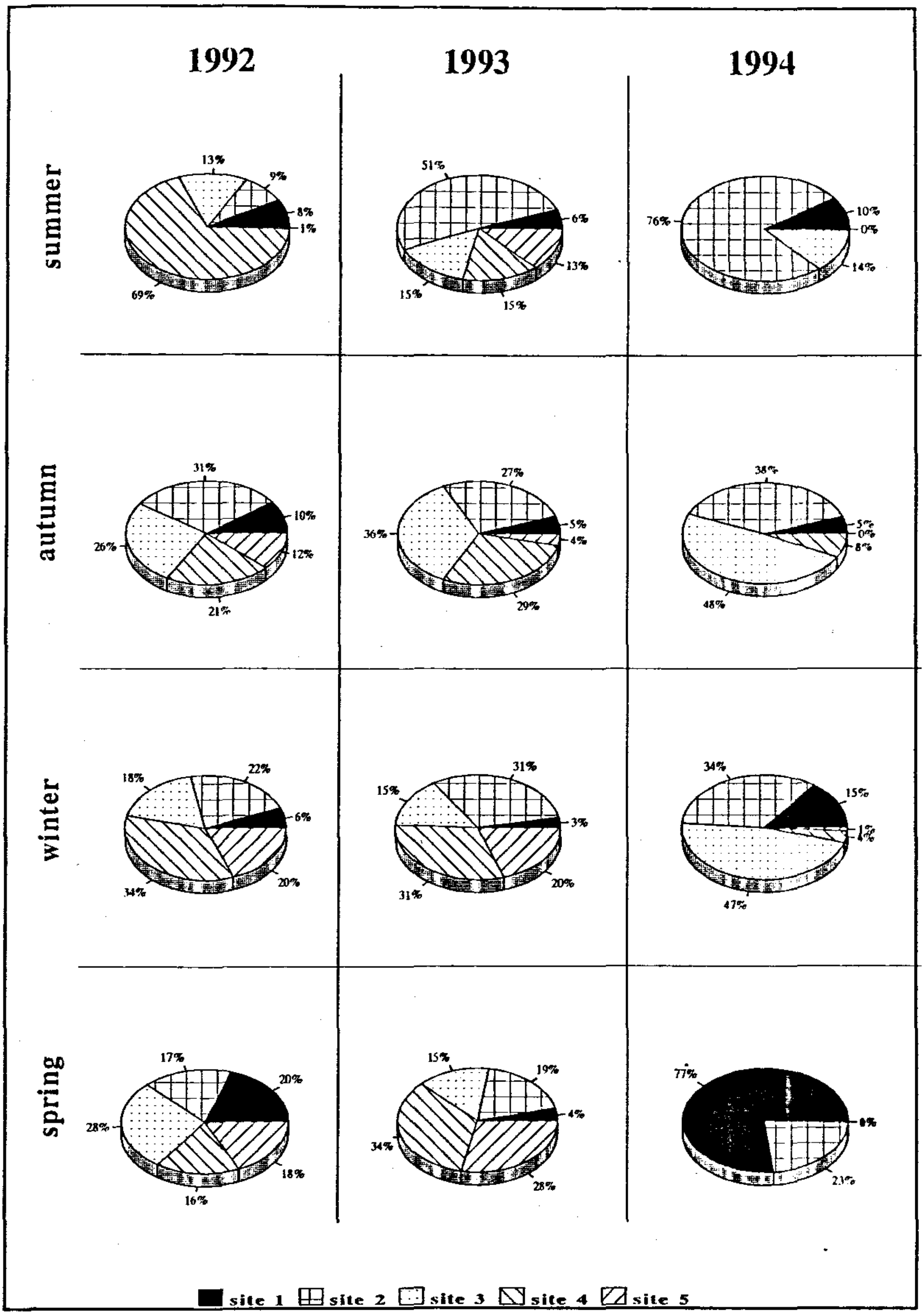


Figure 5.14: Seasonal percentage contribution of the estuarine component of the benthos at each sampling site, from 1992 to 1994

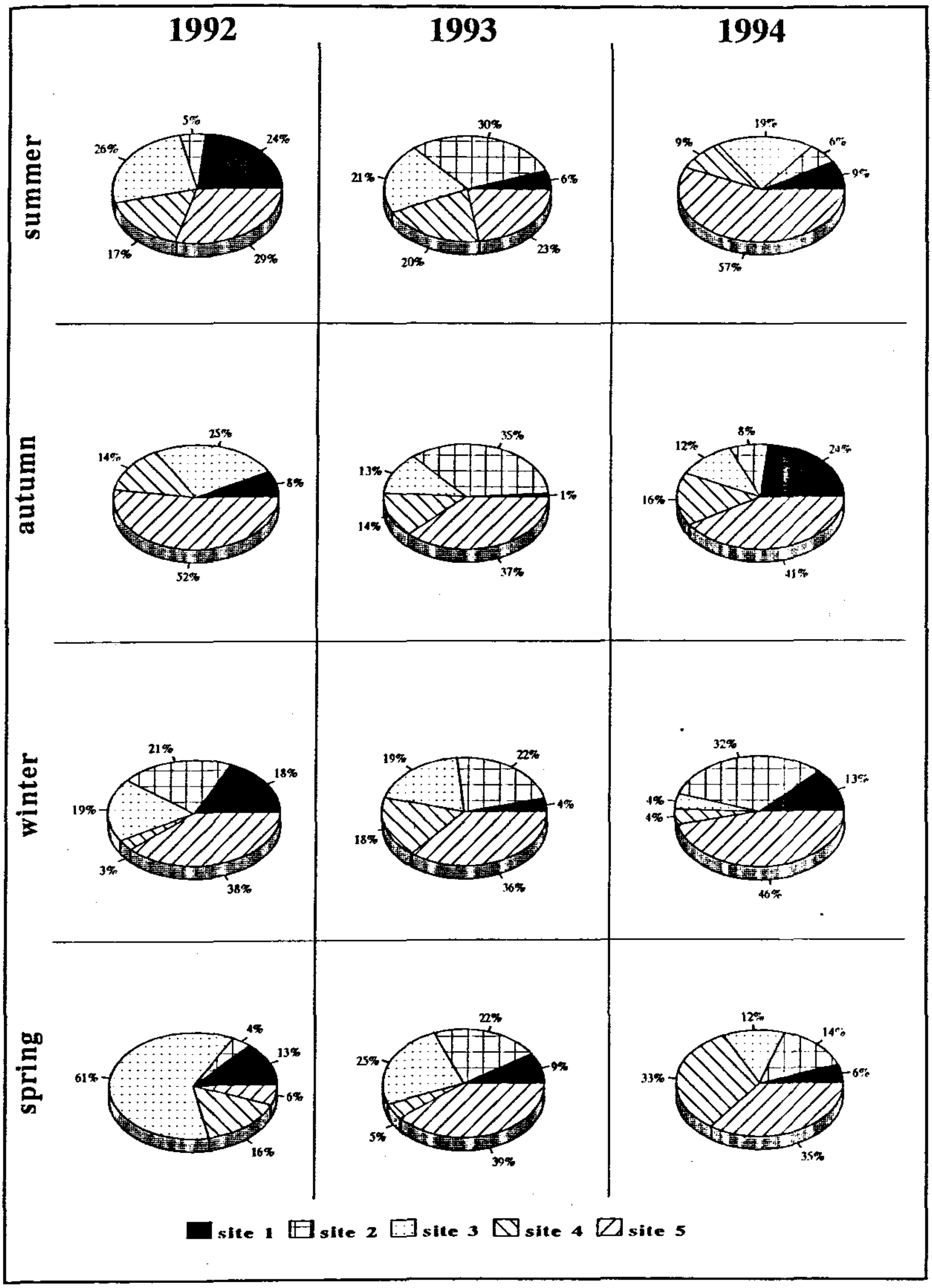


Figure 5.15: Seasonal percentage contribution of the freshwater component of the benthos at each sampling site, from 1992 to 1994

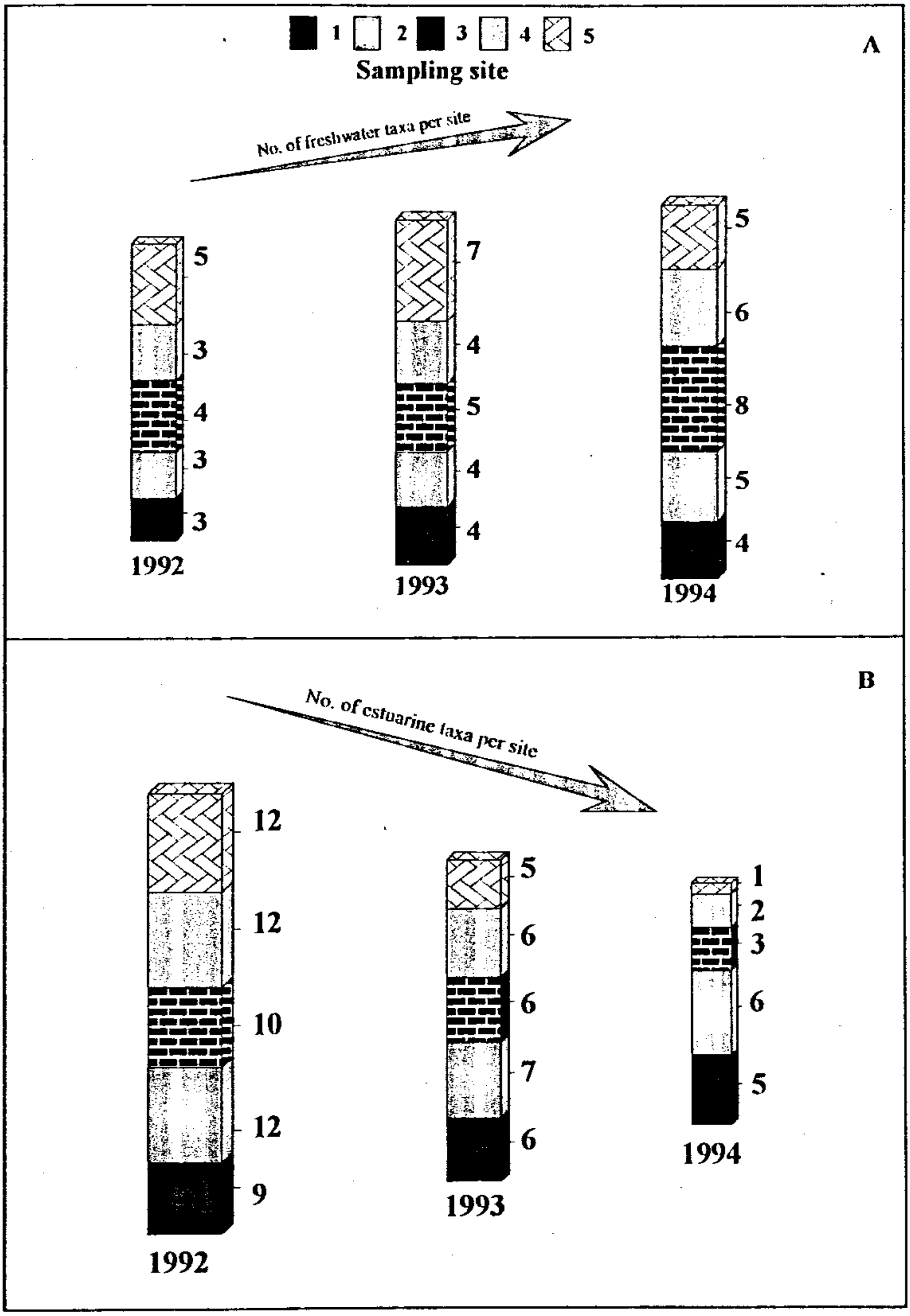


Figure 5.16: The number of freshwater taxa (A) and estuarine taxa (B) at each sampling site from 1992 to 1994

third and fourth most abundant species. *C. keiskamma* was distributed along the estuary in all substrates. *G. lignorum* dominating the benthos at Sites 1 and 2, was replaced by *C. triaenonyx* at Sites 3 and 4. *Grandidierella lignorum* was present at all sampling sites, while *C. triaenonyx* was only present at Sites 3 and 4. During autumn, benthic densities were dominated by *A. digitalis*. Amphipods present were together more abundant than the tanaid and the cumacean. *Apseudes digitalis* was also the most abundant representative during winter (Figure 5.18), followed by *G. lignorum* and *C. triaenonyx* occurring in all substrate types. *Ceratonereis keiskamma* was present and abundant, although less dominant than the other three taxa. During spring *G. lignorum* was the most abundant invertebrate collected from all sampling sites.

During 1993, the numerically most abundant taxa were similar during summer, autumn and winter, and were the same dominant species that occurred in 1992, but *I. truncata* was replaced by the Oligochaeta group. In summer, of the five most dominant taxa *A. digitalis* contributed the most to overall benthic abundance (Figure 5.19). The amphipod *C. triaenonyx* was also responsible for a large proportion of the total density. The greatest combined density of the five dominant taxa was at Site 2. Site 1 had the lowest benthic abundance with regards to the five selected taxa, *Apseudes digitalis* did not occur at this site. This was true for summer, autumn and winter where this polychaete was found to be more abundant towards the lower reaches of the system (Figure 5.20). Although *G. lignorum* and *C. triaenonyx* were able to both co-habit the same niche, *G. lignorum*. was generally numerically more abundant during each of the seasons. During spring, the polychaete *C. keiskamma* was no longer in the top five numerically dominant taxa, and was replaced by *D. ornata*, which was characterised by a single sighting in the upper reaches of the estuary.

During 1994 (Figures 5.21 and 5.22), the five numerically most abundant taxa *were G. lignorum*, *C. triaenonyx*, *A. digitalis*, Oligochaeta and chironomid larvae. Two freshwater taxa were therefore accounting for a large proportion of the abundance of benthos from summer to spring. During all four seasons, *G. lignorum* was the most abundant taxon.

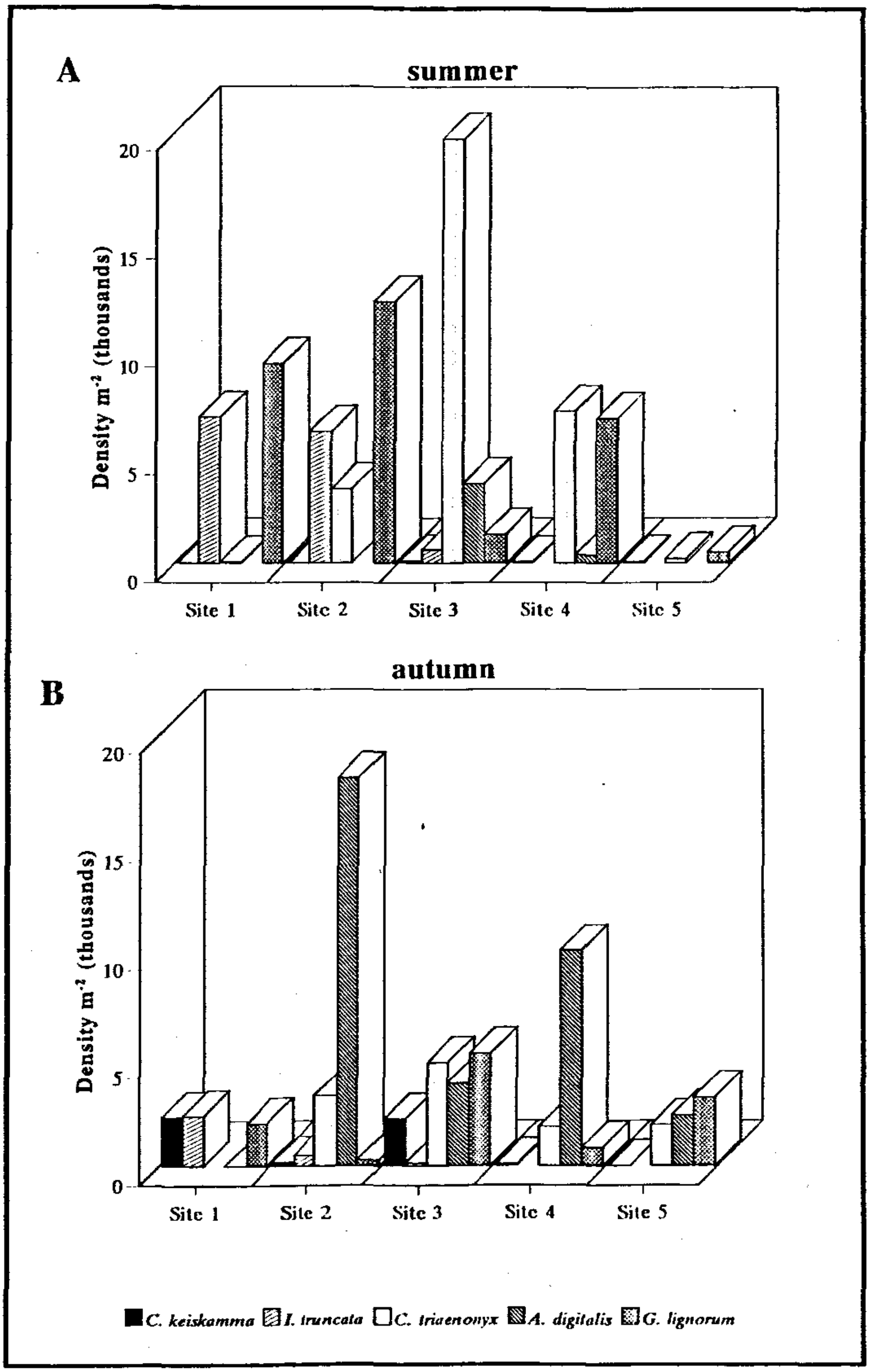


Figure 5.17: Abundance and distribution of the five most dominant taxa during summer and autumn of 1992

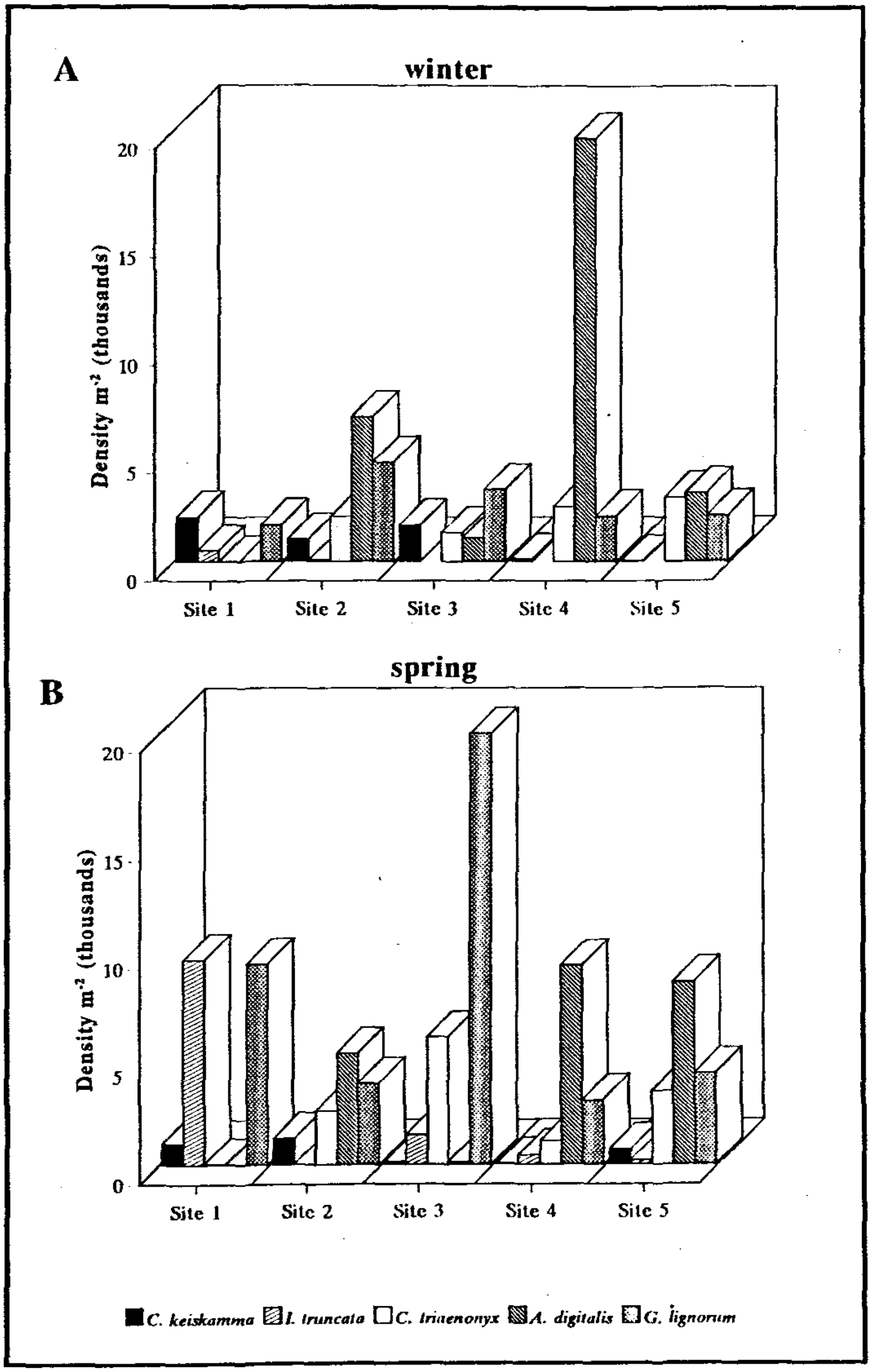


Figure 5.18: Abundance and distribution of the five most dominant taxa during winter and spring of 1992

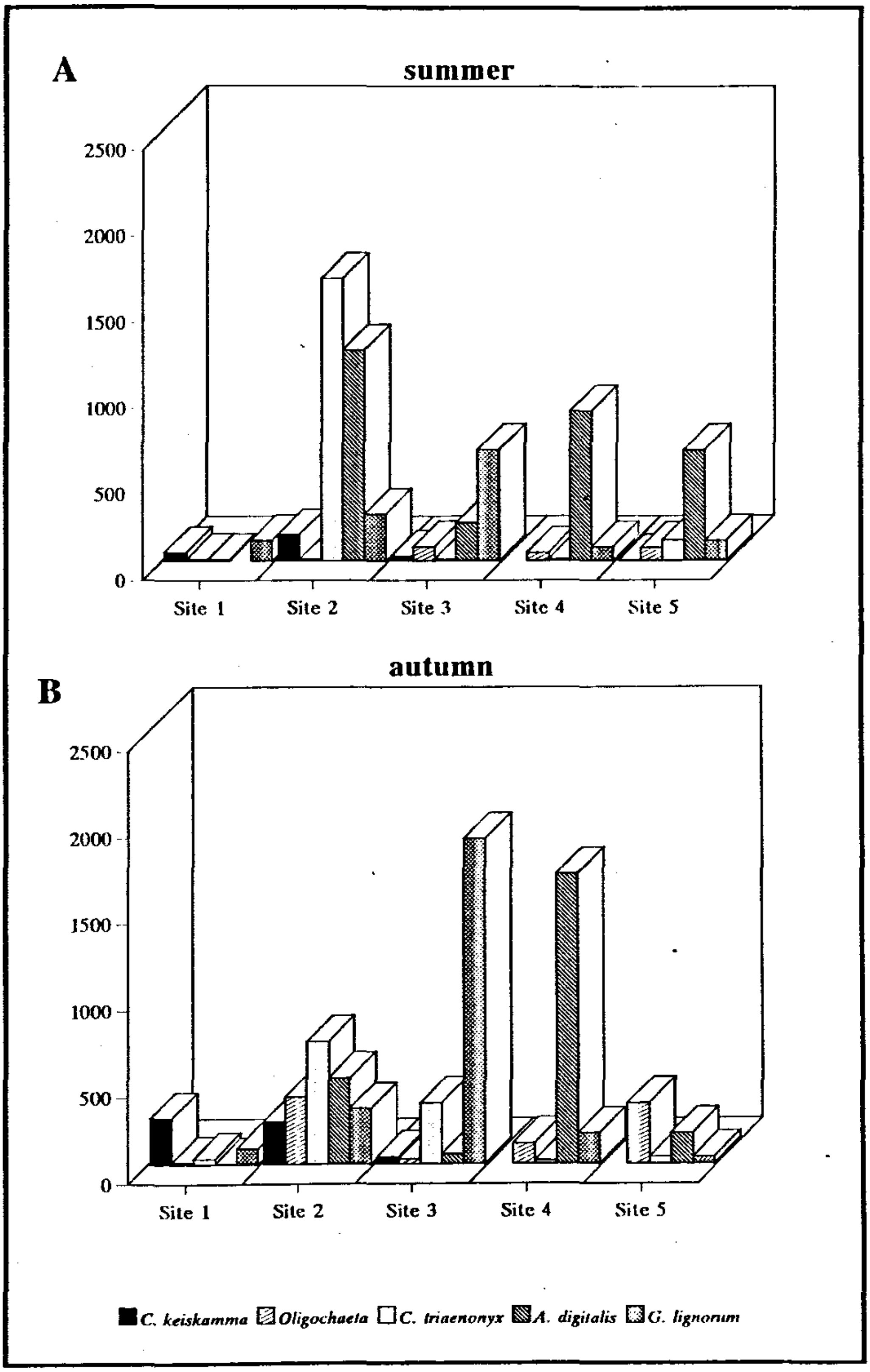


Figure 5.19: Abundance and distribution of the five most dominant taxa during summer and autumn of 1993

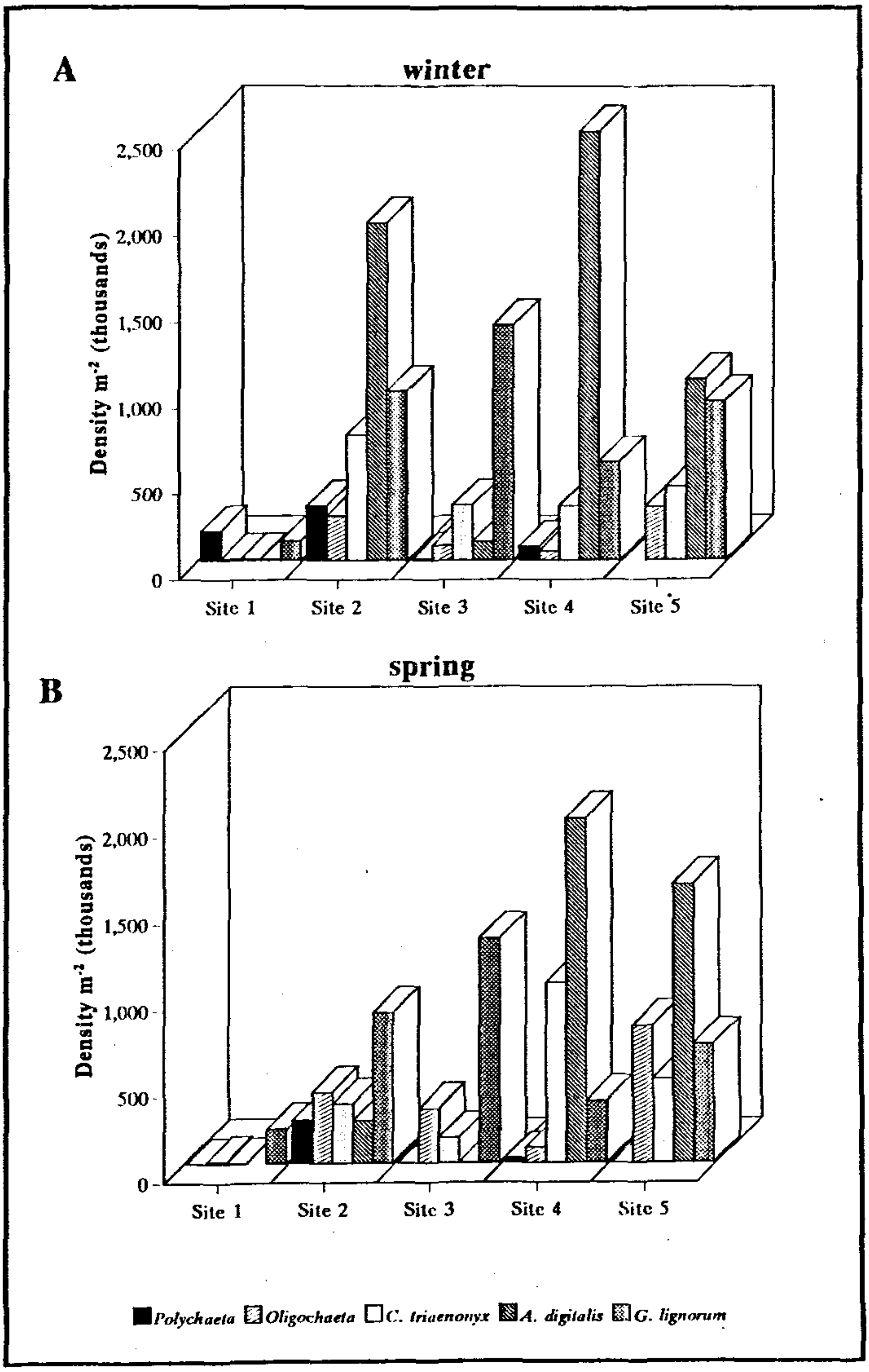


Figure 5.20: Abundance and distribution of the five most dominant taxa during winter and spring of 1993

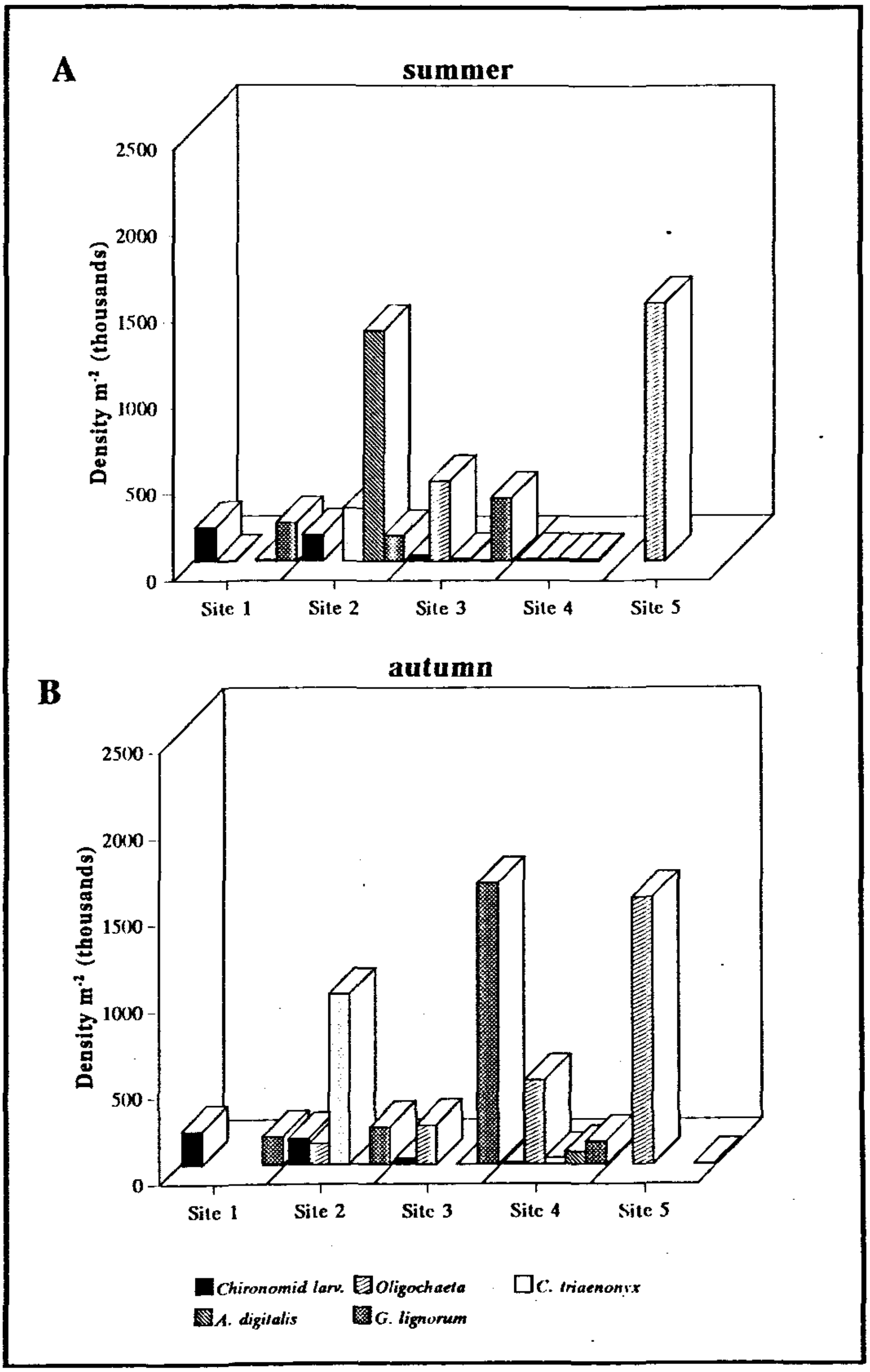


Figure 5.21: Abundance and distribution of the five most dominant taxa during summer and autumn of 1994

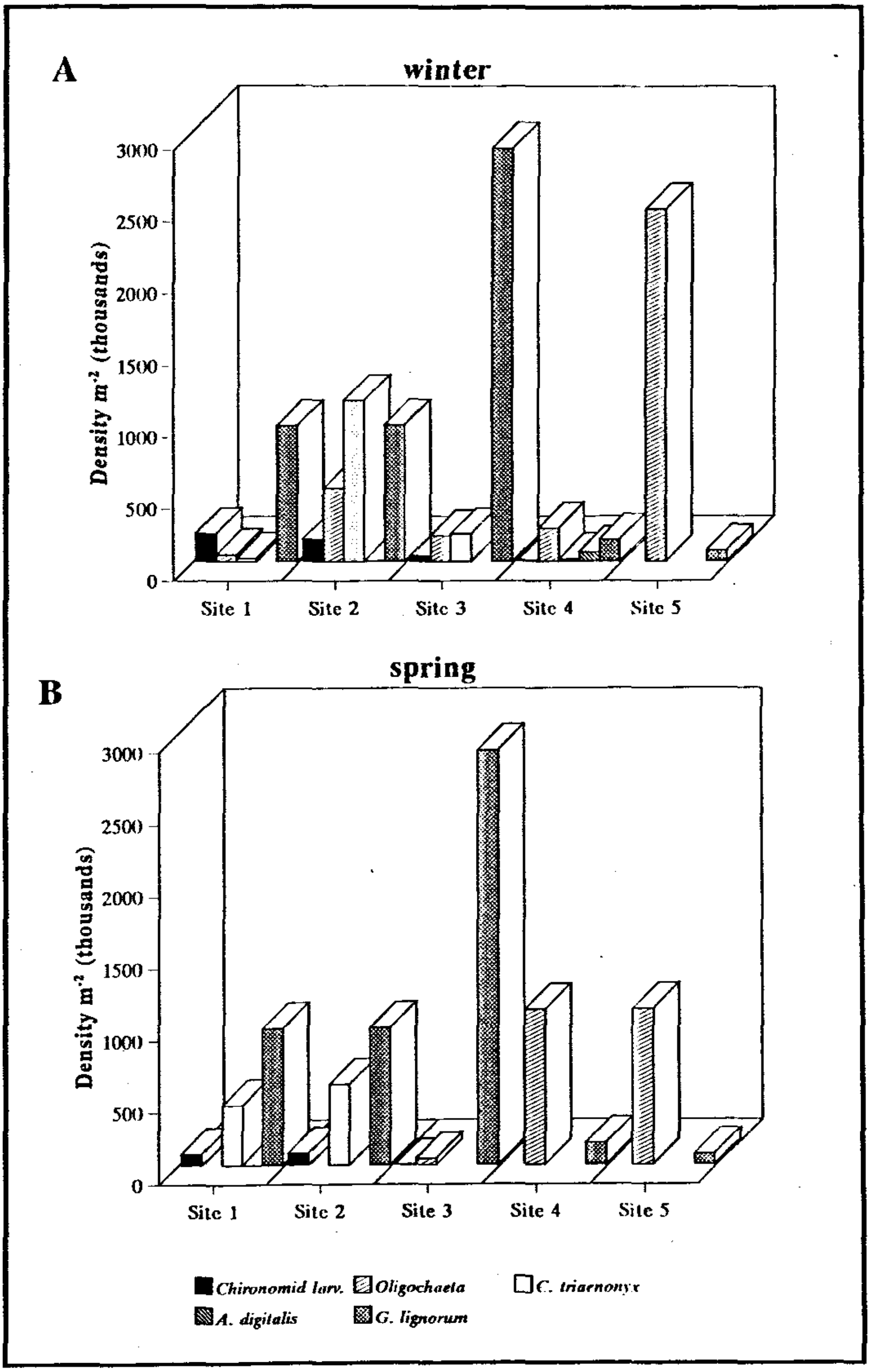


Figure 5.22: Abundance and distribution of the five most dominant taxa during winter and spring of 1994

5.7.7 *Community Classification and Ordination*

To obtain some idea as to the relationships between samples and taxa, Bray - Curtis similarity matrices and dendrograms were calculated for each sampling site and season, as well as for each taxon sampled during each sampling year. The matrices were then used as an input to a non-metric multidimensional scaling (MDS) ordination to confirm relationships between samples and species (Section 5.2.3). Sample relationships are presented in Figures 5.23, 5.25 and 5.27 for 1992, 1993 and 1994, respectively. Species relationships are given by the dendrograms and MDS plots in Figures 5.24, 5.26 and 5.28 for 1992 to 1994.

Cluster analyses of 1992 benthic samples separated four main groups at a Bray - Curtis distance of 100 (Figure 5.23 A). The first group (I) clustered winter samples from Sites 2 - 5, autumn samples from Sites 3 - 5, spring samples from Sites 2, 4 and 5 and summer Site 5. The second group contained the balance of samples from the first group (Site 1 and 3, spring; Site 1 and 2, autumn and Site 1, winter), except for the remainder of samples collected during summer. Group III and IV contained summer samples from Sites 1 - 3, and Site 5, respectively. The MDS plot (2d minimum stress = .13 after 10 runs), gave a clearer indication as to the different groupings at a Bray - Curtis similarity of 50 (Figure 5.23 B). Only two of the original groups were retained at this similar distance, the remainder were divided into smaller components indicating closer relationships between some samples. Specifically, the original Group I (similar distance of 100), was separated into three different components, the first constituted the remaining summer sample (Site 4), the second autumn Site 3, and the fourth winter Sites 2 and 3. The third group contained samples from Sites 4 and 5 during autumn and winter and spring samples from Sites 2, 4 and 5.

Inverse analyses of 1992 taxa are given in Figure 5.24 A and B. Each taxon recorded during 1992 was assigned a specific number, and this was retained in the final plot for ease of interpretation. These numbers and corresponding taxonomic names are presented in Table 5.10. Figure 5.24 A and B are a dendrogram and MDS plot of all species sampled during 1992. Lines at similar distances of 400 and 100 were drawn to cluster

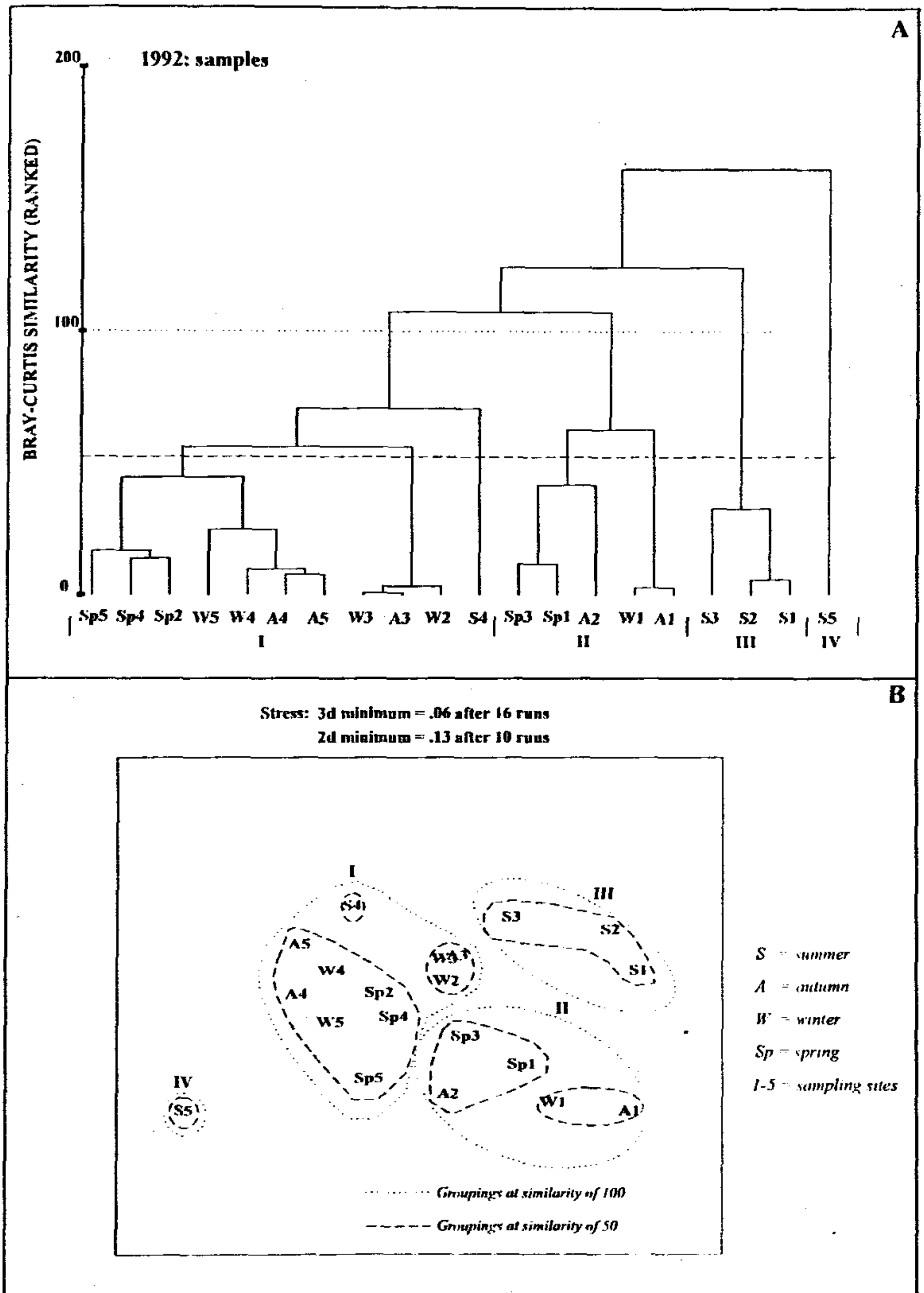


Figure 5.23 A: Bray -Curtis ranked clusters of 1992 benthic samples collected at five sites on a seasonal basis. Lines are drawn at similar distances of 100 and 50

B: 2d result of MDS of the above samples, with lines drawn around groups having similarities of 100 and 50. Stress for MDS is .13 after 10 runs

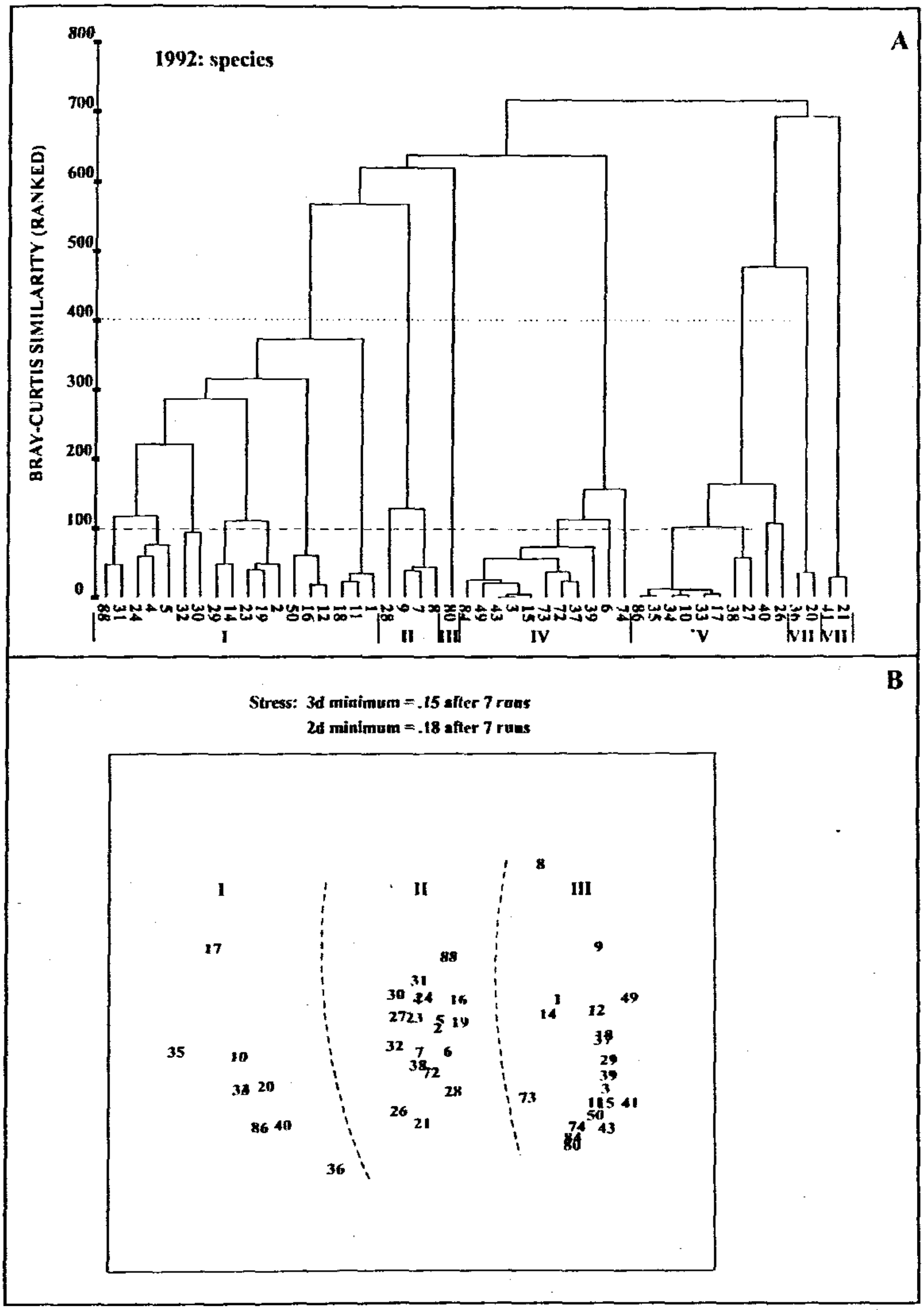


Figure 5.24 A: Bray -Curtis ranked clusters of 1992 benthic species collected at five sites on a seasonal basis. *Lines are drawn at similar distances of 400 and 100*

B: 2d result of MDS of the above samples, with lines drawn between clusters of species grouped in the ordination. Stress for MDS is .18 after 7 runs

Table 5.10: Total list of 88 taxa sampled in the Siyaya Estuary 1992 to 1994, their *PRIMER*-associated numbers, faunal groups and freshwater or estuarine-associated categories

PRIMER number:	Species	Estuarine/ Freshwater sp	Faunal group	PRIMER number:	Species	Estuarine/ Freshwater sp	Faunal group
1	Nematode spp.	F	N	44	Insecta AT1	F	In
2	Platyhelminthes spp.	F	Pl	45	Insecta NT1	F	In
3	Oligochaete spp.	F	O	46	Insecta NT2	F	In
4	*Mercierella enigmata*	E	P	47	Insecta NT3	F	In
5	*Ceratonereis keiskamma*	E	P	48	Insecta NT4	F	In
6	*Desdemona ornata*	E	P	49	Insecta NT5	F	In
7	Polydora sp. T1	E	P	50	Insecta LT1	F	In
8	Prionospio sp. T1	E	P	51	Tridactylidae LT1	F	In
9	*Dendronereis arborifera*	E	P	52	Coleoptera NT1	F	In
10	Polychaete T1	E	P	53	Coleoptera PT1	F	In
11	Polychaete T2	E	P	54	Coleoptera AT1	F	In
12	*Melanoides tuberculatus*	E	G	55	Coleoptera LT1	F	In
13	*Assiminea bifasciata*	E	G	56	Hymenoptera NT1	F	In
14	*Pittaria kochii*	E	Pe	57	Hymenoptera NT2	F	In
15	*Musculus virgiliae*	E	Pe	58	Hymenoptera NT3	F	In
16	Cladocera spp.	E	C	59	Corixidae NT1	F	In
17	Ostracoda spp.	E	Os	60	Diptera PT1	F	In
18	*Dies monodi*	E	I	61	Diptera PT2	F	In
19	*Leptanthura laevigata*	E	I	62	Diptera LT1	F	In
20	*Munna sheltoni*	E	I	63	Diptera LT2	F	In
21	*Eurydice longicornis*	E	I	64	Diptera LT3	F	In
22	*Excirollana natalensis*	E	I	65	Diptera LT4	F	In
23	*Corollana africana*	E	I	66	Diptera LT5	F	In
24	*Corophium triaenonyx*	E	A	67	Diptera LT6	F	In
25	*Grandidierella lignorum*	E	A	68	Diptera AT1	F	In
26	Amphipod T1	E	A	69	Diptera AT3	F	In
27	*Melita zeylanica*	E	A	70	Diptera AT4	F	In
28	*Orchestia ancheidos*	E	A	71	Psychodidae LT1	F	In
29	*Bolttsia minuta*	E	A	72	Ceratopogonidae LT1	F	In
30	*Urothoe tumorosa*	E	A	73	Chironomid spp. L	F	In
31	*Apseudes digitalis*	E	T	74	Chironomid spp. P	F	In
32	*Iphinoe truncata*	E	Cu	75	Chaoborus sp. LT1	F	In
33	*Mesopodopsis africanus*	E	M	76	Chaoborus sp. PT1	F	In
34	*Rhopalophthalmus terrantalis*	E	M	77	Trichoptera LT1	F	In
35	*Gastrosaccus brevifissura*	E	M	78	Ecnomus sp. LT1	F	In
36	Mysidopsis sp. T1	E	M	79	Odonata NT1	F	In
37	Branchiura larvae	E	B	80	Zygoptera LT1	F	In
38	Zoea larvae	E	B	81	Gomphid T1	F	In
39	Prawn post larvae	F	Ma	82	Gomphidae NT1	F	In
40	*Caridina nilotica*	F	Ma	83	Gomphidae NT2	F	In
41	*Lucifer pencillifer*	E	Ma	84	Corduliidae NT1	F	In
42	*Callianassa kraussi*	E	Ma	85	Baetis LT1	F	In
43	*Hymenosoma orbiculaire*	E	B	86	Hydrocarina sp. T1	F	In
				87	Araneae sp. T1	F	In
				88	Prosopistoma LT1	F	In

A = **Amphipoda**
B = **Brachyura**
C = **Cladocera**
Cu = **Cumacea**
G = **Gastropoda**
In = **Insecta**
I = **Isopoda**
M = **Mysidacea**
Ma = **Macura**
N = **Nematoda**
O = **Oligochaeta**
Os = **Ostracoda**
P = **Polychaeta**
Pe = **Pelecypoda**
Pl = **Platyhelminthes**
T = **Tanaidacea**

species into a number of similar groups. At a similar distance of 400, seven similar groups were identified. The MDS plot presented in Figure 5.24 B (2d minimum stress = .18 after 7 runs) shows that any lines representing groupings at a particular similar distance would be confused, due to the number of taxa presented in the diagram. Therefore, by observing the general pattern of grouping (I, II and III), and referring to Table 5.10, it could be established which species were related. The species occurring in each group are presented in Table 5.11

Table 5.11: Species sampled during 1992, and constituting Groups I - III identified by an non-metric multidimensional scaling ordination.

GROUP IDENTIFIED BY MDS ORDINATION		
Group I	**Group II**	**Group III**
Polychaete T1	Platyhelminthes spp.	Nematode spp.
Ostracoda spp.	*Ceratoneries keiskamma*	*Prionospio* sp. T1
Munna sheltoni	*Desdemona ornata*	*Dendronereis arborifera*
Mesopodopsis africanus	*Polydora* sp. T1	Polychaete T2
Rhopalophthalmus terranatalis	Cladocera spp.	Oligochaeta
Gastrosaccus brevifissura	*Leptanthura laevigata*	*Pittaria kochii*
Mysidopsis sp. T1	*Eurydice longicornis*	*Musculus virgiliae*
Caridina nilotica	*Corollana africana*	*Dies monodi*
Hydrocarina sp. T1	*Corophium triaenonyx*	*Bolttsia minuta*
	Orchestia ancheidos	Branchiura larvae
	Amphipod T1	Prawn post larvae
	Melita zeylanica	*Lucifer pencillifer*
	Urothoe tumurosa	*Hymenosoma orbiculaire*
	Apseudes digitalis	Insecta NT5
	Iphinoe truncata	Insecta LT1
	Zoea larvae	Chironomid spp. L
	Insecta AT1	Chironomid spp. P
	Prosopistoma LT1	Zygoptera LT1
	Ceratopogonidae LT1	Corduliidae NT1

Taxa in Group I comprised all mysid taxa sampled, a fairly abundant isopod (*Munna sheltoni*), the ostracods, an unidentified polychaete and the freshwater shrimp *Caridina nilotica*. Group II primarily consisted of all the crustaceans, the cumacean and tanaid. Interestingly, those species that dominated the fauna during 1992 were combined in this group. Several freshwater taxa including insects were also included. The remaining annelids and insects were placed in Group III.

A dendrogram of the cluster analysis of 1993 benthic samples is given in Figure 5.25 A. Three clusters were identified at a Bray - Curtis similarity of 100. Group I constituted 13 of the 20 samples, with the remaining spread over Groups II and III Group II consisted of samples collected in the upper reaches of the Siyaya Estuary during the first half of the year (summer Sites 4 and 5, and autumn Site 5). Group III contained all Site 1 samples from summer, autumn, winter and spring. The MDS of these same clusters (2d minimum stress = .16 after 9 runs), divided the original Group I (similar distance of 100), into three separate components at a Bray - Curtis similarity of 50 (Figure 5.25 B). One of these components consisted of samples from the upper reaches of the Siyaya Estuary during autumn winter and spring, while the remaining components of the original Group I contained samples from summer (Sites 2 and 3), autumn (Sites 2 and 3), winter (Sites 2, 3 and 4) and spring (Sites 2 and 3).

Figure 5.26 A and B represent the inverse analyses of species sampled during 1993. Ten groups were identified at a Bray- Curtis similarity of 300. As was the case with those species sampled during 1992, the resulting dendrogram of cluster analyses was not an accurate representation of the patterns exhibited in the plot of the MDS ordination. Therefore, seven groups were identified by looking at the plot of the MDS (Figure 5.26 B; 2d minimum stress = .16 after 4 runs). Species categorised into each of the seven groups are categorised in Tables 5.12 A and B.

Generally, the classification of taxa into groups I - IV, was as follows; insects dominated Group I, with the exception of Polychaete T2, an isopod, *E. longicornis*, the single cumacean *I. truncata* and the sand prawn *C. kraussi*. Group II and III were characterised with a single insect and three estuarine taxa, respectively. Taxa identified in Group IV

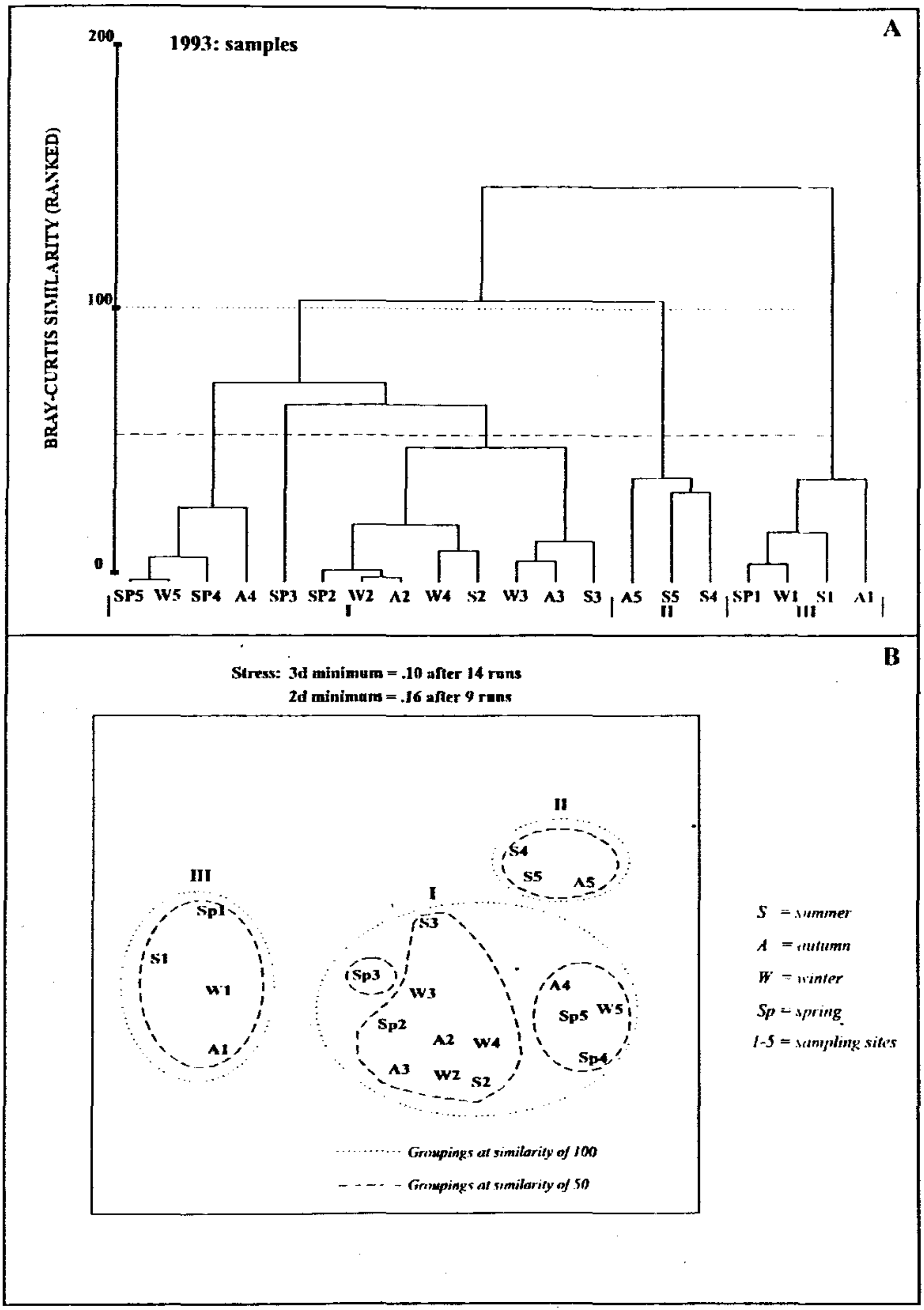


Figure 5.25 A: Bray -Curtis ranked clusters of 1993 benthic samples collected at five sites on a seasonal basis. Lines are drawn at similar distances of 100 and 50

B: 2d result of MDS of the above samples, with lines drawn around groups having similarities of 100 and 50. Stress for MDS is .16 after 9 runs

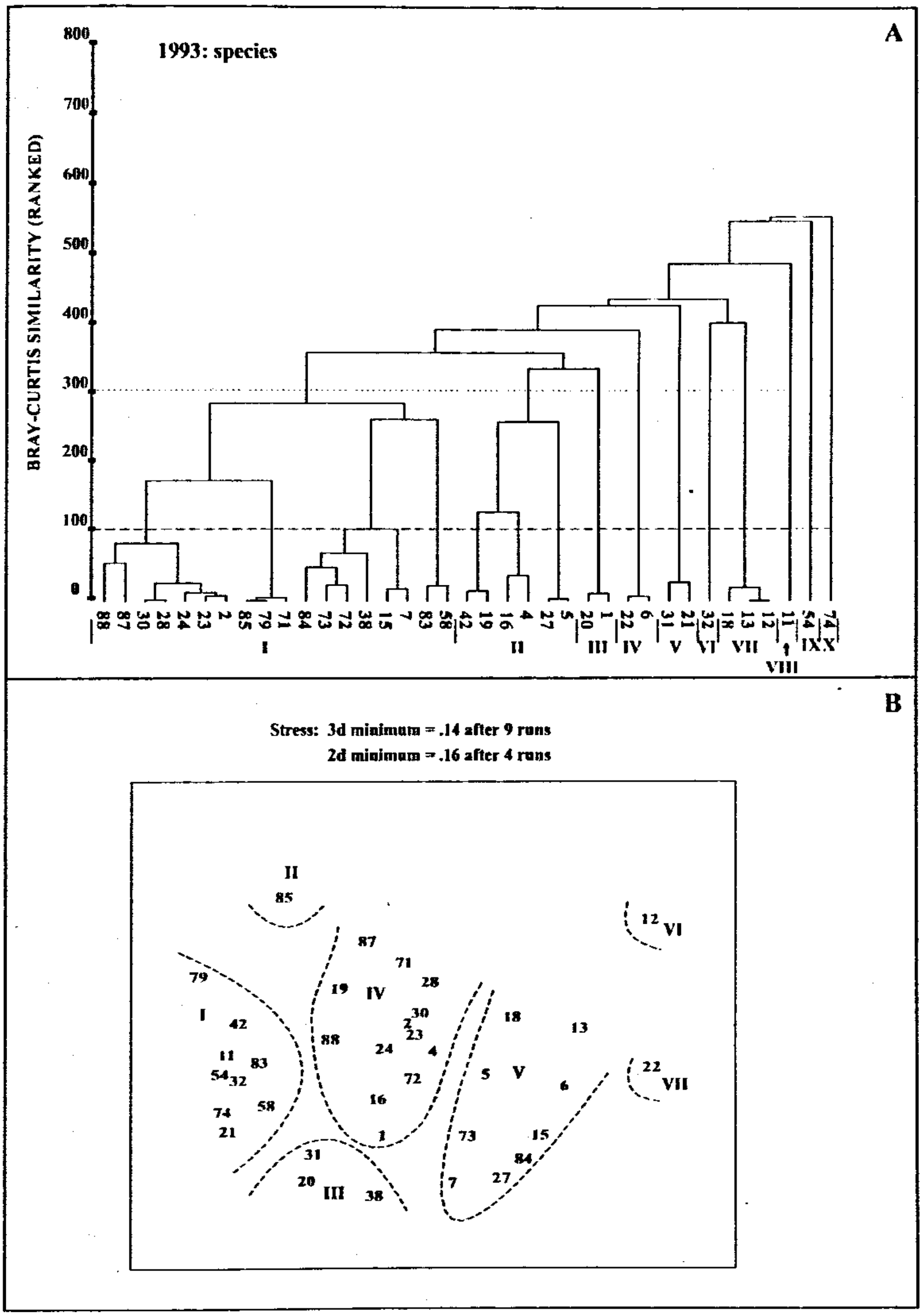


Figure 5.26A: Bray -Curtis ranked clusters of 1993 benthic species collected at five sites on a seasonal basis. Lines are drawn at similar distances of 300 and 100

B: 2d result of MDS of the above samples, with lines drawn between clusters of species grouped in the ordination. Stress for MDS is .16 after 4 runs

were three polychaete taxa, two molluscs, a single isopod and amphipod and two insects. This group primarily consisted of estuarine associated taxa.

Table 5.12 A: Species sampled during 1993, and constituting Groups I - IV identified by an non-metric multidimensional scaling ordination.

GROUP IDENTIFIED BY MDS ORDINATION			
Group I	**Group II**	**Group III**	**Group IV**
Polychaete T2	*Baetis* LT1	*Munna sheltoni*	*Ceratonereis keiskamma*
Eurydice longicornis		*Apseudes digitalis*	*Desdemona ornata*
Iphinoe truncata		Zooe larvae	*Polydora* sp. T1
Calianassa kraussi			*Assimnea bifasciata*
Coleoptera AT1			*Musculus virgiliae*
Hymenoptera NT3			*Dies monodi*
Chironomid spp. P			*Melita zeylanica*
Odonata NT1			Chironomid spp. L
Gomphidae NT2			Corduliidae NT1

Table 5.12 B lists species that were classified into the final three groups (V - VII), identified by the MDS on 1993 species. Group V, was the most variable in terms of different taxa. This group was characterised by representatives from Polychaeta, Nematoda, Platyhelminthes, Isopoda, Cladocera and Insecta. Groups VI and VII contained one species each, from the Phylum Mollusca and Phylum Arthropoda (Isopoda).

Table 5.12 B: Species sampled during 1993, and constituting Groups V - VII identified by an non-metric multidimensional scaling ordination.

GROUP IDENTIFIED BY MDS ORDINATION		
Group V	**Group VI**	**Group VII**
Nematode spp.	*Melanoides tuberculatus*	*Excirollana natalensis*
Platyhelminthes spp.		
Mercierella enigmata		
Cladocera spp.		
Leptanthura laevigata		
Corollana africana		
Corophium triaenonyx		
Orchestia ancheidos		
Urothoe tumurosa		
Ceratopogonidae LT1		
Psychodidae LT1		
Araneae sp. T1		
Prosopistoma LT1		

A dendrogram of the resulting clusters from Bray - Curtis similarity analyses on 1994 samples are presented in Figure 5.27 A. At a similarity of 100, only two clusters were identified. Cluster I contained samples collected at Site 5 (summer, autumn, winter and spring), and samples from Site 3 and 4 collected during spring 1994. The remaining cluster (II), contained the balance of the samples. The resultant MDS (Figure 5.27 B; 2d minimum stress = .10 after 8 runs), gave a more interpretable classification of samples at a similar distance of 50. The original Group I was subdivided into a further two sections, as was Group II into three separate sections. The new groupings at a similar distance of 50 in Group I, grouped together all samples from the upper reaches over four different seasons. At a similar distance of 50, Group II samples were subdivided into those collected in the lower reaches (Sites 1 and 2), and middle to upper reaches of the Siyaya Estuary (Sites 3 and 4) throughout 1994.

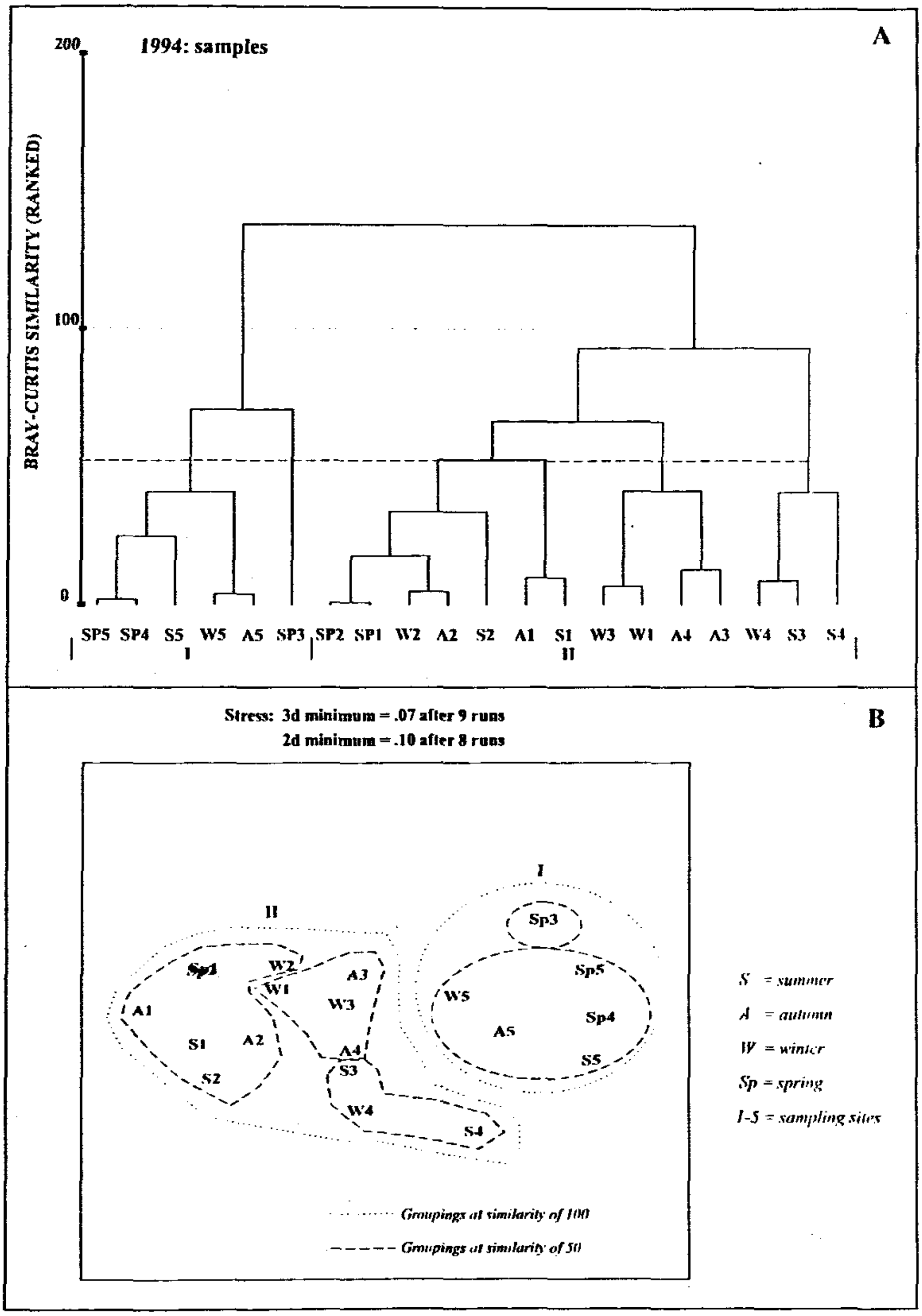


Figure 5.27A: Bray -Curtis ranked clusters of 1994 benthic samples collected at five sites on a seasonal basis. Lines are drawn at similar distances of 100 and 50

B: 2d result of MDS of the above samples, with lines drawn around groups having similarities of 100 and 50. Stress for MDS is .10 after 8 runs

The final cluster analysis and ordination was performed on the 59 species collected during 1994. At a Bray - Curtis similar distance of 300, eight clusters of similar samples were identified (Figure 5.28 A). An ordination plot of this same similarity matrix revealed that these clusters were once again not interpretable on a two dimensional plot. Therefore, the groupings set out by the MDS (Figure 5.28 B; 2d minimum stress = .16 after 4 runs) were used to interpret the similarities of species collected during 1994. From the MDS, six groups were identified on the basis of their degree of 'clumping' together. The taxa constituting these groups are presented in Tables 5.13 A and B.

Table 5.13 A: Species sampled during 1994, and constituting Groups I - III identified by an non-metric multidimensional scaling ordination.

GROUP IDENTIFIED BY MDS ORDINATION		
Group I	**Group II**	**Group III**
Chaoborus sp. LT1	Platyhelminthes spp.	Polychaete T2
	Musculus virgiliae	Insecta LT1
	Grandidierella lignorum	
	Urothoe tumurosa	
	Iphinoe truncata	
	Zoee larvae	
	Prawn post larvae	
	Calianassa kraussi	
	Chironomid spp. P	
	Chaoborus sp. PT1	
	Corduliidae NT1	
	Baetis LT1	
	Araneae sp. T1	
	Prosopistoma LT1	

In a comparison of Groups I - III, the majority of taxa were contained in Group II. This group was characterised by a mixture of both insect and crustacean arthropods and a single non - insect freshwater taxon (Platyhelminthes). Groups I and III contained a single insect taxon and an insect and polychaete taxon, respectively. The remaining groups (IV - VI) identified in the 1994 species MDS are given in Table 5.13 B.

Table 5.13 B: Species sampled during 1994, and constituting groups IV - VI identified by an non-metric multidimensional scaling ordination.

GROUP IDENTIFIED BY MDS ORDINATION		
Group IV	**Group V**	**Group VI**
Nematode spp.	*Ceratoneries keiskamma*	Ostracoda spp.
Mercierella enigmata		Branchiura larvae
Cladocera spp.		
Dies monodi		
Leptanthura laevigata		
Corollana africana		
Eurydice longicornis		
Corophium triaenonyx		
Melita zeylanica		
Diptera AT4		
Psychodidae LT1		
Ceratopogonidae LT1		
Chironomid spp. L		
Trichoptera LT1		

Group IV contained the same number of taxa as Group II, and was also represented by a wide species assemblage. Half the number of taxa were estuarine associated species, while the freshwater taxa were primarily insects (5 taxa). Group V contained a single species, *C. keiskamma,* which was clearly an outlier in the ordination plot. The final Group (IV) contained two taxa, one each of an estuarine and a freshwater species.

To facilitate recognition of taxa belonging to either the freshwater, or estuarine component of the benthos, the configuration of species assemblages set out in each MDS plot were superimposed with codes classifying each taxon as such. Figure 5.39 is representative of the separation of taxa according to whether they were estuarine or freshwater related, during 1992, 1993 and 1994. In 1992, freshwater taxa were not clearly separated from the estuarine component of the benthos, in terms of forming an

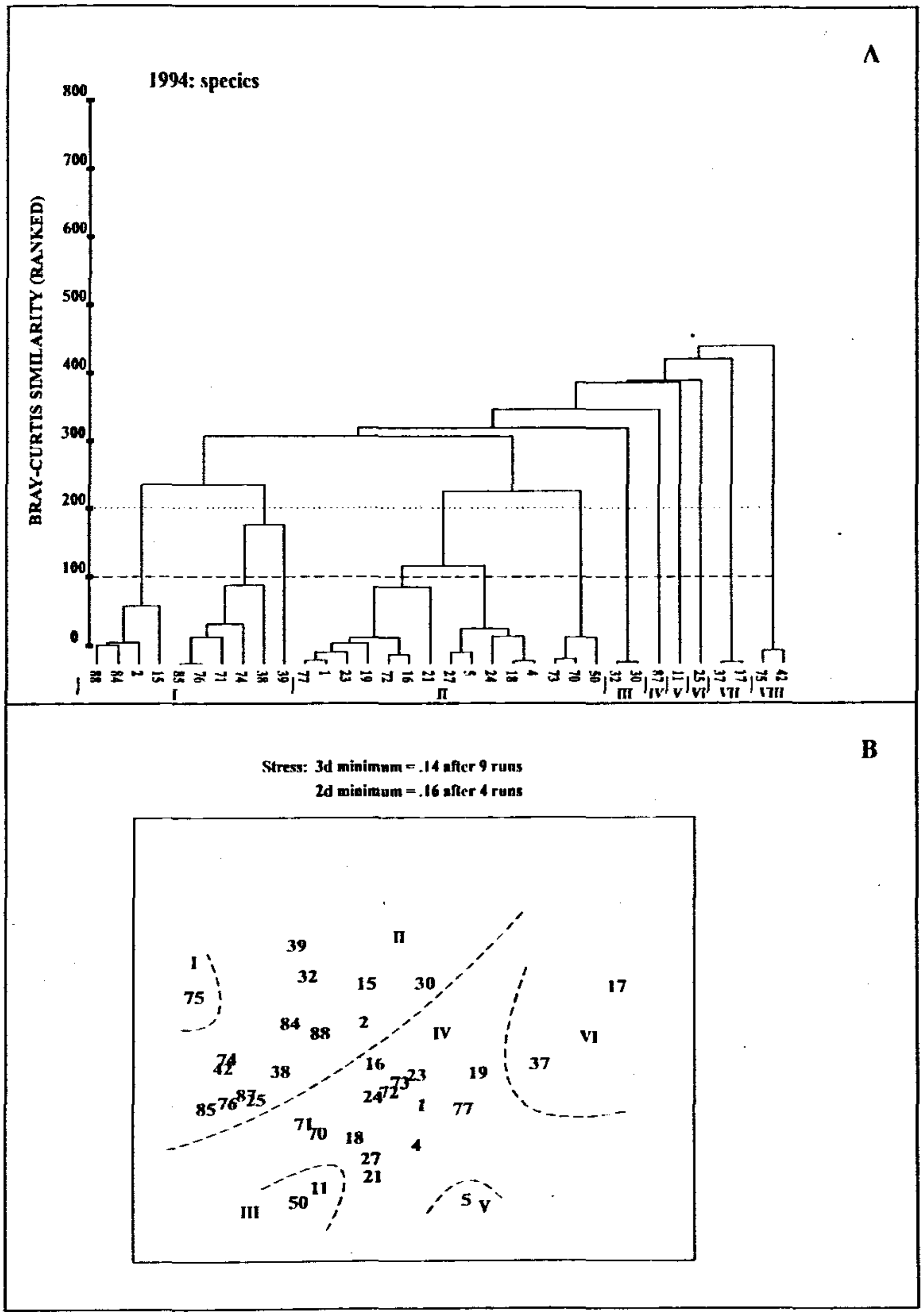


Figure 5.28A: Bray -Curtis ranked clusters of 1994 benthic species collected at five sites on a seasonal basis. Lines are drawn at similar distances of 200 and 100

B: 2d result of MDS of the above samples, with lines drawn between clusters of species grouped in the ordination. Stress for MDS is .16 after 4 runs

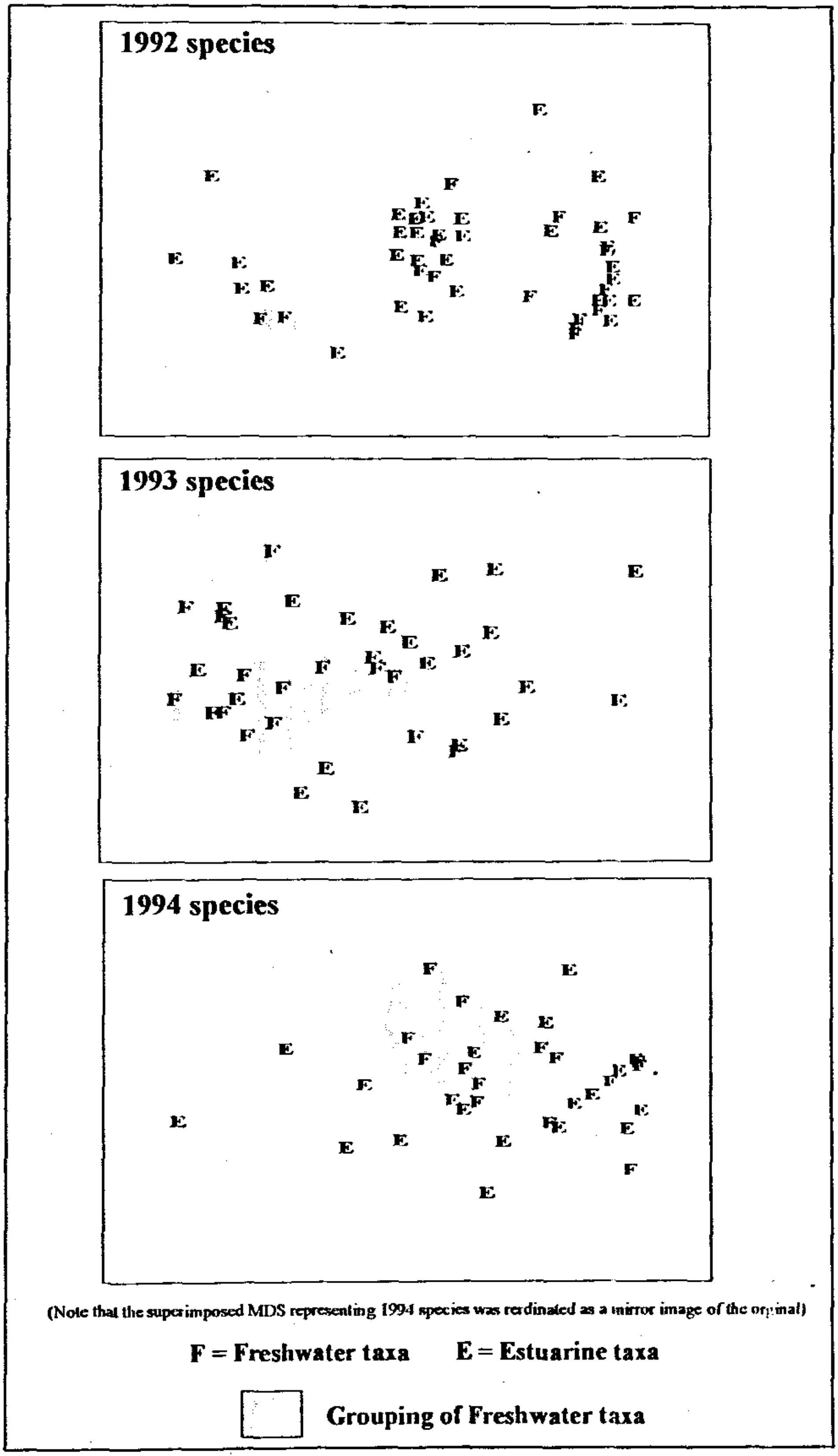


Figure 5.29: MDS plots of species collected from 1992 to 1994, and classified into either freshwater or estuarine-associated taxa. Groups of freshwater taxa are shaded.

aggregation of their own. However, during subsequent years, ordination showed that freshwater taxa were increasingly aggregated together with fewer outliers, to form distinct clusters from the estuarine associated taxa.

Every data point on the inverse analyses plots were then assigned a particular code to categorise each according to whether they were insects or non-insects. This was performed to establish whether a distinct population of insect species was increasing throughout the study period. This increase was suspected to be in response to the changing physico-chemical conditions of the estuary (Chapter 5). Figure 5.30 represents these superimposed codes assigned to each taxon on the original 1992 to 1994 MDS plots. The non-insect components of the benthos were shaded according to whether or not they belonged to the Class Crustacea. In 1992, a distinctly aggregated group of crustaceans occurred amongst the benthos, with one ostracod outlier. Through 1993 and 1994, the crustacean taxa became increasingly disaggregated in terms of similar groupings, and relationships between taxa.

The same superimposed plot was used as a template for distinguishing the insect taxa (by shading). Figure 5.31 showed that during 1992, the insect taxa were relatively spread out in terms of similarity towards each other, with a single cluster and several outliers. During subsequent years the insect taxa were increasingly more aggregated. Figures 5.30 and 5.31 showed the negative relationship that the freshwater and estuarine related components had on each other. That is, when the Crustacea were highly grouped showing similarity of taxa, the Insecta were comparatively disaggregated with few relationships between taxa.

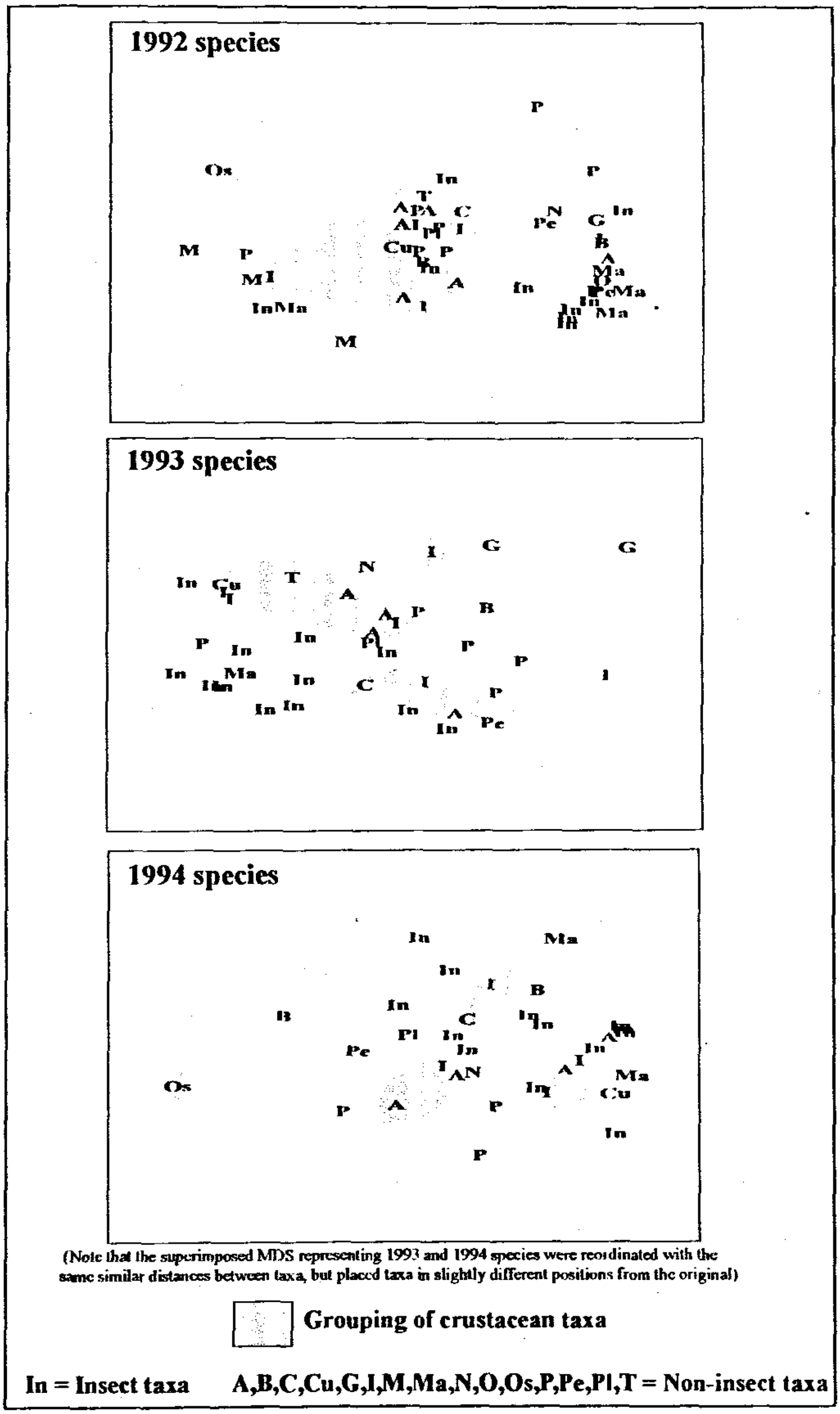
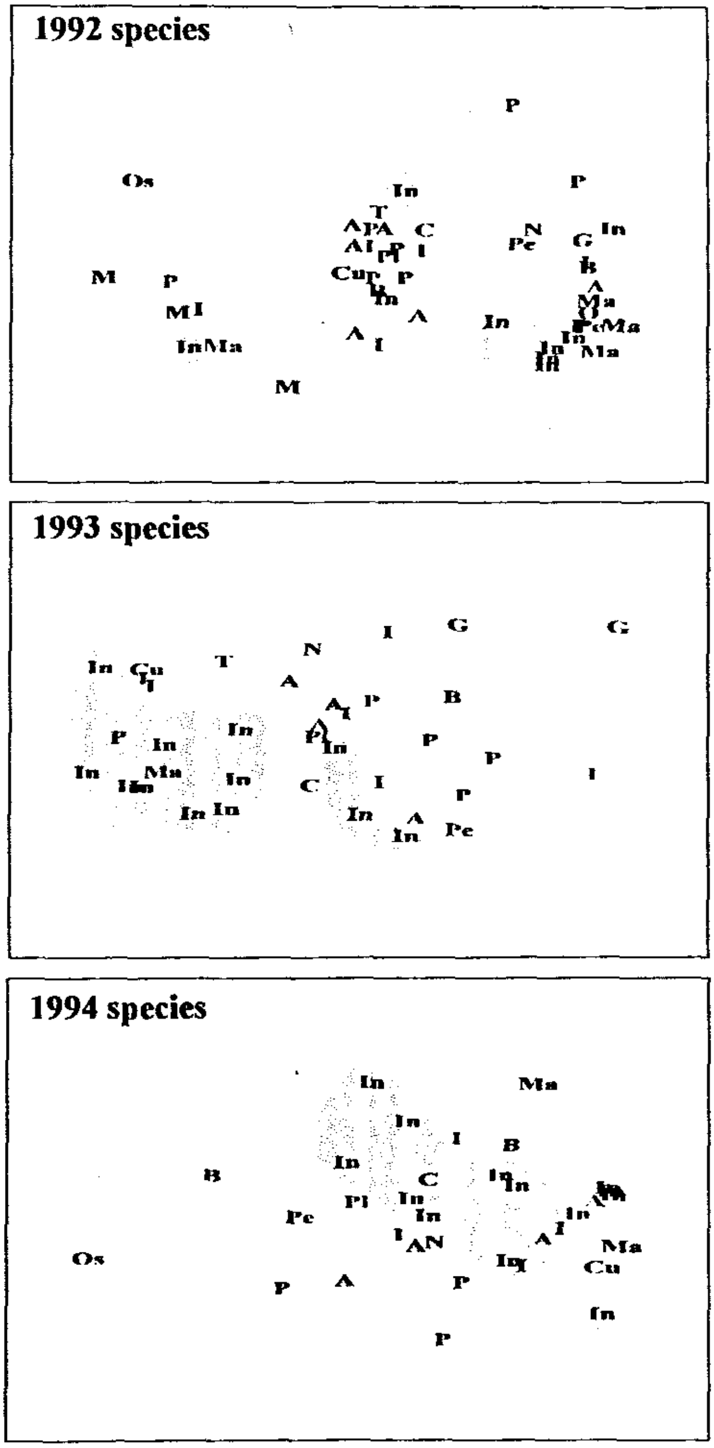


Figure 5.30: MDS plots of species collected from 1992 to 1994, and classified into either insect or non-insect taxa. Groups of crustacean taxa are shaded.



(Note that the superimposed MDS representing 1993 and 1994 species were recordinated with the same similar distances between taxa, but placed taxa in slightly different positions from the original)

Grouping of insect taxa

In = Insect taxa A,B,C,Cu,G,I,M,Ma,N,O,Os,P,Pe,Pl,T = Non-insect taxa

Figure 5.31: MDS plots of species collected from 1992 to 1994, and classified into either insect or non-insect taxa. Groups of insect taxa are shaded.

5.8 Discussion

The benthic community of the Siyaya Estuary may be described as cyclic, as it does not display a constant species composition and density over time (Gray, 1981). In terms of stability, the benthos alternates between neighbourhood and global stability (Section 5.3). The reason being that during this study the species composition shifted towards more freshwater taxa (neighbourhood stability). Despite this, the dominant species remained the same from 1992 to 1994, which is a characteristic of global stability. May's (1974) theory is pertinent to this study, in that over a small spatial scale and time neighbourhood stability is shown by the benthic community, while over a large spatial and temporal scale global stability is more relevant. As no benthic data was available from a time when the estuary was still relatively undegraded (pre 1940s), or between 1980 (the time of inception of the Siyaya Catchment Demonstration Project) and the present study, apart from a single survey conducted in 1983, no measure of resilience of the benthos could be made. That is, no measure could be made of the community returning to its original species composition, as no original species list was available for comparison.

From 1992 to 1994, the benthos of the Siyaya comprised both an estuarine and a freshwater component. The number of estuarine taxa were greater in 1992, but estuarine taxonomic numbers decreased throughout the study period as the number of freshwater taxa increased. The pattern described by McLusky (1974), of an increase of marine species towards the mouth and increase of freshwater species towards the head of an estuary, was characteristic of the situation in the Siyaya. This gradient of species zonation was linked to the inputs of marine and freshwater (Wooldridge, 1995; Section 5.1)

In terms of density, the system was dominated by two amphipod species, *G. lignorum* and *C. triaenonyx*, a tanaid *A. digitalis*, a polychaete *C. keiskamma*, a cumacean *I. truncata* and freshwater oligochaetes and chironomid larvae. *Grandidierella lignorum*, *C. triaenonyx* and *A. digitalis* dominated the benthic fauna throughout the study period, while *I. truncata* was not present in 1993. Oligochaetes were amongst the abundant fauna in 1993, and the polychaete was replaced by chironomid larvae in the five most abundant benthic taxa in 1994. As the system became increasingly fresh those dominant species that were more estuarine (*I. truncata* and *C. keiskamma*) were replaced by freshwater taxa.

Day (1981c) reports that *G. lignorum* is an estuarine species endemic to southern Africa, occurring predominantly in muddy substrata. This species has the ability to extend its distribution to fresh water, which is why it is also found in many of the Zululand coastal lakes (Connell and Airey, 1979). *G. lignorum* forms that part of the invertebrate benthic community having the ability to burrow into sand and mud substrata of estuaries and coastal lakes (Blaber *et al.*, 1983). Likewise, *C. triaenonyx* may extend its distribution to areas of low salinity and both amphipods have been reported by Boltt (1969) as part of the relict estuarine fauna of the fresh water lake, Sibaya. *C. triaenonyx* has a tropical zoogeographical range, that is recorded south of 20° in the Indian Ocean (Day, 1981c). Therefore, *G. lignorum* and *C. triaenonyx* are able to colonise a wide range of sediment types, but none the less do prefer sands of a muddy constituent. It is interesting to note that although both co-habit the same niche, *G. lignorum* was generally numerically more abundant during each of the seasons. This suggests that a certain element of competition has arisen between the two species, with *G. lignorum* seeming to be the more successful of the two. The polychaete *C. keiskamma*, is part of the endemic estuarine species component of southern Africa and is common in muddy substrata in low salinities. It also occurs in Lake Sibaya and the St Lucia system (Day, 1981c), and prefers to build it's burrows in sediments with a low organic content. This species was found exclusively in the lower reaches of the estuary, where the lowest organic contents of sediments were recorded (Chapter 4).

Reavell and Cyrus (1989) reported the occurrence of the tanaid *A. digitalis* in sandy and organically-rich mud substrata from the fresh water coastal lakes in Zululand. This species also has a tubicolous habitat, and is usually associated with submergent macrophytes (Reavell and Cyrus, 1989). This would explain the abundance of this species in the middle to upper reaches of the estuary where there was a large amount of detritus and the freshwater macrophyte *P. pectinatus*. Day (1969) has also reported *A. digitalis* common in the intertidal and shallow water areas of estuaries. Within the Siyaya

Estuary, the dominant benthic taxa are commonly species that are tubicolous and abundant in other KwaZulu-Natal lakes and some estuarine systems (Day, 1981c). Reavell and Cyrus (1989) suggest that there is some habitat partitioning between *A. digitalis* and *G. lignorum*, and that the latter occurs in shallower water. It is precluded from penetrating waters that are deeper than 20 m due to intolerance of high PCO_2 levels in its tubes (Hart, 1979). Since the Siyaya Estuary had an average depth of 1.6m (Chapter 4), this was dismissed as being a reason for resource partitioning in this system.

Some workers have examined the seasonal variation in abundance of certain species Since *G. lignorum* and *C. triaenonyx* were among the most abundant invertebrates in the present study, results of other studies conducted which also recorded these amphipods are presented. Cyrus and Martin (1988) conducted a survey of the zoobenthos at Lake Cubhu, a coastal lake in Zululand. They found that *G. lignorum* numbers reached a peak in early winter, while *C. triaenonyx* numbers reached a peak during spring and summer. This recapitulates the hypothesis that some form of competition exists between the two species, causing them to reach peaks in reproduction at different times of the year. In the Kariega Estuary (eastern Cape Province), the location of sampling station and month of sampling had a significant effect on the abundance of *G. lignorum* (Read and Whitfield, 1989). That is, abundance decreased progressively down the estuary (towards the sea). A clear increase in abundance of the amphipod followed months where flooding of the estuary took place, with localities closest to the source of freshwater input showing the largest increases. From this, it was thus revealed that salinity was a major factor linked to the abundance of *G. lignorum* in the Kariega Estuary. The highest densities of this species occurred in the salinity range 0.5 - 5‰ (Read and Whitfield, 1989). These abiotic factors influencing benthic community composition are explored in Chapter 6.

When the first one-off survey of the Siyaya was carried out over a decade ago (Archibald *et. al.*, 1984) there was a predominance of oligochaetes in the upper half of the estuary (Oceanographic Research Institute, 1991). This was attributed to the fact that these invertebrates prefer organically-rich substrates and tolerate low dissolved oxygen concentrations. During the early 1980's, the species records of the system were related to the physico-chemical conditions of the estuary, and closure of the mouth excluded the presence of numerous invertebrates (Oceanographic Research Institute, 1991). Low diversities and abundance were reported in the central and upper reaches of the estuary, which were again due to the low dissolved oxygen content of the bottom waters. Near the estuary mouth where the dissolved oxygen was not depleted, there was a noticeable increase in both diversity and abundance. The fresh water component of the fauna was found to predominate, and the only noticeable seasonal effect was attributed to the flushing effects of the rains accompanying Cyclones Imboa and Domoina (Oceanographic Research Institute, 1991). During 1983, 37 different taxa were recorded, only two polychaetes (of which *C. keiskamma* was one), three amphipods (*Grandidierella. lutosa*, *C. triaenonyx* and *Afrochiltonia capensis*), two isopods (*Excirolana natalensis* included), the cumacean *I. truncata* and *A. digitalis* were present among other taxa. Begg (1978) concluded that from information available at that time, there was little doubt that utilisation of the estuary by many estuarine species had ceased. In the early 1980's, both the estuarine and freshwater benthic components had the highest densities during summer (Figure 5.32). The highest percentage contribution of estuarine fauna was at Lag 4 (the mouth; refer to historical data in Chapter 4), while the opposite was true of the percentage contribution of the freshwater fauna. Since then, the situation has clearly improved. Species richness over the last 12 years increased from 37 to 59 different taxa in 1994, with a few species present in 1983 having disappeared, while many more were added.

A summary of the general seasonal effect of the abundance and distribution of benthos is given by Nichols and Thompson (1985). That is, changes in the benthos often coincide with seasonal changes in the estuarine environment, and that climatic perturbations (including drought and floods) generally have a widespread effect on the benthic biota. Although densities fluctuated between seasons (Tables 5.4 - 5.6), analysis of variance did not produce a significant result when season was used as a factor to provide reasons for these fluctuations (Table 4.10). This is in contrast to what Eagle (1975) and Boesch *et al.*, (1976) have stated, they maintain that the majority of long-term analyses have revealed strong seasonal patterns.

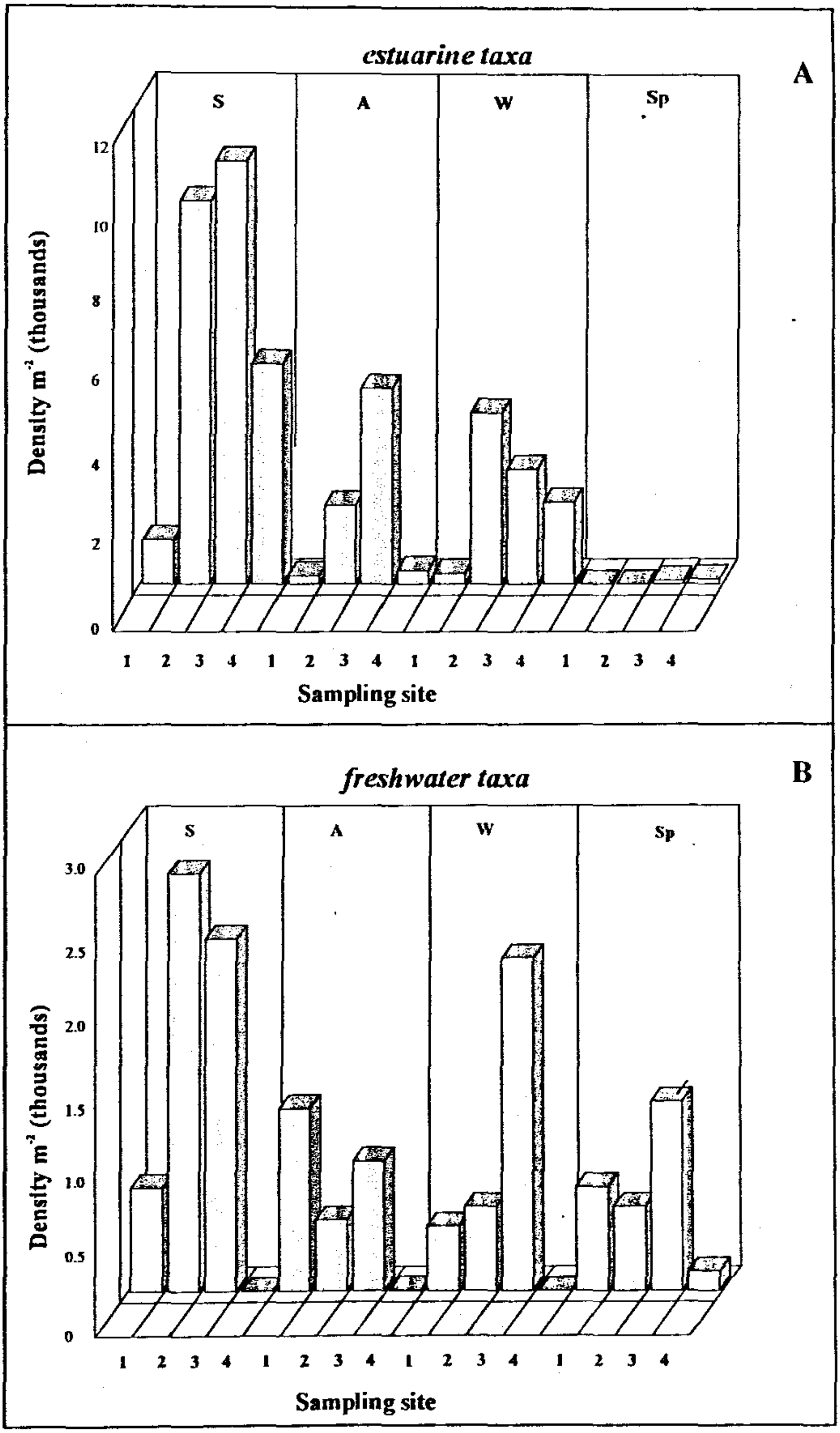


Figure 5.32: Seasonal density of estuarine and freshwater taxa collected at four sites (Lag 1 - 4) during 1983. Lag 1 corresponds to the present Site 4, and Lag 4 to the present Site 1

Factors affecting the overall abundance and distribution of benthos, were related to some aspect of the physico-chemical conditions of the system (Chapter 6), as there were no significant number of benthic predators present. During 1991, *Rhabdosargus sarba* and *Gerres rappi*, both benthic feeders together with open water feeders, only made up 3% of the fish fauna in the Siyaya Estuary (Cyrus and Martin, 1991). Read and Whitfield (1989) stated that low salinities in areas occupied by *G. lignorum*, are unfavourable for major invertebrate predators such as *Mesopodopsis slabberi* and *Rhopalopthalamus terranatalis*. However, representatives of both genera were found to be present in the Siyaya system (albeit on rare occasions). From personal observation of a tank within the laboratory containing a small population of *C. nilotica*, and the tube-building *G. lignorum* and *C. triaenonyx*, it was found that the carid shrimp fed on these two species of amphipods when the latter were either feeding in the water column or crawling along the sediment surface. The amphipods exhibited escape behaviour when *C. nilotica* was feeding. *C. nilotica* occurs in the lentic and lotic waters of southern Africa, and clears debris and epiphytic microflora from the leaves of submerged macrophytes thereby recycling organic matter (Hart, 1979). *C. nilotica* did not dominate the benthos of the Siyaya, nor did it occur in appreciably large numbers. The possible reasons were that it did not have a major food source, or that it was a major prey item. The first reason may be discounted, as there was an abundance of macrophytes in the Siyaya Estuary. From several samples taken, it was seen that large numbers of *C. nilotica* tended to aggregate among the stems and roots of the *P. australis* plants from Sites 1 to 4 along the estuary (*pers. obs.*). Explanations may be that they were either feeding in these areas, or *P. australis* beds provided protection from avian predators. Hart (1979), observed that these shrimps are a major diet of various birds, mainly herons.

The role of small epibenthic crustacean predators in limiting prey populations has been demonstrated by Raffaelli, Conacher, McLachlan and Emes (1989). These workers found that this was true only where high densities of the predators occurred. Bottom-feeding *Pomadasys commersonnii* juveniles, have been reported as including *C. triaenonyx*, and *A. digitalis* as prey items (Graham, 1994). From these findings and that of Whitfield (1989a), it appears that amphipods such as *G. lignorum* and *C. triaenonyx* are highly vulnerable to predators.

The pattern of species richness along the length of the Siyaya was highest in the upper reaches during 1992 (characterised by the lowest densities) and declined to the lowest values during 1994. It was concluded from these analyses, that it was ineffectual to compare measurements of species richness, dominance, diversity and evenness as species richness measurements do not take into account measures of abundance. A single plot of dominance, diversity and evenness was difficult to interpret as all values were similar. However, from this study it was clear that benthos sampled during 1994 was less diverse than either of the two previous years, and that the greatest dominance of samples was shown during this year. This is because dominance is a measure of the probability that two individuals from the same population belong to the same species. Existing data appear to indicate that there is a basic difference in the structure of temperate and tropical/subtropical benthic communities (Wu and Richards, 1981). However, not all benthic communities in the latter environments are highly diverse, as these regions are not necessarily stable and uniform, because of the wide range of environmental conditions experienced there (Wu and Richards, 1981; Long and Poiner, 1994). Generally, the benthos sampled in the upper reaches (and in several cases towards the mouth) of the Siyaya Estuary had taxa with relatively similar abundances. This corresponded to a high measure of evenness. To summarise measurements of distribution and abundance, it could be said that where measurements of diversity were low, measures of dominance, evenness and species richness were high.

Generally, the zoobenthos of the Siyaya Estuary was characterised by a small number of highly abundant species, and a large number of rare species (including those with only a single record of distribution). Several individual species are now discussed in terms of the role they played in structuring the benthic community of the Siyaya Estuary.

It is suspected that many of the taxa present in the estuary have a *k*-selected life history trait (Zajac and Whitlach, 1982). That is, they are less opportunistic and found in systems that are in stages closer to recovery. *Polydora* spp and *Prionospio* spp, are known as indicators of perturbation in the Mediterranean (Panagopoulos, 1989-90). *Polydora* spp. is characterised as a short lived, opportunistic species usually dominating the fauna in areas of organic pollution (Wolff, 1983). Long and Poiner (1994), classified polychaetes in the genus *Prionospio* as second stage colonists, increasing in abundance with a decline in the abundance of first stage opportunists, after a disturbance. With regard to the number of opportunistic species colonising the estuary, no capitellid polychaetes have to the author's personal knowledge ever been recorded, and only several specimens of the genus *Polydora* (Section 5.3). The occurrence of the polychaete *Desdemona ornata*, is interesting, although it was originally reported from the southern hemisphere, it has recently been recorded in a fully marine habitat of the Mediterranean by Panagopoulos (1989-90). This author suggested that the presence of this polychaete in brackish estuaries, may be due to the high organic matter in the sediment, rather than the low salinity. *D. ornata* may well be an opportunistic species, taking advantage of the disturbed and unpredictable environment (Panagopoulos, 1989-90).

Santos and Simon (1980), looked at the recolonisation patterns of benthos following catastrophic disturbance (complete extirpation of the organisms from the area investigated). Defaunation in the Tampa Bay Estuary (Florida), was due to hypoxia (dissolved oxygen levels < 1.0 mg/l), and *Grandidierella bonnieroides* along with seven other species numerically dominated the benthos during the recolonisation process (Santos and Simon, 1980). This provides evidence that the genus *Grandidierella*, and perhaps *G. lignorum* in the Siyaya Estuary is functioning as a successful primary coloniser, and at the same time may be a opportunistic species. That is, it has a life-history strategy tending toward r-selection (exhibited by species that are opportunistic) rather than k-selection, that is characteristic of equilibrium species (Santos and Simon, 1980). *Grandidierella* spp. follow a breeding strategy which has an adult and juvenile dispersal mechanism, as well as brooding their young.

The cluster and ordination analyses performed on samples, and the inverse analyses performed on species showed that samples collected from the upper and lower reaches could be separated. However, in some cases (dis)similar distances of 50 masked the relationship between some samples, as it tended to group only highly related samples. Inverse analyses proved to provide the most interesting results. Amphipods and isopods were generally grouped together, while polychaetes, nematodes and insects were more disaggregated on the periphery of these major groupings. Mysids tended to be grouped together, but also apart from the major group of estuarine taxa. The reason that these fauna cluster separately may be that they are essentially planktonic, swimming and feeding just above the sediment surface (H. Jerling, *pers. comm.*[4]). The ordination plots identifying insect and non-insect taxa, were clearly linked to the physico-chemical state of the estuary. That is, insect taxa became increasingly more clustered from 1992 to 1994, while non-insect taxa became increasingly disaggregated.

The components and distribution patterns of the estuarine fauna form an important energetic cycle based on detrital input from the surrounding dune forests. The feeding cycle presumably then flows around plant material and phytoplankton (the primary producers), to grazers (herbivores and detritivores), carnivores and all contributing to the accumulation of further detritus. This in turn, is utilised and broken down by bacterial decomposers (Odum, 1971; Barnes and Mann, 1980).A recommendation for future analyses of the zoobenthic data, may be to classify the benthos into their functional feeding groups. It is suspected that this may also provide some interesting results in ordination plots, perhaps providing some behavioural reasons for the occurrences of certain species at certain sites, and during certain times of the year. Table 5.14 is a description of the different functional feeding groups, characteristic of estuarine fauna.

Within the Siyaya Estuary, few suspension feeders are expected, given that current speed is slow in the sandy -mud to muddy areas, as required by these animals (Day, *et. al.*, 1989). Thus, in such a system, with finer sediments and more sheltered areas, one would expect the colonisation of deposit-feeding animals.

Before dividing fauna into the aforementioned functional feeding groups, the reservations expressed by Taghon and Greene (1992) should be noted. These authors state that although it is convenient to separate soft sediment invertebrates into different feeding categories, it may be misleading. That is, these categories may not apply to the same species in different locations or under different environmental conditions. Some

[4] Dr H. Jerling, Zoology Department, University of Zululand, P/Bag X1001, KwaDlangezwa, 3886

invertebrates have the ability to switch between deposit and suspension feeding, depending on the flow regime (Taghon and Greene, 1992).

Table 5.14: List and description of the five feeding groups characterising estuarine zoobenthos. (After Wolff, 1983)

FEEDING GROUP	DESCRIPTION
Suspension Feeders	*Feed on organic particles suspended in the water. Potential food sources are phytoplankton, zooplankton, bacteria and detritus.*
Deposit Feeders	***SELECTIVE:*** *Animals separate their food particles from the sediment. The manner in which this is achieved, depends on the invertebrate.*
	NONSELECTIVE: *Animals ingest the sediment as a whole, use digestible particles, and pass the remainder through the gut.*
Predators and Scavengers	*The distinction between these two groups is unclear, but this group may have profound influence on the structure and abundance of benthic communities.*
Grazers	*There is an arbitrary difference between this group and selective deposit feeders. Grazers feed mostly on micro and macroalgae, seagrasses and rarely vascular plants.*
DOM feeders	*Rare in estuarine systems, due to providing an insufficient nutrient requirement.*

Gray (1981), relates this idea of trophic groupings to the concepts of stability and competition. He states that in benthic communities on a small spatial scale pattern, there are three trophic groups:

- Deposit Feeders - reworking the sediment
- Suspension Feeders - not building tubes
- Suspension Feeders - building tubes and stabilising the sediment.

Therefore, by interference there is competition where one species prevents another from exploiting a resource in the sediments.

The findings of several studies looking at the benthic macrofauna of a number of different estuaries and coastal lakes in southern Africa are discussed below. The aim of this was to provide some background with which to compare results obtained in this study.

De decker and Bally (1985) looked at the benthic macrofauna of the Bot River Estuary in the Cape (34°21'S 19°07'E). This estuary is fairly comparable to the Siyaya Estuary in terms of morphological characteristics, in that it is usually separated from the sea by a sandbar, is fairly short (7 km) and shallow in depth (maximum depth below mean sea level is 2.5 m) (De decker and Bally, 1985). These authors state that the sediments of the estuary range from fine to medium sands with 'glutinous' mud in sections, silt is occasionally deposited by flocculation at the head of the estuary. The major difference between the Bot River and Siyaya estuaries (besides seasonal variation in temperatures due to geographical location), is the salinity level (De decker and Bally, 1985). The salinity of the Bot River Estuary varied between 21‰ and 23‰, whereas that of the Siyaya was rarely over 5‰. A total number of 25 species were recorded, including polychaetes, molluscs, isopods and amphipods (in order of decreasing representation). Of the species recorded in the Bot River Estuary, the amphipods *C. triaenonyx*, *M. zeylanica* and *O. ancheidos*, the tanaid *A. digitalis* and the polychaete *D. ornata* also occurred in the Siyaya Estuary during the present study. *A. digitalis* was numerically dominant in the Bot River Estuary (De decker and Bally, 1985). The Bot River Estuary was therefore characterised as being low in diversity due to limited recruitment and resembles a coastal lake in terms of species composition (De decker and Bally, 1985). This is the situation found in the Siyaya Estuary.

That is, the benthic macrofauna are impoverished in comparison with the densities and diversities found in tidal estuaries (Day, 1981c), and as a temporarily open/closed estuary, has a faunal composition resembling that of a coastal lake with relict estuarine fauna (Lake Sibaya; Allanson, Hill, Boltt and Schultz, 1966). Lagoa Poelela in Mozambique is a drowned river valley system, cut in much the same fashion as the other southern African coastal lakes (Sibaya, Nhlange and Swartvlei) (Boltt, 1975). At the time that it was studied, the salinity of the lake was 8‰, and had a benthic crustacean component similar to that found in the Siyaya Estuary. The difference is that representation of the genus *Grandidierella,* although dominating the fauna, is a different species to that found in the Siyaya. That is, *G. bonnieroides* is found in place of *G. lignorum*, and also *that C. triaenonyx* (the second most dominant amphipod in the Siyaya), is absent from this system. The mollusc, *M. virgilliae*, shares numerical dominance in Lagoa Poelela with *G. bonnieroides* (Boltt, 1975)

Whitfield (1989b), looked at the benthic community of the Swartvlei Estuary (34°01'S 22°46'E). This is an estuary with extensive eelgrass beds in the lower and middle reaches, thus contributing to detrital aggregates within the estuary and the following species in common with the Siyaya Estuary were found, amphipods: *C. triaenonyx*, *G. lignorum*, *M. zeylanica* and *O. ancheidos*; the cumacean *I. truncata*, the isopod *P. latipes*, the mysid *G. brevissura* and the polychaete *P. sexoculata*. Of these species only *C. triaenonyx, I truncata, G. brevissura* and *P. sexoculata* were not recorded amongst those species collected by Broekhuysen and Taylor (1959) from the Kosi Bay Estuary system. In the Kosi system, other species present that were common to those occurring in the Siyaya were *C. keiskamma, D. arborifera, D. monodi, C. nilotica, H. orbiculaire*, and *A. bifasciata.*

Davies (1982), looked at the zoobenthos of some southern cape coastal lakes, specifically those in the vicinity of Swartvlei. The occurrence *of C. keiskamma, C. triaenonyx, G. lignorum, M. zeylanica* and *A. digitalis* were common to the Siyaya Estuary. It is noteworthy that the polychaete *Mercierella enigmata* was dominant within the Swartvlei, but occurred only on a single occasion within the Siyaya Estuary. Likewise the small, relict marine, mollusc, *Musculus virgilliae* was dominant in terms of abundance, but was considered to be 'rare' in the Siyaya Estuary from 1992 to 1994. The polychaete *M. enigmata*, is a fouling species with a world-wide distribution (Wolff, 1983). The high abundance of invertebrates in the Swartvlei, have been associated with large standing stocks of submerged littoral macrophyte communities (Davies, 1982).

From the results obtained in this chapter, it maybe concluded that the effects of improved catchment management practices have had a positive effect on the zoobenthos of the estuary. Albeit that the prevailiing drought conditions also had an effect on the benthos, in terms of changing the physico-chemical state of the estuary, and resulting in a change in species composition. The recovery capacity of benthic animals in formerly degraded estuaries is based on several factors: currents, sedimentation, sediment structure, temperature, oxygen concentration and type of pollutant (Cato, Olsson and Rosenberg, 1980). Shallow estuaries show more resiliency in terms of recovery from degradation than deeper waters. Organisms here are opportunists and are adapted to rapidly colonising areas by reproducing several times annually with great numbers of larvae (Cato, *et. al.*, 1980). The aforementioned factors of sediment structure, temperature and dissolved oxygen concentration are dealt with in the following Chapter 6.

6.0 THE EFFECT OF PHYSICO-CHEMICAL VARIABLES ON THE SPATIAL AND TEMPORAL COMMUNITY STRUCTURE OF ZOOBENTHOS IN THE SIYAYA ESTUARY

6.1 Rationale

The objective of this chapter is to attempt to describe by means of multivariate techniques (numerical classification and ordination), the distribution and abundance of the benthic macrofauna (Chapter 5) in relation to the physico-chemical parameters (Chapter 4) sampled from 1992 to 1994. As introduced in Section 5.2, estuarine benthic invertebrates are influenced by a number of physical and chemical environmental factors. The most important have been listed as salinity, temperature, dissolved oxygen, and the nature of the substratum (Gray, 1981). Generally, in studies that have examined the effect of certain physico-chemical parameters on zoobenthos, little attention has been focused on relating the nature of these communities to additional measurements of water chemistry. A detailed investigation of the water quality of the Siyaya Estuary was performed as part of this study, and described in Chapter 4. Besides the conventional use of variables such as salinity, temperature, oxygen, substratum and depth, other physico-chemical parameters have been used in this chapter to examine the reasons for the observed distribution patterns and abundance of the benthos. These additional water quality parameters are listed in Section 6.3.

6.2 Introduction

It was suspected that the benthos of the Siyaya Estuary is mainly controlled by abiotic environmental factors, in the absence of major predators. The concept of Vannote, Minshall, Cummins, Sedell and Cushing (1980), is in part comparable to the situation within the Siyaya Estuary. That is, there is a continuum of physical gradients (decreasing salinity from mouth to headwaters of the Siyaya, for example) and associated biological adjustments from headwaters to river mouths. Vannote *et al.* (1980), proposed that these adjustments were predictable. The idea of biological adjustments along a physical gradient is dealt with in this chapter. However, as estuaries are themselves unpredictable environments, it is questionable how applicable the latter part of this concept is, in terms of consistency in predictability of biotic adjustments along a gradient.

Studies of large-scale spatial patterns in invertebrate community structure have found that geographical factors or water chemistry are the major determinants of community structure (Chapter 4; Section 6.1). These factors are more important than either the stability or variability of site characteristics (Death, 1995). Hildrew and Townsend (1987) developed a model predicting that communities in unstable habitats will be dominated by species with good colonising abilities (Figure 6.1). The model also predicts that sessile grazers and filter feeders will dominate communities at sites of high productivity and stability with increasing dominance of more mobile species as stability decreases (Death, 1995).

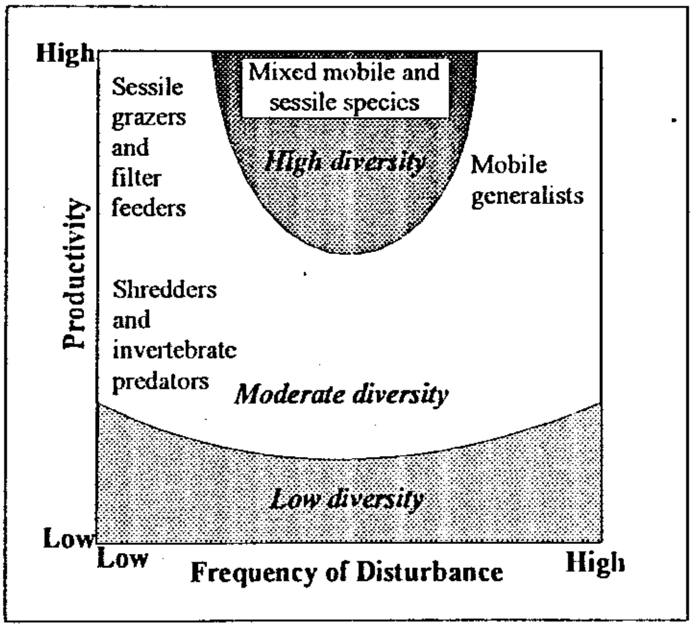


Figure 6.1: The disturbance-productivity-diversity model relating community structure to environmental stress. (After Hildrew and Townsend, 1987)

To be able to incorporate the theory of the model into this study, it had to be determined if the physico-chemical conditions within the estuary provided an environment that induced either neighbourhood or global stability (Section 5.3) within the benthic community. By referring to the model (Figure 6.1), the benthos of the Siyaya Estuary can be classified in terms of productivity and diversity, either as a community dominated by filter feeders (low frequency of disturbance and high stability) or mobile generalists (high frequency of disturbance).

The following paragraphs deal with the limiting effects of various physico-chemical variables on zoobenthic communities. Each variable is considered as an effect on its own, as few studies have dealt with the limiting effects of a combination of variables. In some estuaries, particularly in areas characterised by a distinct seasonality in climate, temperature may be an important limiting factor for some organisms. There is, as would be expected, a certain amount of variability between sea and riverwaters. The temperature of seawater varies less than freshwater, and river temperatures are higher than seawater during summer, and lower in winter (Branch and Branch, 1985). This variability is extended to within estuaries themselves, where the upper reaches experience a far wider range of temperature differences than other regions (Branch and Branch, 1985). There are several limiting temperatures for some animals, where breeding and feeding cease to occur (Day, 1981c). In this respect it is the combination of low temperature and low salinity that is lethal to organisms (Day, 1981c). This may be a problem in western Cape estuaries (winter rainfall area), as both low temperature and salinity conditions occur at the same time every year.

Low dissolved oxygen levels appear to be more limiting in terms of distribution of benthic species, than extremes of temperature and salinity (Rainer and Fitzhardinge, 1981). Oxygen is both an essential element in the metabolic processes of aerobic organisms and an important indicator of water quality of the environment. The oxygen content of the substratum is important for infaunal benthos. Coarse sands have higher oxygen concentrations than fine sands and muds (Knox, 1986). A vertical gradient of oxygen concentration exists in sediments. Animals living in the deeper layers, adapt to this environment, by either pumping in oxygen-enriched water through their burrows, or developing siphons which extend to the sediment surface, as shown by Gray (1981). This 'pumping', has been personally observed in laboratory tanks containing the amphipods *G. lignorum* and *C. triaenonyx*. Within their burrows, these animals position themselves on their dorsal surfaces with their anterior ends pointing towards the entrance. By constantly moving their pleiopods back and forth, and the occasional sweeping motion of the telson, water is drawn through the burrow and circulated via a constant current. Day (1981b) states that generally, in southern African estuaries (including those that are periodically closed), there is little evidence for much oxygen depletion. This, is not necessarily true for the Siyaya Estuary, as it has been anoxic on numerous occasions in the upper reaches at Site 5 (Chapter 4: Physico-chemical Parameters).

The importance of turbidity in affecting the penetration of light into water, is manifested by the modification of primary production. Levinton (1982), proposed that turbidity also inhibits behavioural characteristics in estuarine fauna. For example, light influences the lateral and vertical movement of organisms to and from feeding grounds creating a strong timing mechanism (Levinton, 1982).

The substratum is a major controlling factor in the distribution of estuarine benthos (Kennish, 1986; Richards and Bacon, 1994). Differences in substrate type are usually associated with obvious differences in community composition (Rainer and Fitzhardinge, 1981; Richards and Bacon, 1994). Coarse-grained sediments, with intense drainage are the most inhospitable of environments. However, fine muds with tightly packed smaller grains are also unfavourable (Gray, 1981). In general, the number of taxa and productivity of substrates composed of small particles are less than those of larger, more heterogeneous substrates (Richards and Bacon, 1994) This may be in part due to the low oxygen concentration within the sediment, and fewer interstitial spaces for fauna to maintain a living space. Therefore, medium-grained sediments must support the majority of benthic fauna.

As geomorphology and landuse play a role in determining benthic community structure (Tate and Heiny, 1995), it is important that surface water chemistry be included in the analyses of factors affecting benthos. Results of chemical analyses in Chapter 4 showed that Na^+ and Cl^- ions were relatively high, as compared to other systems that are considered to be fresh, while nutrient levels were low. These results may play a significant role in determining the benthic community structure of the Siyaya Estuary. That is, the levels of these particular ions may explain why relict estuarine species dominate this system, despite the fact that salinity levels dropped between 1992 to 1994 from 6‰ to 0‰ and turning the upper reaches of the Siyaya into a freshwater system.

With regard to the above factors affecting animal-habitat relationships, a study conducted in Chesapeake Bay (Diaz and Schaffner, 1990) revealed that the major factor governing organism distribution, is salinity. At high salinity levels, patterns of organism distribution are correlated with sediment type. Oxygen availability also had an effect by influencing benthic organisms' metabolic processes (Diaz and Schaffner, 1990).

As allochthonous detritus is considered to be a major energy source in rivers (Section 4.1.3.2), it is expected that the distribution of invertebrates and detritus should be related. Corkum (1992), suggests that no real significant relationship exists between the two, because of the variability of food quantity within and among sites. For this reason, the occurrence of certain benthic invertebrates in the upper reaches of the Siyaya Estuary (particularly within the highly organic sediments at Site 5), could not be attributed to the amount of detritus alone. Detritus plays an important role in aquatic ecosystems by stabilising the source of food created by seasonally fluctuating primary production (Wolff, 1980).

6.3 Methods of Data Analysis

As it is common to link environmental parameters to population distribution through multivariate analyses by ordination and classification procedures (Chester, Ferguson and Thayer, 1983), this was the method employed for linking abiotic and biotic samples from the Siyaya Estuary. The program ***BIOENV*** in the ***PRIMER*** statistical package was used as a method of linking multivariate community structure to environmental variables (Clarke and Ainsworth, 1993; Clarke and Warwick, 1994).

BIOENV aims to relate the biotic (benthic density) to environmental patterns (physico-chemical characteristics) as schematically outlined in Figure 6.2.

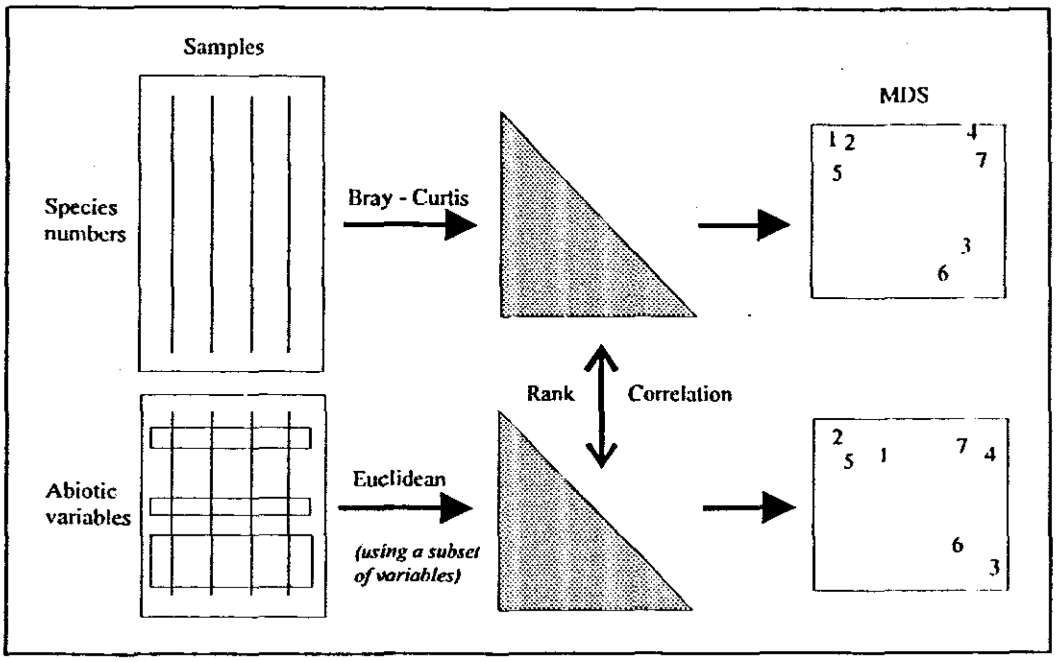


Figure 6.2: Schematic diagram of the *BIOENV* procedure. (After Clarke and Warwick, 1994)

MDS = non metric multidimensional scaling ordination

Bray - Curtis and Euclidean refer to type of sim/dissimilarity measure

Each biotic sample was related to the physico-chemical parameters measured in concordance, by following a sequence of steps. This method was repeated for data collected over the three consecutive years.

Step 1: The biotic sample MDS ordination plots obtained through multivariate *PRIMER* analysis (Results: Chapter 5) were used as a template on which various measurements of abiotic variables were superimposed.

Step 2: The five abiotic parameters used to describe the benthos were depth, oxygen, salinity, temperature, and turbidity.

Step 3: A specific symbol was used to describe each physico-chemical parameter, and these were plotted in proportion to the measurement obtained at each sampling site, during each season.

Step 4: Steps 1 - 3 were repeated for 1992 - 1994 data. However, since a water quality and sediment study was performed in 1994, data from these analyses were used as well as the variables listed in Step 2.

Step 5: Sediment characteristics superimposed on the 1994 benthic sample MDS were the mean particle diameter, the percentage silt and the percentage organic content. The remaining variables described the water quality of the estuary and were pH, conductivity, alkalinity and calcium, sodium, and chloride ions.

The pH was selected as a variable that may affect the benthos, because of the effect it has on other water quality variables depending on its deviation from neutrality (Section 4.1). Results from Chapter 4 indicated that the salinity levels in the estuary decreased in consecutive years, as the system remained isolated from the sea and this situation was exacerbated by worsening drought conditions. Since Na^+ and Cl^- levels were elevated during sampling periods as were measurements of Ca^{2+} and $CaCO_3^-$ (alkalinity) at other times, these variables could together provide some idea as to how each, or a combination of several affected the benthic community structure. Na^+ and Cl^- are an alternate measure of the salinity of water, while high Ca^{2+} concentrations and alkalinity indicate freshwater conditions.

The final step aimed to divulge some statistical relationship between combinations of physico-chemical parameters and single variables in terms of accounting for the variability in the biotic data. This portion of the analyses revealed what variable(s) were ultimately responsible for the spread of data across three years. As a full physico-chemical data set was available for 1994 (sediment characteristics and a variety of water quality characteristics), this was used to interpolate the environmental factors that were affecting the benthos. The fact that environmental parameters may change significantly from year to year was acknowledged, nonetheless it was assumed that 1994 data could provide a more or less accurate account of the general situation within the estuary. The premise adopted in this type of analyses, is that samples having similar values for a known set of environmental variables should have a similar species composition. An ordination based on this abiotic information would group sites in the same way as for the biotic plot (Clarke and Warwick, 1994). The agreement in pattern between abiotic and biotic plots are then tested on the underlying similarity matrices using a correlation coefficient. The similarity matrices are based on the normalised Euclidean Distance for abiotic data (Chapter 4) and Bray - Curtis Similarity for biotic data (Chapter 5).

Step 6: MDS ordinations were performed on each physico-chemical variable, as well as on specific combinations of these parameters at increasing levels of complexity. Results were then compared with the biotic MDS ordination plot, for similar groupings of data points. The weighted Spearman (ρ_w) rank correlation was calculated for permutations of abiotic variables through the program *BIOENV* in the *PRIMER* statistical package. The weighted Spearman rank correlation is given as:

$$\rho_w = 1 - \frac{6}{N(N-1)} \sum_{i=1}^{N} \frac{(r_i - s_i)^2}{(r_i - s_i)}$$

ρ_w lies in the range (-1,1) and values around zero correspond to the absence of any match between the two patterns.

6.4 Results

The groups of sampling sites distinguished on the basis of species abundances to the environmental data are given in Figures 6.3 to 6.7.

Figure 6.3 presents the results of superimposing 1992 measurements of depth (6.3 b), oxygen (c), salinity (d), temperature (e) and turbidity (f) on 1992 biotic data (a). The original biotic MDS (stress = .13 after 10 runs) showed four distinct clusters in the final plot (I - IV), as set out in the original Bray - Curtis cluster analysis at a similar distance of 100 (Chapter 5). To examine if these groups differed from each other on the basis of the abiotic variables, each abiotic plot was examined for groupings of similar

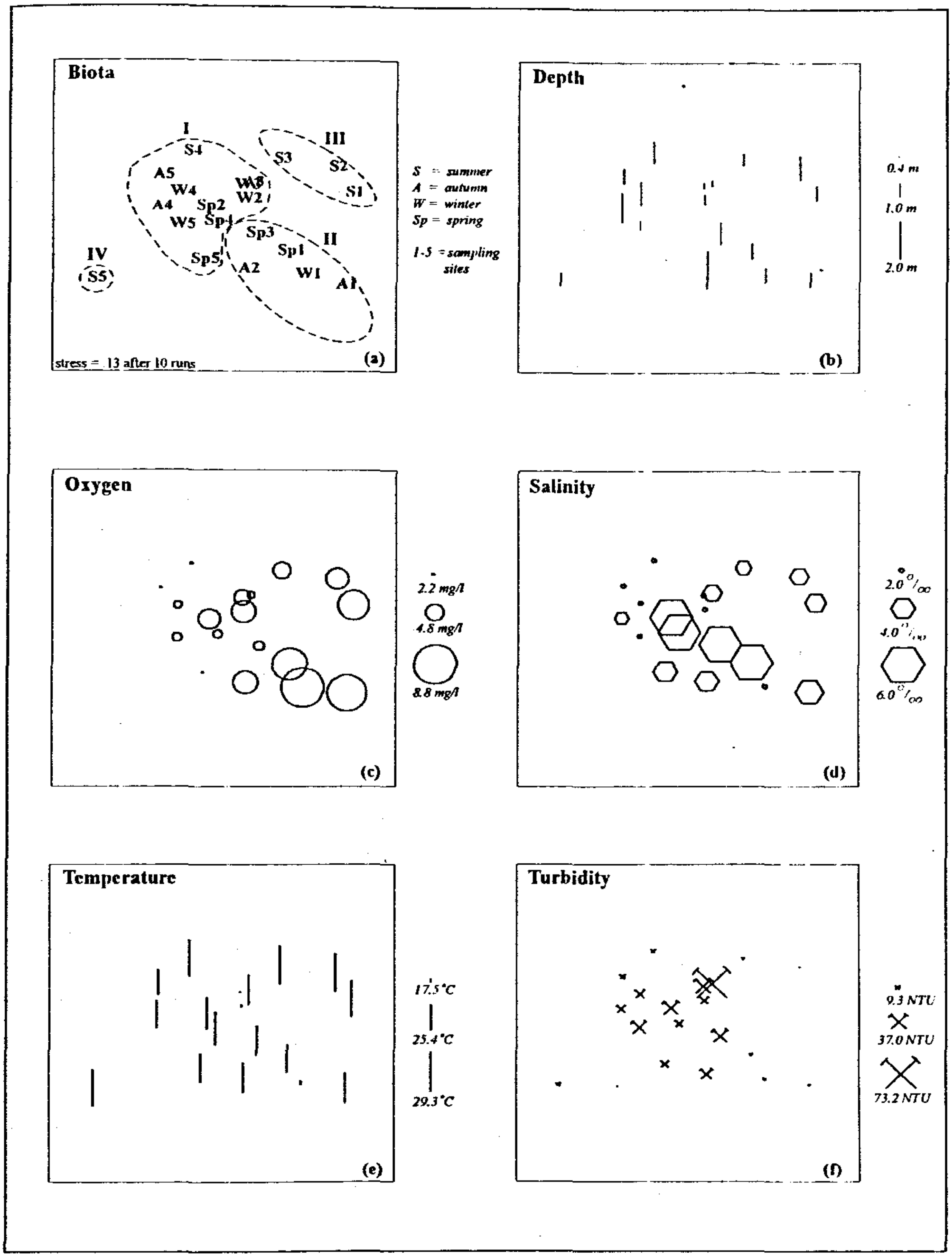


Figure 6.3: Siyaya Estuary Benthos 1992. a) MDS of seasonal benthic samples at the five sites as in Figure 5.23; b) - f) the same MDS but with superimposed symbols representing depth, oxygen, salinity, temperature and turbidity. (Stress = .13)

measurements. Neither depth (b) nor temperature (e) were responsible for causing samples to be clustered together. Oxygen (c) was responsible for distinguishing Groups I, III and IV from Group II, which was characterised by high dissolved oxygen levels. Samples constituting Group II were autumn, winter and spring biotic samples from Site 1, samples from Site 2 in autumn, and Site 3 in spring. Generally, these samples were collected in the lower reaches of the estuary where the sediments were categorised as medium - grained sands (Chapter 4). Group IV was distinguishable from the rest on the basis of salinity (d). Group IV consisted of a single sample collected during summer 1992, in the upper reaches of the estuary where the salinity was generally 0‰. Although Groups I and II were characterised by samples with relatively high salinity measurements, the range between these and other samples within the group was too great to permit a distinction to be made between Groups I, II and III. Groups III and IV were distinguishable from the rest on the basis of turbidity (f) measurements. Turbidity measurements within these two groups were <9.3 NTU, and were from samples collected in summer 1992, from Sites 1, 3 and 5. Note that the remaining summer sample (Site 4), is also within this turbidity range, but is part of the cluster of samples constituting Group I. These results may be summarised by stating that in 1992, salinity, turbidity and to all appearances oxygen played a key role in distinguishing samples from one another, and therefore governing the distribution and abundance of benthic species.

When 1993 variable measurements were superimposed on biotic data (Figure 6.4), it was found that depth (b), salinity (d) and temperature (e) were not responsible for causing intergroup variability. The original MDS ordination plot grouping clusters of 1993 species samples was first presented in Chapter 5, and identified three groups of similar samples at an arbitrarily chosen Bray - Curtis distance of 100. Figure 6.4 (a) shows these three groups with their corresponding species samples (MDS 2d minimum stress = .16 after 9 runs). Groups I, II and III were clearly distinguishable from each other on the basis of differing dissolved oxygen levels (Figure 6.4 c). Species samples contained in Group III were characterised as being from areas with a relatively high dissolved oxygen level (>6.1 mg/l). The four samples constituting Group III were from Site 1 collected during each season. Samples in Group II were characterised as being from areas that could be described as anoxic (Chapter 4). The samples in this group

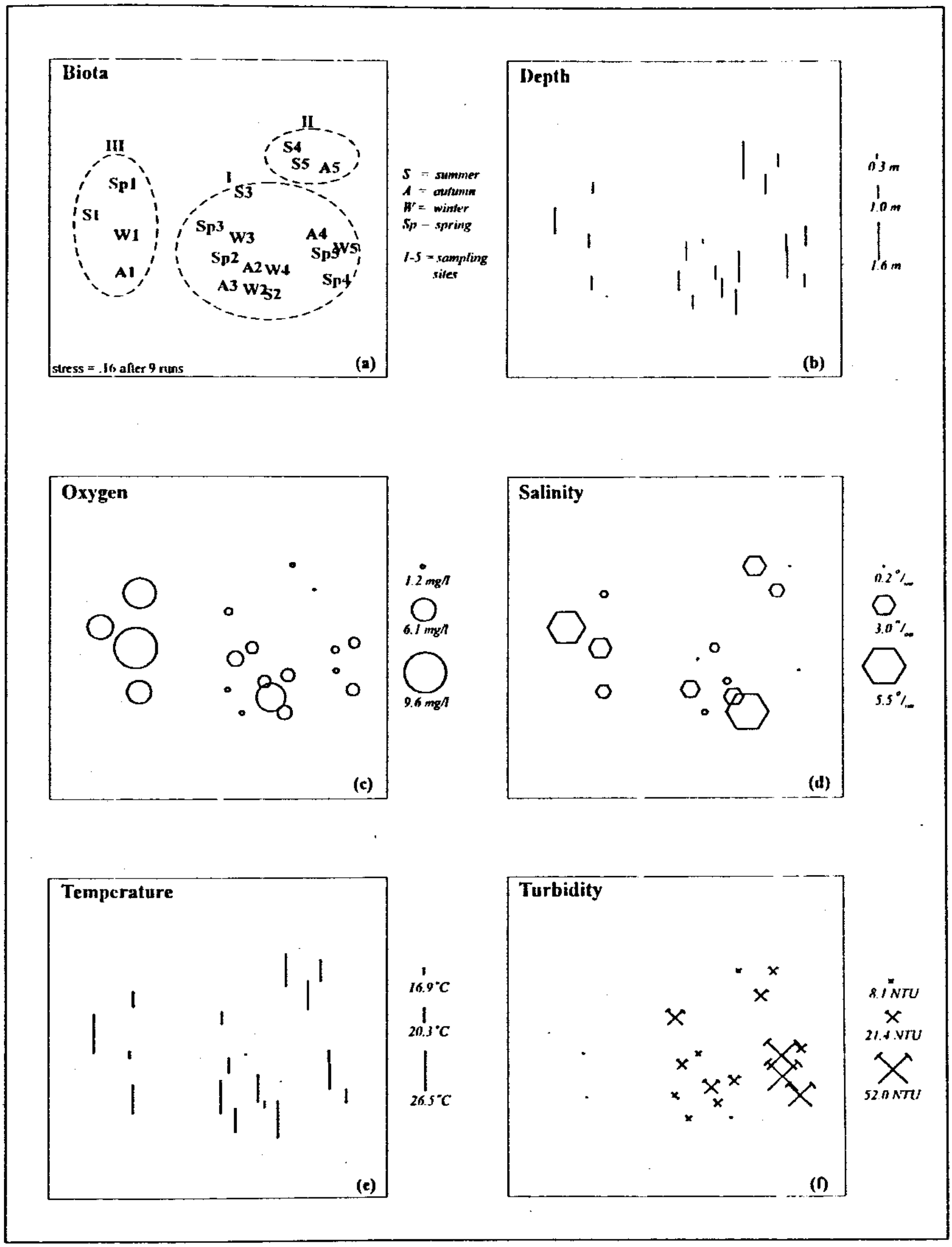


Figure 6.4: Siyaya Estuary Benthos 1993. a) MDS of seasonal benthic samples at the five sites as in Figure 5.25; b) - f) the same MDS but with superimposed symbols representing depth, oxygen, salinity, temperature and turbidity. (Stress = .16)

were collected in the upper reaches of the estuary (Sites 4 and 5), during autumn and winter and were specified as having dissolved oxygen levels <1.2 mg/l. Samples from the final group (I) were more variable with regards to dissolved oxygen levels (2.0 - 6.0 mg/l), and were all generally collected from the middle to lower, and middle to upper reaches of the estuary. Only two groups were distinguishable on the basis of turbidity measurements throughout 1993 (Figure 6.4 f). Groups I and II were clearly different from Group III, while the former two were indistinguishable from each other. Group I turbidity measurements were from samples collected at Site 1, and were <8.0 NTU throughout 1993. Turbidity measurements in Groups I and III ranged from 8.1 NTU to 60 NTU (Chapter 4). It is noteworthy that turbidity measurements from the upper reaches of the estuary during autumn, winter and spring were >45 NTU, in contrast to those in the lower reaches (Group I) which were much lower. Therefore, throughout 1993 an increasing gradient of turbidity existed from the lower to upper reaches of the estuary, and this variable was in part responsible for distinguishing certain benthic samples from one another.

Figure 6.5 (a) is the plot of 1994 biotic samples created in Chapter 5. The MDS was generated with a 2d minimum stress of .10 after 8 runs, and distinguished two groups at a Bray - Curtis similarity of 100. Group I contained those samples collected at Sites 3, 4 and 5 in spring, and Site 5 in summer, autumn and winter. Of the five variables superimposed on the biotic MDS ordination plot, only salinity (d) and turbidity (f), had any effect in structuring the nature of the sample groups. Samples within Group I, were from areas where the salinity was <0.5‰, and the turbidity was >20 NTU. The turbidity measurements corresponding to species samples clustered in Group II were relatively low (< 15 NTU). From Figure 6.5, it is apparent the turbidity had a negative relationship with both salinity and oxygen. That is, as either salinity or oxygen increased, turbidity levels decreased. This was not as apparent from plots of variables from either of the two previous years.

Substrate characteristics described by the mean particle diameter, percentage silt and percentage organic content of the sediments, were also overlayed onto the plot of the result of an MDS ordination of biotic samples (Figure 6.6 b, c and d). All three

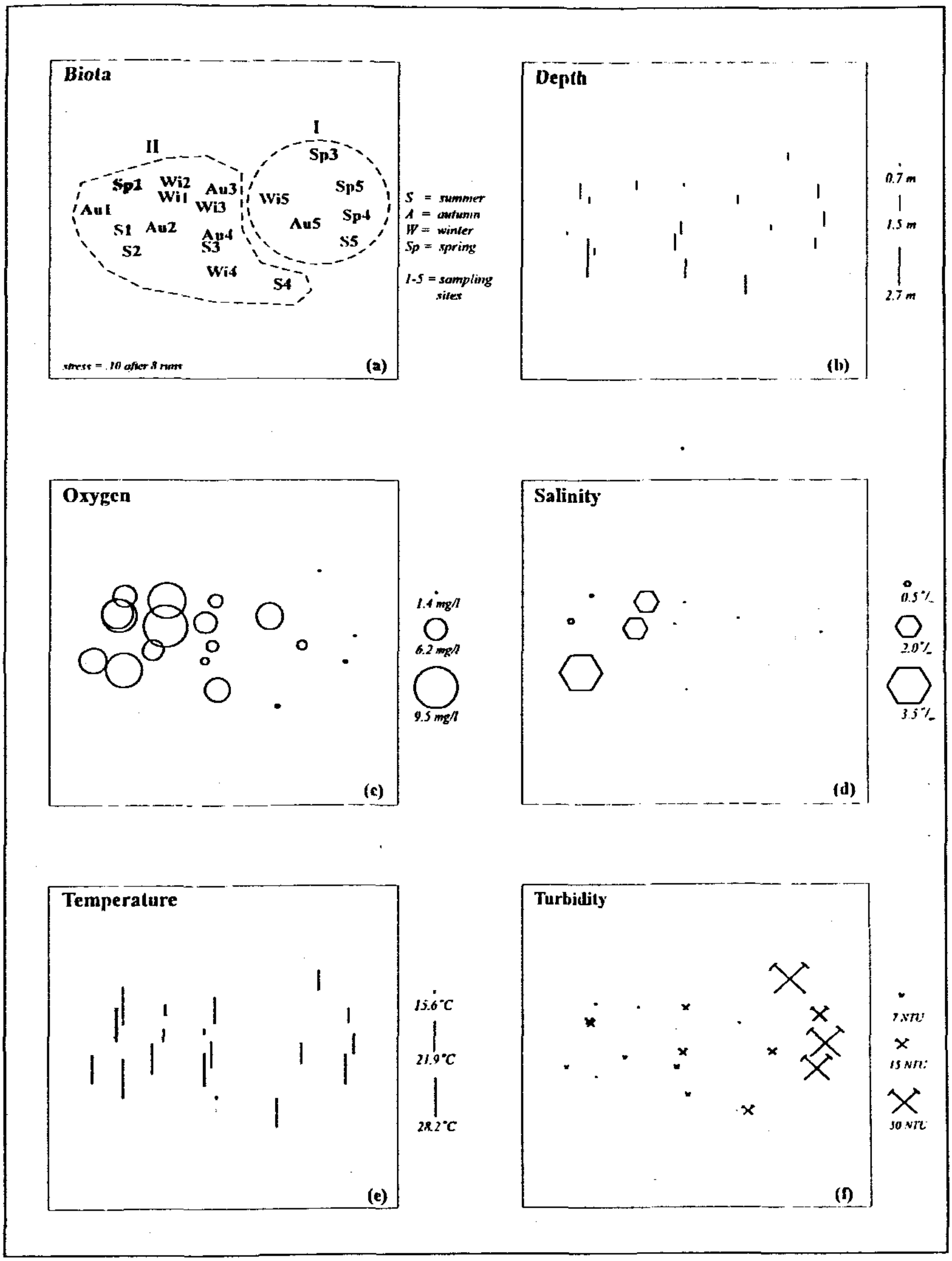


Figure 6.5: Siyaya Estuary Benthos 1994. a) MDS of seasonal benthic samples at the five sites as in Figure 5.27; b) - f) the same MDS but with superimposed symbols representing depth, oxygen, salinity, temperature and turbidity. (Stress = .13)

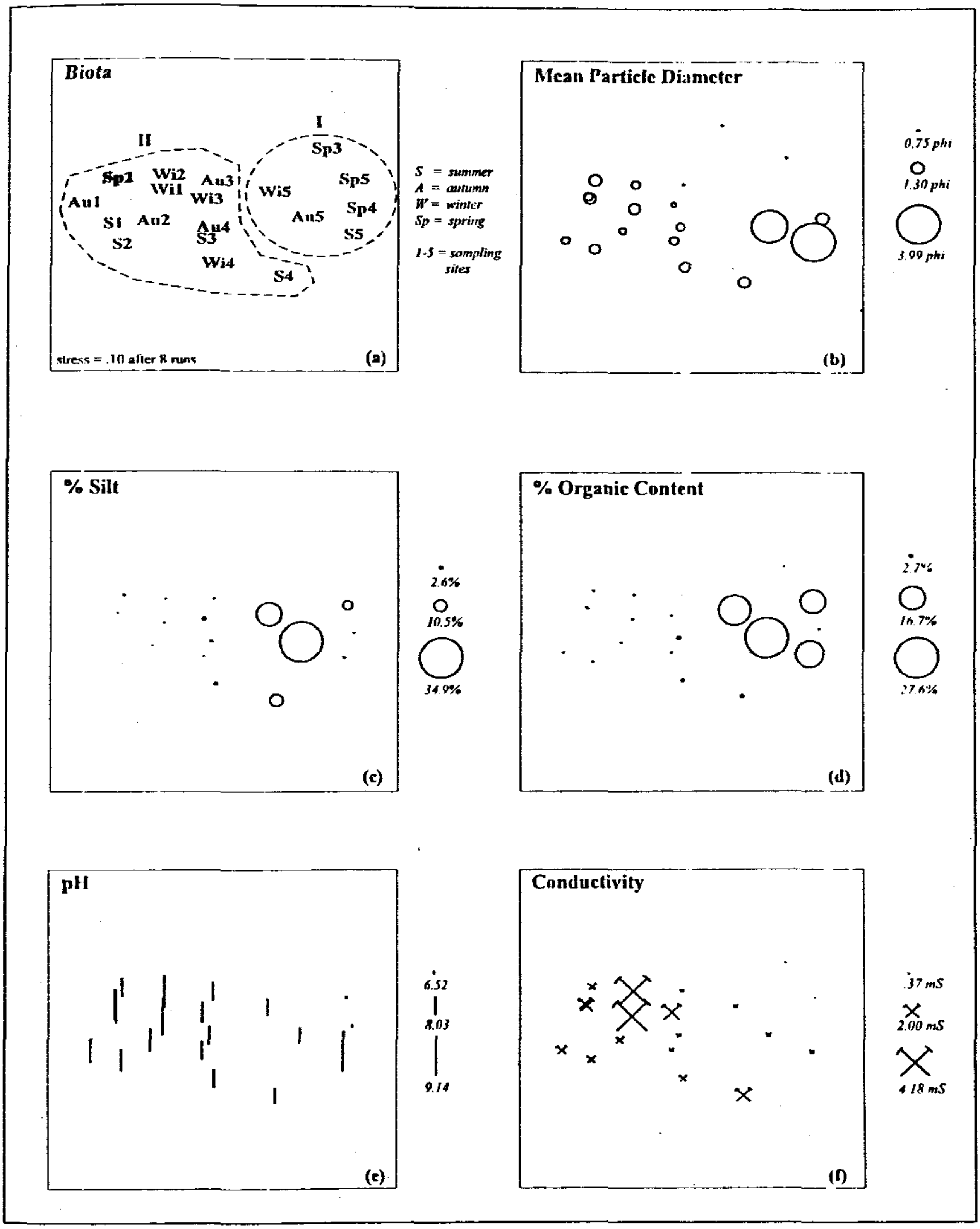


Figure 6.6: Siyaya Estuary Benthos 1994. a) MDS of seasonal benthic samples at the five sites as in Figure 5.27; b) - f) the same MDS but with superimposed symbols representing the mean particle diameter, % silt, % organic content, pH and conductivity. (Stress = .10)

sediment characteristics played some role in determining the differences between the species sample groups. However, there were several outliers which did not fit the pattern of fully separating the Groups I and II from each other. The mean particle diameter (b) associated with samples from Group II, characterised sediments that were a finer sand (bordering on the silt/mud fraction), than those samples in Group I. The percentage silt (c) and organic content (d) were also greater in areas where Group I samples were collected. The pH level (e) between the two groups did not differ greatly, thereby providing no explanation for separating the samples. The conductivity (f) related to Group II biotic samples was much greater than those measurements taken in the upper reaches of the estuary (relating to the first biotic sample group). Of the four ionic measurements used to describe the 1994 biotic data, only Na^{+} (d) and Cl^{-} (d) were sufficiently different in either of the two biotic sample groups to have an effect on the benthos (Figure 6.7). Both Na^{+} and Cl^{-} concentrations were much less in the upper reaches of the estuary (Group I), during 1994. The alkalinity (b) of the water at each sampling site was fairly similar, while Ca^{+} (a) ion levels were more variable but not greatly distinguishable between Groups I and II.

As the abiotic variables had only been superimposed onto the biotic sample plots, each variable was put through an MDS ordination, to examine the nature of the resultant clusters. Increasingly complex combinations of variables, were also subject to MDS analyses (Refer to Step 6 in Section 6.3). The resultant plots were then compared to the biotic MDS plot, and if the same samples were grouped together, variables used in the relevant abiotic MDS were then assumed to be responsible for causing biotic intersample differences. To prove that the combinations of variables that seemed to structure the data were a true reflection of the actual situation, the data was subjected to a weighted Spearman rank correlation, ρ_w (Table 6.1). The greater the deviation from zero towards +1, the greater the chance that the physico-chemical parameter or combination of parameters was accounting for the variability in the biotic data. From Table 6.1, the single parameter accounting for the most variability amongst the biotic data, was pH (ρ_w = .395). This was interesting, as results of the superimposition of pH on the biotic data did not account for differences between the groups set out in the biotic MDS. The best two variable combination was pH and the mean particle diameter of sediments (ρ_w =

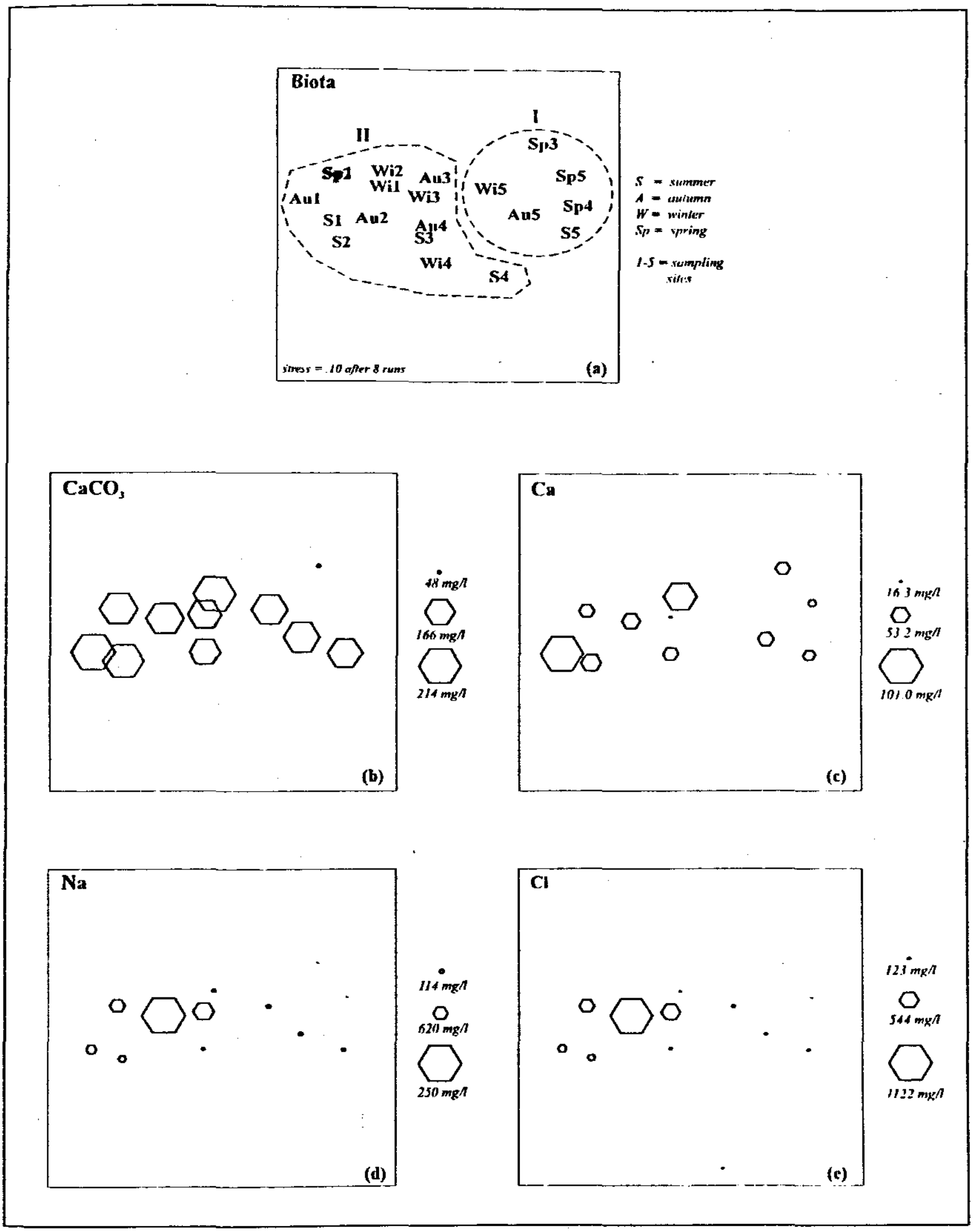


Figure 6.7: Siyaya Estuary Benthos 1994. a) MDS of seasonal benthic samples at the five sites as in Figure 5.27; b) - e) the same MDS but with superimposed symbols representing $CaCO_3$, Ca, Na and Cl. (Stress = .10)

.443). The most satisfactory combination of variables accounting for most of the global variability within the data was a combination of turbidity, oxygen, percentage organic content of the sediment and pH (ρ_w = .521). The best single, two, three, four and five variable combinations are presented in Figure 6.8. Figure 6.8 d, e, and f (minimum stresses of .04 after 10 runs, .08 after 6 runs and .11 after 6 runs, respectively) show that the physico-chemical MDS plots clearly separate the sampling sites in a manner similar to the MDS ordination of the biotic samples.

Table 6.1: Combinations of the 10 environmental variables, taken k at a time, yielding the best matches of biotic and abiotic similarity matrices for each k, as measured by weighted Spearman rank correlation (ρ_w). Bold type indicates overall optimum and shading indicates variable combinations presented in an MDS plot.

k	Best variable combinations (ρ_w)		
1	pH (.395)	O_2 (.339)	Tb (.316)
2	Mpd, pH (.443)	O_2, pH (.428)	Tb, %OC (.427)
3	Tb, O_2, %OC (.519)	Tb, %OC, pH (.487)	Tb, O_2, %Slt (.480)
4	**Tb, O_2, %OC, pH (.521)**	Tb, O_2, %OC. T (.498)	Tb, O_2, % Slt, pH (.497)
5	Tb, O_2, D, %OC, pH (.514)	Tb, O_2, %OC, pH, T (.510)	Tb, O_2, %OC, pH. Mpd (.493)
6	Tb, O_2, D, %OC, pH,T (.489)	Tb, O_2, D, %OC, pH, Mpd (.477)	
7	Tb, O_2, D, %OC, pH, Mpd. % Slt (.460)		
8	Tb, O_2, D, %OC, pH, Mpd. % Slt, T (.431)		
9	Tb, O_2, D, %OC, pH, Mpd. % Slt, T, Conduct. (.375)		
10	Tb, O_2, D, %OC, pH, Mpd. % Slt, T, Conduct., Sal. (.300)		

Tb = *turbidity*
Mpd = *mean particle diameter*
T = *temperature*
D = *depth*
Sal = *salinity*
%OC = *% organic content*
% Slt = *% silt content*
O_2 = *oxygen*
Conduct. = *conductivity*

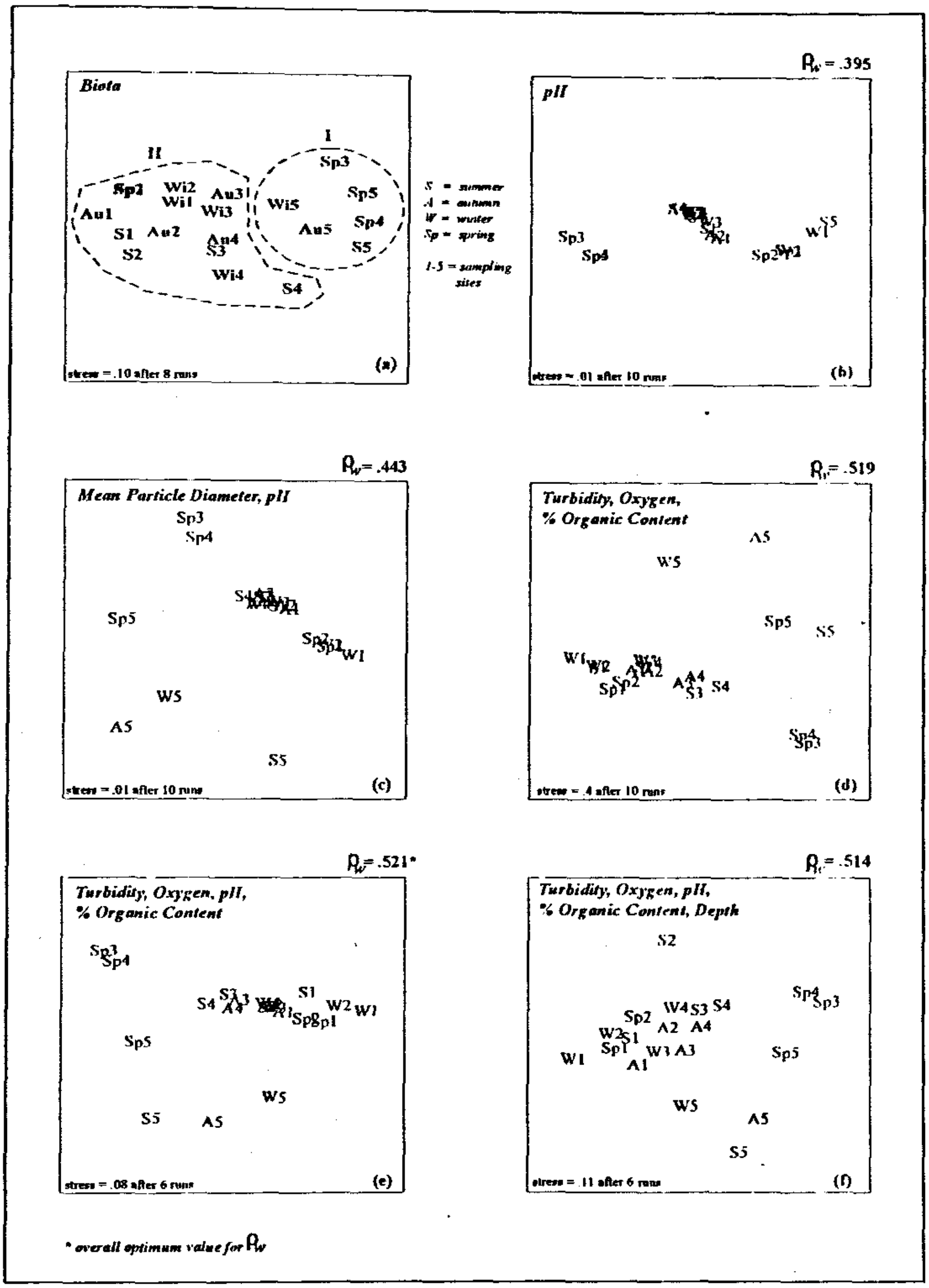
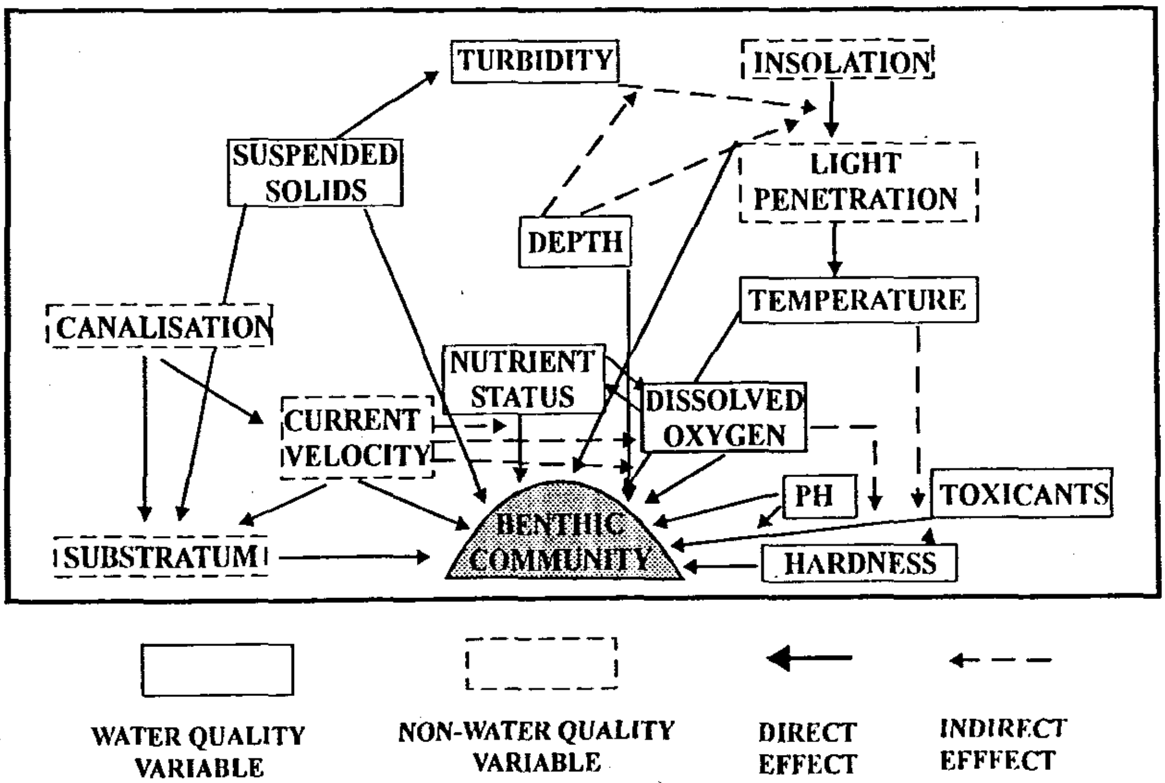


Figure 6.8: Siyaya Estuary Benthos 1994. a) MDS of seasonal benthic samples at the five sites as in Figure 5.27; b) - f) MDS ordinations based on pH, pH and mean particle diameter, turbidity, oxygen and % organic content, turbidity, oxygen, pH and % organic content (the combination 'best matching' the biotic pattern) and turbidity, oxygen, pH, % organic content and depth. The relevant Spearman's weighted rank co-efficients are given above each ordination. (Stress = .10)

6.5 Discussion

The structure and composition of the benthos is determined by a number of interacting factors, including biotic interactions and the water quality characteristics of the estuary. The latter are presented in this chapter as a means of describing environmental factors affecting the distribution and abundance of the benthos. A single independent physico-chemical parameter cannot be considered responsible for affecting the nature of the benthos. This is because there is a strong interrelationship between certain physico-chemical parameters, which are usually 'cause and effect' type situations where a change in a certain parameter causes either a direct or indirect effect on another. This is diagramatically portrayed in Figure 6.9.

Figure 6.9: Major water quality and other variables potentially affecting benthos, showing both direct and indirect interactions between variables (After Dallas and Day, 1993)



In order to survive, each species of organism requires a certain combination of physical and chemical conditions (Dallas, Day and Reynolds, 1994). Benthic species are therefore adapted to living in water containing a particular combination of chemicals with certain concentration limits, and also within specific physical conditions.

Dallas *et. al.*, (1994) have listed the effect of some natural variables on aquatic organisms. Those that are relevant to this study are given in Table 6.2.

<u>Table 6.2:</u> The effects of some natural variables on aquatic organisms (After Dallas, *et. al.*, 1994)

WATER QUALITY VARIABLES	MAJOR EFFECTS
	Physical Factors
Temperature	• Determines metabolic rate • Determines availability of nutrients and toxins • Determines oxygen saturation level • Changes provide cures for breeding, migration etc.
Turbidity	• Determines degree of penetration of light, hence vision, photosynthesis.
	Chemical Factors
pH	• Ionic balance • Chemical species therefore availability • Gill functioning
Conductivity, salinity, TDS, individual ions	• Osmotic balance • Ionic balance • Water balance
Nutrients	• Not usually toxic *per se* but eutrophication affects community structure
Dissolved oxygen	• Respiration

The effect that any physico-chemical variable has on a benthic organism, is directly dependent on that organism's tolerance range to that particular variable. The range at which the organism is most ideally suited and which growth rates and reproductive output are greatest, is termed the optimum range (Dallas *et al.*,1994). This explains why only certain organisms are found in the upper deoxygenated regions of the Siyaya Estuary, while others are only abundant during those periods when the salinity was greater than zero.

From the results presented in the current chapter, it was clear that no single variable was responsible for affecting the distribution of the benthos. It was rather a combination of certain physico-chemical parameters. In the Chesapeake Bay study (refer to section 6.1), it was found that the distribution and abundance of estuarine benthos was influenced by certain physico-chemical parameters, within a particular range. It must be added that the level at which these factors become limiting are variable (within a particular system), and dependent on the system's biotic and abiotic characteristics. That is, where salinity may be limiting in one system that has a permanent connection to the sea, in another periodically open estuary sediment particle size or nutrient input may be the major environmental influence structuring benthic communities. The Siyaya Estuary is a good example of this, whereby salinity levels are more or less stable during periods of closure (0-6‰; see Chapter 4).

The findings from analysing the effect of the physico-chemical variables on the spatial and temporal benthic community structure by superimposition of measurements on a MDS plot of biotic samples, were threefold. Firstly, not all of the variables considered had an effect on the benthic community and secondly, of those variables that were important in terms of structuring the benthos, few were persistent throughout the study. That is, a different combination of variables distinguished benthic samples from one another each year. Depth and temperature showed insufficient difference to have any influence in separating biotic samples. The reasons for this may be that the climate of the area (Chapter 2) is such that great temperature differences between seasons are not experienced, and the estuary is sufficiently shallow (mean depth = 1.6 m; Chapter 4) to be well-mixed so that no great difference exists between variables measured at the top and bottom of the estuary. The third finding of the analyses was a function of the analysis technique. The superimposition of measurements of variables onto a spread of biotic data in the program *BIOENV* was only useful as an exploratory tool. These superimpositions only provided some indication as to the abiotic characteristics associated with the spatial and temporal samples, and not variables responsible for creating certain clusters of samples between sites and seasons. This was determined at a later stage of the analysis through the calculation of a rank correlation co-efficient, and generation of individual MDS ordination plots of all variables. The single variable accounting for the most variability in the biotic data was pH. However, by superimposing pH values onto biotic samples at the exploratory stage of analysis, the pH of the different 'groups' or clusters identified at the Bray - Curtis similarity of 100, were indistinguishable. The rank correlation of increasingly complex combinations of variables showed that the globally most successful combination of variables accounting for the variability of the biotic data was turbidity, oxygen, the percentage organic content of sediments and pH (Table 6.1). It was thus a combination of water physical (turbidity) and chemical (oxygen and pH) components, as well as sediment characteristics that had a combined function in affecting the benthos. The effects of these variables are discussed below with particular reference to benthic organisms.

Dallas, *et. al.* (1994), state that low concentrations of dissolved oxygen may cause various sublethal effects such as changes in behaviour, blood chemistry, growth rate and food intake, as well as lethal effects. The ecological effects of low dissolved oxygen (<2 mg/l), on benthos are lower species diversity, lower biomass and changes in community composition (Dauer, Rodi and Ranasinghe, 1992). These authors observed that in hypoxic areas of Chesapeake Bay (USA), there was a higher dominance in density of opportunistic species (oligochaetes) and lower dominance of opportunistic species (bivalves and polychaetes). Heinis, Sweerts and Loopik (1994), observed that at comparable temperatures, the silty sediments of Lake Maarsseveen (The Netherlands) consume three times as much oxygen as sandy sediments. The presence of chironomid larvae in the fairly anoxic upper reaches of the Siyaya Estuary may be in part due to a variety of adaptive mechanisms found among chironomid larvae, enabling them to cope with diminished oxygen concentrations (Heinis, *et al.*, 1994). One physiological adaptation, is that some chironomid species synthesise the respiratory pigment haemoglobin. Because chironomid haemoglobin has a high affinity for oxygen, it is functional at relatively low external oxygen concentrations (Heinis, *et al.*, 1994).

Anaerobic conditions in the upper reaches of the Siyaya Estuary prevent the development of a population of secondary consumers and detritivores to utilise the excess detritus and the reeds prevent it from being flushed from the system by floods (Schleyer and Roberts, 1987). The detrital food chain in the Siyaya Estuary was studied by these authors, as it was considered important to manage the Siyaya. The results of this studied showed that the litter input (1.6 $kg/m^{2}/yr$) exceeded the estimated mineralisation rate, and the presence of *P. australis* exacerbated the problem of litter input and consequently detritus formation and anaerobic conditions (Schleyer and Roberts, 1987).

The above determines the amount of organic substances present in the sediment (particularly at Site 5). Table 6.1 shows that the percentage organic content of the sediments was only considered an important physico-chemical variable when it was combined with other physico-chemical factors. From Figure 6.6, it is evident that the mean particle diameter, percentage silt and organic content are related. That is, the highest organic content within the sediment was present in the upper reaches of the estuary in those areas where the percentage silt was the highest, along with sediments characterised by the smallest particle diameter. Those reaches of the estuary particularly around Sites 4 and 5 were also characterised by high turbidity levels (Figures 6.4 and 6.5) Continuos high levels of turbidity may result in a change in the community composition, depending on which organisms are best able to cope with the alteration in habitat, in the form of settled suspensoids (Dallas and Day, 1993).

Changing the pH of the water changes the concentrations of both H^{+} and OH^{-} ions, which in turn affects the ionic and osmotic balance of aquatic organisms. Relatively small changes in pH are not normally lethal, although sublethal effects such as impaired growth rates and reduced fecundity may occur as a result of increased physiological stress placed on the organism by increased energy requirements (Dallas and Day, 1993; Dallas, *et. al.*, 1994). No gradient of pH existed from the upper to lower reaches of the estuary, from 1992 to 1994.

The salinity regime remained more or less stable throughout the study years, therefore multivariate analyses showed that it did not have a great effect on the benthos. However, this must be questioned as it is due to the fact that the mouth has remained closed, that the benthic community is so structured with an expanding freshwater component. Closure of the mouth has led to near fresh conditions, therefore precluding the existence of any stenohaline marine components. Cyrus and Martin (1991) showed that during 1991, there was a well-developed salt wedge starting approximately 0.5 m beneath the surface, and extending the length of the sampling area. This soon disappeared, and uniform salinities were present throughout the system. The dominance of oligochaetes, and presence of nematodes and diptera larvae in the upper reaches of the Siyaya Estuary are comparable to the situation encountered in the Forth Estuary, Scotland by McLusky (1987). The fauna of the upper Forth Estuary (salinity = 1 ‰) was dominated by large populations of oligochaetes, plus occasional nematodes and diptera larvae.

It has long been recognised that the nature of the substratum is of the greatest importance in determining the nature of the bottom flora and fauna (Morgans, 1956). Although this factor was not part of the most important variables affecting the benthos, it is still considered as an important factor for the following reasons. The various soft bottoms, such as gravels, sands and muds show differences in biota and analysis of the nature of substrates with regard to mineralogical constitution and particle size, are important in describing the ecology of benthos. Morgans (1956) notes that two features of soft substrata affect benthos, texture and dead organic matter. Boltt (1969) hypothesised that *G. lignorum* will only build tubes in mud if sand is unavailable. This proved to be true in the Siyaya, as the highest densities of *G. lignorum*, were chiefly in areas characterised by a muddy sand substrate (Chapter 5). *Ceratoneries keiskamma* preferred substrata that were sandy and was not abundant where the substrate was muddy or contained much detritus. In fact, *C. keiskamma* was virtually absent throughout the study from the middle and upper reaches of the estuary. Kalejta (1992), has proved that a correlation exists between distribution of *C. keiskamma* and sediment characteristics. That is *C. keiskamma* seems to be confined to fine sediments in the Berg River Estuary in the western Cape (Kalejta and Hockey, 1991; Kalejta, 1992). Cohen (1986) found that the gastropod *M. tuberculata* is a shallow burrower and was primarily restricted to soft mud with only an occasional specimen being found on coarse substrates. This may explain the rare occurrence of *M. tuberculata* in the Siyaya Estuary. In the Siyaya, those areas characterised by muddy sediments, were also regions of large amounts of detritus and sediment organic content, perhaps limiting the ability of this species to effectively construct burrows. Large numbers of *M. tuberculata* have been recorded in Lake Nhlabane (L. Vivier[3], *pers. comm.*) and Lake Nsezi (*pers. obs.*), two Zululand coastal lakes. Cyrus and Martin (1988), determined that the most important factor which determined the abundance and distribution of each species within Lake Cubhu (Zululand), appeared to be the type of substrate. In their investigations they found that the highest densities of benthic animals occurred in sandy substrata, while areas with detritus supported a greater number of species. Cyrus and Martin (1988) noted that while both *G. lignorum* and *C. triaenonyx* occurred in sandy substrata, the former was numerically dominant here, but decreased markedly in detrital areas. This was not the case with *C. triaenonyx*. Therefore *C. triaenonyx* appears to have a greater adaptability to varying habitats, and perhaps *G. lignorum* requires a non-detrital substrate in which to construct its tubes.

Perhaps due to competition that may exist between *C. triaenonyx*, *C. keiskamma* and *I. truncata*, the former did not occur in areas where the latter species were more abundant. A further explanation may be that *C. triaenonyx* is unable to construct burrows out of coarse-grained, marine sands and is therefore limited to areas where the substrate is a muddy sand with a small detrital input. This proved to be true, as Rao and Shyamasundari (1963) established that this amphipod constructs its tubes of fine silt and cements grains together with a tanned protein. Cyrus and Martin (1988), suggested

[3] Mr L. Vivier, Coastal Research Unit of Zululand, Department of Zoology, Private Bag X1001, KwaDlangezwa, 3886

that due to its tube-building behaviour, *C. triaenonyx* was able to exploit a wider variety of habitats than *G. lignorum*. This was not so in the Siyaya Estuary, as *G. lignorum* was the most abundant species in the estuary, occurring in all substrate types (Chapter 5).

Work by Snelgrove and Butman, (1994), shows that there is little evidence that sedimentary grain size alone is the primary determinant of infaunal species distributions. In addition to grain size, other proposed causative factors include organic content, microbial content, food supply and trophic interactions (Snelgrove and Butman 1994). This confirms the results of using physico-chemical parameters to provide reasons for the distribution of benthos in this study. The sedimentary grain size did not prove to be as important as the percentage organic content of the sediments, and this was only in combination with a number of other physico-chemical parameters.

7.0 GENERAL DISCUSSION AND CONCLUSIONS

The aims of this chapter are firstly to concatenate the findings of the physico-chemical analyses (Chapter 4), the description of the zoobenthic community structure (Chapter 5) and the results of how the former affects the latter in the Siyaya Estuary (Chapter 6). The second aim is to make some general comparisons with other degraded estuaries in the province, and finally to make some suggestion as to how the findings of this study could be incorporated into other projects that are currently underway in South Africa (the Estuarine Health Index, for example).

The results of the present study have indicated that catchment restoration efforts have had some effect on the state of the Siyaya Estuary, with particular reference to the zoobenthic component. This effect seems to be positive, as there has been an increase in both the number of taxa (37 in 1988 to 59 in 1994) and density of zoobenthos since the first survey was conducted in 1988. Many benthic species that are found in both small, generally closed KwaZulu-Natal estuaries and large systems open to the sea, were also found in this study. This implies that past habitat changes did not necessarily exclude many species, but did limit populations. However, monitoring the effects of catchment rehabilitation alone was difficult due to the prevailing drought conditions. This secondary effect on the Siyaya Estuary introduced other factors into the study, such as freshening of conditions due to the continued closure of the mouth. The response was an increase in the number of freshwater taxa, with a subsequent decrease in the original number of estuarine-associated taxa. Despite this, the estuarine component continues to dominate the zoobenthic fauna and over the three year study period the most dominant taxa throughout the estuary were two estuarine amphipods (*G. lignorum* and *C. triaenonyx*) and a tanaid (*A. digitalis*).

Of all the techniques applied to the data in the present study, the classification and ordination analyses provided the most useful information as to the underlying patterns in community structure. This was particularly relevant to the study, due to the presence of two components in the zoobenthos. The influence of the freshening of conditions was clearly observed in ordinations of species assemblages along the length of the estuary. This was especially so during the latter stages of the study, where freshwater taxa became increasingly aggregated towards each other, suggesting a closer relationship or an increase in the similarity between taxa.

The results of the physico-chemical section of this study emphasised the importance of conducting a detailed survey of such parameters when using them to describe zoobenthos. It was ultimately a combination of several physico-chemical parameters that were responsible for the most variability in the zoobenthic data. That is, turbidity, dissolved oxygen, pH and the percentage organic content within the sediments structured the zoobenthic community of the Siyaya Estuary. The single most important variable responsible for affecting the distribution and abundance of the benthos was pH, second and third in importance were oxygen and turbidity. By looking at the effects of the physico-chemical environment, it was concluded that combinations of variables are important in structuring benthic communities. This is despite the fact that when considered separately, some variables have a greater effect than others in structuring benthic communities. A second recommendation for similar studies is that each system is unique, and therefore subject to a different set of environmental influences. It is only once such a study has been completed, that the important variables and their combinations become apparent. Therefore a pilot study is an important consideration before commencing such a project. For example, if a more detailed water quality study had not been conducted in 1994, the important influence of pH on the benthos would not have been known. The impact of the increasing stands of *P. australis* on the zoobenthos of the estuary can only be speculated. Although it appears as if these areas provide shelter for several macrobenthic species (*C. nilotica* included), it is unknown what effect these reeds may have on tubicolous species like *G. lignorum* and *C. triaenonyx* for example. It is clear that unless some plan is implemented in the near future, the Siyaya Estuary will continue to decrease in depth, and perhaps be divided into areas of shallow pools as dense stands of *P. australis* encroach inwards from the banks into the open water areas.

7.1 Comparison of the Siyaya Estuary with other degraded KwaZulu-Natal estuarine systems

Regional changes to KwaZulu-Natal's estuaries through modifications to catchment basins by poor agricultural and forestry practices have become a serious problem. The smaller estuaries, much more than the larger, are particularly sensitive to environmental change (Reddering and Rust, 1990). The symptoms of degradation are altered river flow, increased flooding, poor water quality, reduced biotic diversity, impaired ecosystem functioning and reduced aesthetic and recreational values (Wiseman and Sowman , 1991). Based on these factors, the majority of KwaZulu-Natal's estuaries are degraded to some degree and are in need of some management operation to restore each to their former conditions.

Blaber, Hay, Cyrus and Martin (1984) compared the ecology of two degraded estuaries on the north coast of South Africa with that of an estuary (Mhlanga) in good condition. That is, one that has been conserved in a relatively natural state. Both degraded estuaries (Tongati and Mdloti) had an impoverished zoobenthic component, dominated by fresh water species and *Prionospio* spp., an estuarine polychaete. Table 7.1 compares the number of different taxa present in the Tongati, Mdloti and Siyaya Estuaries. The Mhlanga Estuary was characterised by an abundant benthic component, with a high species diversity. In comparison to these degraded systems, the Siyaya Estuary has a good species richness, and comparatively high benthic densities. With regards to other estuarine systems in the immediate vicinity of the Siyaya (St Lucia and Mlalazi estuaries), some species are common to all, but the benthos of the Siyaya tends to be more similar to the coastal lakes which also have relict estuarine species present (Boltt, 1969; Day, 1981c; Cyrus and Martin, 1988).

Table 7.1: Comparison of taxonomic groups found in three degraded estuaries on the north coast of KwaZulu-Natal. The presence of these groups in each estuary is marked with an 'X', with the corresponding number of species (if available) in parentheses

Taxa	TONGATI	MDLOTI	SIYAYA
Platyhelminthes			X
Nematoda			X
Hirudinea	X	X	X
Oligochaeta	X	X	X
Polychaeta	X (5)	X (5)	X (8)
Mollusca		X (3)	X (4)
Cladocera			X
Ostracoda			X
Isopoda			X (6)
Amphipoda		X (1)	X (7)
Cumacea			X (1)
Tanaidacea		X (1)	X (1)
Mysidacea			X (4)
Macura	X (1)	X (3)	X (4)
Brachyura	X (1)	X (1)	X (2)
Insecta	X (3)	X (4)	X (45)

A later study concerned with sedimentation in the Mhlanga Estuary was undertaken by Cooper (1989). This system was selected as it was considered to be representative of the numerous small estuaries along this stretch of the coast. The reasons being that most of it's 118 km^2 catchment was under cultivation, the mouth was usually closed to the sea by a sandbar, and it was subject to serious sedimentation with the added problem of *Phragmites* reeds. The conclusions drawn from the study were that the Mhlanga Estuary has shown little morphological change over the past 50 years, suggesting that a state of dynamic equilibrium has now been reached between sediment accumulation when the estuary is closed, and scour when the mouth does open (Cooper, 1989). In Chapter 2 it was mentioned that the sediment yield of the Siyaya Catchment is 100 tons per km^2 per annum (McCormick and Cooper, 1992). Although restoration has only been in progress for the past 15 years (which may be still too early to tell) it is possible that many open/closed estuaries do reach a state of dynamic equilibrium between sediment accumulation and scour during their histories.

In South Africa, reported restoration efforts have mainly taken place in KwaZulu-Natal, with rehabilitation of the Siyaya and Isipingo estuaries involving the restoration of riparian vegetation and wetland systems (Wiseman and Sowman, 1991). The Isipingo situated to the south of the Durban metropolitan area, was originally an area of the finest estuarine and mangrove habitats on the entire KwaZulu-Natal coast (Cooper, 1985). Up to 1952, much of the indigenous vegetation was cleared for sugarcane cultivation, market gardening and township development. Degradation was further accelerated by the construction of the main airport for the city of Durban, and the development of the Prospecton industrial area (Kalicharran and Diab, 1993). The principle issues surrounding the type of degradation taking place in the estuary were inadequate water flow, due to canalisation of streams feeding the estuary, poor water quality entering the Isipingo Estuary as a result of upstream industrial and social effluent, and the impact on the littoral zone (beach and surrounding vegetation) which had already begun at the turn of the century. The ensuing rehabilitation program was devised to incorporate a divided administrative control (municipalities of Durban, Amanzimtoti and Isipingo), as well as short to long-term actions (Kalicharran and Diab, 1993).

Restoration of the Sezela estuary included efforts to recycle industrial waste water, adopting improved effluent treatment methods and the flushing of invasive plants and anoxic sediments to the sea (Ramm, Cerff and Harrison, 1987a). Although a management program was implemented to document degradation that had taken place, this system is unlike other KwaZulu-Natal estuary in that it is relatively unaffected by siltation. This is due to the presence of a dam upstream. Despite this, restoration of the

Sezela is a good indication of the ability of KwaZulu-Natal's coastal systems to respond to positive efforts of integrated restoration management (Ramm, *et. al.*, 1987a).

7.2 The relevance of utilising estuarine zoobenthos as a tool for monitoring catchment rehabilitation

Estimates of benthic macrofaunal community structure may be used to indicate environmental health as they:

1) are relatively sedentary, therefore cannot avoid deteriorating conditions
2) have relatively long life spans (indicate and integrate water/sediment quality conditions)
3) can be classified into functional groups, each exhibiting differing tolerances to stress
4) are important food sources for economically or recreationally important species, and
5) play a significant role in recycling of nutrients and other chemicals between the sediments and water column

(after Dauer, 1993)

Estuarine benthic infauna are very susceptible to fluctuations in their environment because they often are limited in their mobility. However, in any design involving benthos as indicators of environmental health, knowledge of the vertical distribution of macrobenthic species within the sediment is important for understanding population and community dynamics. The vertical position occupied by benthic species can provide information about feeding modes and potential interactions with other species. This same argument may be applied to the effects of different pollutants or environmental change on benthos.

7.3 Incorporation of results into a Community Degradation/Estuarine Health Index

Coastal zone management is often hampered by ineffective collection of multidisciplinary information and, often ineffectual transfer of information from scientist to end-user (Cooper, Ramm and Harrison, 1995). The evaluation, restoration and maintenance of water quality and associated living resources are major goals of environmental management (Dauer, 1993). This author considers the important role of biological criteria as components of water quality standard programmes as :

1. they are direct measures of the state of the biota
2. they may uncover problems not detected or underestimated by other methods
3. they provide some indication as to the progress of restoration efforts

The assumptions made in this study to develop a model were that healthy benthic communities are characterised by high biomass and dominated by long-lived, deep-dwelling species, and high species richness (Dauer, 1993). Species richness is therefore low in areas that are stressed. Community changes from dominance by long-lived equilibrium species in relatively unstressed situations to dominance by short-lived opportunistic species in relatively stressed situations. The basic concept of this model to separate species into **equilibrium** and **opportunistic** species could easily be applied to the benthos of the Siyaya Estuary, given that a database now exists over several years. Species that were present in the initial study could be considered to those which colonised the estuary during it's 'stressed state' (the period of heavy silt deposition).

In South Africa, the **Estuarine Health Index (EHI)**, was developed to incorporate the physical, chemical, biological as well as aesthetic aspects of estuaries into an integrated measure of estuarine health (Cooper *et. al.*, 1995). It also arose out of the need to reduce large data sets for particular areas to a single value (acceptable or unacceptable, in terms of environmental condition). Attempts to collate data in a manner that may be utilised by the end-user, have resulted in developments in various fields, GIS being a good example. In terms of the conceptual basis of the **EHI**, as set out by Cooper *et. al.*, (1995), this study carried out on the Siyaya Estuary, generally fits in well in considering the physico-chemical and biological criteria of the system (Figure 7.1).

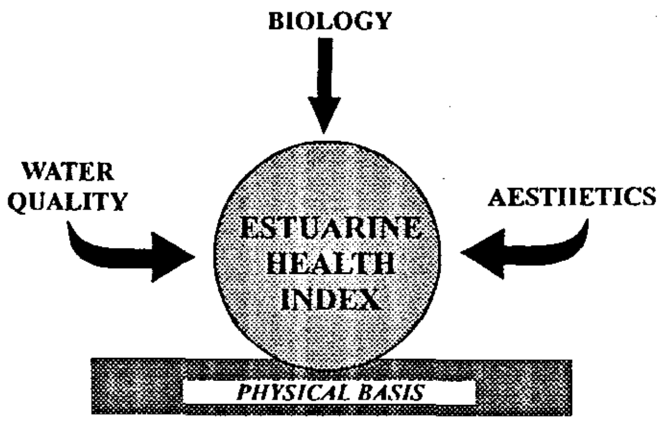


Figure 7.1 Conceptual Model of criteria used as input into the Estuarine Health Index. (After Cooper *et. al.*, 1995).

Based on their physical properties, that is geomorphological characteristics the estuaries in the KwaZulu-Natal province were classified into several groups. The Siyaya Estuary on the basis of its catchment geology and geomorphology could be placed into ***Group 1A***. Cooper *et. al.*, (1995), describe Group 1 estuaries as being small-catchment estuaries, and those in subdivision A, as those having catchments >30 km^2, narrow floodplains, predominantly sand-yielding catchments and are generally closed. However, these workers argue strongly in favour of using fish as the biological input to the Estuarine Health Index. A degradation index for rank ordering KwaZulu-Natal's estuaries was developed six years ago. The objective is to apply a numerical method of ranking community degradation in various systems, to assess and perhaps manage any change that has occurred. The major advantage of this method, is that biological aspects of these aquatic systems are also included, not only aspects of water quality (Ramm, Cerff and Harrison 1987b). In terms of providing an invertebrate faunal biological input, this project on the benthos of the Siyaya could prove to be useful in its contribution to the degradation index database, as well as providing a comprehensive picture of the structure and fluctuation of the benthic community of a small temporarily open/closed estuarine system.

Catchment planning can be a very effective means of achieving conservation objectives but in South Africa there are few examples of successful projects. More projects of this nature will be called for or even demanded in the years ahead. This may only be achieved if there is a strong willingness and co-operation from the landowners themselves. To convince a farming community to implement certain changes that may require modification of their farms, to expend money in bringing about these changes, and to sustain the effort required over a long period of time, is not an easy task. Nevertheless, it is regarded as essential, if soil loss, as the most important single threat to the continued welfare of KwaZulu-Natal's estuaries, is to be controlled.

In the words of Reddering and Rust (1990), "estuaries are natural assets with considerable ecological, aesthetic and recreational value, and are not renewable in short the term". Increasingly, innovative practices will be required to maintain these systems in a viable form and safeguard their natural beauty. The Siyaya Estuary is therefore a system which was once significantly degraded, but for the past 15 years through appropriate management and restoration practices, is well on its way to recovery.

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APPENDIX I

Indices of Richness, Diversity, Dominance and Eveness calculated for samples collected during summer (S), autumn (A), winter (W) and spring (Sp), at each sampling site (1-5) from 1992 - 1994.

MEASUREMENT

Site	Richness *Margalef (1958)*	Diversity *Shannon & Weaver (1963)*	Dominance *Pielou (1986)*	Eveness *Simpson (1949)*
		1992		
S1	3.23	0.624	0.531	0.278
S2	3.46	0.614	0.510	0.299
S3	3.75	0.612	0.487	0.328
S4	4.24	0.667	0.522	0.269
S5	6.06	0.882	0.657	0.225
A1	1.88	0.568	0.629	0.306
A2	2.86	0.199	0.179	0.838
A3	2.90	0.638	0.572	0.259
A4	2.72	0.398	0.369	0.562
A5	2.63	0.587	0.564	0.302
W1	2.53	0.515	0.515	0.368
W2	3.17	0.628	0.548	0.297
W3	1.99	0.620	0.650	0.283
W4	2.56	0.300	0.278	0.657
W5	2.46	0.539	0.518	0.321
Sp1	2.85	0.437	0.392	0.431
Sp2	3.38	0.632	0.537	0.281
Sp3	3.66	0.431	0.350	0.521
Sp4	4.13	0.594	0.474	0.373
Sp5	5.52	0.671	0.486	0.293
		1993		
S1	2.44	0.701	0.735	0.245
S2	2.39	0.590	0.566	0.312
S3	2.95	0.665	0.616	0.299
S4	2.96	0.464	0.430	0.491
S5	3.52	0.667	0.582	0.320
A1	1.88	0.555	0.656	0.373
A2	2.28	0.717	0.717	0.217
A3	2.25	0.388	0.388	0.576
A4	1.79	0.321	0.356	0.668
A5	2.91	0.595	0.571	0.344
W1	3.38	0.697	0.646	0.258
W2	2.85	0.635	0.570	0.307
W3	2.29	0.490	0.490	0.466
W4	3.09	0.461	0.402	0.504
W5	2.70	0.647	0.600	0.269
Sp1	2.97	0.747	0.717	0.219
Sp2	2.77	0.752	0.697	0.220
Sp3	2.56	0.482	0.463	0.464
Sp4	1.69	0.452	0.500	0.423
Sp5	1.92	0.585	0.614	0.300

cont.