

**A STUDY OF THE RELATIONSHIP BETWEEN  
ENVIRONMENTAL CONDITIONS AND SALT MARSH  
ZONATION AT LANGEBAAN LAGOON.**

**A dissertation submitted to the Faculty of Arts in candidacy for the  
degree of Master of Arts.**

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## **Abstract**

This study is aimed at elucidating and providing some understanding of the underlying causal processes that generate patterns in the salt marsh communities of Langebaan Lagoon. The study area forms part of the West Coast National Park and is the largest tract of salt marsh in South Africa. An overview of the current literature on salt marsh ecology is discussed and a synopsis of local research of salt marshes is presented. The general nature of the study site is described in historical, geological, hydrological and ecological context.

The zonation of the plant communities is a distinctive feature of the salt marshes at Langebaan. To establish the nature of this zonation and to achieve the stated objectives, transects were established at three sites around the lagoon. The vegetation was accurately surveyed using a continuous quadrat system to measure the apparent zonation. Sample sites were allocated to the transects and soil cores were extracted for the testing of a comprehensive range of edaphic factors. The results of these tests are graphically displayed to demonstrate the existence of environmental gradients, and these gradients are then linked to specific species which represent the various zones. In this manner, associations between the species and environment could be ascertained. The species and environmental data were subjected to canonical correspondence analysis, a powerful ordination technique in an attempt to unravel and illuminate the complex relationships in the species-environment.

Clear vegetation zonation was confirmed for all three transects and distinct gradients of many environmental variables were established. From these analyses, certain edaphic factors, such as tidal inundation, salinity and to a lesser degree soil texture, appeared to exert considerable influence on species distributions. The patterns of zonation appears to be

appears to be cryptically related to the range of environmental parameters measured in this study. The overall relationship between salt marsh species and the tested environmental variables remains largely unaccountable at the species level and is better understood at the wider scale of upper, middle and lower marsh. The results show that remarkable seasonal stability exists in each of the transects. Evidence of inconsistencies in this study show that factors other than those examined here also influence zonation patterns. Biotic factors such as inter-species competition, succession, resilience and disturbance are factors that would explain transitions in the zones that are not immediately apparent from environmental gradients. It is suggested in the light of the findings of this research, that, further research, should concentrate on the biotic component of the salt marshes as this is essential if a greater understanding of the complex biophysical relationship is to be attained. Appropriate management can only be applied to salt marshes once the processes that govern them are better understood.

## **Acknowledgements**

I would like to thank my thesis supervisor Associate Professor M.E. Meadows for the support, advice and considerable time that he has dedicated to this study. I am also indebted to Dr M. O'Callaghan for sharing his knowledge on salt marshes and for the many hours spent helping me with the statistics. Furthermore I am also grateful to the following people: My brothers, Messrs. Brent and Rory Reaper for their computer expertise; Mr Julian Smit for his professional assistance during the survey; The National Parks Board at Langebaan for permission to undertake this study; Mr G. Thompson for the soil chemical analysis; the Zoology Dept. at UCT for the nutrient analysis and accommodation at Langebaan. Finally, thanks to all the friends who gave up their time to assist during the fieldwork.

## **Dedication**

This thesis is dedicated to my wife Colleen and my parents Desmond and Mary, whose consistent love and support has enabled me to complete this study.

# Contents:

Abstract	i
Acknowledgements	iii
Dedication	iv
Contents	v
List of figures	viii
List of tables	xi
Chapter 1 Introduction	1
1.1 Introduction to the project	1
1.2 Problem statement, aim and objectives	5
Chapter 2 An introduction to the ecology of salt marshes	7
2.1 Introduction and approach	7
2.2 Salt marshes: - a global perspective	8
2.3 Contemporary themes in salt marsh study programs	13
2.3.1 Tidal inundation	15
2.3.2 Salinity	18
2.3.3 Soil moisture (waterlogging)	20
2.3.4 Nutrient limitation	22
2.3.5 Succession and interspecific competition	26
2.3.6 Disturbance and resilience	30
2.3.7 Evolutionary adaptation	33
2.4 Saltmarsh research in South Africa	38
Chapter 3 The study site	42
3.1 Rational for choice of site	42
3.2 Site location, description and historical development	44
3.3 Physiographical features	48
3.3.1 Climate	49
3.3.2 Geology and geomorphology	51
3.3.3 The lagoon (Physical and hydrological characteristics)	53
3.4 Local ecology	56
3.5 Vegetation	58
Chapter 4 Methodology	61
4.1 Introduction	61
4.2 Vegetation analysis and soil sampling	62
4.2.1 Vegetation survey	62
4.2.2 Soil sampling	66
4.3 Soil analysis	70

4.3.1 Sample preparation	70
4.3.2 Nitrate, nitrite and phosphate determination	71
4.3.3 Soil moisture content	72
4.3.4 Soil organic matter determination	72
4.3.5 Conductivity, pH and soil nutrient (trace element) determination	73
4.3.6 Soil texture analysis	76
4.3.7 Transect height and position survey	78
4.3.8 Analysis of results	79
<b>Chapter 5 Presentation of Results</b>	<b>82</b>
5.1 Introduction	82
5.2 The occurrence and organisation of salt marshes species	83
5.2.1 Oostewal	83
5.2.2 Geelbek	89
5.2.3 Schrywershoek	95
5.2.4 Continuity and seasonal variation	100
5.3. Trends in the environmental parameters	101
5.3.1 Oostewal	102
5.3.2 Geelbek	107
5.3.3 Schrywershoek	112
5.3.4 Oostewal: Variation in environmental gradients over time	117
5.4 Relationships between salt marsh species and environmental parameters	127
5.4.1 Oostewal	128
5.4.2 Geelbek	133
5.4.3 Schrywershoek	138
5.4.4 Oostewal: Variation in environmental parameters per species over time.	143
5.4.5 Overview	150
5.5 The relationship between soil texture and species occurrence.	151
5.5.1 Oostewal	152
5.5.2 Geelbek	155
5.5.3 Schrywershoek	157
5.5.4 Overview of the sediment characteristics in all transects.	159
5.6 Canonical correspondence analysis	160
5.6.1 Oostewal	162
5.6.2 Geelbek	165
5.6.3 Schrywershoek	167
5.6.4 Oostewal: Variation over time	170
5.6.5 Ordination of the texture analysis	173
<b>Chapter 6 Discussion and conclusion</b>	<b>180</b>
6.1 Review of objectives	180
6.2 Vegetation - environment relationships	184
6.3 Implication for conservation	188
6.4 Conclusions	189

<b>References</b>	<b>191</b>
<b>Appendices:</b>	<b>199</b>
<b>A: Table of species found in the three transects and associated species numbers</b>	<b>200</b>
<b>B: Species cover and position within the transects</b>	<b>201</b>
<b>C: Species ranking, allocation of soil samples and transect summary data</b>	<b>207</b>
<b>D: Environmental data</b>	<b>210</b>
<b>E: Soil texture data</b>	<b>215</b>
<b>F: Summaries of survey data</b>	<b>218</b>
<b>G: Summaries of Statistical analysis</b>	<b>223</b>

# List of figures

	Page:
Figure 1.1:	Location of the study site (after O'Callaghan 1993) 3
Figure 2.1:	World distribution of salt marshes (Long & Mason 1983) 10
Figure 3.1:	Access and proximity of the study site to Cape Town 45
Figure 3.2:	Localised map of Langebaan Lagoon and surrounding farms 47
Figure 3.3:	Precipitation in the study area (Flemming 1977) 49
Figure 3.4:	Average wind conditions at Langebaan Lagoon (Schulze 1965) 50
Figure 3.5:	Local geology (after Flemming 1977) 52
Figure 5.1:	The distribution and cover (%) of plant species at Oostewal 85
Figure 5.2:	Oostewal species cover and position area chart 86
Figure 5.3:	Oostewal species cover and position (3D) 87
Figure 5.4:	Oostewal species cover and position (3D AREA) 88
Figure 5.5:	The distribution and cover (%) of plant species at Geelbek 91
Figure 5.6:	Geelbek species cover and position area chart 92
Figure 5.7:	Geelbek species cover and position (3D) 93
Figure 5.8:	Geelbek species cover and position (3D AREA) 94
Figure 5.9:	The distribution and cover (%) of plant species at Schrywershoek 96
Figure 5.10:	Schrywershoek species cover and position area chart 97
Figure 5.11:	Schrywershoek species cover and position (3D) 98
Figure 5.12:	Schrywershoek species cover and position (3D AREA) 99
Figure 5.13:	Oostewal soil analysis results (sample session 1) 103
Figure 5.14:	Oostewal soil analysis results (sample session 1) 104
Figure 5.15:	Oostewal soil analysis results (sample session 1) 105
Figure 5.16:	Oostewal soil analysis results (sample session 1) 106
Figure 5.17:	Geelbek soil analysis results 108
Figure 5.18:	Geelbek soil analysis results 109
Figure 5.19:	Geelbek soil analysis results 110
Figure 5.20:	Geelbek soil analysis results 111
Figure 5.21:	Schrywershoek soil analysis results 113
Figure 5.22:	Schrywershoek soil analysis results 114
Figure 5.23:	Schrywershoek soil analysis results 115

Figure 5.24:	Schrywershoek soil analysis results	116
Figure 5.25:	Oostewal soil analysis results (sample session 2)	118
Figure 5.26:	Oostewal soil analysis results (sample session 2)	119
Figure 5.27:	Oostewal soil analysis results (sample session 2)	120
Figure 5.28:	Oostewal soil analysis results (sample session 2)	121
Figure 5.29:	Oostewal soil analysis results (sample session 3)	122
Figure 5.30:	Oostewal soil analysis results (sample session 3)	123
Figure 5.31:	Oostewal soil analysis results (sample session 3)	124
Figure 5.32:	Oostewal soil analysis results (sample session 3)	125
Figure 5.33:	Oostewal species grouping per environmental parameter	129
Figure 5.34:	Oostewal species grouping per environmental parameter	130
Figure 5.35:	Oostewal species grouping per environmental parameter	131
Figure 5.36:	Oostewal species grouping per environmental parameter	132
Figure 5.37:	Geelbek species grouping per environmental parameter	134
Figure 5.38:	Geelbek species grouping per environmental parameter	135
Figure 5.39:	Geelbek species grouping per environmental parameter	136
Figure 5.40:	Geelbek species grouping per environmental parameter	137
Figure 5.41:	Schrywershoek species grouping per environmental parameter	139
Figure 5.42:	Schrywershoek species grouping per environmental parameter	140
Figure 5.43:	Schrywershoek species grouping per environmental parameter	141
Figure 5.44:	Schrywershoek species grouping per environmental parameter	142
Figure 5.45:	Oostewal species grouping per environmental parameter (session 2)	144
Figure 5.46:	Oostewal species grouping per environmental parameter (session 2)	145
Figure 5.47:	Oostewal species grouping per environmental parameter (session 2)	146
Figure 5.48:	Oostewal species grouping per environmental parameter (session 3)	147
Figure 5.49:	Oostewal species grouping per environmental parameter (session 3)	148
Figure 5.50:	Oostewal species grouping per environmental parameter (session 3)	149
Figure 5.51:	Oostewal soil texture results	153
Figure 5.52:	Oostewal soil texture results	154
Figure 5.53:	Geelbek soil texture results	156
Figure 5.54:	Schrywershoek soil texture results	158
Figure 5.55:	Oostewal - Biplot of environmental variables and species	163
Figure 5.56:	Geelbek - Biplot of environmental variables and species	166

Figure 5.57:	Schrywershoek - Biplot of environmental variables and species	168
Figure 5.58:	Oostewal - (sample session 2) biplot of environmental variables and species	171
Figure 5.59:	Oostewal - (sample session 3) biplot of environmental variables and species	172
Figure 5.60:	Oostewal - (sediment analysis) biplot of environmental variables and species	174
Figure 5.61:	Geelbek - (sediment analysis) biplot of environmental variables and species	175
Figure 5.62:	Schrywershoek - (sediment analysis) biplot of environmental variables and species	177

## List of tables

	Page:
Table 1: Seasonal salinity ranges in selected parts of Langebaan Lagoon (Flemming 1977)	55
Table 2: Elements measured in the saturated water extract	74
Table 3: Elements measured in the citric acid extract	74
Table 4: Sieve aperture sizes	77
Table 5: Class terms and particle diameters (after Wentworth 1922)	77
Table 6: Species found in the three transects and associated species numbers	200
Table 7: Oostewal:- Species ranking, allocation of soil samples	207
Table 8: Oostewal:- Summary information	207
Table 9: Geelbek:- Species ranking and allocation of soil samples	208
Table 10: Geelbek:- Summary information	208
Table 11: Schrywershoek:- Species ranking and allocation of soil samples	208
Table 12: Schrywershoek:- Summary information	209

# **Chapter 1 Introduction**

## **1.1 Introduction to the project**

Coastal salt marshes are an important component in the ecological web of estuaries and marine lagoons. They form the primary basis of a highly productive ecosystem. Wetlands occupy 0.4% of the world's area yet they produce 2.3% of the world's net productivity (Lieth and Whittaker 1975). In terms of grams produced per annum only tropical rain forests equal the net productivity yield of salt marshes (Reimold 1977). Water interacting with salt marshes due to tidal flow becomes nutrient enriched with detrital particles, derived from the breakdown of litter found within the marsh. These nutrients then provide the fuel for sustaining a dense invertebrate fauna that is found in the substrate of tidal flats which in turn supports wading avifauna and inshore breeding fish stocks. Salt marshes also stabilise and protect areas subject to erosion. They bind the sediment with root systems, while shoots decrease flow and wave energy.

The degradation of salt marshes through pollution, and development has been shown to have a direct influence on the well being of humankind, both in the aesthetic and economic sense. This has resulted in increasing attention being focused on the management of these natural resources. Prior to management proposals being formulated, a fundamental understanding of the processes governing the development, growth and maintenance of salt marshes has to be established. In South Africa relatively little research on salt marshes has been conducted when considering the work done in Europe and North America. When making such comparisons it should be borne in mind that the United States Of America has

approximately 3.2 million hectares of salt marsh (Teal 1962) and Britain some 40 500 hectares (Ranwell 1972) while South Africa has some 17 000 hectares (O'Callaghan 1993). While South Africa has considerably less than the aforementioned examples this does not negate the need for research in this field when viewed in global climatic context. On the contrary, the physical position of Southern Africa in the dry Sub-Tropical High Pressure Belts, mean that salt marshes are a relatively scarce resource. The rainfall is low (average 500 mm) and there are few perennial rivers and therefore relatively few estuaries.

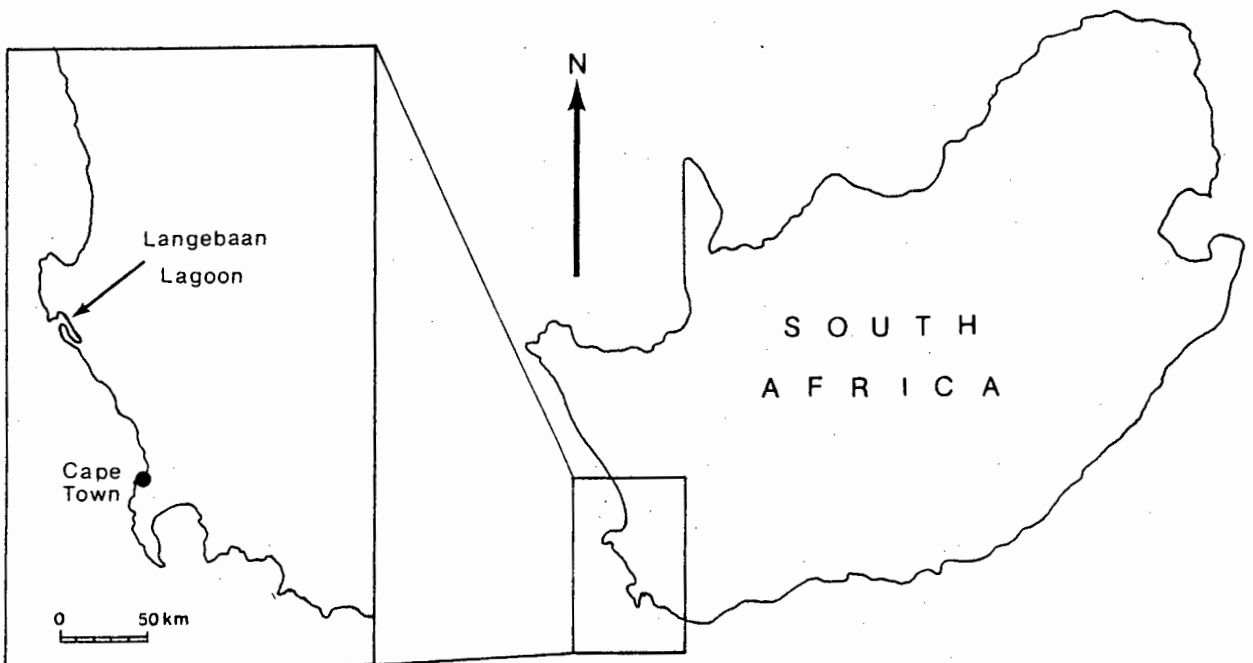
In South Africa coastal salt marshes are only associated with estuaries. Estuaries and their associated wetlands are under constant pressure from expanding industrial, agriculture and residential development. Great pressure comes from the increasing demand for recreational development and water extraction. Salt marshes are ideal sites for any such developments being relatively level, easily stabilised and reclaimed by infilling. The past two decades have seen the development of various coastal studies in both the Cape Province and Natal. The Begg (1978) reports on the Natal estuaries were undertaken under the auspices of the Natal Town and Regional Planning Commission. Reports on Cape estuaries have been conducted by the Estuarine and Coastal Research Unit (E.C.R.U.) which was established by the National Research Institute For Oceanography (N.R.I.O.) in 1979 (Heydoorn & Tinley 1980).

The E.C.R.U. reports are largely descriptive in nature, helping to provide a synthesis on available knowledge of various estuarine systems. These surveys highlight the various dynamic components that make up estuarine systems. These components can essentially be divided into two major categories:

- (1) Abiotic characteristics (e.g. hydrology, catchment characteristics, geology, geomorphology, pollution, and estuarine dynamics).
- (2) Biotic characteristics (e.g. Flora and fauna).

This project combines both these categories in an attempt to elucidate any relationships that may occur between them. Hence an attempt is made to break away from a purely descriptive account of the occurrence of saltmarsh plant species. Instead, the emphasis is on the analysis of the dynamics and mechanics of environmental gradients to provide an understanding and explanation of the distribution of saltmarsh flora.

This study was undertaken on the salt marshes of Langebaan Lagoon, a shallow marine lagoon extending Southwards from Saldanha Bay on the West coast of South Africa. (See Figure 1.1). A site description and justification for choice thereof are fully dealt with in Chapter 3 of this report.



**Figure 1.1: Location of the study site**  
(after O'Callaghan 1993).

The study attempts to avoid a 'one-off' static approach to environmental conditions by monitoring select environmental changes over a period of one year. In this way it was hoped to show trends and fluctuations in these conditions caused by seasonal change. The major thrust of this study is to understand the influence of a select number of environmental conditions on the arrangement and structure of the Langebaan salt marsh. At the same time the study also aims to provide a basis for the monitoring of these salt marshes in the future. At present the Langebaan lagoon and its immediate surroundings all fall within the West Coast National Park and are thus under the mindful auspices of the South African National Parks Board. This means that an ecological system that has been classified as a wetland of international importance (in terms of the Ramsar Convention of 1985) and today enjoys the kind of protection that should assure its ecological integrity in the future.

The majority of the fieldwork and laboratory research for this project was conducted during the late 1980's, with the statistical analysis, levelling and write up taking place on a part-time basis in 1994/95. It is hoped that the research under taken here will contribute not only to a greater understanding of the Langebaan lagoon salt marshes, but also in the long - term, a better monitoring and management of this tremendous ecological asset to assure its survival for future generations

## **1.2 Problem statement, aim and objectives**

The most striking feature of salt marsh vegetation is its arrangement into distinct, continuous bands or zones. These zones are characteristic of salt marshes throughout the world (Ranwell, 1972; Chapman, 1974; Vince & Snow, 1984;). Closer examination usually reveals that each zone is occupied by one or more dominant species which gives it a distinct appearance in terms of height, colour and texture.

The aim of this study is to elucidate and provide some understanding of the underlying causal processes that generate patterns in the salt marsh communities of the Langebaan lagoon.

The objectives of this study:

- 1) Establish the nature of zonation at Langebaan.
- 2) Determine the extent and continuity of plant zonation throughout the salt marsh system at Langebaan.
- 3) Determine if environmental gradients can be detected in the salt marshes.
- 4) Establish if there is any association between plant zonation and environmental gradients
- 5) Determine whether levels in the environmental variables are the same for similar plant species in different locations within the salt marsh system.
- 6) Identify any seasonal variation in the environmental gradients and corresponding vegetation.

7) Determine the extent of influence and significance of environmental factors on salt marsh vegetation patterns.

Overall this research is aimed to provide information and data on these salt marshes. This should provide a greater understanding of the complex nature of the ecological interactions governing these salt marshes. This work is also intended to serve as a reference for comparative studies and provide baseline data which may aid future management of this resource.

## **Chapter 2      An introduction to the ecology of salt marshes**

### **2.1 Introduction and approach**

The purpose of this section is to provide a broad overview of the various theoretical standpoints which are reflected in the literature of salt marsh studies. The objective here is to provide a comprehensive theoretical background to this study and a unified theoretical basis from which the experimental work will extend. The review of literature is comprehensive and contemporary. As relatively little experimental salt marsh research has been undertaken in South Africa to date, by far the greater proportion of this overview concentrates on work done in the Northern countries.

As with any other ecological field, salt marsh research has developed into a highly specialised science over the past sixty years. From the largely descriptive accounts of floristic pattern by Chapman (1938) and Tansley (1939), salt marsh research has grown into a holistic integrated field. In the 1960's and 1970's, research concentrate on edaphic environmental factors as the causal mechanism of zonation. Sen and Rajpurohit (1982) point out that the ecology of halophytes has a broad appeal to many disciplines. These cover fields as widely diverse as climatology, soil science, phytogeography, adaptive biology and agriculture. Literature shows that ecologists study these plants to gain greater insight into estuarine ecosystems, biology of dominant genera, germination ecology, water relations, salt excretion and senescence. In the eighties and nineties some researchers (Roozen & Westhoff 1985; Bertness et al. 1987; Bertness 1991; Orson & Howes, 1992) became disillusioned with the focus on edaphic causal mechanisms and this led to the more recent

examination of the role of species competition, community structure disturbance and dispersal mechanisms.

As in any study it is always important to take cognisance of the scale at which the study is undertaken. Chapman (1974) examined and classified salt marshes on a global scale providing a broad description of salt marshes and their global distribution.) Some studies have concentrated on a regional scale often comparing salt marshes within a similar climatic region or country (Adam 1981; Ayyad & El-Ghareeb 1982; Corre 1985; Partridge & Wilson 1988) Most in-depth studies are however undertaken on a much smaller scale often only considering a single tract of salt marsh (Eleuterius & Eleuterius 1979; Armstrong et al 1985; Beeftink 1985 b ; Rozema et al. 1985 b; Vevle 1985; Zedler 1986).

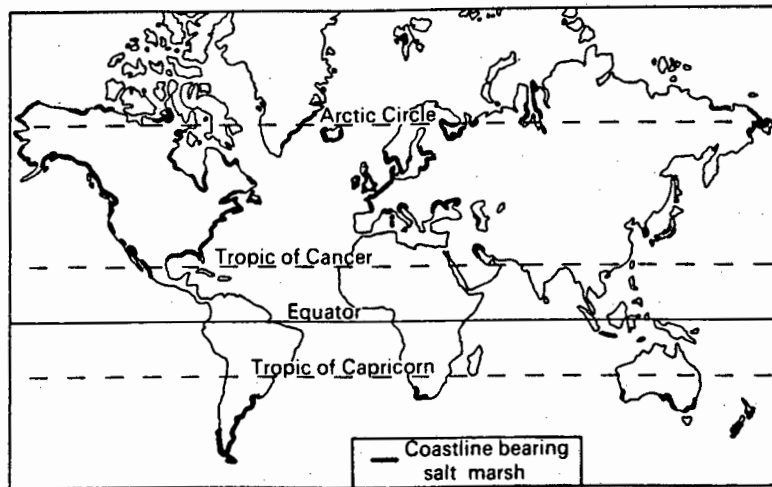
## **2.2 Salt marshes:- a global perspective**

Broadly speaking, halophytic (salt-adapted) plants occur either where terrestrial soils and marine sediments meet (coastlines) or in highly evaporative environments where salt precipitation occurs (deserts). They are found between the extremes of the supralittoral and the upper littoral zone, where salinities vary between  $>38\text{‰}$  to  $5\text{‰}$  (Long & Mason 1983). Halophytes can be found in two major coastal community types - salt marshes, which are found mainly in the temperate to sub-polar climates, and mangrove swamps, which are found in the tropics and subtropics (Boaden & Seed 1985; Meadows 1985). Salt marshes are bound to low energy coastlines often restricted to sheltered areas, where the relatively low activity of wind and wave energy permits the accretion of silt (Pethick 1984). No

matter where in the world salt marshes are found they have certain similarities in appearance and species composition (Ranwell 1972).

Given the climatic zones and coastal requirements of salt marshes it, follows that the distribution of the plants depends on the chance factors of migration or introduction. The northern and southern limits of salt marsh occurrence differs from continent to continent and coastline to coastline due to local variations in climate. For instance, the positive and negative anomalies brought about by the influence of polar or equator bound currents cause large differences in average temperature between places on the same latitude. Accurately estimating the climatic limits of a plant species on a global scale is very difficult. There has been no accurate mapping of the coverage of the world's salt marshes and therefore no accurate measurement of total area of this habitat exists (Long and Mason 1983).

Figure 2.1 shows the approximate distribution of salt marshes on a global scale. Salt marshes occur between  $\pm 26^{\circ}\text{S}$  and  $56^{\circ}\text{S}$  in the southern hemisphere and in the northern hemisphere between  $\pm 22^{\circ}\text{N}$  and  $70^{\circ}\text{N}$ . On coasts with a high rainfall, landward penetration is usually limited. On coasts of low rainfall or extreme seasonal drought, salt marshes extend further landward (Beefink 1979) Frost damage appears to be the major factor determining the limits of mangroves. The factors determining salt marsh distribution are less clear, but include length of day, frost frequency, rainfall and temperature (Ranwell 1972).



**Figure 2.1** World distribution of salt marshes, Long and Mason (1983)

Chapman (1974) distinguishes nine major regional salt marsh floristic types adapted to the specific climates in which they occur. These are:

- Arctic
- North European
- Mediterranean
- Eastern North America
- Western North America
- Chinese, Japanese and Pacific Siberian
- South American
- Tropical
- Australia and New Zealand

These are loosely based associations. Each group has characteristic species which impart a degree of inherent similarity to the group as a whole. Chapman (1974) is still the only researcher to have examined salt marshes on a truly global scale.

The majority of research has taken place on a regional or local scale. At the regional scale, differences are noticeable within areas covered by salt marsh. These stem from differences in climate, land form, conditions of salinity and tidal range. A prerequisite for salt marsh development is a protected section of coastline, this protection is often afforded by physical features. It is these dominant physical features which Beefink (1977) used for the basis of a classification system for salt marsh types. These are: 1) lagoonal, 2) beach plain, 3) polderland (artificial), 4) estuarine, 5) Wadden / barrier island, 6) bog / peat. To these six types Westhoff (1985) adds a seventh, the cliff top type, found on the flat tops of cliffs which are inundated with salt spray. A full description of each type can be found in Beefink (1977) and Long & Mason (1983). A brief outline of the lagoonal type is necessary for this research as the salt marshes at Langebaan fall into this category.

Lagoonal marshes may occur where a spit or peninsula partially encloses a body of tidal water with only a narrow connection to the sea. This restricted contact with the open ocean causes a considerable decrease in wave energy and also reduces tidal amplitude. Langebaan and the Knysna Lagoon in South Africa are prime examples of this salt marsh type. The alluvial substrates of salt marshes vary considerably due to the variety of sediment from marine and estuarine sources. In colder climates, where the supply of organic material exceeds breakdown and removal, salt marshes often develop on organic - rich peatland sediments (Hemond & Chen 1990). Along the coasts of Britain, France and the Baltic lands, shingle is frequently a dominant building component of salt marshes (Randall 1977). The texture of salt marsh soils can vary widely from coarse sands to very fine clays (Pethick 1984).

The majority of research on salt marshes has been conducted on tidal salt marshes, obviously strongly linked to marine influences. Salt marsh vegetation is also to be found in non tidal environments. Inland saline's are a typical part of arid and semi-arid regions. They occur mostly on fossil salt deposits, or around salty springs. Inland salt marshes and salt pans develop in the seepage basins of deserts and sites with a basin shaped topography into which saline waters flow from surrounds or as a result of a rise in saline underground water. Salinities and the types of salts in these habitats vary widely. The halophytes found growing around these inland salt marshes have the same biogeography and floristic composition as maritime salt marshes. Despite the lack of tidal influence, zonation is strongly evident as a result of a salinity gradients in the soils surrounding these salt water bodies. (Ayyad & El - Ghareeb 1982; Zahran 1982).

World wide the flora of salt marshes is restricted to a few genera which form part of a group of vascular plants commonly known as salt marsh plants or halophytes. It needs to be pointed out that salt marsh vegetation is not solely composed of halophytes but often contains a number of more widespread species. The most common salt marsh genera are:- *Salicornia and Sarcocornia* (glassworts or marsh samphires), *Limonium* (sea lavenders), *Plantago* (plantains), *Spartina* (sea / cord grasses) and *Juncus* (rushes) (Chapman 1974). How these genera position themselves on a salt marsh depends largely on the conditions of the marsh involved. In Britain the cord grasses are found on the lower extremes; the glassworts, sea lavenders, plantains are found on the middle to upper marsh and the rushes are found predominantly on the upper marsh (Adam 1981)

In all vegetation types the pattern of variation in community composition is essentially continuous. For practical purposes it is often necessary to impose a classification system

upon the variation. Early salt marsh research often involved classification of communities by dominance as was suggested by Tansley (1949). Adam (1981) criticises this approach as it only works well in communities which are represented by pure stands of a single species. The dominance emphasis means that the minor floristic components are practically ignored. Adam (1981) suggests the use of a Braun - Blanquet method of approach to plant sociology. In this approach, groups are distinguished according to full species composition with no emphasis on dominance.

Salt marsh plants in the lowest part of the marsh begin to colonise areas between the tidal levels of mean high water neap (MHWN) and mean high water (MHW). Any plants occurring below this are considered to be truly marine and are usually excluded from the salt marsh vegetation proper (Chapman 1974). The eelgrass *Zostera* is thus often not considered to be a true salt marsh plant, even though it may be found interspersed with true salt marsh plants which dominate the lowest section of the marsh. The upper limit of the salt marsh is found where saline influences are reduced to the extent that glycophytes become dominant. This upper limit is found normally between the levels mean high water spring (MHWS) and extreme high water of springs (EHWS) (Beefink 1977).

### **2.3 Contemporary themes in salt marsh study programs**

One of the objectives of plant ecology is to understand why plant communities occupy certain regions and not others. The idea is to try and understand the processes that generate distribution patterns in natural communities. There is a strong biogeographical element here, as the elements of space and time become central to any such discussion.

Salt marshes provide an excellent opportunity for the examination of all aspects of plant community relationships. Low species diversity and high species consistency presents an important challenge for research. The strong zonation which is a general characteristic of most salt marshes throughout the world is indicative of a small and consequently sharp ecotone (area of transition) between the various species within salt marshes.(Chapman 1974). Not surprisingly this zonation can easily be assumed to correspond with a sudden change in the environmental gradient. However, literature shows that on such a gradient there are a multitude of factors operating in any salt marsh (Vince & Snow 1984; Roozen & Westhoff 1985; Pennings & Callaway 1992). This makes the understanding of salt marsh zonation a somewhat complex issue. The simple appearance of salt marshes communities belies the intricate nature of the environmental gradients. Not surprisingly, a fully integrated understanding of the processes which interact to govern patterns in salt marshes has yet to be achieved.

From a general survey of salt marsh literature it appears as if most researchers are in agreement on the types of environmental factors which govern the distribution of salt marshes and the species which are found within them.

Essentially these factors include:

- 1) Tidal inundation
- 2) Salinity (both soil and water)
- 3) Soil moisture (waterlogging)
- 4) Nutrient limitation
- 5) Succession and interspecific competition
- 6) Disturbance
- 7) Evolutionary adaptation

An overview of the research done around these factors is essential to an understanding of salt marsh ecosystem dynamics. It should be pointed out from the onset that no one environmental factor can ever be regarded as totally responsible for salt marsh plant zonation. The factors which may apply to a particular marsh may or may not apply to other salt marshes, each is unique in their own environmental circumstances (Rozema et al. 1985a; Pennings & Callaway 1992). Each of these environmental factors will need to be examined if an understanding of their role and relative importance is to be gained

### ***2.3.1 Tidal inundation***

Chapman (1974) describes the tide as the “master factor” in the distribution of salt marsh plants. Most of the above mentioned environmental factors show some sort of relationship to tidal inundation and hence slope and elevation (Zedler 1977; Eleuterius & Eleuterius 1979).

The response of marine organisms to tidal fluctuations is well documented (Connell 1961; Stephenson & Stephenson 1972; Branch & Branch 1981). The zonation of marine organisms in the inter-tidal ecotone is mainly determined by their ability to resist desiccation. For the terrestrial plants in the salt marsh the reverse is true. The plants ability to survive inundation by salt water becomes the major determinant of zonation. Pennings & Callaway (1992) find that soil characteristics in coastal salt marshes generally show gradients from low to high marsh that correspond with elevation and frequency of tidal inundation. Populations of salt marsh plants typically form distinct and predictable zones

when superimposed on these gradients (Nixon 1980; Vince & Snow 1984; Olf et al. 1988). Experiments have shown that the success and productivity of many salt marsh species depends on their tolerance to tidal inundation (Mahall and Park 1976).

Olf et al. (1988) examined the effect of tidal inundation frequencies on salt marsh vegetation on a salt marsh in the West Frisian Islands in the Netherlands. Correlation's between annual changes in the cover of major species and fluctuations in the monthly frequency of inundation by sea water were examined. They found that both elevation and season influence inundation frequency and variation in plant cover.

Salt marshes and their associated zonation can be linked to inundation, just how strongly this link exists is not straight forward. It appears that in some salt marshes the relationship between inundation and zonation is a strong one (Niering & Warren 1980; Bertness 1991a). These are usually salt marshes that have a marked slope. The converse seems to be the case for the gently sloping salt marsh. Here it appears that there is little evidence of a strong correlation between zonation and tidal inundation (Snow & Vince 1984, Rozema et al. 1985b). Here zonation tends to become less distinct. Adam (1981) found that, in British salt marshes, zonation tended to be better developed in areas with a large tidal range. In areas with a small tidal, range plant communities tended to be arranged in mosaics rather than distinct zonal bands. He also concludes that the visual distinctiveness of zones (sharpness of the ecotone) depended largely on the gradient of the marsh surface, such that the steeper salt marsh exhibited a more marked ecotone than the gently sloped salt marsh.

The association between inundation and salt marsh vegetation pattern has led to a generally accepted division of the marsh into three major zones. Upper, middle and lower marsh are the most common distinctions (Long and Mason, 1983). The boundaries of these zones are based on relative rather than absolute height (Niering & Warren 1980, Adam 1981). The relative tidal height (i.e. to that site) is more applicable in salt marsh community studies because there is a greater tendency for similar salt marsh species to be found around a locally established high tide mark rather than the nationally established 1.5 m above mean sea level. The reason for this is that frequency and duration of tides vary in different locations according to local factors, such as wind direction, storms, currents and local hydrology. These broadly defined units may not be strongly correlated to distinctive plant boundaries, although it does provide a rough framework of broad groupings of plants for general discussion purposes.

Due to excessive inundation, the lower part of a salt marsh is often considered to be a more stressful environment for vascular plants to grow in. The upper marsh may be a relatively less stressful environment for vascular plants, as it is less affected by inundation. Pennings & Callaway (1992) point out that this may not hold true for all salt marshes. In temperate regions, salt marshes in Mediterranean climates are different. They find that salt marshes in a Mediterranean - climate do not exhibit a simple monotonic gradient of severity of physical factors across marsh elevations. In the summer drought months, conditions in the upper marsh can become hyper-saline. This is due to high evaporation rates, making conditions in this section of the marsh more difficult for plants to survive in, than the lower elevations. Lack of inundation can cause salinity to become a more important factor in salt marsh zonation than inundation in certain climates.

### 2.3.2 Salinity

Salinity is the degree of saltiness of water and is defined as the total amount of dissolved solids in water in parts per thousand (‰) by weight (Hale & Margham 1988). There is a strong link between salinity and tidal inundation (Chapman 1938). Salt marsh plants (halophytes) are able to survive in areas where non-saline plants (glycophytes) cannot survive. In coastal locations the former plant group replaces the latter where the inundating water exceeds an average salt concentration of  $5 \text{ g l}^{-1}$  (Long & Mason 1982).

The saline environment of coastal salt marshes is maintained mainly through twice daily submergence by sea water. The salinity of this water is not constant due to seasonal variation in the input of fresh water and evaporation rates. In estuaries, salt marshes also experience varying water salinities due to differences in the mixing ratios of sea and river water. Biological and mechanical composition of the soil can also affect salinity as organisms living in the soil can greatly influence the rate at which water penetrates the substrate and evapotranspiration by salt marsh plants has the effect of concentrating salts in the soil. Similarly the composition of the soil (coarse or fine particle size) will determine the rate at which salts will leach downwards. (Smart & Barko 1978; Long & Mason 1983).

Another source of salt affecting salt marshes is that which is brought in by wind. Sea spray has a profound effect on the salinity of salt marshes (Ranwell 1972, Rozema et al. 1982). The aerial parts of salt marsh plants become salt encrusted due to sea spray. Rozema et al. (1982) calculate that salt spray deposition on the upper parts of salt marshes in North - Holland amounts to  $150 \text{ kg NaCl ha}^{-1}$  per year.

Salt brought in by tides and wind will ultimately result in higher salt concentrations in salt marsh soils. Sea water contains many salts which are the product of the weathering of rock material. The dominating ions are Na and Cl and these have attracted the most attention in salt marsh studies (Chapman 1974; Sen & Rajpurohit 1982). Many other ions (Ca, K, Mg, B and Mn) have a much higher concentration in sea water than in nutrient solutions used for optimal plant growth. An excessive concentration of these ions (salts) can present potential stress factors to plant growth and may even be toxic (Rozema, et al. 1985b).

It is difficult to separate the influence of the inundation and salinity factors, the two primary stress factors in salt marsh vegetation ecology. Most other factors affecting salt marsh vegetation are either directly or indirectly linked to these. The major problem presented to vascular plants in a saline environment is that of osmoregulation since different species of salt marsh plants have varying abilities to cope with salinity and will position themselves according to the salinity gradient in the soil. Halophytes have special adaptive mechanisms to cope with high salinity as shown below in the section on biotic adaptation. This adaptivity is the feature which distinguishes halophytes from glycophytes and allows tolerance of high salt levels (Marcum & Murdoch 1992). It can also be argued that without saline conditions halophytes would not have conditions conducive to their growth - because it reduces the competition, but this is really a circular argument as salinity can be seen to be stimulating as well as limiting growth in these plants. The salinity in salt marshes can also be linked to soil moisture content.

### ***2.3.3 Soil moisture (waterlogging)***

Salt marsh soils are characterised by a high soil moisture content, although there is a general decline in soil moisture from the low marsh to the high marsh. As would be expected, the soil moisture is greatest in the section of the marsh which experiences the most frequent inundation (Seliskar 1985). Tidal activity causes the marsh to be flooded and drained on a twice daily basis, which in turn causes fluctuations in the height of the water table in the marsh. The flooding and drainage rates on a salt marsh depend on the nature of the topography, elevation and soil characteristics (Armstrong et al. 1985; O'Callaghan 1993).

The topography of mature salt marshes is generally similar from marsh to marsh and distinctive physiographic features are to be found. These largely flat areas are covered by a fine network of drainage creeks in which the dendritic pattern is most common. Interspersed between these creeks are small pools and open salt pans. The creeks enable water to flow both on and off the salt marsh. Steeper marshes with a predominantly fine soil structure drain quicker and thus allow less time for infiltration of soil moisture. Similarly, flat marshes which have a high clay and organic matter content will almost always be permanently waterlogged (Ranwell 1972). Soil salinity can also effect soil moisture content. Due to the hygroscopic effect of salt, soils on the marsh with high salinity hold and absorb water more readily than do soils with a lower salinity.

Soils which are waterlogged on a regular or permanent basis present a 'challenging' biochemical condition for plant growth. Waterlogging severely limits the rate at which oxygen can diffuse into soils often causing an anaerobic condition (Hemond & Chen 1990;

Christian et al. 1983). Armstrong (1976) points out that, in soils under these conditions, organisms derive their energy by anaerobic respiration. In this process electrons are utilised causing the conversions of chemical compounds to a reduced state which is generally reflected in salt marsh soils as a lowering of the oxidation-reduction potential (redox) of the whole soil (Long and Mason 1993).

In salt marsh soils redox typically decreases with depth, ranging from 250 mV upwards in surface sediments with traces of oxygen down to - 500 mV or lower in highly reduced soil environments (Long and Mason 1983). Reduced conditions make salt marshes susceptible to the accumulation of heavy metals, which is mainly caused by the precipitation of metal ions by sulphide ions. Hence, salt marsh ecosystems are very susceptible to pollutants from industry (McLusky 1981). The black or grey colouration a few mm below the surface of the soil and the pervading smell of hydrogen sulphides serves as proof that most salt marsh soils are in a reduced state (Rozema et al. 1985 a ).

The effects of a high soil moisture content on salt marsh plants have been well studied (Ranwell 1972; Armstrong 1976; De Laune et al 1981; Snow & Vince 1984). Essentially, waterlogged soils provide an extremely hostile environment to plant growth and salt marsh plants have developed special mechanisms to overcome the anoxic and often toxic environment. Different species have different abilities to overcome these effects and clearly this will influence the distribution of that species. Plants which dominate the lower marsh (e.g. *Zostera capensis* or *Spartina maritima*) will have to have a greater tolerance to the effects of waterlogging than plants (e.g. *Limonium depurpuratum* or *Sarcocornia pillansii*) found on the more elevated sections of the middle and upper marsh. High soil moisture content also effects the uptake of nutrients in vascular plants often limiting availability.

### ***2.3.4 Nutrient limitation***

The influence of mineral nutrition on the zonation of halophytes in salt marshes has been studied by a number of researchers (Bradshaw 1969; Epstein 1969; Pigott 1969; Rozema et al. 1985a; Rozema 1985 b; George and Antoine 1982; DeLaune et al. 1981). The importance of nutrients on the distribution and growth of plants is well recognised (Bradshaw 1969).

The effects of nutrients on the growth of salt marsh plants is a relatively unexplored field and there is a general lack of understanding of the role of nutritive influences. Chadwick & Harding (1969), point out that parent rock material determines the soil type and this in turn can influence nutrient content. This may be the case for terrestrial soils, but need not necessarily apply to salt marshes, where soils are deposited either by fluvial or marine processes. The structure of salt marsh soils depends largely on the source of sediment and the hydrological energy regime. The chemical nature of salt marsh soils will also be influenced by the chemical composition of the inundating water and the length of inundation. Sea water provides a plentiful supply of metal ions essential to plants, that is K, Mg, B, Li, and Ca, however the two most important non - metal elements nitrogen and phosphorus, occur at concentrations 3 -4 times lower in order of magnitude (Long and Mason 1983).

All higher order plants need at least sixteen essential chemical elements for growth. Apart from carbon and the elements of water these include: potassium, calcium, magnesium, nitrogen, phosphorus, sulphur, iron, manganese, zinc, copper, boron, cobalt and molybdenum (Epstein 1965). The actual amounts of these elements acquired by the plant from the soil differs enormously, differences which are not necessarily a direct reflection of the concentrations of these elements in the soil. This situation may occur because the element is in a form which the plant cannot directly utilise, or the plant selectively absorbs the nutrients it requires for growth. The capacity for plants to be selective is remarkable but not absolute, hence plant distribution is limited by nutrient availability (Epstein 1965). Most glycophytes do not require sodium as an essential element as do halophytes.

Epstein (1965) points out that excessive concentration of nutrients can cause two distinct problems. Firstly the element in excess can cause metabolic derangement by competing for entry into the plant with elements in lower concentrations. Once absorbed the excessive element poisons enzymes and disrupts the structure of the cell water and interfere with the mechanisms of the cell. Secondly high external concentrations of an element leads to a high osmotic pressure which the plant must counteract by raising internal osmotic pressures, or failing this loses its cell water. The ability of halophytes to control their osmotic potential through selective ion transport and their ability to continue absorbing essential nutrients has allowed these plants to thrive in the ecotone between land and sea.

Pigott (1969) points out, that although the special problem of salinity tolerance has attracted much attention, other aspects of the mineral nutrition have been largely neglected but may also be important in relation to distribution within salt marshes. Studies on salt marsh plants indicate that the sediment redox potential has an effect on the exchange of

nutrients. The process of anaerobic respiration causes denitrification of soils. Smart (1982) reports that a number of studies have examined the growth response of *Spartina alterniflora*. Two forms of this species are to be found in North American salt marshes - a tall and a short form. Smart (1982) finds that nitrogen limitation appears to be responsible for the stunted growth in the short form and that Nitrogen addition brings about a dramatic increase in productivity. Similar studies have been conducted by Stewart et al. (1972) where the roles of nitrogen and phosphorus are examined in salt marshes. They find that the lower sections of the marsh have a greater availability of nitrate, the most important form of nitrogen available on the marsh as it is readily absorbed by the plant (Stewart et al. 1973). The general lack of nitrogen in salt marsh sediments may be beneficial to pioneer salt marsh plants as the lush, brittle growth induced by nitrogen excesses could cause severe damage to the plant from wave action (Ranwell 1972).

Phosphorus deficiency has also been reported by Pigott (1969). He observed that *Salicornia* seedlings become withered and shrunken while the upper parts turn yellow or red indicating a lack of phosphate. Using greenhouse experiments he finds that phosphate alone does not produce a massive improvement in growth, but that combining phosphate and nitrogen produces a striking improvement in growth rates. This implies that phosphate plays a lesser role in the stimulation of growth rates. Considerable seasonal fluctuations can occur in the levels of extractable phosphorus (Nixon 1980). While sea water contains little phosphorus, coastal and estuarine sediments suspended in the water constitute a valuable source to salt marshes.

Hydrogen ion concentration in salt marsh soils exerts profound effects on nutrient availability and on the concentration of ions which may have a toxic effect in the soil (De

Laune et al. 1981). High pH values have been found to retard availability of potassium, phosphorus and iron due to competition for sites on soil ion exchange complexes, while a decrease in pH can lead to an increase in the solubility of metallic cations, especially true in the case of aluminium, and can cause toxicity. Aluminium in its soluble form can interfere with nutrient uptake and inhibits root growth (Ranwell 1972). Rozema et al. (1985a) note that the pH in salt marshes is generally high (6.0 - 8.0) due to the presence of a high carbonate content (decaying shells). In reduced conditions iron - sulphide and other ions precipitate easily into forms which are unavailable to plants.

The response of salt marsh species to iron and manganese has been documented by Rozema et al. (1985b). Using hydroculture experiments they examine the effects of iron and manganese toxicity in various salt marsh plants. They find that the plant roots are adapted to prevent the toxic effects of both these elements. It is pointed out that the complex nature of the variation in the salt marsh soils makes for difficult generalisation from cultured controlled environments. They conclude that it is difficult to judge whether these two elements do exert a toxic effect in salt marsh soils and whether they do play a role in the distribution of salt marsh species.

It becomes quite clear that there is no complete understanding of the effects of nutrients on the zonation of halophytes. Research has tended to concentrate on the effect of salinity on nutrient uptake. Research has borrowed heavily from work done in freshwater environments or involved experimentation in controlled laboratory conditions. This begs the question: "Do these results reflect what would happen in a salt marsh?" Given the range of influences and the associated fluctuations, at best the answer would be "Perhaps some of the time." Currently there are huge gaps in our knowledge on the actual effects of the many other

essential nutrients, both macro and micro. The complex nature of chemical reactions are perplexing enough for the experts to fathom out, making the task of providing general guidelines for the layperson involved in management of salt marsh resources an onerous one. If anything salt marshes could be conserved and admired for the very complexity that we have yet to understand.

### ***2.3.5 Succession and interspecific competition***

If salt marshes are considered in the broader geomorphological context, then they can be seen as playing a role in the preparation of an area which is undergoing an evolutionary development from a marine to a land surface. This occurs when sediments begin to accumulate on a sheltered shoreline and the surface eventually is raised to a level above mean sea level. As this process occurs marine vegetation is replaced by terrestrial vegetation; salt marsh plants are the pioneer plants in this process. Vascular plants assist accretion of the surface by trapping sediments and their root systems protect the surface from erosion (Chapman 1974). This process may take a few years or centuries and depends on factors such as degree of protection of the site, rates of sediment accumulation and supply of suspended sediment (Long and Mason 1983).

Ultimately the primary salt marsh plants will be succeeded by glycophytes which are typical for that particular climatic region. For example the salt marshes at Langebaan could ultimately be replaced by the lowland Fynbos characteristic of that Mediterranean climate. The reclamation of land from the sea has enabled Dutch researchers to closely monitor plant

succession in salt marshes leading to an understanding of successional processes that has enabled them to convert former marine areas to farmlands (Chapman 1974).

Rozema et al. (1985a) have examined the role of succession in salt marshes and have also attempted to correlate plant distribution and zonation to the process of succession. Roozen & Westhoff (1985) have examined succession in the plant communities of the tidal salt marsh of the Boschplaat on the Frisian island of Terschelling in the Netherlands. Using permanent plots they examined changes that have occurred in the vegetation over some 30 years. They challenge the idea that zonation merely reflects the underlying physical and chemical environment and suggest that succession may play a greater role. They feel that the short term nature of studies in the past, has led to inconclusion about the role of succession. Results show that in the long term (> 30 years) there is considerable change in the marsh. An analysis of the results shows four distinct successional trends, each restricted to a particular altitudinal zone in the marsh. As there was little interaction between the zones, the implication was that zonation in the short term (<30 years) was not the result of succession. They find the major reason for zonation on this time scale to be environmental conditions.

Beeftink (1985a), who also based his research on the Boschplaat, examined interactions in the *Plantagagini-Limonietum* section of the marsh. He also finds that environmental conditions play a major role in determining plant distribution. He points out that interspecific competition is very difficult to test and finds that environmental factors and

genetic differences influence growth parameters in various ways at different sites at different times. This makes generalisations about succession very difficult. He challenges methods of vegetation study, the criterion used to define plant communities (species composition, abundance and cover percentages) may be insufficient if a greater understanding of plant dynamics is to be achieved. Beefink (1985a p. 43) states “ The danger exists that only measurable and testable phenomena will be recognised as the only existing. Nature, a plant community and a plant or animal are more than that.”(sic).

Pennings & Callaway (1992) have examined the relative importance of the role which competition and physical factors play in determining salt marsh plant zonation. They find that both competition and physical factors are important determinants of marsh zonation. The importance each factor varies in different elevations of the marsh. The lower marsh is characterised by a strong correlation between physical factors and plant zonation. The middle and to a lesser extent the upper marsh is where species tend to exclude each other through competition.

The importance of competition in the zonation of salt marsh plants became increasingly apparent with the advent of experimental manipulations of salt marsh vegetation in the field (Vince & Snow 1984; Seliskar 1985; Bertness 1991a Bertness 1991b). In many studies the correlation between physical factors and zonation has been poor (Ranwell 1972; Watkinson & Davy 1985; Zedler 1977). The significance of competition is also suggested by the fact that abrupt boundaries exist between different marsh vegetation zones whereas edaphic factors change gradually across the marsh (Pennings & Callaway 1992). In many marshes the conditions for plant growth are thought to deteriorate monotonically with lower elevations (Armstrong et al. 1985). This is not always the case, as Mediterranean salt

marshes often have severe conditions in the elevated parts during dry summer seasons (Zedler 1986). Competition between species can cause boundaries to fluctuate with the dominant species displacing the subordinate to a poorer habitat (Bertness 1991b).

Another factor that points to the importance of competition is that growth and survivorship of a salt marsh plant may be better outside of its observed habitat. The restriction of plants to a 'preferred' site comes about through competition or differential dispersal or both. A species' physiological amplitude may be considerably wider than its ecological amplitude (Vince and Snow 1984). Bertness (1991 b ) examines the role of competition in determining zonation in a New England salt marsh. He finds strong resemblance between the maintenance of intertidal zonation on rocky shorelines and salt marsh plant communities. In both these environments competitive dominants monopolise physically benign habitats and displace subordinates to physically stressful habitats.

From the literature the role of competition in the maintenance of plant zonation in salt marshes had been largely ignored up until the 1980's. Now it is apparent that competition and succession do have an important role in future studies if a complete understanding of salt marsh dynamics is to be achieved.. Once a better understanding of how plants react to changes in the physical and competitive environment is achieved, the plants themselves could become useful indicators of the 'health' of their environment. Monitoring changes in plant cover is relatively easier and cheaper to achieve, than expensive laboratory testing of the salt marsh environment. Salt marshes could prove very useful as a coastal management tool for gauging changes to our environment.

### ***2.3.6 Disturbance and resilience***

Disturbance of salt marshes can be anthropogenic or natural. The effect of disturbance plays a role in the distribution of salt marshes plants and salt marshes. Disturbance can occur on a local or regional scale. Exactly what constitutes a disturbance is difficult to define, but for the purposes of this study, any external input anthropogenic or natural which is detrimental to the growth of salt marsh plants, will be considered to be a disturbance. The ability of plants to cope with disturbance is called resilience or ecological stability, a subject on which there is large literature.

Different salt marsh plants have varying capacities to deal with disturbances. Disturbances often lead to mortality of a species which can lead to bare patch formation. The colonisation of these bare patches can lead to useful insights into the process of colonisation and succession. Bertness & Ellison (1987) have studied bare patch colonisation. They find that disturbance from wrack ( plant material that accumulates along the high water mark) plays a major role in generating pattern in New England salt marshes communities. Dead *Spartina* stems are rafted onto the high marsh, covering salt marsh plants long enough to cause mortality. Seasonal production and tidal transport of wrack material cause predictable temporal and spatial patterns of disturbance. Wrack disturbance is greatest in the summer after the growing season and affects predominantly the upper portions of the marsh. Different salt marsh plant species have different abilities to cope with wrack cover. The period of cover can also vary - short term disturbances (2 - 4 week periods) and any longer period is considered to be long term cover (Bertness & Ellison 1987).

The disturbance along the driftline in a salt marsh can also include the affect of the decomposition of wrack which can lead to temporal nutrient enrichment of this area. Some species are restricted to this belt of the drift zone for this very reason (Rozema et al. 1985a).

Consumer pressure on seed set can also have an effect on the abundance and distribution of salt marsh plant species. Until recently this was a largely ignored aspect of salt marshes studies. Seed predation by insects, birds and mammals in salt marshes limits the production of many of the dominant perennials in salt marshes (Bertness et al. 1987). Some plants flowers are more delectable than others putting them at a disadvantage in terms of sexual expression within the marsh community.

Anthropogenic disturbances in salt marshes are usually on a larger scale and may have greater long term effects. As populations grow so does the human influence on the salt marsh environment. The industrial developments of the twentieth century have led to three major forms of coastal use or misuse: (a) large-scale destruction for industrial, harbour and commercial purposes; (b) recreational use, resulting in large-scale housing developments and building activities; (c) increasing frequency and capacity of oil transports in an ageing fleet often resulting in oil pollution through wreckage, illegal cleaning and dumping (Westhoff 1985). The effects of oil on salt marshes have been well documented. The salt marsh plants affected most are those on the lower marsh where substantial mortality is induced if heavy or frequent doses are incurred. In cases of light dosing with oil salt marsh plants show remarkable resilience (Hershner & Lake 1980).

A large percentage of salt marsh has been disturbed or lost through reclamation for agricultural purposes. For instance, in Essex, more than 15 000 ha of salt marsh have been reclaimed (Long & Mason 1983). Cultivation and mining in catchment areas has a huge effect on water quality and silt inflow in estuaries and the adjacent coastline, which in turn will negatively effect any salt marsh found in the vicinity. (Ranwell 1972). Estuarine barrages schemes disturb tidal regimes of salt marshes, a drop in tides can lead to desiccation, desalination, increased aeration and increased mineralisation, all detrimental to salt marshes (Van Noordwijk-Puijk et al. 1979).

One of the most powerful influences humankind has had on European salt marshes is the deliberate introduction of *Spartina anglica* to particular sites and its subsequent unchecked spread. It is now to be found invading salt marshes in Australia, New Zealand and the Western U. S. A., where it is flourishing. In South Africa, *Spartina maritima* (a sub-species of *Spartina anglica*) was introduced from the United States and is well established in salt marshes in the Western Cape. (Bond & Goldblatt 1984). *Spartina anglica* out-competes local algal communities and drastically reduces variety in marshes to which it has been introduced (Ranwell 1972).

Indirect cropping by domestic animals has been practised for many centuries (Westhof 1985). Grazing causes trampling (an effect which salt marshes have a low tolerance), manuring and selective feeding. Other anthropogenic influences include, turf cutting, spraying of insecticides and herbicides.

Natural disturbance forms part of the ecological cycle in salt marshes and succession and subsequent zonation patterns in plants are definitely influenced by disturbance. The

disturbance brought about by mans activities have a less benign character. Ranwell (1972 p. 38) sums up the situation: "Directly or indirectly, the character of most salt marshes throughout the world today has been largely determined by human activities past or present just as in other habitats.

### ***2.3.7 Evolutionary adaptation***

From the above it is difficult to envisage a habitat more hostile than that of the salt marsh environment. It takes a uniquely adapted plant to endure and survive conditions such as high and low salinity, anaerobic conditions, heavy metals and toxins, waterlogging, low nitrogen and phosphorus, mechanical damage from waves, predation and strong interspecific competition. Indeed the halophytes occupying salt marshes are a superb example of adaptation. It is beyond the scope of this study to go into much detail on the complexities of biophysiological adaptation but description of basic adaptations to environmental stress is warranted.

Sea water has a salinity of  $\pm 36\text{‰}$  (Day 1981) and inundation of salt marsh soils therefore causes high salinity levels therein. Salt spray can further increase soil salinity and coat aerial parts. In some salt marshes hyper-saline conditions can result from high evaporation rates, seasonal or even diurnally. All salt marsh plants must therefore have the ability to withstand salinity. The degree of tolerance in each species is an important factor in determining distributional limits of a species within a salt marsh. (Long & Mason 1983). The physiological effects of salinity on plants are threefold: osmotic; nutritional and toxic.

Salt marsh plants need to keep a very low osmotic potential (i.e. high osmotic pressure) to avoid losing tissue fluids to saline soils and sea water. To achieve this end these plants accumulate a high concentration of osmotically - active substances such as sodium and chlorine in the tissues. These substances however, interfere with enzymes and therefore affect nutrition. Halophytes must therefore be able to selectively accumulate ions and have metabolic adaptations which exclude sodium and chlorine to cope with these concentrations (Epstein 1969). Maintenance of a favourable ionic balance within halophytes is accomplished by various mechanisms depending on species. These include salt secretion (e.g. *Spartina* sp.), compartmentalisation (e.g. *Limonium* sp.), succulence (e.g. *Sarcocornia* sp.), abscission of salt saturated organs (e.g. *Avicennia* sp.) and salt exclusion (e.g. *Salicornia* sp.) (Smart 1982). Some plants have increased concentrations of proline, polyols sorbitol and glycine betaines to prevent inactivity of enzymes and other essential structures. (Rozema et al. 1985 a ).

The other problem facing salt marsh plants in terms of water relations are the fluctuations in soil salinity. As mentioned earlier, the upper marsh can become hyper - saline in dry periods and the plant would respond by decreasing osmotic potential to prevent dehydration. However this part of the marsh can also experience a sudden drop in salinity due to heavy rainfall. Under these circumstances the plant will take up water until hydrostatic pressure is exerted by the cell wall. The osmotic gradient is so extreme that pressures of 30 times that of the atmosphere can be applied to the cell wall. To tolerate this stress, cell walls in halophytes have to be strong and flexible in the short term and in the longer term be able to facilitate decrease in cell solute concentrations (Long & Mason 1983).

The final mechanism employed by salt marsh plants to decrease intake of salts is to decrease transpiration. Salt marsh plants adopt morphological features that limit water loss, which include xeromorphic structures such as reduced leaf and stem surfaces, leaf rolling, waxy cuticles, leaf hairiness (Rozema et al. 1985 a ).

The other stress adaptation concerning halophytes concerns the complications brought about by inundation. This results in soils becoming waterlogged which reduces the entry of air into the salt marsh sediments. In the short term daily tidal action causes changes in the water potential and aeration of the soil. In the long term inundation causes low redox potential and an accumulation of phytotoxins ( $Fe_2$  ,  $Mn_2$  , sulphide, ammonium and  $CO_2$ ) (Smart 1972). Halophytes are therefore distinguishable from other plant types not only by tolerance to salinity, but also tolerance of waterlogged soils

Anaerobic and reduced conditions are fatal to most terrestrial plant species where the lack of oxygen normally kills root structures and carbon dioxide even in small doses can stunt plant growth. Manganese and boron can be toxic in high concentrations and in a reduced form, more readily available for uptake in plants, the same applies to the phytotoxic heavy metals: zinc, mercury, lead and copper, elements which are relatively abundant in salt marsh sediments. Sulphides are also predominant in salt marsh sediments and are toxic to root systems. These are produced during anaerobic decomposition of organic material by sulphite-reducing bacteria (Rozema et al. 1985 b ; Long & Mason 1983).

Different strategies are employed by salt marsh plants to tolerate waterlogged conditions. These include: preference, resistance, avoidance and root aerenchym. Rozema et al. (1985 b) examine the response of salt marsh species to iron and manganese. They find salt marsh

plants have different tolerances to the toxic effects of these elements, generally the lower marsh species are less sensitive. This ability to cope with iron and manganese toxicity seems to be linked to a high root porosity, well developed aerenchym, radial oxygen loss and exclusion by oxidation of these elements at the roots. They conclude that lower salt marsh plants actually have a preference for high iron and manganese sites and this will accordingly influence plant distribution.

Most salt marsh plants have developed mechanisms to resist the toxic effects found in waterlogged soils. Reciprocal transplanting between extremes of plant zones has shown that salt marsh plants have morphometric capabilities, that is they can adapt morphologically and anatomically to changes in environment. (Snow & Vince 1984). Soil moisture has been found to be the most significant factor in bringing change to halophyte morphology (Seliskar 1985). Plants relocated into wetter soils show remarkable development of aerenchyma tissue. This tissue contains large air filled cells and is found mainly in the roots, allowing the plant to oxygenate its immediate surroundings. This is especially true of *Spartina* which shows clear evidence of this activity by the coating of red ferric oxide precipitate found on the roots and their surroundings (personal observation). Plants which oxygenate their soil environment show greater mutual benefit from this process by the close grouping of many individuals. (Pennings & Callaway 1992). Plants without aerenchyma can adopt the strategy to avoiding anoxic conditions by growing a fine set of roots close to the soil surface.

Salt marsh plants also have to survive submergence which leads to a restriction of gaseous exchange, shading and mechanical damage of wave action. These plants have to be able to cope with a lack of oxygen and carbon dioxide, components vital for photosynthesis

(Ranwell 1972). Some plants have leaves which are adapted to trap a film of air while roots develop aerenchyma tissue to cope with inundation. Root systems are well developed to anchor the plant against wave action. Leaves are also small and strong to prevent mechanical damage (Chapman 1974)

Salt marsh plants show remarkable adaptation to an extremely variable environment. It is this complexity of adaptation which makes halophytes different from other plant groups. The fact that fewer species of plants occupy salt marshes does not necessarily imply that an overall comprehension of the biophysical dynamics will become less complicated. In fact, it could be argued, that it is due to the complex nature of the salt marsh environment that relatively few species have managed to evolve the specialised features needed to sustain life in the salt marsh environment. Most of the discussion thus far has revolved around salt marsh research in countries other than South Africa, the subject of the next section.

## 2.4 Salt marsh research in South Africa

Salt marsh research in South Africa has been a relatively neglected field. This is perhaps not surprising when considering the relatively small area occupied by salt marshes in compared to the many other vegetation types in this country. More than 22 000 plant species grow within South Africa's borders, with the Cape Floral Kingdom, the geographically smallest yet one of the species richest floral kingdoms in the world, alone consisting of about 8500 species (Bond & Goldblatt 1984). As a distinct vegetation type, tidal salt marshes only occupy approximately 170 km<sup>2</sup> in a country of about 1 224 040 km<sup>2</sup>. Salt marshes exist in approximately 70 of the 155 estuaries of along the Cape Coastline, of these, only the Knysna Estuary is relatively extensive at approximately 18.27 km<sup>2</sup> (11%). Langebaan Lagoon has by far the most extensive salt marsh at about 57 km<sup>2</sup> (34%) (O'Callaghan 1990a). Salt marshes have been somewhat overlooked in South Africa mainly due to their limited expanse, but also because most of the major biological studies on estuaries have emphasised faunal aspects (Day 1981; Day 1959; Grindley 1985).

The conditions for salt marsh development are specific with the main requirement being a low energy coastline. The South African coastline, in comparison to other coastlines, is relatively straight, offering few sheltered bays and thus affording little opportunity for salt marsh development. Due to the dry nature of the African sub-continent and the lack of glacial activity in the past, fluvial erosion processes have been retarded and little indentation into the coastline has occurred. Hence the coastline today is preserved in much the same form as it was after the break-up of Gondwanaland (Branch and Branch 1981).

To date most accounts of salt marsh flora in South Africa have been largely descriptive in nature. The first extensive account of the distribution and classification of South African vegetation was conducted by J. P. H. Acocks. In "Veld Types of South Africa", Acocks (1988) did a broad survey of all South Africa plant communities. In this survey, no mention of salt marsh plant communities or the more common salt marsh plants is made. This oversight is mainly due to the regional scale of the study and the extremely localised nature of salt marsh plants in South Africa.

Salt marsh vegetation features more prominently in zoological and ecological studies of South Africa estuaries (Scott et. al. 1951; Millard & Scott 1955; Day 1981). In these studies salt marsh plants are examined mainly for their role in primary production of estuarine systems. The majority of these studies have taken place under the auspices of the University of Natal (Natal coastline), the University of Cape Town, (Western and Southern Cape) and Rhodes University (Eastern Cape).

As the population has expanded and standards of living increased, the South African coastline has come under increasing pressure from coastal development. In response to the need for an integrated, holistic coastal management policy, the National Research Institute For Oceanology (NRIO) a sub-branch of the South Africa Council For Scientific And Industrial Research (CSIR), established the Estuarine And Coastal Research Unit (ECRU). ECRU was established in 1979 with the aim of:

- a) Providing information for an overall management policy for the South African coastline.
- b) Compiling a synthesis of knowledge on estuaries of the Cape.

- c) Identifying gaps in information , conduct research on these and stimulate research institutions to undertake research in this field.
- d) Contribute to impact assessments on proposed developments in the coastal environment.

This project of ECRU was similar to the estuarine survey conducted by Begg (1978) and culminated in a series of reports. The first published was "The Estuaries of the Cape, Part 1 - Synopsis of the Cape Coast, Natural Features, Dynamics and Utilisation." (Heydorn and Tinley 1980). This provided a broad overview of all physical aspects of the Cape Coastline. This was followed by: "The Estuaries of the Cape, Part 2", which examined and provided information on individual systems. These reports were primarily concerned with coastal management and hence the botanical survey's were generally limited to a species list and little or no discussion thereof. Due to the specific focus on estuarine environments, Langebaan Lagoon with the greatest concentration of salt marsh vegetation in South Africa did not qualify for discussion as an individual system in ECRU's reports.

Until recently wetlands and particularly salt marshes were generally excluded from vegetation research in South Africa (Cowling 1984; O'Callaghan 1993). Consequently, there is relatively little literature available on South Africa salt marsh vegetation dynamics. Christie (1981) has examined the role of salt marsh vegetation in the primary production of Langebaan Lagoon, while Boucher & Jarman (1977) have classified the vegetation around the lagoon into various communities including the salt marshes. According to this classification salt marsh communities are distinguished from other communities by the presence of *Sarcocornia pillansii*. This community was then further subdivided into *Juncus kraussii* Dense Sedgelands and *Chenolia-Salicornia* Dwarf Succulent Shrublands. Boucher

et al. (1986) completed an extensive survey of the Cape coastal vegetation from the Orange River to the Sundays River in which they describe the occurrence of salt marsh vegetation and the nature of salt marsh communities.

The most comprehensive account of salt marsh community structure and dynamics to date, have been conducted by O'Callaghan (1990 a; 1990 b; 1990 c; 1992; 1993; 1994 a; 1994 b; 1994 c; 1994 d). O'Callaghan (1992) has systematically studied and classified the South African *Salicornieae* and conducted extensive research on the salt marsh vegetation of the Berg River, Uilkraals River, Kleinmond Lagoon and Langebaan Lagoon. O'Callaghan (1990 b; 1990 c) has also examined the ecology of a number of estuaries on the False Bay coastline. Reaper (1986) conducted a survey of the estuarine vegetation on the Klaasjagers River, to examining the effect of soil characteristics on vegetation patterns. A general account of the geographical location and organisation of the salt marsh vegetation of the Knysna Lagoon is provided by Grindley (1985).

## **Chapter 3      The study site**

### **3.1 Rational for choice of site**

The Langebaan salt marsh was chosen after a careful examination of a number of potential sites which are to be found around the numerous estuaries in the South Western Cape. The choice of site was made as a result of the following considerations:

Firstly, of the 155 rivers along the Cape coast, many are not estuarine in character and do not have salt marshes. Salt marshes are only to be found at approximately 70 Cape Estuaries. The most extensive of these are: Swartkops Estuary (1.7 km<sup>2</sup>), Olifants Estuary (2 km<sup>2</sup>), Knysna Estuary (18.27 km<sup>2</sup>) and Langebaan Lagoon (57 km<sup>2</sup>). These four systems alone account for approximately 76% of the Cape's coastal salt marshes, with Langebaan being by far the largest at 32% (O'Callaghan 1990a). The salt marsh at Langebaan, by the very nature of its size, is an important ecological component on the Cape coast and this alone makes it an ideal site for this study.

Secondly, one of the objectives of this study is to provide information to facilitate better monitoring and management of the Cape's salt marshes. The Langebaan Lagoon forms the focal point of the 187.12 km<sup>2</sup> West Coast National Park which was proclaimed in 1985. The system has also been classified as a wetland of international importance in terms of the Ramsar Convention criteria of 1975, mainly because it supports more birdlife than any other wetland in South Africa (Robinson 1990). One of the specific objectives of the West Coast

National park is: "To manage the park in such a way that optimum environmental quality will be achieved ....."(Robinson 1990 p 6). It is hoped that this study will go some way to provide information which can be used by the management of the National Parks Board to implement this objective.

Thirdly, prior to the National Parks Board management of the West Coast National Park, the shores of Langebaan Lagoon were bounded by a number of privately owned farms. The names and boundaries of these farms are still in place today. One of the reasons that these salt marshes have survived in a near pristine state over the past century is thanks mainly to their relative inaccessibility and remoteness. Until 1993 the only means of access to the southern and western lagoon area was via a badly potholed dust road. The land, being privately owned by farmers, has helped ensure limited public access to the salt marshes either on foot, motor vehicle or by boat. The result is that relatively little disturbance in the form of pollution, trampling or bait collection has taken place and this pristine nature makes these marshes an ideal environment in which to undertake research.

Fourthly, the Langebaan Lagoon has no rivers flowing into it , so unlike the estuaries there is no massive flux of river and sea water on both a daily tidal and seasonal basis (wet / dry seasons). This has resulted in salt marsh organisms being exposed to a more consistent saline regime, water clarity and tidal depth than would have been the case in an estuary. Arguably, this has resulted in a salt marsh system with well defined plant community assemblages, which manifest themselves in clearly discernible zonation patterns. This makes the area an ideal site to study zonation in salt marshes.

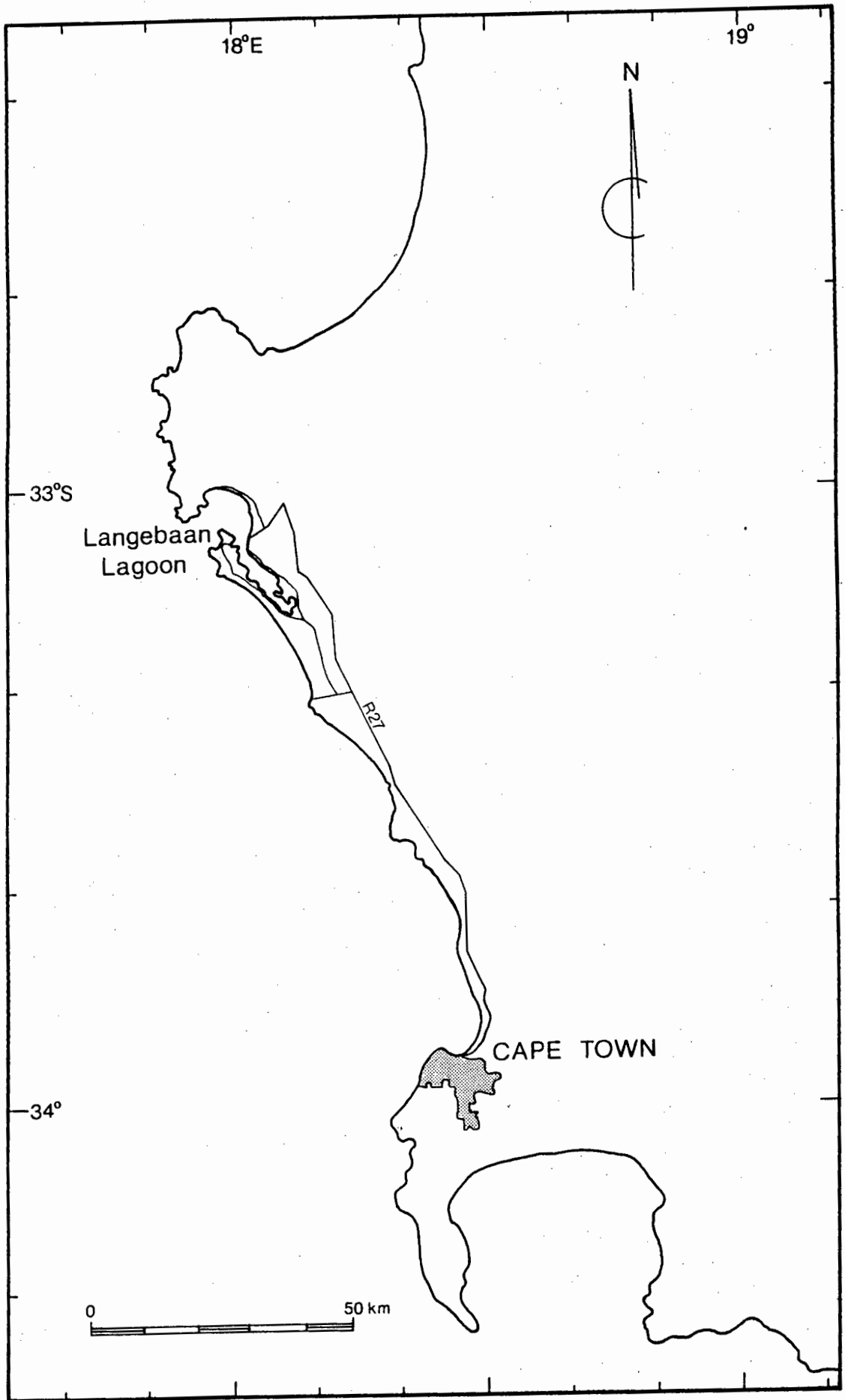
Fifthly, permission for thoroughfare over private land to gain access the salt marshes was obtainable through a single controlling body (National Parks Board).

Finally, the relatively close proximity of this study site meant that transport costs would not be prohibitive. The use of the U.C.T Zoology Department's research house at Klein Oostewal also made for reasonable accommodation costs.

### **3.2 Site location, description and historical development**

Langebaan Lagoon is found at:  $33^{\circ} 05' S$  ;  $33^{\circ} 12' 30'' S$  and  $18^{\circ} E$  ;  $18^{\circ} 08' E$  (see Figure 3.1). For an initial overview the area is best viewed using the South African 1:50 000 topographical map sheet 3317BB & 3318AA Saldanha (Third edition). On maps with a smaller scale Saldanha Bay (off which Langebaan Lagoon forms the southern extension) can be discerned easily as a major indentation and prominent peninsula in the coastline south of St. Helena Bay and north of Cape Town.

Langebaan Lagoon is situated roughly 100 km north of Cape Town and is reached by taking the West Coast Road (R 27) to either the Postberg or further north, the Langebaan turn - off (see Figure 3.1) The Postberg road leads to the southern tip of the lagoon where the road splits to provide access to either the Donkergat Peninsula along the west shore or Langebaan Village via the eastern shore of the lagoon. Access to this entire area is controlled by the National Parks Board and a levy is payable at the entrance control point. The Postberg Peninsula forms the long narrow arm which protects the lagoon from the Atlantic Ocean. The calm conditions in the Lagoon are ideal for the formation of salt marshes, which are especially prevalent in the southern section.

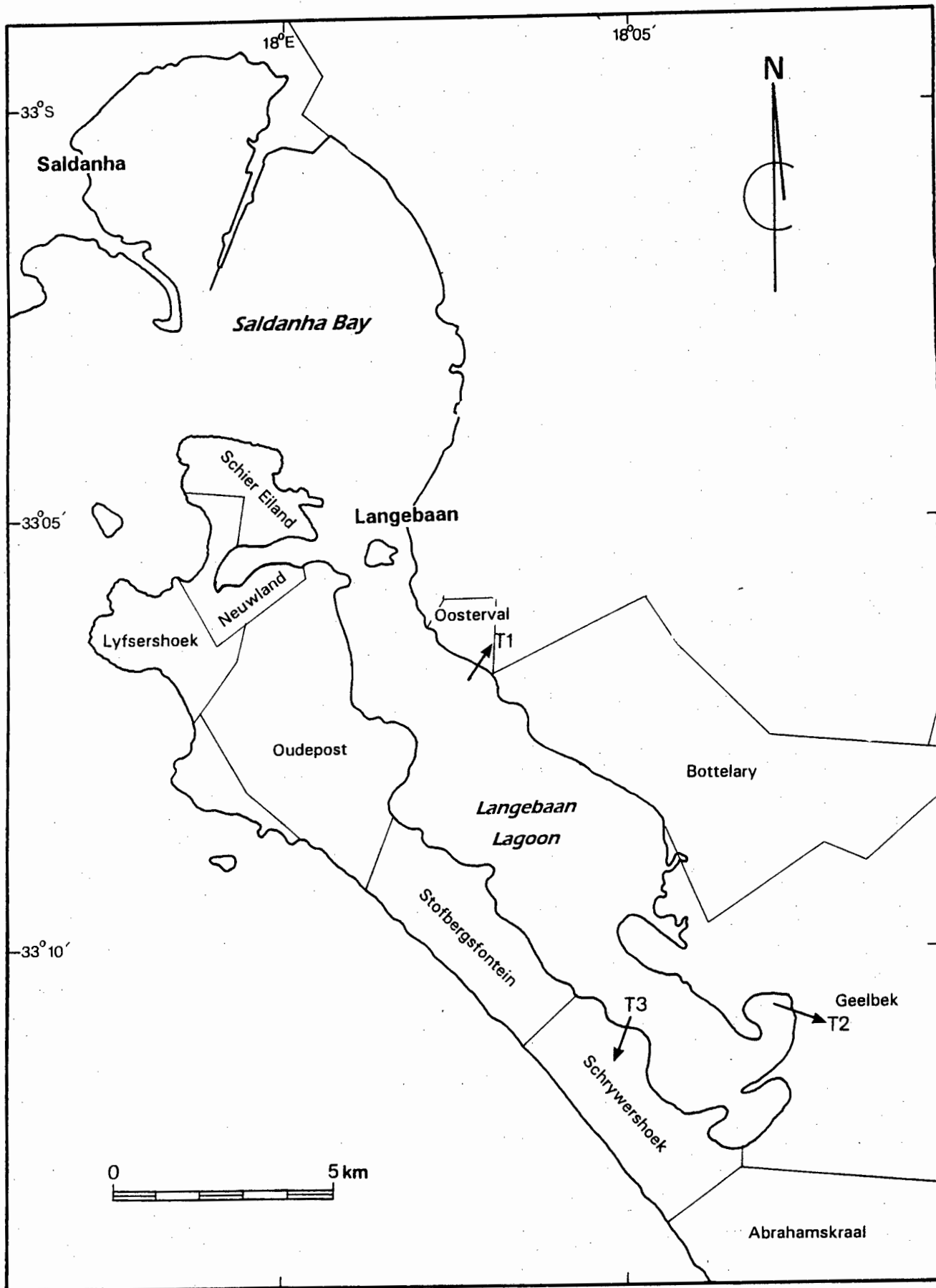


**Figure 3.1: Access and proximity of the study site to Cape Town**

The human history of the area makes for fascinating reading, but for the purpose of this dissertation, will be not be discussed in detail. The pre-colonial history of human occupation along the Cape coastline is a field which has attracted much investigation by archaeologists, social anthropologists and historians from various research institutions in South Africa. There a substantial literature written on the pre-colonial history of the Cape, but a general overview of this era is well provided by Wilson & Thompson (1982).

The Langebaan village was founded some time around 1870 primarily as a fishing village. Today the small village has mushroomed into the most popular holiday resort on the West Coast. The resort is well supported by visitors from Cape Town and the regional farming district. The lagoon is well suited for safe swimming, angling, sailing and water skiing. The South Africa Military has been active in this area since World War II, when a large airforce base was opened in nearby Langebaanweg. The South Africa Navy until 1991 operated an air-sea rescue base from the Langebaan which has since closed down. The army has a Special Forces barracks in the town and a military training ground (Donkergat) on the farm Schier Eiland in the northern most sector of the Peninsula (see Figure 3.2).

The Langebaan Village in the past served mainly as a market and service centre for the local farming community. Mixed farming was practised, essentially to supply the food requirements of the local community. A number of farms are to found around the lagoon (Figure 3.2). Moving in an anticlockwise direction around the lagoon from Langebaan, Village these are: Oostewal; Bottellary, Geelbek, Schrywershoek, Stofbergfontein, Oudepost and Nieuwland. All these farms bound onto the lagoon and with the exception of Oudepost and Nieuwland which have rocky shorelines, all have salt marshes.



**Figure 3.2: Localised map of Langebaan Lagoon and surrounding farms.**

With the advent of modern transport infrastructures this area became readily accessible to Cape Town and other markets. This ultimately changed the function of the area from primary production to recreation / conservation. The sandy, nutrient poor soils, low rainfall and frequent strong winds had traditionally made farming this area extremely difficult and often financially marginal. Commercial large scale farming or intensive cultivation are contemporary farming practises, both of which are not suitable to the Langebaan area. For these reasons farms surrounding the lagoon have not been commercially viable since early in this century (Green 1958).

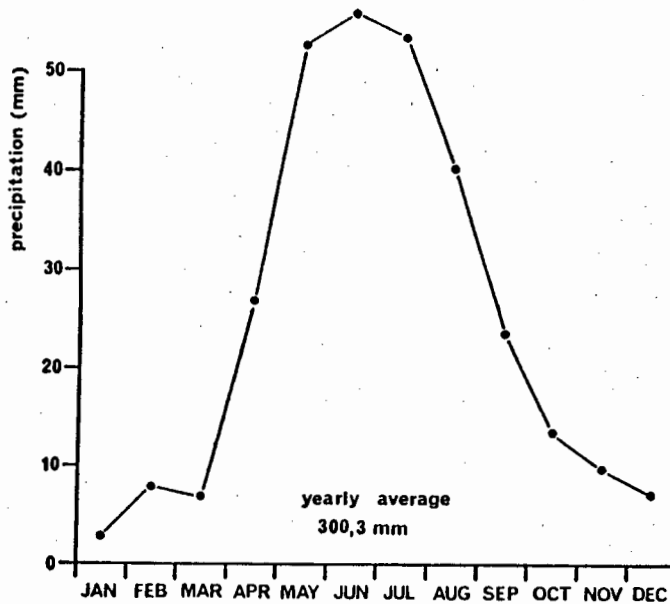
Increasing demand for recreational development and the growing industrial developments in Saldanha Bay, has since the seventies led to an ever increasing threat to the Langebaan Lagoon ecosystem. The West Coast National Park was proclaimed in 1985 and extended over some 60 km<sup>2</sup>. In 1987 the privately owned Postberg Nature Reserve was included adding a further 18 km<sup>2</sup>. By 1990 the Parks Board had purchased or negotiated the inclusion of all the farms which border the lagoon. This means that an area of 187.12 km<sup>2</sup> (including the lagoon) falls directly under the control and scientific management of the National Parks Board.

### **3.3 Physiographical features**

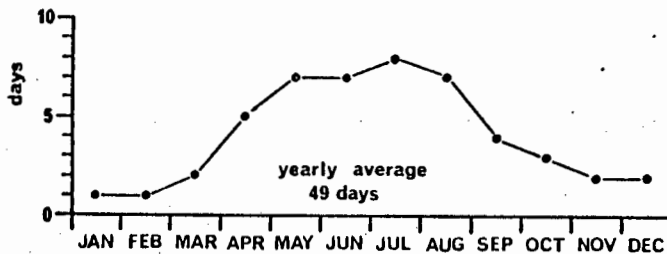
This section of the site description deals with the physical characteristics of the study site. Langebaan Lagoon is intricately linked to Saldanha Bay, especially with reference to hydrology. For this reason descriptions of the physical nature of the research area will include descriptions of Saldanha Bay. This section will examine the following physical aspects: 1) Climate; 2) Geomorphology and geology; 3) Lagoon hydrology

### 3.3.1 Climate

The research area falls within the northern fringe of the South Western Cape's "Mediterranean" climatic zone. Typically the area experiences winter rainfall followed by summer drought (see Figure 3.3). The average annual rainfall is between 253.1 to 269.9 mm (Christie 1981), half of which falls during the months of May, June and July (Schulze 1965).



A: Monthly averages of precipitation over a period of 21 years; 1940 - 1961.



B: Nr. of days with rain; monthly averages over a period of 21 years; 1940 - 1961

**Figure 3.3: Precipitation in the study area.**

(taken from Flemming 1977)

Essentially the area can be climatically classified as semi - arid with very little potential for surface run - off. Thus there is little potential for the removal and transportation of sediment in the catchment area which means that the sediments in the study area are predominantly of marine origin.(Flemming 1977). The salt marshes which fringe the lagoon receive little fresh water input from meteoric or terrestrial sources except at Geelbek, where there are signs of groundwater seepage, in an area dominated by freshwater reeds (*Phragmites australis*) (Shannon & Stander 1977; O'Callaghan 1994a). The other salt marsh sites have little or no representation of true fresh water plants, indicating little fresh water seepage.

The moderating effect of the ocean makes for low seasonal temperature fluctuations. Annual temperatures range from a winter night time low of 5.1° C to a high of 34° C at midday in summer (Day 1959). Due to the study site's situation in the prevailing anticyclonic sub - tropical high pressure systems, winds blow predominantly out of the south. Whilst the South-easterly Trade Winds are dominant in the upper atmosphere in this region, friction at surface level results in winds blowing in a south-westerly direction over the Langebaan district (see Figure 3.4). Strong (25 km/h), south-westerly winds blow persistently from September to April and only the intrusion of cyclonic frontal systems during winter brings variation in the form of north-westerly winds.

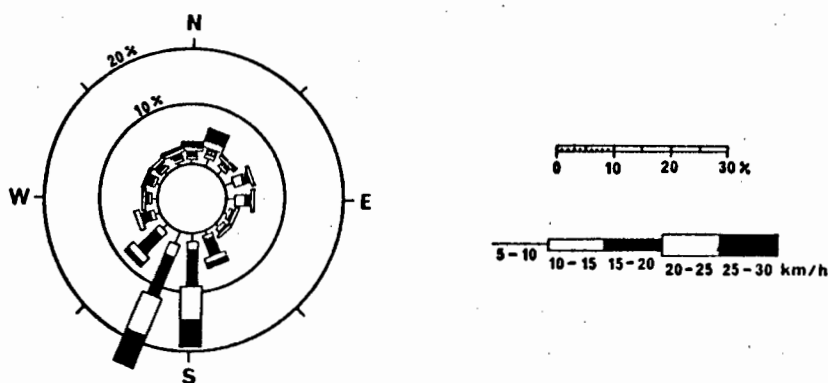
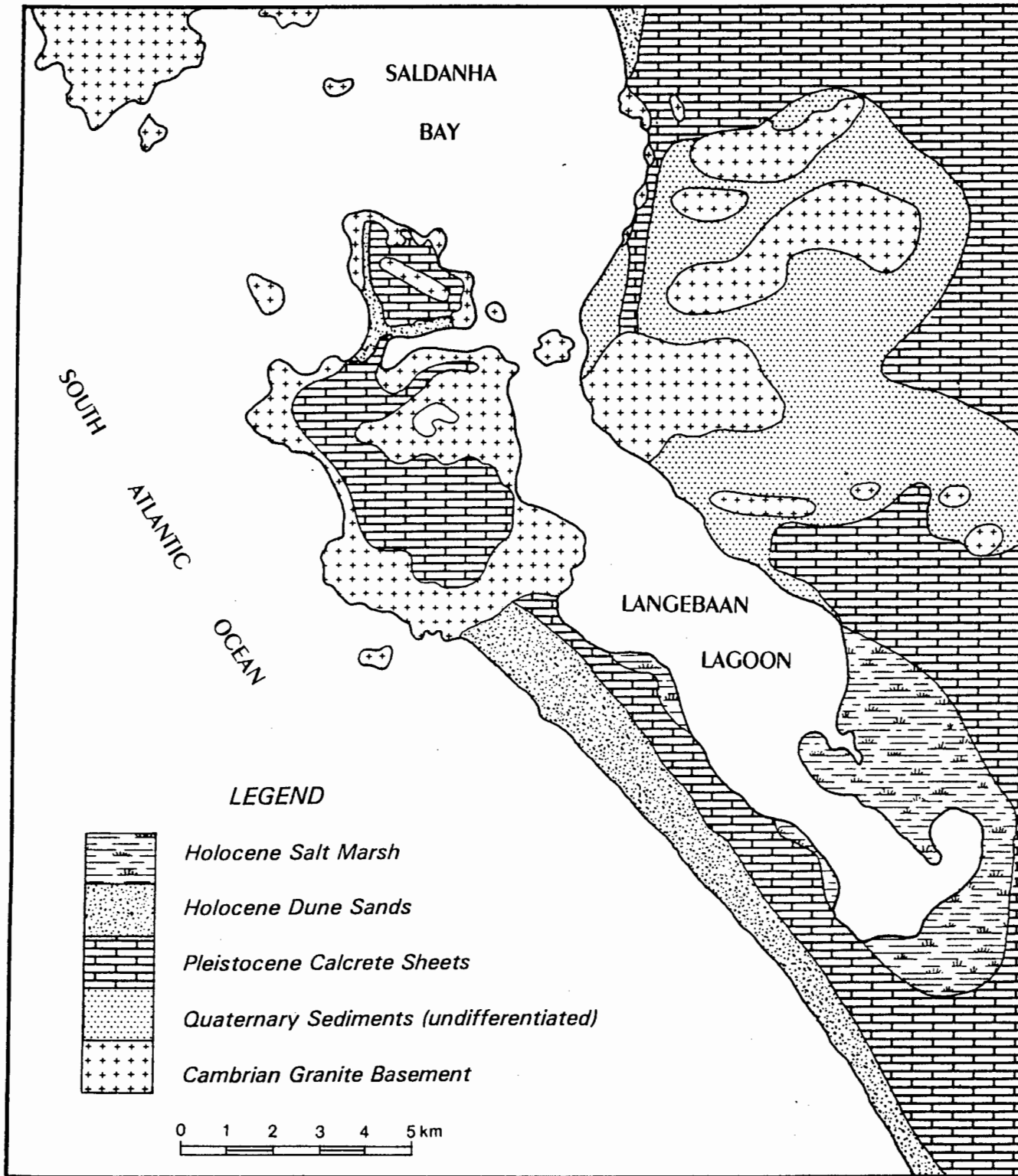


Figure 3.4: Average wind conditions at Langebaan Lagoon (Schulze 1965).

### ***3.3.2 Geology and geomorphology***

The historical development of geology and resultant geomorphology of this region is briefly described in this section. Saldanha Bay and Langebaan Lagoon have been created by the dramatic sea level changes which have occurred during the Cenozoic era. Palaeological evidence suggests sea levels have been 140 m higher and some 100 m lower than at present. During the lower periods large barrier sand dunes built up along the coastline. In the late Tertiary period during most recent sea level advances ( $\pm 9000$  years ago), these dunes were submerged and washed away. The barrier dune which forms the Donkergat Peninsula was broken through at the rocky headlands which today mark the mouth of Saldanha Bay. These headlands prevented lateral erosion, ensuring the survival of the dune peninsula. The slack behind the dune flooded to form the Langebaan Lagoon (Gordon 1990).

Figure 3.5 shows the local geology of the onshore region of the study site. Broadly speaking the geology of the study site is relatively uncomplicated. The general relief around the area is dominated by the erosion resistant Cape granites which form a foundation of the entire area. These granites form a sub branch of the Cape granites called the Darling granites (Flemming 1977). The rocky headlands surrounding the mouth of Saldanha Bay, the islands and highlands around the lagoon are all composed of Darling granite. Originally these granites intruded into Malmesbury Shales which in turn were covered by Table Mountain Sandstones (T.M.S.). Today the Malmesbury Shales and T.M.S. have been eroded away exposing outcrops of the granite basement. The numerous marine transgressions and regressions of the Tertiary and Quaternary periods have resulted in deposits of sediments over the granite foundation. Extensive calcrete sheets (the fossil remains of oyster beds) are found in and around the lagoon, providing excellent evidence of



**Figure 3.5: Local geology.**

(After Flemming 1977)

marine inundation in the past. Outcrops of these sheets have been found under all the salt marshes at Langebaan Lagoon and these appear to be important as they form a stable platform onto which the salt marsh develops. The calcrete outcrop Geelbek is clearly discernible as a step which is marked by the vegetation boundary between *Sarcocornia* and *Scirpus*.

### ***3.3.3 The Lagoon (Physical and hydrological characteristics)***

The Langebaan Lagoon is separated from Saldanha Bay by Skaapeiland (Sheep Island), situated in the mouth of the lagoon. From here to Geelbek in the south the lagoon is 14.5 km in length. At the widest point it is approximately 4.0 km. With an average depth of 1 - 2 m the lagoon is relatively shallow with a maximum depth of 6m to be found in the channels on either side of Skaapeiland (Flemming 1977).

During tidal fluctuation, the lagoon interchanges water with Saldanha Bay which is approximately twenty times bigger than the lagoon.. During tidal fluctuations half the lagoon water passes into the bay, effectively causing the lagoon to behave much as a lung does, where residual water remains in the system, partial exchange occurs with the Bay and little direct exchange occurs with the “fresh” coastal water from the Atlantic (Shannon & Stander 1977). This slow water change rate with the Atlantic effectively means that pollution in Saldanha Bay or the lagoon would not be readily dispersed and this could have serious consequences for the survival of the salt marsh vegetation. This makes management of the water quality in the lagoon and bay an important priority. For all intents and purpose the lagoon water is consider to be pure sea water despite there being evidence of fresh

water seepage into the Lagoon mainly during the winter months. While this has little or no measurable effect on the lagoon water, it could have bearing on the distribution of the salt marsh vegetation. Fresh water seepage is evident at Oostewal and Geelbek.

The clarity and shallow nature of the lagoon waters results in relatively high water temperatures (approximately 14° C in winter to 25° C in summer) when compared to the average 15° C of the coastal waters (Flemming 1977). Day (1959) found that during the day water temperatures generally increase from the mouth to the head. This is due to the shallow nature of the lagoon towards the head which allows for greater solar heating. Water temperatures have a direct consequence on the ability of water to hold dissolved gasses which in turn effects the growth performance of salt marsh vegetation.

As can be expected the shallow and warm nature of the lagoon leads to higher evaporation rates and consequently higher salinities (See Table 1). Saldanha Bay and the coastal waters both have an annual average salinity of 34.9 ‰ while the lagoon in the summer average shows an increases in salinity from the mouth (34.8 ‰) to the head (38 ‰) (Christie 1981). O'Callaghan reports finding salinities as high as 140 ‰ in the creeks of Geelbek, while Flemming (1977) reports a high of 48 ‰ for the same area. In winter, while the salinities at the mouth remain fairly consistent due to larger water volumes and intermixing with the bay, the opposite is true for the headward side of the lagoon. Smaller water volumes and little exchange means that heavy winter rainfall can bring salinities down to 33 ‰ at Geelbek (Christie 1981). Langebaan Lagoon appears to have a far greater scale of saline fluctuations than estuarine environments. The freshwater influence on a seasonal basis forms an important component in any discussion on the salt marshes of this region.

**Table 1: Seasonal salinity ranges in selected parts of Langebaan Lagoon. (Flemming 1977).**

STATION	WINTER	SUMMER
Mouth	33	34
Kraalbaai	32	34
Bottelary	30	34.5
Churchhaven	32	35
Geelbek	33	36.5
Salt Marsh Creek (Geelbek)	22	48

The Hydrological Tidal Tables of the South African Navy (1987 to 1994) all show a spring tidal range or mean high water springs (MHWS) of 1.76 m for Saldanha Bay. Although there is a semi-diurnal tidal cycle in the bay, the tidal current here is barely noticeable moving at a speed of 0.15m/s (Shannon & Stander 1977) This is not the case at Langebaan Lagoon, for when the tide in the bay turns, the water from the lagoon becomes temporarily dammed due to the obstruction of Skaapeiland causing the water to surge through the narrow channels on either side of the island, setting up strong currents of approximately 1.3 m/s. Before the lagoon has had time to empty incoming tides begin to push, which has the effect of reducing tidal ranges in Langebaan Lagoon (Day 1959, Shannon & Stander 1977).

Accurate estimates of tidal levels in the lagoon are difficult to ascertain as there has never been any large scale official tidal survey. O'Callaghan (1994) provides some detailed of tidal characteristics at various salt marsh sites, but long term research has yet to be carried out to establish subtle variations in tidal levels caused by tidal lag, strong winds and basin

morphology. Such a study would certainly help to provide a better understanding of the subtle differences in height found between the three salt marsh transects in this study. As discussed in Chapter 2, tidal inundation plays a crucial role in the floristic arrangement of salt marshes. The zonation of the salt marshes at Langebaan Lagoon is extremely well defined, more so than in similar vegetation found along estuaries. The lower tidal range of some 1.4 m in the lagoon (1.76m in Saldanha Bay) may restricted the vegetation to narrower vertical bands making the zonation patterning very striking in the region. The tidal effects on the specific salt marshes examined in this study is discussed in Chapter 6. Actual tidal measurements are discussed in Chapter 4 under the section on levelling.

In the lagoon the disturbance of sediments by hydraulic action of tidal currents is restricted to the deeper channels. As with the tides, wave action is attenuated in the lagoon. Oceanic swells are not appreciable here because of the shelter afforded by Eland's Point (Elandspunt) and Skaapeiland. The limited fetch of the wind on the lagoon results in a wave height which seldom exceeding more than 15 cm (Day 1959). This is another factor which may contribute to the apparent limitation of the vertical ranges of the plants. Since storm surges and wave action during tidal extremes play a role in determining the vertical extent to which salt marsh species will develop (Chapman 1974), at Langebaan Lagoon low tidal amplitude and reduced wave heights would suggest a narrower vertical limitation in the salt marsh plant distribution.

### **3.4 Local ecology**

The coastal area of the Langebaan Lagoon provides an ideal setting for a National Park. This park is situated in a division of the Lowland Fynbos known as the Strandveld

formation, an area which is particularly threatened by coastal development. The park provides an opportunity to conserve and enhance a unique ecosystem unparalleled anywhere else in southern Africa. On a yearly basis this region becomes home to half the world's total population of a sub-species of the swift tern, a quarter of the world's Cape gannet population and approximately 15 and 12 percent respectively of the world's population of crowned cormorants and African black oystercatchers (Robinson 1990). Whereas the majority of these birds are waders, there are also colonies of endangered Jackass penguins on Marcus, Jutten, Vondeling and Malgas Islands. The area around the lagoon is also home to multitude of terrestrial bird species, with some two hundred species on the bird list of this area (Underhill 1990).

The waters of the lagoon are rich in invertebrate organisms with some five hundred species having been recorded (Gordon 1990). The nutrient rich, upwelled waters of the west coast have an abundance of plankton, although as Gordon (1990), points out, this plankton source does not reach Langebaan Lagoon. The reasons for this are twofold; firstly, the plankton is effectively filtered out of the water by the massive beds of white mussels (*Donax serra*) which proliferate in the channels through which the intertidal water supply moves into Langebaan Lagoon and Saldanha Bay. Secondly, and more importantly, the nutrients particularly the nitrates on which the plankton thrive, are drained and utilised by the prolific salt marshes (Gordon 1990). Hence, the salt marsh plants assume primary importance in the supply of energy to the entire food chain in the richest lagoon ecosystem in South Africa (Gordon 1990).

The nutrient supply from the plants comes mainly after the summer growing season when the salt marshes die back. Christie (1981) examined primary production in the Langebaan

Lagoon finding high phosphate levels in summer and corresponding low nitrate levels for the same period. This is caused by the release of phosphates by decaying plant matter and the consumption of nitrates by salt marsh plants during the growing season. Bacteria feed on the decaying plant matter breaking it down into a more easily digestible food particles. Bacterium and detritus provide food for a huge invertebrate population which inhabits the extensive sandbanks and mudflats in the lagoon shallows. These in turn become food for higher order predators such as birds. Besides sandsharks, which can lie hidden under the sand, the lagoon generally has a paucity of fish species perhaps because fish may be easily targeted by predators in the clear shallow waters (Day 1981). The large number of birds frequenting the area has a major impact on the ecology of the lagoon. They consume an estimated 150 tonnes of invertebrates on an annual basis, of which about a third is returned to the lagoon and salt marshes as guano. This provides a rich source of fertiliser to the salt marshes upon which the bird life ultimately depends for its own food source (Gordon 1990).

The importance of the salt marshes to the overall functioning of the Langebaan Lagoon ecosystem should not be underestimated as they form the basis of a food chain which supports the entire unique ecosystem. The proclamation of the lagoon and its surrounds as a National Park has resulted in the salt marshes receiving the protection and care which will ensure a sustained future for this natural resource.

### **3.5 Vegetation**

The vegetation of the Langebaan area is for purposes of this study, considered as consisting of two components: terrestrial vegetation and halophytic vegetation. This section entails a description of both.

Acocks (1988) indicates in his vegetation survey of this area that three Veld Types can be distinguished, namely: West Coast Strandveld; Coastal Rhenosterbosveld and Cape Macchia. He describes the West Coast Strandveld as being the largest component of this district, consisting of either 'Dense, dwarf, semi-succulent scrub' or 'Strandveld proper, an open, semi-succulent scrub of Fynbos form and intermediate between the Coastal Fynbos and the Succulent Karoo (Acocks 1988, p.75). Acocks describes the Rhenosterbosveld as a mixture of grass and Fynbos which merges into the drier Strandveld. He finds more than half of his 12 principle species of Coastal Fynbos in the Strandveld, indicating a strong presence of the Cape Macchia Veld Type. Acocks makes no mention of halophytic vegetation in the area.

Taylor & Boucher (1973), using satellite imagery to determine vegetation boundaries of the South-Western Cape are mostly in agreement with the Acocks' account of the vegetation, but also note a distinctive boundary demarcating halophytic vegetation from terrestrial vegetation around Langebaan Lagoon. An extensive well detailed survey of the terrestrial vegetation in the Langebaan area has been conducted by Boucher & Jarman (1977). Using colour air photographs and a Braun - Blanquet methodology, they could discern 20 terrestrial plant communities in this vicinity. From this survey the majority of the plant communities could be linked to distinct soil conditions. In this report marsh communities are treated as a distinct halophytic component characterised by the presence of *Sarcocornia pillansii*.

The salt marshes of Langebaan Lagoon are similar in floristic composition to most other salt marshes in the world. They too are characterised by a few cosmopolitan genera,

namely: *Spartina*, *Sarcocornia*, *Salicornia*, *Limonium* and *Juncus*. As in other salt marshes these genera arrange themselves on a shoreline roughly between the highest (HAT) and lowest (LAT) astronomical tides. In areas where fresh water seepage occurs *Phragmites* and *Scirpus* are prevalent, this is especially the case at Geelbek.

In this study the eelgrass *Zostera* was also included as a part of the salt marsh community. Research on salt marshes often excludes *Zostera* as it can in the strictest sense be regarded as a true aquatic plant. (Zedler 1977; Adam 1981; Long & Mason 1983;) The *Zostera* at Langebaan Lagoon is readily found interspersed in the lower *Spartina* dominated parts the salt marsh (Pers. obs.) and plays an important ecological role in the nutrient cycling of the lagoon system (Christie 1981). Appendix A lists all plant species that were encountered within the studies transects. Appendix B shows the species composition and percentage cover of each belt quadrat survey.

# **Chapter 4      Methodology**

## **4.1 Introduction**

The aim of this chapter is to provide detail of the various approaches, methods and techniques utilised in this study. It is hoped that this will ensure accurate replication should the need arise for comparative or monitoring purposes in the future. Where deemed necessary a justification for the choice of approach, method or technique is given.

This study is aimed at elucidating and understanding the underlying causal processes that have generated patterns in salt marsh communities. Choices of approach, method and technique have to provide a framework within which this aim can be addressed. A complicating factor is the existence of a multitude of environmental variables that can exert influence on a plant species in any given place at any given time. No single study has ever, or perhaps could ever, hope to account for all such influences. As is the case with most research, a form of selection becomes necessary. In this study, this selection process has taken into account current and previous salt marsh research and the limitations inflicted by availability of analytical equipment, funding, time and expertise. Four distinct components in the methodology of this study provide a useful breakdown for this section. These are:

- a) Vegetation analysis and soil sampling.
- b) Soil analysis
- c) Transect height and position survey
- d) Analysis of results

In some instances these sections are further sub - divided to provide additional detail of the methodology employed.

## **4.2 Vegetation analysis and soil sampling**

### ***4.2.1 Vegetation survey***

A primary objective of this study was to establish whether or not plant zonation could be statistically or quantitatively distinguished in the salt marshes of Langebaan Lagoon. If zonation was evident, then the remaining objectives could be realised. As discussed, the majority of salt marshes are characterised by relatively clear plant zonation. When compared to the majority of salt marshes in the Western Cape, Langebaan Lagoon shows a remarkable range and degree of zonation. This makes this region an ideal site for studying salt marsh zonation.

The zones in salt marshes result from the arrangement of vegetation into distinctive continuous bands or zones running roughly at right angles to the direction of tidal inundation. First impressions can however be misleading. When viewed from some distance, these zones appear to be comprised of a single species. Closer examination usually reveals that each zone is occupied by one or more dominant species which in combination gives each zone a distinctive appearance due primarily to differing combinations of floristics.

Determination of the floristic composition and the mapping of the salt marsh was an important component in this study as it established the location of species and the occurrence of distinct communities along each transect. Comparison between transects would make it possible to determine the occurrence of these communities in similar environments at different locations on the shores of Langebaan Lagoon.

Numerous techniques can be employed to systematically study vegetation. Traditionally, transect surveys are the most commonly used for examining species distribution and vegetation changes along environmental gradients (Tansley 1926; Vince & Snow 1984). Transect surveys have also proved to be a popular method for the study and analysis of salt marsh vegetation (Campbell & Gray 1989; Zedler 1977; Adam 1981; Vince & Snow 1984; Vevele 1985; Bertness & Ellison 1987 and Partridge & Wilson 1988). The decision to use a transect survey was based on the assumption that these would provide an adequate platform from which the salt marsh could be floristically described, mapped and sampled and thereby achieve the objectives of this study

A preliminary survey of the lagoon shoreline showed a predominance of salt marsh in three areas (Refer to Figure 3.2):

- 1) The eastern shore : - a continuous strip of salt marsh stretching from the farms Klein Oostewal to Bottelary.
- 2) The southern shore : - the head of the lagoon where the largest expanse of salt marsh is to be found around the farm Geelbek.
- 3) The western shore ( peninsula): - salt marsh similar in extent to the eastern shore, but restricted to bays between prominent rocky headlands. The largest

expanse of salt marsh is found on the farms Schrywershoek and Stofbergfontein.

The imposition of scale, time and budget on this research meant that ultimately three transects were established. These were set up on the salt marshes at Oostewal, Geelbek, and Schrywershoek ( Marked respectively as T1, T2 & T3 in Figure 3.2). These particular sites were chosen primarily to represent a range of microtopographical and floristic the salt marshes at Langebaan Lagoon. Further considerations taken into account were the acquisition of right of entry to the site, the physical ease of accessibility, a relatively low level of disturbance and limited access to the general public to ensure little disturbance of the transect markers and the vegetation to be sampled.

The transects were set up at right angles to the lagoon and clearly defined at the upper and lower limits by two sturdy wooden stakes. The upper limit of each marsh was chosen to correspond with an area above the Highest Astronomical Tide (HAT). The lower limit was set in the bare mud below the *Zostera* zone which was common to the lowest part of all three transects, albeit rather sparse on the Schrywershoek site.

The vegetation was mapped during early January 1988 using a metre square quadrat system along a line transect. Similar approaches have been used by Vince & Snow (1984) and Jacobsen & Jacobsen (1989). A steel 1m<sup>2</sup> quadrat was constructed for this purpose. Piano wire was strung across the quadrat dividing it into a grid of 16 equal parts. A line strung between the transect markers served as the median marker for the grid. The marsh could then be accurately surveyed and re-surveyed meter by metre within a belt 0.5 m

either side of the transect line. This survey system was also used for the allocation and retrieval of soil samples.

An advantage of using a continuous belt to chart the vegetation is that, the whole area is sampled according to a known plan and this avoids erroneous inferences that could arise from recording arbitrarily chosen lines (transects) or random sample plots thought to be typical of a larger area (Tansley 1926).

The study was guided by the principles of a Braun-Blanquet approach to the classification and interpretation of vegetation. This floristic-sociological approach is based on three essential ideas (Whittaker 1973):

- 1) Plant communities are recognised by their floristic composition. The species composition of communities expresses their relationships to one another better than any other characteristic.
- 2) Of the species which make up the communities, some are more sensitive expressions of a given relationship than others. For classification and indication of environment, this approach uses those species with ecological relationships which make them more effective indicators (diagnostic species).
- 3) Diagnostic species are used to organise the communities into a hierarchical classification.

This organisation and hierarchy is invaluable for the understanding and communication of community relationships and provides useful guidelines for this research.

The vegetation in each transect was mapped firstly by identifying and then calculating the percentage cover of each species in every quadrat. The grid divisions within the quadrat helped to simplify this calculation. The Braun-Blanquet approach suggests the use of cover

and abundance to describe vegetation. Abundance relates to the density of individuals per area and to all intents and purposes it is practically impossible to identify individual (i.e. single) salt marsh plants from an examination of aerial structures.(Long & Mason 1983; Pers. obs.). Thus, for this study, dominance is determined by the conspicuousness of the aerial parts of each species (viewed from above). The majority of salt marsh plants only grow to a height of a few centimetres (Pers. obs.) such that vegetation layers were not distinguishable and consequently not be taken into consideration as suggested by the Braun-Blanquet approach (Whittaker 1973).

The details of the vegetation survey were recorded on graph paper during the field research and this information was then later transferred onto a spreadsheet. The results of the surveys for Oostewal, Geelbek and Schrywershoek can be seen in Appendix B

#### ***4.2.2 Soil sampling***

The testing of physical and chemical components of the soil necessitated the removal of soil samples from the three transects for laboratory analysis. The grid system superimposed on the vegetation was also used for the allocation and retrieval of soil samples. This aim of this section is to detail these processes.

The vegetation survey provided the percentage cover of the various species found within each transect. The species which occupied the greatest percentage is designated as the “dominant” species of that particular quadrat. Each species was then ranked according to the total number of quadrats in which they were found to be dominant. Soil samples were

then proportionately allocated to each dominant species according to the number of quadrats (and therefore the size of the area) occupied.

Certain constraints were applicable to this allocation; firstly, to facilitate sufficient representation, at least two samples were allocated to the lowest ranking dominant species. Due to the expense of soil analysis, samples were limited to 40 per transect. The allocated number of samples for each species was then assigned to the quadrats displaying the greatest degree of dominance for a particular species within each transect. Appendix B contains spreadsheets showing species occurrence within each transect, the percentage cover of each species and also indicates the quadrats from which samples were taken. Appendix C contains tables showing the details of the species ranking, allocation of soil samples and a summary of the number of quadrats, number of species, number of samples, number of "non-dominant" species and length of each transect.

The nature of the substrate in the salt marsh at Langebaan meant that the extraction of soil samples by coring was not a straight forward matter. The corer had to be capable of sampling substrate that could be wet (very soft and mobile) or dry (hard and difficult to penetrate). After consideration of a number of a range of techniques suggested by Smith and Atkinson (1975) it was decided instead to adopt a coring method similar to that used by Vince & Snow (1984). This essentially entailed using a stainless steel tube to extract cores.

The soil core samples were all extracted using a slightly modified Penguin stainless steel prawn pump. The only modification made to the pump was to sharpen the leading edge of the tube to make penetration of the substrate easier. This corer proved to be very effective for sampling both wet and dry sediments. A one way valve in the handle at the top of the

pump allows air to be expelled when pushed into the sediment. On extraction this valve closes inducing a pressure lower than the external atmospheric pressure. This ensures the core remains intact inside the tube with little disturbance or mixing occurring during extraction. Once extracted the plunger serves as an excellent aid to gently eject the core.

Cores of 65 mm diameter and approximately 250 mm depth were extracted. The depth of sample was decided after an examination of ten trial cores from the top, middle and bottom of an adjacent area of each transect. Examination showed the roots and rhizomes of the salt marsh plants were mainly confined to the upper 180 - 200 mm of the soil, hence the decision to take soil cores to a depth of 200 mm. Similar depths for soil samples in salt marshes were used by Vince & Snow (1984), Jaworski & Tedrow (1985) and Hemond & Chen (1990).

After each sample was extracted, the corer was rigorously cleaned and dried to ensure that subsequent cores were not contaminated by the remains of previous samples. After extraction each core was carefully placed in labelled polythene bags. Cores from each site were then packed into covered plastic trays for transportation back to the laboratory. Here the samples were frozen to  $-20^{\circ}\text{C}$  to preserve the nitrite, nitrate and phosphate contents.

The three transects were sampled on 2 February 1988. Sampling started at Oostewal at 07.00h, Geelbek at 09.25h and Schrywershoek at 12.05h with all sampling completed by 14.00h. On that day, spring low tides occurred during daylight ensuring that enough time was available to complete all sampling. During spring low tide the entire salt marsh is

exposed, making access easier and sampling of the lower marsh possible. Henceforth this sample session will be referred to as 'sample session 1'

One of the objectives of this study was to test for seasonal variation in the environmental gradients and corresponding vegetation. To achieve this a second set of samples (henceforth referred to as 'sample session 2') were taken from Oostewal four months later during the winter season on 29 June 1988 and finally a third set of samples (henceforth referred to as 'sample session 3') was collected four months later during Spring on 25 October 1988. As with the first sampling session, the second and third sampling sessions involved taking 80 samples (40 per season) from the same locations within the transect. As with the former, these latter sampling sessions were conducted during spring low tides during daylight hours.

With the limitation of a maximum of 200 samples to be chemically analysed, it was decided to limit the testing for seasonal variation to one transect. The Oostewal transect was chosen as it contained the greatest variety of plant species and as it was the shortest transect also had the best coverage in terms of samples per area which meant the sampling was more continuous. A simple index of sample coverage per transect was obtained by dividing the number of samples by the total number of quadrats and expressing the result as a percentage. The resultant scores are:

Oostewal:	75.5%
Geelbek:	25.6%
Schrywershoek:	46.5%

Ultimately, this meant that the information derived from the Oostewal transect would be considered to have greater inferential reliability over the Geelbek and Schrywershoek sites.

### **4.3 Soil analysis**

The soil samples taken from the three transects were subjected to analysis of various physical and chemical properties. Availability of facilities and budget were the immediate determinants as to which soil tests were to be undertaken. The soil sediment analysis, organic carbon content, soil moisture content and preparation of samples and extracts were undertaken at UCT in the laboratories of the Department of Environmental and Geographical Science. The nitrate, nitrite and phosphate determinations were conducted in the Department of Zoology at UCT. The soil nutrient analysis was completed by the Department of Soil Science at Elsenberg, which is the Agricultural Research Institute for the Western Cape Winter Rainfall region. All testing was done in accordance with standard soil evaluation techniques and methodologies. A brief description of each of the methods of analysis utilised in this research will ensue.

#### ***4.3.1 Sample preparation***

The soil cores were prepared according to the requirements of the various tests. Initially the soil samples were frozen to prevent loss and contamination of soil nitrogen and phosphate. Once a soil solution was extracted (see section 4.3.2 below) batches of samples were allowed to thaw inside the polythene bags in order to undergo testing for soil moisture (see section 4.3.3). The remainder of each sample was then air dried in evaporation basins over a week so as not to disturb the chemical status of the ions and organic matter as prescribed by Jackson (1958). Partial cementation in the dried soil as a result of salts and caking was destroyed by gentle crushing between the fingers during the drying process. The sample was

then crushed (not pulverised) using a mortar and pestle and passed through a 2mm sieve to remove stones, plant remains, shell fragments and gravel.

This was the standard method used to prepare soil samples so that subsequent analysis could be carried out on a known weight of 'fine earth' fraction (Smith & Atkinson 1975). The 'fine earth' fraction is routinely used in soil analysis as only material less than 2 mm in diameter is considered to be chemically and physically active in the soil. The 'fine earth' sample was then partitioned by using a V-profile chute splitter until splits of 2-5g were achieved for the organic carbon determination (see section 4.3.4). The soil material was then split to samples of approximately 150g which were subsequently dispatched to Elsenberg for the nutrient analysis (see section 4.3.5). The remaining 'fine earth' from each sample was then retained for use in the event of loss or damage during testing.

#### ***4.3.2 Nitrate, Nitrite and Phosphate determination***

As is suggested by Mostert (1983), the soil samples were frozen within 24 hours of extraction to preserve the status of these micronutrients. A section  $\pm$  20 cm from top of core was cut and allowed to defrost for 3 hours at room temperature. From this, 25g of soil was weighed and thoroughly mixed with 20 ml of purified water. The solution was allowed to settle for 15 minutes and then filtered through a Millipore filter system using Whatman gf/f glass microfibre filters. The filtered soil solution was then stored in capped polyethylene viles and frozen to  $-20^{\circ}$  C.

Within three weeks of initial extraction of the soil samples, the frozen extracts were analysed on a Technicon AA II autoanalysis system using standard procedure as described

by the Technicon industrial systems manual (Anon. 1973) and Mostert (1983). The results of each sample session are expressed in  $\text{mg } \ell^{-1}$  as shown in Appendix D.

#### ***4.3.3 Soil moisture content***

The soil moisture content of each sample was measured using the gravimetric technique as described by Smith & Atkinson (1972). Essentially the test involves the weighing of the soil in its field state following which it is thoroughly oven dried and re-weighed. The weight loss is expressed as a percentage of the dry weight, which gives a measure of the moisture content. The results are shown in Appendix D.

#### ***4.3.4 Soil organic matter determination***

Soil organic carbon has an important bearing on the nutrient status of soils, its accurate determination is therefore an important component in any soil research (Jackson 1958). An initial decision to determine organic matter by ignition was overturned in favour of the more precise Walkely-Black method of organic carbon determination. This is a standard technique in soil analysis in which soil is digested in a mixture of chromic and sulphuric acids. The latter's heat of dilution means that no external heat is applied resulting in 90-95% of elementary carbon being retained. Organic carbon is oxidised to carbon dioxide by the chromic acid which becomes reduced to chromic sulphate. As the amount of chromic acid consumed is proportional to the amount of organic carbon in the soil it is necessary to determine the former by titrating the unreacted excess of chromic acid with a standard

ferrous solution (Smith & Atkinson 1975, p.175). The Walkley-Black methodology as described by Smith & Atkinson (1975, p.175-176) was used in this research. The results for each sampling session are shown in Appendix D.

#### ***4.3.5 Conductivity, pH and soil nutrient (trace element) determination***

All the above determinations were undertaken by the Department of Soil Science at Elsenberg. The 'fine earth' samples (150g) were split to a 50g sample and a 5g sample. The former sample was used to make a saturated water extract and the latter was used to make a citric acid extract. A brief description of the preparation of each extract follows. It should be noted that testing at Elsenberg was conducted on 'fine earth' samples (i.e. dried not field moist samples). All extracts were filtered through Whatman GF/F microfibre filters.

The saturated water extract: - 50g of the 'fine earth' sample was mixed with double distilled water until at the "moisture saturation percentage"(Jackson 1958, p.46). At this point the pH of the sample was measured and subsequently left to stand for half an hour. The sample was then put into a vacuum flask and a filtered saturated water extract drawn out of it. This solution was used to conductometrically determine the soil salinity. The saturated water extract was used to determine the nutrient status of the soil. Table 2 shows the range of elements measured from the saturated water extract:

**Table 2:- Elements measured in the saturated water extract**

<b>Element</b>	<b>Symbol</b>
1) Potassium	K
2) Calcium	Ca
3) Magnesium	Mg
4) Copper	Cu
5) Manganese	Mn
6) Iron	Fe
7) Boron	B
8) Sodium	Na

The citric acid extract: - the acid solution was prepared as follows; 50g of citric acid dissolved in 5 litres of water, heated on a hot plate to 70°C and placed in container for dispensing into sample. This solution (50 ml) was mixed with 5g of soil and heated to 70°C in an oven for one hour. Samples need to be tightly sealed and shaken every 10 minutes. The solution is then filtered and cooled before undergoing nutrient analysis. Table 3 shows the range of elements measured from the citric acid extract:

**Table 3:- Elements measured in the citric acid extract.**

<b>Element</b>	<b>Symbol</b>
1) Chlorine	Cl
2) Sodium	Na
3) Phosphor	P
4) Potassium	K

5) Calcium	Ca
6) Magnesium	Mn
7) Copper	Cu
8) Zinc	Zn
9) Manganese	Mn
10) Iron	Fe
11) Aluminium	Al
12) Boron	B

These two methods of extraction were used to show which nutrients could be considered to be immediately available to the salt marsh plants (saturated water extract) and which nutrients were potentially available to these plants (citric acid extract). The results of these tests can be seen in Appendix D; strength is indicated in p.p.m. (parts per million)

All trace elements were determined by atomic spectroscopy (with the exception of Cl) using either a direct current plasma (D.C.P.) analytical technique or atomic absorption. Due to the excessive concentrations of Na and Cl in the salt marsh soils and the D.C.P. analyser not routinely set-up for these two elements, the Na was determined using atomic absorption and the Cl by titration (see Jackson 1958, p. 261). A full discussion of the method and principles of atomic spectroscopy is considered to be beyond the scope of this research, there are excellent accounts of this technique in Jackson (1958); Winefordner (1976) and Hamilton (1980). The advantage of the D.C.P. technique is its rapid ability to accurately analyse the quantity and quality of up to 20 elements at a time. The choice of elements to be analysed was determined largely by the set-up at Elsenberg. At the time of this research the soils

laboratory was primarily geared towards maximising crop production, hence the particular range of elements examined in this research.

#### ***4.3.6 Soil texture analysis***

A soil texture analysis was completed to establish whether the salt marsh soil within each floristic zone displayed unique particle size characteristics. Due to the large number of sub-samples taken from the original cores, it was deemed necessary to take extra cores from each floristic zone which could be used in their entirety for a particle size analysis. Appendix E contains the data of this analysis.

A mechanical analysis was employed, a method by which the constituent soil particles are separated by sieving. The approach to texture analysis suggested by Buller & McManus (1979) was adopted for this research. The soil cores were placed in open evaporating basins and dried at 60°C for 18 hours. The aggregates in the sample were then gently eliminated by gentle crushing between the fingers. To obtain a representative sub-sample a V-profile mechanical splitter was used to gain splits of roughly 100g. Due to the presence of more than a few percent of clays, a wet-sieving procedure at 0.063 mm (63µm) was employed to remove the fines (Buller & McManus 1979, p. 99-100). The remaining sediment was oven dried at 105°C for 18 hours and re-weighed to ascertain the percentage weight of the silt and clay.

The remainder of the sample was dry sieved through a nest of sieves in a mechanical shaker for 15 minutes, a duration which leads to acceptable reproducibility (Buller & McManus

1979, p. 99). The sieves were arranged so that meshes became progressively finer downwards. Table 4 shows the aperture sizes of the sieves used:

**Table 4:- Sieve aperture sizes**

Sieve apertures (mm)	Sieve apertures ( $\mu\text{m}$ )
2	2000
1	1000
0.5	500
0.25	250
0.125	125
0.063	63

The Wentworth grain-size classification was used to derive class terms for the various grain sizes (Wentworth 1922). Table 5 shows the class terms assigned to the seven particle diameters distinguished in this study:

**Table 5:-Class terms and particle diameters (after Wentworth 1922)**

Class term (fraction)	Particle diameter
Granule	> 2mm
Very coarse sand (V.C.SD.)*	> 1mm
Coarse sand (C.SD.)*	> 0.5mm
Medium sand (M.SD.)*	> 0.25mm
Fine sand (F.SD.)*	> 0.125mm
Very fine sand (V.F.SD.)*	> 0.063mm
Silt and clay	< 0.063mm

\* Class term abbreviation

The results of the soil particle size analysis are presented in tabular form in Appendix E. In the discussion of the results, pie charts showing the average percentage soil fraction for each of the above classes are used.

#### ***4.3.7 Transect height and position survey***

Accurately ascertaining the correct altitude of each quadrat within the transects was an important assignment in this research. As stated by Eleuterius & Eleuterius (1979), and discussed in Chapter 2, tidal inundation and altitude of the salt marsh are found to be strongly associated. It follows that the environmental gradients found in salt marsh soils also appear to be correlated to altitude (Long & Mason 1983). At the same time of the level survey, the position of the top peg of each transect was also established by triangulation.

The height of each quadrat was measured at metres intervals (horizontal) along the transect line, at points corresponding with the centre of each quadrat. This exercise was completed using a Kern single-reflex surveyor's level, tripod and telescopic levelling staff. Thus the relative heights from the top to bottom peg of each transect were established.

The next exercise was to survey in the top pegs of each transect. Appendix F contains the details of this survey. A Wild TC 1000 total station was used to fix the positions of the transects from the surrounding trigonometrical beacons through triangulation.

The heights of the transects were then surveyed in from local bench marks which were established by O'Callaghan in the late 1980's (O'Callaghan 1994 a , b). These had been surveyed in from bench marks formerly established by the CSIR.. Appendix F contains the heights and positions of the top pegs of each transect and surveyed heights of each transect

#### ***4.3.8 Analysis of results***

To gain meaningful insight and understanding from the results of the above analytical procedures, the raw data were sorted, visually analysed from graphs and statistically tested using a multivariate ordination technique. An attempt was made to investigate the data in a manner which would directly address the aim and objectives as stated in Chapter 1. Initially the raw data were put into spread-sheets where sorting was convenient. From here the raw data were formatted for display in Appendices, plotting data trends, comparing data trends and input into a Fortran ordination programme. Ostensibly the data can be seen as consisting of two components: data on the occurrence and abundance of a number of species at a series of sites and data on a number of environmental variables measured at the same. Initially these two components are treated separately, thereafter the analysis increasingly combines them in an attempt to gauge any relationships between them.

The species cover abundance and location results of each transect were plotted onto area charts. For comparative purposes these charts were then combined with the transect heights to create a profile. Combining more than two charts in most cases proved impractical as the scale of axes was invariably extremely different and the chart tended to become cluttered.

As will be recalled from section 4.2.2, soil samples were taken on three occasions. Sample session 1 involved the sampling of all three transects, while the other two sessions involved

As will be recalled from section 4.2.2, soil samples were taken on three occasions. Sample session 1 involved the sampling of all three transects, while the other two sessions involved sampling only at Oostewal to ascertain seasonal variation. The data from these sampling sessions were examined using univariate plots created with Microsoft Excel. Using this method, the trends of each variable could be ascertained within each transect. Similarly, comparisons of trends could also be made between the three transects.

Univariate plotting was used as an exploratory exercise to look at how trends varied within and between transects. While this technique gave a reasonable qualitative overview of variate performance, it did not quantify the species-environment relationship. An objective of this study was to determine the extent of influence and significance of environmental factors on salt marsh vegetation patterns. This required a multivariate analysis technique that related community composition to known variation in the environment. After deliberation on the suitability of various statistical programmes CANOCO (Ter Braak 1987) was selected. CANOCO an acronym of CANOnical Community Ordination contains a suite of multivariate analyses specifically tailored for the data analysis of community ecology. The programme is therefore an ideal for the investigation of species-environment relationships. Conveniently, the programme also has facilities to graphically display results, thus simplifying interpretation and presentation.

Canonical Correspondence Analyses (Ter Braak 1987) were used to examine the relative importance of the environmental variables on the salt marsh vegetation. This direct gradient analysis technique (as opposed to indirect methods of ordination and cluster analysis) uses canonical ordination to avoid the assumption of linearity and detect unimodal relationships between species and external variables (Whittaker 1973, Ter Braak 1986, Gauch &

CANOCO allows for an interactive procedure whereby the results can be examined to establish whether the maximum benefits of the analysis are being attained. The main source of interference in this particular procedure, is the problem of multicollinearity. Multicollinearity is a problem which is well known to occur in multiple regression techniques (Ter Braak 1987) and happens when the environmental variables strongly correlate to each other. Various techniques can be used to overcome this problem, the most obvious being the dropping of strongly correlated variables.

The standard CANOCO iterative procedure (as described by Ter Braak 1987) was used to ascertain the best arrangement of the data. Complete data sets were subject to the analysis and from these results the majority of strongly co-correlated variables thinned out according to the prescribed procedure. In this way the important variables (i.e. with the greatest eigenvalue scores) are maintained and those with a low eigenvalue scores are removed until the iterative ordination algorithm reaches convergence. The results of the CANOCA are presented as correlation matrices (see Appendix G) and ordination biplot diagrams in chapter . The method of interpreting these diagrams is fully discussed in the programme handbook. (Ter Braak 1987) and will be briefly described in the section on correspondence analysis in the following chapter.

## **Chapter 5      Presentation of results**

### **5.1 Introduction**

The purpose of this chapter is to present and discuss the graphical and statistical results of the various analyses described in the previous chapter. The study has generated a wealth of data which prompt much discussion and comment. To provide a focus, only information which pertains to the aims and objectives (Chapter 1) will be presented in detail, although most of the data is provided in the appendices. This chapter is divided into five sections which present the results of the various tests and observations undertaken within each transect, namely:

- 1) The occurrence and organisation of salt marsh species.
- 2) Trends in the environmental parameters.
- 3) Relationships between salt marsh species and environmental parameters.
- 4) The relationship between soil texture and species occurrence.
- 5) Canonical correspondence analysis.

Each of these sections begins with a brief introduction explaining the approach and objective. In a few instances, due to space limitations in diagrams the various species may be referred to by number rather than name. A key to the numerical representation of the species can be found in Table 6 in Appendix A.

Discussion of the results within each of the five sections follow a similar pattern. In sample session 1, the three transects are discussed in the following order:- Oostewal, Geelbek and Schrywershoek. Examination of seasonal variation concerns only the Oostewal transect

which is discussed in the order:- sample sessions one, two and three i.e. February, June and October respectively. Hereonin when referring to the top of the transect this will mean the first quadrat (i.e. 1) and, in all three transects the most elevated part of the gradient.

## **5.2 The occurrence and organisation of salt marshes species**

Central to this research was the examination of the arrangement of the various plant species within each transect. Even to the casual observer, zonation of the salt marsh at the three transect sites is self evident. Closer examination was required to ascertain the nature of this zonation and more specifically if this zonation was caused by various species predominating in specific areas. The results of the vegetation survey of each transect are shown in Appendix B. Figures 5.1 to 5.12 of this section graphically demonstrate these results. The longer transects are presented in two or three sections to alleviate the technical problem of overcrowded graphics. The results of each transect are graphically portrayed in four different ways to highlight various aspects of the data. Where necessary specific charts are referred to, otherwise comments pertain to all four styles. In the interest of brevity no attempt is made to comment on every single species, rather comment is restricted to general or more obvious trends within each transect.

### **5.2.1 Oostewal**

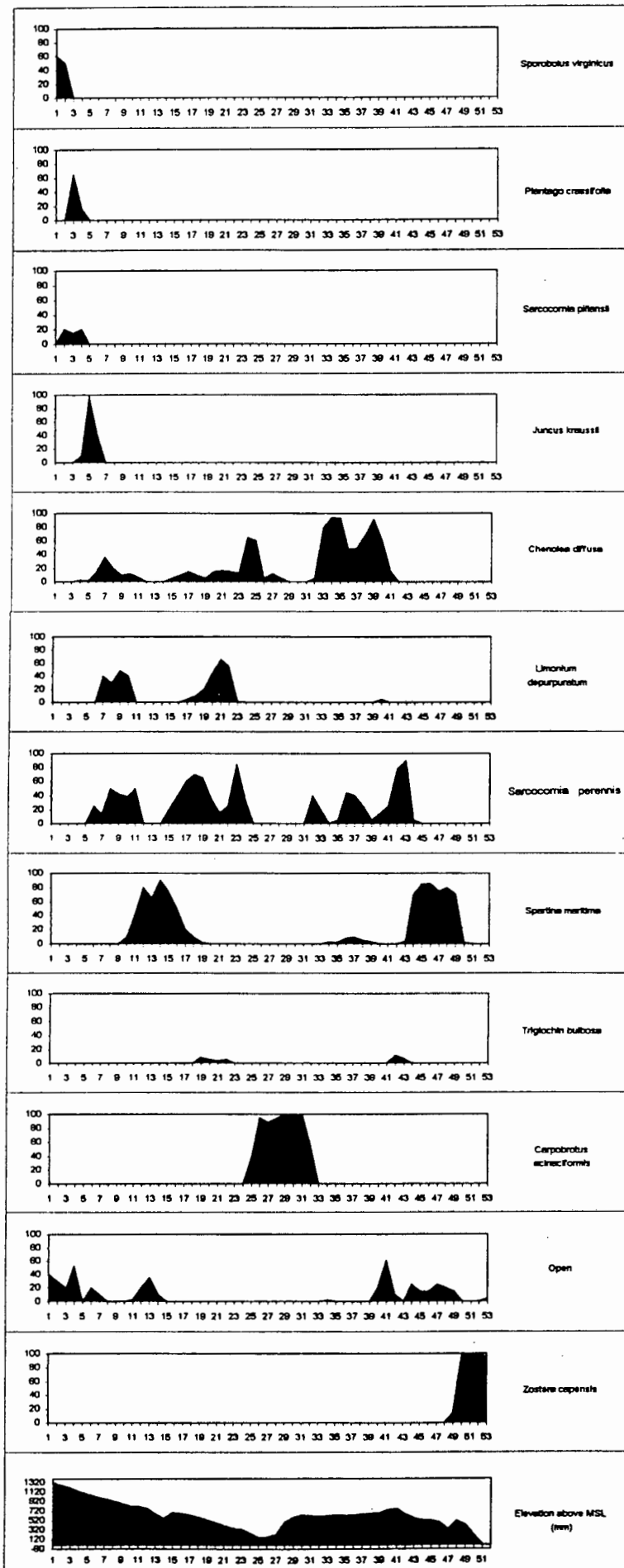
Oostewal, the shortest of the three transects (53m), was also found to be the steepest (average gradient 1:40) and contained the most species (11). A glance at the profile shown in the elevation chart in Figure 5.1 also suggests that this transect in comparison with the

other two (Figures 5.5 & 5.9) shows the greatest degree of altitudinal variation within its length. This suggests the existence of a relationship between altitudinal variation and species richness.

Figure 5.1 shows the occurrence of species from the top to the bottom of the transect. With the exception of *Chenolia diffusa* and *Sarcocornia perennis* which were found in varying quantities in a number of quadrats, most species appeared to dominate (i.e. occupy the greatest cover) specific areas within the transect. Figure 5.1 also clearly shows that certain species have preferences for the particular parts of the transect. Taking extreme cases such as *Zostera capensis* and *Sporobolus virginicus* clearly demonstrates this point, but this situation is not so obvious for other species such as *Spartina maritima* which shows a distinct preference in both the upper and lower parts of the marsh. Closer examination, however, reveals that the *Spartina sp.* in the upper part of the marsh dominates an area on the banks of a creek making that part of the marsh more susceptible to inundation. The patch of *Juncus sp.* around quadrat 3 suggests the presence of fresh water seepage as this sedge does not tolerate high salinities. *Carpobrotus sp.*, normally found at the terrestrial edge of some salt marshes, was found to dominate the elevated slopes of the raised section between quadrats 26 and 37. Bare patches of ground with no plant cover were relatively scarce, found mainly at the very top of the transect and in the areas where *Spartina sp.* occurred.

Figure 5.2 is an area chart which clearly illustrates the position and domination of particular plant species in specific sites within the transect. From this chart it can be seen how the dominance of a particular species within a particular area can lead to the zonation pattern so typical of salt marshes. Figures 5.3 and 5.4 are three dimensional (3D) charts, with the

**Figure 5.1:** The distribution and cover (%) of plant species at Oostewal



**Figure 5.2: Oostewal species cover and position area chart**

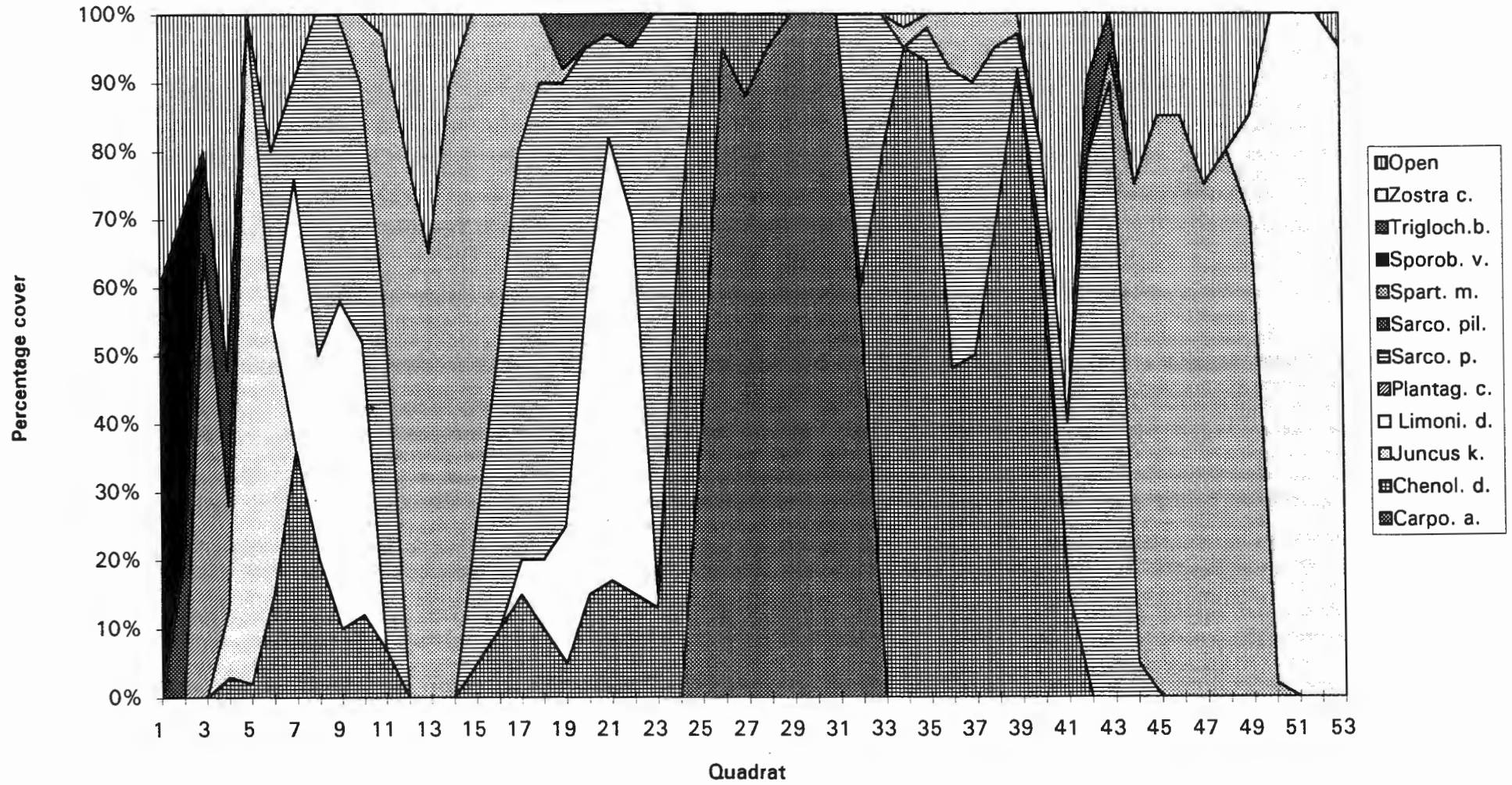
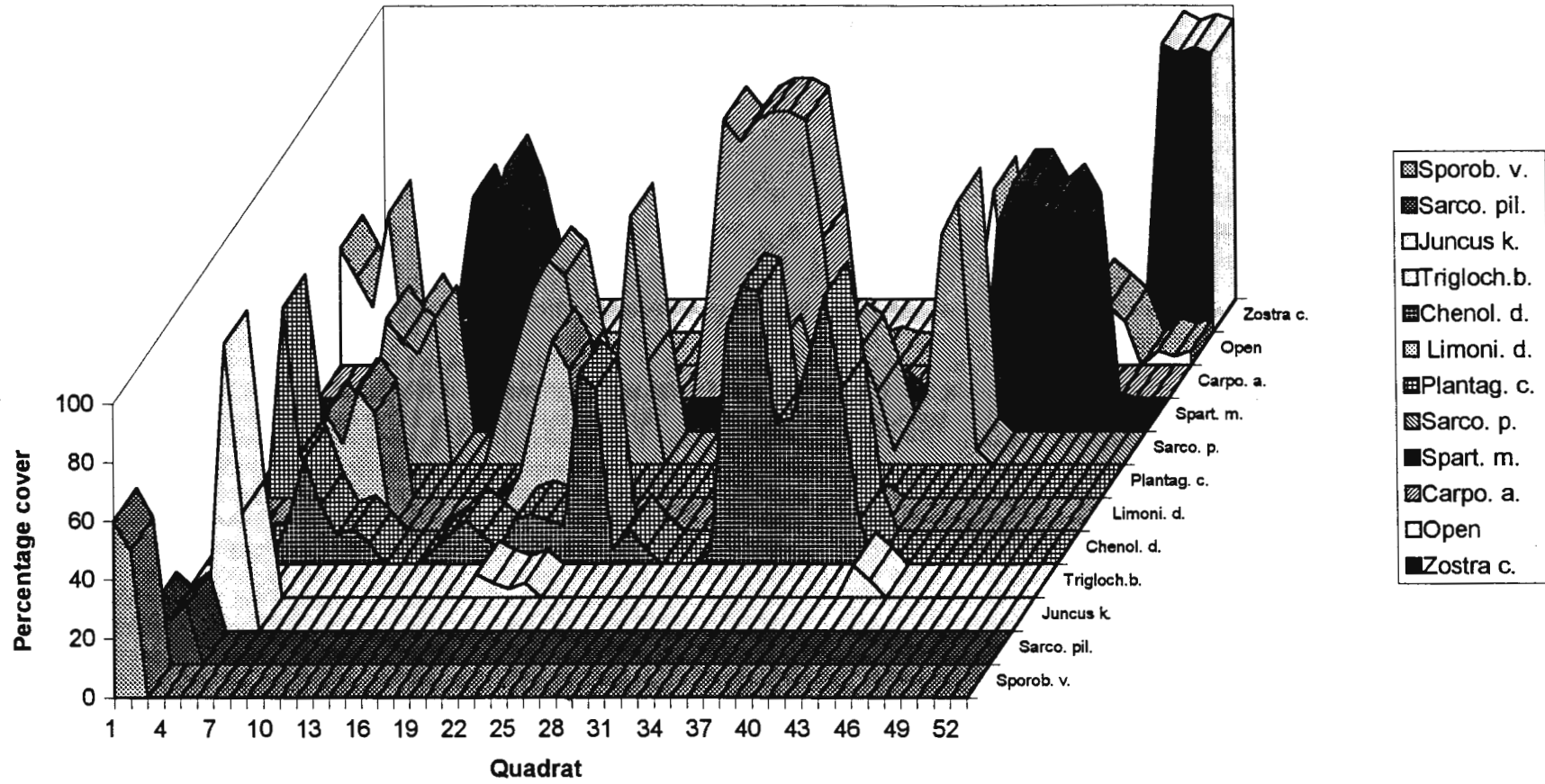
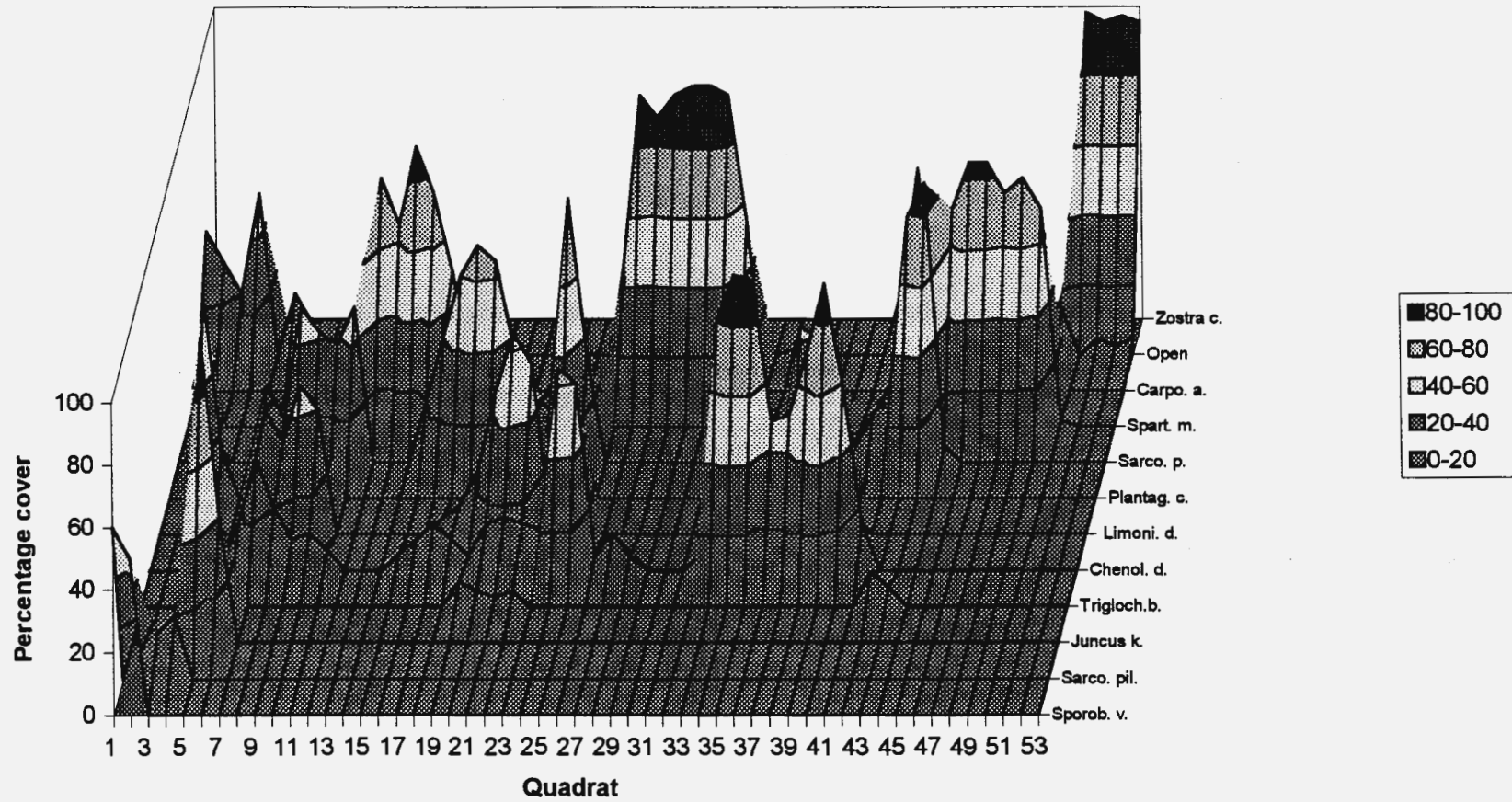


Figure 5.3: Oostewal species cover and position (3D)



**Figure 5.4: Oostewal species cover and position (3D AREA)**



former clearly illustrating the percentage cover and position of the various species and the latter a 3D surface chart more specifically illustrating the degree of cover for the various species.

From the above results there can be little doubt that plant zonation is evident in the grouping of the various plant species in the Oostewal transect. In some cases there is strong correlation between elevation and species position and cover but in other cases this relationship is not so clearly apparent. The assignment of divisions such as upper, middle and lower within the marsh serves as an aid to discussion. These divisions are arbitrary and will be used in general terms to describe the associations within the salt marsh. In general terms in order from top to bottom of the transect *Sporobolus virginicus*, *Plantago crassifolia*, *Sarcocornia pillansii*, *Juncus kraussii* and *Carpobrotus acinaciformis* are seen to occupy the upper or elevated parts of the salt marsh. *Limonium depaurpuratum*, *Chenolea diffusa*, *Sarcocornia perennis* are seen to occupy the middle salt marsh and *Spartina maritima* and *Zostera capensis* occupy the lower marsh.

### **5.2.2 Geelbek**

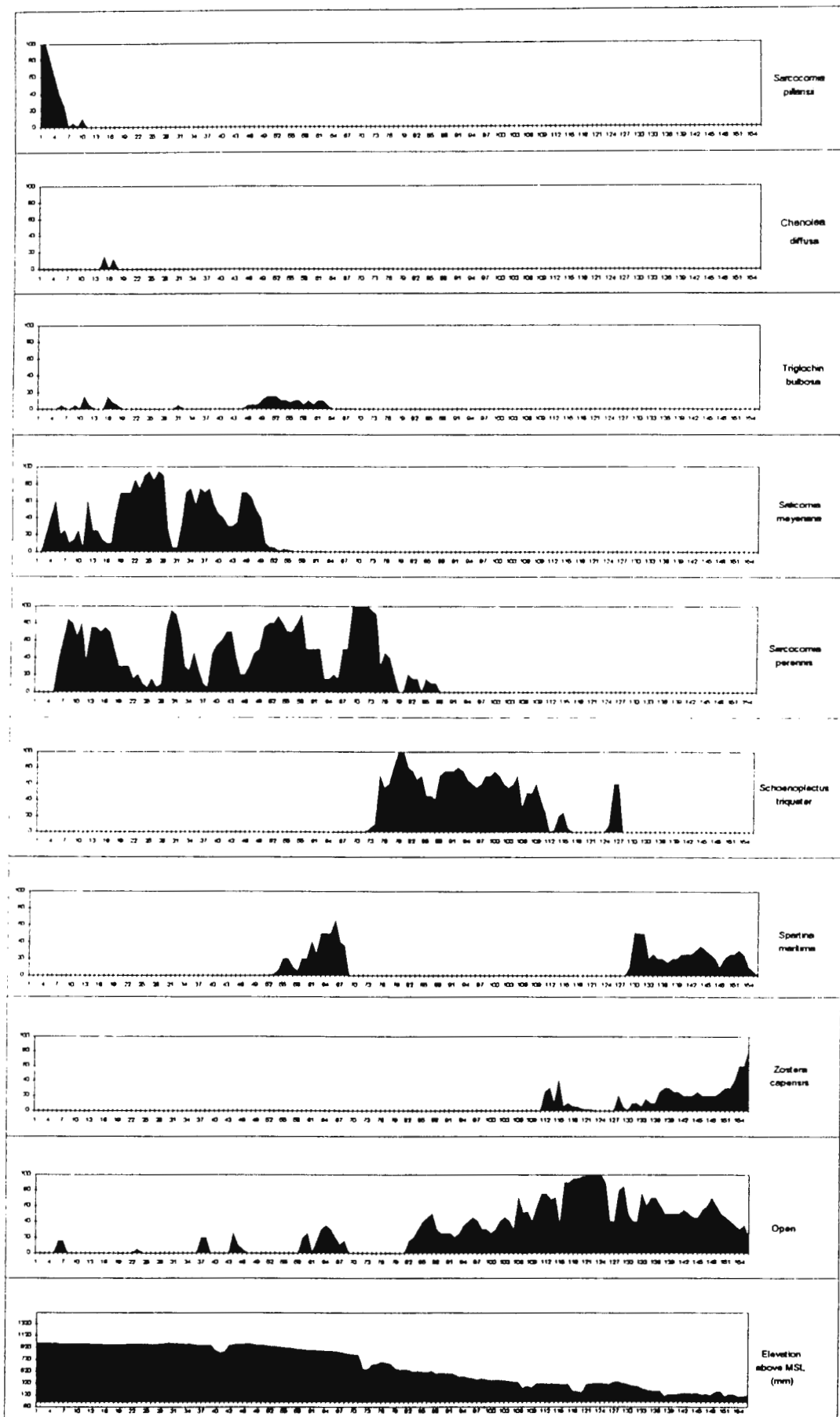
Geelbek is the longest (156m) of the three transects with an average gradient of 1: 165. Eight species of plants were found to exist within the transect, two of which did not occur with sufficient cover abundance to qualify as “dominant” (See Table 10 in Appendix C). An examination of the elevation chart in Figure 5.5 reveals that the profile of the transect is relatively regular with the exception of creeks (quadrats 40 and 119) and the sharp break or step recorded at quadrat 73. This step, as mentioned in Chapter 3, marks the discontinuity of the calcrete sill which underlies this salt marsh. The area below the step in the transect is

characterised by its wet, muddy nature, whilst the area above the step is firm under foot and relatively dry at tidal lows.

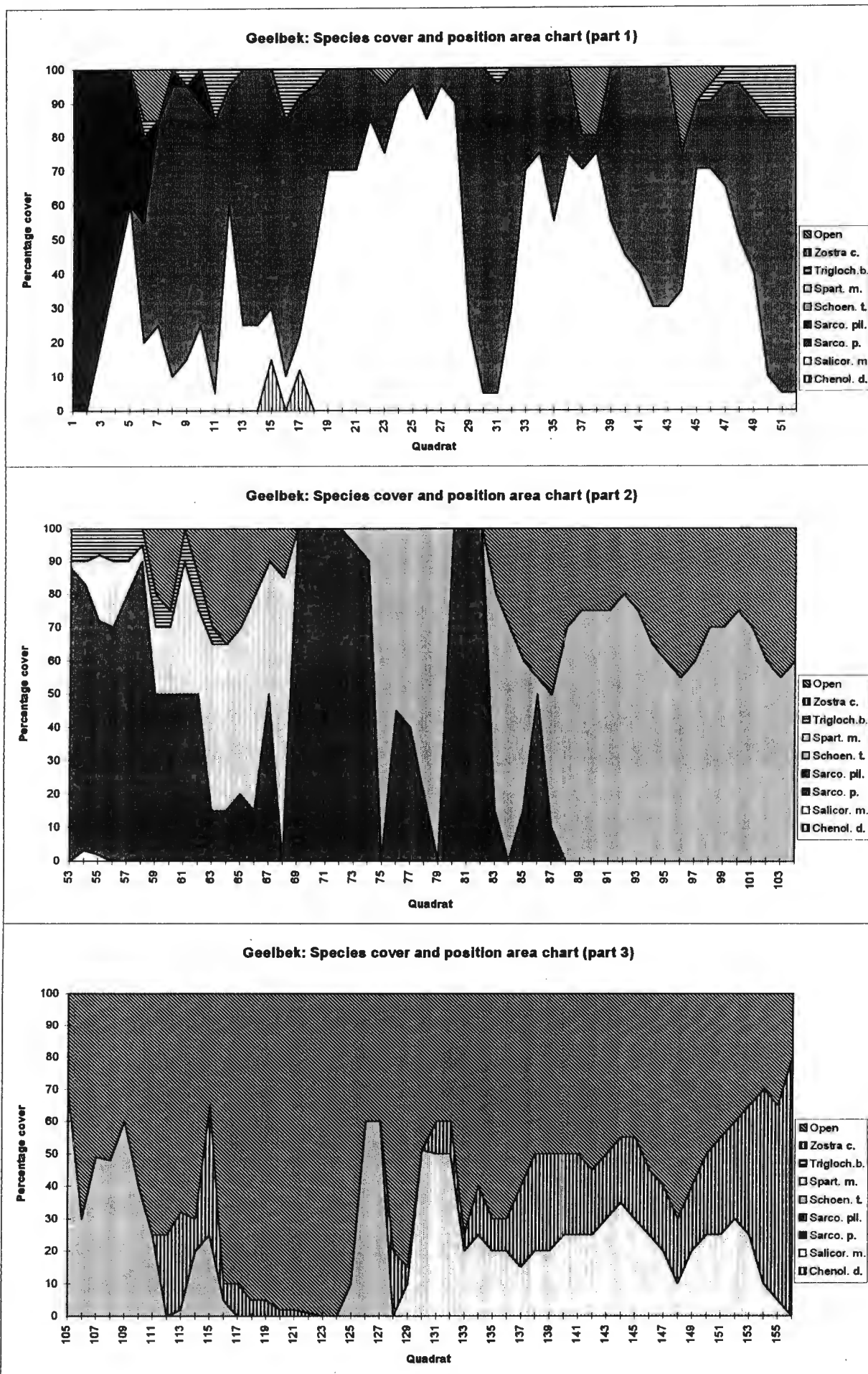
The zonation of the plant species at Geelbek is more noticeable than at Oostewal, probably due to lower numbers of dominant species and the relative lack of terrestrial species which make this transect more representative of true salt marsh vegetation. The results of the species and cover survey (Figures 5.5 & 5.6) clearly show the existence of domination of various species within specific areas within the transect. *Sarcocornia pillansii* clearly dominates the first 5 quadrats of the transect, from quadrat 5 to 50 alternating bands of dominance by the annual *Salicornia meyeriana* and *Sarcocornia perennis* are evident (see Figures 5.6, 5.7 & 5.8). The open or bare patches of ground are confined mainly to the area below the step, the creeks and the band of *Spartina sp.* above the step. The step also marks an abrupt change between *Sarcocornia perennis* and *Schoenoplectus triqueter*. This latter species is not a salt marsh plant and like the *Juncus sp.* found at Oostewal indicates the presence of fresh water seepage from beneath the calcrete sill. The presence of fresh water seepage is further supported by the large stands of *Phragmites australis* some 250 metres to the east of the transect and has also been noted by O'Callaghan (1994 a & b). *Zostera sp.* and *Spartina sp.* are found to dominate the lowest end of this transect.

These results show strong evidence of plant zonation caused by the dominance of cover by various species in particular quadrats within the transect. The relationship between elevation and species position is perhaps stronger here than in the Oostewal transect, but does not account for the sharp transitions between adjacent zones found roughly at the same height. Generally, the species *Sarcocornia pillansii*, *Chenolea diffusa*, *Triglochin bulbosa* and *Salicornia meyeriana* occupy the upper reaches, *Sarcocornia perennis* occupies both upper

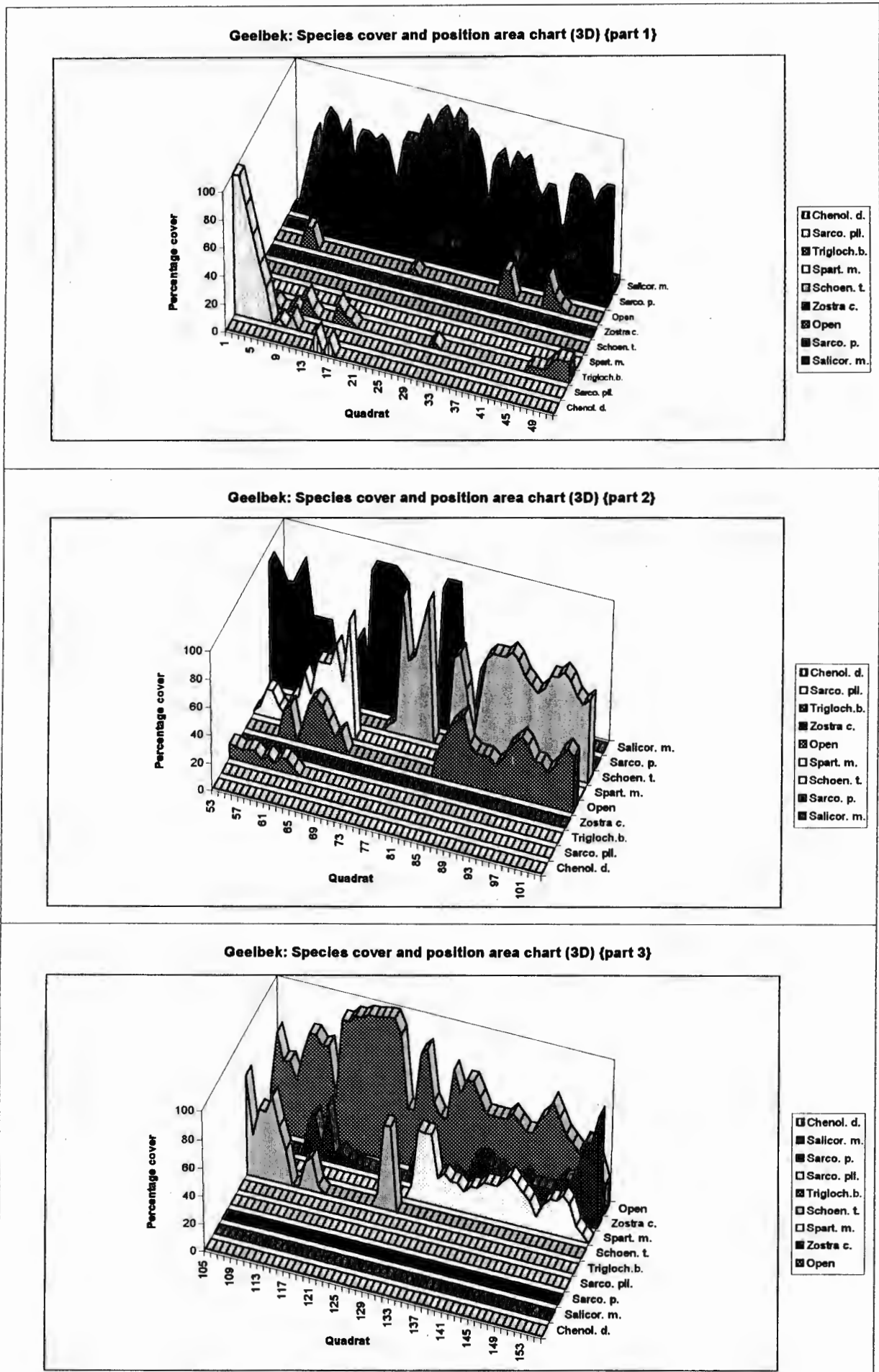
**Figure 5.5:** The distribution and cover (%) of plant species at Geelbek



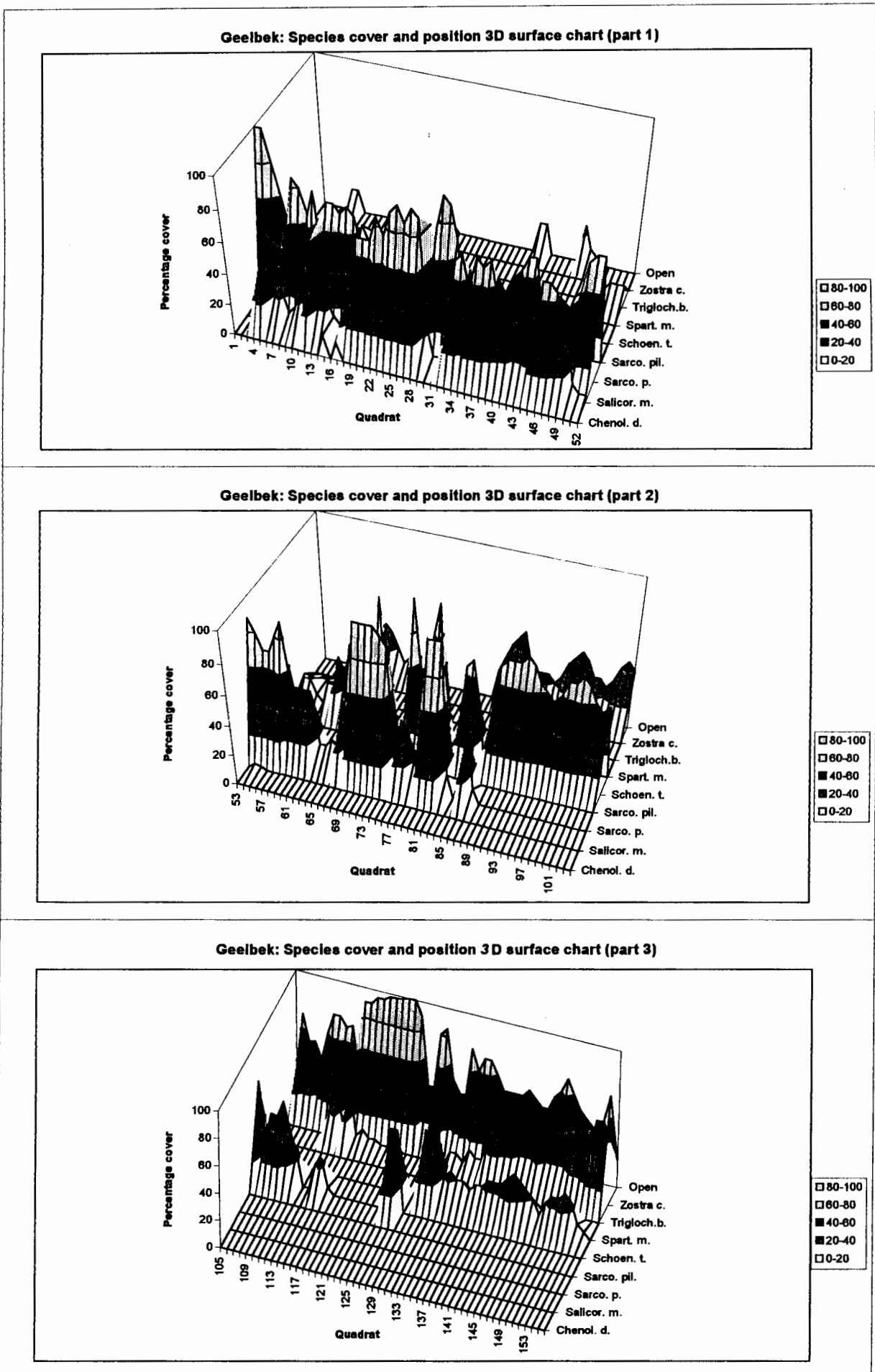
**Figure 5.6: Geelbek species cover and position area chart**



**Figure 5.7: Geelbek species cover and position (3D)**



**Figure 5.8: Geelbek species cover and position (3D AREA)**



and middle, *Schoenoplectus triqueter*, *Spartina maritima*, *Zostera capensis* and Bare patches occupy the lower salt marsh.

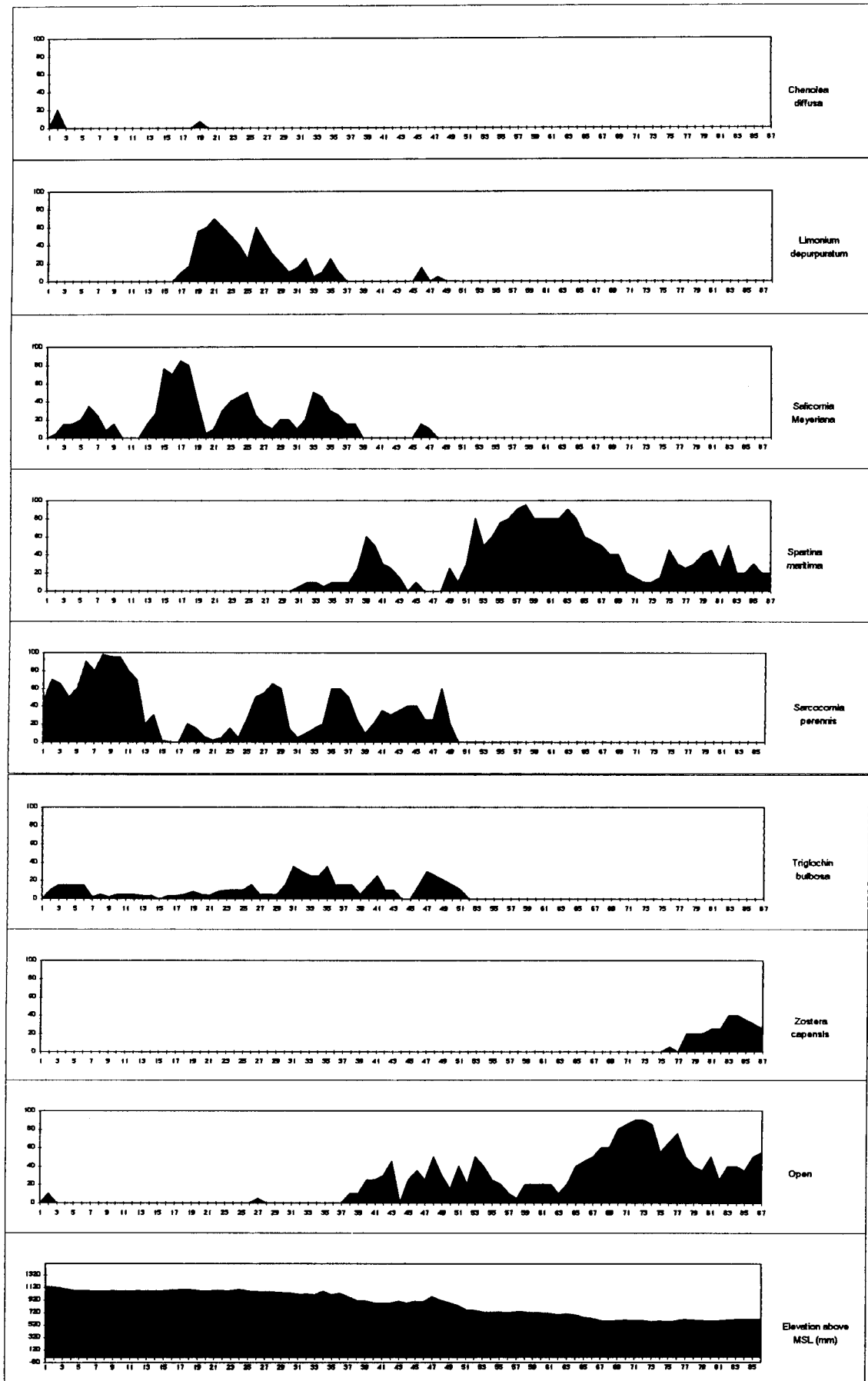
### 5.2.3 Schrywershoek

The transect at Schrywershoek has a length of 86 metres and, like Geelbek has no truly terrestrial plants. Seven plant species were noted, with five found to be dominant (See Tables 11 & 12 in Appendix C). With an average gradient of 1: 215 this was the least inclined of all the transects and might therefore, be the least clearly zoned. Figure 5.9 illustrates elevation, confirming the gentle gradient and the lack of any sudden breaks in the profile. Only at quadrat 48 is there a noticeable change in the gradient.

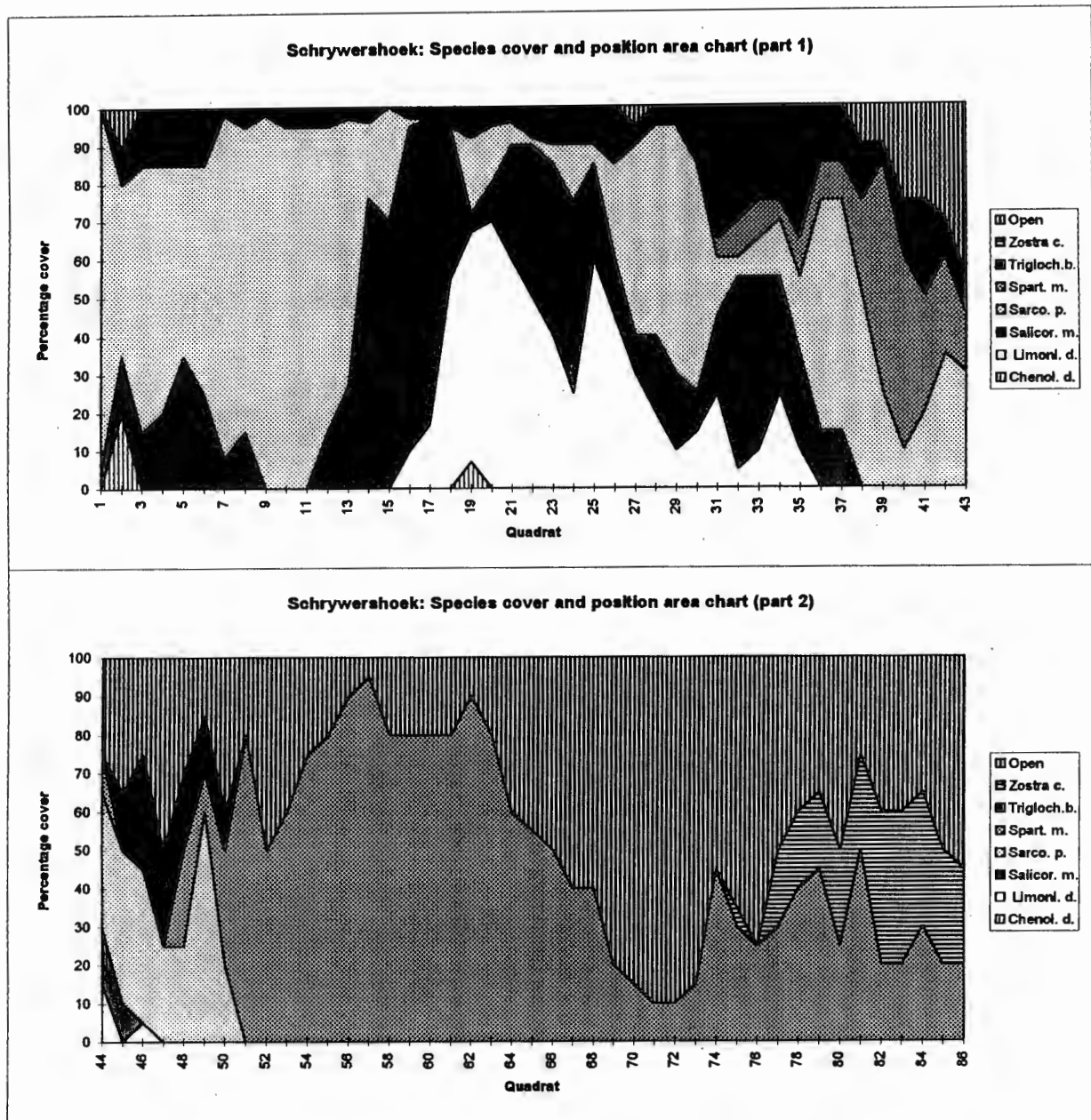
From an examination of Figures 5.9 to 5.12 it can be seen that, as was the case at Geelbek, alternating bands of *Sarcocornia perennis* and *Salicornia meyeriana* are found in the first 50 quadrats, but here associated with *Triglochin bulbosa* and a marked band of *Limonium depurpuratum* between quadrats 18 - 29. The concave surface between quadrats 36 - 47 provides a depression which is waterlogged and occupied by *Spartina maritima* and *Sarcocornia perennis*. Although the change in the profile at quadrat 47 is subtle, it marks a change in the plant community (see Figures 5.9 & 5.10). Here, *Spartina sp.* interspersed with open patches of mud becomes prominent, with patches of *Zostera sp.* found at the lowest end of the transect. There is a noticeable lack of bare patches within the upper reaches of the transect where dense plant cover predominates in the upper salt marsh.

As a result of the larger number of species competing for space on the upper reaches of the salt marsh, zonation within the plant communities is less well defined than in the other two

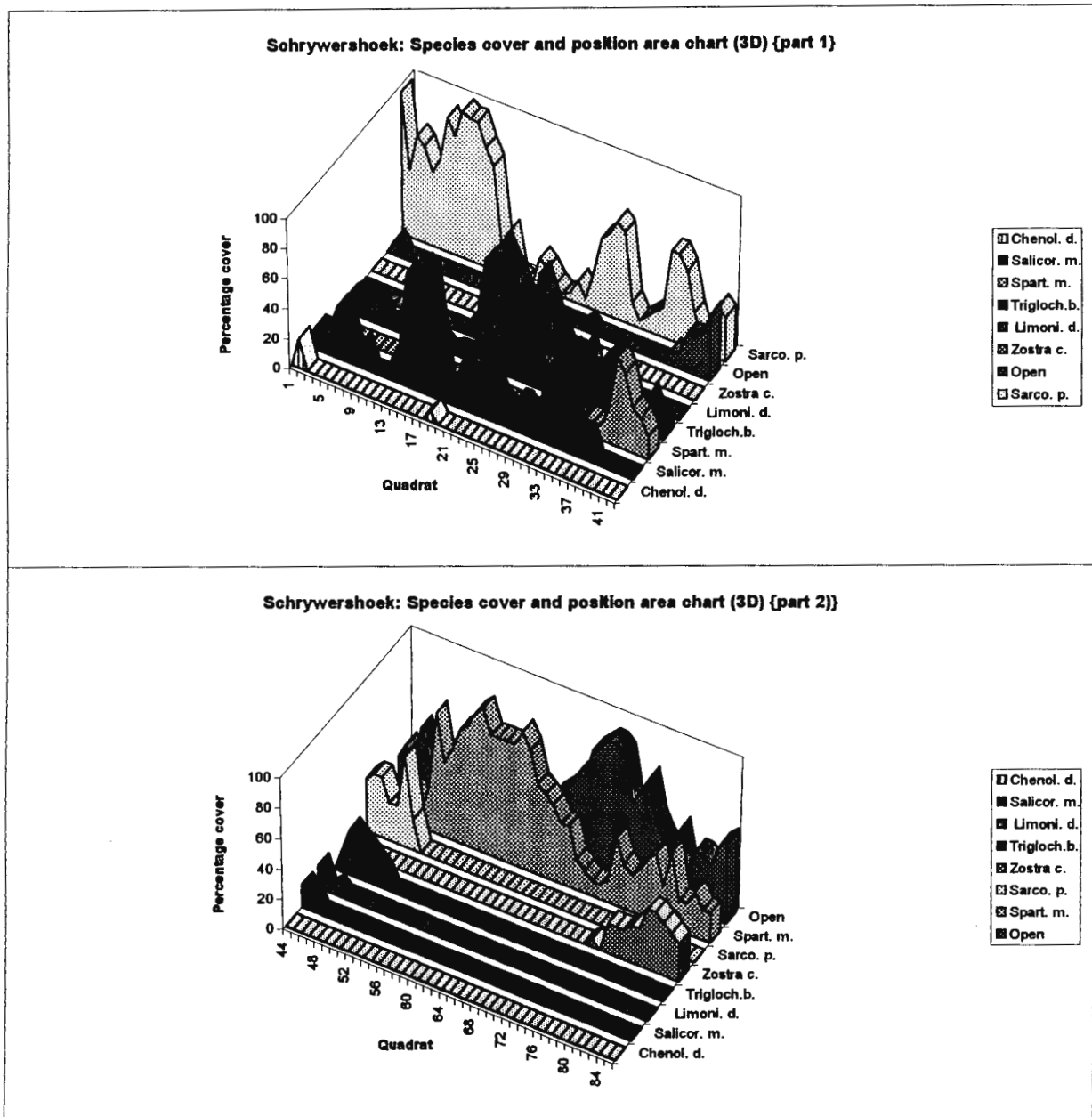
**Figure 5.9:** The distribution and cover (%) of plant species at Schrywershoek



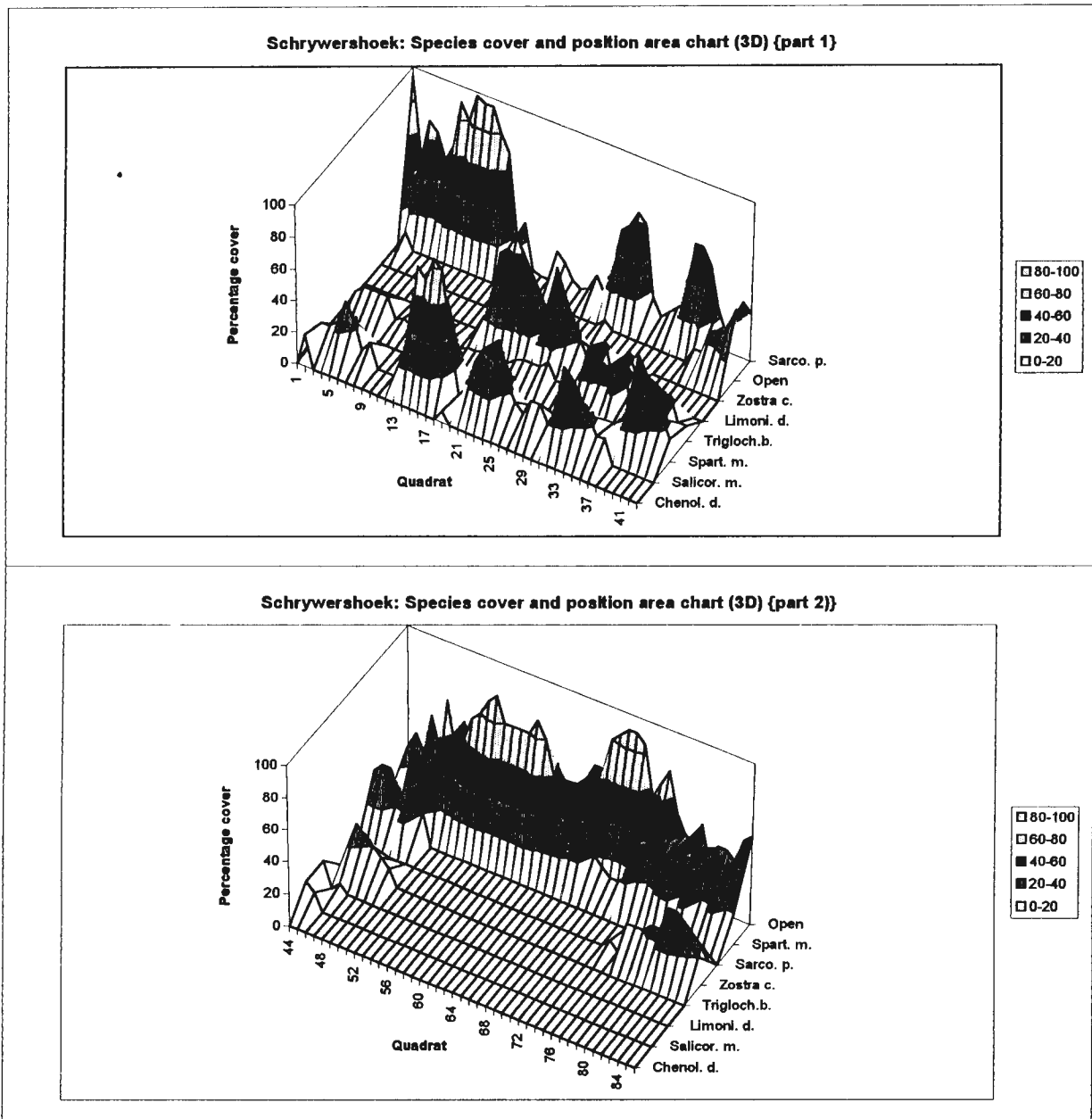
**Figure 5.10: Schrywershoek species cover and position area chart**



**Figure 5.11: Schrywershoek species cover and position (3D)**



**Figure 5.12: Schrywershoek species cover and position (3D AREA)**



transects but nevertheless still discernible. The lower half of the marsh displays zonation more clearly. The general arrangement of species (upper, middle and lower) within the salt marsh is explained in the above.

#### ***5.2.4 Continuity and seasonal variation***

An objective of this research is to determine the extent of continuity of plant zonation throughout the salt marsh system at Langebaan. There is little doubt that zonation occurs in all the salt marshes examined, however it should be borne in mind that the differing nature of each transect's topography and the presence or absence of non-halophytic plants complicates direct comparison between transects.

A general overview of Figures 5.1 to 5.12 shows certain similarities between the positions of the various zones. The heights of corresponding plant zones however, are often found to be different. Comment will only be made on the species which were found in a minimum of two transects. A generalised description moving from the lowest to the highest point in the transect gradients is warranted. The terms upper, middle and lower marsh will be arbitrarily used to facilitate this description.

In all three transects *Zostera sp.* occupied the lowest parts of the gradient; this zone is followed by a band of *Spartina sp.*, but this latter species is also occasionally found in the wetter depressions in the middle sections of the marshes. The middle section of the gradients are generally dominated by *Sarcocornia perennis* which, in the case of Geelbek and Schrywershoek, is interspersed with dominant bands of *Salicornia meyeriana* towards the upper part of the middle section. *Triglochin sp.*, *Limonium sp.*, and *Chenolia sp.* are

interspersed within the middle salt marsh dominants and in a few cases reached dominance. The upper part of the salt marsh was usually defined by the presence of *Sarcocornia pillansii* whereafter non-halophytic vegetation dominates.

The heights of corresponding vegetation zones were found to be different. In comparison with Oostewal, corresponding species at Geelbek appear to be displaced approximately 80 mm higher up the gradient. In comparison to Oostewal this displacement appears to be approximately 500 mm higher. These displacements were also noted by O'Callaghan (1994 a) who attributes the phenomenon to an interaction between tidal currents, channel and bay characteristics and the predominant south-easterly winds which literally increase tidal levels, thus pushing water higher up the transect. Seasonal variation was examined only at Oostewal where random surveys within each species type showed no change in vegetation dominance or position between seasons.

### **5.3. Trends in the environmental parameters**

The purpose of this section is to establish whether gradients are discernible. For ease of comparison the results have been plotted with a linear regression trendline. The trendline was plotted using the linear equation  $y = ax + b$  the results of which are displayed on each chart. The results of the three transects in sample session 1 are examined first, followed by an examination for any seasonal variation at the Oostewal transect. Comment is confined to the general nature of trends and is not made on each

single measured parameter, only those that show exceptional variation, range or deviation from the expected norm will be commented on. Overall, this section is aimed at addressing the objective to determining if environment gradients are detectable in salt marshes. In all figures the quadrats are shown from left to right, with quadrat 1 always representing the top of the transect. Elevation of the quadrats is shown in figures 5.1, 5.5 and 5.9.

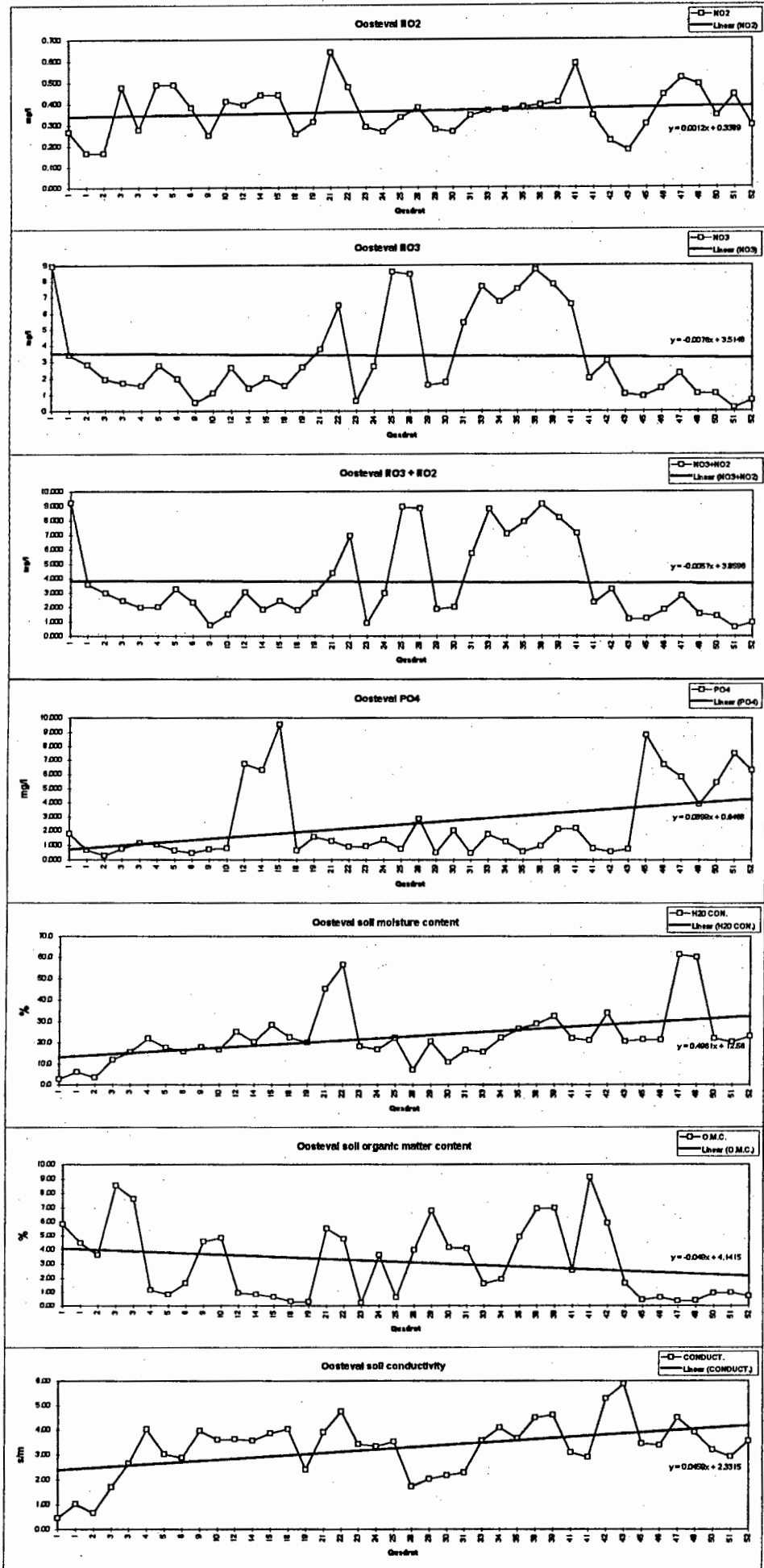
### **5.3.1 Oostewal**

The following discussion refers to Figures 5.13, 5.14, 5.15 and 5.16.

With the exception of NO<sub>3</sub>, soil organic matter content and Sat. Fe which reflected decrease (negative trend) and pH and Sat. Mn which reflect no change (a neutral trend), all other parameters display a general increase (positive trend) from the top to the bottom of the transect. Throughout the majority of these charts there is a clear decline in value of variables between quadrats 25 - 34 an area which coincides with the occurrence of *Carpobrotus sp.*. This species is well recognised for its ability to colonise coastal soils of low nutrient status (Bond & Goldblatt 1984 , p. 320).

The elevated area (Quadrats 25 - 40) towards the bottom of the transect (See Figure 5.1) display an increase in value in most parameters, but particularly in nutrient NO<sub>3</sub> and soil organic matter. This may be the result soil enrichment from the guano of numerous birds which show a preference to roost on this elevated berm (Pers. obs.). When comparing the distribution of plant species (See Figure 5.1) to these environmental parameters, (with the exception of *Chenolia sp.* which correlates to a degree with NO<sub>3</sub>) there does not appear to be any single environmental parameter with a strong positive or negative correlation. The general positive trend from the top to the bottom of the transect could suggest that sea

**Figure 5.13: Oostewal soil analysis results (Sample session 1)**



**Figure 5.14: Oosteval soil analysis results (Sample session 1)**

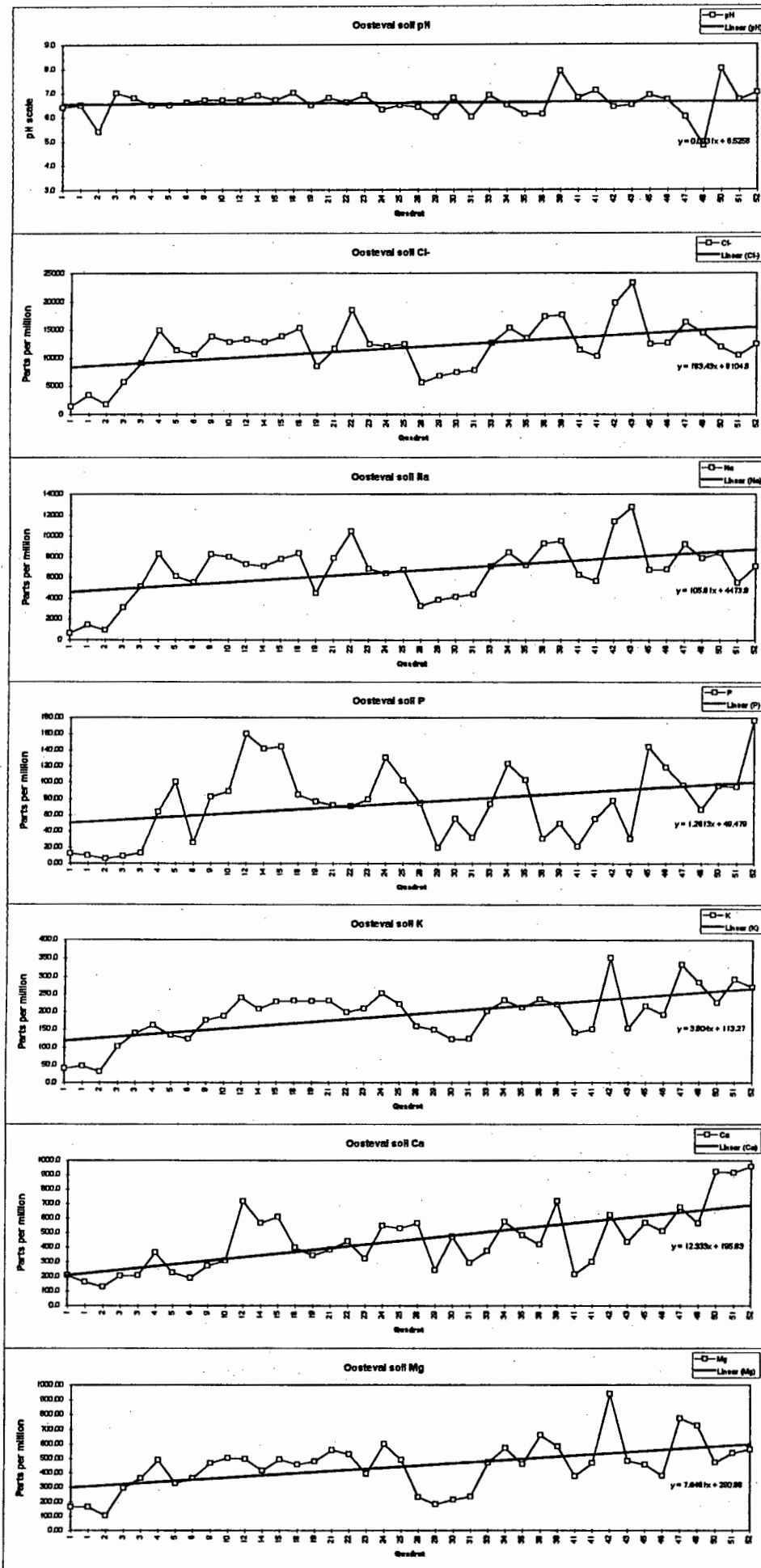


Figure 5.15: Oosteval soil analysis results (Sample session 1)

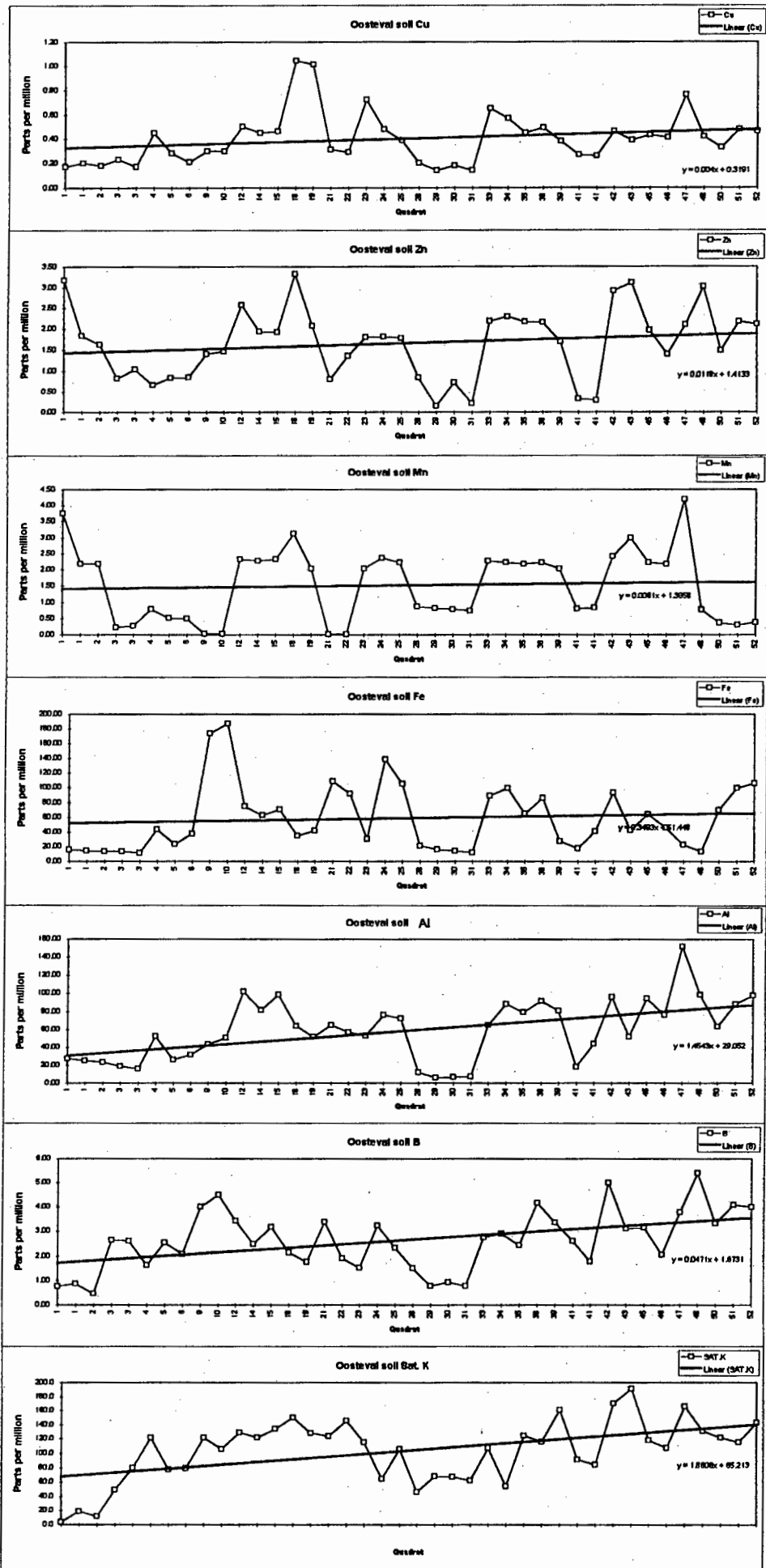
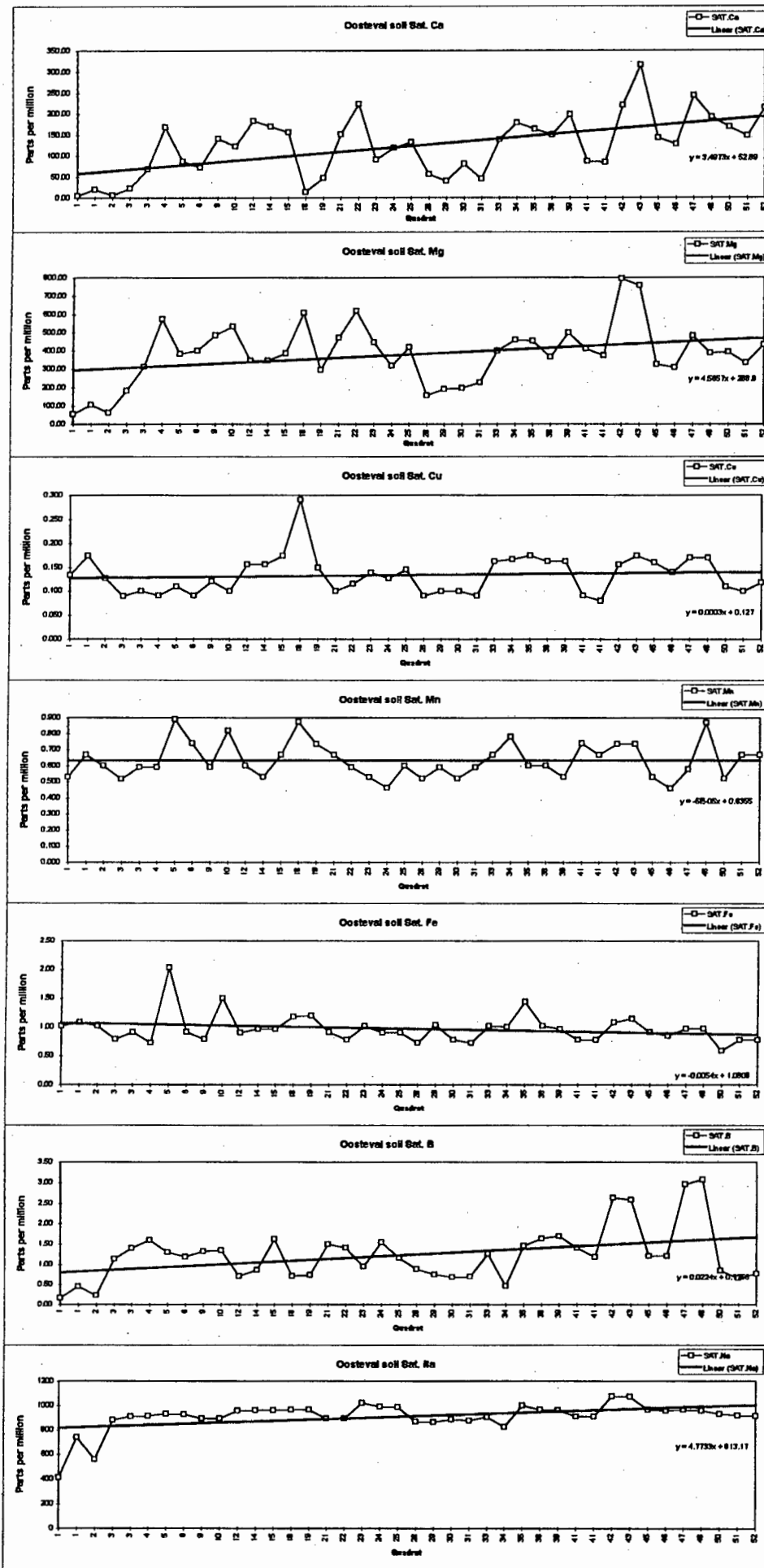


Figure 5.16: Oosteval soil analysis results (Sample session 1)



water is the source of the nutrients and exerts a major influence in the case of most parameters. However, if the general topography of this transect is taken into consideration the elevation of the bottom section makes this area less susceptible to inundation. In other words topography appears to be the main cause of anomalies in these trends.

### **5.3.2 Geelbek**

The following discussion refers to Figures 5.17, 5.18, 5.19 and 5.20.

The trends in the Geelbek soil analysis results show a remarkable difference to those seen at Oostewal. In fact the major trends are in the opposite direction to those at Oostewal, with the majority of parameters showing a decline in value when traced from the top to the bottom of transect. These results are more typical of a salt marsh during summer season, as mentioned in Chapter 2, salinities generally increase towards the top end of the salt marsh due to evaporation. The trends evident in soil conductivity, Cl and Na support this notion. This reversal may be induced by the presence of fresh water seepage during winter.

The only element which reflects a positive trend is NO<sub>3</sub> which may be depleted in the upper reaches of the salt marsh by plant demand during the growing season, similarly PO<sub>4</sub> with the exception of quadrats 3 - 31 shows a general paucity in the middle marsh region. This may indicate that these two nutrients are replenished during inundation. The step in the profile previously mentioned (see Figure 5.9) can clearly be traced as a sudden break throughout all the measured parameters at quadrat 75. The fresh water influence below this step can also be seen in the soil conductivity, pH and most ionic elements. The trace element metals have noticeably higher concentrations in the upper and middle sections of the salt marsh which could increase the likelihood of toxicity in these soils.

Figure 5.17: Geelbek soil analysis results

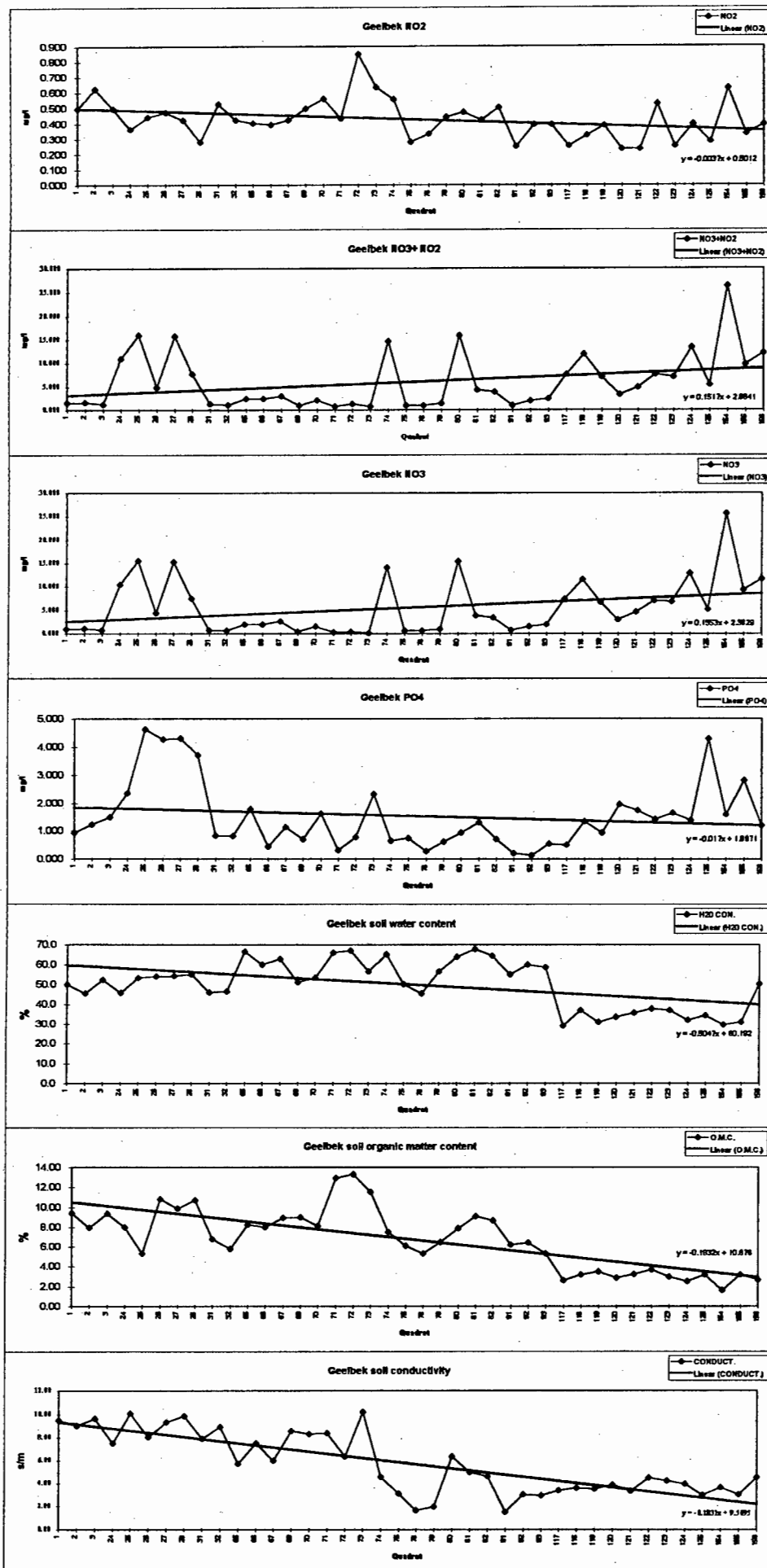
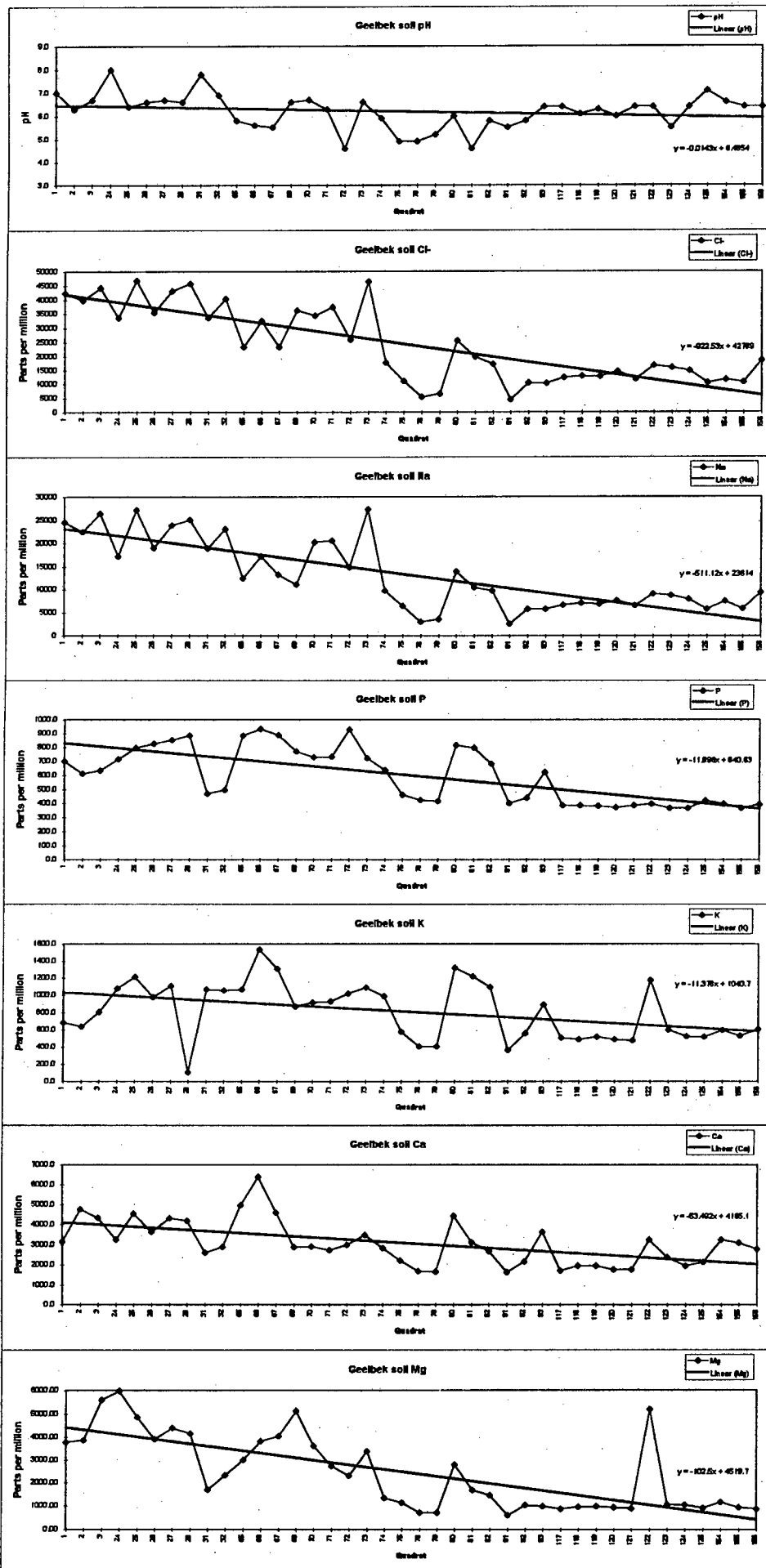


Figure 5.18: Geelbek soil analysis results



**Figure 5.19: Geelbek soil analysis results**

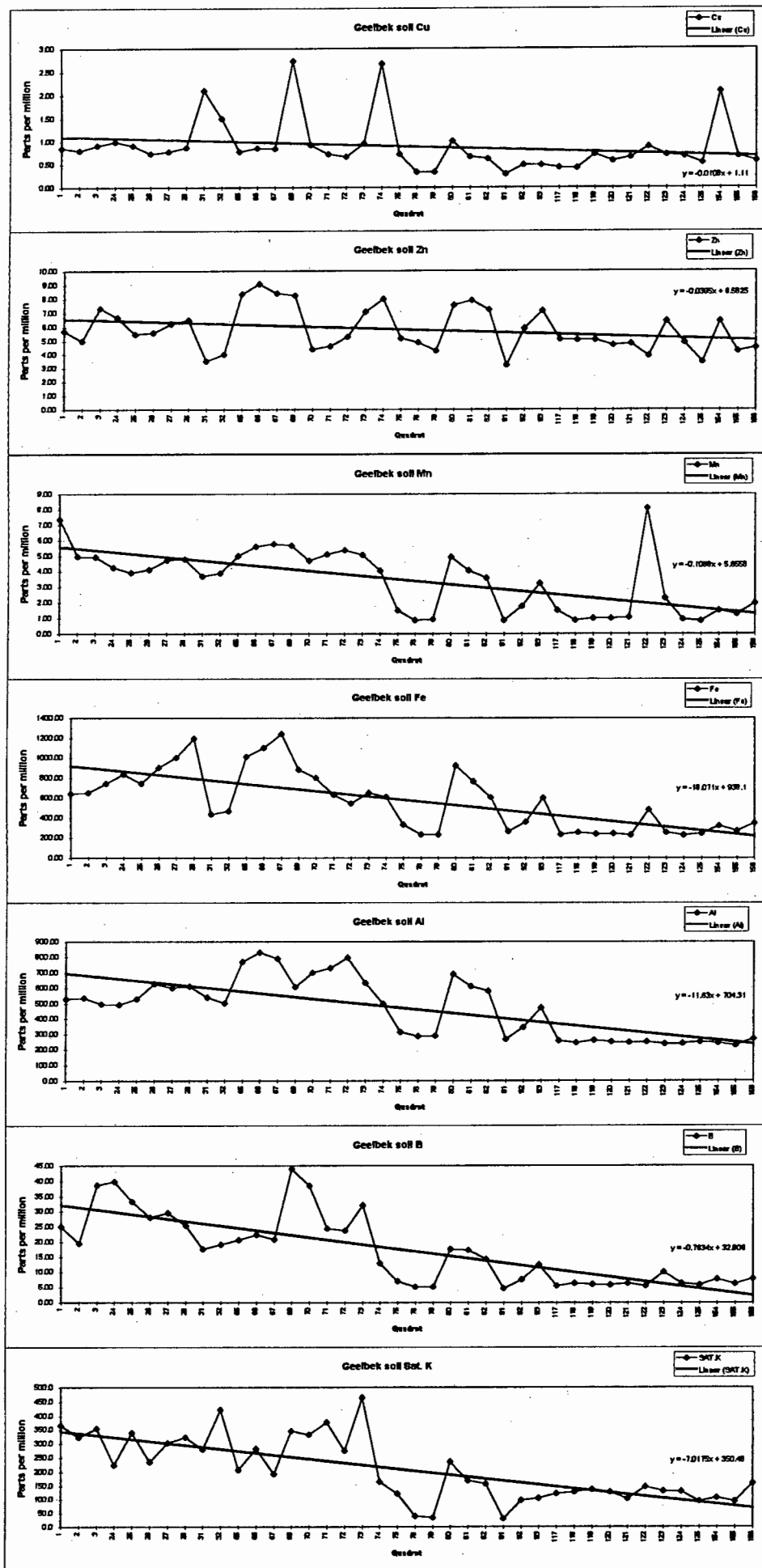
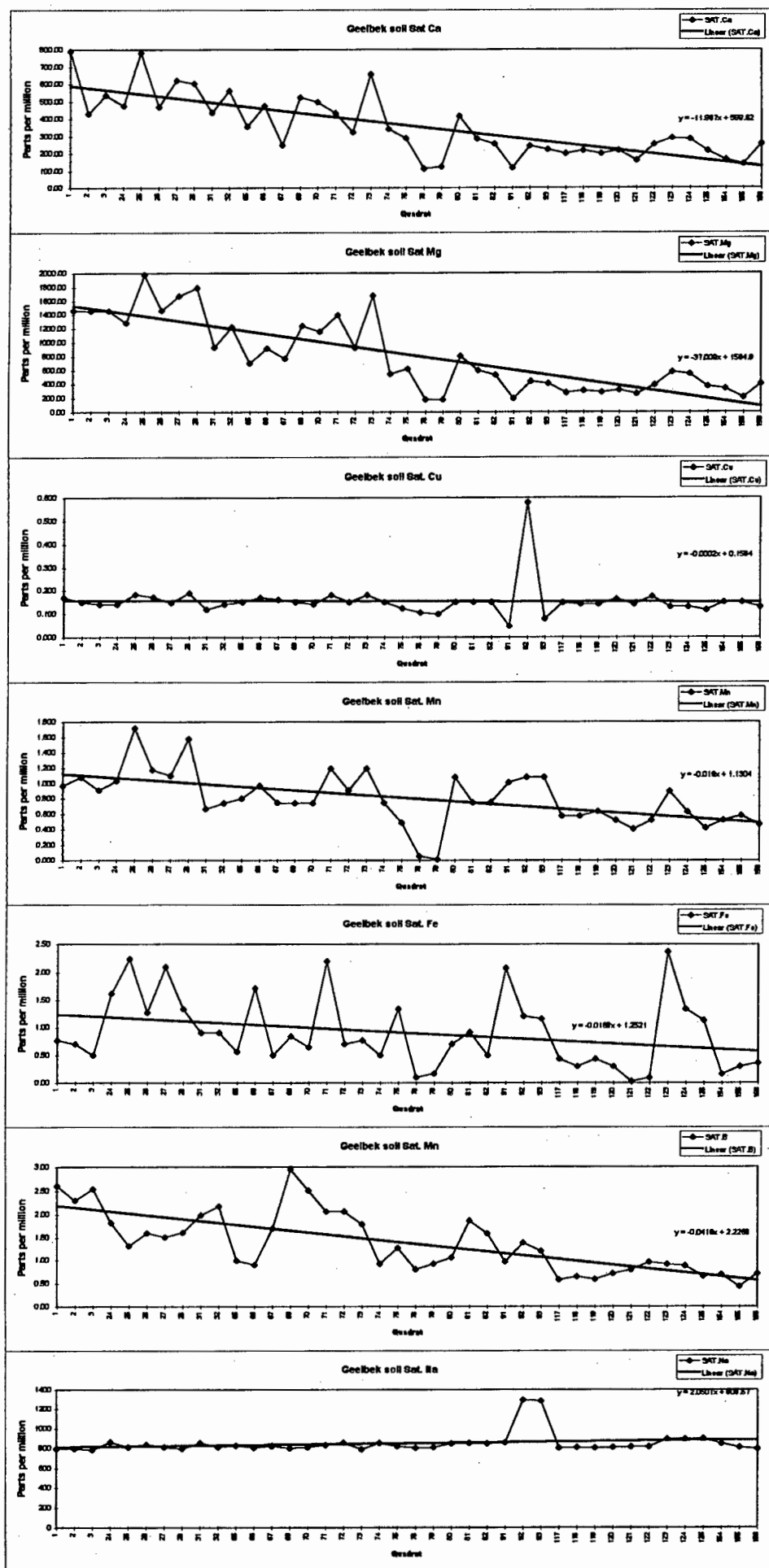


Figure 5.20: Geelbek soil analysis results



The trend indicated by soil moisture content is unusual considering that it would normally be expected that the lower reaches should be wetter. This anomaly may be due to the nature of the soil substrate, as the fine sediments in the upper/middle marsh may have better water retention abilities than the coarser sediments in the lower marsh (Soil sediments are dealt with in section 5.5)

As with Oostewal, no single parameter appears to explain the location or abundance of any particular species (See Figure 5.1 & 5.5) but it appears that the sudden change in the transect profile has a noticeable effect on all the environmental parameters.

### **5.3.3 Schrywershoek**

The following discussion refers to Figure 5.21, 5.22, 5.23 and 5.24.

An examination of the Schrywershoek soil analysis trends shows that these are similar to those found at Geelbek. With the exception of the nutrients NO<sub>2</sub>, NO<sub>3</sub> and PO<sub>4</sub>, all other parameters show a marked decline in value from the top to the bottom of the transect. The trend increase in these nutrients may suggest that the dense plant growth in the upper marsh utilises these nutrients causing this paucity. The only way to test whether this indeed the case, would be to conduct a similar elemental analysis on the plant material. The regression trends also suggests that the nutrients may be replenished during sea water inundation.

For reasons similar to those identified in section 5.3.2 the upper marsh is found to be more saline. The pH trend appears to follow a similar pattern to the Na and Cl<sup>-</sup> suggesting a possible link between the two. The slight change in the transect profile (Quadrat 48 in Figure 5.9) is reflected as a sharp break between *Sarcocornia perennis* and *Spartina*

Figure 5.21: Schrywershoek soil analysis results

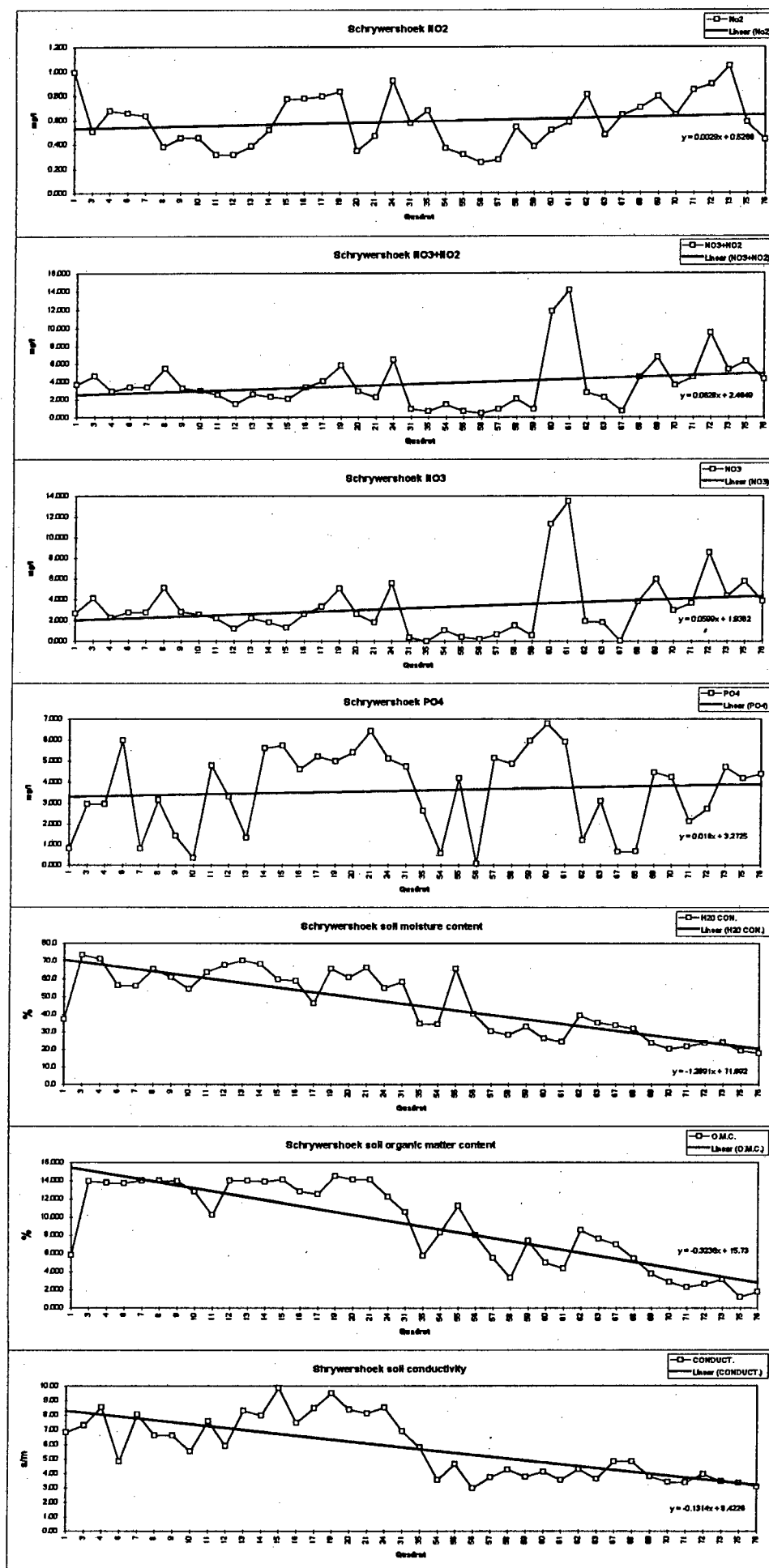
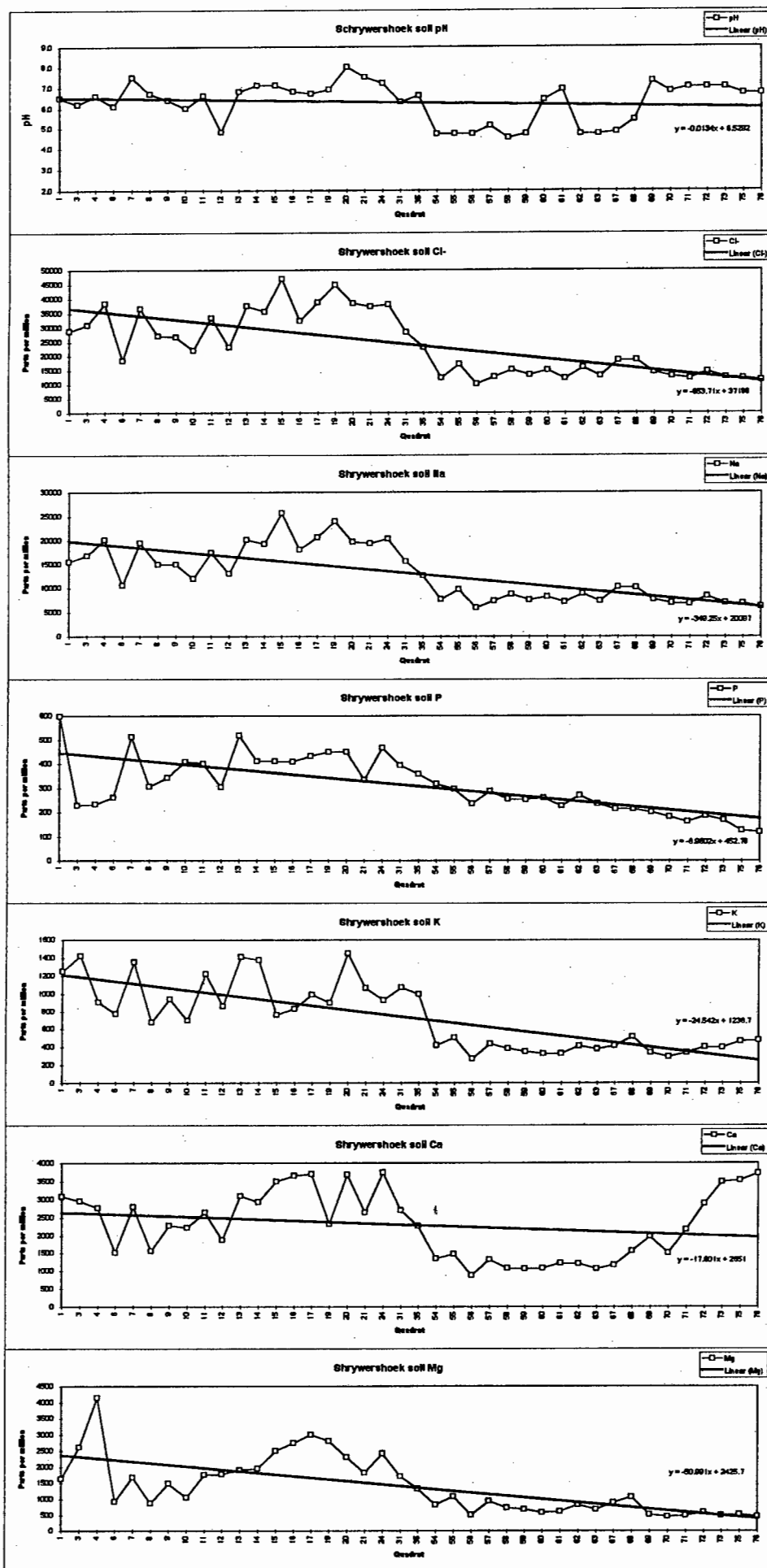


Figure 5.22: Schrywershoek soil analysis results



**Figure 5.23: Schrywershoek soil analysis results**

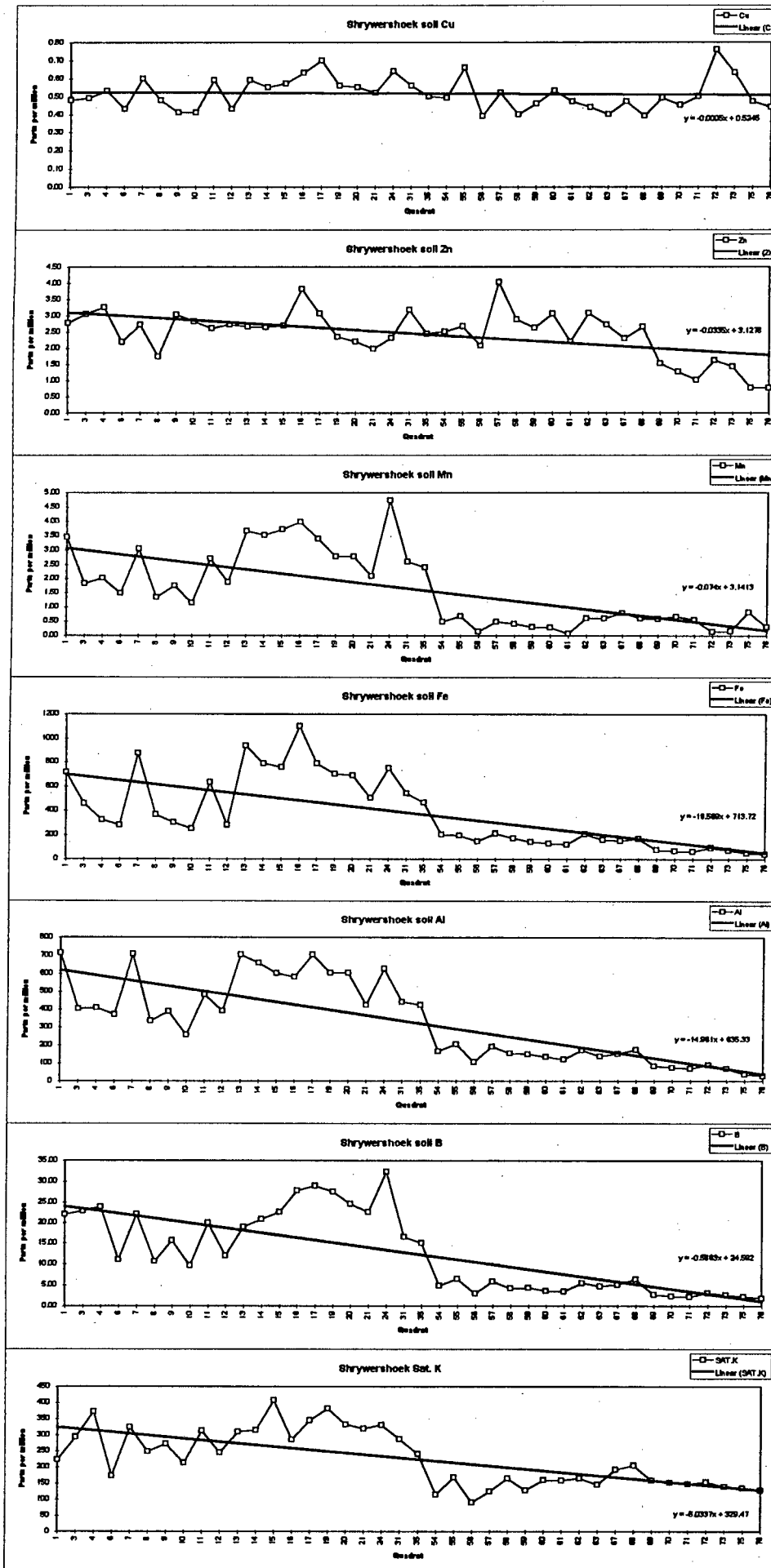
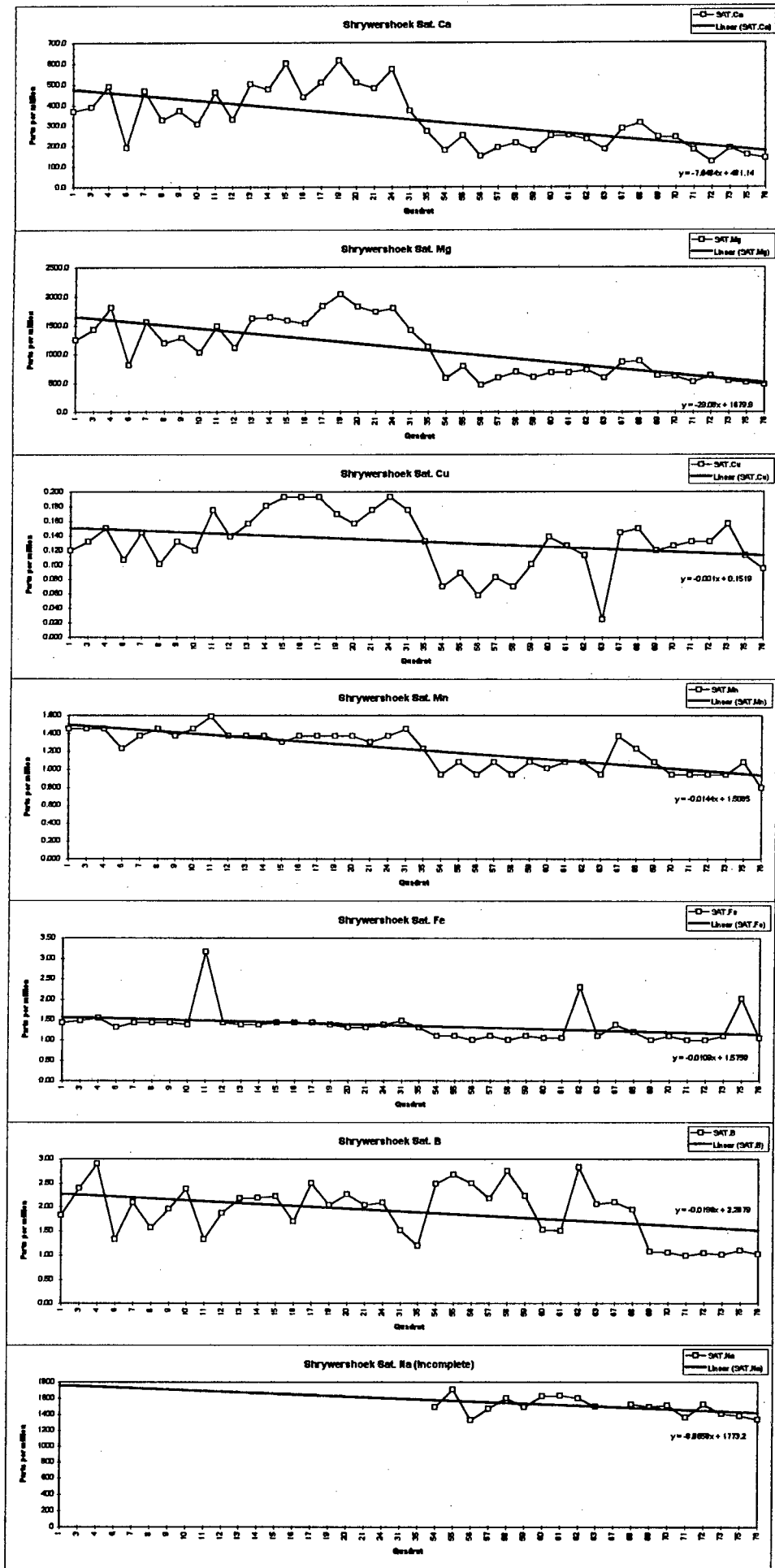


Figure 5.24: Schrywershoek soil analysis results



*maritima* and this change is discernible throughout most of the parameters shown here between quadrats 35 & 54. Most trace metals appear to be heavily concentrated on the middle marsh between quadrats 12 to 54 where plants with the ability to withstand the effects of toxicity would be situated. It appears that *Salicornia meyeriana*, *Sarcocornia perennis*, *Limonium sp.* and *Triglochin sp.* have this ability

As was the case in the other two transects, a comparison between the species distribution and cover (Figure 5.9) and the trends of the various environmental parameters shows little conclusive evidence of any specific relationship between the two.

#### ***5.3.4 Oostewal: Variation in environmental gradients over time***

This section refers to Figures 5.13 to 5.16; 5.25 to 5.28 and 5.29 to 5.32.

The objective of this section is to ascertain if there are any differences in the environmental gradients over time. It should be noted that soil organic matter content, soil moisture content and PO<sub>4</sub> were not tested in the second and third sample sessions. Only slight changes in the values of the parameters are apparent in all three sample sessions, so in general it could be argued that seasonality produces little change to the nutrient characteristics.

Given that even under the best laboratory conditions, the same sample subjected to the same test under the same conditions may yield different results, the parameters in each sample session show remarkable consistency and continuity in the trends. At first glance, Cu appears to be radically different from session 1 to 2. Closer examination reveals the

Figure 5.25: Oostewal soil analysis results (Sample session 2)

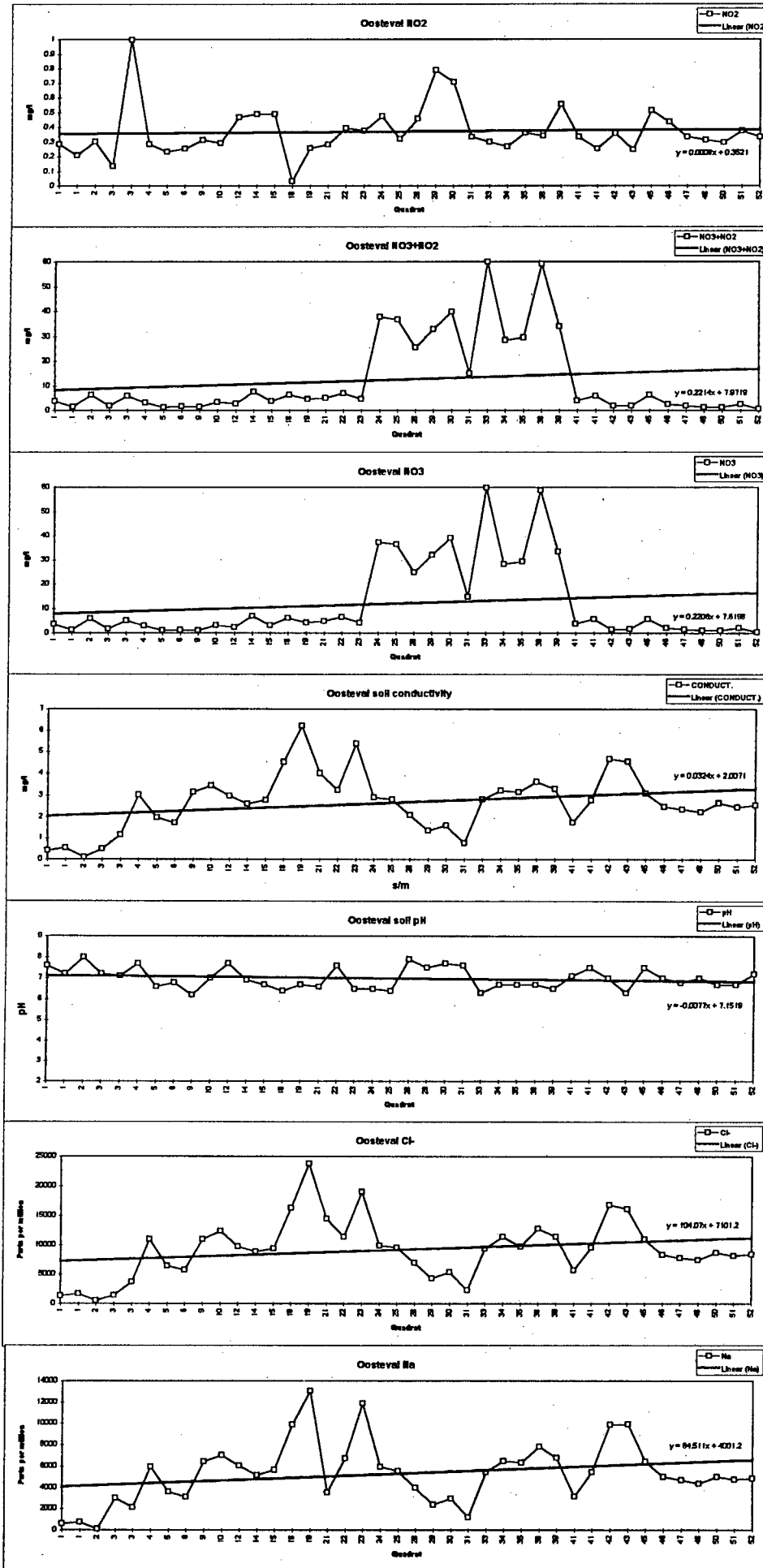


Figure 5.26: Oosteval soil analysis results (Sample session 2)

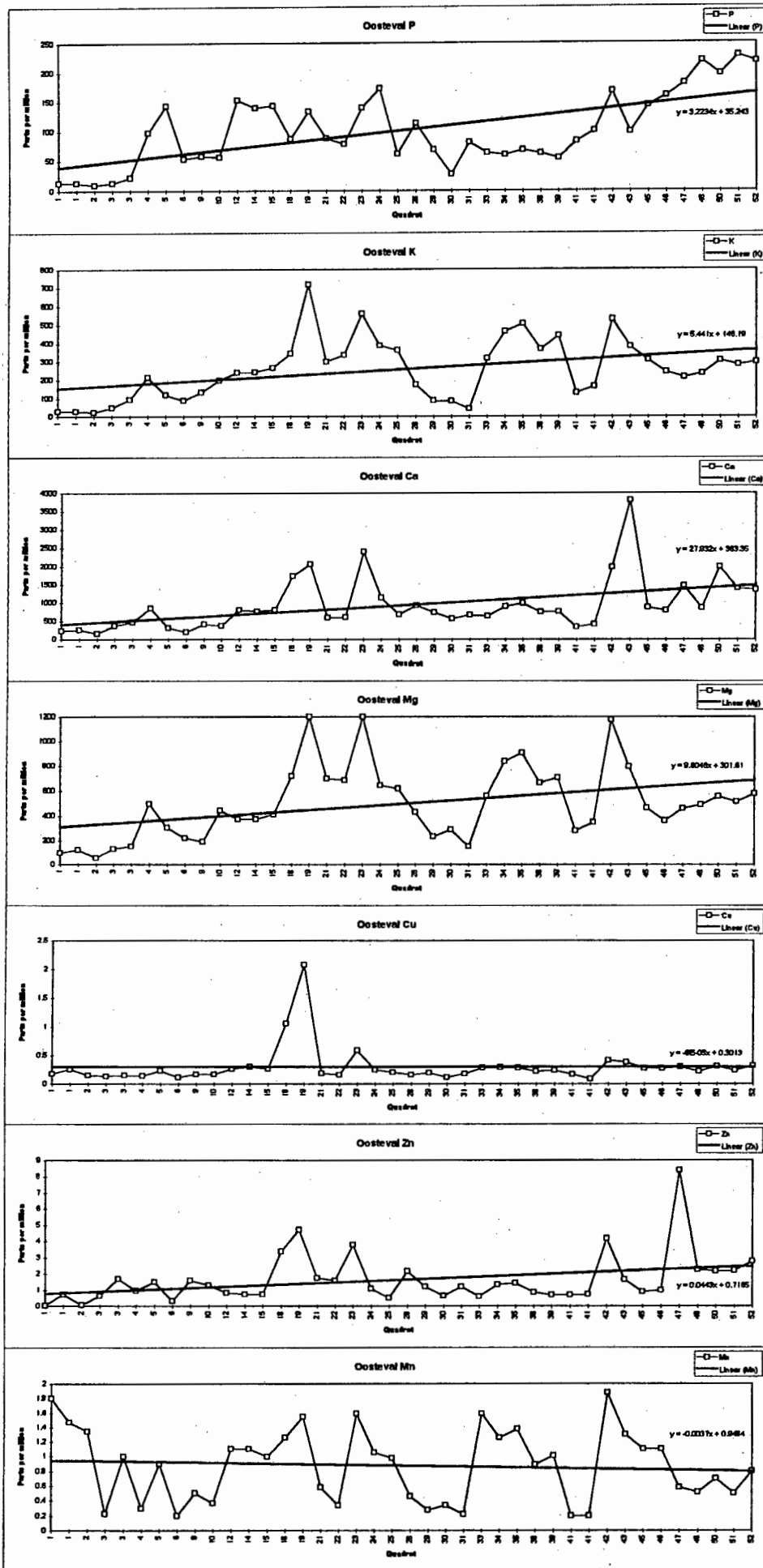
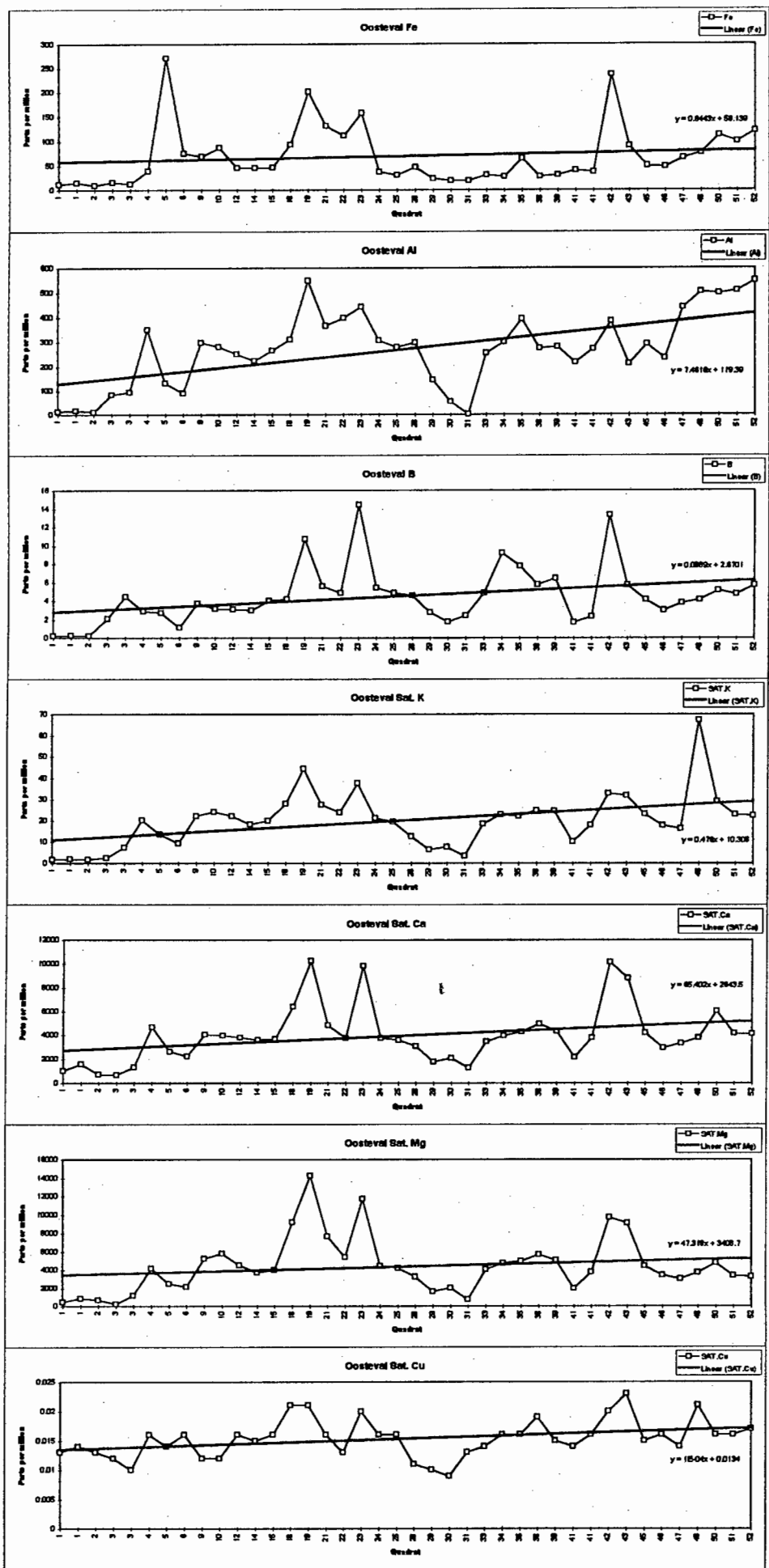


Figure 5.27: Oosteval soil analysis results (Sample session 2)



**Figure 5.28: Oosteval soil analysis results (Sample session 2)**

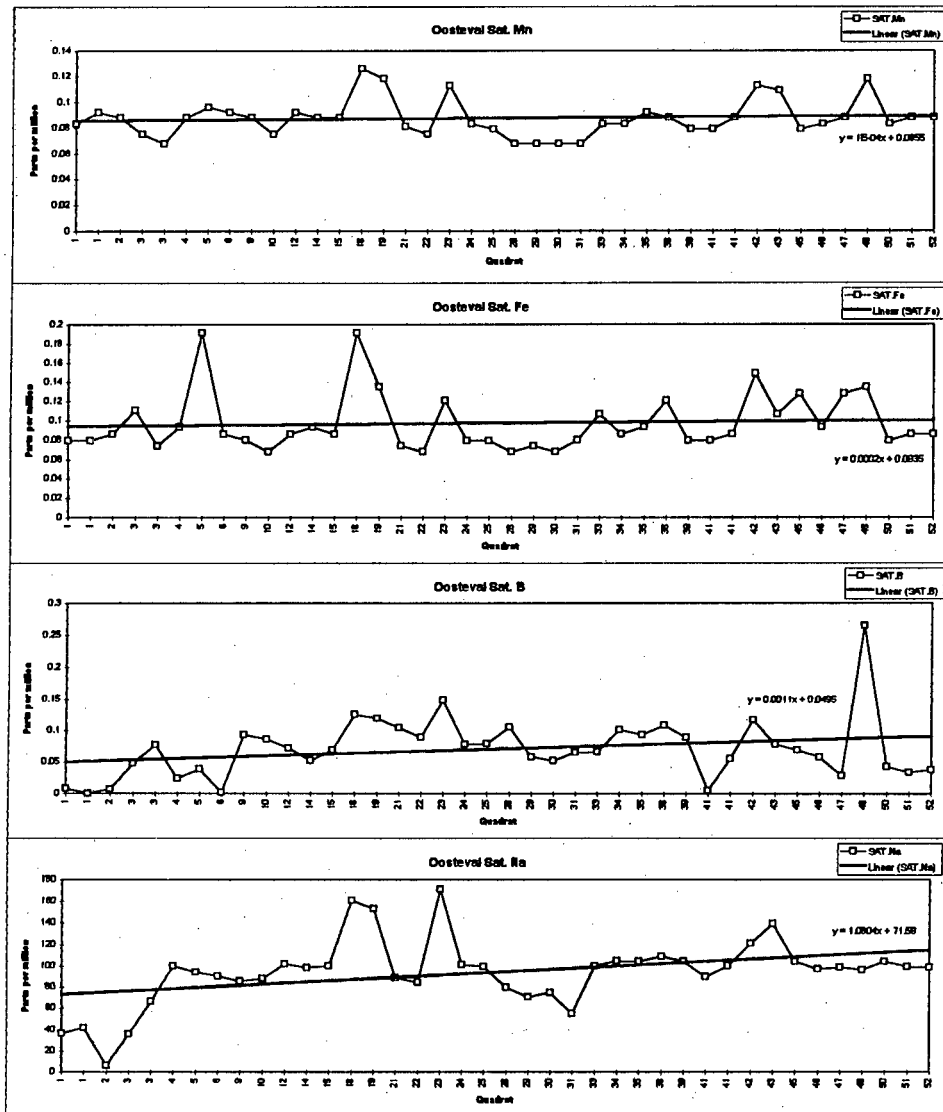


Figure 5.29: Oosteval soil analysis results (Sample session 3)

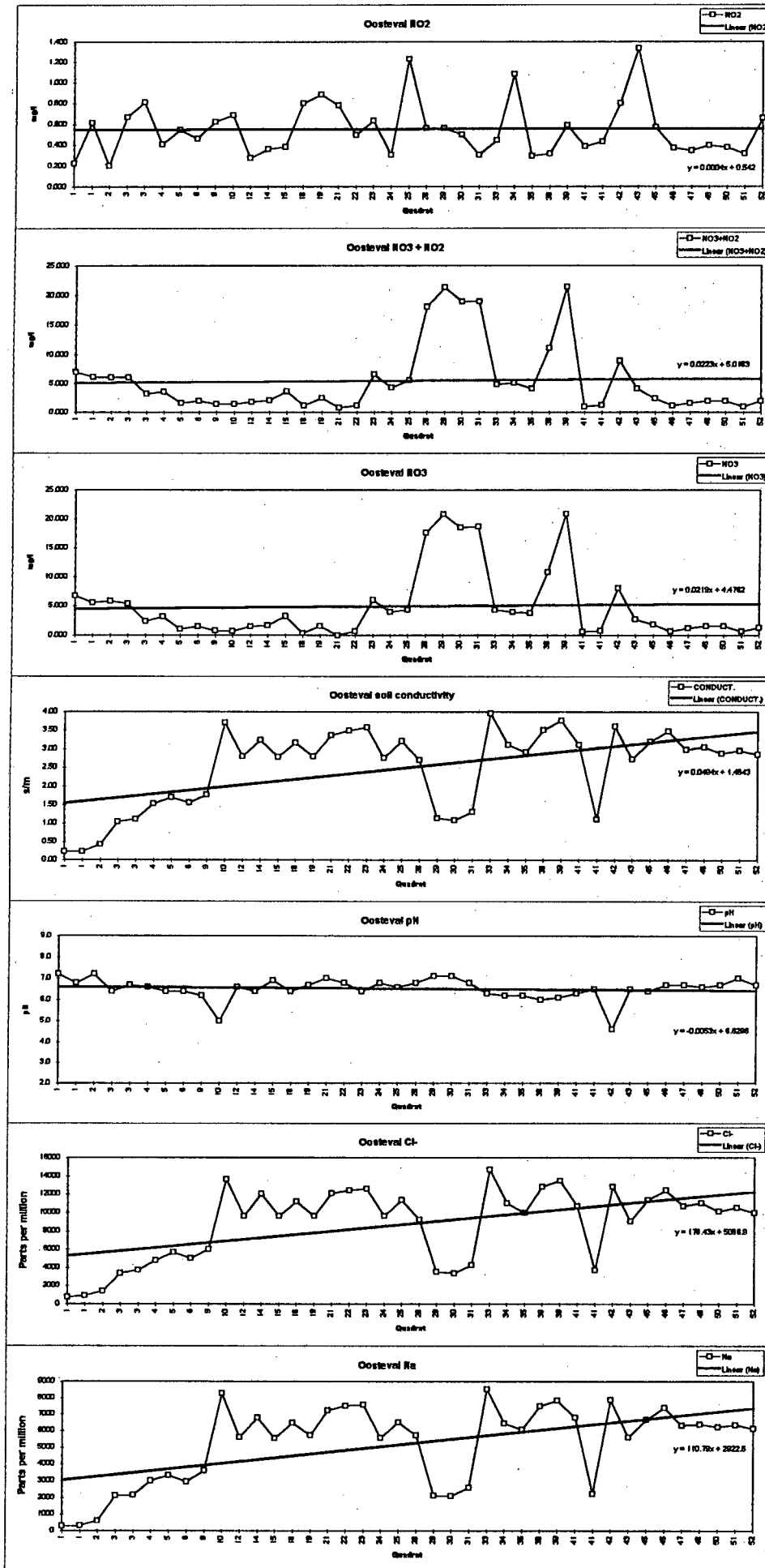


Figure 5.30: Oosteval soil analysis results (Sample session 3)

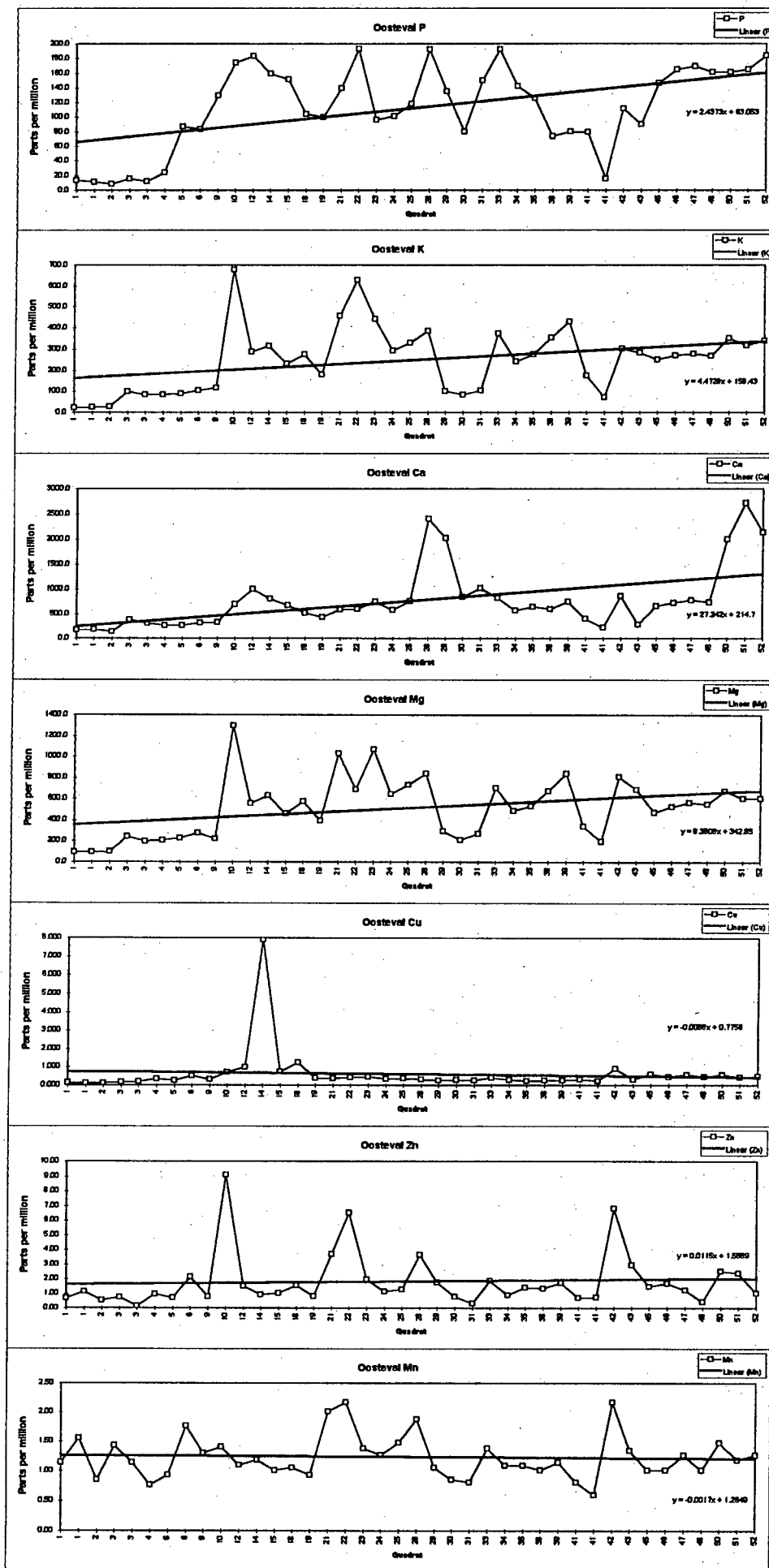


Figure 5.31: Oostewal soil analysis results (Sample session 3)

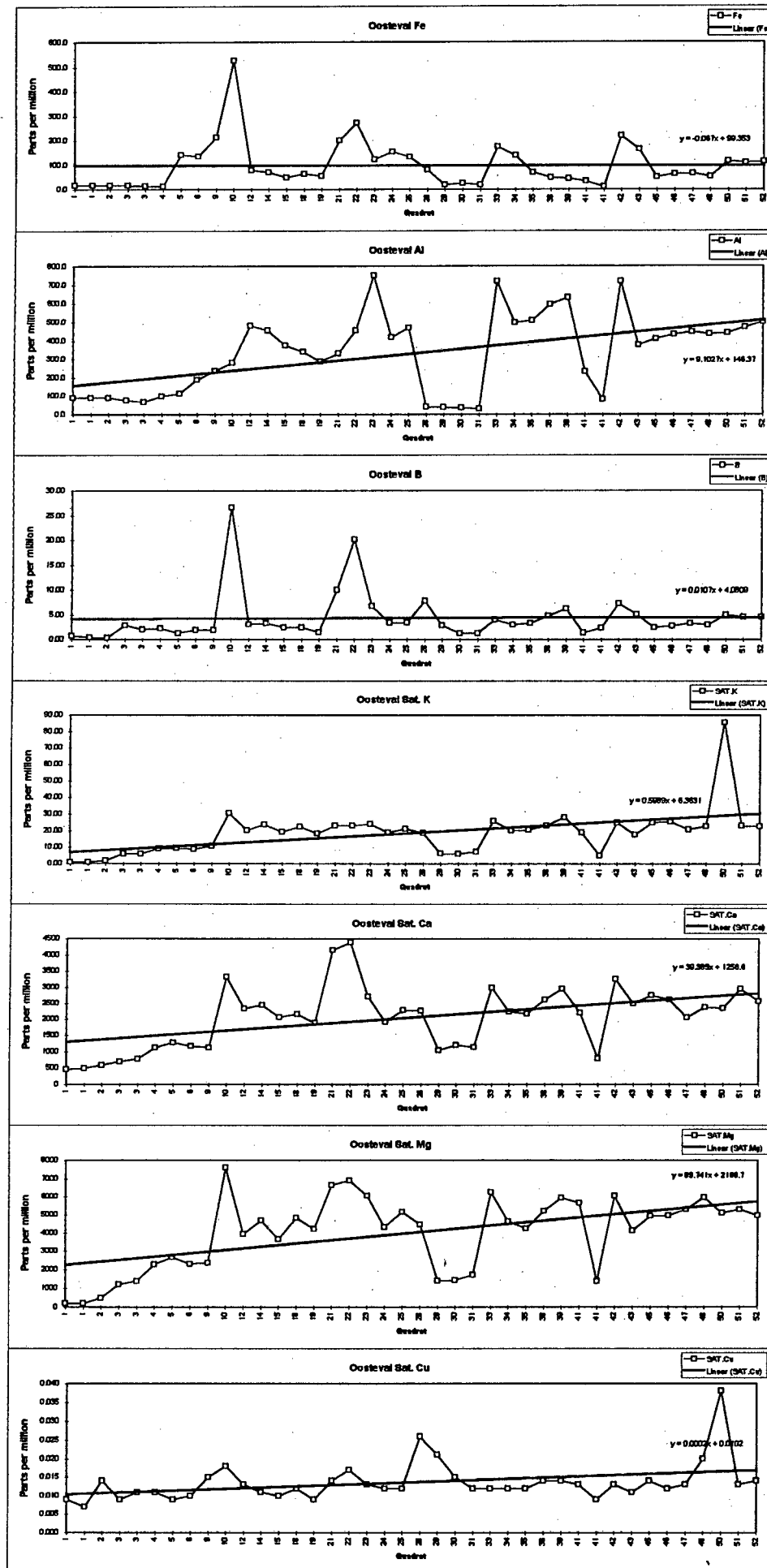
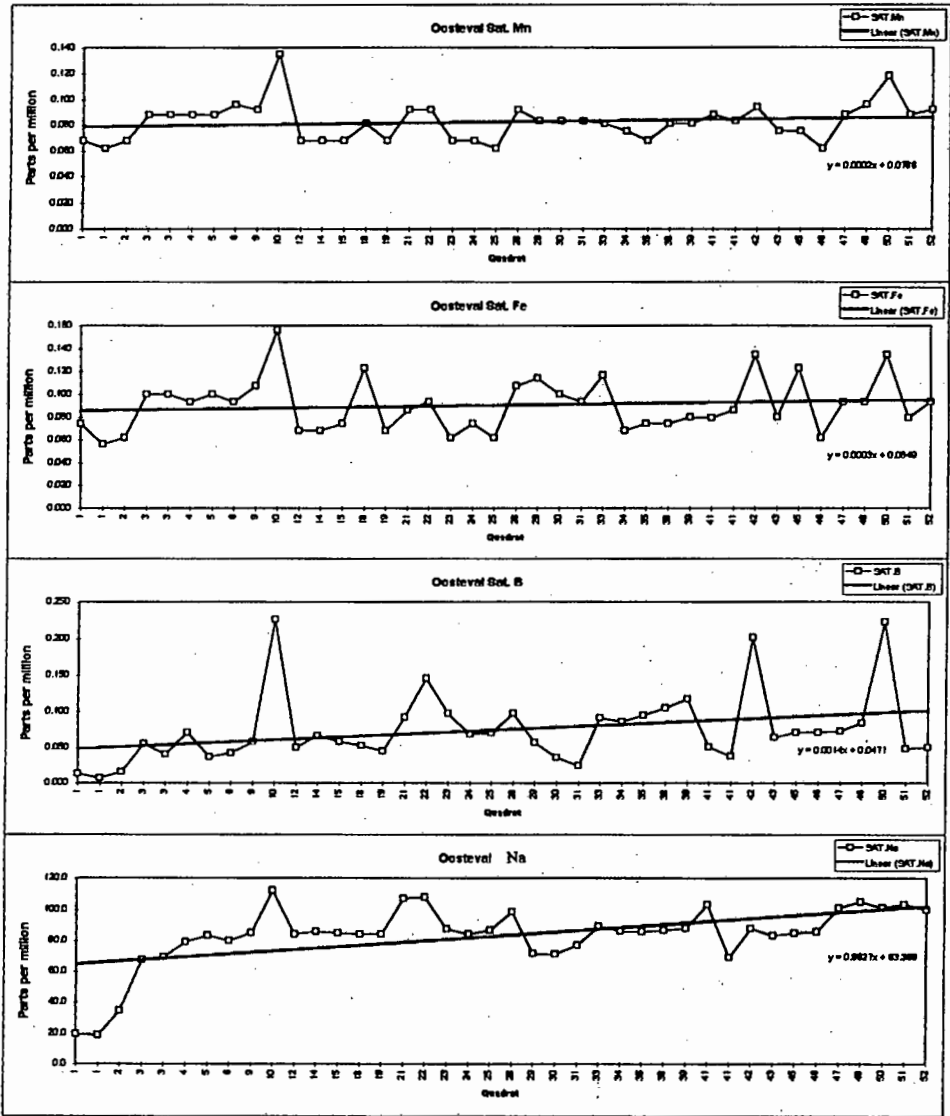


Figure 5.32: Oosteval soil analysis results (Sample session 3)



appearances are different only because of scale adjustments to accommodate an extreme outlier (e.g. sample 19).

The reduction in values noted in sample session 1 between quadrats 29 to 31 can also be traced in both sample sessions 2 and 3. Soil acidity which is generally regarded as an excellent indicator of soil chemical stability (Jackson 1954) remains consistent throughout all three sampling sessions.

Evidence of parameter consistency over time suggests that this particular transect has strong resilience to seasonal variation. This lack of change in environmental variables is mirrored by the absence of any seasonal variation in the plant assemblages as mentioned in section 5.3.3.

## 5.4 Relationships between salt marsh species and environmental parameters

This section is primarily concerned with the objective of determining the extent of influence and significance of environmental factors on the occurrence of particular salt marsh plant species. In the previous section, environmental trends within each transect were examined and general comment was restricted to any apparent relationships between these and vegetation zonation. In this section, a more direct method of comparison is employed. This was achieved by arranging the environmental results by species, rather than by position. Plotting these results diagrammatically makes it possible to compare the range of each environmental parameter for each species. Species numbers (originally assigned to the alphabetically listing of genus as shown in Table 6 in Appendix A) were arranged to provide a common order in each chart to simplify comparison. (see Figures 5.33 to 5.50)

The examination of these results follows a similar pattern to the previous sections as explained in the introduction to this chapter. In this section, species numbers may be used in place of species names (See Table 6 in Appendix A for key to names). As in the previous sections, comment is restricted to examples which are especially pertinent to the objective of this section. In this instance, the most relevant charts are those with elements which show the least *within group* variation and the greatest *between group* variation (“group” in this instance referring to species and “element” relates to environmental parameters).

### *5.4.1 Oostewal*

All discussion herein refers to Figures 5.33 to 5.36.

From the above Figures, the following environmental parameters appear to be the most important for all species as they generally show the lowest degree of within-group variation and the greatest degree of between-group variation, viz. PO<sub>4</sub>; Conductivity; Cl<sup>-</sup>; K; Ca; Cu; Mn; Al; Sat. Ca; Sat. Cu. and height (above M.S.L.).

Two environmental factors were found to show little variation within and between all species groups. This consistency across all species shows parameter with a fine range indicating they are unlikely to be responsible for zonation. These are: pH; and Sat. Fe.

In a number of cases, distinctly high or low levels of a particular environmental parameter (large inter-group range) were seen to be preferred (or tolerated) by certain species groups. As can be seen from the charts there are many instances where this occurs, for example: PO<sub>4</sub>; O.M.C.; Mn; Zn; Fe; Al and height. These parameters may well define tolerance levels for particular species and determine the location of that species within the salt marsh.

The relatively large number of species at Oostewal makes the comparison of the environmental levels per species grouping an intricate task. In a number of cases, environmental parameters appear to provide unique conditions to each species, while in other cases some parameters appear to exert more influence than others. A multivariate statistical analysis of the species-environment would quantify and perhaps shed more light on the nature of these relationships.

**Figure 5.33: Oosteval:- Species grouping per environmental parameter**

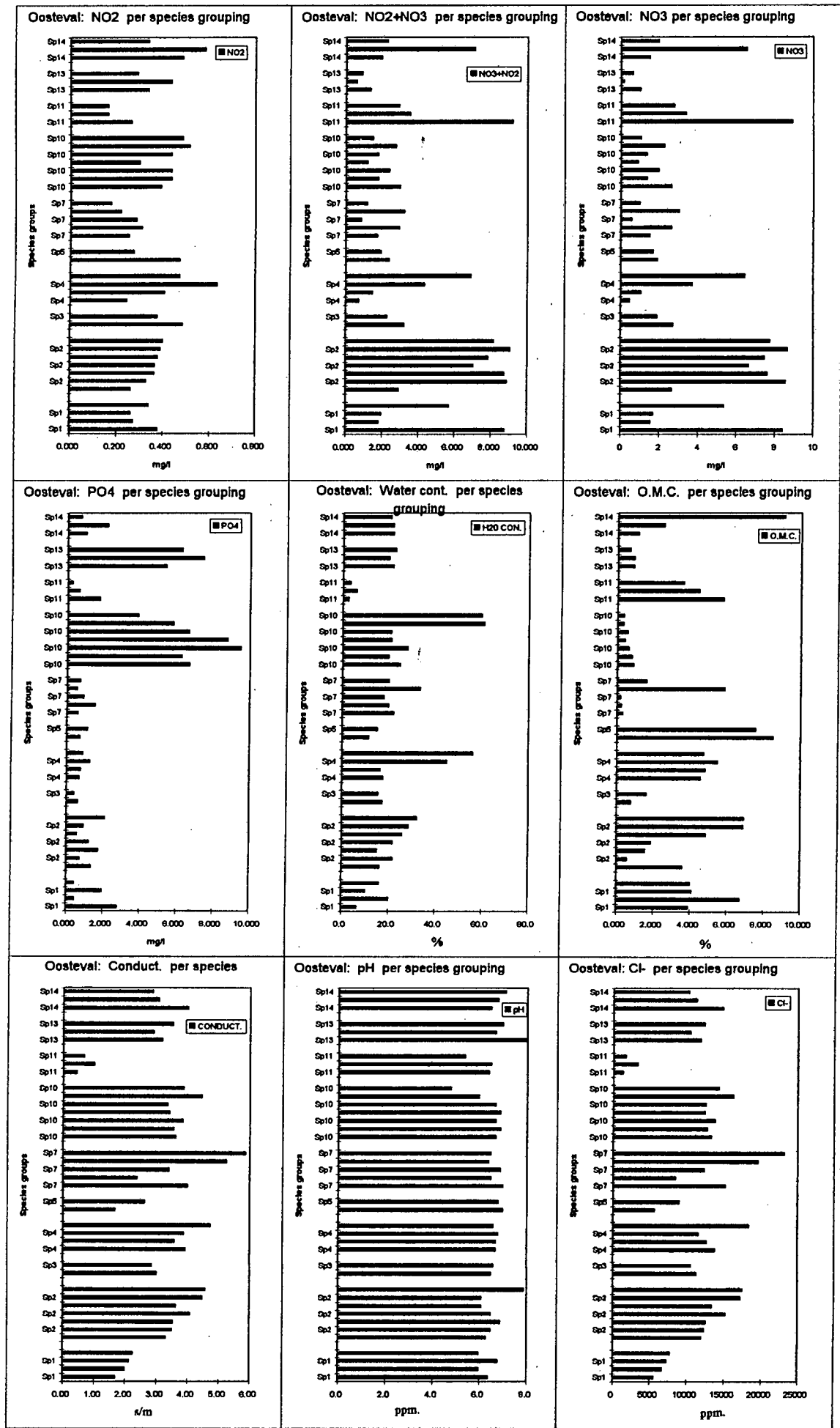
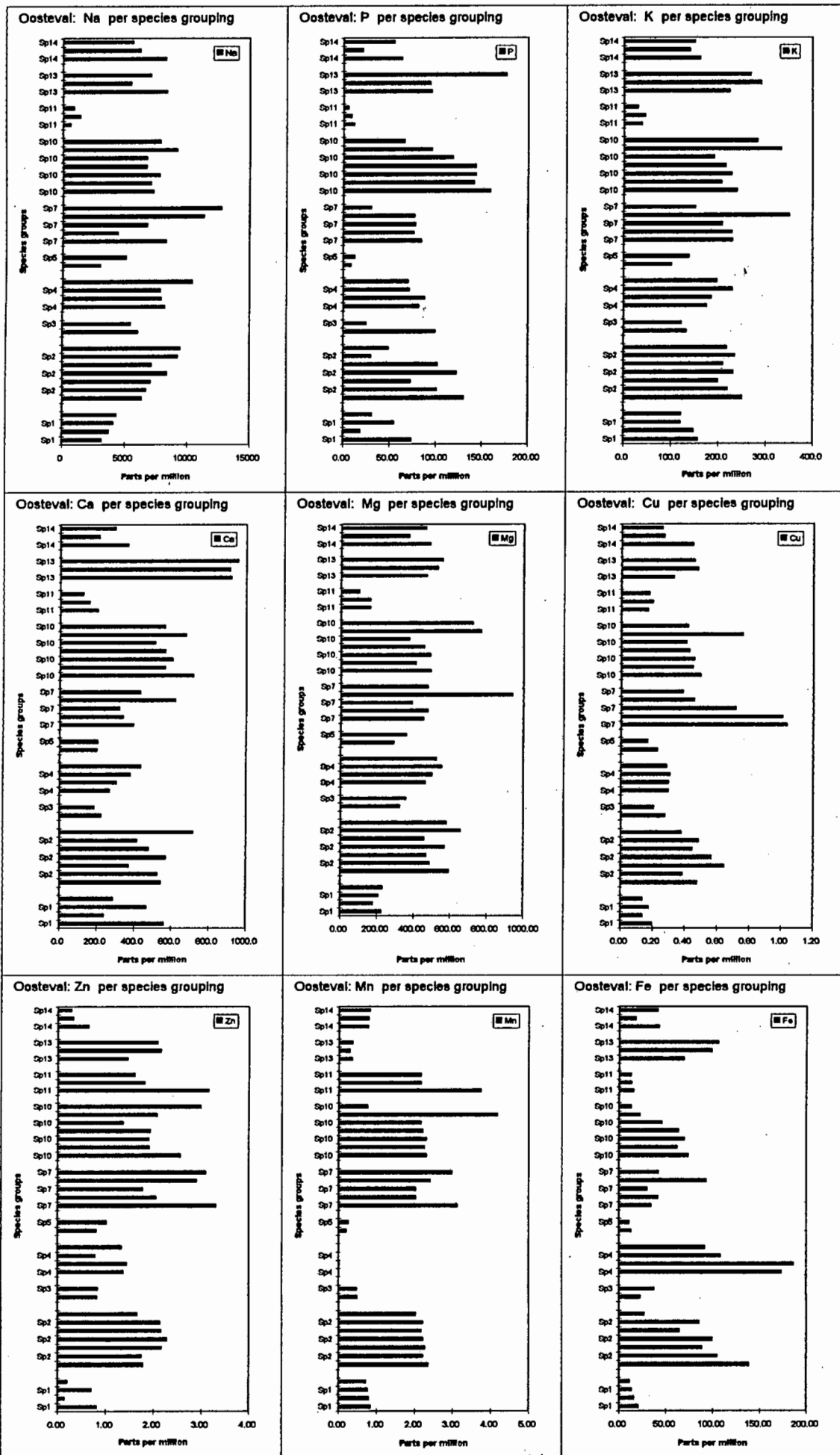
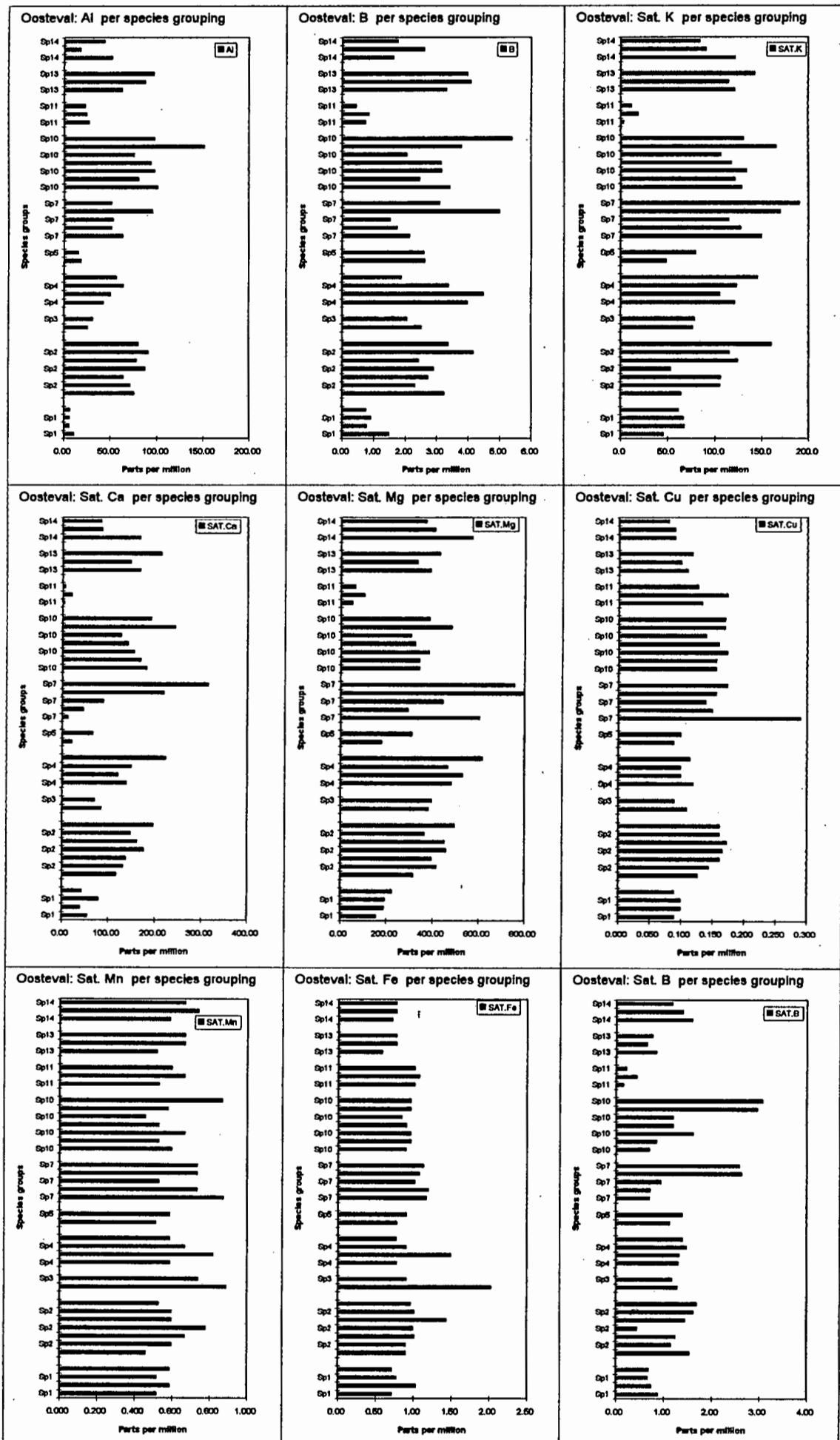


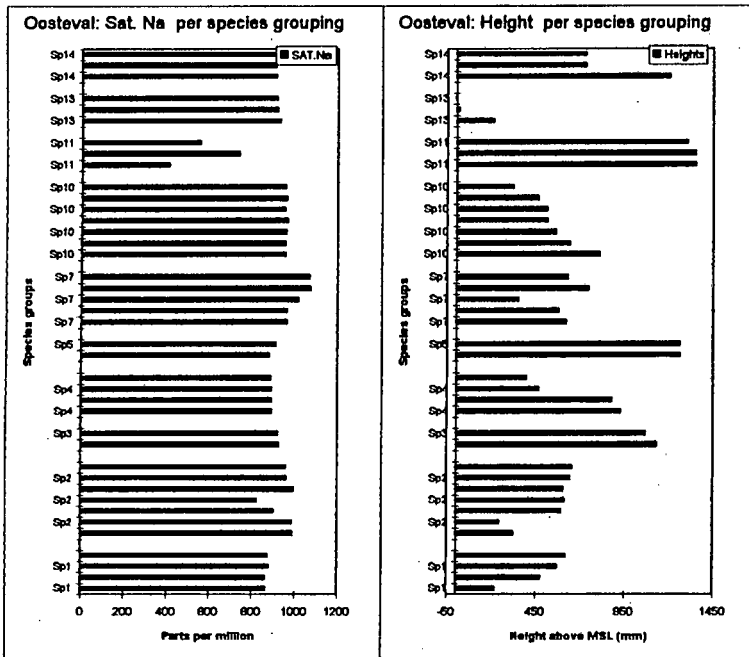
Figure 5.34: Oosteval:- Species grouping per environmental parameter



**Figure 5.35: Oosteval:- Species grouping per environmental parameter**



**Figure 5.36: Oosteval:- Species grouping per environmental parameter**



#### 5.4.2 Geelbek

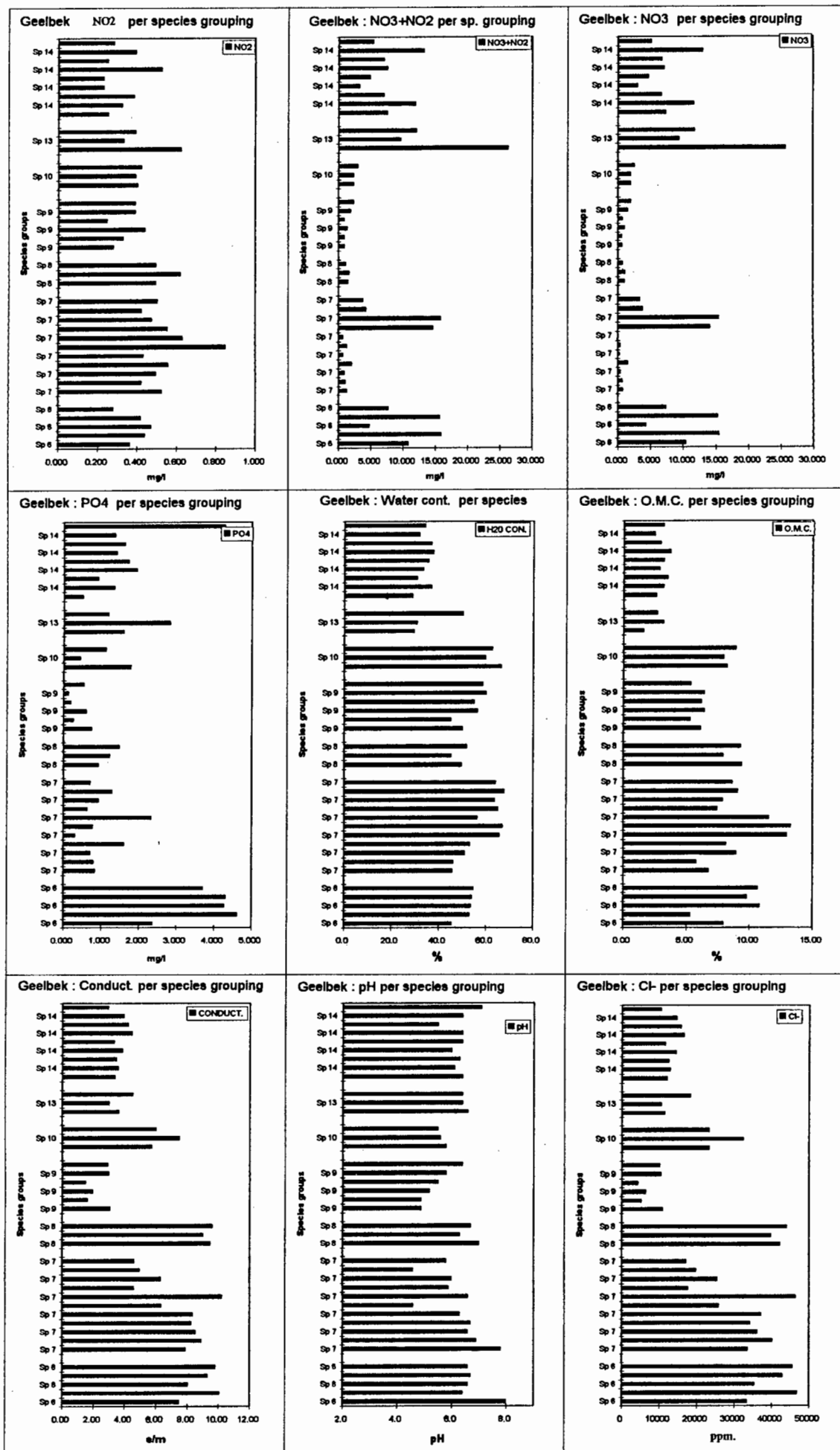
All discussion herein refers to Figure 5.37 to 5.40

Considering the relationship between the environmental variables and species occurrence (See Figures 5.37 to 5.40), the following environmental parameters appear to exert the most influence on all species within this transect. As noted in section 5.3, this importance is by virtue of the unique status of that parameter for each species, as reflected by similar within group characteristic and different between group status. These are: moisture content; O.M.C.; conductivity; Cl<sup>-</sup>; Na; Ca; Zn and height above M.S.L.

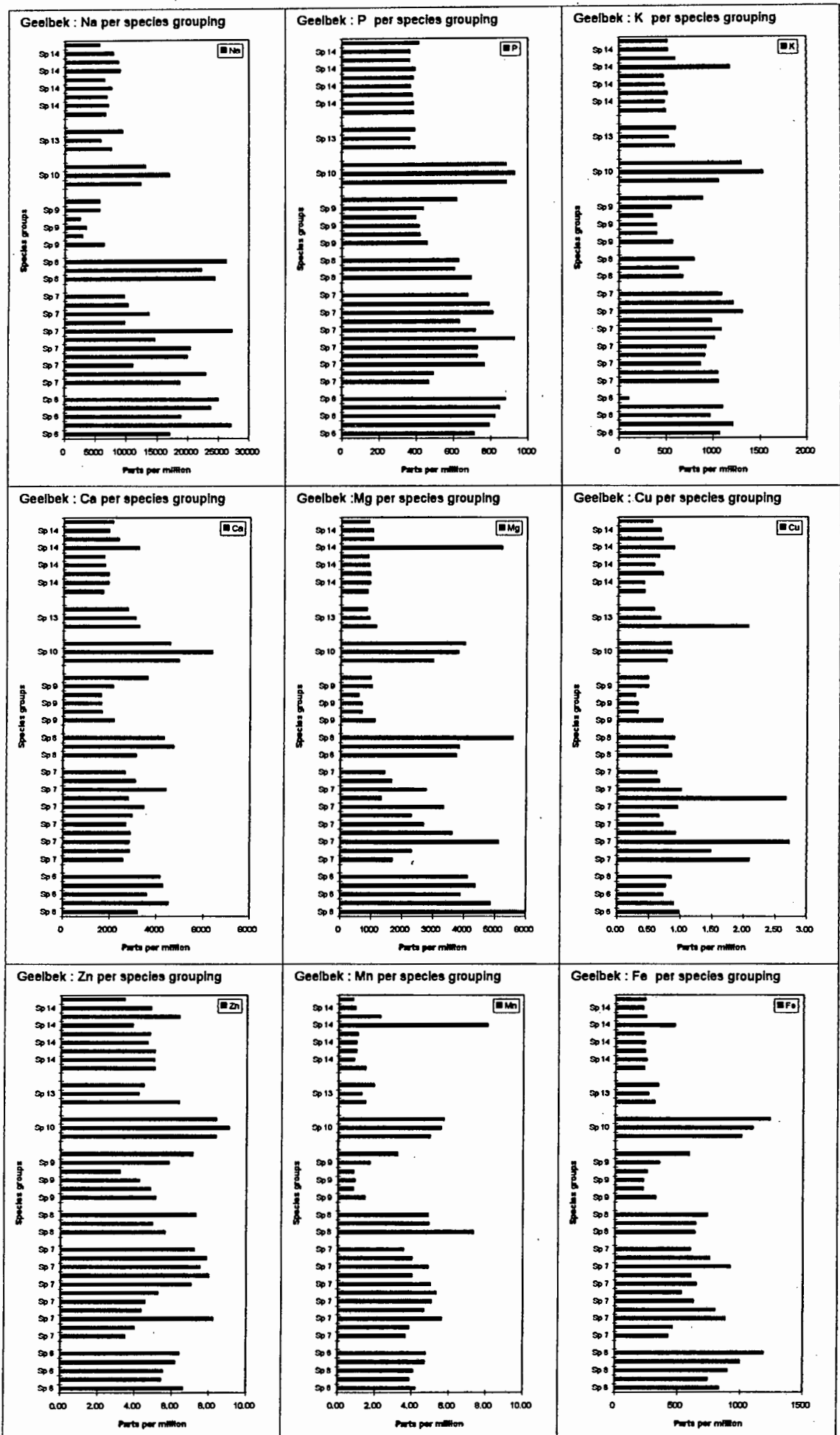
The parameters which show the greatest degree of consistency across all species are NO<sub>2</sub>; pH; Cu; Sat. Cu and Sat. Na. These parameters are the least likely to explain the between group variance. Across the majority of graphs, bare patches and *Zostera capensis* generally seem to prefer or tolerate lower strengths of all trace elements, whilst *Salicornia meyeriana*, *Sarcocornia perennis* and *Sarcocornia pillansii* occupy regions of higher value. The values for the nutrients NO<sub>3</sub> and PO<sub>4</sub> appear to be very low for *Schoenoplectus triqueter*, *Sarcocornia pillansii*, and *Sarcocornia perennis*.

With fewer species, the relationships between environmental factors and those species becomes more apparent at Geelbek than was the case at Oostewal. Overall however, there appear to be fewer elements which exert a major influence across all species. From these graphical results, height above M.S.L. appears to play the greatest role in determining species location.

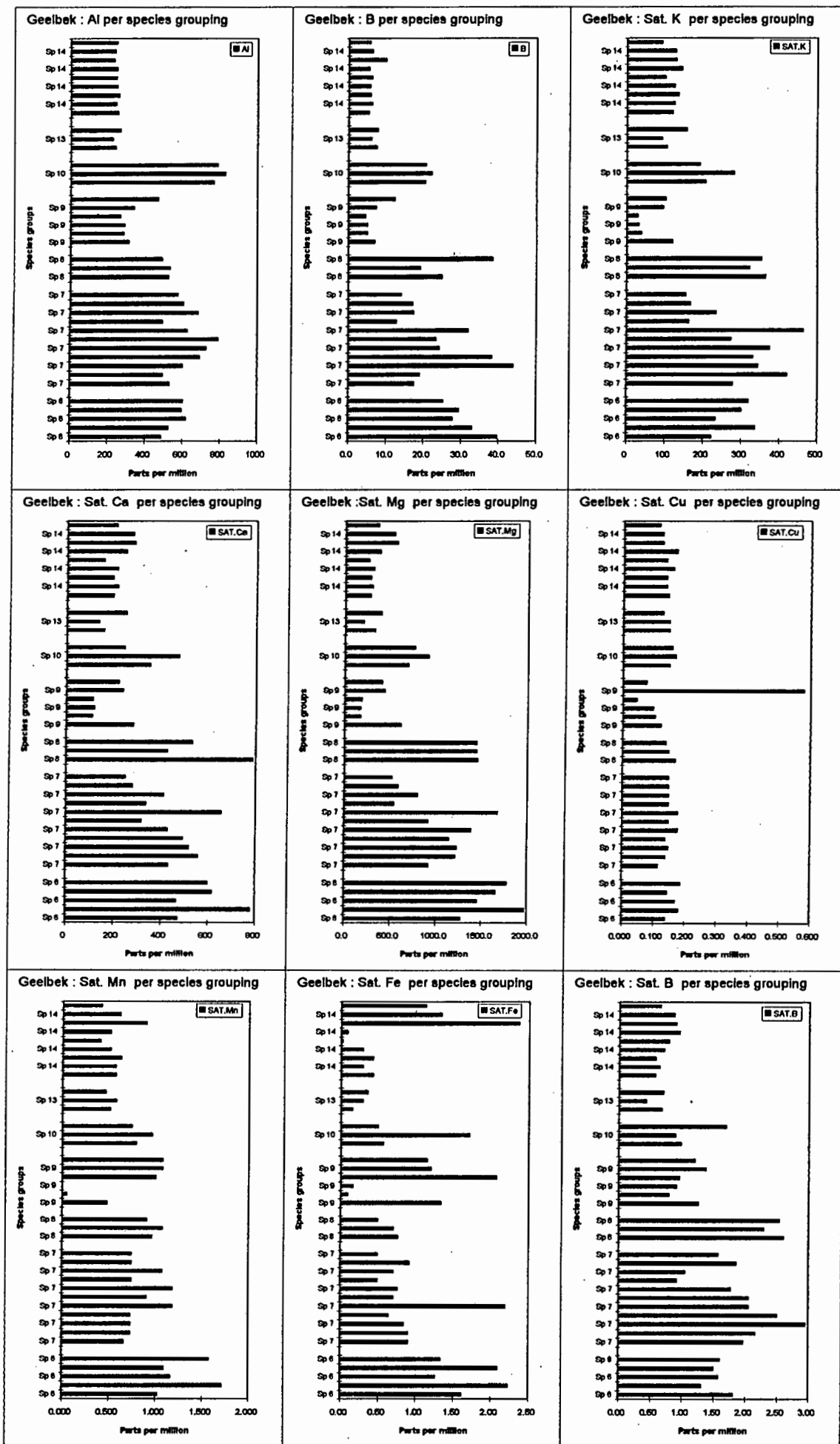
**Figure 5.37: Geelbek:- Species grouping per environmental parameter**



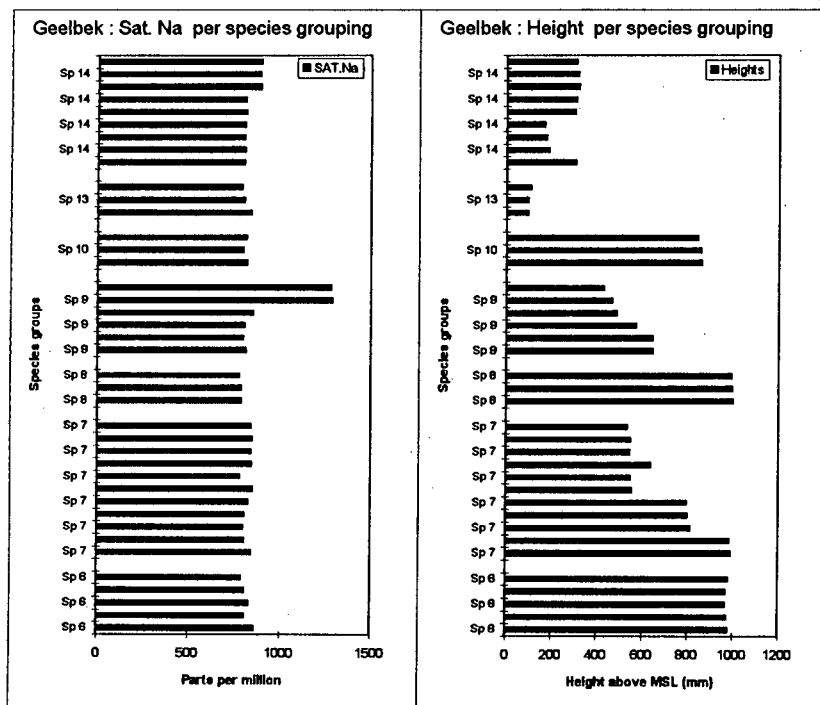
**Figure 5.38: Geelbek:- Species grouping per environmental parameter**



**Figure 5.39: Geelbek:- Species grouping per environmental parameter**



**Figure 5.40: Geelbek:- Species grouping per environmental parameter**



### 5.4 3 Schrywershoek

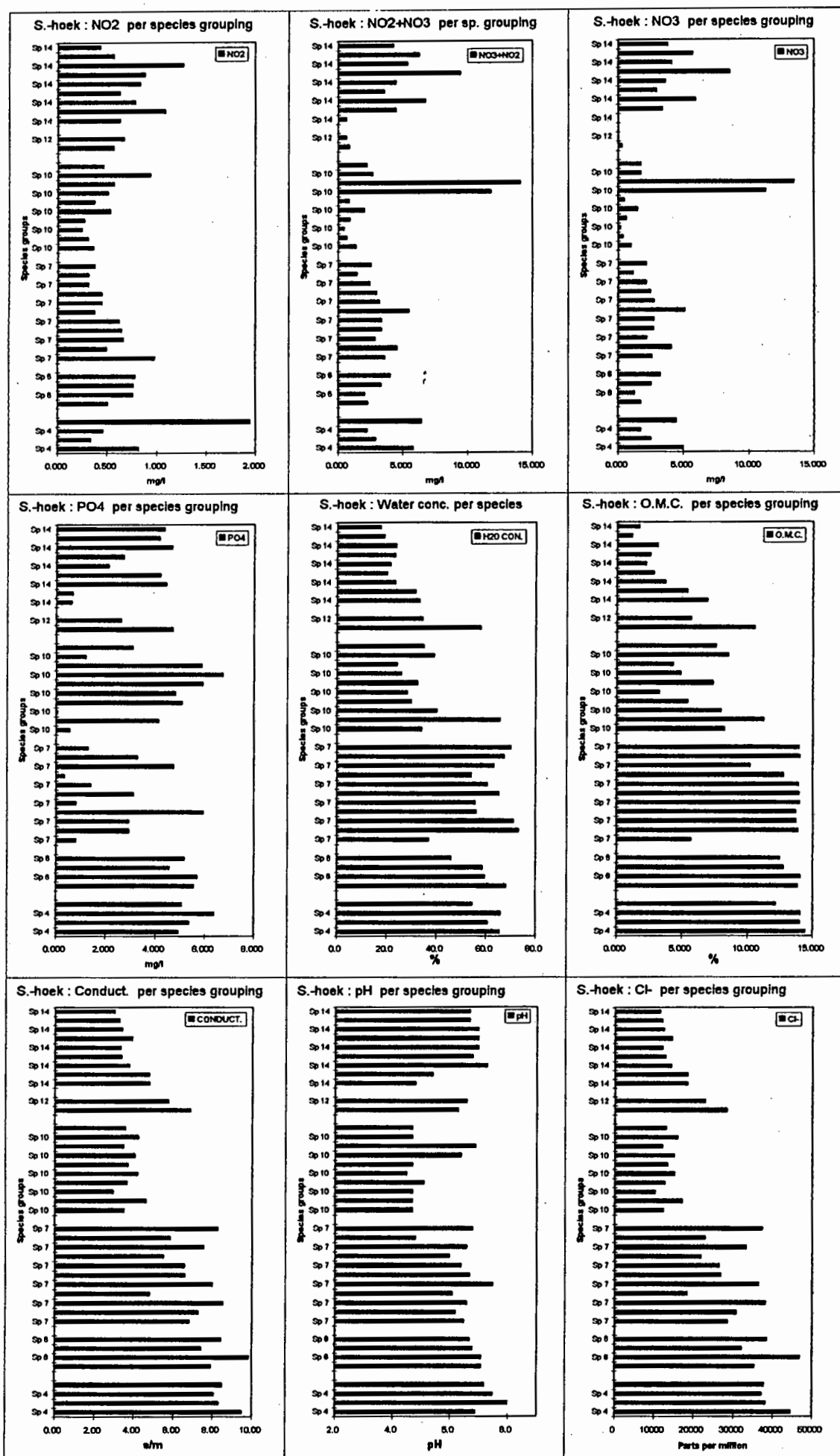
All discussion herein refers to Figures 5.41 to 5.44

The environmental factors which appear to exert the most influence in this transect are: Conductivity; Cl<sup>-</sup>; Na; P; Mn; Al; B and Sat. Cu. The majority of these plots seem to reflect a dichotomy between *Limonium depurpuratum*, *Salicornia meyeriana*, *Sarcocornia perennis*, *Triglochin bulbosa* and *Spartina maritima* & bare patches. This is especially apparent for Moisture content; O.M.C.; conductivity; Cl<sup>-</sup>; Na; Al; B; and saturated extracts K; Ca and Cu. Generally *Limonium depurpuratum*, *Salicornia meyeriana*, *Sarcocornia perennis* & *Triglochin bulbosa* show a tendency towards elevated levels in the variables, while species *Spartina maritima* & bare patches generally reflect lower levels. This dichotomy is particularly well represented by height above M.S.L.

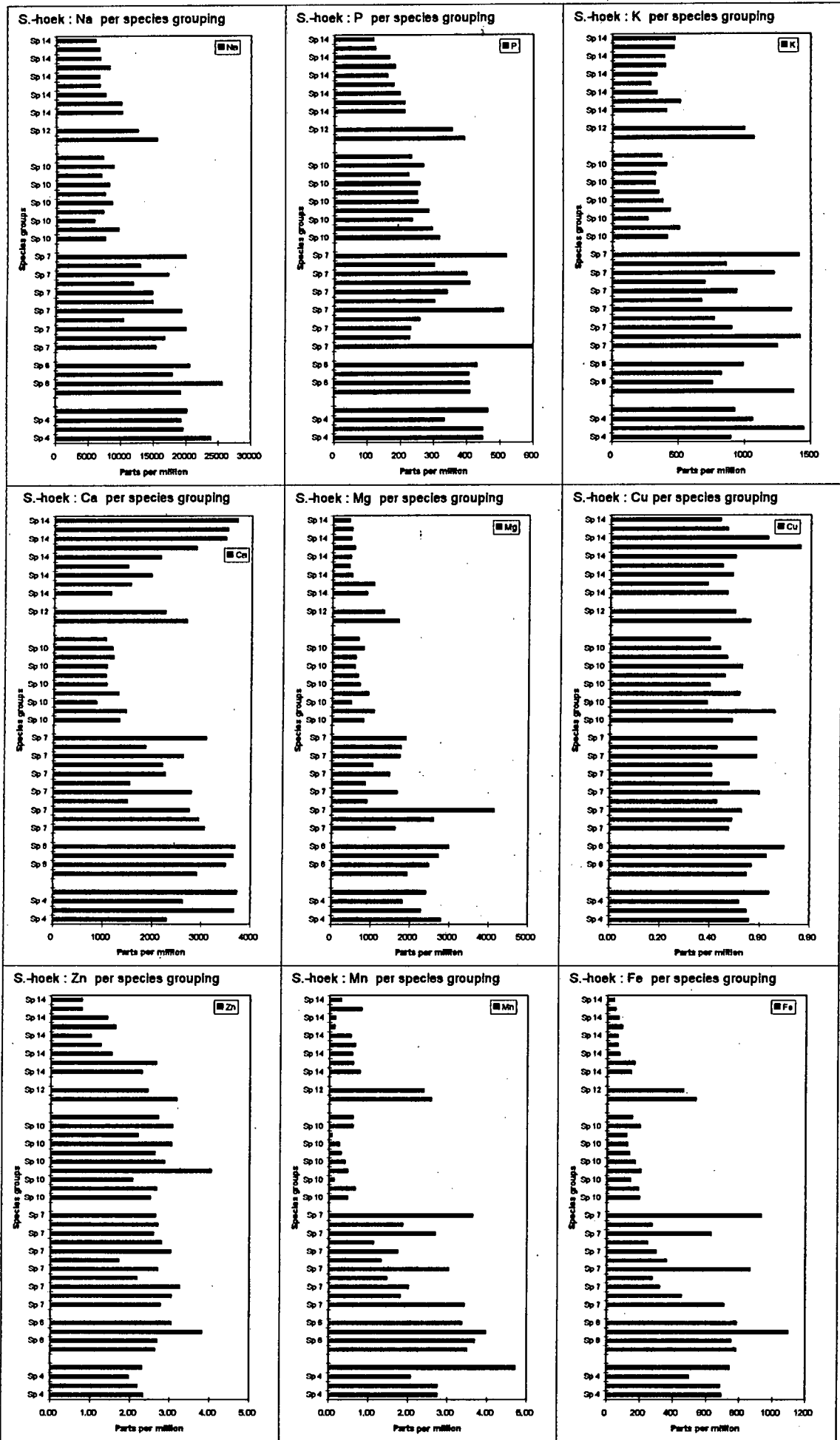
Unlike the other two transects, Schrywershoek does not exhibit much species variation and displays a narrow range across all species. Consistency across all species could be seen for: Cu and Sat. Fe., hence only these two parameters appear to exert little influence on community structure. Notably, *Spartina maritima* shows a sharp preference or tolerance for a more acidic environment.

Schrywershoek has the lowest number of species which should, perhaps have had the effect of revealing the variable / species relationships more clearly. This most certainly would have been the case had the variables showed a marked difference from species to species. This transect demonstrates, however, that fewer species do not necessarily make complex relationships easier to comprehend - an idea expounded in Chapter 2 as a reason for the popularity of ecological studies on salt marshes (Long & Mason 1984)

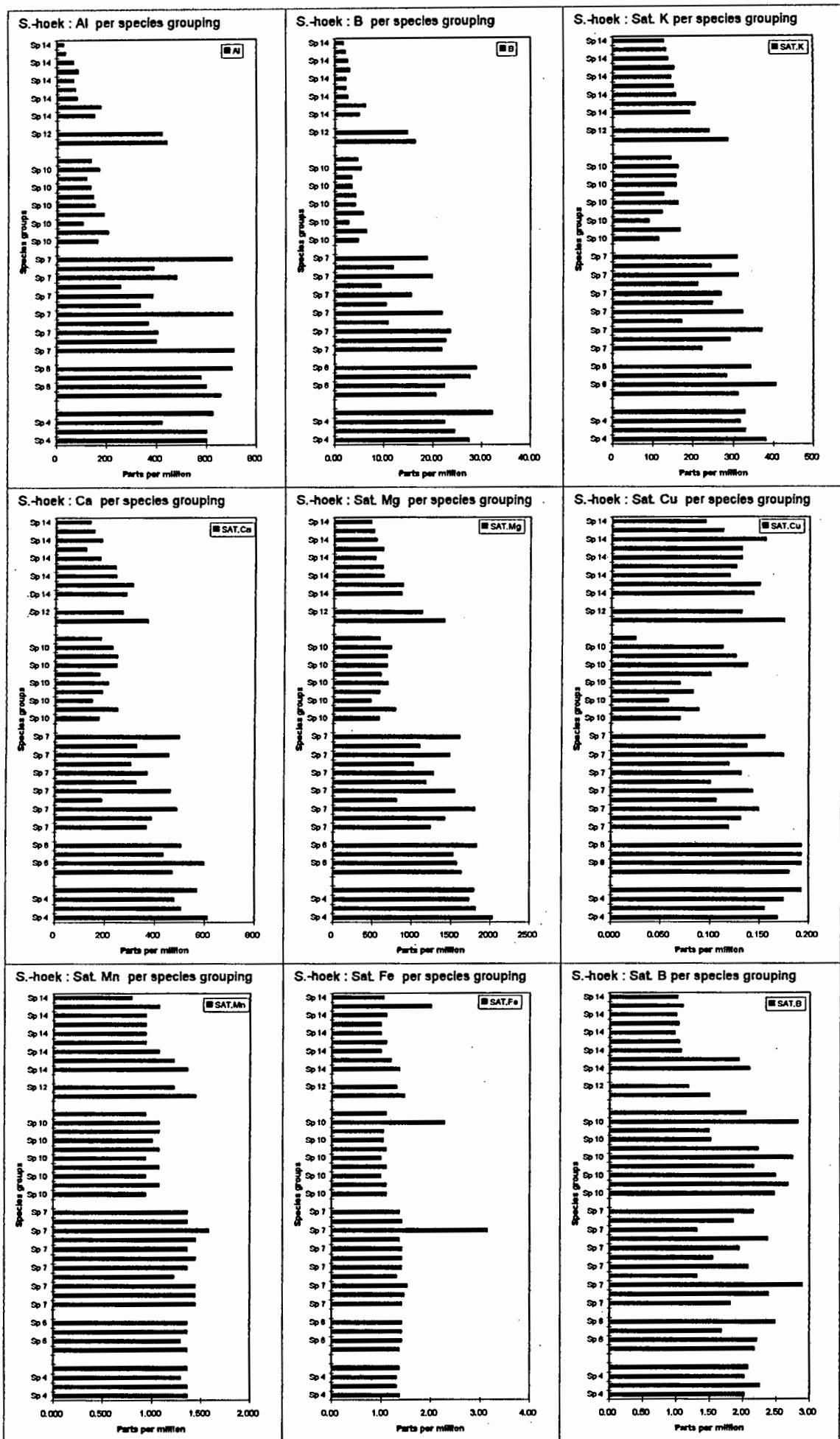
**Figure 5.41: Schrywershoek: -Species grouping per environmental parameter**



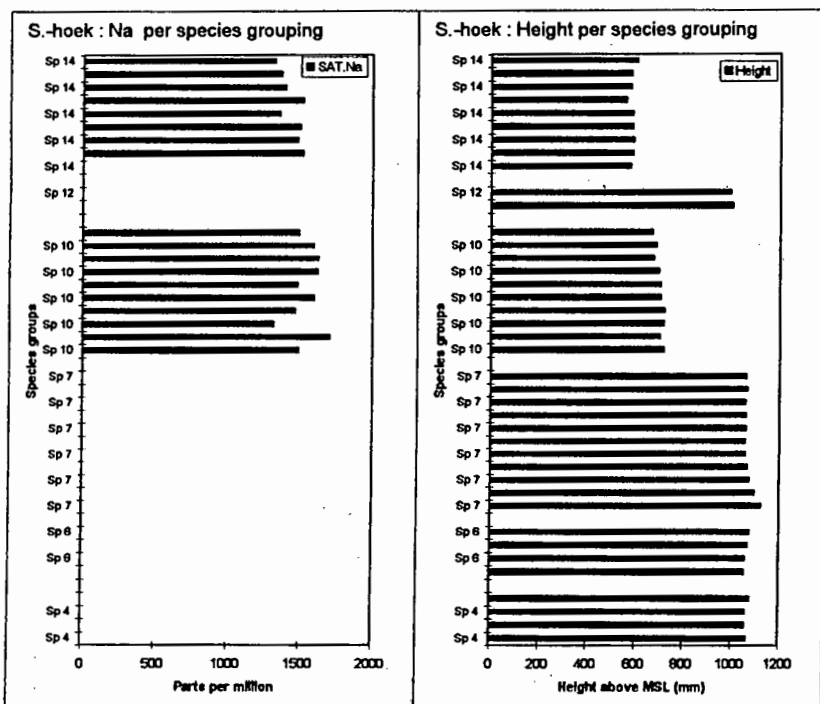
**Figure 5.42: Schrywershoek: -Species grouping per environmental parameter**



**Figure 5.43:Schrywershoek:-Species grouping per environmental parameter**



**Figure 5.44: Schrywershoek:-Species grouping per environmental parameter**



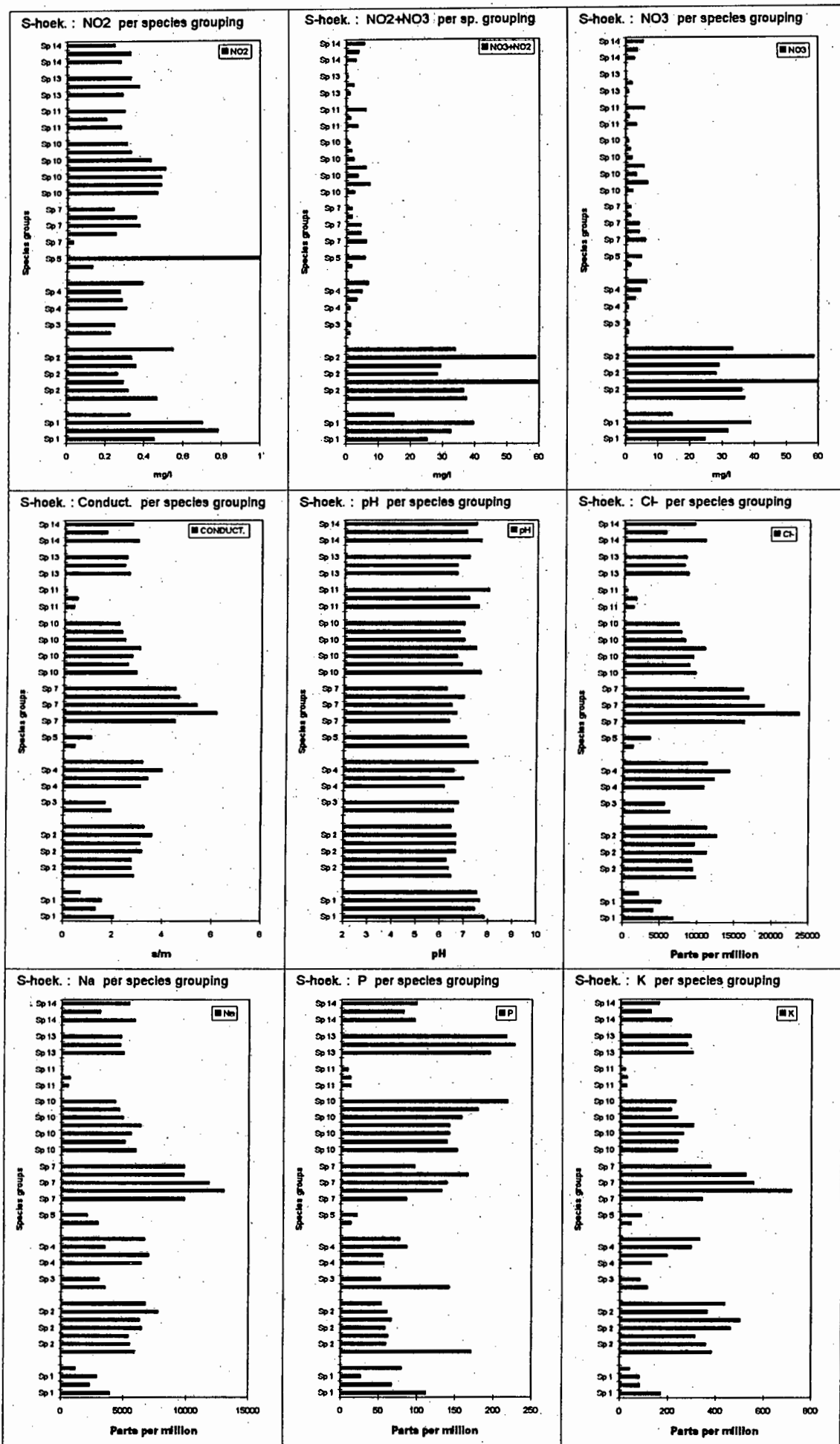
#### **5.4.4 Oostewal: Variation in environmental parameters per species over time**

All discussion herein refers to Figures: 5.33 to 5.36; 5.45 to 5.46 & 5.48 to 5.50.

As in section 5.3 the discussion here involves the comparison of three series of results taken at even intervals over the period of a year. (It should be noted that the parameters PO<sub>4</sub>, moisture content and O.M.C. were not measured for sample sessions 2 & 3.) The objective here is to ascertain if there has been any noticeable change in the environmental levels as grouped per species. (N.B. - comparisons of the same parameter between Figures may have to take into account scale changes which were made to accommodate large variation in ranges. This can have the effect of making similar results look very different)

Considering the results of the section on environmental trends, it was not surprising to find that very little fluctuation appears to have occurred due to seasonal change. In this section however, greater detail of fluctuation can be ascertained as these species/parameter bar charts show finer detail than the parameter trends line charts. It can be seen that the majority of levels of the environmental parameters appear to remain static over time when the general trends are considered. Closer examination and comparison at the individual species level, reveals that while the majority of levels remain constant, a number of species show minor fluctuation. For example NO<sub>3</sub> remains markedly constant over time for *Juncus kraussii*, *Limonium depurpuratum*, *Plantago crassifolia*, *Sarcocornia perennis*, *Spartina maritima*, *Sporobolus virginicus*, *Zostera capensis* & bare patches, but *Carpobrotus acinaciformis* & *Chenolea diffusa* show a fourfold increase in sample session 2, returning close to original levels in session 3. Similarly, pH maintains a similar shape across all species

Figure 5.45: Oosteval:-Species grouping per environmental parameter (Session 2)



**Figure 5.46: Oostewal:-Species grouping per environmental parameter (Session 2)**

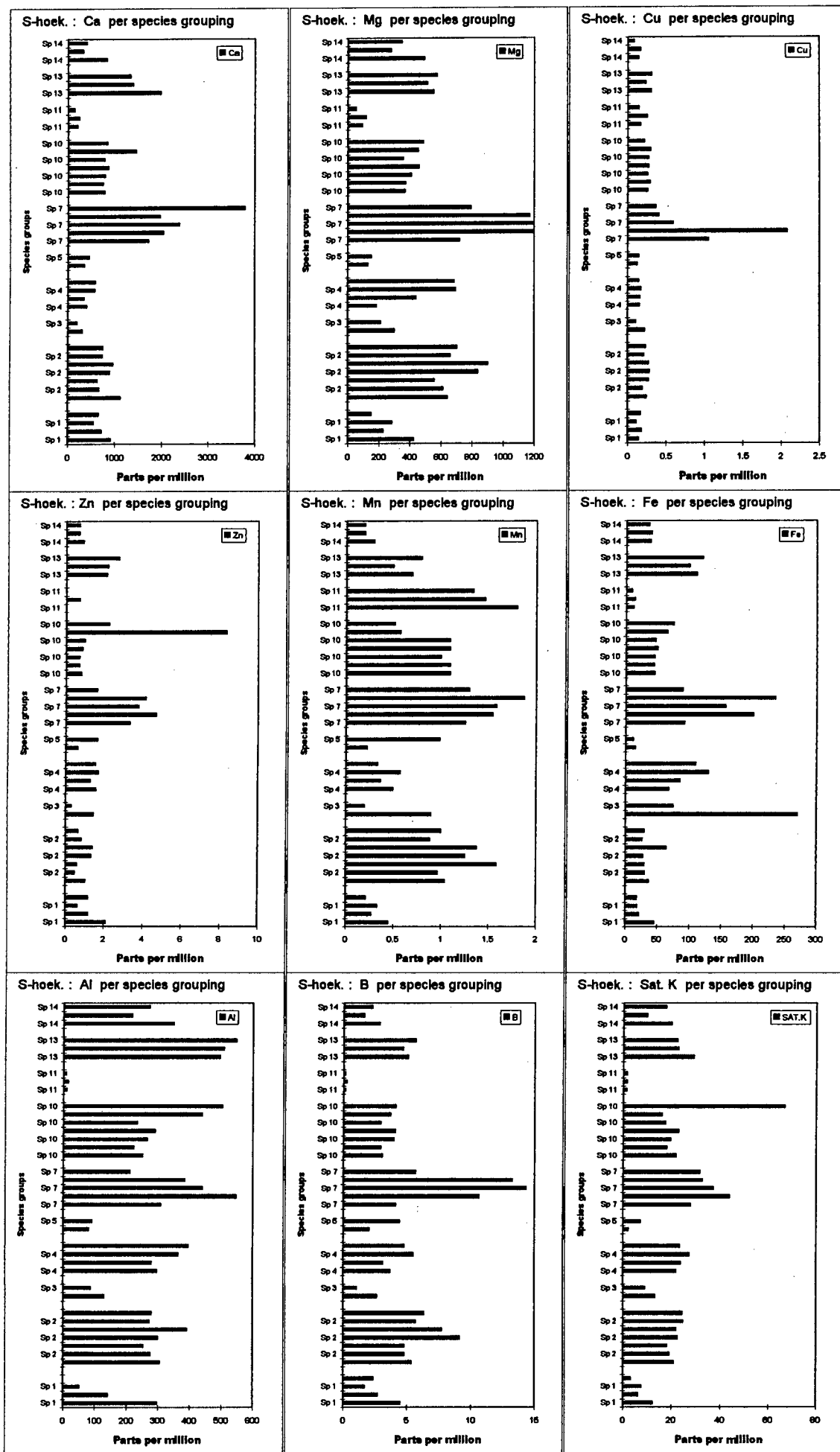
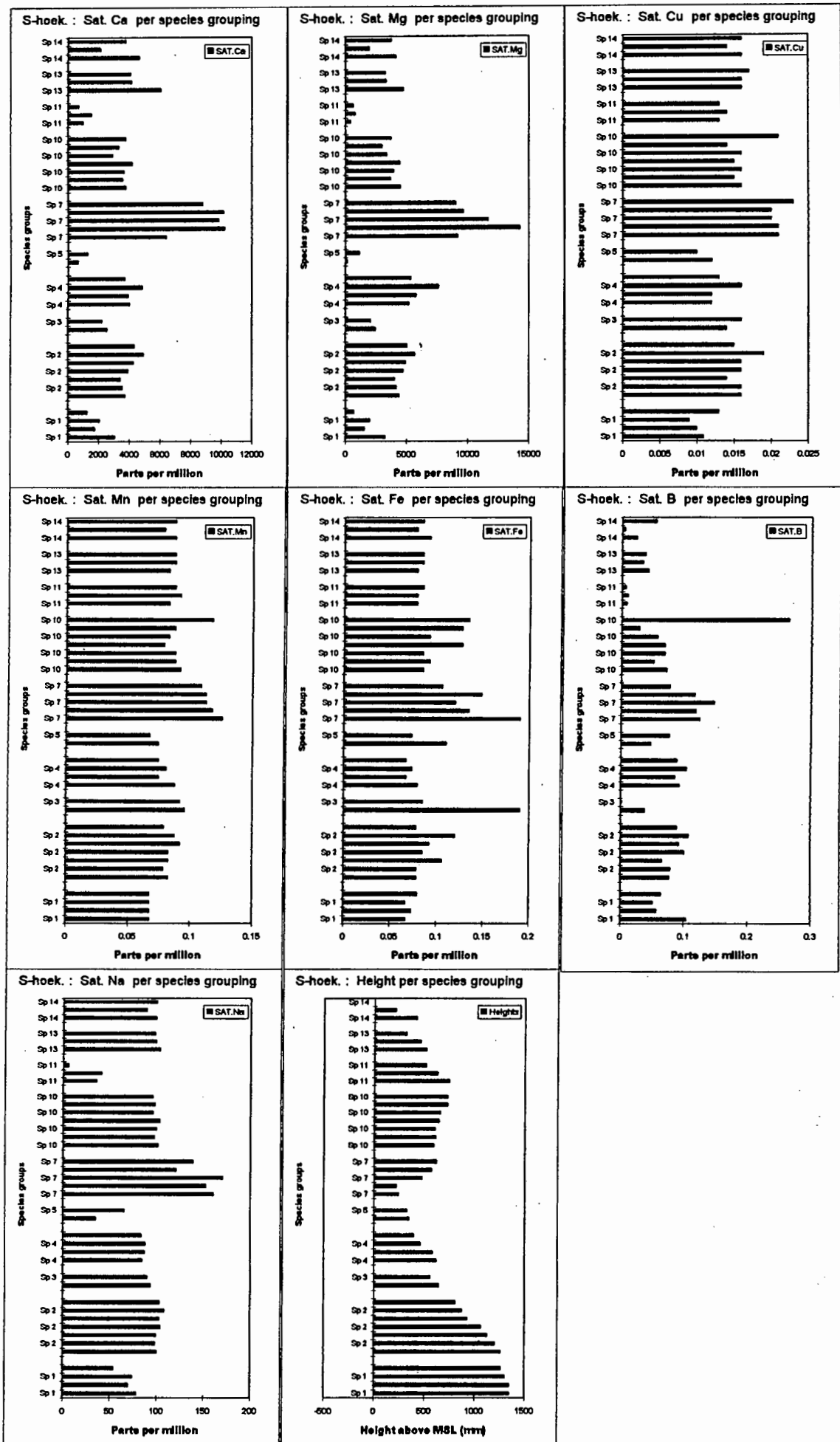
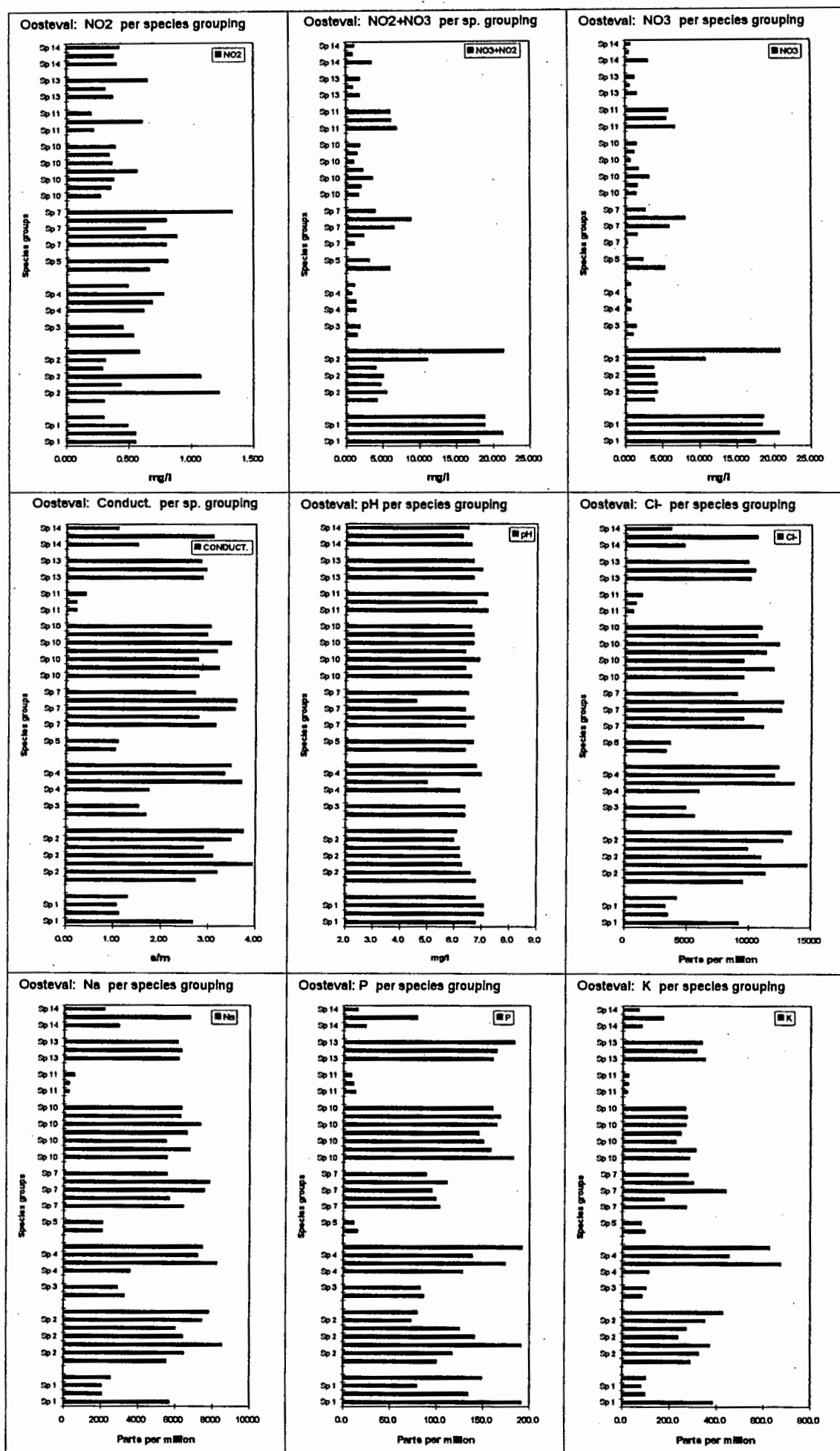


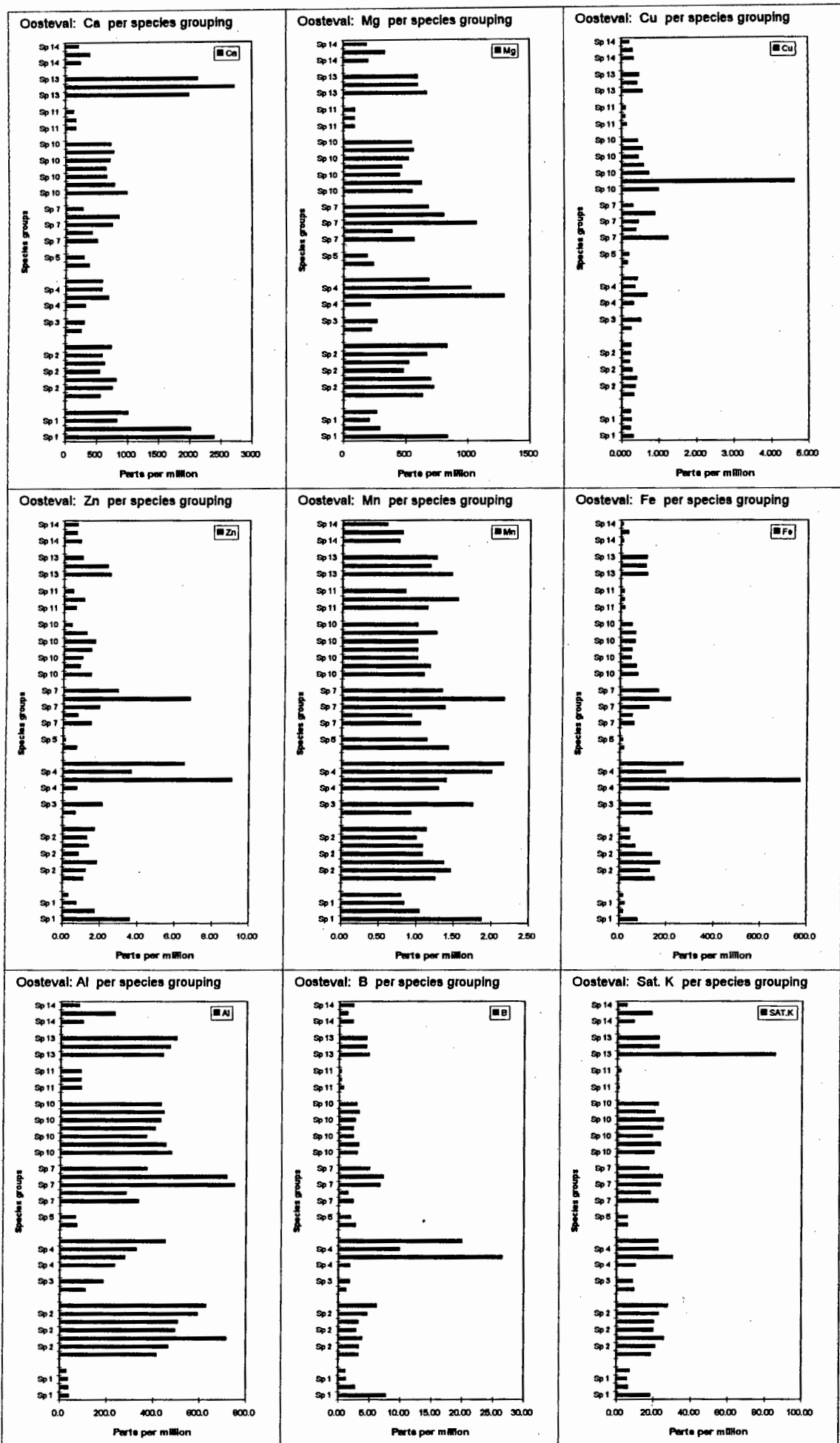
Figure 5.47: Oostewal:-Species grouping per environmental parameter (Session 2)



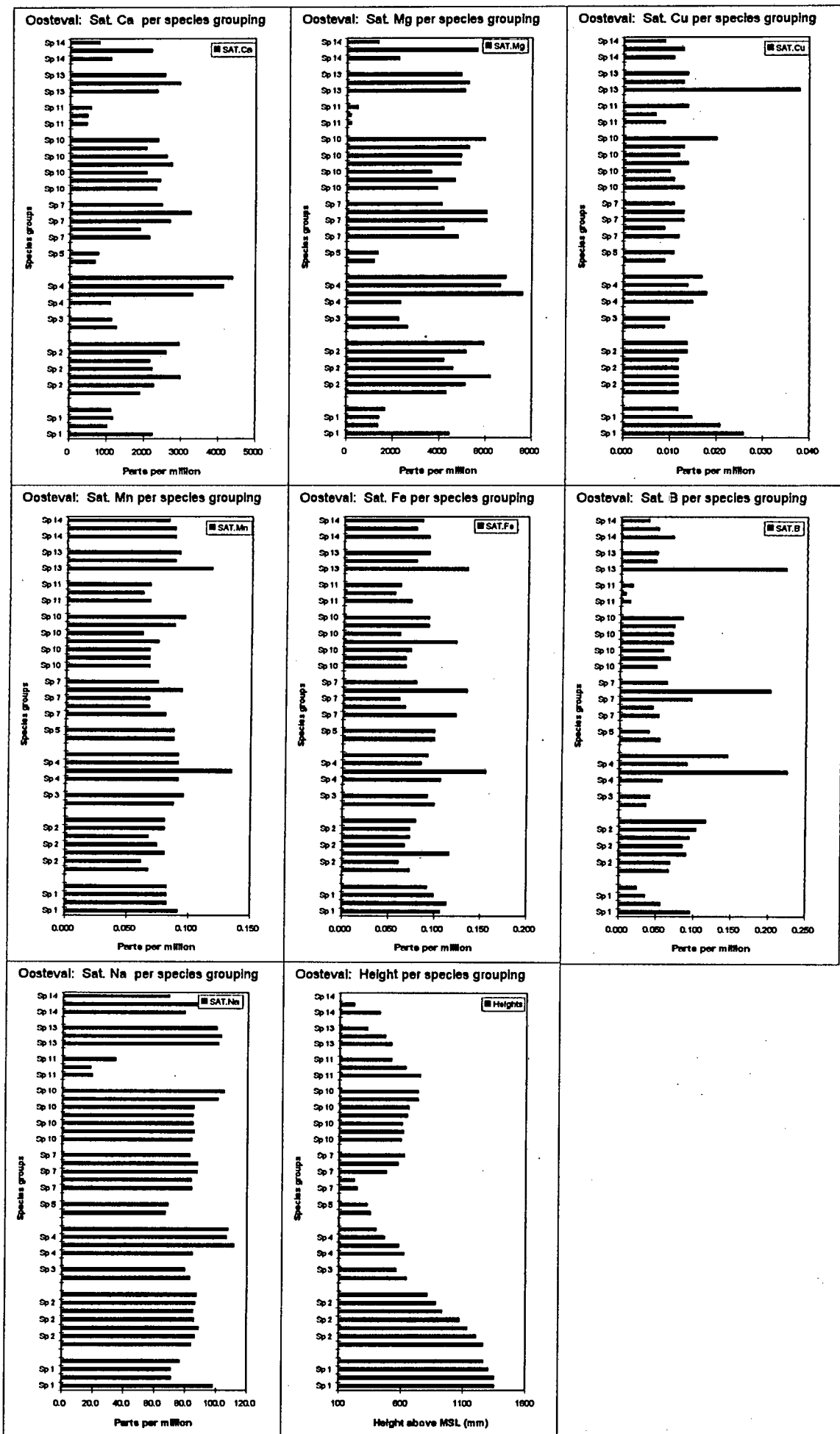
**Figure 5.48:Oosteval:-Species grouping per environmental parameter (Session 3)**



**Figure 5.49:Oosteval:-Species grouping per environmental parameter (Session 3)**



**Figure 5.50: Oosteval: -Species grouping per environmental parameter (Session 3)**



but closer examination reveals an increase towards alkalinity for all species in session 2 & 3. These fluctuations are minor and clearly have no influence on community size or position.

#### **5.4.5 Overview**

In this section it is apparent that a number of environmental parameters appear to exert more influence on the species communities. Parameters which appear to be more influential in one transect may not hold the same influence in the other transects. Conductivity, Cl<sup>-</sup> and height above M.S.L. appear to be the only influential parameters common to all transects. Comparisons by observation tend to overlook the more subtle changes in these charts. Increasingly it is apparent that subtle variation within the transects may not influence species occurrence or position.

Oostewal, the transect with the largest number of species also appears to have the greatest number of important parameters (i.e. the factors considered to have the greatest influence), while Schrywershoek the transect with the lowest number of species appears to have the least. Thus, there is suggestion of a direct relationship between species number and variation within environmental variables. Caution, however, needs to be exercised in such an assumption, as the transect with the larger number of species has fewer samples to represent the environmental parameters. This has the effect of diminishing the chances of within group variation and could therefore falsely enhance the appearance of within group homogeneity

These Figures have been ordered sequentially by species number, hence the species are not necessarily arranged in the order of appearance in the transect. This may have had the unintentional effect of exaggerating the differences between groups. These observations will need to be quantified to gain more insight and a better understanding of the nature

and extent of the influence of the environmental parameters on salt marsh vegetation patterns.

## **5.5 The relationship between soil texture and species occurrence.**

In this section the results of the soil textual analysis (described in Chapter 4) are presented, described and discussed. Samples were taken from quadrats dominated by a particular species and therefore, considered to be representative of the sediment most suited to that species. To facilitate presentation, the analysis results were averaged and presented as pie charts. Appendix E contains the results of the raw data and shows the method employed to gain the average results for each species. As was the procedure in other sections, the results of each of the three transects are individually examined. Considering firstly, that sediment stability is a prerequisite for salt marsh development and secondly, taking into account the well developed nature of the salt marshes in question, it was considered unlikely that sediment texture would undergo significant change in the period of a year. Hence, change in textural characteristics over time was not tested and, for purposes of this study, therefore considered to be static.

Each Figure contains pie charts showing the average soil texture for each species. Individual charts show the percentage value for each fraction of the soil analysis. Comparisons are made between these charts for each transect to ascertain whether there are textural characteristics unique to each species. This is followed by a comparison of the textural conditions to determine the extent continuity between the three transects. (Refer to section

4.3.6 in Chapter 4). To simplify discussion and provide focus in this section the seven textural classes will be reduced to three as follows:

- 1) Course texture (granule, very coarse sand; course sand)
- 2) Medium texture (medium sand; fine sand)
- 3) Fine texture (fine sand; silt & clay)

For purposes of this discussion textural classes with a cumulative representation of less than (<)20% will be considered insignificant and more than (>) 60% highly significant.

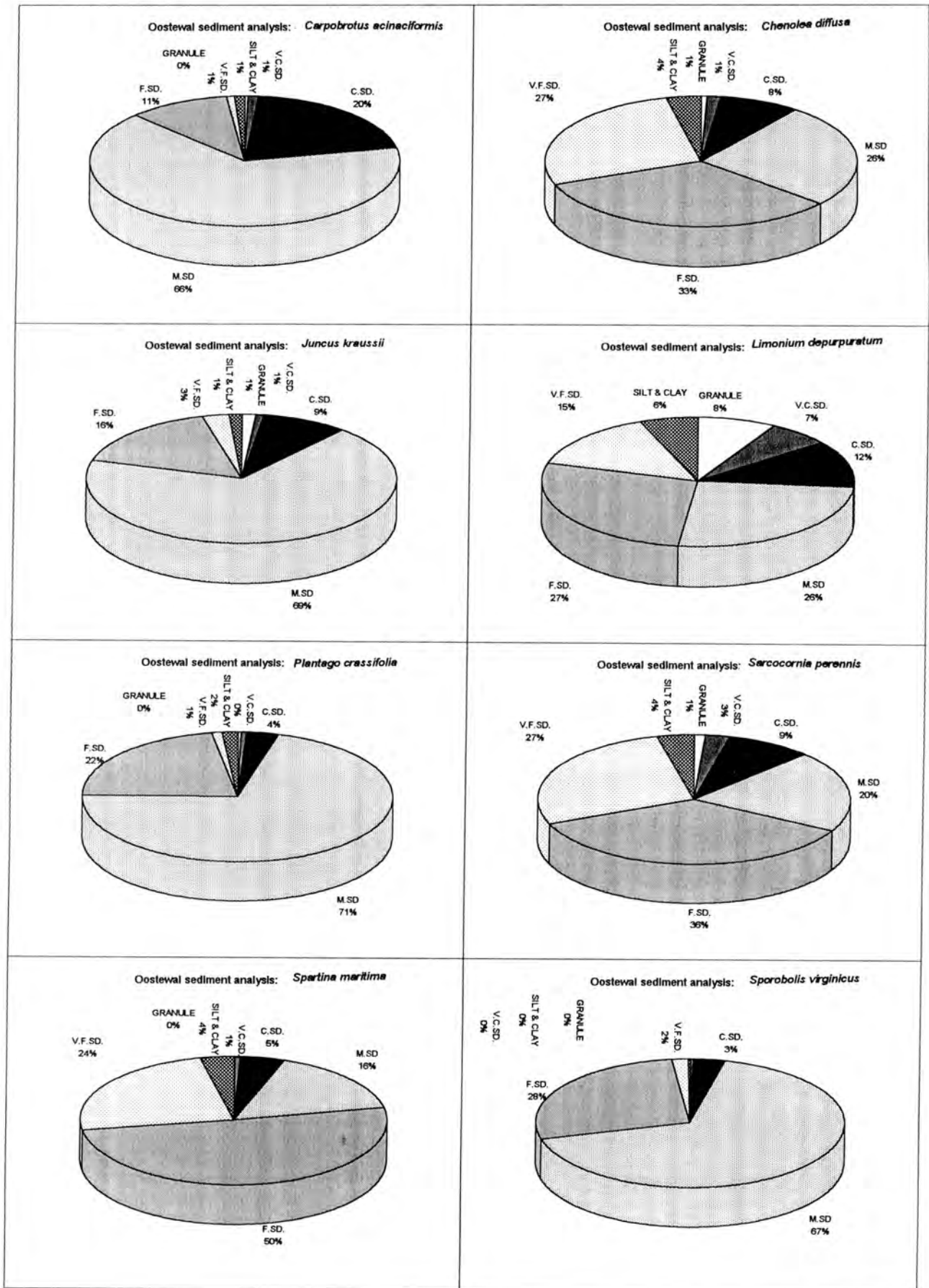
### 5.5.1 Oostewal

All discussion herein refers to Figure 5.51 to 5.52.

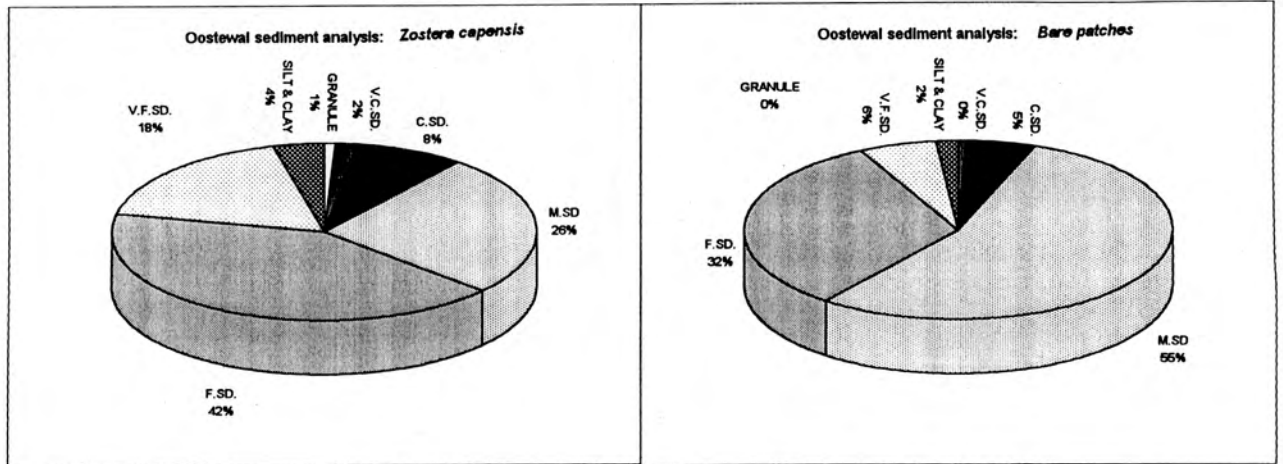
Across the entire range of species the following observations could be made:

- 1) Coarse texture: *Carpobrotus acinaciformis* and *Limonium depurpuratum* are the only two species with significant values in this class.
- 2) Medium texture: All the species with the exception of *Limonium depurpuratum* (53%), *Sarcocornia perennis* and *Chenolea diffusa* (59%) have highly significant values in this class (i.e. > 60%).
- 3) Fine texture: This class appears significant for *Chenolea diffusa*, *Limonium depurpuratum*, *Sarcocornia perennis*, *Spartina maritima* and *Zostera capensis*.

**Figure 5.51: Oostewal:- Soil texture results**



**Figure 5.52:Oostewal:- Soil texture results**



From this analysis it is clear that the medium texture class characterises this transect. Only two species have significant representation for the coarse class and five species have significant values for the fine class. Reference to Figure 5.1 confirms that the coarse, medium and fine sediments generally corresponds with the species found in the respective upper, middle and lower salt marsh. Therefore the texture appears to become coarser with increase in altitude.

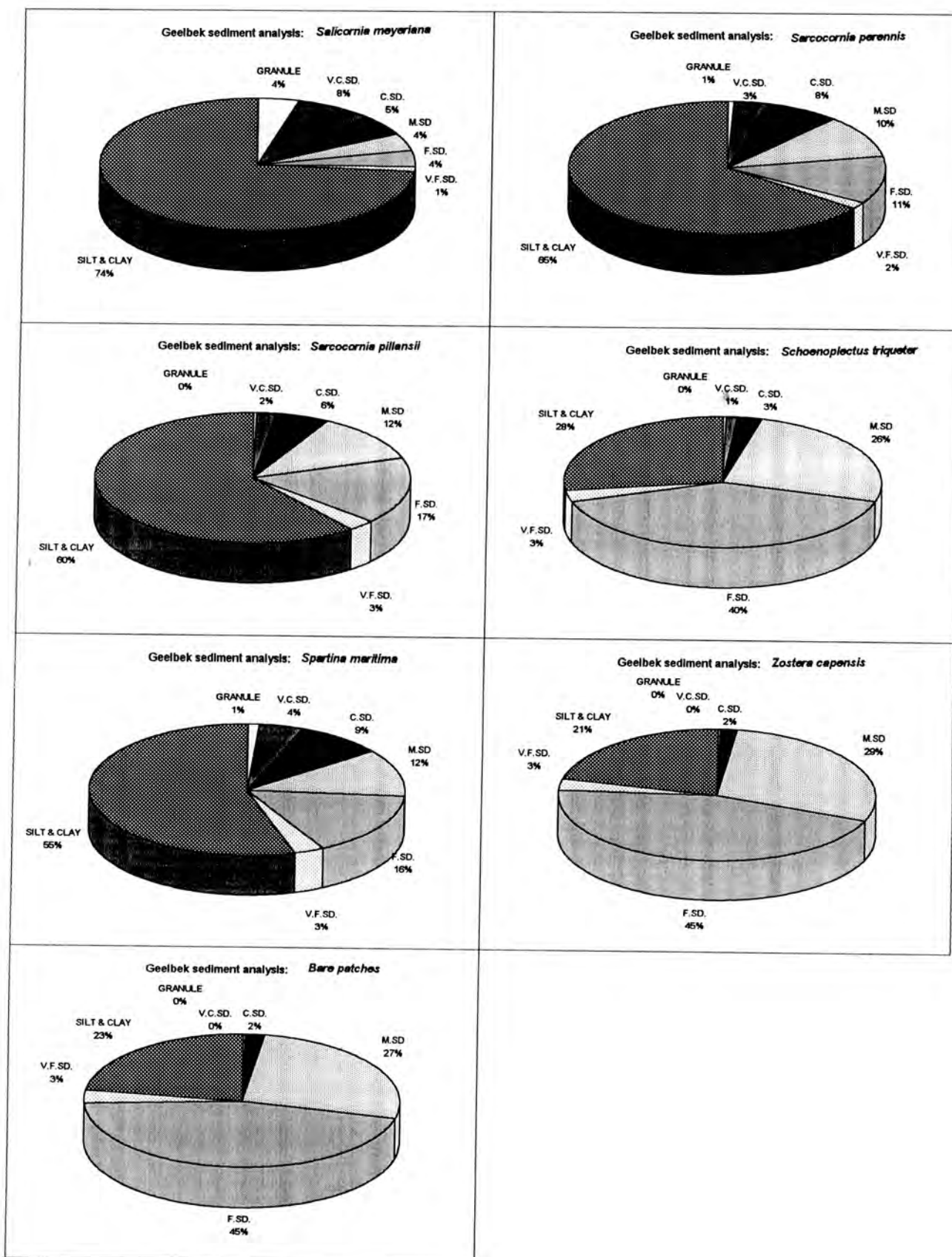
### 5.5.2 Geelbek

All discussion herein refers to Figure 5.53.

The following observations were made after an examination of the sediment characteristics of all species:

- 1) Coarse texture: This textural class is insignificant across all species.
- 2) Medium texture: Two species and the bare patches are found to have highly significant levels in this class (*Schoenoplectus triqueter*, *Zostera capensis*), while significant levels can be found in *Sarcocornia perennis* (21%), *Sarcocornia pillansii* (29%) and *Spartina maritima* (28%).
- 3) Fine texture: This is the predominant class, with highly significant levels in *Salicornia meyeriana*, *Sarcocornia perennis*, *Sarcocornia pillansii* and *Spartina maritima*. Significant representation is also found in the remaining species.

**Figure 5.53:Geelbek:- Soil texture results**



There is a clear distinction between the sediments above and below the step (See section 5.22 & Figure 5.17). The coarser sediments predominate below the step and the finer sediments above. There is a sharp transition between the medium and fine sediment classes which appears to correspond with the step. The transect is clearly predominated by the fine texture class.

### 5.5.3 *Schrywershoek*

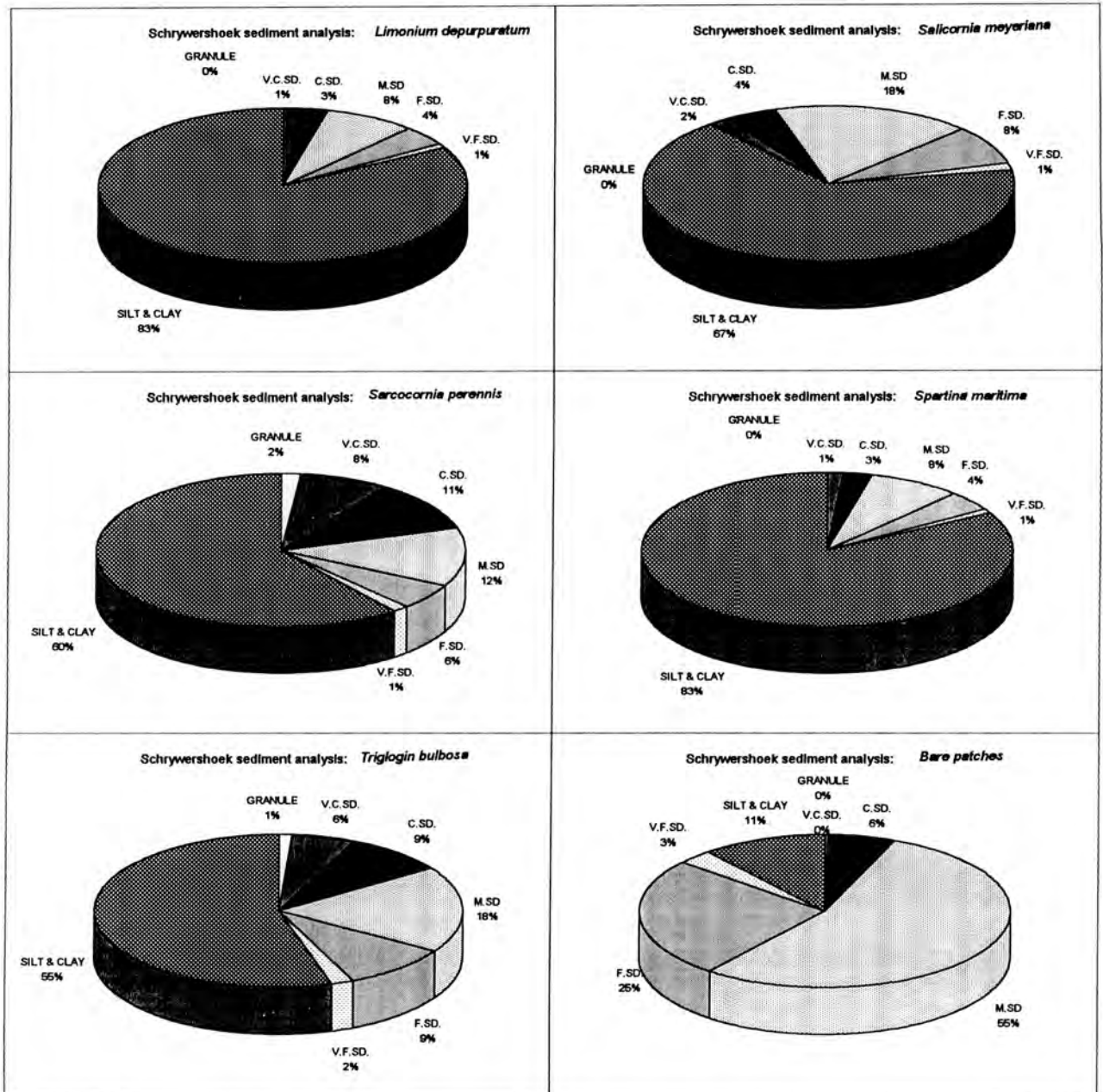
All discussion herein refers to Figure 5.54

The following observations were made across the entire range of species:

- 1) Coarse texture: No species have significant values in this class.
- 2) Medium texture: In this class the bare patches record highly significant values, while *Salicornia meyeriana* and *Triglochin bulbosa*, record significant levels.
- 3) Fine texture: With the exception of bare patches and *Triglochin bulbosa* (55%) all species recorded highly significant percentages in this textural class.

These results are similar to those discussed in Geelbek, the difference here, being a greater predominance of the fine texture. Reference to Figure 5.9 confirms the existence of a gradient of finer to coarser sediments from the top to the bottom of the transect. The bare patches are characterised by the higher levels of coarse sediment possibly as a result of greater exposure to wave action.

**Figure 5.54: Schrywershoek :- Soil texture results**



#### *5.5.4 Overview of the sediment characteristics in all transects.*

From the above a number trends in the nature of the salt marsh sediments become apparent. There appear to be distinct textural gradients in each of the transects. At Oostewal this gradient is less distinctive, but is generally opposite to the other transects, in that the sediments generally decrease in size from the top to the bottom. At Geelbek and Schrywershoek the finer sediments predominate in the middle and upper parts of the transect. Overall, the sediments at Oostewal recorded higher levels of coarser sediment suggesting that the water energy levels (i.e. turbidity preventing fine sediment deposition) are higher here, than is the case at the other two sites. Bare patches in all three transects reflect high levels of coarse material, perhaps as a result of the absence of protection of plant cover which allows the finer material to be washed away.

A comparison of the sediment characteristics reflected by *Sarcocornia perennis* and *Spartina maritima* (species which occurred in all three transects) shows consistency in texture in the case of Schrywershoek and Geelbek. At Oostewal these same species were associated with coarser sediments, apparently indicating that salt marsh plants can tolerate a range of textural conditions. Associations between texture and salt marsh plant species are apparently not discernible at a species level, at best, associations can be discerned at a scale of upper, middle and lower salt marsh.

## 5.6 Canonical correspondence analysis

The examination of the relationships between various environmental parameters and the corresponding vegetation has thus far relied on inference from monotone responses. In many instances, these relationships are not easily distinguishable. This is partly due to the size of the data set which has the affect of increasing the overall complexity, but also due to subtlety of many changes in parameter values. In many instances the environmental variables are highly co-variable, and so it is impossible to separate their independent effects. The need for a more comprehensive statistical test to analyse and visualise the relationships between many species and environmental variables is therefore apparent. The computer programme CANOCO (**CAN**Onical **C**ommunity **O**rdination) proved to be the most suitable package and was used to subject the data to canonical correspondence analysis (see Chapter 4 for details on the technique).

The summarised results of this ordination technique can be seen in Appendix G. The solution of the analysis is displayed in an ordination diagram with the species represented by endpoints (+) and the environmental variables as lines (see Figures 5.55 to 5.62). The ends of these lines will hereon be known as the line end (i.e. the furthest point away from the centre point or origin). These diagrams are plotted from the weighted scores shown in Appendix G for each ordination diagram. In the methodology chapter, a brief description of the method of interpretation is necessary, as the discussion here is primarily based on the information inferred by these ordination diagrams.

The construction of the diagram allows the following interpretation as described by Ter Braak (1986): Firstly, each line determines a direction or axis in the diagram, obtained by extending the line in both directions (in your mind or on paper). The species endpoint position relative to the line indicates the relationship of that species to that particular environmental variable. Secondly, the inferred weighted average is higher than average if the endpoint of a species lies on the same side of the origin (i.e. the centerpoint of the axis) as the line end, and is lower than average if the origin lies between the endpoint and the line end. Thirdly, the length of the line is equal to the rate of change in the weighted average as inferred from the biplot and is therefore a measure of how much the species distributions vary along that environmental variable. This means that the length of the line represents the importance of the variable i.e. the longer the line the more important the variable and vice versa.

The approach to this section is similar to that of previous sections in this chapter. Discussion begins with the individual transects, followed by an examination of variation over time (Oostewal only) and finally an examination of the textural analysis. In the ordination diagrams, the environmental variables are numbered whilst in most cases the species are named using abbreviations. A key for these numbers and the abbreviations is provided below. To facilitate discussion, the species and variables are referred to by name rather than number.

In some instances the species endpoint is not labelled due to space limitations, these points can however be determined by examining the species-environment performances in the pertinent figures in this chapter. In most cases however the missing labels have been identified and inserted on the diagrams. As explained in the methodology chapter, the

ordination plots represent only those variables deemed to be the most relevant following an iterative process to eliminate problem or unimportant (low scoring) variables. Each discussion begins with a comment on the significance (reliability) of each ordination. This was determined, firstly by examining the percentage variance of the species-environment relation and secondly, the P-value of a Monte Carlo test of significance, for the overall test.

The following species abbreviations apply to the ordination diagrams:

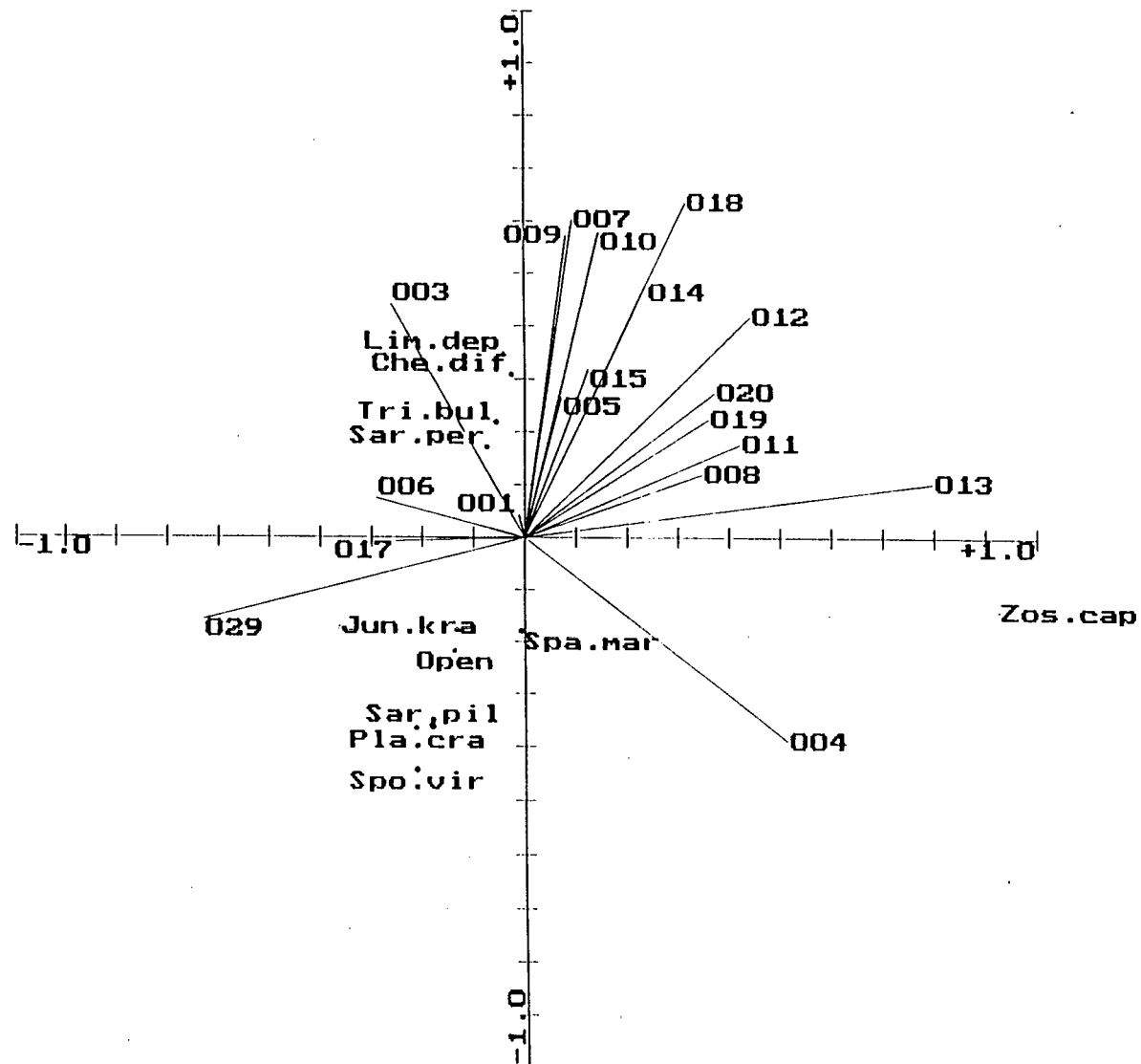
Car.aci	<i>Carpobrotus acinaciformis</i>
Che.dif	<i>Chenolea diffusa</i>
Jun.kra	<i>Juncus kraussii</i>
Lim.dep	<i>Limonium depurpuratum</i>
Pla.cra	<i>Plantago crassifolia</i>
Sal.Mey	<i>Salicornia meyeriana</i>
Sar.per	<i>Sarcocornia perennis</i>
Sar.pil	<i>Sarcocornia pillansii</i>
Sch.tri	<i>Schoenoplectus triqueter</i>
Spa.mar	<i>Spartina maritima</i>
Spo.vir	<i>Sporobolus virginicus</i>
Tri.bul	<i>Triglochin bulbosa</i>
Zos.cap	<i>Zostera capensis</i>
Open	Bare patches

### **5.6.1 Oostewal**

All discussion hereon refers to Figure 5.55.

The first four ordination axes account for an average cumulative percentage variance of 45% of the species-environment relationship, the environmental variables thus accounts for 45% of the species composition. The Monte Carlo overall test showed a highly significant P-value of 0.01.

**FIGURE 5.55:** Oostewal - Biplot of environmental variables (line) and species (.)



An examination of the ordination diagram for Oostewal reveals the following:

- 1) The combination of environmental variables results in two distinct species groupings:- *Limonium depurpuratum*, *Chenolea diffusa*, *Triglochin bulbosa*, and *Sarcocornia perennis* (hereon referred to as group A) and *Juncus kraussii*, bare patches, *Sarcocornia pillansii*, *Plantago crassifolia*, *Sporobolus virginicus* and *Spartina maritima* (hereon referred to as group B). The species *Zostera capensis* lies well outside these two groups.
- 2) The most important variables appear to be height above M.S.L, PO<sub>4</sub>, calcium, NO<sub>3</sub>, conductivity, chlorine, sodium and potassium.
- 3) Group A is strongly correlated to NO<sub>3</sub>, and appears to be more affected by the variables in the top right quadrant of the biplot, while group B is less affected by those variables and more strongly correlated with height above M.S.L.
- 4) Group B appears to be a distinctive group of plants which tend to occupy the upper reaches of the transect (i.e. upper marsh), while group A tends to occupy the middle marsh areas. Because *Spartina maritima* occupied sites in both the upper (a creek) and lower marsh, it tends to be displaced towards group B rather than towards the lower marsh indicator *Zostera capensis* as may have been expected.
- 5) *Zostera capensis* appears to be strongly correlated with calcium and PO<sub>4</sub>.

From the above it appears as if the species are grouped according to preferences which can be broadly described as upper, lower and middle marsh. With the exception of *Zostera*

*capensis* and perhaps *Spartina maritima* it remains difficult to ascribe the occurrence of each individual species to a particular set of these environmental variables. The conditions representing the open areas suggests that disturbance may be the causal factor, not differences in the environmental variables as, the conditions in these bare areas do not appear to be significantly different from other areas within the marsh where plant species are well established.

### **5.6.2 Geelbek**

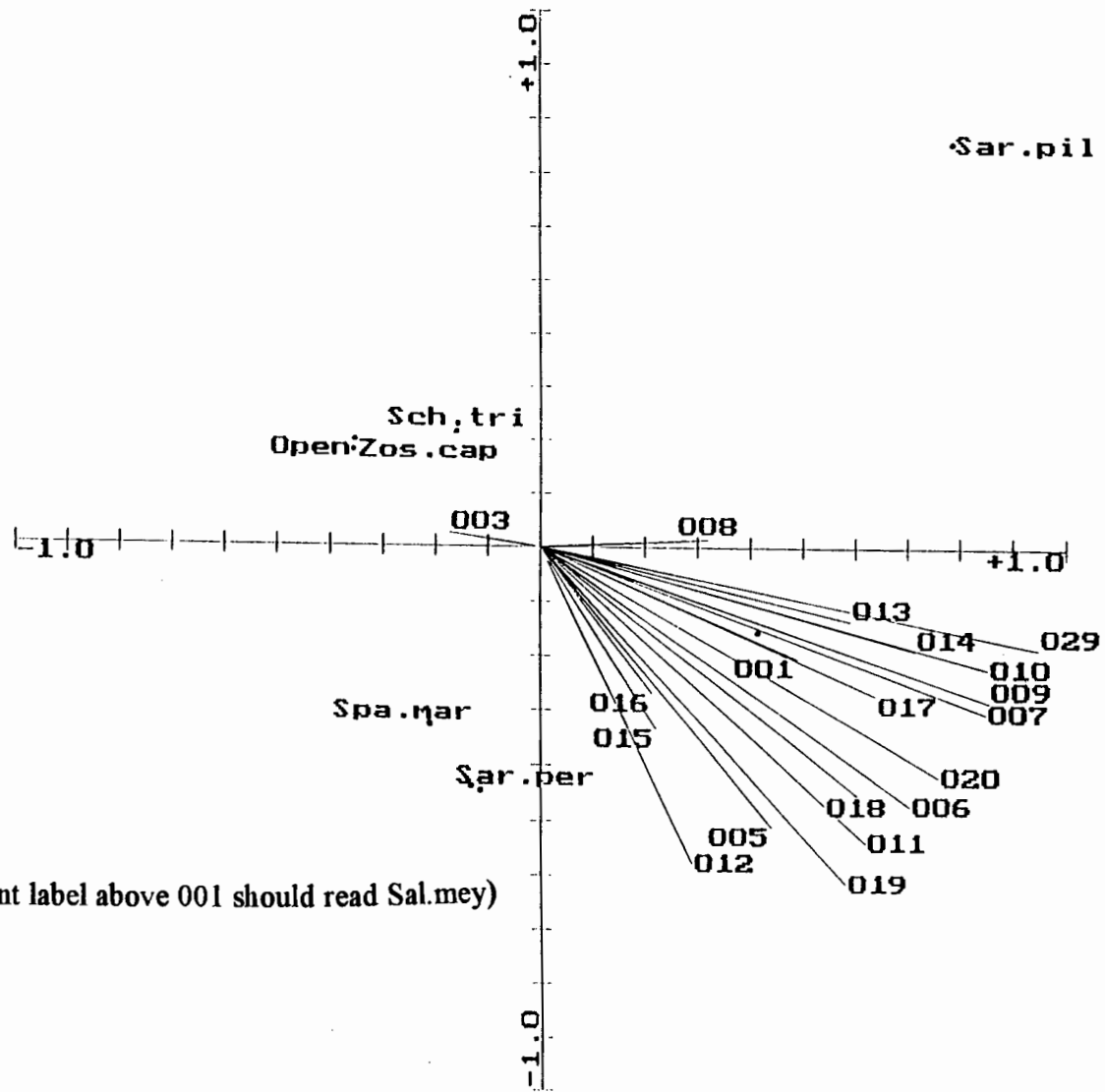
All discussion hereon refers to Figure 5.56.

The first four ordination axes account for an average cumulative percentage variance of 55% of the species-environment relationship, the environmental variables thus accounts for 55% of the variation in species composition. The Monte Carlo overall test showed a high level of statistical significance with a P-value: 0.01.

An examination of the ordination diagram for Geelbek reveals the following:

- 1) The combination of environmental variables results in a diffuse species distribution. Most environmental variables appear to be strongly aligned with the exception of NO<sub>3</sub>.
- 2) There is no clear distinction as to which particular environmental variable is the most important as there are eight which appear to be equally dominant. These are: height above M.S.L., sodium, chlorine, conductivity, boron, soil organic matter, phosphorus and aluminium. Of these, height above M.S.L,

**FIGURE 5.56:** Geelbek - Biplot of environmental variables (line) and species (.)



(Note: the missing species endpoint label above 001 should read Sal.mey)

conductivity and aluminium appear to be marginally more important than the others.

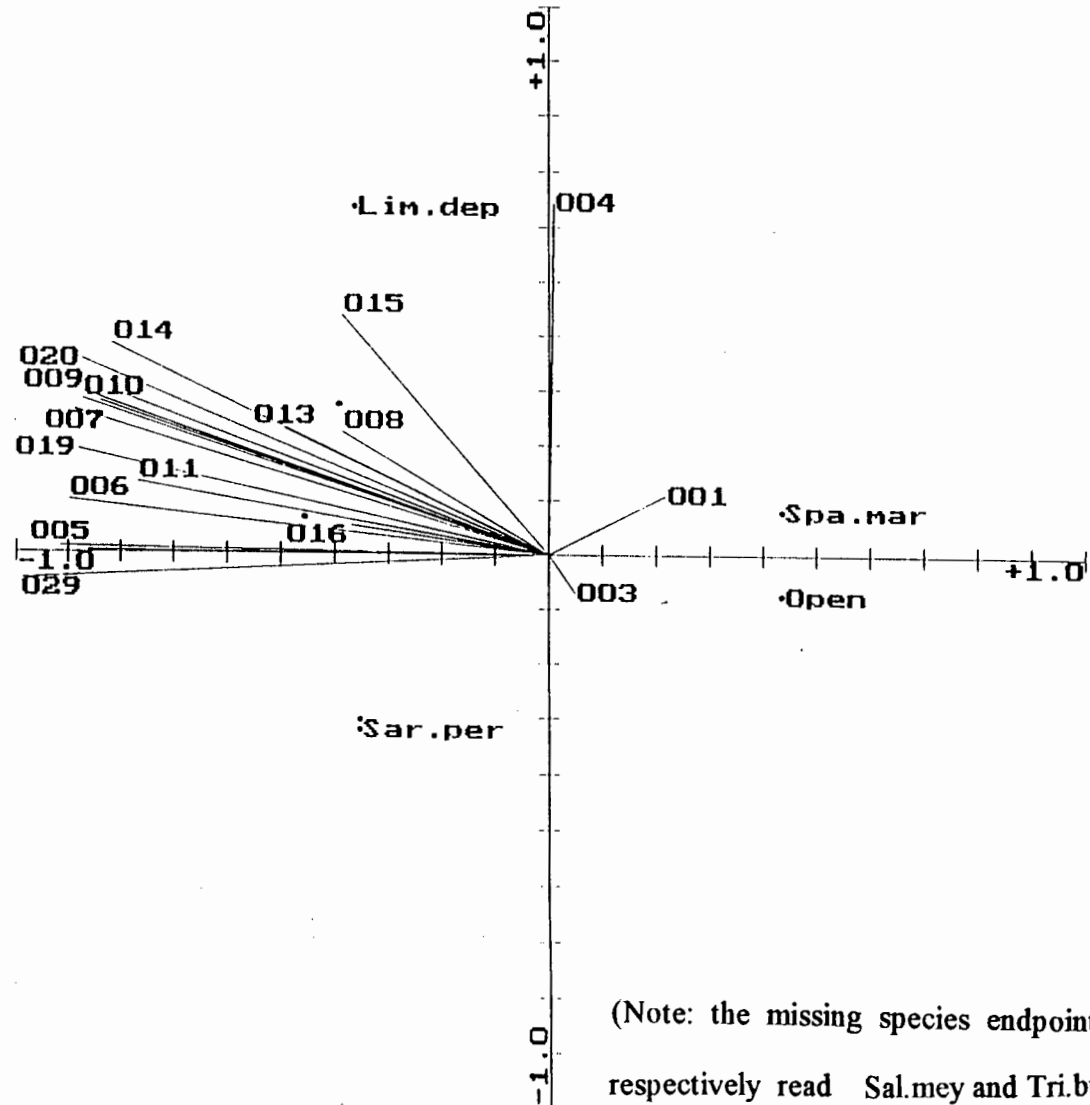
- 3) *Sarcocornia pillansii*, *Salicornia meyeriana* and *Sarcocornia perennis* are highly correlated with the eight most important variables and, to a lesser extent, so is *Spartina maritima*.
- 4) The strongest grouping of species is seen between *Schoenoplectus triqueter*, *Zostera capensis* and bare patches which in this instance represents the species on lower marsh. These three species (i.e. those found below the step) appear to prefer similar conditions in lower concentrations of the environmental variables. The other four species (i.e. those found above the step) show a greater tolerance of higher concentrations of all variables.

In this ordination diagram, the similar response of the environmental variables makes interpretation very difficult. Establishing the exact role of the environmental conditions which have resulted in this particular arrangement of species is not possible. It is, however, apparent that the salt marsh plants are ordered (from right to left in the diagram) across the gradient, presented by all the variables (with the exception of NO<sub>3</sub>). This arrangement of salt marsh species in the diagram accords well with the observed spatial distributions. NO<sub>3</sub> is the only variable which aligns differently from the rest indicating a change in direction in the gradient, i.e., unlike the other variables, NO<sub>3</sub> values increases from the top to the bottom of the transect.

### **5.6.3 Schrywershoek**

All discussion hereon refers to Figure 5.57.

**FIGURE 5.57:** Schrywershoek - Biplot of environmental variables (line) and species (.)



(Note: the missing species endpoint labels near 008 and 016 should respectively read Sal.mey and Tri.bul)

The first four ordination axes account for an average cumulative percentage variance of 75% of the species-environment relationship, the environmental variables thus accounts for 75% of the variation in species composition. The Monte Carlo overall test shows a high significance at P-value: 0.01.

An examination of the ordination diagram for Schrywershoek reveals the following:

- 1) The combination of environmental variables results in a pattern of species distribution very similar to that of Geelbek.. In this case the ordination plot has swung 180°, but all the environmental variables remain strongly co-correlated, with the exception of NO<sub>2</sub>, NO<sub>3</sub> and PO<sub>4</sub>.
- 2) The most important variables appear to be boron, height above M.S.L, chlorine, sodium, conductivity and aluminium.
- 3) It appears as if the nutrients NO<sub>2</sub>, NO<sub>3</sub> and PO<sub>4</sub> behave very differently to the majority of variables, particularly NO<sub>3</sub> which shows the same reversal observed in the previous ordination diagram.
- 4) The species can generally be divided into two groups: i.e.- those species to the left of the y-axis in the diagram (*Sarcocornia perennis*, *Limonium depurpuratum*, *Salicornia meyeriana*, *Triglochin bulbosa*) and those to the right (*Spartina maritima*, bare patches). The former group are species which generally occur on the elevated top and middle sections of the marsh and the latter group, corresponds to the species and open areas found at the bottom of the marsh.

- 5) As occurred in the Geelbek ordination, the species appear to be correlated to a gradient presented by the data which corresponds to the top and bottom of the transect.

The conditions and species arrangements in this ordination are very similar to those in the previous section, the only difference being the arrangement of the lines representing the variables mentioned in point 3 above. *Limonium depurpuratum* appears to be strongly correlated to PO4 and *Spartina maritima* and open patches to NO2 and NO3. The patches of open ground are strongly associated with *Spartina maritima* which accords well with observed spatial distribution in the marsh. Once again the bare patches appear to be devoid of vegetation for reasons not explained by the set of environmental variables tested.

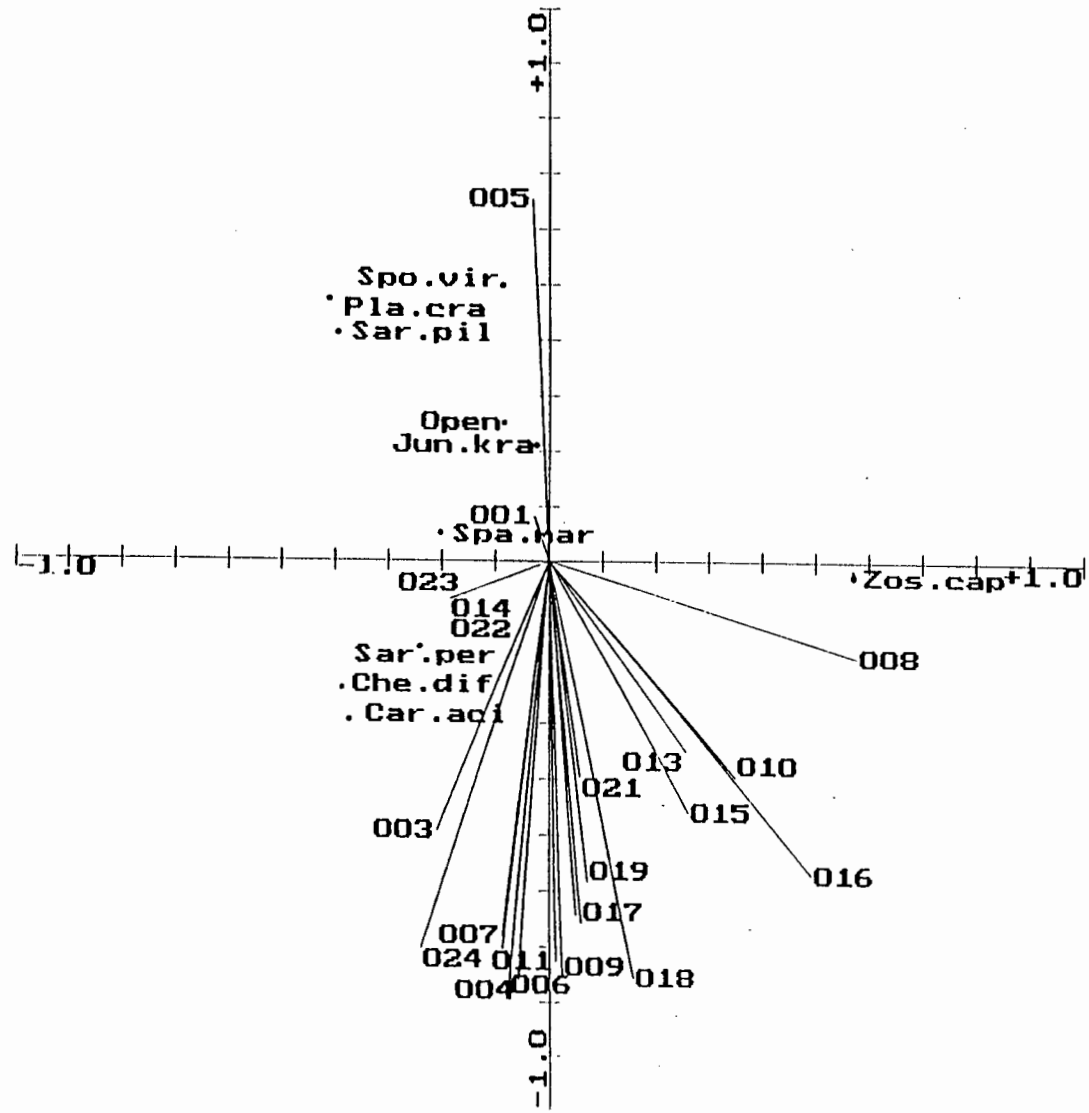
#### ***5.6.4 Oostewal: Variation over time***

All discussion hereon refers to Figures 5.58 and 5.59

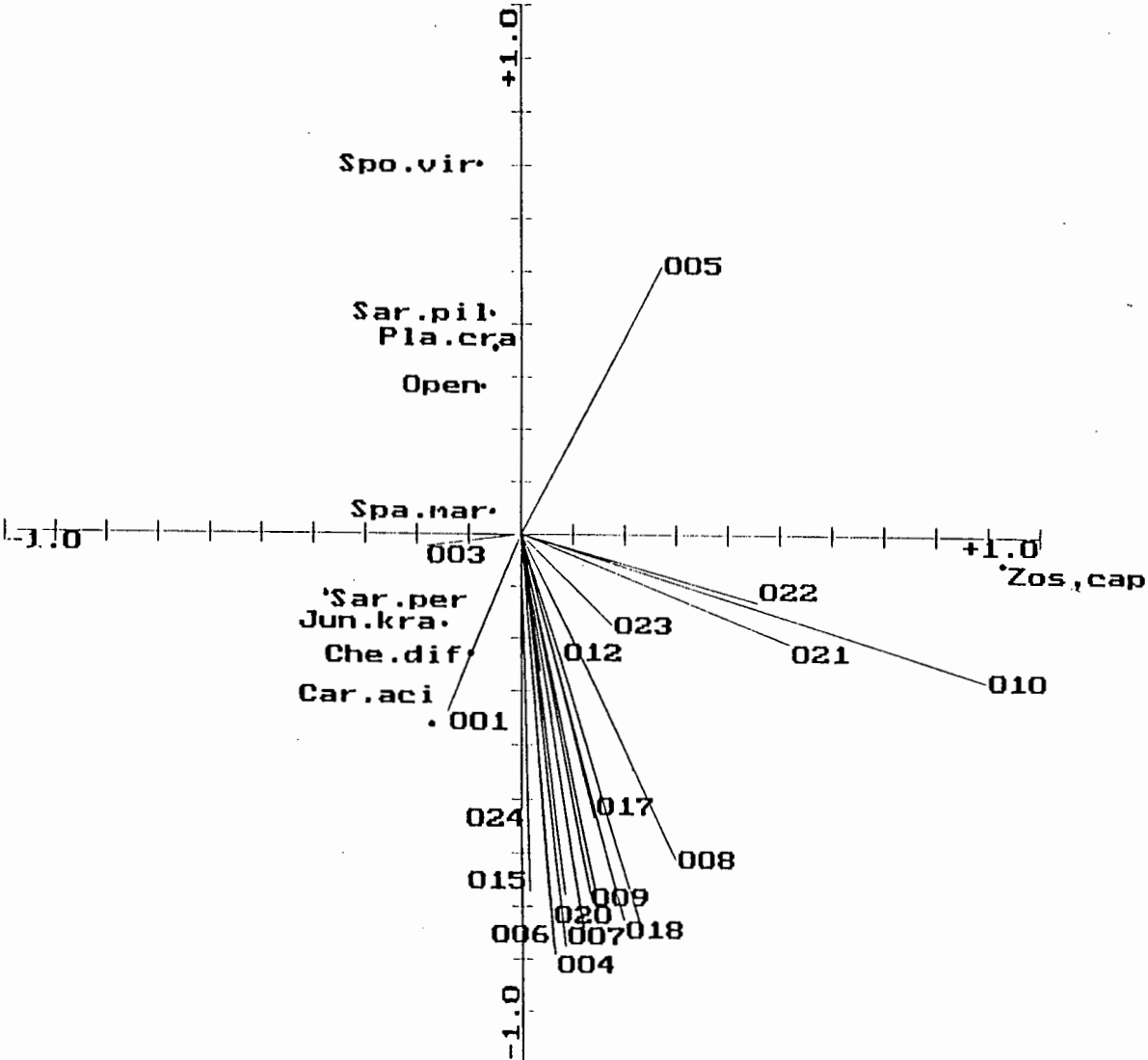
This section is used to verify the stability of the environmental - species relationship over time. This will involve a brief comparison between the second and third sample sessions. These sample sessions are comparable as they contain the same set of environmental variables. The primary objective is to confirm or revoke the earlier finding of negligible change over time.

In Figures 5.58 and 5.59 the first four ordination axes account for an average cumulative percentage variance of 46% and 49% (respectively) of the species-environment relationship. The Monte Carlo overall test showed a high significance in both cases at P-value: 0.01

**FIGURE 5.58:** Oostewal - (Sample session 2) - Biplot of environmental variables (line) and species (.)



**FIGURE 5.59:** Oostewal - (Sample session 3) - Biplot of environmental variables (line) and species (.)



An examination of these ordination diagrams for Oostewal revealed the following:

- 1) The arrangement of the environmental variables does vary to some degree and the relative importance of a number of variables marginally. The overall pattern does not reflect any major changes.
- 2) The endpoints representing the species, in most cases show little variation in position in these diagrams (i.e. little change between sessions). This is especially true of *Zostera capensis*, *Spartina maritima*, *Sporobolus virginicus*, *Sarcocornia pillansii*, bare patches, *Sarcocornia perennis*, *Chenolea diffusa* and *Carpobrotus acinaciformis*. Only *Juncus kraussii* appears to undergo a major change and this may well result from influxes of fresh water during the winter period.

From these ordination diagrams it appears that over time there are some minor changes within the environmental variables themselves, but this change is not radical enough to invoke much variation in the vegetation, hence for all intents and purposes the relationships over time between species and environment remain static.

#### ***5.6.5 Ordination of the texture analysis***

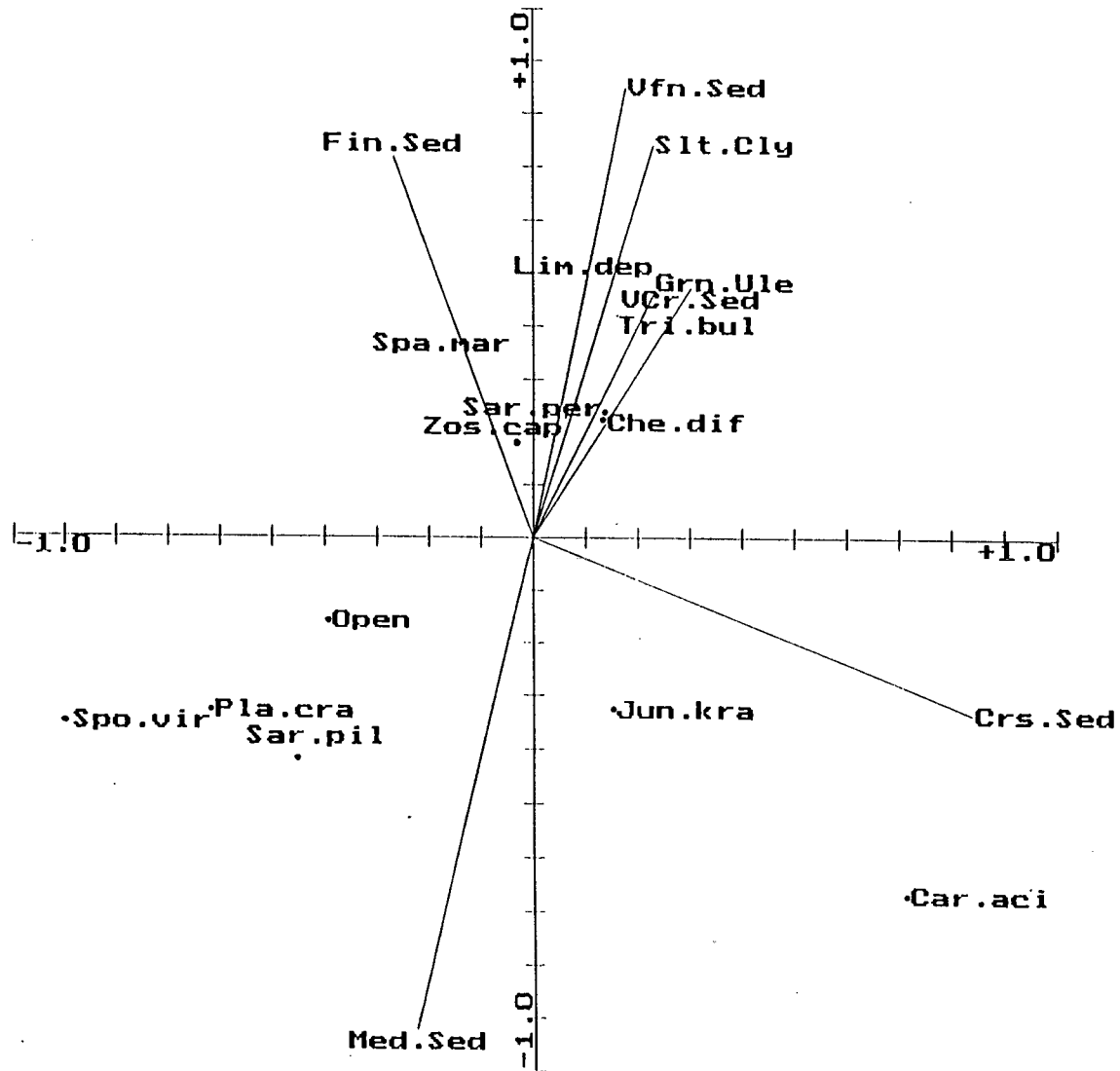
All discussion hereon refers to Figures 5.60, 5.61 and 5.62.

(Due to the smaller number of variables, abbreviated variable names and species names are displayed on the ordination diagrams)

**FIGURE 5.60:** Oostewal - (Sediment analysis) - Biplot of environmental variables (line) and species (.)

**Key:**

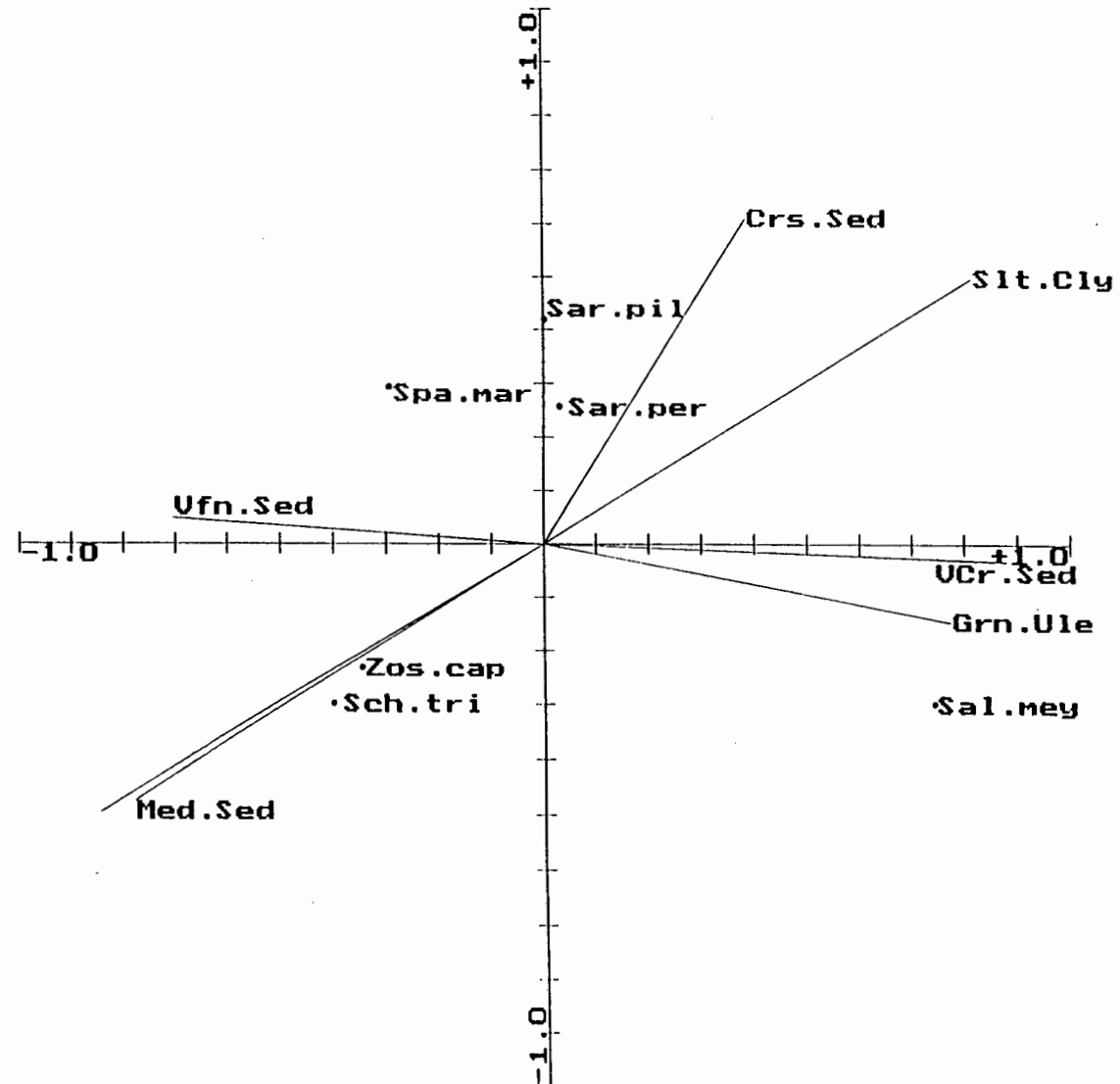
- Gm.Ule Granule
- VCr.Sed Very coarse sand
- Crs.Sed Coarse sand
- Med.Sed Medium sand
- Fin.Sed Fine sand
- Vfn.Sed Very fine sand
- Slt.Cly Silt and clay



**FIGURE 5.61:** Geelbek - (Sediment analysis) - Biplot of environmental variables (line) and species (.)

**Key:**

- Gm.Ule Granule
- VCr.Sed Very coarse sand
- CrS.Sed Coarse sand
- Med.Sed Medium sand
- Fin.Sed Fine sand
- Vfn.Sed Very fine sand
- Slt.Cly Silt and clay



In this section the relationship between species and soil texture characteristics are examined for each transect. The first four ordination axes accounts for an average cumulative percentage variance of 68%, 65% and 84% (with respect to numerical order of figures) of the species-environment relationship. The Monte Carlo overall test shows a high significance for all three at P-value: 0.01.

An examination of the ordination diagram for each transect revealed the following:

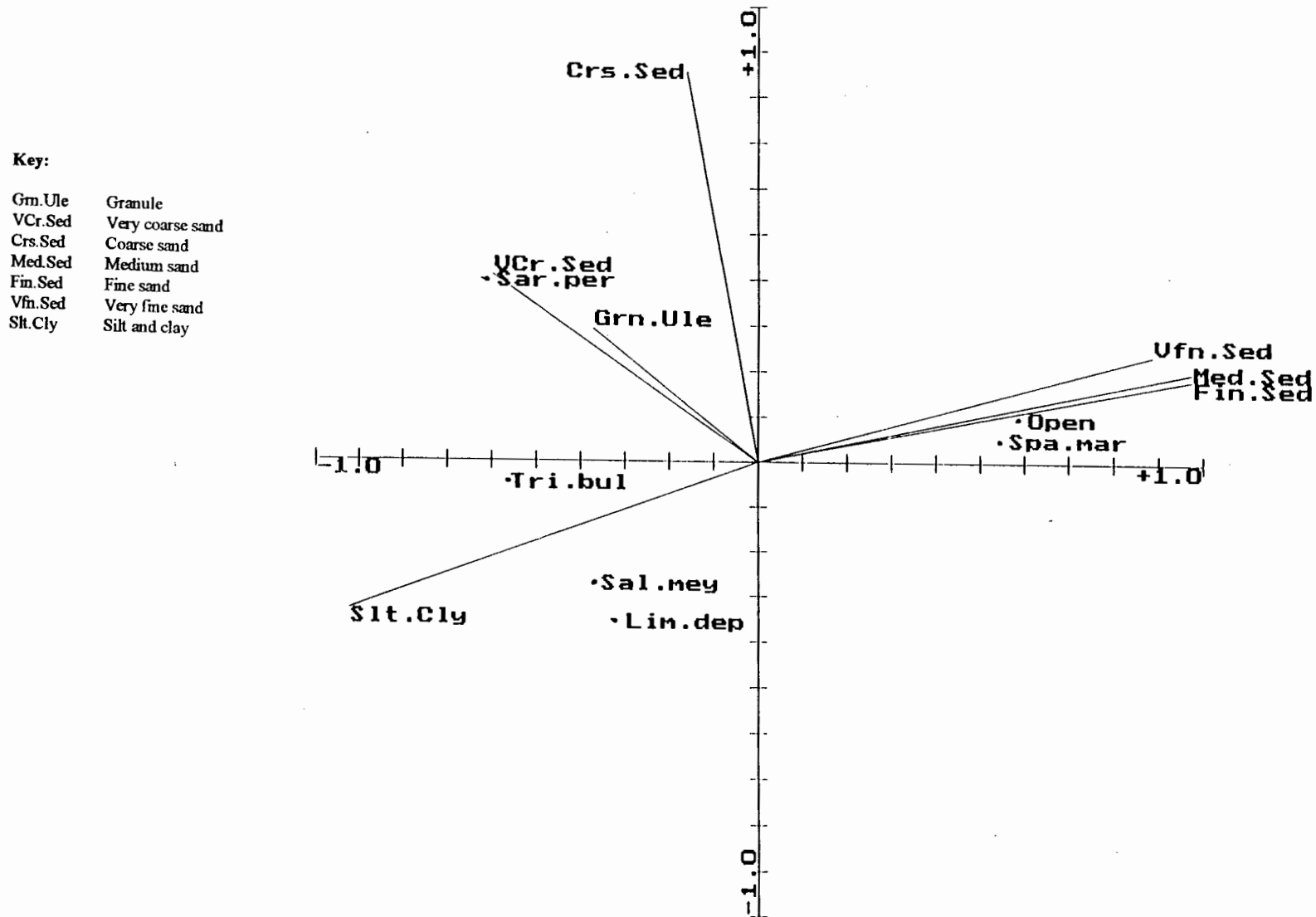
1) Oostewal (Figure 5.60):

The combination of environmental variables results in a number of distinct species responses. These are the *Sarcocornia pillansii*, *Plantago crassifolia*, *Sporobolus virginicus* and bare patches in the lower left hand quadrant which are strongly correlated to Medium Sediments. *Juncus kraussii* and *Carpobrotus acinaciformis* in the lower right quadrant are strongly correlated to Coarse Sediments, similarly *Spartina maritima* is strongly correlated to Fine Sediments. The relationships of the remaining species (*Limonium depurpuratum*, *Triglochin bulbosa*, *Chenolea diffusa*) are extremely difficult to determine as they are correlated to the remaining textural classes (Very Fine Sediments, Silt & Clay, Granule).

2) Geelbek (Figure 5.61):

In this ordination, the positions of the species are more difficult to explain than was the case at Oostewal. The length of the lines indicates the importance of Silt & Clay and Medium Sediments and Fine Sediments. The

**FIGURE 5.62:** Schrywershoek - (Sediment analysis) - Biplot of environmental variables (line) and species (.)



species below the step in the marsh (*Schoenoplectus triqueter*, *Zostera capensis*) are strongly correlated to Medium & Fine Sediments, the species on the upper and middle marsh (*Sarcocornia pillansii*, *Sarcocornia perennis*) are more strongly associated with Silt & Clay with perhaps the exception of *Salicornia meyeriana* which unlike any of the other species is associated with coarser sediments. *Salicornia meyeriana* is the only annual salt marsh species in these transects and consequently, dies back in the winter leaving large open patches (Pers. obs.), which, due to exposed, may lose the finer sediments through wind and water action, hence the coarser nature of the sediments

### 3) Schrywershoek (Figure 5.62)

From the ordination diagram three distinct groups of environmental variables can be seen in the lower left (Silt & Clay), upper left (Very Coarse, Granule, Course) and upper right (Fine, Very Fine, Medium) quadrants. The most important textural classes appear to be Medium & Fine Sediment and Silt & Clay. The upper and middle marsh species (( *Triglochin bulbosa*, *Salicornia meyeriana*, *Limonium depurpuratum*) are strongly associated with Silt & Clay, with the exception of *Sarcocornia perennis* which is also influenced by the coarser sediment classes. *Spartina maritima* and open patches are strongly associated to the Very Fine, Medium & Fine Sediment classes.

A review of the previous section on textural analysis, shows that the majority of the general relationships described, are supported by the findings in the above. These ordinations serve to clarify the associations of species and texture within each transect. The diagrams show up

some distinct differences between transects. The results have generally been discussed in each of the above sections in this chapter. The final chapter serves to relate these results to the aims and objectives and provide an overview of the findings of this research.

## **Chapter 6      Discussion and conclusion**

The purpose of this chapter is to provide a general overview of the findings of the research and to review and discuss the various aims and objectives as stated in Chapter 1. This review will draw on the results established here, as well as the results of other researchers in this field. The study has examined a multitude of environmental variables which in turn have generated a substantial set of results. These results have been thoroughly explored in an attempt to gain a greater insight into the structure and functioning of the salt marsh vegetation at Langebaan Lagoon. The aim of this research has been to elucidate and provide some understanding of the underlying causal processes that generate patterns in the salt marsh communities of the Langebaan Lagoon. In order to achieve this aim a number of objectives had to be realised.

### **6.1 Review of Objectives**

The first objective was to establish the existence or otherwise distinct vegetation of zonation. Zonation is the term used to describe the arrangement of salt marsh communities into more or less coherent bands or zones, each usually characterised by one or two dominant plant species. The salt marsh vegetation at Langebaan Lagoon reveals relatively clear plant zonation, a phenomenon that indeed appears to be the result of the spatial arrangement of the constituent species, creating a distinctive appearance for each zone, through differing combinations of height, colour and texture. From the vegetation analysis of the three transects in this study, there is evidence that particular salt marsh species are dominant in particular areas within the marsh. The exact nature of the species distribution within the transect is revealed in Figures 5.1 to 5.12. These figures confirm that species

occupy particular areas within the salt marsh and it is this arrangement which causes the observed zonation patterns.

The actual boundaries between zones is seldom well defined, as there is usually a transition between these zones where intermixing of species occurs. The zones are not always monospecific, and may include a number of species, although it is usual for one species in particular to determine the general appearance of that zone. The results suggest the existence of a relationship between species richness and the nature of the transect profile. The greater the variation in the profile and gradient (and therefore the height above M.S.L.) the greater the species richness. There also appears to be a relationship between the distinctiveness of zonation and the number of species, where the greater number of species at Oostewal results in a less distinct pattern of zonation, while, in the case of Geelbek and Schrywershoek, fewer species result in a more distinctive zonation pattern. The relationship between height above sea level and zonation is noticeable on the scale of upper, middle and lower marsh but, does not account for the transitions between adjacent zones found roughly at the same height. There is, however, little doubt that vegetation zonation does exist in salt marshes at Langebaan.

The second objective was to determine the extent and continuity of plant zonation throughout the salt marsh system at Langebaan. The existence of zonation was established for all three transects and the nature of this zonation (i.e. the general sequence of zones) was found to be very similar in the case of Geelbek and Schrywershoek, but somewhat different at Oostewal. The presence of non-halophytic species within the transect at Oostewal complicates the issue of establishing continuity between the transects. If the true salt marsh species (halophytes) are the only plants taken into consideration then there is

evidence of continuity across all three transects. This continuity is reflected in the correspondence of the positions of the various zones across all three transects as explained in section 5.2. Taking the true salt marsh species into consideration, in all three transects the upper part of the salt marsh is defined by the presence of *Sarcocornia pillansii*, which confirms the findings of Boucher & Jarman (1977). In all three transects *Zostera capensis* consistently occupied the lowest zone, although at Schrywershoek in a much reduced manner.

The third objective was to determine if environmental gradients could be detected in the salt marshes. In all three transects, most of the environmental variables measured showed a marked trend (from the top to the bottom of the transect) which strongly suggests the existence of environmental gradients within the salt marshes. Section 5.3 gives specific detail on the majority of these trends and a number of apparent anomalies are explained. These trends appear to be related to height above M.S.L. but, in general there appears to be no direct correlation between these gradients and plant zonation.

The fourth objective was to establish the existence of any association between plant zonation and the environmental gradients. This objective is confirmed, as there is measurable association between plant zonation and environmental gradients. This is due to the fact that the majority of environmental variables manifest themselves as gradients within each transect (as mentioned above) and the various species zones are arranged across this gradient. This association is confirmed in general terms.

The fifth objective was to determine whether levels in the environmental variables were the same for similar plant species in different locations within the salt marsh system. This

objective proved difficult to strongly substantiated because only two species (*Spartina maritima*, *Sarcocornia perennis*), together with bare patches, achieved dominance (and were therefore sampled) across all three transects. A comparison of the levels of the various environmental parameters for the two species which occurred in all three transects suggests that the levels of most environmental variables remain broadly similar between Geelbek and Schrywershoek. By comparison, the majority of environmental variables for the same species at the Oostewal transect generally show a greater degree of variability. These findings suggest that salt marsh plant species may be tolerant to a range of levels in many environmental variables. The environmental conditions for particular species are not, therefore, identical from transect to transect, and the suggestion is that most salt marsh species are associated with a range of values for the various environmental parameters.

The sixth objective was to identify any seasonal variation in the environmental gradients and the corresponding vegetation. Seasonal variation was only tested at Oostewal and was determined by comparing the results of the three sample sessions each taken at four month intervals. Although there appear to be minor variations between these three sampling sessions, the overwhelming impression is one of stability, clearly evident both in graphic representation and in the ordination results.

The seventh objective was to determine the extent of influence and significance of the environmental variables on salt marsh vegetation patterns. In the primary analysis of results, comparisons were made between the range of each environmental parameter for each species. In essence this involved the comparison of within-group and between-group variation. The environmental variables with the lowest degree of within-group variation and the greatest degree of between-group variation were established. This exercise indicated

that three variables were consistently important to all three transects namely conductivity, Cl and height above M.S.L.

Canonical correspondence analysis was used to quantify the relative importance of the environment-species relationship, in an attempt to clarify the nature of this relationship. Despite the power of this analysis, the relationship between the environmental variables and species remains largely cryptic at the individual species level. At the broader scale of upper, middle and lower salt marsh, the association between species and environment becomes more tangible. At this scale the ordination diagrams generally show an arrangement of species into communities that accords well with observed spatial distribution. The ordinations also revealed that Height above M.S.L, Na, Cl, conductivity, NO<sub>2</sub>, NO<sub>3</sub>, PO<sub>4</sub> and sediment texture are the most important determinants of species variation.

## **6.2 Vegetation - environment relationships.**

From the results of this research there is little doubt that the arrangement of species in the salt marshes of Langebaan results in clear zonation patterns, which characterises salt marshes the world over. In an attempt to understand the underlying causal processes which may generate these patterns a large number of environmental factors have been examined. Despite the wide range of variables measured, and despite an extensive analysis of the data, the role of environmental influences on the salt marsh species at Langebaan Lagoon remains largely difficult to establish, especially at the scale/level of species.

If the scale of the study is increased from the species level, and the salt marsh is considered at the level of the three divisions (upper middle and lower marsh) suggested by O'Callaghan

(1993), then it is possible to establish the ranges of the variables that correlate to each of the three divisions. These divisions in the marsh which have been shown to be characterised by various groups of species (as described in section 5.2.4) can then be linked to the ranges of each environmental values for each division. Using this larger scale tends to make the relationships between environment and species more apparent but leads to a general, rather than specific understanding of the complexity of these relationships.

The study has shown that any assumption that zonation boundaries correspond to sharp changes in soil nutrient properties is certainly unsubstantiated in the case of Langebaan salt marshes. Sharp changes in elevation do, however, appear to cause marked changes in salt marsh vegetation (e.g. the calcrete step at Geelbek). Clearly there are many factors other than those tested in this study which influence salt marsh species. The simple appearance of these salt marshes communities clearly belies the intricate nature of the processes which govern species patterns, a finding which concurs with that of Roozen & Westhof (1985), Pennings & Callaway (1992) and Vince and Snow (1984). From the findings of this research it becomes apparent, however, that a number of variables appear to exert more influence than others.

Chapman's (1974) suggestion that the distribution of salt marsh vegetation can be related to tidal fluctuation appears to be substantiated by the findings in this study. There is little doubt from the results in this research that height above mean sea level correlates strongly to species position within all three transects. Height above sea level determines the frequency of tidal inundation; thus it appears that the salt marsh plants ability to resist water cover (inundation) is an important determinant of position within the transect. The importance of inundation in determining patterning of species in salt marshes is also

demonstrated by Pennings & Callaway (1992) and Olff et al. (1988). Variations or displacements in height above mean sea level found between similar species in different transects, can be attributed to local variation in tidal levels caused by wind and currents, a finding which concurs with that of O'Callaghan (1993). The lack of distinctiveness of zones (i.e. diffuse nature of the ecotone) may be the result of the reduced tidal amplitude experienced at Langebaan Lagoon, a phenomenon, which has been described elsewhere by Adam (1981), Snow & Vince (1984) and Rozema et al. (1985 a).

In all three transects conductivity, Na and Cl appear to be more consistently correlated to species distribution than other variables. These three variables collectively account for the salinity of the sediments. At Oostewal, the species which showed the greatest correlation to the highest salinity values (*Sarcocornia perennis* in particular) was generally found in the lower parts of this transect. The same species was found in the upper parts of the salt marsh at both Geelbek and Schrywershoek, where the greatest salinity values were measured. This apparent dichotomy in salinities appears to be the result of different evaporation rates. At Oostewal the salt water drains away quickly due to the steeper gradients; on the other two, flatter, marshes, the salt water tends to drain very slowly, allowing greater evaporation and concentration of salts in the soil. Similar elevated salinity levels have been attributed to evaporation by Zedler (1986) and Eleuterius & Eleuterius (1979).

Many of the measured environmental variables consist of nutrients and elements which are considered to significantly affect plant growth (Jackson 1958; Chadwick & Harding 1969; DeLaune et al. 1981). The levels of these particular environmental variables have been shown to vary in all three transects and in some cases could be strongly associated with

particular plant species, but on the whole the relationships between species and soil nutrients remains unresolved.

This apparent lack of understanding may be the result of various weakness or limitations in the study. The sampling strategy and number of samples may have been inadequate to gain clear insight into the species-environment relationships. This may be true for Geelbek and Schrywershoek, where forty samples may have been insufficient to adequately reflect environmental trends, but at Oostewal, practically every quadrat was sampled and the statistical clarity of the species-environment relationship did not improve markedly.

The study was been geared towards the examination of the influence of edaphic factors as the causal mechanisms of zonation. This may have resulted in a one sided approach, in which the biotic component (other than vegetation mapping) has been largely taken for granted. The results present information on the levels of various elements in the soil, but the exact relationship between these nutrients and the plants remains unknown. A more holistic approach, which should perhaps be employed in the future studies, would be to subject the plants to the same elemental analysis as the soils. In this way the actual relationship between the plants and the nutrients could be ascertained.

The emphasis on edaphic factors has clearly shown that similar species can tolerate a range of conditions and further suggests that a number of different zones can occupy areas with very similar conditions. From these observations it becomes apparent that interspecific competition, longevity and perhaps succession, play a role in influencing species occurrence within the transect and therefore, an effect on zonation. Competition between species may well result in the boundaries that exist between different zones where edaphic factors remain

consistent. The fact that species appear to be able to tolerate a range of conditions suggests that in most instances the species physiological amplitude is considerably wider than its ecological amplitude. This ecological amplitude may be determined by competition as has been suggested by Snow & Vince (1984). The role of competition in determining zonation is perhaps an area of research that needs to be investigated at Langebaan Lagoon if an understanding of salt marsh zonation is perhaps to be achieved.

The examination of bare patches in this research has revealed that the environmental conditions in these areas are not substantially different from other areas within the salt marsh, yet they are found to contain no plant growth. This suggests that perhaps disturbance (either anthropogenic or natural) has occurred. Bertness and Ellison (1987) have studied bare patch colonisation and have noted that salt marsh species have varying resilience to disturbance. There is definite evidence of wrack disturbance at all the study sites, especially along the high tide marks after storms. O'Callaghan (1994 a) has reported on the effects of grazing at Geelbek. The effect of disturbance appears to play a role in species distribution and warrants further investigation in terms of its nature, distribution, frequency and degree of impact.

### **6.3 Implication for conservation**

The general sensitivity of salt marshes to anthropogenic activities is discussed in Chapter 2 and is well recorded in literature (Lieth & Whittaker 1975; Beefink 1977; Heydom & Tindley 1980; Day 1981; Christie 1981; Long & Mason 1983; Westhof 1985; Huntley 1989 and O'Callaghan 1990 b & c). The nature and biotic diversity of the salt marshes at Langebaan Lagoon are directly related to the characteristics of coastal environment in which they are situated. The shores of Saldanha Bay are home to a growing industrial

complex and the prospect of increased pollution levels appears to be a possibility. Research needs to establish the effects of such pollution on the salt marsh at Langebaan as they form the primary production base of a biologically rich ecosystem. The data and the results of this research will hopefully be used as an indication of the present state of the salt marshes for future monitoring purposes. Further research on the dynamics of the biotic components and disturbance would complement this study and help to further illuminate the complex processes governing salt marshes. A sound understanding of ecological processes would ensure appropriate management of South Africa's largest salt marsh.

## **6.4 Conclusions**

This research has served to confirm the immense complexity of the relationships which govern salt marsh patterns. A thorough investigation of a large range of edaphic factors has revealed and confirmed that environmental gradients do exist within the salt marshes at Langebaan Lagoon. The study confirms that the apparent zonation is the arrangement of species within salt marshes. The overall relationship between salt marsh species and the tested environmental variables remains largely unaccountable at the species level and is better understood at the scale of upper, middle and lower marsh.

From the examination of the edaphic factors there are clear signs that the salt marsh vegetation responds to salinity and inundation. If the complexity of the species-environment relationship in these salt marshes is to be understood, then here is a clear need to conduct further investigation of the biotic component, particularly the role of interspecific competition, succession, longevity, disturbance and plant adaptations. Such research would complement this research and should provide a more holistic view of the processes governing salt marsh species patterns.

This study has clearly shown that the simplistic appearance (few species) of salt marshes does not stem from a simplistic biophysical environment. In fact, the opposite is possible: - the complexity of the biophysical environment determines that only a few highly evolved species have the specialised features to survive in the salt marsh environment. Once a better understanding of how plants react to changes in the physical and competitive environment has been achieved, then the plants themselves could become useful indicators of the condition of their environment. This would make management of these natural resources cheaper and easier, as simple monitoring of changes in plant cover would indicate changes in the underlying environment.

The aim of this research has been to elucidate and provide some understanding of processes that generate patterns in the salt marsh communities of the Langebaan Lagoon. Most of the stated objectives have been realised and this study has served to show the complex nature of a number of physical processes that govern the salt marsh distribution at Langebaan Lagoon. An understanding of the processes that generate patterns in these salt marshes at the species level remains cryptic and here the aim has not been fully realised. However, when, the species-environment relationships are considered at the wider scale of upper, middle and lower marsh then this aim has essentially been achieved.

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# **Appendices**

- A: Table of species found in the three transects and associated species numbers**
- B: Species cover and position within the transects**
- C: Species ranking, allocation of soil samples and transect summary data**
- D: Environmental data**
- E: Soil texture data**
- F: Summaries of survey data**
- G: Summaries of Statistical analysis**

**Appendix: A      Table of species found in the three transects.  
and associated species numbers.**

**Table: 6: Table of species and associated numbers.**

<b>Families</b>	<b>Genera</b>	<b>Species</b>	<b>Species number</b>
Mesembryanthemaceae	Carpobrotus	acinaciformis	Sp.1
Chenopodiaceae	Chenolea	diffusa	Sp.2
Juncaceae	Juncus	kraussii	Sp.3
Plumbaginaceae	Limonium	depurpuratum	Sp.4
Plantaginaceae	Plantago	crassifolia	Sp.5
Chenopodiaceae	Salicornia	meyeriana	Sp.6
Chenopodiaceae	Sarcocornia	perennis	Sp.7
Chenopodiaceae	Sarcocornia	pillansii	Sp.8
Cyperaceae	Schoenoplectus	triqueter	Sp.9
Poaceae	Spartina	maritima	Sp.10
Poaceae	Sporobolus	virginicus	Sp.11
Juncaginaceae	Triglochin	bulbosa	Sp.12
Zosteraceae	Zostera	capensis	Sp.13
Open/ Bare patches	No species / open areas		Sp.14

Species names and spelling thereof has been sourced from Bond & Goldblatt (1984).

# Appendix B

## Oosteval: Species cover and position within the transect

TRANSECT 1 : OOSTEVAL			SPECIES COVER (%) AND LOCATION WITHIN TRANSECT													
QUADRAT	SAMPLE NO.	SP. NO.	GENUS AND SPECIES													
			Carp. a.	Chenol. d.	Juncus k.	Limoni. d.	Plantag. c.	Salicor. m.	Sarco. p.	Sarco. pil.	Schoen. t.	Spart. m.	Sporob. v.	Trigloch. b.	Zostr. c.	Open
1	1 & 2	11											60			40
2	3	11								20			50			30
3	4 & 5	5					65			15						20
4	6	14		3	10		15			20						52
5	7	3		2	98											
6	8	3		15	40				25							20
7				38		40			14							10
8				20		30			50							
9	9	4		10		48			42							
10	10	4		12		40			38			10				
11				7					50			40				3
12	11	10										80				20
13												65				35
14	12	10										90				10
15	13	10		5					20			75				
16				10					40			50				
17				15		5			60			20				
18	14	7		10		10			70			10				
19	15	7		5		20			65			2		8		
20				15		45			35					5		
21	18	4		17		65			15					3		
22	17	4		15		55			25					5		
23	18	7		13		2			85							
24	19	2		65					35							
25	20	2	40	80												
26			95	5												
27			88	12												
28	21	1	95	5												
29	22	1	100													
30	23	1	100													
31	24	1	100													
32			55	5					40							
33	25	2		80					20							
34	26	2		95								3				2
35	27	2		93					5			2				
36				48					44			8				
37				50					40			10				
38	28	2		70					25			5				
39	29	2		92					5			3				
40				80		5			15							20
41	30 & 31	14		15					25							80
42	32	7							79					11		10
43	33	7							90			4		6		
44									5			70				25
45	34	10										85				15
46	35	10										85				15
47	36	10										75				25
48	37	10										80				20
49												70			15	15
50	38	13										2			98	
51	39	13													100	
52	40	13													100	
53															95	5

Appendix B (cont.)

Geelbek: Species cover and position within the transect

APPENDIX : X																
TRANSECT 2 : GEELBEK			SPECIES COVER (%) AND LOCATION WITHIN TRANSECT													
QUADRAT	SAMPLE NO.	SP. NO.	GENUS AND SPECIES													
			Carp. a.	Chenol. d.	Juncus k.	Limoni. d.	Plantag. c.	Salicor. m.	Sarco. p.	Sarco. pil.	Schoen. t.	Spart. m.	Sporob. v.	Trigloch.b.	Zostr. c.	Open
1	1	8								100						
2	2	8								100						
3	3	8								80						
4									20							
5									40							
6									60							
7									20	35	25			5		15
8									25	60						15
9									10	85	5					
10									15	80				5		
11									25	85	10					
12									5	80				15		
13									60	35				5		
14									25	75						
15				5					25	75						
16									20	75						
17									10	75				15		
18				2					10	80				8		
19									45	50				5		
20									70	30						
21									70	30						
22									70	30						
23									85	15						
24	4	8							75	20						5
25	5	8							80	10						
26	6	8							85	5						
27	7	8							85	15						
28	8	8							85	5						
29									90	10						
30	9	7							25	75						
31	10	7							5	85						
32									5	90				5		
33									30	70						
34									70	30						
35									75	25						
36									55	45						
37									75	25						
38									70	10						20
39									75	5						20
40									55	45						
41									45	55						
42									40	60						
43									30	70						
44									30	70						
45									35	40						25
46									70	20						10
									70	20				5		5

Appendix B (cont.)

Geelbek: Species cover and position within the transect

47								85	30							5			
48								50	45							5			
49								40	50							10			
50								10	75							15			
51								5	80							15			
52								5	80							15			
53									88				2			10			
54								3	80				7			10			
55								2	70				20			8			
56									70				20			10			
57									80				10			10			
58									80				5			5			
59									50				20			10			20
60									50				20			5			25
61									50				40			10			
62									50				25			10			15
63									15				50			5			30
64									15				50						35
65	11	10							20				50						30
66	12	10							15				65						20
67									50				40						10
68	13	10											85						15
69	14	7							100										
70	15	7							100										
71	16	7							100										
72	17	7							100										
73	18	7							95				5						
74	19	7							90				10						
75	20	8											100						
76									45				55						
77									40				60						
78	21	8							20				80						
79	22	9											100						
80	23	7							100										
81	24	7							100										
82	25	7							100										
83									15				65						20
84													70						30
85									15				45						40
88									50				5						45
87									10				40						50
88													70						30
89													75						25
90													75						25
91	26	9											75						25
92	27	9											80						20
93	28	9											75						25
94													65						35
95													60						40
96													55						45
97													60						40
98													70						30
99													70						30
100													75						25
101													70						30
102													60						40



Appendix B (cont.)

Schrywershoek: Species cover and position within the transect

TRANSECT 3 : SKRYWERSHOEK			SPECIES COVER (%) AND LOCATION													
QUADRATE	AMPLE NO	SP. NO.	GENUS AND SPECIES													
			Carpo. a.	Chenol. d.	Juncus k.	Limoni. d	Plantag. c	Salicor. m	Sarco. p.	Sarco. pil.	Echoen. t.	Spart. m.	Eporob. v.	Trigloch. b	Zostrac. c.	Open
1	1	7						5	95							
2				20				15	45					10		10
3	2	7						15	70					15		
4	3	7						20	65					15		
5								35	50					15		
6	4	7						25	60					15		
7	5	7						8	90					2		
8	6	7						15	80					5		
9	7	7							98					2		
10	8	7							95					5		
11	9	7							95					5		
12	10	7						15	80					5		
13	11	7						27	70					3		
14	12	6						78	20					4		
15	13	6						70	30							
16	14	6				10		85	2					3		
17		6				17		80						3		
18						55		40						5		
19	15	4		7		60		5	20					8		
20	16	4				70		10	15					5		
21	17	4				60		30	6					4		
22						50		40	2					8		
23						40		45	5					10		
24						25		50	15					10		
25	18	4				60		25	5					10		
26						45		15	25					15		
27						30		10	50					5		5
28						20		20	55					5		
29						10		20	65					5		
30						15		10	60					15		
31	19	12				25		20	15			5		35		
32						5		50	5			10		30		
33						10		45	10			10		25		
34						25		30	15			5		25		
35	20	12				10		25	20			10		35		
36								15	60			10		15		
37								15	60			10		15		
38									50			25		15		10
39									25			60		5		10
40									10			50		15		25
41									20			30		25		25
42									35			25		10		30
43									30			15		10		45
44						15		15	35			10				25
45									10					15		35
46						5			40					30		25
47									25					25		50
48									25			25		20		30
49									60			10		15		15
50									20			30		10		40
51												80				20



## Appendix C

### SPECIES RANKING, ALLOCATION OF SOIL SAMPLES AND TRANSECT SUMMARY DATA.

Table 7 - Oostewal: - Species ranking and allocation of soil samples

Species	Number of dominant quadrats	Rank	Number of samples allocated
<i>Spartina maritima</i>	11	1	7
<i>Chenopodium diffusa</i>	10	2	7
<i>Sarcocornia perennis</i>	9	3	5
<i>Carpobrotus acinaciformis</i>	7	4	4
<i>Limonium depuratum</i>	6	5	4
<i>Zostera capensis</i>	4	6	3
No species (open patch)	2	7	3
<i>Sporobolus virginicus</i>	2	8	3
<i>Juncus kraussii</i>	1	9	2
<i>Plantago crassifolia</i>	1	10	2

Table 8 - Oostewal : Summary information

Total species found:	11 (excluding open patches)
Quadrats:	53
Length	53 m
"Non dominant" species:	2 ( <i>Triglochin bulbosa</i> ; <i>Sarcocornia pillansii</i> )
Samples:	40

## Appendix: C (cont.)

Table 9 - Geelbek: - Species ranking and allocation of soil samples

Species	Number of dominant quadrats	Rank	Number of samples allocated
<i>Sarcocornia perennis</i>	47	1	11
No species (open patch)	41	2	9
<i>Schoenoplectus triqueter</i>	28	3	6
<i>Salicornia meyeriana</i>	23	4	5
<i>Spartina maritima</i>	8	5	3
<i>Zostera capensis</i>	5	6	3
<i>Sarcocornia pillansii</i>	4	7	3

Table 10 - Geelbek : Summary information

Species found:	8 (excluding open patches)
Quadrats:	156
Length:	156 m
"Non dominant" species:	2 ( <i>Triglochin bulbosa</i> , <i>Chenolia diffusa</i> )
Samples:	40

Table 11 - Schrywershoek: - Species ranking and allocation of soil samples

Species	Number of dominant quadrats	Rank	Number of samples allocated
<i>Sarcocornia perennis</i>	25	1	11
<i>Spartina maritima</i>	20	2	10
No species (open patch)	17	3	9
<i>Salicornia meyeriana</i>	9	4	4
<i>Limonium depurpuratum</i>	7	5	4
<i>Triglochin bulbosa</i>	2	6	2

## Appendix: C (cont.)

Table 12 - Schrywershoek: Summary information

Species found:	7 (excluding open patches)
Quadrats:	86
Length	86 m
"Non dominant" species:	2 ( <i>Chenolea diffusa</i> ; <i>Zostera capensis</i> )
Samples:	40

# Appendix D: Environmental data

# Oosteval: Table of results

Quad. no.	Species	Element no.	Elements:																											
			Units:																											
			mg/l	mg/l	mg/l	mg/l	%	%	S/m	pH	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28			
1	Sp 11	1	0.267	9.208	8.941	1.791	2.8	5.799	0.48	6.4	1349.0	842.0	12.10	39.1	206.0	163.20	0.17	3.17	3.75	16.00	27.30	0.76	3.5	4.40	52.56	0.133	0.531	1.02	0.16	413
1	Sp 11	2	0.167	3.564	3.397	0.672	6.0	4.476	1.02	6.5	3373.0	1434.0	9.43	46.7	182.0	163.20	0.20	1.83	2.18	14.10	25.10	0.86	19.1	20.40	103.80	0.174	0.668	1.08	0.45	740
2	Sp 11	3	0.167	2.970	2.803	0.299	3.4	3.614	0.68	5.4	1775.0	925.0	5.99	31.3	128.0	102.00	0.18	1.62	2.18	13.30	23.30	0.46	11.7	5.80	63.48	0.127	0.600	1.02	0.22	560
3	Sp 5	4	0.478	2.412	1.936	0.787	11.8	8.538	1.69	7.0	5680.0	3089.0	8.94	102.0	204.0	292.80	0.23	0.82	0.22	13.60	18.70	2.64	49.0	22.20	181.20	0.089	0.516	0.78	1.13	884
3	Sp 5	5	0.278	1.980	1.704	1.167	15.4	7.573	2.64	6.8	9053.0	5115.0	13.00	139.0	208.0	361.20	0.17	1.04	0.27	11.70	16.00	2.61	80.0	68.00	312.00	0.100	0.590	0.91	1.40	913
4	Sp 14	6	0.488	2.010	1.522	1.039	22.0	1.143	4.02	6.5	14910.0	8304.0	63.70	162.0	366.0	489.60	0.45	0.68	0.79	43.30	52.60	1.64	122.0	168.00	573.60	0.090	0.590	0.72	1.60	914
5	Sp 3	7	0.488	3.247	2.759	0.649	17.6	0.807	3.02	6.5	11380.0	6092.0	100.00	134.0	226.0	327.60	0.28	0.83	0.51	23.30	26.00	2.54	77.3	86.00	384.00	0.110	0.890	2.03	1.30	931
6	Sp 3	8	0.380	2.320	1.94	0.455	15.8	1.646	2.87	6.6	10650.0	5634.0	25.50	124.0	190.0	361.20	0.21	0.85	0.49	37.80	31.70	2.08	79.2	72.00	399.60	0.090	0.740	0.91	1.18	928
9	Sp 4	9	0.248	0.754	0.508	0.733	17.8	4.572	3.98	6.7	13845.0	8225.0	82.30	176.0	270.0	466.80	0.30	1.39	0.03	174.00	43.30	4.00	122.0	140.60	484.80	0.120	0.590	0.78	1.32	898
10	Sp 4	10	0.410	1.508	1.098	0.800	16.6	4.840	3.60	6.7	12780.0	7985.0	88.60	187.0	308.0	502.80	0.30	1.46	0.04	187.00	50.70	4.50	106.0	122.80	534.00	0.100	0.820	1.50	1.34	895
12	Sp 10	11	0.393	3.030	2.637	6.728	25.0	0.909	3.63	6.7	13313.0	7308.0	160.00	240.0	718.0	496.80	0.50	2.58	2.32	74.50	102.00	3.44	129.0	183.20	345.60	0.156	0.600	0.91	0.71	959
14	Sp 10	12	0.439	1.818	1.379	6.287	20.2	0.824	3.57	6.9	12851.0	7108.0	142.00	207.0	666.0	414.00	0.45	1.93	2.27	62.50	81.20	2.47	122.0	170.00	345.60	0.156	0.531	0.97	0.86	961
15	Sp 10	13	0.439	2.424	1.985	9.533	28.2	0.640	3.86	6.7	13845.0	7806.0	144.00	229.0	608.0	493.20	0.46	1.92	2.32	70.40	98.30	3.18	134.0	155.40	386.40	0.174	0.668	0.97	1.62	963
18	Sp 7	14	0.256	1.782	1.526	0.634	22.4	0.338	4.02	7.0	15265.0	8344.0	85.20	231.0	398.0	466.80	1.04	3.32	3.13	34.90	64.00	2.15	150.0	13.20	605.88	0.290	0.875	1.18	0.71	965
19	Sp 7	15	0.311	2.970	2.659	1.567	20.0	0.269	2.39	6.5	8520.0	4478.0	76.90	230.0	344.0	480.00	1.01	2.07	2.04	42.20	52.20	1.78	128.0	46.80	295.20	0.150	0.737	1.20	0.73	966
21	Sp 4	16	0.638	4.372	3.734	1.300	45.2	5.513	3.90	6.8	11644.0	7906.0	72.30	231.0	382.0	556.60	0.31	0.80	0.01	109.00	64.90	3.40	124.0	150.40	470.40	0.100	0.670	0.91	1.49	896
22	Sp 4	17	0.478	6.935	6.459	0.900	56.4	4.757	4.75	6.6	18460.0	10458.0	71.00	198.0	438.0	528.00	0.29	1.35	0.02	92.10	57.20	1.90	146.0	224.00	619.20	0.115	0.590	0.78	1.41	893
23	Sp 7	18	0.289	0.891	0.602	0.933	18.0	0.219	3.42	6.9	12425.0	6849.0	79.00	209.0	322.0	393.80	0.72	1.79	2.04	30.90	53.30	1.53	115.0	90.00	446.40	0.139	0.631	1.02	0.95	1022
24	Sp 2	19	0.267	2.970	2.703	1.361	16.6	3.827	3.33	6.3	12070.0	6431.0	131.00	252.0	548.0	597.80	0.48	1.80	2.37	139.00	78.20	3.25	64.7	118.20	318.60	0.127	0.462	0.91	1.55	994
25	Sp 2	20	0.333	8.911	8.578	0.746	22.2	0.588	3.52	6.5	12425.0	6749.0	102.00	221.0	528.0	489.60	0.39	1.77	2.23	105.00	72.40	2.33	106.0	132.80	418.80	0.145	0.600	0.91	1.16	990
28	Sp 1	21	0.381	8.814	8.433	2.833	7.0	3.967	1.71	6.4	5609.0	3238.0	74.50	159.0	566.0	229.20	0.20	0.83	0.86	21.60	11.60	1.50	46.4	56.00	167.20	0.090	0.520	0.72	0.89	870
29	Sp 1	22	0.278	1.856	1.58	0.500	20.6	6.758	2.02	6.0	6745.0	3823.0	19.20	149.0	242.0	181.20	0.14	0.15	0.81	16.50	6.30	0.79	68.4	40.00	190.80	0.100	0.590	1.04	0.75	867
30	Sp 1	23	0.267	2.010	1.743	2.000	10.6	4.151	2.16	6.8	7384.0	4159.0	55.80	122.0	472.0	212.40	0.18	0.72	0.79	13.90	7.00	0.93	67.5	80.80	195.60	0.100	0.520	0.78	0.68	885
31	Sp 1	24	0.343	5.729	5.380	0.466	16.4	4.069	2.27	6.0	7810.0	4398.0	31.90	123.0	292.0	235.20	0.14	0.21	0.74	11.90	7.20	0.78	62.0	44.00	225.60	0.090	0.590	0.72	0.70	878
33	Sp 2	25	0.367	8.788	7.655	1.765	15.4	1.596	3.56	6.9	12603.0	7108.0	73.60	201.0	376.0	472.80	0.65	2.18	2.28	89.00	65.00	2.75	107.0	139.00	399.60	0.162	0.668	1.02	1.26	906
34	Sp 2	26	0.370	7.085	6.695	1.250	22.2	1.903	4.10	6.5	15285.0	8424.0	123.00	233.0	574.0	572.40	0.57	2.29	2.23	100.00	88.40	2.91	54.2	178.00	460.56	0.167	0.781	1.00	0.46	827
35	Sp 2	27	0.382	7.879	7.497	0.588	26.2	4.891	3.65	6.1	13490.0	7188.0	103.00	211.0	482.0	462.00	0.45	2.17	2.18	65.10	79.10	2.44	125.0	163.00	454.80	0.174	0.600	1.44	1.46	1000
38	Sp 2	28	0.393	9.091	8.698	0.956	28.8	6.925	4.50	6.1	17324.0	9282.0	30.70	238.0	418.0	658.80	0.49	2.15	2.23	85.80	91.80	4.17	118.0	149.20	367.20	0.162	0.600	1.02	1.63	966
39	Sp 2	29	0.405	8.182	7.777	2.132	32.4	6.950	4.59	7.9	17673.0	9501.0	49.70	220.0	718.0	583.20	0.38	1.68	2.04	27.70	80.80	3.38	161.0	198.20	498.00	0.162	0.531	0.97	1.70	964
41	Sp 14	30	0.585	7.113	6.528	2.208	22.0	2.548	3.09	6.8	11360.0	6251.0	21.20	140.0	214.0	376.60	0.27	0.33	0.80	18.00	18.30	2.81	91.0	86.00	410.40	0.090	0.740	0.78	1.41	910
41	Sp 14	31	0.341	2.320	1.979	0.779	21.0	9.111	2.89	7.1	10295.0	5693.0	55.30	160.0	300.0	466.80	0.26	0.29	0.84	41.60	44.00	1.78	84.2	83.80	374.40	0.080	0.670	0.78	1.18	912
42	Sp 7	32	0.222	3.267	3.045	0.560	33.8	5.884	5.28	6.4	19703.0	11401.0	78.00	352.0	622.0	940.80	0.46	2.91	2.42	93.50	95.90	5.01	170.0	220.00	795.60	0.166	0.737	1.08	2.64	1077
43	Sp 7	33	0.178	1.188	1.01	0.746	20.4	1.648	5.88	6.5	23253.0	12775.0	30.70	163.0	434.0	481.20	0.39	3.11	2.99	42.90	51.90	3.12	191.0	316.00	767.60	0.174	0.737	1.14	2.59	1073
45	Sp 10	34	0.301	1.212	0.911	8.800	21.4	0.438	3.44	6.9	12498.0	6749.0	144.00	216.0	568.0	458.40	0.43	1.95	2.23	64.10	94.60	3.16	118.0	142.00	328.40	0.160	0.530	0.91	1.21	968
46	Sp 10	35	0.439	1.818	1.379	6.891	21.2	0.805	3.37	6.7	12903.0	6789.0	119.00	192.0	512.0	378.00	0.41	1.38	2.18	46.40	76.50	2.06	107.0	128.00	308.40	0.140	0.460	0.85	1.21	957
47	Sp 10	36	0.517	2.784	2.267	5.844	61.2	0.369	4.48	6.0	16330.0	9222.0	96.50	334.0	676.0	771.60	0.76	2.09	4.19	22.70	152.00	3.80	166.0	244.00	483.60	0.170	0.580	0.97	2.97	966
48	Sp 10	37	0.488	1.546	1.058	3.898	60.2	0.396	3.90	4.8	14378.0	7906.0	66.80	284.0	566.0	724.80	0.42	3.01	0.77	13.50	98.30	5.40	131.0	192.00	388.80	0.170	0.870	0.97	3.08	959
50	Sp 13	38	0.341	1.392	1.051	5.422	22.0	0.908	3.19	8.0	11893.0	8391.0	96.00	225.0	922.0	471.60	0.33	1.47	0.37	70.00	63.30	3.33	122.0	168.00	393.60	0.110	0.520	0.59	0.85	933
51	Sp 13	39	0.439	0.619	0.18	7.466	20.2	0.941	2.91	6.7	10473.0	5534.0	94.60	292.0	914.0	534.00	0.48	2.17	0.30	99.50	88.30	4.10	115.0	147.40	333.60	0.100	0.670	0.78	0.66	922
52	Sp 13	40	0.293	0.928	0.635	6.299	23.0	0.705</																						

# Appendix D: Environmental data (cont.)

# Geelbek: Table of results

Qued. no.	Species	Element no.	Elements:																																																							
			NO2		NO3+NO		NO3		PO4		H2O CON.		O.M.C.		CONDUCT.		pH		Cl		Na		P		K		Ca		Mg		Cu		Zn		Mn		Fe		Al		B		SAT.K		SAT.Ca		SAT.Mg		SAT.Cu		SAT.Mn		SAT.Fe		SAT.B		SAT.Na	
			mg/l	mg/l	mg/l	mg/l	%	%	S/m				ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm				
1	Sp 8	41	0.497	1.519	1.022	0.942	49.8	9.40	9.49	7.0	42352	24519	698.00	682.0	3160.0	3768.00	0.86	5.67	7.38	642.00	529.0	25.00	365.0	790.00	1464.00	0.170	0.970	0.77	2.61	796																												
2	Sp 8	42	0.622	1.709	1.087	1.234	45.4	7.93	9.02	6.3	39831	22373	608.00	638.0	4760.0	3856.00	0.80	4.99	4.95	650.00	535.0	19.40	323.0	430.00	1452.00	0.150	1.080	0.71	2.30	794																												
3	Sp 8	43	0.497	1.215	0.718	1.494	52.2	9.35	9.63	6.7	44198	26419	631.00	802.0	4340.0	5592.00	0.91	7.32	4.93	743.00	495.0	38.80	355.0	534.00	1452.00	0.140	0.910	0.50	2.54	784																												
24	Sp 6	44	0.365	10.889	10.504	2.372	45.8	8.00	7.53	8.0	33548	17213	715.00	1078.0	3240.0	5976.00	0.99	6.65	4.25	838.00	492.0	39.80	224.0	476.00	1284.00	0.141	1.030	1.62	1.82	866																												
25	Sp 6	45	0.442	15.968	15.526	4.623	53.4	5.35	10.07	6.4	48860	27185	795.00	1216.0	4560.0	4872.00	0.91	5.47	3.92	745.00	530.0	33.20	339.0	782.00	1980.00	0.183	1.720	2.24	1.32	813																												
26	Sp 6	46	0.472	4.839	4.367	4.281	54.0	10.83	8.06	6.6	35500	19013	825.00	974.0	3640.0	3912.00	0.74	5.56	4.12	902.00	624.0	28.00	235.0	470.00	1464.00	0.171	1.170	1.27	1.59	839																												
27	Sp 8	47	0.422	15.726	15.304	4.315	54.4	9.85	9.33	6.7	43026	23832	851.00	1108.0	4320.0	4392.00	0.78	6.21	4.73	1002.00	600.0	29.80	302.0	620.00	1668.00	0.147	1.100	2.10	1.51	813																												
28	Sp 8	48	0.281	7.742	7.461	3.718	55.0	10.69	9.85	6.6	45724	25121	883.00	107.0	4200.0	4140.00	0.87	6.45	4.79	1192.00	608.0	25.40	322.0	602.00	1788.00	0.189	1.580	1.34	1.61	795																												
31	Sp 7	49	0.528	1.329	0.801	0.844	46.0	6.79	7.91	7.8	33854	18833	488.00	1084.0	2800.0	1704.00	2.10	3.52	3.69	432.00	537.0	17.70	280.0	436.00	930.00	0.118	0.670	0.91	1.98	852																												
32	Sp 7	50	0.425	1.139	0.714	0.812	46.4	6.82	8.93	6.9	40293	23068	496.00	1054.0	2900.0	2328.00	1.49	4.02	3.89	464.00	501.0	19.20	422.0	562.00	1224.00	0.140	0.740	0.91	2.17	811																												
65	Sp 10	51	0.404	2.424	2.020	1.786	66.6	8.27	5.75	5.8	23359	12456	886.00	1064.0	4960.0	3000.00	0.78	8.38	5.00	1013.00	788.0	20.80	207.0	354.00	700.80	0.150	0.800	0.57	0.99	826																												
66	Sp 10	52	0.394	2.424	2.030	0.455	60.0	8.00	7.51	5.8	32483	17169	932.00	1534.0	6400.0	3816.00	0.86	9.06	5.80	1099.00	830.0	22.30	282.0	476.00	916.80	0.170	0.970	1.72	0.90	806																												
67	Sp 10	53	0.424	3.030	2.608	1.136	63.0	8.94	6.02	5.5	23359	13244	888.00	1310.0	4800.0	4032.00	0.85	8.39	6.74	1239.00	789.0	20.80	193.0	248.00	771.60	0.160	0.750	0.50	1.70	823																												
69	Sp 7	54	0.497	0.949	0.452	0.714	61.2	8.99	8.57	6.8	36210	11198	770.00	870.0	2880.0	5136.00	2.73	8.24	5.65	885.00	604.0	44.00	346.0	522.00	1236.00	0.150	0.740	0.85	2.96	804																												
70	Sp 7	55	0.560	2.089	1.529	1.623	63.6	8.17	8.30	6.7	34258	20141	730.00	918.0	2920.0	3624.00	0.93	4.38	4.69	802.00	698.0	38.40	332.0	496.00	1153.20	0.140	0.740	0.65	2.51	814																												
71	Sp 7	56	0.435	0.759	0.324	0.325	66.0	12.98	8.39	6.3	37275	20566	732.00	930.0	2720.0	2712.00	0.73	4.60	5.10	632.00	731.0	24.40	376.0	432.00	1392.00	0.180	1.190	2.20	2.06	833																												
72	Sp 7	57	0.850	1.329	0.479	0.779	67.2	13.31	6.37	4.6	25915	14834	931.00	1018.0	3000.0	2304.00	0.67	5.29	6.35	540.00	798.0	23.80	275.0	322.00	926.40	0.150	0.910	0.71	2.06	860																												
73	Sp 7	58	0.632	0.759	0.127	2.338	56.6	11.57	10.23	6.6	46505	27353	720.00	1090.0	3480.0	3360.00	0.98	7.05	5.05	653.00	631.0	32.00	465.0	658.00	1680.00	0.180	1.190	0.77	1.78	789																												
74	Sp 7	59	0.556	14.887	14.111	0.649	65.4	7.50	4.60	5.9	17750	9860	635.00	990.0	2840.0	1344.00	2.68	8.01	4.05	610.00	498.0	13.00	164.0	340.00	548.40	0.150	0.750	0.50	0.93	851																												
75	Sp 9	60	0.281	0.968	0.887	0.753	60.2	6.12	3.10	4.9	11005	6450	461.00	574.0	2200.0	1128.00	0.72	5.15	1.49	331.00	318.0	7.09	121.0	286.00	620.40	0.123	0.490	1.34	1.27	821																												
78	Sp 9	61	0.332	0.968	0.838	0.274	45.4	5.31	1.63	4.9	6325	2963	423.00	405.0	1680.0	708.00	0.33	4.86	0.88	230.00	287.0	5.16	40.0	110.60	177.60	0.105	0.058	0.10	0.80	807																												
79	Sp 9	62	0.442	1.452	1.010	0.616	56.6	6.46	1.97	5.2	6497	3563	417.00	407.0	1660.0	708.00	0.33	4.27	0.95	231.00	292.0	5.27	33.4	122.40	180.00	0.099	0.011	0.17	0.92	812																												
80	Sp 7	63	0.475	15.923	15.448	0.942	64.0	7.90	6.34	6.0	25660	13907	815.00	1319.0	4440.0	2784.00	1.02	7.56	4.93	923.00	888.0	17.60	236.0	416.00	807.60	0.150	1.080	0.71	1.06	848																												
81	Sp 7	64	0.424	4.303	3.879	1.299	68.0	9.09	4.98	4.6	19809	10479	796.00	1222.0	3120.0	1680.00	0.67	7.89	4.05	762.00	609.0	17.30	168.0	284.00	595.20	0.150	0.750	0.92	1.66	854																												
82	Sp 7	65	0.505	3.909	3.404	0.714	64.4	8.67	4.64	5.8	17218	9781	680.00	1096.0	2880.0	1440.00	0.63	7.23	3.58	606.00	679.0	14.30	157.0	254.00	529.20	0.150	0.750	0.50	1.58	848																												
91	Sp 9	66	0.251	0.968	0.717	0.205	65.2	6.22	1.51	5.5	4438	2589	400.00	362.0	1640.0	600.00	0.29	3.24	0.88	261.00	268.0	4.73	30.8	116.40	194.40	0.048	0.010	2.08	0.97	858																												
92	Sp 9	67	0.392	1.936	1.544	0.137	60.2	6.42	3.01	5.8	10473	5773	440.00	558.0	2160.0	1032.00	0.49	5.86	1.76	357.00	343.0	7.48	97.0	242.00	444.00	0.560	1.080	1.21	1.38	1294																												
93	Sp 9	68	0.392	2.419	2.027	0.548	58.8	5.35	2.95	6.4	10224	5753	620.00	894.0	3640.0	984.00	0.49	7.15	3.24	597.00	473.0	12.50	104.0	222.00	411.60	0.077	1.080	1.16	1.21	1287																												
117	Sp 14	69	0.254	7.609	7.355	0.513	29.2	2.62	3.39	6.4	12248	6889	366.00	503.0	1720.0	876.00	0.43	5.09	1.49	234.00	267.0	5.51	122.0	197.60	279.60	0.147	0.578	0.43	0.58	809																												
118	Sp 14	70	0.325	11.956	11.631	1.346	37.0	3.20	3.62	6.1	12958	7188	386.00	487.0	1940.0	948.00	0.42	5.04	0.88	254.00	245.0	6.30	126.0	216.00	302.40	0.141	0.578	0.30	0.65	813																												
119	Sp 14	71	0.386	7.065	6.679	0.929	31.0	3.51	3.50	6.3	12603	6929	382.00	516.0	1940.0	972.00	0.72	5.07	1.01	237.00	262.0	6.02	137.0	197.40	282.00	0.141	0.634	0.43	0.59	809																												
120	Sp 14	72	0.234	3.261	3.027	1.956	33.6	2.89	3.86	6.0	14555	7688	373.00	487.0	1780.0	936.00	0.58	4.70	1.01	241.00	252.0	6.82	127.0	214.00	316.80	0.163	0.522	0.30	0.72	813																												
121	Sp 14	73	0.234	4.891	4.657	1.731	35.8	3.23	3.34	6.4	11715	6530	387.00	476.0	1760.0	900.00	0.66	4.81	1.08	227.00	248.0	6.37	102.0	167.40	261.60	0.141	0.410	0.02	0.80	818																												
122	Sp 14	74	0.528	7.608	7.080	1.410	37.8	3.73	4.47	6.4	16685	9102	398.00	1180.0	3240.0	6208.00	0.89	3.90	8.10	478.00	250.0	5.80	146.0	252.00	388.80	0.173	0.522	0.09	0.96	816																												
123	Sp 14	75	0.254	7.065																																																						

# Appendix D: Environmental data (cont.)

# Schrywershoek: Table of results

Quad. no.	Species	Sample no.	Elements:																													
			NO2		NO3+NO2		NO3	PO4	H2O CON.	O.M.C.	CONDUCT.	pH	Cl.	Na	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al	B	SAT.K	SAT.Ca	SAT.Mg	SAT.Cu	SAT.Mn	SAT.Fe	SAT.B	SAT.Na
			mg/l	mg/l	mg/l	mg/l	%	%	S/m	%	S/m	8	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	Sp 7	81	0.989	3.649	2.660	0.812	37.2	5.750	6.83	6.5	28765	15527	597.0	1253.0	3080.0	1632.00	0.48	2.78	3.44	713.00	713.00	22.00	223.0	370.00	1248.00	0.120	1.460	1.43	1.82			
3	Sp 7	82	0.505	4.622	4.117	2.955	73.4	13.918	7.30	6.2	30885	18817	229.0	1424.0	2980.0	2818.00	0.49	3.05	1.82	455.00	402.00	22.80	293.0	388.00	1428.00	0.132	1.450	1.48	2.39			
4	Sp 7	83	0.674	2.919	2.245	2.955	71.2	13.783	8.55	6.6	38340	20084	232.0	908.0	2760.0	4144.00	0.53	3.26	2.03	324.00	408.00	23.80	373.0	490.00	1812.00	0.150	1.450	1.54	2.90			
6	Sp 7	84	0.653	3.405	2.752	5.974	56.4	13.716	4.82	6.1	18460	10521	280.0	774.0	1520.0	912.00	0.43	2.20	1.49	281.00	369.00	11.10	173.0	190.20	812.40	0.107	1.230	1.32	1.32			
7	Sp 7	85	0.832	3.405	2.773	0.812	56.0	14.019	8.02	7.5	36565	19460	512.0	1355.0	2800.0	1680.00	0.60	2.72	3.04	871.00	707.00	22.10	324.0	466.00	1660.00	0.144	1.370	1.43	2.09			
8	Sp 7	86	0.379	5.500	5.121	3.141	65.4	13.985	6.61	6.7	26980	14985	305.0	618.0	1680.0	884.00	0.48	1.74	1.34	368.00	338.00	10.70	249.0	328.00	1191.60	0.101	1.450	1.43	1.56			
9	Sp 7	87	0.453	3.250	2.797	1.429	60.8	13.952	6.59	6.4	26625	14898	342.0	940.0	2280.0	1488.00	0.41	3.04	1.76	303.00	387.00	16.70	272.0	372.00	1284.00	0.132	1.370	1.43	1.95			
10	Sp 7	88	0.453	3.000	2.547	0.357	54.4	12.810	6.54	6.0	22010	11970	409.0	701.0	2220.0	1056.00	0.41	2.82	1.15	251.00	267.00	9.61	213.0	306.00	1030.00	0.120	1.450	1.38	2.38			
11	Sp 7	89	0.316	2.500	2.184	4.773	63.6	10.220	7.57	6.6	33370	17390	401.0	1221.0	2640.0	1752.00	0.59	2.61	2.70	634.00	482.00	20.00	313.0	458.00	1488.00	0.175	1.590	3.16	1.32			
12	Sp 7	90	0.316	1.500	1.184	3.312	67.6	14.019	5.89	4.8	23075	13030	303.0	862.0	1880.0	1778.00	0.43	2.72	1.89	278.00	390.00	12.00	245.0	328.00	1107.00	0.138	1.370	1.43	1.86			
13	Sp 7	91	0.383	2.578	2.195	1.316	70.4	13.985	8.28	6.8	37453	20058	519.0	1412.0	3100.0	1898.00	0.59	2.66	3.65	938.00	704.00	19.00	310.0	500.00	1620.00	0.156	1.370	1.38	2.17			
14	Sp 6	92	0.515	2.308	1.793	5.592	68.4	13.885	7.95	7.1	35500	19261	411.0	1377.0	2920.0	1944.00	0.56	2.65	3.51	788.00	660.00	20.80	314.0	474.00	1644.00	0.181	1.370	1.38	2.18			
15	Sp 6	93	0.768	2.077	1.309	5.724	59.8	14.120	9.87	7.1	47038	25700	410.0	762.0	3500.0	2496.00	0.57	2.70	3.71	757.00	602.00	22.60	408.0	600.00	1684.00	0.193	1.300	1.43	2.22			
16	Sp 6	94	0.774	3.355	2.581	4.605	58.8	12.809	7.46	6.8	32305	18032	408.0	830.0	3660.0	2736.00	0.63	3.83	3.98	1101.00	581.00	27.80	285.0	436.00	1538.00	0.193	1.370	1.43	1.69			
17	Sp 6	95	0.792	4.074	3.282	5.197	46.2	12.516	8.46	6.7	38695	20880	433.0	992.0	3700.0	3000.00	0.70	3.06	3.38	787.00	706.00	29.00	345.0	508.00	1638.00	0.193	1.370	1.43	2.49			
19	Sp 4	96	0.828	5.856	5.028	4.967	65.8	14.490	9.51	6.9	44730	23956	450.0	900.0	2320.0	2808.00	0.56	2.36	2.77	699.00	604.00	27.60	382.0	614.00	2040.00	0.169	1.370	1.38	2.03			
20	Sp 4	97	0.343	2.928	2.585	5.395	61.0	14.087	8.34	8.0	38340	19665	450.0	1451.0	3680.0	2304.00	0.55	2.21	2.77	690.00	604.00	24.80	332.0	508.00	1824.00	0.156	1.370	1.32	2.26			
21	Sp 4	98	0.465	2.253	1.788	6.419	66.2	14.120	8.10	7.5	37275	19370	334.0	1066.0	2640.0	1824.00	0.52	1.99	2.09	503.00	425.00	22.80	319.0	480.00	1740.00	0.175	1.300	1.32	2.03			
24	Sp 4	99	1.949	6.462	4.513	5.101	54.8	12.204	8.51	7.2	37985	20282	466.0	930.0	3740.0	2424.00	0.64	2.32	4.73	748.00	629.00	32.40	331.0	572.00	1800.00	0.193	1.370	1.38	2.09			
31	Sp 12	100	0.573	0.901	0.328	4.730	58.2	10.556	6.89	6.3	28400	15671	394.0	1074.0	2700.0	1704.00	0.56	3.18	2.60	541.00	442.00	16.50	287.0	372.00	1416.00	0.175	1.450	1.48	1.61			
35	Sp 12	101	0.675	0.676	0.001	2.635	34.6	5.715	5.78	6.6	23075	12605	356.0	999.0	2260.0	1320.00	0.50	2.45	2.40	463.00	424.00	15.00	240.0	272.00	1132.80	0.132	1.230	1.32	1.19			
54	Sp 10	102	0.368	1.420	1.054	0.564	34.2	8.270	3.52	4.7	12425	7646	317.0	417.0	1346.0	816.00	0.49	2.52	4.48	201.00	165.00	4.91	115.0	177.80	591.60	0.070	0.943	1.11	2.48	1493		
55	Sp 10	103	0.314	0.710	0.396	4.173	65.8	11.263	4.65	4.7	17281	9661	295.0	606.0	1480.0	1080.00	0.66	2.68	0.68	195.00	207.00	6.58	168.0	262.00	794.40	0.089	1.080	1.11	2.68	1709		
56	Sp 10	104	0.261	0.473	0.222	0.075	40.4	8.001	2.98	4.7	10295	5892	235.0	271.0	880.0	604.00	0.39	2.08	0.14	146.00	105.00	2.95	91.0	150.80	478.80	0.058	0.943	1.00	2.49	1326		
57	Sp 10	105	0.272	0.946	0.674	5.113	30.2	5.481	3.70	5.1	12780	7327	285.0	437.0	1320.0	938.00	0.52	4.04	0.48	211.00	191.00	5.85	124.0	190.20	596.40	0.083	1.080	1.11	2.17	1474		
58	Sp 10	106	0.536	2.046	1.510	4.850	28.4	3.295	4.24	4.5	16265	8663	253.0	382.0	1080.0	720.00	0.40	2.88	0.41	174.00	164.00	4.30	164.0	214.00	699.60	0.070	0.943	1.00	2.75	1601		
59	Sp 10	107	0.377	0.909	0.532	5.940	32.8	7.398	3.74	4.7	13490	7567	251.0	350.0	1060.0	672.00	0.46	2.63	0.31	141.00	148.00	4.40	127.0	178.20	609.60	0.101	1.080	1.11	2.23	1488		
60	Sp 10	108	0.513	11.818	11.305	6.767	26.2	4.943	4.09	6.4	16088	8185	268.0	325.0	1080.0	588.00	0.53	3.06	0.28	128.00	136.00	3.85	159.0	248.00	687.60	0.138	1.010	1.05	1.52	1629		
61	Sp 10	109	0.576	14.091	13.515	5.902	24.4	4.370	3.54	6.9	12248	7048	225.0	329.0	1220.0	612.00	0.47	2.21	0.08	122.00	119.00	3.55	158.0	250.00	690.00	0.126	1.080	1.05	1.50	1631		
62	Sp 10	110	0.942	2.727	1.785	1.203	39.4	8.573	4.27	4.7	15975	8843	269.0	413.0	1200.0	816.00	0.44	3.08	0.61	205.00	171.00	5.46	164.0	230.00	738.00	0.113	1.080	2.29	2.83	1600		
63	Sp 10	111	0.471	2.252	1.781	3.108	35.2	7.615	3.61	4.7	13135	7327	234.0	376.0	1060.0	684.00	0.40	2.72	0.61	159.00	139.00	4.78	145.0	184.00	597.60	0.025	0.943	1.11	2.05	1497		
67	Sp 14	112	0.637	0.676	0.039	0.642	33.6	6.950	4.83	4.8	18460	10166	213.0	413.0	1160.0	888.00	0.47	2.31	0.78	149.00	161.00	5.11	192.0	284.00	872.40	0.144	1.370	1.38	2.10			
68	Sp 14	113	1.096	4.505	3.409	0.676	31.8	5.446	4.81	5.4	18638	10126	213.0	516.0	1560.0	1068.00	0.39	2.68	0.61	168.00	176.00	6.38	205.0	312.00	885.60	0.150	1.230	1.21	1.94	1626		
69	Sp 14	114	0.790	6.757	5.967	4.459	23.6	3.765	3.79	7.3	14378	7666	199.0	340.0	1980.0	516.00	0.49	1.54	0.59	79.10	83.20	2.71	156.0	244.00	637.20	0.120	1.080	1.00	1.08	1489		
70	Sp 14	115	0.637	3.604	2.967	4.223	20.4	2.858	3.40	6.8	12958	6829	180.0	291.0	1600.0	444.00	0.45	1.27	0.67	68.10	76.50	2.38	161.0	242.00	627.60	0.126	0.943	1.11	1.05	1610		
71	Sp 14	116	0.841	4.505	3.664	2.128	21.6	2.268	3.36	7.0	12248	6749	161.0	336.0	2160.0	480.00	0.50	1.02	0.55	85.80	70.10	2.31	146.0	181.40	532.80	0.132	0.943	1.00	0.99	1364		
72	Sp 14	117	0.892	9.459	8.567	2.736	23.6	2.822	3.94	7.0	14555	8246	184.0	400.0	2880.0	576.00	0.78	1.63	0.14	93.00	88.20	3.16	163.0	122.20	632.40	0.132	0.943	1.00	1.04	1626		
73	Sp 14	118	1.274	5.405	4.131	4.696	24.0	3.160	3.42	7.0	12603	6849	167.0	393.0	3480.0	480.00	0.63	1.43	0.16	71.90	68.90	2.89	138.0	187.00	546.00	0.156	0.943	1.11	1.01	1406		
75	Sp 14	119	0.576	6.306	5.730	4.178	19.2	1.177	3.31	6.7	12248	6749	125.0	467.0	3520.0	516.00	0.47	0.78	0.82	53.10	36.60	2.25	134.0	155.00	518.40	0.113	1.080	2.02	1.10	1379		
78	Sp 14	120																														

# Appendix D: Environmental data (cont.)

# Oostewal: Second sampling session results

Qued. no.	Species	Sample no.	Elements:																																																	
			NO2		O3+NO2		NO3		CONDUCT.		pH		Cl-		Na		P		K		Ca		Mg		Cu		Zn		Mn		Fe		Al		B		SAT.K		SAT.Ca		SAT.Mg		SAT.Cu		SAT.Mn		SAT.Fe		SAT.B		SAT.Na	
			mg/l	mg/l	mg/l	S/m		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm			
1	Sp 11	1	0.283	3.777	3.494	0.41	7.8	1349	580	13	28.3	220	96.6	0.173	0.03	1.8	12.1	12.5	0.2	1.83	998	457.2	0.013	0.083	0.079	0.008	36.1																									
1	Sp 11	2	0.208	1.438	1.23	0.54	7.2	1704	729	13.3	29.6	260	122.4	0.26	0.73	1.47	14.6	16.4	0.3	1.89	1582	823.2	0.014	0.092	0.079	0	41.4																									
2	Sp 11	3	0.302	6.23	5.928	0.11	8	533	118	9.3	22.9	160	57.1	0.15	0.05	1.34	9.8	9.99	0.2	1.75	726	681.6	0.013	0.088	0.086	0.007	5.92																									
3	Sp 5	4	0.135	1.846	1.711	0.48	7.2	1420	2999	13.6	49.4	368	132	0.131	0.651	0.227	16.1	83.2	2.06	2.37	890	198	0.012	0.075	0.111	0.048	35.6																									
3	Sp 5	5	0.995	6	5.005	1.15	7.1	3728	2107	22.3	92.1	462	163.6	0.149	1.7	0.994	13.1	92.9	4.47	7.39	1298	1174.8	0.01	0.068	0.074	0.077	66.2																									
4	Sp 14	6	0.283	3.166	2.883	3.01	7.7	11005	5931	96.9	216	848	498.8	0.143	0.939	0.3	39.2	351	2.86	20.2	4680	4176	0.016	0.088	0.093	0.024	99.7																									
5	Sp 3	7	0.23	1.357	1.127	1.96	6.6	6390	3568	143	118	316	304.8	0.23	1.49	0.9	271	131	2.7	13.5	2600	2496	0.014	0.096	0.191	0.039	94.1																									
6	Sp 3	8	0.251	1.583	1.332	1.73	6.8	6680	3092	63	86.4	202	218.4	0.114	0.32	0.2	75.7	88.7	1.1	9.36	2240	2124	0.016	0.092	0.088	0.002	90.4																									
9	Sp 4	9	0.311	1.385	1.074	3.14	6.2	11005	6450	57	134	412	189.2	0.165	1.6	0.5	69	299	3.73	22.1	4060	5244	0.012	0.088	0.08	0.093	85.6																									
10	Sp 4	10	0.29	3.462	3.172	3.44	7	12354	7023	55.4	198	362	442.8	0.172	1.3	0.369	86.6	281	3.18	24.1	3968	5820	0.012	0.075	0.088	0.086	88																									
12	Sp 10	11	0.468	2.75	2.282	2.96	7.7	9763	6020	153	239	800	373.2	0.265	0.83	1.1	46	253	3.1	22.2	3820	4524	0.016	0.092	0.088	0.072	102																									
14	Sp 10	12	0.489	7.5	7.011	2.6	6.9	8875	5147	140	243	770	374.4	0.296	0.73	1.1	45.5	225	3	18.3	3580	3708	0.016	0.088	0.093	0.052	98.1																									
15	Sp 10	13	0.489	3.75	3.261	2.78	6.7	9408	5645	143	267	806	411.6	0.265	0.73	1	46.2	268	4	20	3680	3972	0.016	0.088	0.086	0.069	100																									
18	Sp 7	14	0.033	6.23	6.197	4.52	6.4	16330	9882	87	346	1740	721.2	1.06	3.36	1.26	93	311	4.15	28.2	6440	9204	0.021	0.126	0.191	0.125	161																									
19	Sp 7	15	0.255	4.553	4.298	6.21	6.7	23785	13082	133	718	2060	1200	2.08	4.72	1.56	201	549	10.7	44.3	10260	14280	0.021	0.118	0.135	0.119	163																									
21	Sp 4	16	0.28	5.077	4.797	4	6.8	14484	3552	87.3	301	594	698.4	0.182	1.75	0.576	131	366	5.56	27.6	4860	7644	0.016	0.081	0.074	0.104	88.7																									
22	Sp 4	17	0.394	7	6.608	3.23	7.8	11360	6740	77.8	336	604	688.8	0.165	1.58	0.337	111	398	4.84	23.8	3760	5388	0.013	0.075	0.068	0.089	84.4																									
23	Sp 7	18	0.377	4.553	4.178	5.39	6.5	18993	11884	140	561	2400	1200	0.592	3.8	1.59	158	443	14.4	37.7	9860	11724	0.02	0.113	0.121	0.148	171																									
24	Sp 2	19	0.472	37.668	37.196	2.9	6.5	9940	5961	172	386	1140	645.6	0.25	1.07	1.06	37.5	307	5.4	21.1	3740	4484	0.018	0.083	0.079	0.078	101																									
25	Sp 2	20	0.321	36.661	36.34	2.8	6.4	9585	5557	60.6	362	680	618	0.2	0.51	0.973	31	279	4.82	19.4	3580	4212	0.018	0.079	0.079	0.079	99.1																									
28	Sp 1	21	0.466	25.385	24.929	2.09	7.9	6923	3977	113	174	932	428.4	0.156	2.15	0.456	46.5	299	4.54	12.5	3100	3278	0.011	0.068	0.068	0.105	79.5																									
29	Sp 1	22	0.788	32.772	31.984	1.35	7.5	4260	2371	67.8	87.9	730	232.9	0.19	1.21	0.277	23	144	2.75	6.45	1770	1820	0.01	0.068	0.074	0.068	70.6																									
30	Sp 1	23	0.705	39.864	39.159	1.6	7.7	5325	2940	27.5	84.9	568	288	0.119	0.644	0.337	19.6	63.6	1.72	7.76	2080	2040	0.009	0.068	0.068	0.052	74.5																									
31	Sp 1	24	0.332	15	14.668	0.75	7.8	2308	1187	80.4	43.8	688	153.6	0.178	1.22	0.217	19.4	1.84	2.43	3.43	1278	754.8	0.013	0.068	0.08	0.065	54.5																									
33	Sp 2	25	0.297	60	59.703	2.79	6.3	9408	6469	82.9	317	636	561.6	0.28	0.82	1.59	30.6	256	4.83	18.4	3480	4088	0.014	0.083	0.107	0.068	100																									
34	Sp 2	26	0.266	28.5	28.234	3.22	6.7	11360	6500	59.4	485	906	838.8	0.29	1.35	1.26	28	301	9.2	22.8	3980	4752	0.018	0.083	0.086	0.101	105																									
35	Sp 2	27	0.362	29.538	29.176	3.14	6.7	9783	6350	67.1	506	984	906	0.28	1.44	1.38	64.9	394	7.8	22.2	4300	4944	0.016	0.092	0.093	0.093	104																									
38	Sp 2	28	0.34	59.077	58.737	3.61	6.7	12780	7811	61.7	368	764	664.8	0.22	0.85	0.89	27.7	276	5.76	24.9	4980	5688	0.019	0.088	0.121	0.108	109																									
39	Sp 2	29	0.553	34	33.447	3.3	6.5	11360	6801	53.9	441	762	708	0.241	0.69	1.01	30.4	282	6.4	24.7	4380	5076	0.015	0.079	0.079	0.089	104																									
41	Sp 14	30	0.335	4.07	3.735	1.75	7.1	5680	3128	82.3	130	342	280.8	0.172	0.694	0.2	40.6	219	1.67	10	2160	1980	0.014	0.079	0.079	0.005	89.6																									
41	Sp 14	31	0.251	5.879	5.628	2.78	7.5	9685	5449	99.6	163	414	349.2	0.09	0.737	0.2	36.8	274	2.32	18	3800	3792	0.018	0.088	0.086	0.055	100																									
42	Sp 7	32	0.358	1.917	1.559	4.67	7	16883	9860	167	528	1980	1176	0.413	4.18	1.88	236	386	13.3	33.1	10180	9672	0.02	0.113	0.149	0.117	121																									
43	Sp 7	33	0.245	1.981	1.736	4.54	6.3	18153	9904	97.8	382	3800	795.6	0.376	1.66	1.3	90.4	212	5.7	32.1	8820	9072	0.023	0.109	0.107	0.078	139																									
45	Sp 10	34	0.511	6.25	5.739	3.1	7.5	11005	6420	143	309	882	460.8	0.278	0.89	1.1	50.2	293	4.1	23.2	4220	4478	0.015	0.079	0.128	0.069	104																									
46	Sp 10	35	0.436	2.5	2.064	2.49	7	8343	5002	159	242	798	360	0.278	1	1.1	47.6	235	3	17.8	2940	3456	0.016	0.083	0.093	0.058	96.9																									
47	Sp 10	36	0.335	1.809	1.474	2.36	6.8	7810	4724	180	215	1468	456	0.301	8.4	0.578	66	441	3.75	16.3	3340	3048	0.014	0.088	0.128	0.029	98.5																									
48	Sp 10	37	0.314	1.357	1.043	2.24	7	7455	4372	219	234	856	488.4	0.219	2.26	0.516	75.9	505	4.14	67.2	3820	3732	0.021	0.118	0.135	0.265	98.1																									
50	Sp 13	38	0.293	1.357	1.064	2.66	6.7	8698	5031	196	305	1998	555.6	0.207	2.15	0.7	112	498	5.1	29.4	6080	4764	0.018	0.083	0.079	0.043	104																									
51	Sp 13	39	0.377	2.487	2.11	2.46	6.7	8165	4753	228	283	1402	514.8	0.241	2.21	0.5	99.9	509	4.73	23	4200	3360	0.016	0.088	0.086	0.034	99.6																									
52	Sp 13	40	0.335	0.678	0.343	2.56	7.2	8449	4839	217	297	1358	576	0.318	2.77	0.8	121	550	5.69	22.5	4120	3264	0.017	0.088	0.086	0.038	98.5																									

KEY:	Sp. 1 = <i>Cerro. s.</i>	Sp. 5 = <i>Plantag. c.</i>	Sp. 9 = <i>Scirpus t.</i>	Sp. 13 = <i>Zostera c.</i>
	Sp. 2 = <i>Chenop. d.</i>	Sp. 6 = <i>Salicor. m.</i>	Sp. 10 = <i>Spart. m.</i>	Sp. 14 = <i>Open</i>
	Sp. 3 = <i>Juncus t.</i>	Sp. 7 = <i>Sarco. p.</i>	Sp. 11 = <i>Sporob. v.</i>	
	Sp. 4 = <i>Limoni. d.</i>	Sp. 8 = <i>Sarco. pl.</i>	Sp. 12 = <i>Trigloch. b.</i>	



## Appendix E: Soil Texture data

### Oostewal

Quad no.	SPECIES	1 GRANULE ( > 2mm) %	2 V.C.SD. ( > 1mm) %	3 C.SD. ( > 0.5mm) %	4 M.SD ( > 0.25mm) %	5 F.SD. ( > 0.125mm) %	6 V.F.SD. ( > 0.063mm) %	7 SILT & CLAY ( < 0.063mm) %
29	Sp 1	0.16	0.84	19.70	66.39	10.90	0.94	1.07
30	Sp 1	0.34	0.70	19.87	65.49	11.63	0.95	1.02
31	Sp 1	0.18	1.53	21.60	65.60	9.17	0.66	1.26
	AVERAGE Sp 1	0.23	1.02	20.39	65.83	10.57	0.85	1.11
33	Sp 2	0.00	1.10	7.25	25.48	37.38	27.79	1.00
34	Sp 2	0.16	0.83	5.67	17.49	41.07	31.55	3.24
35	Sp 2	1.76	2.38	11.60	34.98	19.99	22.86	6.43
	AVERAGE Sp 2	0.64	1.44	8.17	25.99	32.81	27.40	3.55
5	Sp 3	0.95	1.06	13.37	55.69	22.42	4.97	1.54
6	Sp 3	2.63	1.45	9.00	62.87	19.89	2.32	1.84
	AVERAGE Sp 3	1.79	1.26	11.18	59.28	21.15	3.64	1.69
9	Sp 4	5.71	1.95	12.11	51.20	21.48	5.62	1.94
21	Sp 4	6.65	8.62	14.99	14.43	29.68	18.82	6.80
22	Sp 4	11.42	9.27	8.27	11.57	30.70	19.31	9.46
	AVERAGE Sp 4	7.93	6.61	11.79	25.73	27.29	14.58	6.06
3	Sp 5	0.33	0.57	3.27	70.91	22.74	0.90	1.28
3	Sp 5	0.25	0.27	3.79	71.18	21.16	1.03	2.32
	AVERAGE Sp 5	0.29	0.42	3.53	71.04	21.95	0.96	1.80
23	Sp 7	0.25	0.47	2.73	15.38	43.13	33.51	4.52
42	Sp 7	0.37	0.52	3.19	15.00	46.04	33.72	1.16
43	Sp 7	2.74	6.51	21.08	29.77	18.82	14.90	6.18
	AVERAGE Sp 7	1.12	2.50	9.00	20.05	36.00	27.38	3.95
14	Sp 10	0.12	0.79	4.99	16.58	52.01	21.94	3.57
45	Sp 10	0.00	0.66	5.05	17.58	42.67	30.43	3.61
46	Sp 10	0.00	0.47	3.69	15.17	56.81	19.93	3.93
	AVERAGE Sp 10	0.04	0.64	4.57	16.44	50.50	24.10	3.70
1	Sp 11	0.15	0.19	2.30	65.70	29.66	1.58	0.42
1	Sp 11	0.00	0.17	3.24	68.49	26.05	1.68	0.37
2	Sp 11	0.17	0.16	4.04	66.74	27.36	1.49	0.03
	AVERAGE Sp 11	0.11	0.18	3.19	66.98	27.69	1.58	0.27
49	Sp 13	0.99	2.00	9.14	27.63	39.55	16.26	4.42
50	Sp 13	0.93	1.68	8.88	26.19	39.64	18.28	4.41
51	Sp 13	0.57	1.23	7.45	23.08	45.87	18.60	3.20
	AVERAGE Sp 13	0.83	1.64	8.49	25.63	41.69	17.71	4.01
4	Sp 14	0.22	0.63	5.82	70.01	20.88	1.28	1.16
41	Sp 14	0.03	0.27	5.53	70.15	20.63	0.83	2.56
41	Sp 14	0.00	0.44	4.44	24.06	54.35	15.74	0.96
	AVERAGE Sp 14	0.08	0.45	5.26	54.74	31.95	5.95	1.56

## Appendix E: Soil Texture data (cont.)

### Geelbek

Quad no.	Sp no.	1 GRANULE ( > 2mm) %	2 V.C.SD. ( > 1mm) %	3 C.SD. ( > 0.5mm) %	4 M.SD ( > 0.25mm) %	5 F.SD. ( > 0.125mm) %	6 V.F.SD. ( > 0.063mm) %	7 SILT & CLAY ( < 0.063mm) %
25	Sp 6	9.21	9.68	5.66	4.45	3.99	0.79	66.22
27	Sp 6	2.64	5.71	4.33	3.32	3.29	1.07	79.64
28	Sp 6	0.93	7.28	6.46	4.50	4.51	1.50	74.82
	AVERAGE Sp 6	4.26	7.55	5.48	4.09	3.93	1.12	73.56
69	Sp 7	0.10	1.16	8.20	8.88	8.81	2.24	70.60
72	Sp 7	1.19	5.40	10.99	15.16	18.12	1.82	47.32
82	Sp 7	0.52	3.00	4.03	7.46	7.54	1.36	76.09
	AVERAGE Sp 7	0.60	3.19	7.74	10.50	11.49	1.80	64.67
1	Sp 8	0.00	0.10	2.36	8.24	13.21	1.67	74.41
2	Sp 8	0.48	3.15	7.29	11.95	15.55	4.77	56.82
3	Sp 8	0.12	2.46	7.43	15.73	21.17	1.44	51.66
	AVERAGE Sp 8	0.20	1.90	5.69	11.97	16.64	2.63	60.96
74	Sp 9	0.13	0.71	2.29	29.68	40.18	2.11	24.89
77	Sp 9	0.09	0.75	1.94	25.08	41.10	2.83	28.22
78	Sp 9	0.37	1.82	3.74	22.02	39.05	3.51	29.49
	AVERAGE Sp 9	0.20	1.09	2.66	25.60	40.11	2.81	27.53
65	Sp 10	1.96	5.52	9.72	11.68	14.33	2.16	54.63
66	Sp 10	1.07	4.09	8.10	13.09	20.33	3.83	49.49
68	Sp 10	0.39	3.47	9.19	10.11	12.70	3.25	60.88
	AVERAGE Sp 10	1.14	4.36	9.00	11.63	15.79	3.08	55.00
154	Sp 13	0.00	0.31	2.08	29.02	45.69	2.73	20.17
155	Sp 13	0.00	0.14	1.61	28.91	45.72	3.14	20.47
156	Sp 13	0.00	0.19	1.69	28.77	43.61	2.61	23.13
	AVERAGE Sp 13	0.00	0.21	1.79	28.90	45.01	2.83	21.26
122	Sp 14	0.00	0.09	1.72	28.56	45.32	2.72	21.60
123	Sp 14	0.13	0.63	2.16	24.12	45.61	3.92	23.42
124	Sp 14	0.00	0.12	1.76	27.54	44.56	2.99	23.01
	AVERAGE Sp 14	0.04	0.28	1.88	26.74	45.16	3.21	22.68

## Appendix E: Soil Texture data (cont.)

### Schrywershoek

Quad no.	Sp no.	1 GRANULE ( > 2mm) %	2 V.C.SD. ( > 1mm) %	3 C.SD. ( > 0.5mm) %	4 M.SD ( > 0.25mm) %	5 F.SD. ( > 0.125mm) %	6 V.F.SD. ( > 0.063mm) %	7 SILT & CLAY ( < 0.063mm) %
19	Sp 4	0.00	0.29	0.99	5.42	2.95	0.61	89.74
20	Sp 4	0.20	1.25	2.68	6.87	3.07	0.63	85.30
21	Sp 4	0.16	1.90	3.97	12.36	6.37	1.31	73.92
	AVERAGE Sp 4	0.12	1.15	2.55	8.22	4.13	0.85	82.98
14	Sp 6	0.23	1.55	4.47	12.82	5.46	0.97	74.51
16	Sp 6	0.00	0.24	1.59	11.93	6.01	1.36	78.86
17	Sp 6	0.87	2.97	7.10	27.92	12.35	2.02	46.76
	AVERAGE Sp 6	0.37	1.59	4.39	17.56	7.94	1.45	66.71
1	Sp 7	0.40	5.00	10.39	14.94	6.25	1.24	61.78
9	Sp 7	0.35	3.77	6.29	6.45	3.17	0.86	79.12
11	Sp 7	4.62	14.26	15.38	15.75	7.47	2.01	40.51
	AVERAGE Sp 7	1.79	7.68	10.68	12.38	5.63	1.37	60.47
56	Sp 10	0.37	0.89	6.06	48.57	25.98	3.64	14.49
57	Sp 10	0.31	0.54	5.20	51.14	27.84	2.93	12.03
62	Sp 10	0.03	0.18	6.09	54.84	24.77	3.54	10.55
	AVERAGE Sp 10	0.24	0.54	5.78	51.52	26.20	3.37	12.36
31	Sp 12	0.40	3.34	9.60	23.77	12.47	2.58	47.86
35	Sp 12	1.98	7.89	7.79	12.98	6.29	1.28	61.80
	AVERAGE Sp 12	1.19	5.61	8.69	18.37	9.38	1.93	54.83
69	Sp 14	0.04	0.12	5.60	55.40	25.36	3.66	9.82
71	Sp 14	0.07	0.18	6.14	55.62	24.92	2.73	10.35
72	Sp 14	0.00	0.33	5.68	52.60	25.95	3.50	11.95
	AVERAGE Sp 14	0.04	0.21	5.81	54.54	25.41	3.30	10.70

## Appendix F: Summaries of survey data.

**Oosteval:** Top peg height: 1.354 m above MSL (All heights from ground level at pegs)  
 Bottom peg height: -0.026 m above MSL  
 Top peg position: 33° 07' 01''S 18° 03' 03''E

**Geelbek :** Top peg height: 1.102 m above MSL  
 Bottom peg height: 0.110 m below MSL  
 Top peg position: 33° 11' 34''S 18° 07' 28''E

**Schrywershoek:** Top peg height: 1.127 m above MSL  
 Bottom peg height: 0.614 m above MSL  
 Top peg position: 33° 11' 08''S 18° 04' 55''E

Quadrat survey results											
Heights given in metres above MSL											
Oosteval		Geelbek						Shrywershoek			
Quadrat no.	Height (m)	Quadrat no.	Height (m)	Quadrat no.	Height (m)	Quadrat no.	Height (m)	Quadrat no.	Height (m)	Quadrat no.	Height (m)
1	1.354	1	1.002	61	0.879	121	0.304	1	1.127	61	0.701
2	1.309	2	1.000	62	0.874	122	0.311	2	1.122	62	0.680
3	1.268	3	0.998	63	0.873	123	0.321	3	1.102	63	0.691
4	1.210	4	0.998	64	0.867	124	0.318	4	1.080	64	0.675
5	1.136	5	0.995	65	0.863	125	0.310	5	1.072	65	0.641
6	1.074	6	0.993	66	0.860	126	0.301	6	1.072	66	0.622
7	1.019	7	0.992	67	0.847	127	0.350	7	1.064	67	0.592
8	0.979	8	0.991	68	0.830	128	0.345	8	1.064	68	0.583
9	0.933	9	0.992	69	0.817	129	0.323	9	1.067	69	0.590
10	0.883	10	0.991	70	0.805	130	0.306	10	1.065	70	0.595
11	0.826	11	0.988	71	0.801	131	0.279	11	1.064	71	0.591
12	0.815	12	0.989	72	0.560	132	0.270	12	1.072	72	0.590
13	0.770	13	0.985	73	0.554	133	0.235	13	1.065	73	0.565
14	0.647	14	0.980	74	0.641	134	0.209	14	1.061	74	0.582
15	0.565	15	0.978	75	0.650	135	0.194	15	1.062	75	0.577
16	0.684	16	0.976	76	0.679	136	0.188	16	1.074	76	0.585
17	0.663	17	0.973	77	0.665	137	0.199	17	1.082	77	0.609
18	0.626	18	0.971	78	0.650	138	0.103	18	1.082	78	0.601
19	0.586	19	0.971	79	0.575	139	0.136	19	1.072	79	0.590
20	0.531	20	0.974	80	0.551	140	0.133	20	1.062	80	0.586
21	0.471	21	0.978	81	0.554	141	0.139	21	1.066	81	0.580
22	0.399	22	0.980	82	0.540	142	0.152	22	1.072	82	0.599
23	0.355	23	0.981	83	0.514	143	0.153	23	1.065	83	0.609
24	0.329	24	0.983	84	0.521	144	0.144	24	1.084	84	0.608
25	0.249	25	0.978	85	0.516	145	0.150	25	1.061	85	0.610
26	0.165	26	0.972	86	0.502	146	0.128	26	1.054	86	0.614
27	0.174	27	0.975	87	0.521	147	0.139	27	1.045		
28	0.226	28	0.982	88	0.481	148	0.117	28	1.047		
29	0.481	29	0.993	89	0.498	149	0.179	29	1.040		
30	0.579	30	0.999	90	0.491	150	0.184	30	1.030		
31	0.626	31	0.994	91	0.489	151	0.104	31	1.007		
32	0.614	32	0.990	92	0.470	152	0.136	32	1.011		
33	0.599	33	0.985	93	0.434	153	0.130	33	1.001		
34	0.619	34	0.979	94	0.438	154	0.099	34	1.054		
35	0.610	35	0.970	95	0.411	155	0.100	35	0.998		
36	0.617	36	0.965	96	0.407	156	0.110	36	1.022		
37	0.614	37	0.963	97	0.381			37	0.962		
38	0.650	38	0.962	98	0.393			38	0.913		
39	0.663	39	0.962	99	0.381			39	0.902		
40	0.664	40	0.870	100	0.371			40	0.872		
41	0.735	41	0.840	101	0.373			41	0.864		
42	0.754	42	0.860	102	0.370			42	0.865		
43	0.634	43	0.969	103	0.365			43	0.890		
44	0.565	44	0.976	104	0.355			44	0.864		
45	0.520	45	0.979	105	0.343			45	0.891		
46	0.520	46	0.983	106	0.334			46	0.882		
47	0.469	47	0.987	107	0.234			47	0.968		
48	0.326	48	0.980	108	0.267			48	0.910		
49	0.504	49	0.969	109	0.250			49	0.872		
50	0.426	50	0.962	110	0.311			50	0.830		
51	0.217	51	0.958	111	0.317			51	0.756		
52	0.020	52	0.950	112	0.311			52	0.751		
53	-0.026	53	0.941	113	0.314			53	0.725		
		54	0.934	114	0.311			54	0.721		
		55	0.926	115	0.302			55	0.722		
		56	0.920	116	0.300			56	0.707		
		57	0.908	117	0.307			57	0.723		
		58	0.900	118	0.190			58	0.725		
		59	0.891	119	0.180			59	0.710		
		60	0.883	120	0.170			60	0.709		

## Appendix F: Summaries of survey data (cont.)

### LANGEBAAAN TRANSECTS SURVEY :

Name	Y	Lo19	X	Height
<u>Constants :</u>	<u>0.00</u>	<u>+3600000.00</u>		<u>0.00</u>
Trig132	+ 82569.59	+ 79025.11		62.60
Trig136	+ 72514.25	+ 76792.89		287.50
Trig144	+ 80485.81	+ 65862.60		160.80
Trig150	+ 92553.97	+ 65203.69		194.00
Trig278	+ 84261.97	+ 60381.37		176.90
Trig279	+ 85875.98	+ 66383.45		132.80
Trig322	+ 78875.08	+ 59534.35		126.90
P1	+ 88198.70	+ 65835.25		7.39
P2	+ 88363.95	+ 65857.36		11.792
P3	+ 88579.81	+ 65870.32		0.77
P4	+ 83384.36	+ 77654.36		54.49
P5	+ 84880.68	+ 75750.70		54.22
P6	+ 81205.11	+ 77283.26		34.21
P7	+ 79752.32	+ 77073.13		22.31
P8	+ 80625.06	+ 74985.77		4.57
P9	+ 81735.92	+ 74396.93		- 0.85
P10	+ 85468.87	+ 73764.33		22.49
P11	+ 85729.06	+ 73436.68		- 0.90
TRANS1	+ 88584.23	+ 65859.64		0.82
	- 33°07'01."5361 S + 18°03'03."2215 E			
TRANS2	+ 81646.57	+ 74198.56		- 1.61
	- 33°11'34."1521 S + 18°07'28."0975 E			
TRANS3	+ 85598.75	+ 73438.33		- 1.00
	- 33°11'08."3784 S + 18°04'55."8006 E			

## Appendix F: Summaries of survey data (cont.)

The above co-ordinates and heights are given in units of metres. The heights are at a datum of mean sea level (MSL) as used by the Department of Surveys and Mapping for the South African heighting system.

Co-ordinates were calculated as follows:

- an "open-ended TRAVERSE"; effectively a series of "POLARS" from successive set-up stations.
- POLARS are calculated as follows:

$$Y_{TO} = Y_{FROM} + D \times \sin(\alpha)$$

$$X_{TO} = X_{FROM} + D \times \cos(\alpha)$$

where  $D$  = horizontal distance between points, and  
 $\alpha$  = the angular deviation from  $90^\circ$ .

- As each successive station's co-ordinates have been determined, the observations from that station are "oriented". This is done by calculating "JOIN" directions from the set-up point to all other observed points of known co-ordinates. The average correction is then applied to the other points that were observed from the set-up station.

## Appendix F: Summaries of survey data (cont.)

- JOINS directions are calculated as follows:

$$DIRN = \arctan\left(\frac{X_{TO} - X_{FROM}}{Y_{TO} - Y_{FROM}}\right)$$

- Distances as observed have already been corrected for curvature of the earth and refraction of the light path. This is done by internal calculations in the Wild TC1000 total station.

Heights were calculated as follows :

$$\Delta h = D \tan(\alpha) + \frac{1-k}{2r} D^2 + H.I. - H.T.$$

where D and  $\alpha$  are the same as above, and  $(1-k)/2r$  is the correction for curvature of the earth and refraction of the light path, for the vertical angles, as a function of distance. These corrections are tabulated in standard lists as provided by the Department of Surveys and Mapping.

H.I. = Height of Instrument

H.T. = Height of Target

- This process of "TRIGONOMETRICAL HEIGHTING" is extended from point-to-point from the Trig beacon to the Transect point.

## Appendix F: Summaries of survey data (cont.)

### DRIEHOEKMETINGSTASIES / TRIGONOMETRICAL STATIONS

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Page/Bladsy No 1

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Nr. Stasie	Lo.19		Hoogte	Opmerkings
No. Station	Y	Int.M. X	Height	Remarks
132 ABRAHAMSKRAAL	82569,59	3679025,11	62,6	
136 GROOT ZWARTBERG	72514,25	3676792,89	287,5	
144 MASSENBERG	80485,81	3665862,60	160,8	
150 POSTBERG	92553,97	3665203,69	194,0	
278 KARNBERG	84261,41	3660381,37	176,9	
279 MOOIMAAK	85875,98	3666383,45	132,8	
322 SOUTKUIL	78875,08	3659534,35	126,9	

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## Appendix G: Summaries of the statistical analyses

The following are included for each analysis:

### 1) Summaries of the statistics.

The following abbreviations and numbers apply in the correlation matrices:

SpAx1	Species Axis 1
SpAx2	Species Axis 2
SpAx3	Species Axis 3
SpAx4	Species Axis 4
EnvAx1	Environmental Axis 1
EnvAx2	Environmental Axis 2
EnvAx3	Environmental Axis 3
EnvAx4	Environmental Axis 4
Nit.Rte	Nitrite
Nit.Ite	Nitrate
Phs.Ate	Phosphate
Wte.Con	Moisture content
Org.Mat	Organic matter content
Con.duc	Conductivity
Aci.Dty	pH
Cit.Cht	Chlorine
Cit.Sod	Sodium
Cit.Phs	Phosphor
Cit.Pot	Potassium
Cit.Cal	Calcium
Cit.Mag	Magnesium
Cit.Cop	Copper
Cit.Znc	Zinc
Cit.Man	Manganese
Cit.Irn	Iron
Cit.Alu	Aluminium
Cit.Bor	Boron
Sat.Pot	Potassium
Sat.Cal	Calcium
Sat.Mag	Magnesium
Sat.Cop	Copper
Sat.Man	Manganese
Sat.Irn	Iron
Sat.Bor	Boron
Sat.Sod	Sodium
Hgh.Msl	Height above mean sea level

**Note:** The abbreviations with the leaders Cit. and Sat. denote the types of extract process as discussed in Chapter 4.

## Appendix: G (cont.)

2) The environmental variables are represented by the following numbers :

001	Nitrite
002	Nitrite + Nitrate
003	Nitrate
004	Phosphate
005	Moisture content
006	Organic matter content
007	Conductivity
008	pH
009	Chlorine (Cit. extract)
010	Sodium (Cit. extract)
011	Phosphor (Cit. extract)
012	Potassium (Cit. extract)
013	Calcium (Cit. extract)
014	Magnesium (Cit. extract)
015	Copper (Cit. extract)
016	Zinc (Cit. extract)
017	Manganese (Cit. extract)
018	Iron (Cit. extract)
019	Aluminium (Cit. extract)
020	Boron (Cit. extract)
021	Potassium (Sat. extract)
022	Calcium (Sat. extract)
023	Magnesium (Sat. extract)
024	Copper (Sat. extract)
025	Manganese (Sat. extract)
026	Iron (Sat. extract)
027	Boron (Sat. extract)
028	Sodium (Sat. extract)
029	Height above mean sea level

# OOSTEWAL: CANOCO OUTPUT SUMMARY

Number of samples                    29    Number of species                    15    Number of occurrences                    107

\*\*\*\* Weighted correlation matrix (weight = sample total) \*\*\*\*

SPEC AX1	1.0000							
SPEC AX2	-.0283	1.0000						
SPEC AX3	.0340	-.0322	1.0000					
SPEC AX4	.0155	-.0046	.0138	1.0000				
ENVI AX1	.9762	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	.9440	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.9598	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.9034	.0000	.0000	.0000	1.0000
Nit.Rte	-.0108	.0405	-.2980	.2162	-.0111	.0429	-.3105	.2393
Nit.Ite	-.2537	.4167	.3759	.1710	-.2599	.4414	.3917	.1893
Phs.Ate	.5018	-.3675	-.5882	.0343	.5141	-.3893	-.6128	.0380
Wte.Con	.0700	.2519	-.4951	-.0863	.0717	.2669	-.5159	-.0955
Org.Mat	-.2838	.0702	.5032	-.2526	-.2908	.0744	.5243	-.2796
Con.Duc	.0921	.5696	-.5168	.0567	.0944	.6034	-.5385	.0628
Aci.Dty	.3390	.1122	.0643	.0671	.3473	.1189	.0670	.0743
Cit.Cht	.0804	.5406	-.5051	.0868	.0824	.5727	-.5262	.0961
Cit.Sod	.1426	.5468	-.4899	.0265	.1461	.5792	-.5104	.0293
Cit.Phs	.4116	.1664	-.5943	.2226	.4217	.1763	-.6192	.2464
Cit.Pot	.4318	.3944	-.5418	.0645	.4423	.4178	-.5646	.0714
Cit.Cal	.7799	.0969	-.3475	.1456	.7989	.1027	-.3621	.1612
Cit.Mag	.2330	.4546	-.4280	.0131	.2387	.4816	-.4460	.0145
Cit.Cop	.1209	.3010	-.4349	-.0121	.1239	.3189	-.4531	-.0133
Cit.Znc	.1496	.0906	-.2454	-.1595	.1533	.0960	-.2557	-.1765
Cit.Man	-.2467	-.0071	-.2213	-.0341	-.2527	-.0075	-.2306	-.0377
Cit.Irn	.3086	.5996	-.0893	-.1537	.3162	.6351	-.0930	-.1701
Cit.Alu	.3512	.2115	-.5903	.0742	.3598	.2240	-.6150	.0822
Cit.Bor	.3638	.2588	-.4052	.0485	.3727	.2741	-.4222	.0537
Hgh.Msl	-.6159	-.1496	.6152	-.0917	-.6309	-.1585	.6409	-.1016
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4

Nit.Rte	1.0000							
Nit.Ite	.1111	1.0000						
Phs.Ate	.2322	-.3447	1.0000					
Wte.Con	.5405	.0328	.2000	1.0000				
Org.Mat	-.0678	.3135	-.4948	-.1114	1.0000			
Con.Duc	.2106	-.0208	.0825	.6267	-.1658	1.0000		
Aci.Dty	.0260	-.0502	.1515	-.2418	.1136	.0898	1.0000	
Cit.Cht	.1639	-.0025	.0689	.5960	-.1739	.9910	.0839	1.0000
Cit.Sod	.1946	-.0389	.0765	.6159	-.1540	.9881	.1417	.9837
Cit.Phs	.1330	-.2448	.6400	.2206	-.5509	.3661	.1505	.3313
Cit.Pot	.2454	-.1276	.4000	.6609	-.3220	.6952	-.0013	.6582
Cit.Cal	.1161	-.1411	.6689	.4008	-.3768	.4533	.2491	.4437
Cit.Mag	.2344	-.0140	.1616	.7236	-.0708	.7882	-.0923	.7589
Cit.Cop	-.0361	-.0845	.1429	.2343	-.5150	.3402	.0025	.3406
Cit.Znc	-.4522	.0861	.1618	.1007	-.2891	.2070	-.3044	.2413
Cit.Man	-.3506	.2942	.1241	-.0353	-.2329	.0497	-.2076	.0895
Cit.Irn	-.0114	-.0220	.0291	.0524	.0181	.3654	.1184	.3081
Cit.Alu	.1789	-.0326	.5806	.6089	-.3685	.5648	-.1369	.5414
Cit.Bor	.2498	-.1923	.2983	.5198	-.0321	.6094	-.0668	.5713
Hgh.Msl	-.2892	.3281	-.5955	-.5470	.4539	-.6025	-.1208	-.5908

Nit.Rte      Nit.Ite      Phs.Ate      Wte.Con      Org.Mat      Con.Duc      Aci.Dty      Cit.Cht

Cit.Sod	1.0000							
Cit.Phs	.3414	1.0000						
Cit.Pot	.6716	.6247	1.0000					
Cit.Cal	.4686	.6913	.7590	1.0000				
Cit.Mag	.7715	.3914	.9120	.5947	1.0000			
Cit.Cop	.3033	.3941	.5804	.3033	.4023	1.0000		
Cit.Znc	.1982	.2286	.3615	.3639	.2984	.4721	1.0000	
Cit.Man	.0142	.0926	.1059	.0802	.0633	.4584	.6527	1.0000
Cit.Irn	.3723	.4806	.3968	.2989	.3902	.0349	.0587	-.2675
Cit.Alu	.5272	.6867	.8540	.7825	.7583	.4972	.4811	.4026
Cit.Bor	.6100	.3624	.7396	.5644	.7940	.1089	.2503	-.2053
Hgh.Msl	-.6123	-.6062	-.7838	-.7725	-.6621	-.3919	-.1930	.0464

Cit.Sod      Cit.Phs      Cit.Pot      Cit.Cal      Cit.Mag      Cit.Cop      Cit.Znc      Cit.Man

Cit.Irn	1.0000			
Cit.Alu	.2969	1.0000		
Cit.Bor	.4903	.5879	1.0000	
Hgh.Msl	-.2374	-.6801	-.6431	1.0000

Cit.Irn      Cit.Alu      Cit.Bor      Hgh.Msl

N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0244	
2	SPEC AX2	.0000	1.0593	
3	SPEC AX3	.0000	1.0419	
4	SPEC AX4	.0000	1.1070	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Nit.Rte	.3686	.1118	4.0851
3	Nit.Ite	3.2565	2.6957	3.0802
4	Phs.Ate	2.6051	2.6968	6.6688
5	Wte.Con	23.7389	13.2318	10.8026
6	Org.Mat	2.9586	2.6655	3.9611
7	Con.Duc	3.4083	1.1187	172.1788
8	Aci.Dty	6.6222	.5447	5.6549
9	Cit.Cht	12418.2500	4440.2716	136.3219
10	Cit.Sod	6947.3330	2553.8794	111.3175
11	Cit.Phs	78.6683	45.3603	5.8876
12	Cit.Pot	197.1416	71.7336	41.5500
13	Cit.Cal	454.8333	216.2834	24.2615
14	Cit.Mag	473.5334	158.5003	30.5361
15	Cit.Cop	.4264	.2032	7.5256
16	Cit.Znc	1.7989	.7721	9.3113
17	Cit.Man	1.6011	1.1255	17.2003
18	Cit.Irn	63.3445	44.2816	5.5927
19	Cit.Alu	65.0694	30.5795	48.5071
20	Cit.Bor	2.8200	1.1224	10.2191
29	Hgh.Msl	497.5834	292.8325	6.6959

\*\*\*\* Summary \*\*\*\*

Axes	1	2	3	4	Total inertia
Eigenvalues	: .930	.744	.665	.548	5.440
Species-environment correlations	: .976	.944	.960	.903	
Cumulative percentage variance					
of species data	: 17.1	30.8	43.0	53.1	
of species-environment relation:	21.8	39.2	54.8	67.6	
Sum of all unconstrained eigenvalues					5.440
Sum of all canonical eigenvalues					4.270

\*\*\*\* Summary of Monte Carlo test \*\*\*\*

Test of significance of first canonical axis:	eigenvalue =	.93
	F-ratio =	3.09
	P-value =	.93
Overall test	: Trace =	4.27
	F-ratio =	2.74
	P-value =	.01

( 99 permutations under full model)

# GEELBEK: -CANOCO OUTPUT SUMMARY

Number of samples

29 Number of species

14 Number of occurrences

73

Weighted correlation matrix (weight = sample total)

SPEC AX1	1.0000	-						
SPEC AX2	.0032	1.0000						
SPEC AX3	-.0073	-.0279	1.0000					
SPEC AX4	-.0401	-.0250	.0070	1.0000				
ENVI AX1	.9825	.0000	.0000	-.0001	1.0000			
ENVI AX2	-.0001	.9602	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.9523	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.8920	.0000	.0000	.0000	1.0000
Nit.Rte	.4806	-.1958	-.3445	-.2138	.4891	-.2039	-.3618	-.2397
Nit.Ite	-.1717	.0242	.6909	-.1252	-.1747	.0252	.7255	-.1403
Phs.Ate	.2231	-.0722	.7497	-.0822	.2270	-.0752	.7873	-.0922
Wte.Con	.4316	-.4894	-.3166	.3279	.4393	-.5097	-.3324	.3677
Org.Mat	.6930	-.4531	-.2244	.0908	.7054	-.4718	-.2357	.1018
Con.Duc	.8345	-.2923	.0891	-.2420	.8493	-.3043	.0936	-.2713
Aci.Dty	.3144	.0133	.3266	-.2314	.3200	.0139	.3429	-.2594
Cit.Cht	.8405	-.2714	.1234	-.2128	.8554	-.2826	.1296	-.2385
Cit.Sod	.8399	-.2133	.1230	-.2033	.8548	-.2221	.1292	-.2279
Cit.Phs	.6081	-.5168	.0227	-.0181	.6189	-.5382	.0238	-.0203
Cit.Pot	.2850	-.5544	-.1044	-.1228	.2900	-.5773	-.1097	-.1376
Cit.Cal	.5815	-.1286	.1480	-.1217	.5918	-.1339	.1554	-.1364
Cit.Mag	.7032	-.1814	.2138	-.1749	.7157	-.1889	.2245	-.1960
Cit.Cop	.2176	-.3207	-.0759	-.1808	.2214	-.3340	-.0797	-.2027
Cit.Znc	.2106	-.2588	-.0953	-.0546	.2143	-.2695	-.1001	-.0612
Cit.Man	.6283	-.2606	-.1800	-.2265	.6395	-.2713	-.1890	-.2539
Cit.Irn	.5911	-.4325	.1260	-.0384	.6016	-.4504	.1323	-.0430
Cit.Alu	.5719	-.5902	-.2146	-.0754	.5821	-.6146	-.2253	-.0845
Cit.Bor	.7472	-.4025	.0573	-.0862	.7604	-.4192	.0602	-.0966
Hgh.Msl	.9324	-.1780	.0027	.0202	.9491	-.1853	.0029	.0228

Nit.Rte	1.0000							
Nit.Ite	-.1101	1.0000						
Phs.Ate	-.0808	.4650	1.0000					
Wte.Con	.3048	-.3304	.1629	1.0000				
Org.Mat	.3944	-.4258	.0315	.7934	1.0000			
Con.Duc	.5122	-.1385	.3157	.3860	.6874	1.0000		
Aci.Dty	.2290	.1787	.3483	-.3251	-.0718	.3830	1.0000	
Cit.Cht	.4764	-.1205	.3391	.3828	.6822	.9975	.3893	1.0000
Cit.Sod	.4827	-.1053	.3544	.3713	.6551	.9705	.3656	.9763
Cit.Phs	.3371	-.1743	.2228	.7626	.8382	.6874	-.0840	.6773
Cit.Pot	.5053	-.0939	-.0113	.5291	.4389	.4495	.0244	.4275
Cit.Cal	.4505	-.0057	.3304	.4811	.4891	.6392	.0553	.6362
Cit.Mag	.4232	-.0482	.3238	.3243	.5703	.7882	.3239	.7834
Cit.Cop	.5105	-.1335	-.0321	-.0848	.0831	.4100	.4374	.3769
Cit.Znc	.2402	-.0284	-.0878	.4943	.3709	.2541	-.2060	.2371
Cit.Man	.5760	-.2687	-.0035	.5477	.6893	.7146	.1049	.6936
Cit.Irn	.3253	-.1063	.2555	.6519	.7084	.6867	.0680	.6770
Cit.Alu	.4354	-.3699	.0109	.8004	.8605	.6893	-.0816	.6687
Cit.Bor	.4508	-.1689	.2622	.4770	.7168	.8594	.3323	.8500
Hgh.Msl	.4298	-.2158	.2111	.5482	.7625	.8577	.2132	.8612

	Nit.Rte	Nit.Ite	Phs.Ate	Wte.Con	Org.Mat	Con.Duc	Aci.Dty	Cit.Cht
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Cit.Sod	1.0000							
Cit.Phs	.6344	1.0000						
Cit.Pot	.4136	.6054	1.0000					
Cit.Cal	.6394	.7443	.5596	1.0000				
Cit.Mag	.7237	.6740	.5339	.7023	1.0000			
Cit.Cop	.2927	.1141	.2663	.1911	.3159	1.0000		
Cit.Znc	.1753	.6103	.4455	.5639	.3745	.1320	1.0000	
Cit.Man	.6558	.7168	.6545	.6706	.8053	.2841	.3997	1.0000
Cit.Irn	.6228	.9163	.5693	.8256	.7693	.1943	.6541	.7347
Cit.Alu	.6366	.9394	.6794	.6774	.5817	.2006	.5348	.7287
Cit.Bor	.7787	.7598	.4974	.5791	.8341	.3910	.4240	.6594
Hgh.Msl	.8441	.7484	.4428	.6834	.7688	.2610	.3469	.6783

	Cit.Sod	Cit.Phs	Cit.Pot	Cit.Cal	Cit.Mag	Cit.Cop	Cit.Znc	Cit.Man
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Cit.Irn	1.0000			
Cit.Alu	.8480	1.0000		
Cit.Bor	.7422	.7228	1.0000	
Hgh.Msl	.7390	.7254	.8141	1.0000

Cit.Irn      Cit.Alu      Cit.Bor      Hgh.Msl

N name      (weighted) mean      stand. dev.      inflation factor

1	SPEC AX1	.0000	1.0180	
2	SPEC AX2	.0000	1.0415	
3	SPEC AX3	.0000	1.0501	
4	SPEC AX4	.0000	1.1211	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Nit.Rte	.4159	.1122	7.5902
3	Nit.Ite	5.1646	4.7707	3.4096
4	Phs.Ate	1.6002	1.2269	8.5500
5	Wte.Con	48.8833	11.7789	12.0180
6	Org.Mat	6.6624	3.1882	22.9688
7	Con.Duc	5.9817	2.6353	2798.2425
8	Aci.Dty	6.3056	.6654	5.0207
9	Cit.Cht	24940.9500	13238.0026	2398.7583
10	Cit.Sod	13736.8300	7512.9515	45.1613
11	Cit.Phs	594.9722	196.7506	90.6993
12	Cit.Pot	804.0277	310.1984	10.0954
13	Cit.Cal	3059.4440	967.5223	16.4196
14	Cit.Mag	2523.7780	1656.4246	28.8260
15	Cit.Cop	.8506	.4288	3.3103
16	Cit.Znc	5.7311	1.5117	6.0289
17	Cit.Man	3.5050	1.9772	19.7408
18	Cit.Irn	571.1111	299.8643	28.1052
19	Cit.Alu	465.5555	193.6034	176.9850
20	Cit.Bor	17.8031	11.6717	21.1056
29	Hgh.Msl	412.4166	297.9627	8.1296



# SCHRYWERSHOEK: CANOCO OUTPUT SUMMARY

Number of samples                    36    Number of species                    14    Number of occurrences                    106

\*\*\*\* Weighted correlation matrix (weight = sample total) \*\*\*\*

SPEC AX1	1.0000							
SPEC AX2	.0043	1.0000						
SPEC AX3	-.0050	-.0701	1.0000					
SPEC AX4	-.0039	-.0307	.0181	1.0000				
ENVI AX1	.9974	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	.9060	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.9342	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.8967	.0000	.0000	.0000	1.0000
Nit.Rte	.2170	.0985	-.4381	.1068	.2175	.1088	-.4690	.1191
Nit.Ite	.0498	-.0637	-.6201	-.2022	.0499	-.0703	-.6638	-.2255
Phs.Ate	.0091	.5834	.0475	.1362	.0091	.6440	.0509	.1519
Wte.Con	-.9126	.0105	.1488	.0057	-.9150	.0116	.1593	.0064
Org.Mat	-.8975	.0877	.1876	.0481	-.8998	.0969	.2008	.0537
Con.Duc	-.8852	.2366	-.0152	.0371	-.8875	.2612	-.0163	.0413
Aci.Dty	-.3857	.2018	-.5797	-.1172	-.3867	.2228	-.6205	-.1307
Cit.Cht	-.8630	.2653	-.0501	.0373	-.8653	.2929	-.0536	.0417
Cit.Sod	-.8706	.2547	-.0368	.0671	-.8729	.2812	-.0394	.0748
Cit.Phs	-.7656	.1184	.2028	-.0198	-.7676	.1308	.2171	-.0220
Cit.Pot	-.8604	.0034	.0059	-.0663	-.8626	.0038	.0063	-.0739
Cit.Cal	-.4914	.2065	-.5341	.0827	-.4927	.2279	-.5717	.0923
Cit.Mag	-.8148	.3466	-.0108	.1318	-.8169	.3826	-.0115	.1470
Cit.Cop	-.3862	.3950	-.2912	.2015	-.3872	.4361	-.3118	.2247
Cit.Znc	-.3689	.0475	.6630	.2885	-.3699	.0524	.7097	.3218
Cit.Man	-.8365	.2509	-.0813	.1639	-.8387	.2770	-.0870	.1827
Cit.Irn	-.7948	.2612	.0147	.2213	-.7969	.2884	.0158	.2468
Cit.Alu	-.8789	.1715	.0581	.1194	-.8812	.1893	.0622	.1331
Cit.Bor	-.8720	.3199	-.0142	.0362	-.8743	.3531	-.0152	.0404
Hgh.Msl	-.9895	-.0441	.0225	.0149	-.9921	-.0487	.0241	.0167
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4

Nit.Rte	1.0000								
Nit.Ite	.3803	1.0000							
Phs.Ate	-.2115	-.1312	1.0000						
Wte.Con	-.3237	-.1556	-.0218	1.0000					
Org.Mat	-.2966	-.1923	-.0045	.9578	1.0000				
Con.Duc	-.0785	-.0605	.0451	.8545	.8456	1.0000			
Aci.Dty	.1477	.4479	.2376	.1992	.1889	.4273	1.0000		
Cit.Cht	-.0613	-.0410	.0696	.8272	.8228	.9967	.4647	1.0000	
Cit.Sod	-.0594	-.0470	.0652	.8360	.8339	.9975	.4438	.9983	
Cit.Phs	-.0915	-.1946	-.0938	.6254	.6584	.7823	.2842	.7699	
Cit.Pot	-.2327	-.0629	-.0819	.8100	.7460	.8197	.4130	.8070	
Cit.Cal	.1868	.3843	.0753	.2958	.2532	.5302	.6766	.5559	
Cit.Mag	-.0333	-.0644	.1057	.7795	.7796	.9226	.3179	.9167	
Cit.Cop	.2098	.1513	.3060	.2777	.2848	.5534	.5832	.5758	
Cit.Znc	-.1736	-.5524	-.0539	.4618	.4882	.4008	-.3731	.3568	
Cit.Man	-.0236	-.0574	.0480	.7142	.7108	.8906	.4305	.8873	
Cit.Irn	-.0463	-.1006	.0468	.7052	.7126	.8718	.4124	.8703	
Cit.Alu	-.0701	-.1185	.0033	.7735	.7879	.9179	.3826	.9098	
Cit.Bor	-.0298	-.0270	.0978	.7902	.7919	.9464	.4269	.9408	
Hgh.Msl	-.2680	-.0536	-.0002	.9070	.8890	.8576	.3698	.8345	

	Nit.Rte	Nit.Ite	Phs.Ate	Wte.Con	Org.Mat	Con.Duc	Aci.Dty	Cit.Cht
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Cit.Sod	1.0000							
Cit.Phs	.7741	1.0000						
Cit.Pot	.8010	.7578	1.0000					
Cit.Cal	.5456	.3729	.5590	1.0000				
Cit.Mag	.9218	.7018	.7688	.5692	1.0000			
Cit.Cop	.5683	.4653	.4190	.6527	.5793	1.0000		
Cit.Znc	.3781	.4893	.3285	-.1478	.4971	.1371	1.0000	
Cit.Man	.8927	.8472	.8001	.6332	.8687	.6157	.3584	1.0000
Cit.Irn	.8768	.8772	.8076	.5692	.8569	.6535	.4506	.9457
Cit.Alu	.9149	.9147	.8749	.5230	.8740	.5677	.4550	.9464
Cit.Bor	.9407	.7859	.8223	.5967	.9573	.6069	.4374	.9259
Hgh.Msl	.8421	.7523	.8640	.4589	.7930	.3702	.3747	.8019

	Cit.Sod	Cit.Phs	Cit.Pot	Cit.Cal	Cit.Mag	Cit.Cop	Cit.Znc	Cit.Man
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Cit.Irn	1.0000			
Cit.Alu	.9509	1.0000		
Cit.Bor	.8978	.9279	1.0000	
Hgh.Msl	.7822	.8687	.8463	1.0000

Cit.Irn      Cit.Alu      Cit.Bor      Hgh.Msl

N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0026	
2	SPEC AX2	.0000	1.1038	
3	SPEC AX3	.0000	1.0704	
4	SPEC AX4	.0000	1.1152	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Nit.Rte	.6229	.2313	2.5743
3	Nit.Ite	2.7739	1.7862	2.8872
4	Phs.Ate	3.7934	1.8672	2.4612
5	Wte.Con	45.7667	18.3979	73.4231
6	Org.Mat	9.1841	4.6970	29.0176
7	Con.Duc	5.8947	2.1005	1029.0011
8	Aci.Dty	6.3750	.9172	5.9398
9	Cit.Cht	24677.5800	10990.7918	973.1642
10	Cit.Sod	13380.6900	5769.6013	1445.8492
11	Cit.Phs	311.1389	120.0979	14.2564
12	Cit.Pot	754.1944	378.3054	35.5005
13	Cit.Cal	2378.8880	920.3857	8.8455
14	Cit.Mag	1374.8890	794.8382	26.6092
15	Cit.Cop	.5094	.0769	4.6821
16	Cit.Znc	2.4428	.7612	6.1661
17	Cit.Man	1.7014	1.3263	39.3364
18	Cit.Irn	387.6861	300.9754	26.1086
19	Cit.Alu	340.1111	229.8221	134.7557
20	Cit.Bor	13.1536	9.6176	55.4309
29	Hgh.Msl	407.0277	229.7626	26.8139

\*\*\*\* Summary \*\*\*\*

Axes	1	2	3	4	Total inertia
Eigenvalues	: .989	.479	.347	.276	2.407
Species-environment correlations	: .997	.906	.934	.897	
Cumulative percentage variance					
of species data	: 41.1	61.0	75.4	86.9	
of species-environment relation:	46.3	68.7	85.0	97.9	
Sum of all unconstrained eigenvalues					2.407
Sum of all canonical eigenvalues					2.135

\*\*\*\* Summary of Monte Carlo test \*\*\*\*

Test of significance of first canonical axis

P-value = .0.01

Overall test

:P-value = 0.01

# OOSTEWAL: (SECOND SAMPLE) CANOCO OUTPUT SUMMARY

Number of samples                      29 Number of species                      15 Number of occurrences                      107

\*\*\*\* Weighted correlation matrix (weight = sample total) \*\*\*\*

SPEC AX1	1.0000							
SPEC AX2	-.0150	1.0000						
SPEC AX3	.0119	-.0070	1.0000					
SPEC AX4	-.0288	.0051	.0305	1.0000				
ENVI AX1	.9691	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	.9836	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.9530	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.9030	.0000	.0000	.0000	1.0000
Nit.Rte	-.0176	.0701	-.0265	-.2039	-.0181	.0713	-.0278	-.2259
Nit.Ite	-.2654	-.4276	.3053	-.4059	-.2739	-.4347	.3203	-.4495
Con.Duc	-.1298	-.7573	-.1531	.1164	-.1340	-.7699	-.1606	.1289
Aci.Dty	.0310	.6651	-.1081	-.1099	.0319	.6762	-.1134	-.1217
Cit.Cht	-.1479	-.7628	-.1598	.1051	-.1526	-.7754	-.1677	.1164
Cit.Sod	-.1516	-.6725	-.1377	.0797	-.1564	-.6836	-.1445	.0883
Cit.Phs	.5414	-.2815	-.5550	.1292	.5587	-.2861	-.5824	.1430
Cit.Pot	-.0571	-.7397	-.0334	-.1352	-.0589	-.7520	-.0350	-.1497
Cit.Cal	.2957	-.4279	-.1894	-.0352	.3051	-.4350	-.1988	-.0390
Cit.Mag	-.0629	-.7091	.0225	-.0304	-.0649	-.7209	.0236	-.0337
Cit.Cop	-.0261	-.2697	-.2096	.0607	-.0269	-.2742	-.2199	.0672
Cit.Znc	.2224	-.3876	-.0154	.2242	.2295	-.3940	-.0162	.2483
Cit.Man	-.2038	-.0129	-.0681	-.1803	-.2103	-.0132	-.0714	-.1997
Cit.Irn	.2164	-.4910	-.0989	.2413	.2233	-.4991	-.1038	.2672
Cit.Alu	.4230	-.6275	-.2172	-.0976	.4366	-.6379	-.2279	-.1081
Cit.Bor	-.0065	-.6522	.1145	-.0579	-.0067	-.6631	.1201	-.0641
Sat.Pot	.0798	-.7756	-.1647	.0739	.0823	-.7885	-.1729	.0819
Sat.Cal	.0119	-.5835	-.1163	.1349	.0123	-.5932	-.1220	.1494
Sat.Mag	-.1522	-.6889	-.1232	.1235	-.1570	-.7004	-.1293	.1368
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4

Nit.Rte	1.0000							
Nit.Ite	.0808	1.0000						
Con.Duc	-.1007	.1247	1.0000					
Aci.Dty	.1076	-.3745	-.4729	1.0000				
Cit.Cht	-.1006	.1376	.9747	-.4697	1.0000			
Cit.Sod	-.1148	.1355	.9488	-.4353	.9164	1.0000		
Cit.Phs	.0746	-.2456	.3393	-.1263	.3167	.3037	1.0000	
Cit.Pot	.0179	.3417	.8689	-.4467	.8107	.8541	.3463	1.0000
Cit.Cal	-.0787	-.0853	.7205	-.3710	.6871	.7529	.5923	.7499
Cit.Mag	-.0879	.2514	.8822	-.4228	.8519	.8533	.3343	.9644
Cit.Cop	-.2682	-.0610	.6536	-.3367	.5590	.6936	.2210	.6151
Cit.Znc	-.1036	-.2454	.7086	-.2961	.6466	.7010	.4521	.6580
Cit.Man	.0790	.2405	.2287	-.1367	.1978	.2640	-.0676	.4127
Cit.Irn	-.1564	-.3009	.7209	-.2145	.6770	.6566	.4692	.6358
Cit.Alu	-.0386	-.0066	.6549	-.2735	.6093	.5928	.7264	.6822
Cit.Bor	.1045	.2503	.7592	-.4144	.7186	.7381	.3172	.8962
Sat.Pot	-.0543	.0900	.9675	-.4525	.9361	.9141	.4711	.8808
Sat.Cal	-.1475	-.0247	.9168	-.3982	.8895	.9040	.4019	.8267
Sat.Mag	-.1547	.0581	.9556	-.4601	.9678	.9086	.2724	.8055

Nit.Rte      Nit.Ite      Con.Duc      Aci.Dty      Cit.Cht      Cit.Sod      Cit.Phs      Cit.Pot

Cit.Cal	1.0000							
Cit.Mag	.7840	1.0000						
Cit.Cop	.7028	.6045	1.0000					
Cit.Znc	.7883	.7291	.7419	1.0000				
Cit.Man	.3646	.3897	.4774	.2856	1.0000			
Cit.Irn	.7303	.7300	.5504	.8664	.1724	1.0000		
Cit.Alu	.6977	.6783	.3858	.6547	-.1087	.6716	1.0000	
Cit.Bor	.6916	.8999	.4787	.7233	.4021	.6966	.6279	1.0000
Sat.Pot	.7899	.8778	.6115	.7334	.2027	.7556	.7598	.7819
Sat.Cal	.8621	.8812	.6721	.8078	.3578	.8236	.6245	.7792
Sat.Mag	.7488	.8685	.6479	.7336	.3135	.7502	.5628	.7202

Cit.Cal      Cit.Mag      Cit.Cop      Cit.Znc      Cit.Man      Cit.Irn      Cit.Alu      Cit.Bor

Sat.Pot	1.0000		
Sat.Cal	.9213	1.0000	
Sat.Mag	.9191	.9354	1.0000

Sat.Pot	Sat.Cal	Sat.Mag
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N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0319	
2	SPEC AX2	.0000	1.0166	
3	SPEC AX3	.0000	1.0493	
4	SPEC AX4	.0000	1.1074	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Nit.Rte	.3465	.1509	3.5776
3	Nit.Ite	10.4142	15.7972	4.0408
4	Con.Duc	2.8064	1.3048	219.4802
5	Aci.Dty	6.9194	.4483	2.5250
6	Cit.Cht	9515.7780	4388.7350	127.9202
7	Cit.Sod	5624.1670	2820.9014	24.4757
8	Cit.Phs	104.5611	61.9508	4.7579
9	Cit.Pot	275.5195	159.3104	170.6341
10	Cit.Cal	903.8888	589.7970	32.0873
11	Cit.Mag	523.2555	295.0889	141.7427
12	Cit.Cop	.2871	.2113	24.6887
13	Cit.Znc	1.4509	1.1026	28.8395
14	Cit.Man	.9344	.4743	4.8702
15	Cit.Irn	67.2639	51.9121	9.8588
16	Cit.Alu	288.7692	145.3166	13.2409
17	Cit.Bor	4.4794	2.7327	19.4647
18	Sat.Pot	20.0692	9.6046	84.7162
19	Sat.Cal	4198.3880	2364.1839	51.3547
20	Sat.Mag	4512.7440	2678.4670	88.2213

\*\*\*\* Summary \*\*\*\*

Axes	1	2	3	4	Total inertia
Eigenvalues	: .927	.807	.664	.571	5.440
Species-environment correlations	: .969	.984	.953	.903	
Cumulative percentage variance					
of species data	: 17.0	31.9	44.1	54.5	
of species-environment relation:	21.3	39.8	55.0	68.1	
Sum of all unconstrained eigenvalues					5.440
Sum of all canonical eigenvalues					4.358

\*\*\*\* Summary of Monte Carlo test \*\*\*\*

Test of significance of first canonical axis: eigenvalue = .93  
F-ratio = 3.28  
P-value = .59

Overall test : Trace = 4.36  
F-ratio = 3.39  
P-value = .01

( 99 permutations under full model)

# OOSTEWAL: ( THIRD SAMPLE) CANOCO OUTPUT SUMMARY

Number of samples                      36    Number of species                      15    Number of occurrences                      107

\*\*\*\* Weighted correlation matrix (weight = sample total) \*\*\*\*

SPEC AX1	1.0000								
SPEC AX2	-.0057	1.0000							
SPEC AX3	-.0075	.0263	1.0000						
SPEC AX4	-.0006	-.0100	.0150	1.0000					
ENVI AX1	.9891	.0000	.0000	.0000	1.0000				
ENVI AX2	.0000	.9714	.0000	.0000	.0000	1.0000			
ENVI AX3	.0000	.0000	.9517	.0000	.0000	.0000	1.0000		
ENVI AX4	.0000	.0000	.0000	.8670	.0000	.0000	.0000	1.0000	
Nit.Rte	-.1357	-.3391	-.3179	-.0290	-.1372	-.3491	-.3340	-.0334	
Nit.Ite	-.1855	-.0052	-.2170	-.5223	-.1875	-.0054	-.2280	-.6025	
Con.Duc	.0597	-.7974	.3383	-.0352	.0604	-.8208	.3554	-.0406	
Aci.Dty	.2752	.4981	.0285	.1569	.2783	.5128	.0300	.1809	
Cit.Cht	.0560	-.7796	.3459	-.0432	.0566	-.8025	.3634	-.0499	
Cit.Sod	.0794	-.7820	.3188	-.0152	.0803	-.8050	.3350	-.0175	
Cit.Phs	.2934	-.6208	.5036	.1826	.2967	-.6390	.5292	.2106	
Cit.Pot	.1257	-.6671	.1216	.1274	.1271	-.6867	.1277	.1469	
Cit.Cal	.8922	-.2949	.1721	-.0545	.9020	-.3036	.1809	-.0629	
Cit.Mag	.0776	-.6787	.1041	.0643	.0785	-.6987	.1094	.0741	
Cit.Cop	.0793	-.2751	.5980	.2171	.0802	-.2831	.6283	.2504	
Cit.Znc	.0431	-.3400	-.1216	.3075	.0436	-.3500	-.1278	.3547	
Cit.Man	.0303	-.2555	-.2717	.2785	.0306	-.2630	-.2855	.3213	
Cit.Irn	-.0054	-.6413	-.2374	.4056	-.0055	-.6602	-.2495	.4679	
Cit.Alu	.1330	-.6676	.2706	-.2784	.1344	-.6872	.2843	-.3211	
Cit.Bor	.1345	-.5318	-.1164	.2052	.1360	-.5475	-.1223	.2367	
Sat.Pot	.1937	-.7357	.3950	-.0221	.1959	-.7573	.4150	-.0254	
Sat.Cal	.1266	-.6879	.2111	.1884	.1280	-.7082	.2218	.2173	
Sat.Mag	.1126	-.7426	.2528	.0923	.1138	-.7645	.2657	.1065	
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4	

Nit.Rte	1.0000								
Nit.Ite	-.0053	1.0000							
Con.Duc	.1673	.0489	1.0000						
Aci.Dty	-.2094	-.2212	-.4058	1.0000					
Cit.Cht	.1507	.0620	.9975	-.4040	1.0000				
Cit.Sod	.1561	.0428	.9976	-.4065	.9973	1.0000			
Cit.Phs	-.0264	-.3348	.7694	-.1311	.7715	.7685	1.0000		
Cit.Pot	.1379	.0453	.8320	-.2679	.8420	.8454	.7015	1.0000	
Cit.Cal	-.1347	-.1137	.4220	.1369	.4213	.4352	.5883	.4163	
Cit.Mag	.2476	.1122	.8322	-.2913	.8397	.8430	.6032	.9275	
Cit.Cop	.0111	-.2685	.4912	-.1010	.4867	.4775	.5469	.3729	
Cit.Znc	.1668	.0508	.3931	.1430	.3852	.4074	.3147	.4856	
Cit.Man	.2817	.0180	.2291	.1206	.2365	.2490	.2776	.4616	
Cit.Irn	.3282	-.2115	.4786	-.1770	.4796	.4945	.5640	.6555	
Cit.Alu	.0687	.3085	.8457	-.2894	.8492	.8411	.6523	.6817	
Cit.Bor	.1934	.1625	.5874	.0179	.5839	.5982	.4080	.7130	
Sat.Pot	.1111	.0391	.9754	-.3602	.9767	.9770	.8050	.8550	
Sat.Cal	.1570	-.0122	.8946	-.1662	.8969	.9044	.7535	.9083	
Sat.Mag	.1528	-.0200	.9602	-.3245	.9619	.9697	.7674	.8958	

	Nit.Rte	Nit.Ite	Con.Duc	Aci.Dty	Cit.Cht	Cit.Sod	Cit.Phs	Cit.Pot
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Cit.Cal	1.0000							
Cit.Mag	.3872	1.0000						
Cit.Cop	.2948	.4043	1.0000					
Cit.Znc	.2010	.4213	.2676	1.0000				
Cit.Man	.1389	.4375	.1583	.7843	1.0000			
Cit.Irn	.1824	.6131	.2269	.5978	.6885	1.0000		
Cit.Alu	.4910	.7203	.3775	.4442	.2961	.3772	1.0000	
Cit.Bor	.3291	.6748	.1447	.7932	.6661	.5463	.6058	1.0000
Sat.Pot	.5317	.8526	.5321	.3570	.2207	.4567	.8239	.5513
Sat.Cal	.4458	.8476	.4036	.6361	.4756	.6222	.7385	.7941
Sat.Mag	.4470	.8774	.4380	.4481	.3312	.5683	.7686	.6433

	Cit.Cal	Cit.Mag	Cit.Cop	Cit.Znc	Cit.Man	Cit.Irn	Cit.Alu	Cit.Bor
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Sat.Pot	1.0000							
Sat.Cal	.8860	1.0000						
Sat.Mag	.9521	.9352	1.0000					

	Sat.Pot	Sat.Cal	Sat.Mag
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N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0111	
2	SPEC AX2	.0000	1.0295	
3	SPEC AX3	.0000	1.0508	
4	SPEC AX4	.0000	1.1534	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Nit.Rte	.5579	.2692	1.9343
3	Nit.Ite	3.3781	3.8248	4.9234
4	Con.Duc	2.6003	1.0390	524.7422
5	Aci.Dty	6.5556	.2967	3.3026
6	Cit.Cht	9149.3060	3823.8704	519.6233
7	Cit.Sod	5424.3890	2299.7228	823.2854
8	Cit.Phs	110.1208	57.8469	23.2941
9	Cit.Pot	259.1778	153.2065	18.5279
10	Cit.Cal	684.6388	539.3454	4.0430
11	Cit.Mag	526.9778	279.0227	29.9572
12	Cit.Cop	.4366	.2539	3.8005
13	Cit.Znc	1.6117	1.4274	18.6157
14	Cit.Man	1.2406	.3525	6.3355
15	Cit.Irn	97.8611	73.0803	8.1990
16	Cit.Alu	365.8861	193.7738	16.3380
17	Cit.Bor	3.4500	2.2704	9.7832
18	Sat.Pot	17.9792	8.1246	99.2608
19	Sat.Cal	2136.4890	961.1379	42.8797
20	Sat.Mag	4200.5660	1947.0820	42.3007

\*\*\*\* Summary \*\*\*\*

Axes	1	2	3	4	Total inertia
Eigenvalues	: .965	.762	.664	.425	5.440
Species-environment correlations	: .989	.971	.952	.867	
Cumulative percentage variance					
of species data	: 17.7	31.8	44.0	51.8	
of species-environment relation:	23.7	42.5	58.8	69.2	
Sum of all unconstrained eigenvalues					5.440
Sum of all canonical eigenvalues					4.067

\*\*\*\* Summary of Monte Carlo test \*\*\*\*

Test of significance of first canonical axis:	eigenvalue =	.97
	F-ratio =	3.45
	P-value =	.65
Overall test	Trace =	4.07
	F-ratio =	2.50
	P-value =	.01

( 99 permutations under full model)

# OOSTEWAL: (SEDIMENT ANALYSIS) CANOCO OUTPUT SUMMARY

Number of samples                      28    Number of species                      14    Number of occurrences                      73

\*\*\*\* Weighted correlation matrix (weight = sample total) \*\*\*\*

SPEC AX1	1.0000								
SPEC AX2	-.0855	1.0000							
SPEC AX3	.0020	.0006	1.0000						
SPEC AX4	.0130	-.0291	-.1748	1.0000					
ENVI AX1	.9404	.0000	.0000	.0000	1.0000				
ENVI AX2	.0000	.8968	.0000	.0000	.0000	1.0000			
ENVI AX3	.0000	.0000	.8628	.0000	.0000	.0000	1.0000		
ENVI AX4	.0000	.0000	.0000	.7686	.0000	.0000	.0000	1.0000	
Grn.Ule	.2170	.4141	.5523	.3905	.2308	.4618	.6401	.5081	
VCr.Sed	.2839	.4242	.4469	.2923	.3019	.4730	.5179	.3803	
Crs.Sed	.7900	-.3009	.0991	.1337	.8400	-.3355	.1148	.1739	
Med.Sed	-.2144	-.8289	.1587	.0439	-.2280	-.9242	.1839	.0571	
Fin.Sed	-.2516	.6436	-.4128	.0041	-.2675	.7176	-.4784	.0054	
Vfn.Sed	.1676	.7610	-.1250	-.3268	.1782	.8485	-.1448	-.4252	
Slt.Cly	.2169	.6651	.0999	.1128	.2308	.7414	.1160	.1467	

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
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Grn.Ule	1.0000							
VCr.Sed	.8733	1.0000						
Crs.Sed	.2420	.4146	1.0000					
Med.Sed	-.2801	-.3966	.1422	1.0000				
Fin.Sed	-.1417	-.1260	-.6157	-.7662	1.0000			
Vfn.Sed	.0692	.1751	-.2548	-.9219	.7174	1.0000		
Slt.Cly	.6795	.7958	.1661	-.6349	.1690	.4823	1.0000	

	Grn.Ule	VCr.Sed	Crs.Sed	Med.Sed	Fin.Sed	Vfn.Sed	Slt.Cly
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N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0634	
2	SPEC AX2	.0000	1.1151	
3	SPEC AX3	.0000	1.1590	
4	SPEC AX4	.0000	1.3010	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Grn.Ule	1.3243	2.5314	10.4747
2	VCr.Sed	1.6700	2.3446	19.6172
3	Crs.Sed	8.6450	5.8581	28.7362
4	Med.Sed	41.6004	23.0227	434.4394
5	Fin.Sed	30.7743	13.2305	144.8829
6	Vfn.Sed	13.1389	11.5543	127.8873
7	Slt.Cly	2.8464	2.2486	.0000

\*\*\*\* Summary \*\*\*\*

Axes	1	2	3	4	Total inertia
Eigenvalues	: .797	.714	.617	.318	6.172
Species-environment correlations	: .940	.897	.863	.769	
Cumulative percentage variance					
of species data	: 12.9	24.5	34.5	39.6	
of species-environment relation:	31.5	59.7	84.1	96.6	
Sum of all unconstrained eigenvalues					6.172
Sum of all canonical eigenvalues					2.531

\*\*\*\* Summary of Monte Carlo test \*\*\*\*

Test of significance of first canonical axis:	eigenvalue =	.80
	F-ratio =	3.11
	P-value =	.05
Overall test	: Trace =	2.53
	F-ratio =	2.43
	P-value =	.01

# GEELBEK: (SEDIMENT ANALYSIS) CANOCO OUTPUT SUMMARY

Number of samples                      24 Number of species                      14 Number of occurrences                      73

\*\*\*\* Weighted correlation matrix (weight = sample total) \*\*\*\*

SPEC AX1	1.0000	-							
SPEC AX2	.0082	1.0000							
SPEC AX3	-.0578	-.0245	1.0000						
SPEC AX4	-.0071	-.0337	-.0271	1.0000					
ENVI AX1	.9613	.0000	.0000	.0000	1.0000				
ENVI AX2	.0000	.9539	.0000	.0000	.0000	1.0000			
ENVI AX3	.0000	.0000	.9333	.0000	.0000	.0000	1.0000		
ENVI AX4	.0000	.0000	.0000	.9159	.0000	.0000	.0000	1.0000	
Grn.Ule	.1607	-.4515	.3928	.6681	.1671	-.4733	.4209	.7295	
Crs.Sed	.8957	.0652	-.2419	.2040	.9318	.0683	-.2592	.2228	
Med.Sed	-.1368	.0049	-.8957	.0680	-.1423	.0052	-.9597	.0742	
Fin.Sed	-.3395	.3037	.7609	-.1825	-.3532	.3183	.8153	-.1992	
Vfn.Sed	.1046	-.1613	.8085	-.3655	.1088	-.1691	.8663	-.3990	
Slt.Cly	.1289	-.1963	.7040	.2019	.1341	-.2058	.7543	.2204	

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
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Grn.Ule	1.0000							
Crs.Sed	.1874	1.0000						
Med.Sed	-.3545	.1215	1.0000					
Fin.Sed	-.0631	-.5734	-.7825	1.0000				
Vfn.Sed	.1461	-.2150	-.9284	.7352	1.0000			
Slt.Cly	.6882	.0180	-.7454	.3533	.6158	1.0000		

	Grn.Ule	Crs.Sed	Med.Sed	Fin.Sed	Vfn.Sed	Slt.Cly
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N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0403	
2	SPEC AX2	.0000	1.0483	
3	SPEC AX3	.0000	1.0715	
4	SPEC AX4	.0000	1.0919	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Grn.Ule	1.4154	2.6833	33.7385
3	Crs.Sed	8.6792	5.5747	64.1278
4	Med.Sed	44.9333	23.1323	941.6610
5	Fin.Sed	29.1583	12.5255	284.1266
6	Vfn.Sed	11.3792	11.0516	217.2037
7	Slt.Cly	2.8246	2.2682	19.7336

\*\*\*\* Summary \*\*\*\*

Axes	1	2	3	4	Total inertia
Eigenvalues	: .866	.816	.767	.433	6.008
Species-environment correlations	: .961	.954	.933	.916	
Cumulative percentage variance					
of species data	: 14.4	28.0	40.8	48.0	
of species-environment relation:	28.6	55.6	80.9	95.2	
Sum of all unconstrained eigenvalues					6.008
Sum of all canonical eigenvalues					3.026

\*\*\*\* Summary of Monte Carlo test \*\*\*\*

Test of significance of first canonical axis:	eigenvalue =	.87
	F-ratio =	2.86
	P-value =	.35
Overall test	Trace =	3.03
	F-ratio =	2.87
	P-value =	.01

( 99 permutations under full model)

# SCHRYWERSHOEK: (SEDIMENT ANALYSIS) CANOCO OUTOUT SUMMARY

Number of samples                      17    Number of species                      14    Number of occurrences                      51

\*\*\*\* Weighted correlation matrix (weight = sample total) \*\*\*\*

SPEC AX1	1.0000								
SPEC AX2	.0625	1.0000							
SPEC AX3	-.0075	-.0254	1.0000						
SPEC AX4	-.0196	-.1597	-.3427	1.0000					
ENVI AX1	.9888	.0000	.0000	.0000	1.0000				
ENVI AX2	.0000	.7674	.0000	.0000	.0000	1.0000			
ENVI AX3	.0000	.0000	.6013	.0000	.0000	.0000	1.0000		
ENVI AX4	.0000	.0000	.0000	.6084	.0000	.0000	.0000	1.0000	
Grn.Ule	-.3691	.2247	.2368	.3677	-.3733	.2928	.3939	.6043	
VCr.Sed	-.5912	.3133	.1824	.3569	-.5980	.4083	.3033	.5867	
Crs.Sed	-.1578	.6544	.0815	.1776	-.1596	.8528	.1355	.2920	
Med.Sed	.9618	.1538	-.0310	.0332	.9727	.2004	-.0516	.0546	
Fin.Sed	.9649	.1421	.0448	.0015	.9759	.1852	.0745	.0024	
Vfn.Sed	.8754	.1819	.0607	.0801	.8854	.2371	.1009	.1316	
Slt.Cly	-.9145	-.2549	-.0230	-.0779	-.9249	-.3322	-.0382	-.1283	

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
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Grn.Ule	1.0000							
VCr.Sed	.8380	1.0000						
Crs.Sed	.6470	.6041	1.0000					
Med.Sed	-.2880	-.5005	.0541	1.0000				
Fin.Sed	-.2804	-.5012	.0402	.9905	1.0000			
Vfn.Sed	-.1755	-.3972	.2106	.9421	.9475	1.0000		
Slt.Cly	.1360	.3526	-.2247	-.9824	-.9779	-.9594	1.0000	

Grn.Ule	VCr.Sed	Crs.Sed	Med.Sed	Fin.Sed	Vfn.Sed	Slt.Cly
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N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0114	
2	SPEC AX2	.0000	1.3031	
3	SPEC AX3	.0000	1.6631	
4	SPEC AX4	.0000	1.6436	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Grn.Ule	.4135	.5529	3.9283
2	VCr.Sed	2.0412	2.1386	5.3501
3	Crs.Sed	6.1776	3.3179	3.0201
4	Med.Sed	27.6106	19.5739	56.0380
5	Fin.Sed	13.3341	9.5661	66.5497
6	Vfn.Sed	2.0512	1.0822	14.3142
7	Slt.Cly	48.3735	29.5385	.0000

\*\*\*\* Summary \*\*\*\*

Axes	1	2	3	4	Total inertia
Eigenvalues	: .936	.375	.199	.086	2.756
Species-environment correlations	: .989	.767	.601	.608	
Cumulative percentage variance					
of species data	: 34.0	47.6	54.8	57.9	
of species-environment relation:	58.4	81.8	94.2	99.6	
Sum of all unconstrained eigenvalues					2.756
Sum of all canonical eigenvalues					1.602

\*\*\*\* Summary of Monte Carlo test \*\*\*\*

Test of significance of first canonical axis: eigenvalue = .94  
F-ratio = 5.14  
P-value = .01

Overall test : Trace = 1.60  
F-ratio = 2.31  
P-value = .01

( 99 permutations under full model)