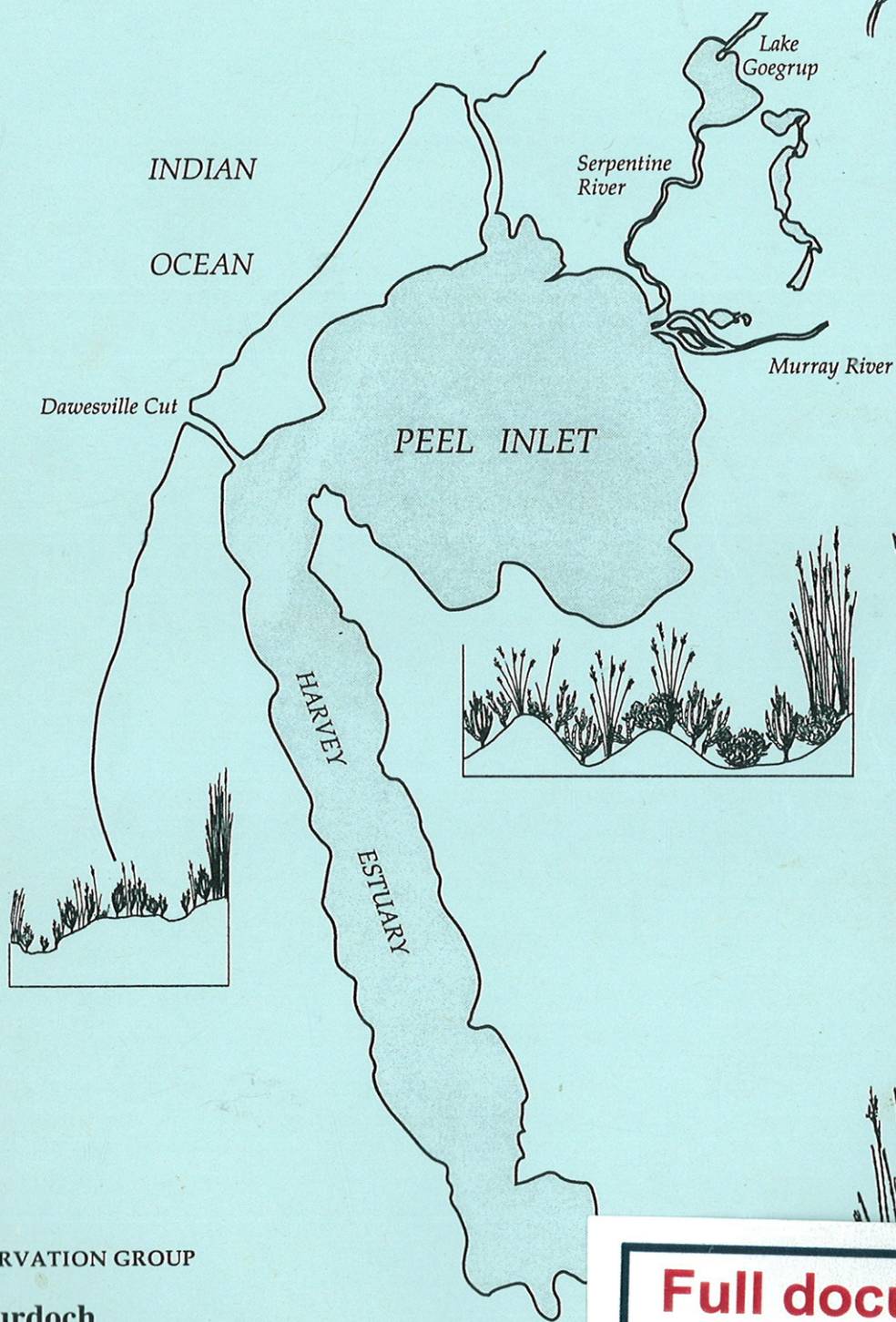


SAMPHIRE MARSHES OF THE PEEL-HARVEY ESTUARINE SYSTEM WESTERN AUSTRALIA



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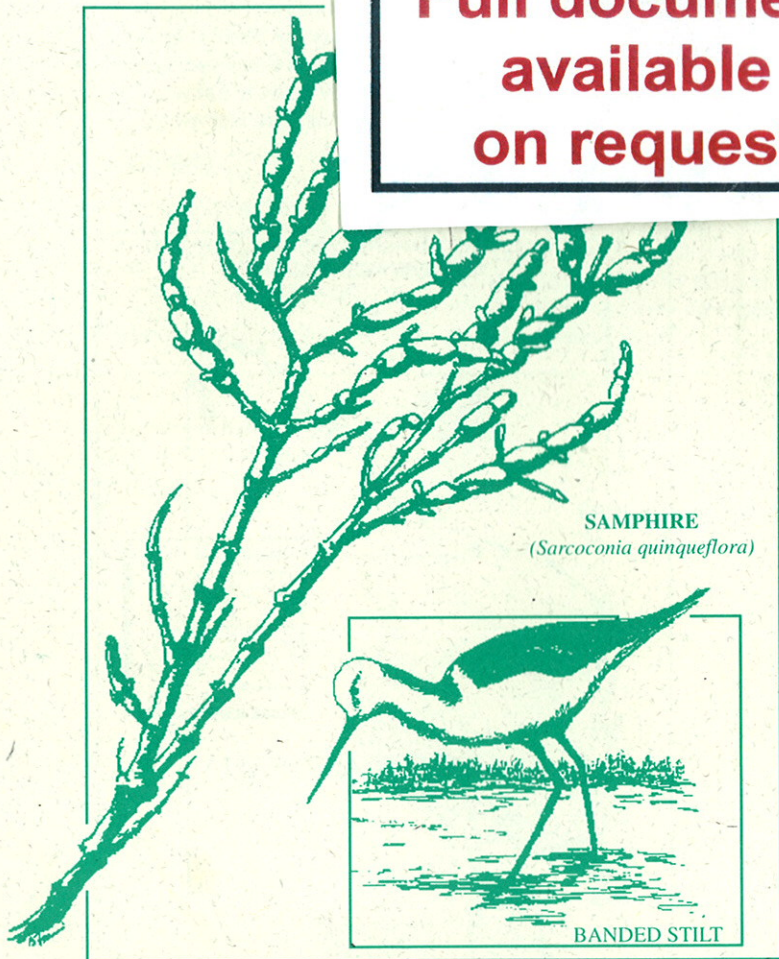
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BJK

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~ A COMMUNITY ASSET ~

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SAMPHIRE
(*Sarcocornia quinqueflora*)

BANDED STILT

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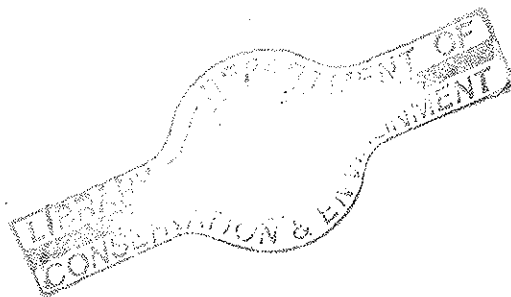
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THE PERIPHERAL VEGETATION OF THE
PEEL-HARVEY ESTUARINE SYSTEM

by

Dennis James Backshall, B.Sc.

Thesis submitted for certificate of Honours studies, 1977, Murdoch
University.



DECLARATION

I hereby declare that, to the best of my knowledge and belief, this thesis contains no material published or written by another person, except where due reference is made in the text.

DJ Backshall.

D.J. Backshall

ABSTRACT

The peripheral vegetation of the Peel-Harvey estuarine system was investigated with the objective of gaining a better understanding of the relationships between estuarine flora and the environment. The surrounding vegetation and soils of the area, and the hydrology and geomorphology of the estuarine system was also considered in some detail.

The peripheral vegetation of the estuary was defined as being vegetation that is obviously influenced by its proximity to the estuarine system, and was subjected to detailed phytosociological analysis. The Braun-Blanquet approach was adopted for use in this study. This led to the definition of 20 vegetation units, and these were classified into four major complexes and three independent units. The boundaries of these were defined along surveyed transects using heterogeneity analysis (Van der Maarel, 1966) to determine the spatial relationships of the units between each other, and with topography.

The vegetation units were then ordinated on the basis of their floristic composition using Principle Axes Ordination (Van der Maarel, 1969) so that the spatial arrangements of the total vegetation sampled could be abstracted. This ordination was then overlaid with environmental data considered likely to be influencing the gradient nature of the vegetation. It was concluded that with the data ordinated, salinity, elevation and soil profile development most clearly reflected gradient trends.

The dynamic nature of the peripheral vegetation ecology was discussed. Special reference is made of salt marsh ontogeny and also the effect that high macroalgal productivity in the estuary was having on the shoreline. It was concluded that the periphery of the system was affected to varying degrees, and that prevailing winds play a major part in the process.

Finally, a study of the diatom flora was undertaken to discover the relationship of the diatom distribution with the vegetation units, and to contribute to the knowledge of diatom ecology in the area.

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CHAPTER ONE

1. Introduction

The Peel-Harvey estuarine system* and associated wetlands are situated in one of the most important tourist areas in the south-west of Western Australia. The recent growth of tourism, combined with industrial and agricultural expansion, has led to a dramatic increase in human influence on the system. As well as having recreational value, the waters of the estuaries are of importance to waterfowl (Serventy, 1930; Riggert, 1966). This is particularly so in drought years when inland wetlands are reduced.

A growing awareness of the intrinsic value of the area and concern that development may be having a negative effect on its ecology, has prompted some Government departments and research institutions to begin work on various aspects of the area. In particular, the Western Australian Environmental Protection Authority has commissioned an investigation into the hydrodynamics and nutrient flow to contribute to an understanding of the effects of development. The fringing vegetation is an integral part of any estuary, and generally reflects any changes occurring in the hydrology. A study of the vegetation ecology of the area was then seen to be an important adjunct to the investigation.

Coastal and salt marsh vegetation in Australia has been described by a number of workers, notably Pigeon (1940), Clarke and Hannon (1967, 1971) in N.S.W, Pattern (1942) and Bridgewater (1974) in Victoria, Wood (1973) in South Australia, and Gardener (1942), Sauer (1964) and McArthur (1957) in Western Australia. The environment and vegetation in these studies varies considerably from that of the Peel-Harvey system thus little ecological information relevant to the area was contributed.

The primary objective of this study was to gain an understanding of the relationships between the vegetation around the periphery of the estuaries with the environment. This objective was facilitated by first classifying

the vegetation into recognisable units. Once these were identified, environmental information about the substrate could be assessed. It follows that if the factors affecting the spatial arrangements of plant groups can be distinguished, then a better understanding of the dynamic processes of the vegetation may be derived.

* Footnote: Although referred to on map locations as Peel Inlet, in this study the estuaries are called Peel estuary and Harvey Estuary, and together they will be referred to as the Peel-Harvey estuarine system.

CHAPTER TWO

2. Description of Study Area

The Peel-Harvey estuarine system extends south of Mandurah, lat. 32°S. For the purpose of the investigation, the vegetation and soils of the area have been divided into three arbitrary units. The marsh unit is comprised of vegetation and soils obviously influenced by the estuary. The surrounding vegetation unit is that considered to be beyond the sphere of influence of the estuary. Between these lie a transitional unit. It was on the marsh and transitional units that the investigation was concentrated, and these vegetational units together are referred to as peripheral vegetation. A description of both the surrounding unit and the estuarine system is necessary before the nature of the periphery can be understood.

2.1 Soils

The soils of the estuary are traversed by the boundaries of three soil systems, typical of the Perth sedimentary basin. These are the Spearwood and Bassendean dune systems and the Pinjarra Plain soil system. Although these are classified further by McArthur and Bettenay (1960) only a description of the higher units is relevant to this study.

The Spearwood dune system consists of a core of aeolianite with a hard capping of secondary calcite overlain by variable depths of yellow or brown sand. Usually surface soils are dominated with yellow quartz sand, with minor ferruginous sandstone and calcrete. However aeolianite is frequently exposed, particularly on the steeper slopes of western Harvey Estuary and Point Grey. This system is the most westward and youngest unit, and topographically shows more elevation and relief than the other systems. Thus the groundwater is more mobile, giving rise to several springs near the hydrogeographical boundary of the estuary. The groundwater is also characteristically rich in dissolved carbonates.

The Bassendean dune system occurs immediately east of the Spearwood system, and although it probably originated as a calcareous sandy coastline, leaching has removed all carbonates and various acidic podsol soil profiles have developed. These typically have some surface organic matter overlying grey to white sands, with weak iron pans at depth. The structure of this unit alters as it nears the study area, because of the diffuse nature of the boundaries of the Spearwood and Bassendean systems, and because of extensive reworking of sediments near the eastern shore of Harvey Estuary. The system has a low profile topography, with the lowest strata becoming waterlogged during winter. The groundwater has a generally higher humic and acidic status than the Spearwood system.

The Pinjarra Plain soils comprise the oldest unit, and vary in colour and texture according to the age of the deposit. The colour progresses from dark brown through yellow to grey with increasing loss and segregation of iron mineral. Light brown and grey soils are those most commonly expressed near the estuary, with a ferruginous hardpan nearing the surface where the system intrudes into Peel estuary near Robert Bay. The topography is level, and much of the groundwater from the rural hinterland is assisted to the estuary via P.W.D. drains. The runoff is seasonal, with the early rains leaching into the system the highest levels of agricultural nutrient input (Black, 1977).

2.2 Vegetation

The vegetation surrounding the estuary has been considerably reduced in both area and density during the last two decades. Scrubland and woodland understory have been thinned by clearing, grazing and annual burns, including those stands on flora and fauna reserves. That which remains has been mapped to show relationships with topography and soils, and sampling areas. The following structural description is based on Specht (1970) and complements the map inside the back cover. The

symbols on the map denote the most commonly occurring species in the dominant layer, and are to be related to the key in Appendix I. The map was compiled after field surveys and examination of aerial photographs supplied by the Department of Conservation and Environment, and is scaled at 1:25000. It outlines the boundaries of the major soil system, the structure of the surrounding vegetation, and the distributions of the sampling sites.

2.2.1 Woodland. Eucalyptus gomphocephala (Tuart) is an indicator of the Spearwood dune system, with Agonis flexuosa occurring as understory. Banksia grandis occurs in the deeper sands on the more elevated areas, while denser stands of open forest occur on the steeper slopes. Where the limestone persists near the surface A. flexuosa infiltrates the transitional vegetation (e.g., Island point, lower Harvey Estuary).

Where the overlying sands occur with depth and are somewhat more leached, mixtures of Jarrah and Marri replace the Tuart-Agonis woodland. A. flexuosa still features in the understory, accompanied by B. grandis and B. attenuata. Jacksonia furcellata and B. littoralis become more common in the transitional vegetation near the estuary.

Jarrah-Marri-Banksia form the denser vegetation on the Bassendean soils with some areas of open forest occurring inland from the estuary. Jarrah is the dominant tree with B. grandis and B. attenuata important in the understory. Nuytsia floribunda, Xanthorrhoea preissii, Casuarina fraserana, Xylomelum occidentale are common and B. littoralis and Acacia cyanophylla are dominant trees near the estuarine fringes.

2.2.2 Low Open Woodland. This is usually a more sparse expression of the woodland previously described, excepting Casuarina obesa -- low open stands near Austin Bay, Eastern Peel estuary and near the inlet delta, northern Peel estuary.

2.2.3 Low Closed Forest. Melaleuca cuticularis and M. raphiophylla form a fringe community on the Harvey River levee and around the Harvey Estuary where beach ridge development has not occurred. The community also borders swamps and lakes along the boundaries of the Spearwood-Bassendean dune systems. Typha sp., Scirpus maritimus and Gahnia trifida form understorey on the river delta, with Juncus maritimus, G. trifida and Atriplex paludosa being more common around the estuary.

2.2.4 Low Open Woodland and Closed Heath. This is typical of the lighter vegetation on the lower and wetter parts of the Bassendean system. The area is a mosaic of slightly elevated and mostly drained topsands, and lower winter submerged peaty sand. Acacia cyanophylla, Eucalyptus rudis, B. littoralis and Nuytsia floribunda form a dispersed upper strata on the drier areas, Melaleuca preissiana and Xanthorrhoea preissii on the intermediate, and Melaleuca raphiophylla, M. hamulosa in the winter-wet areas. The closed heath component is a diverse flora in the drier areas with Hypocalymma angustifolium, Melaleuca thymoides, Leucopogon polymorphous, Astartea fascicularis, Baekea grandiflora and Stirlingia latifolia common. In the wetter areas diversity is reduced with Leptosperma lepticum becoming more dominant. Near the estuary Actinostrobos pyramidalis, Melaleuca hamulosa and Regelia ciliata form a shrub zone.

2.2.5 Closed Scrub. Melaleuca hamulosa and M. raphiophylla form thickets on lowlying wetlands on the Harvey River levee and the Pinjarra plain soils south of Peel estuary.

On the leached beach ridges and elevated sands near the estuary Kunzea ericifolia and Melaleuca teretifolia co-dominate; near the south-eastern Harvey Estuary the stands are mixed with Calothamnus quadrifus and Kunzea micrantha on the elevations, and Melaleuca incana and Actinostrobos pyramidalis on the wetter sands. In more northern areas of the

estuary these are replaced by Jacksonia sternbergiana and J. furcellata. Regelia ciliata becomes co-dominant with M. teretifolia in some northern areas, but is generally restricted to Spearwood transitional sands.

2.2.6 Open Heath. Most of the level saline soil is dominated by Arthrocnemum halocnemoides forming a single strata. This community is discussed as peripheral vegetation in later sections.

2.2.7 Sedgeland. Juncus maritimus is ubiquitous in the estuarine and delta zones, mainly as a pure stand when premanently submerged but becomes mixed with many herbaceous species on elevated sites. Lepidosperma striatum, Machaerina junceum and Gahnia trifida form communities on low winter-wet areas near the estuary.

2.3 Geomorphology

The Peel-Harvey estuarine system is comprised of two large shallow basins connected by a narrow channel which cuts through a barely submerged, but broad marginal shelf. The system is joined to the sea by a 5km long inlet channel which passes through the Spearwood dune system and a tidal delta. The basins have average depths of 102m, and surface areas of 65km² (Peel) and 50 km² (Harvey). The estuarine environments were probably initiated about 6,000 years ago and existing shorelines were stabilised 4,000-5,000 years ago (Logan and Brown, 1975). The system has several geomorphological units which effect the peripheral vegetation.

2.3.1 Marginal platforms. These are shallow terraces, up to 2.5km wide, which fringe the margins of the estuaries and merge with the tidal and river deltas. The shallowness of the water at the margins reduces the wave energy levels which are generated in the deeper basins.

2.3.2 The inlet. This is a relatively narrow channel which has the effect of restricting marine influence on the system. Oceanic tidal flux is damped by approximately 90% limiting tidal exchange with the basins

to about 5% (Andrew, 1975).

2.3.3 Tidal and river deltas. The tidal delta has most of its surfaced shoals covered by marsh flora, although those areas accessible from land are affected by grazing. The Harvey river delta is a large and distinctive sedimentary unit of the classical birdsfoot type. It affords considerable areas of shallow tidal flats, saltmarsh concavities and winter wetlands. The Serpentine and Murray deltas were not included in the study.

2.3.4 Marsh flats. These constitute the greater proportion of wetland flora and have received considerable attention in the study. They occur in sheltered margins of both estuaries, but largely extend behind beach ridges to the north and east of Peel estuary and on the Harvey delta. They are generally waterlogged in winter, often via connecting channels to the estuary.

2.3.5 Beach ridges. These are a prominent feature along most of the shoreline, but are somewhat reduced in leeward areas of western Harvey Estuary where they seldom exceed 1m elevation above high tide mark. The abruptness of the emerging slope and proximity to the water's edge are important factors determining vegetative cover. They predominantly consist of leached siliceous sands of the Uc 1.0 type (Northcote, 1974).

2.4 Hydrology

The nature of the freshwater input into the system has been considerably altered in recent years with the construction of nine dams affecting the four major contributing rivers. Most of the input now stems from the Murray River catchment east of the Darling Scarp, and drainage from the coastal plain. The sediment input of these sources is said to be low (Logan et al., 1975). Most of the recent silt accretion and stabilization is limited to the discharge zone of P.W.D. drains originating

from agricultural areas of the coastal plain.

The input is markedly seasonal, and this factor, coupled with the poor tidal exchange at the inlet, results in high variability in salinity from summer to winter, particularly for Harvey estuary. This estuary ranges from generally fresh in winter to fully marine in summer. Peel estuary has brief periods of being near 10% Cl^- but is generally closer to 20% in winter, and fully marine to hypersaline in summer (Atkins et al., 1977).

Also seasonal is the variation in tidal levels from summer to winter. Higher summer atmospheric pressures consistently lower tidal levels, which results in large areas of marginal platform and marsh units drying to a hard pan. The Bassendean and Pinjarra plain shorelines are predominantly affected in this way.

CHAPTER THREE

3. Methods

3.1 Choice of sites. The location of sampling sites was determined after inspection of recent aerial photographs and several excursions into the field. The major factor influencing site selection was the need for relatively undisturbed vegetative stands. It was decided to include examples of the major geomorphological units in the sampling area while also considering the distribution of the three major soil systems described in 2.1. The natural spread of this distribution coincidentally catered for a third important factor, the incidence of prevailing winds (Appendix II). Restricted accessibility of south-eastern Peel estuary and also south-eastern Harvey Estuary prevented sites being established in these areas, however reconnaissance of the vegetation suggested inclusion would have added little extra information.

At each site two or three transects (depending on the range and variability of the undisturbed vegetation) were extended orthogonally from the water's edge through the marsh and transitional vegetation, and then pegged to mark the direction but not necessarily the length of the transect. These were arbitrarily set at 100 m. apart.

3.2 Data collection

3.2.1 Salinity. It was decided that an initial summer analysis of salinity levels in the soil would provide useful environmental information as this would give an indication of the maximal levels that are tolerated by various vegetational types. Surface soil samples were taken at known intervals along each transect to coincide with observable variations in vegetation and topography. Subsamples were analysed for Cl^- in the laboratory, using methods adopted from Piper (1942) with a model P66 Buchler digital chlorodometer. After analysis and classification of the vegetation (described in Chapter Four) 120 of these samples were found to represent the derived vegetation groups and used in the ordination overlay (Chapter 6).

3.2.2 Primary Soil Profile

This was determined after the vegetation groups had been defined. Using the key to the flora (Appendix III) four replicates were taken from each group, each replicate being derived from a different site. The primary profile form (PPF) was described using Northcote (1974) and Munsel colour charts. A description of important soil parameters used by Northcote is outlined in Appendix IV.

3.2.3 Total Ions and PH

Subsampling of the A horizon for analysis was done in conjunction with description of the primary solum. A 1:5 soil-water extract was later analyzed in a field laboratory, using a Sproule electronic conductivity meter (Model EBB/10). PH was also recorded using a Pye unicam 293 model.

4. Classification of Vegetation

4.1 Introduction

Plant communities are complex phenomena which can be classified using a variety of methods. Different choices of methods for defining community types could imply different classifications of the same vegetation. Because of its proven suitability for classifying vegetation of a similar ecotype (Bridgewater, 1974) the Braun-Blanquet approach was adopted for this study.

The fidelity concept is of prime importance in this approach. It is based on the strong preference of certain species for particular communities. Every species has a potentially wider ecological amplitude than is actually found in natural situations. The amplitude is narrowed by competition with other species, and survival is usually restricted to near optimal habitats (Ellenberg, 1952). Plant species require specific habitats for their persistence, and as a consequence show selective preference for association with certain other species. These selective species are of diagnostic value for the characterization of a community, and are called "character species", "identifying species", or "differential species" depending on the hierarchical level of the classification. Differentiating species are generally used to distinguish sub-associations, and variants of associations, when the survey is at the scale of this study.

The concepts of fidelity and of constancy (presence) can be compared. If a species occurs in a large percentage of sample plots, it will show a high presence value for the vegetation community as represented by the sample plots. If a species is restricted to a certain unit within this community, it demonstrates a high fidelity to this unit, differentiating it from the remainder. These are basic concepts in Braun-Blanquet methodology (Whittaker, 1973).

4.2 Data Analysis

Sampling procedures should be designed to lead to the efficient collection of accurate information about the vegetation. Random sampling is promoted as being appropriate from a statistical viewpoint, but it has inherent impracticalities in vegetation analysis. It often leads to collection of unnecessary information, or to omission of obvious vegetation types. It can also include misleading information from "disturbed" areas. Considering the desire to relate the vegetation environmental factors, it was decided that 1m^2 plots at regular intervals along the pegged transects would be appropriate. The intervals, either 5 or 10 meters, would depend on the gradient nature and homogeneity of the vegetation.

Each quadrat was analysed for species presence and cover % according to the scale:

<u>Cover %</u>	<u>Value</u>
1 - 19	1
20 - 39	2
40 - 59	3
60 - 79	4
80 - 100	5

Plants were identified in the field where possible, or labelled and processed in the laboratory using keys from Blackall and Grieve*(1974, 1975).

When sampling along the transect was found to be adding little extra information, sampling was terminated. Similarly, if the adjacent transect was found to be contributing little extra information to previous data, the site was considered to be adequately sampled (see minimal area curves (Mueller-Dombois and Ellenberg, 1974).

* All plant names derived from the editions are listed in Appendix VII. Plants determined from other sources are indicated.

Recognition of distinct vegetation units or stands implies the occurrence of discontinuities or boundaries in the field. To understand the nature of these vegetation units, definition of their precise location is useful information. To this end, the floristic analysis was complemented with belt transect analysis or "line taxation" (section 5.2). This was achieved by contiguous sampling of $1m^2$ plots along the transect from the water's edge, noting species presence for as far as was feasible.

These data were then transcribed onto computer data cards, as programs were available to aid in the synthesis. The information contained many species unique to a given site. These were eliminated, and the remaining (121) species given a code number. Each plot (= releve) was represented by two data cards, identified by a site and transect number, and the columns on the card represented species. Thus the quantitative value for each species/plot could be entered into its column.

4.3 Data Synthesis

The method used was based on that outlined by Bridgewater (1971). A computer program TABLE-SORT was used to print out a data matrix of species and releves for each transect. This "raw table" was then re-arranged to group species having similar releve preferences together. This was achieved in the printout by simply altering the species-code sequence on a header card in the programme deck. Data from site I is illustrated in Table I. Potentially differentiating species (PDS), those having similar releve preferences, are shown.

Choice of PDS from these tables is visual, but in this study was facilitated by a separate programme which incorporated numerical methods. This programme, ZUMONT-SORT, was based on a strategy outlined by Ceska and Roema (1971) and is summarized in Appendix II.

Releve groups were then formed from the table, differentiated by

	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
ARTI																				
SAL																				
FRAI																				
TRII																				
SUAI												11								
JUNI														33						
ATR: 42			50	56	50	52		14												
MELI																				
ATR: 7			22					14												
GASI																				
SPOI								14		33						25				
PAR: 7			12	22				14		33										
COTI			11																	
ANGI																	33			
CASI																				
ARTI 21												66		100			36		16	
GANI												33								
LEPI 7				14					42											
MELA 7					50				86	66							25			
MACH				100	25	50			28								25			
LEPI 28					28				32											
JACK 42	100		66	14	25				56	66						25	50			100
THYS 21					25					33										
MACR	66	22																		
KUNZ 43	100	45	42				50			66		66	66						16	33
WATS 63		66				50		28				44							16	66
ACAC 7		90			100			17	66					33		100				
DIST 21									33											
CONY					14												100	16		
SAMO			22																	
BRIZ 7																				
HYPO 7			33	14			<u>75</u> <u>100</u>				100		<u>100</u>							<u>80</u>
EHRH 14							<u>75</u> <u>50</u>	56			33	<u>100</u>	<u>77</u>	100	33					<u>80</u>
SILE 14			33	28			<u>50</u>	56			66	<u>100</u>		33	66					
HORD							<u>100</u>				66	66								
ROMU			22				<u>100</u>					33								
CONO:			11				25	50					11	33						16
HAKE: 49			11				14		14											33
							50		56								60			33
																25				

the % frequency of the PDS. A complete "raw table" was then drawn up for all sites, containing only the extracted releve groups, with all species in the selected releves receiving a % presence value. Thus species that do not occur in releve groups defined by PDS are removed from the synthesis.

From this "raw table", a "partial table" was derived, grouping PDS with high presence values together in such a manner as to concentrate most of the information at the head of the table (Table II). In this way, releve groups similar in floristics from around both estuaries were consolidated and differentiated species (DS) were selected. Returning to the raw table, releve groups with high % presence values of their respective DS were then identified and combined. All species which occurred in this combination were again expressed as a % frequency value, and are represented in Table III.

4.4 Classification

The groups shown in Table III can be usefully ordered according to a classification devised by De Smidt (1966). This allowed the hierarchical importance of the units to be realised, without prejudicing the subsequent inclusion of the data into a geographically wider survey. The base level of the classification is the community, with the extremes of its range differentiating into sub-communities and variants. Communities with similar identifying species can be grouped to form a complex. A fragment of a complex is a unit of vegetation analysis of which has not positively revealed the nature of its relationship with neighboring communities.

The classification of groups is shown in Appendix IV

CHAPTER FIVE

5. Transect Analysis

5.1 Introduction. The peripheral vegetation of an estuary is influenced by quite marked variations in substrate conditions in both space and time. Horizontal distance from the littoral zone and vertical distance from a fluctuating water table are two important factors superimposed on other influences. Environmental factors in the substrate subsequently occur as mosaics or attenuate as gradients depending on local conditions. The variations in substrate are generally reflected by alterations in the floristic composition of the vegetation.

Having classified the vegetation into floristic groups it is implied that the groups are recognisably homogenous within and heterogenous outside an arbitrary boundary. The detection of boundaries is dependent on the scale of observation, just as the detection of plant groups is dependent on the scale of sampling. The method outlined by Van der Maarel (1966) is useful for detecting small-scale vegetation boundaries of the type expected in gradient or ecotonal situations.

The calculation is based on information theory, where the difference between two quadrats is measured as the heterogeneity in the set of two quadrats. Each species occurring in only one of the two compared quadrats contributes only one bit of selective information, or usually $\frac{1}{2}$ bit/quadrat. The heterogeneity contribution of a species to a set of quadrats may be found by dividing the difference of performance of the species in each quadrat by the maximum species performance possible. These values are summed for all species and the heterogeneity value (H) derived according to the equation:

$$H = \frac{1}{2} \sum_{i=1}^l \frac{P(ia) - P(ib)}{P \text{ max}} \dots 1$$

where $P(ia)$ = the performance of the i^{th} species in quadrat
 $P(ib)$ = the performance of the i^{th} species in b
 $P \text{ max}$ = maximum performance possible in both

With the vegetation studied, adjacent 2M² quadrats were found to be a suitable scale of observation.

5.2 Results and discussion. Generally, zones with high H values identifying relatively sharp boundaries were found in the steeper parts of environmental gradients. This was described by Van der Maarel as a "Limes convergens" environment, where rather different systems occur on either side of the boundary. The vegetation belonging to this often shows homogenous stands, poor in species and growth forms, and a coarse-grained pattern of zonation. The term ecotone, taken to describe a stress zone or a tension belt, was considered by Van der Maarel as being synonymous with "Limes convergens", and this situation is reflected in the data from the transects (Figs 1-5).

Alternately, a gradual change in one or more environmental factors lends itself to a "Limes divergens" situation where the vegetation is rich in species with low dominance by any one species. This is taken to be synonymous with an ecocline.

The transect examples typify variations in topography found around the estuary, and show the relationships of some vegetational groups to topography and to each other. This information contributes to a better understanding of the ordination of floristics and environmental data which follow in section 6. It should be noted that contiguous quadrat data was not used in the classification of groups. The numbers above the profiles relate to the coded species list appendix VIII. The H graph is superimposed to indicate floristic boundaries.

Figure I. This transect is an example of Marsh formation on the tidal delta unit, N.W. Peel Estuary. The baseline of the transect is mean high tide mark (MHT) as it is for all transects. A small beach ridge has formed, creating a protected depression suitable for *Salicornia* sward development. On the landward edge of the marsh group 7 identifying species emerge, but the relatively steep inclination restricts this community to a narrow zone, and a boundary is indicated at the edge of the marsh unit. Typical beach ridge vegetation develops, beginning with a mosaic of groups 19 and 20 until a stand of group 19 emerges.

Aspect 360^o

Location: Site I

Figure II. This transect typifies the beach ridge development which is a common feature of the estuarine periphery. In this instance, an extensive salt marsh concavity has been enclosed between two ridge systems (the landward edge not shown). The marsh is continually wet just below the surface, although it is inundated seasonally by runoff and a rising water table. A sharp inclination from the water's edge limits development of group 8, which is replaced by an assemblage of species notable for its high proportion of exotics. The boundary indicates the edge of a typical group 18 community which occupies the top of the ridge. The marsh vegetation is comprised of a mosaic of 12 and 14 on the higher ground, with 6 and 7 on the lower levels.

Aspect 280°

Location: Site II

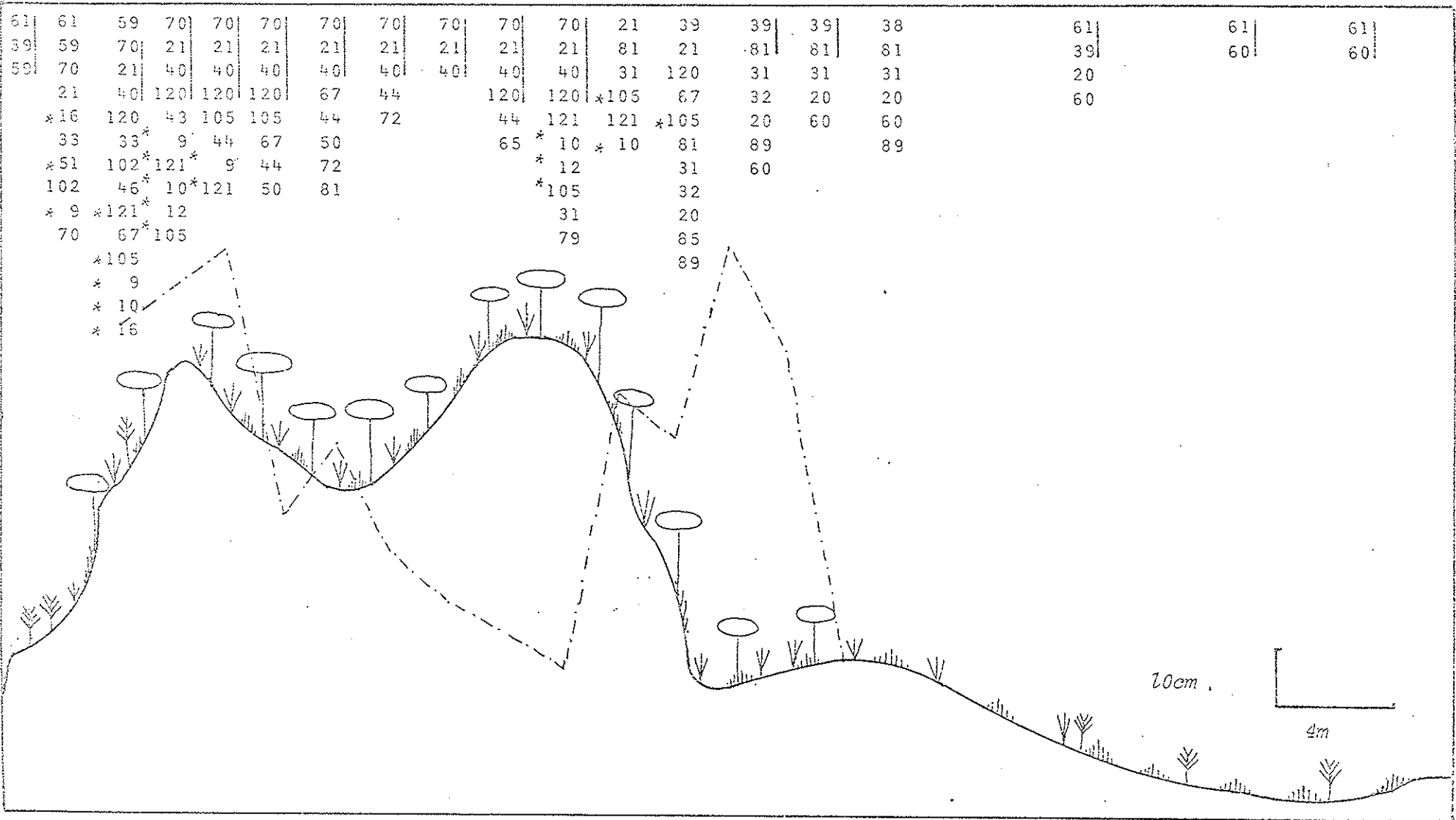


Figure III. This transect typifies sedgeland which develops in sheltered embayments along western Harvey estuary where topography can be stabilised before the construction of a beach ridge. The steep relief of adjacent Spearwood dunes provide a mobile groundwater which helps keep soil salinity to fairly low levels. Groups 7 and 8 are not differentiated from each other near the estuary, but group 7 is fairly clearly separated from intermediate zones. Atriplex paludosa (differential species for group 8) is generally restricted to near the shoreline, otherwise the groups occupy similar habitats in respect to the variables ordinated (section 6).

Aspect 290°

Site: III

39	39	39	39	39	39	61	39	39	39	39	39	39	39	39	39	21	21	32	31	39	39
59	59	61	61	61	61	32	61	61	61	61	61	61	32	32	32	94	31	39	39	81	81
61	61		60	60	32	60	32	32	60	60	60	60	60	89	81	61	39	81	81	20	20
			32	89	60	89	60	60	20	20	20	20	89	89	20	89	81	89	20	33	33
				20	89	20	89	89	81				81	81	81		89	67	15	75	75
				85	20	85	20	20											33	118	118
					85	81	81	81											75	* 12	116
							104	104											113	45	* 10
																			118	103	113
																			112		* 15
																			110		120
																					37

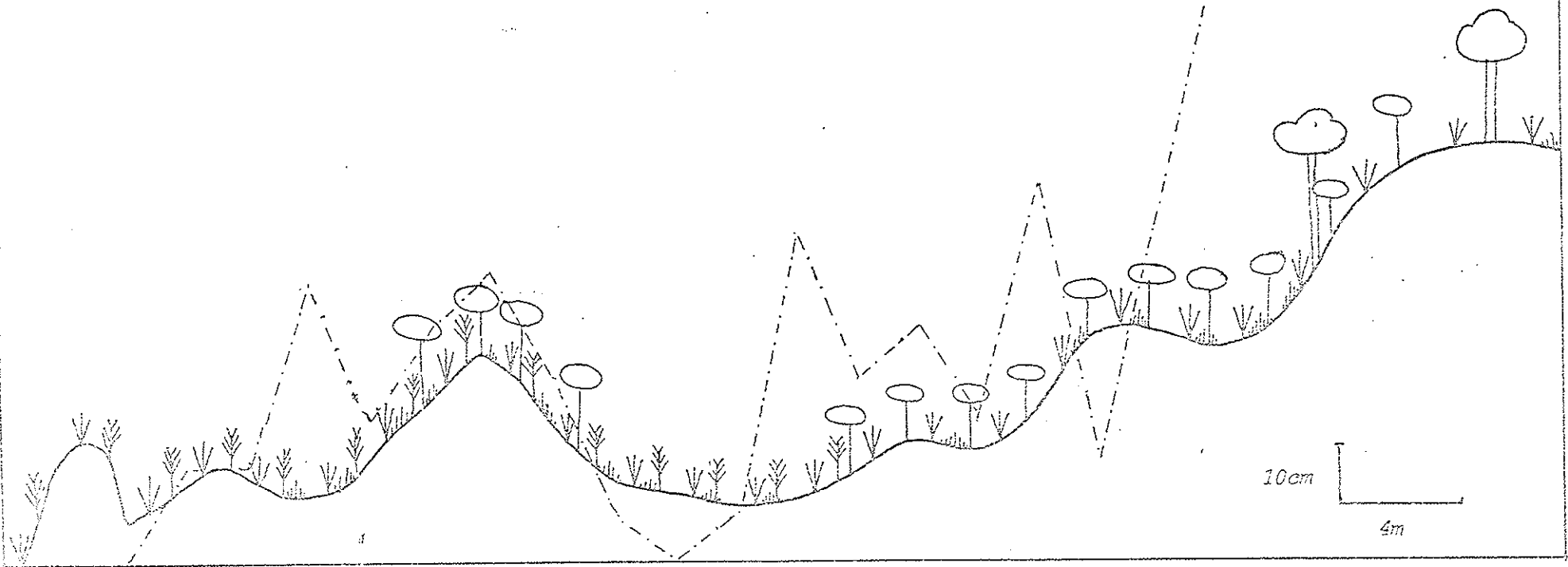
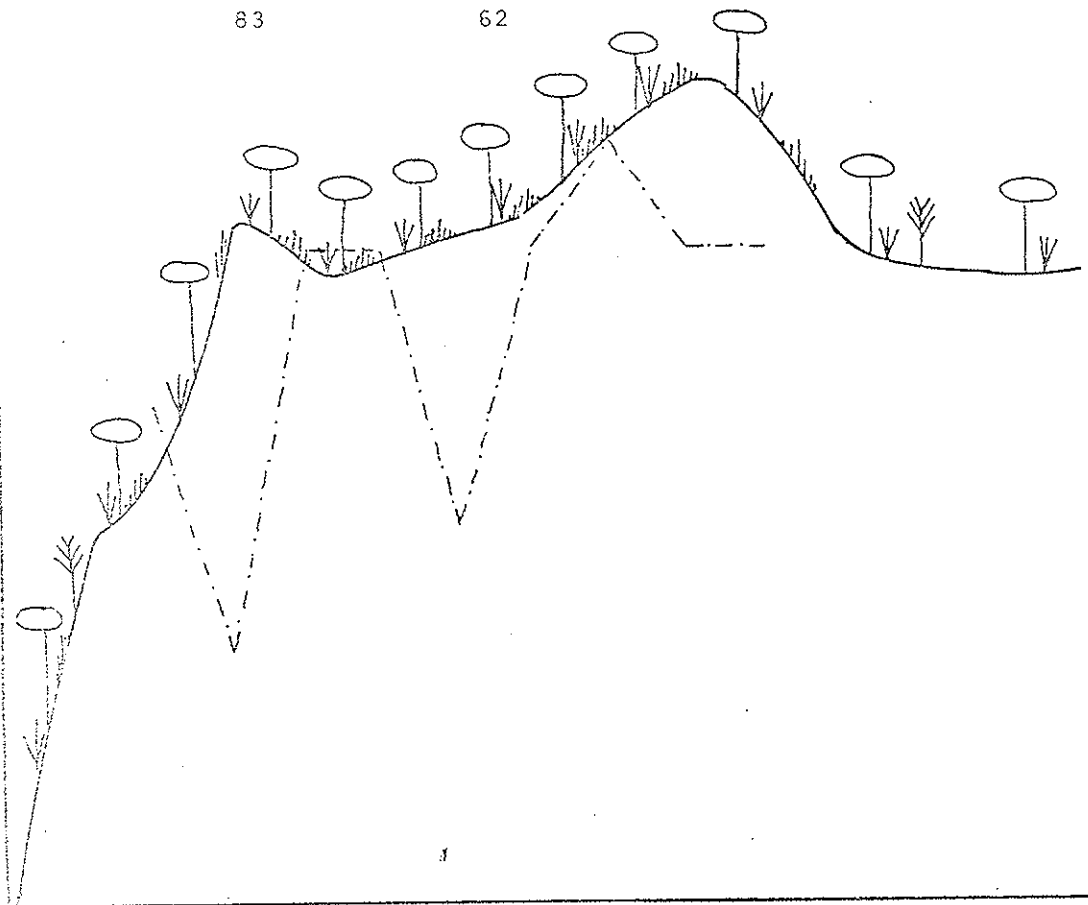


Figure IV. The comparative abruptness of the banks of the eastern Harvey estuary which originate from the Spearwood system is represented here. The high incidence of prevailing winds has restricted marsh development on this system. This contrasts with the Bassendean shores to the south, where silt deposition on the marginal shelf has allowed extensive marsh and ridge development of the types shown in figures 1 and 2. Group 12 typically bridges the estuarine fringe vegetation with the beach ridge unit. A boundary is drawn between the transitional vegetation and the group 19 stand.

Aspect 60° .

Site: X

39	39	39	39	39	39	21	21	21	21	93	21
20	20	20	93	93	93	120	120	120	120	77	77
59	46	46	83	21	43	77	77	77	77		70
62	62	*15	62	68	21	93	78	93	93		40
		*62		*62	69	43	93	78	*15		
		93			*120	23	43				
		83			62						



10 cm

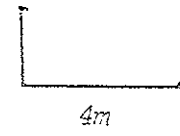
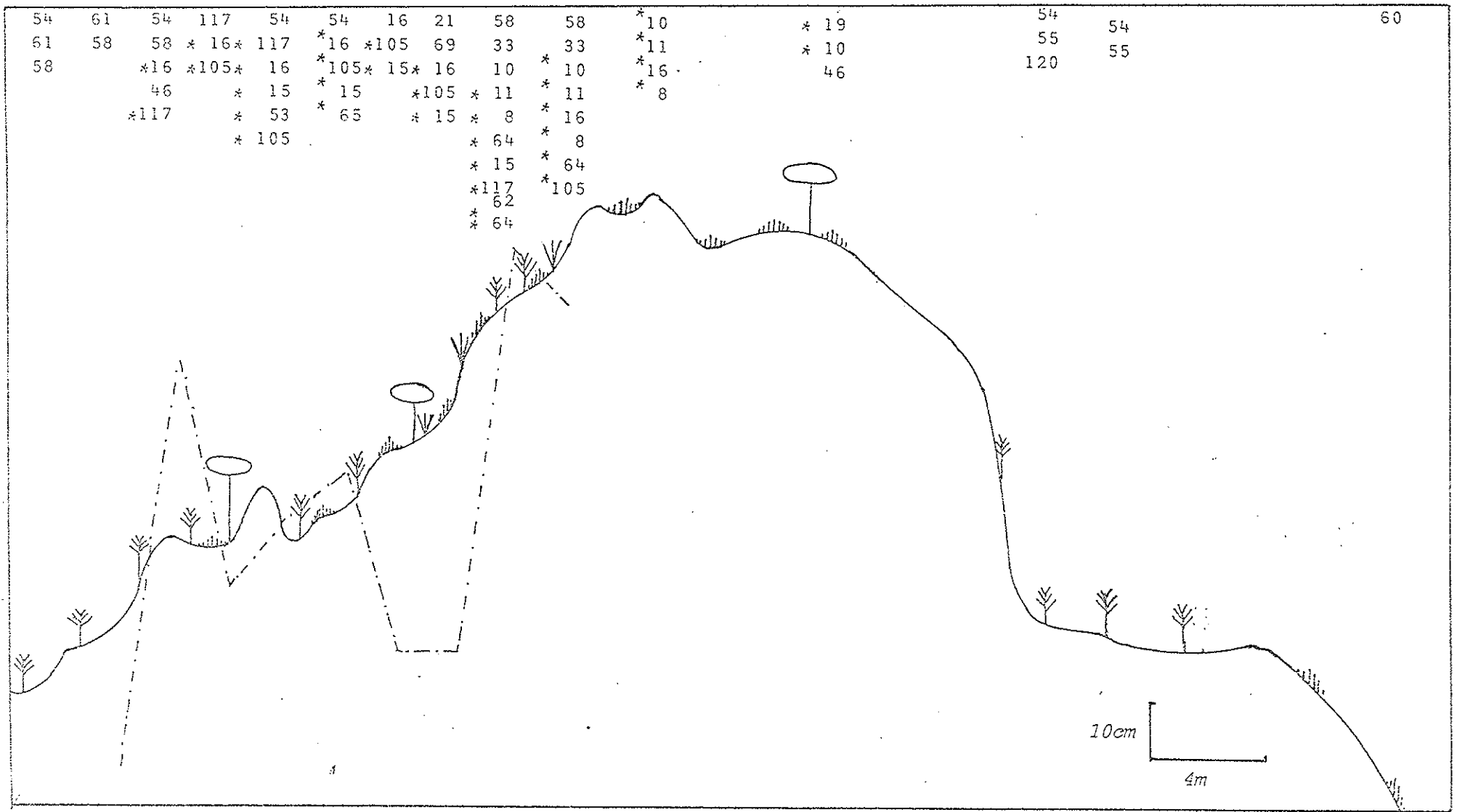


Figure V. A typical profile of the unstable ridge vegetation of the eastern Peel estuary is shown. The marsh unit is seasonally inundated with massive deposits of the algae *Cladophora*, which drifts from the basin with the prevailing winds and high winter tides. This has led to a recession of the marsh vegetation and a predominance of exotic annuals on the ridges. Extensive salt marshes have developed behind these ridges.

Aspect 110°

Site: 16



CHAPTER SIX

6. Ordination of Groups

6.1 Introduction. The question "ordination or classification" has been a feature of the evolution of techniques for analysis of vegetation. The issue has become less important in recent years with the realization that both models can be usefully applied to the same data and may compliment each other in various ways. Some recent examples have included a parallel ordination and classification of sites, with group membership plotted in the ordination (Kershaw, 1968); initial classification followed by ordination of sites within each group (Johnson, 1973); initial ordination from which a divisive polythetic classification is derived (Lambert, 1972); or ordination of groups (Van der Maarel, 1969, 1972). The latter approach has been adopted in this study.

Ordination is the arrangement or plotting of either species or stands on an axis, or in a multidimensional space defined by several axes. The axes may be intended to represent known environmental gradients (direct ordination) or be pure mathematical constructs derived from a matrix of similarities between the quadrats or species (indirect ordination). Direct ordination is a simple method useful for studying the relationship and distribution of species in an area which is apparently influenced by relatively uncomplicated gradient. Indirect ordination methods are more suited to data of the complexity found in this study.

Polar ordination (PO) (Bray and Curtis, 1957) and principal components analysis (PCA) were the two most common methods promoted in ecological literature prior to 1970. Later more mathematically sophisticated methods were introduced; factor analysis and canonical correlation analysis (Austin, 1972), and multiple discriminant analysis (Norris and Barkam, 1970). However no ordination technique has gained universal acceptance by ecologists, generally because weaknesses inherent in different techniques are exposed when applied to different vegetation types.

The major criticism of PO (Bray and Curtis, 1957) was that the direction of the principal axes were defined by pairs of the most different end-point sites. This introduces the risk that sampling has included "outlier" stands quite remote from other stands in terms of ecological distance. These stands may originate from unusual environmental or historical conditions not typical of the sere. The result is unrealistic distances between all other stands ordinated along the axes.

Users of PCA techniques expect to interpret resultant axes (although they are mathematical constructs) directly as a compositional gradient (coenocline) corresponding to environmental gradients. This interpretation involves assumptions problematical with real data. Firstly a linear relationship between the axes and the original species variable is assumed, although in nature species respond to a complex of variables and the success of species along gradients of these show a normal curve relationship. Problems of distortion due to non-linearity affect all multivariate techniques, and attempts to correct for these distortions involve the use of data transformation. The great range of statistical transformations possible have caused some ecologists to wonder how objective these objective methods really are (Beals, 1973). A second problem arises because the axes resulting from indirect ordinations are usually orthogonal by definition, whereas the effects of environmental factors on populations are often not independent, but are correlated (Noy-Meir and Whittaker, 1973).

Vegetation gradients which exhibit a high degree of beta diversity also inflict curvilinear distortion on both polar and non-polar indirect ordinations (Swan, 1970; Noy-Meir and Austin, 1970; Gauch and Whittaker, 1972). Non-polar distortions are often unimodal, but are sometimes bimodal with two or more reversals of slope. Often the extracted axes are devoid of ecological meaning and the ordination can't serve as a heuristic technique for revealing directions of community variation. With high

Beta diversity "principal components can produce from a coenocline a multi-dimensional doodle" (Whittaker and Gauch, 1972). However with "reference set" techniques, e.g., Principal axis ordination (PAO), the poles of the first axis are anchored by specific end-point samples, and coenocline distortion is arch-form. Thus the arrangement of the co-ordinates may not be ecologically meaningless, only the interstand distances can be misleading.

6.2 Method. (PAO) (Van der Maarel, 1969) is less susceptible to the problems just outlined, and is also computationally more efficient than PCA. The extreme-pair criterion of PO is replaced by a choice of reference stands based on a "negative correlation tendency" (NCT) of the matrix set. This allows a choice of stands which will represent the extremes of a gradient rather than the extremes of the total vegetation sample. The NCT values were calculated from a square matrix of similarity values. Each group in the matrix has a column which consists of similarity values between it and every other group. These similarity values were derived by comparisons between unstandardised frequency % scores from Table III.

The similarity coefficient is derived from Sorensen's coefficient, but is modified to take into account both similarity and dissimilarity components; and is called correlation measure $C_{(M)}$

$$C_{(M)} = \frac{4P_{JK} - 1 \dots 2}{P_J + P_K}$$

Where P_J , P_K are the sums of species representation values in stands J and K.

The NCT values are obtained by summing the differences between $C_{(M)}$ values for all columns, ignoring sign. The pair with the highest NCT value become reference stands for the χ axis (groups 3 ($-\chi$) and 7 ($+\chi$)).

To obtain an effective spread of the groups, reference stands for

the axis are chosen from near the centre of the χ axis having the highest NCT values. Busby and Cullen (unpublished) recommend choosing stands within 12.5 units (out of 200) of either side of the origin. Groups 15 and 16 met this criteria.

6.3 Results. The position of these groups on Table 3 suggests that 3 and 7 are extreme stands on some type of environmental gradient, and would be likely to introduce less distortion than ordination of groups 3 and 19. In fact some distortion of transitional vegetation has occurred, but an ecological interpretation of the ordination can be achieved.

The floristic ordination has been coloured to show the relationship of the complexes described in Appendix VI. This has been overlaid by the following environmental information relating to the groups:

(a) Summer salinity (cl^-): These values can be converted to % chlorinity by weight, and related to a conspectus of phanerogamic salt communities produced by Beeftink (1962). He considers that their zonation coincides well with the classification of saline waters known as the Venice system, where:

<u>Zone</u>	<u>% Chlorinity</u> (Mean values at limits)
E = Euhaline	1.65 - 2.2
P = Polyhaline	1.0 - 1.65
M = Mesohaline	0.3 - 1.0

(b) Total ions.

(c) Elevation -- above high tide mark.

(d) Moisture -- of the A horizon at the time of Cl^- analysis.

This was the middle to the end of March, which normally represents end of summer.

D = dry

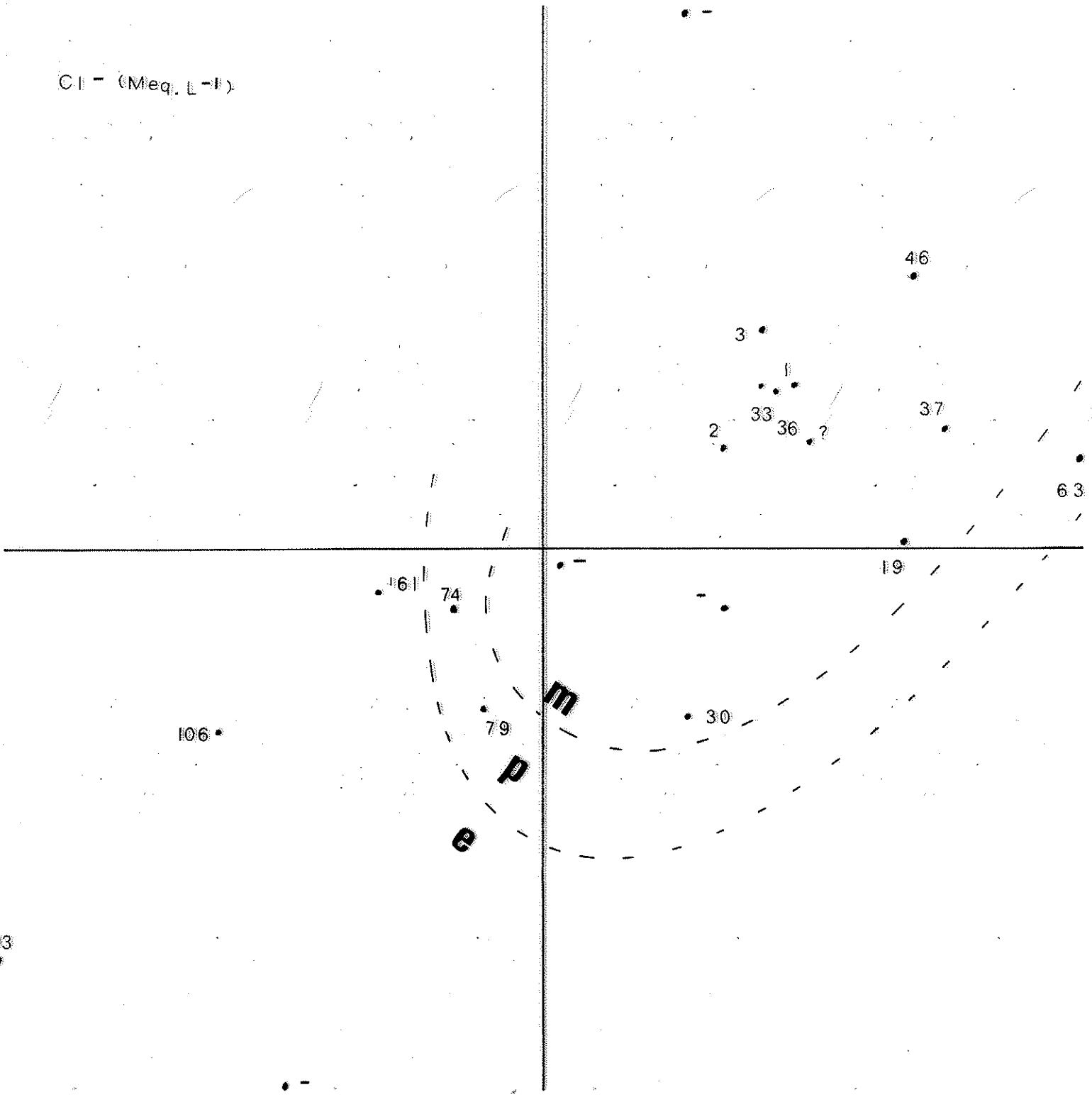
M = moist -- particles will hold together when squeezed

W = wet --- obviously saturated

V = variable

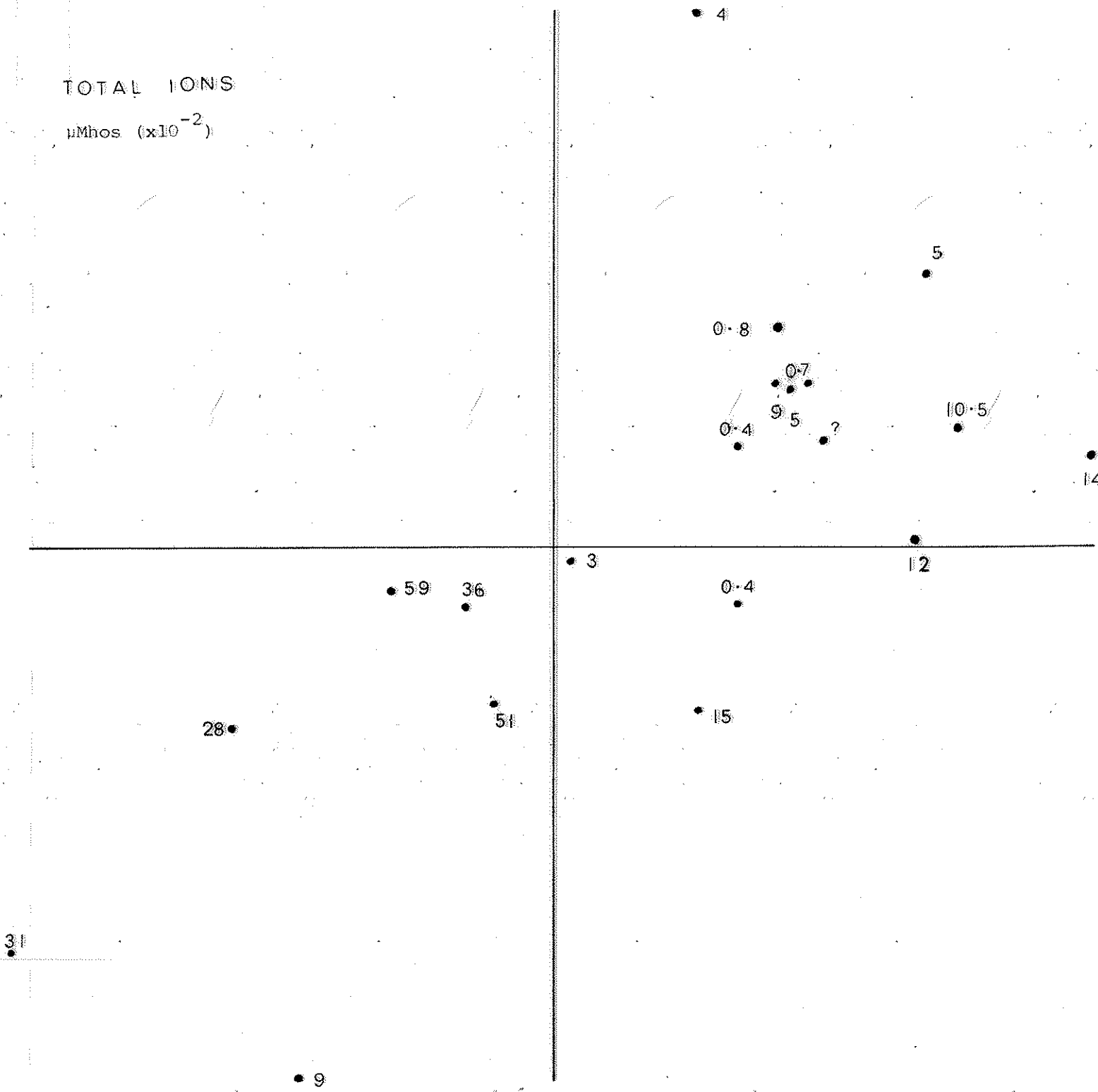
Figure 6. Ordination

Cl - (Meq. L⁻¹)



TOTAL IONS

$\mu\text{Mhos} (\times 10^{-2})$



SOIL PPF

• D

V

U

U

V

V

•?

U

V

• U

V

• D

D

U

D

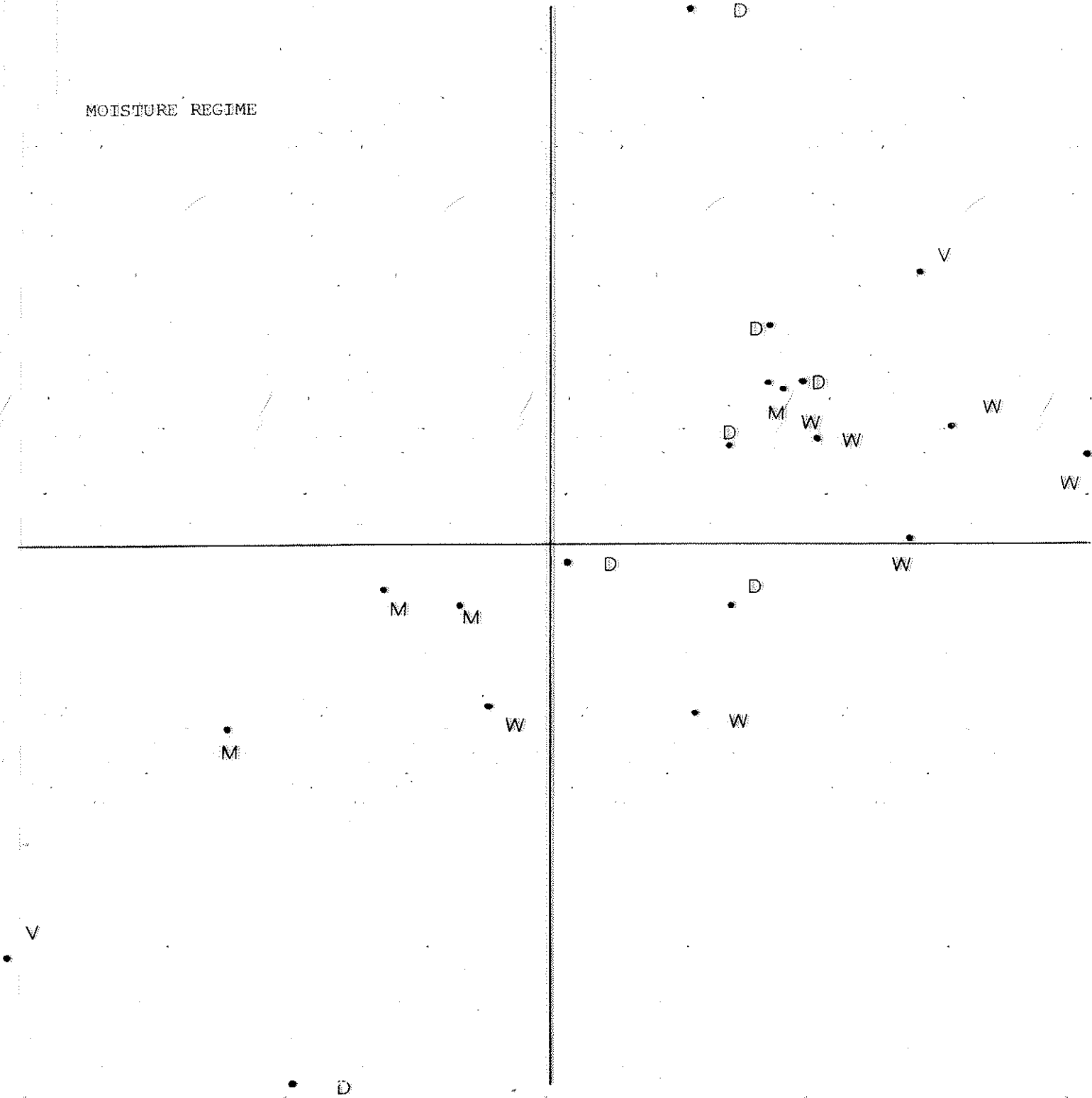
D

D

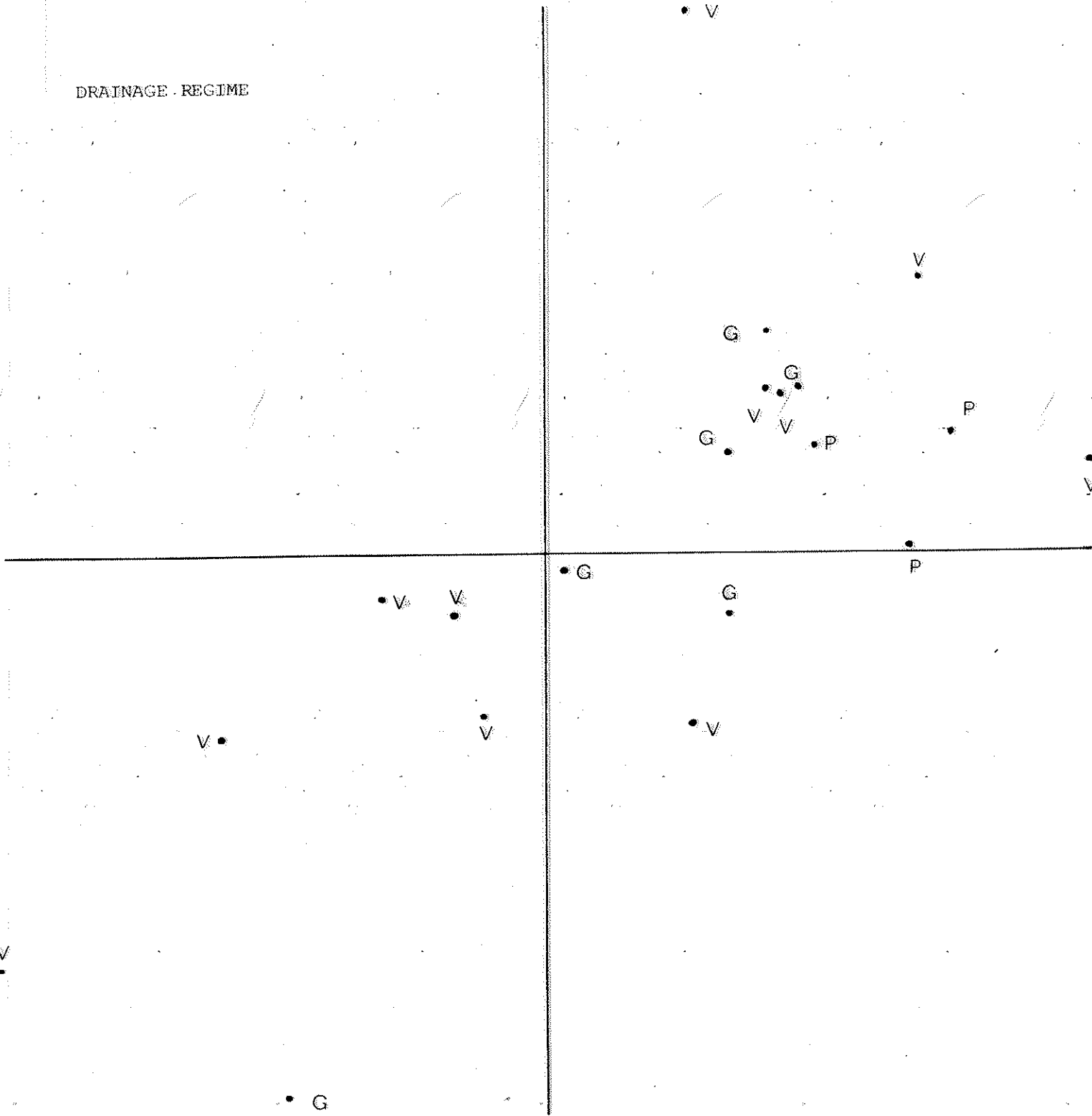
D

• U

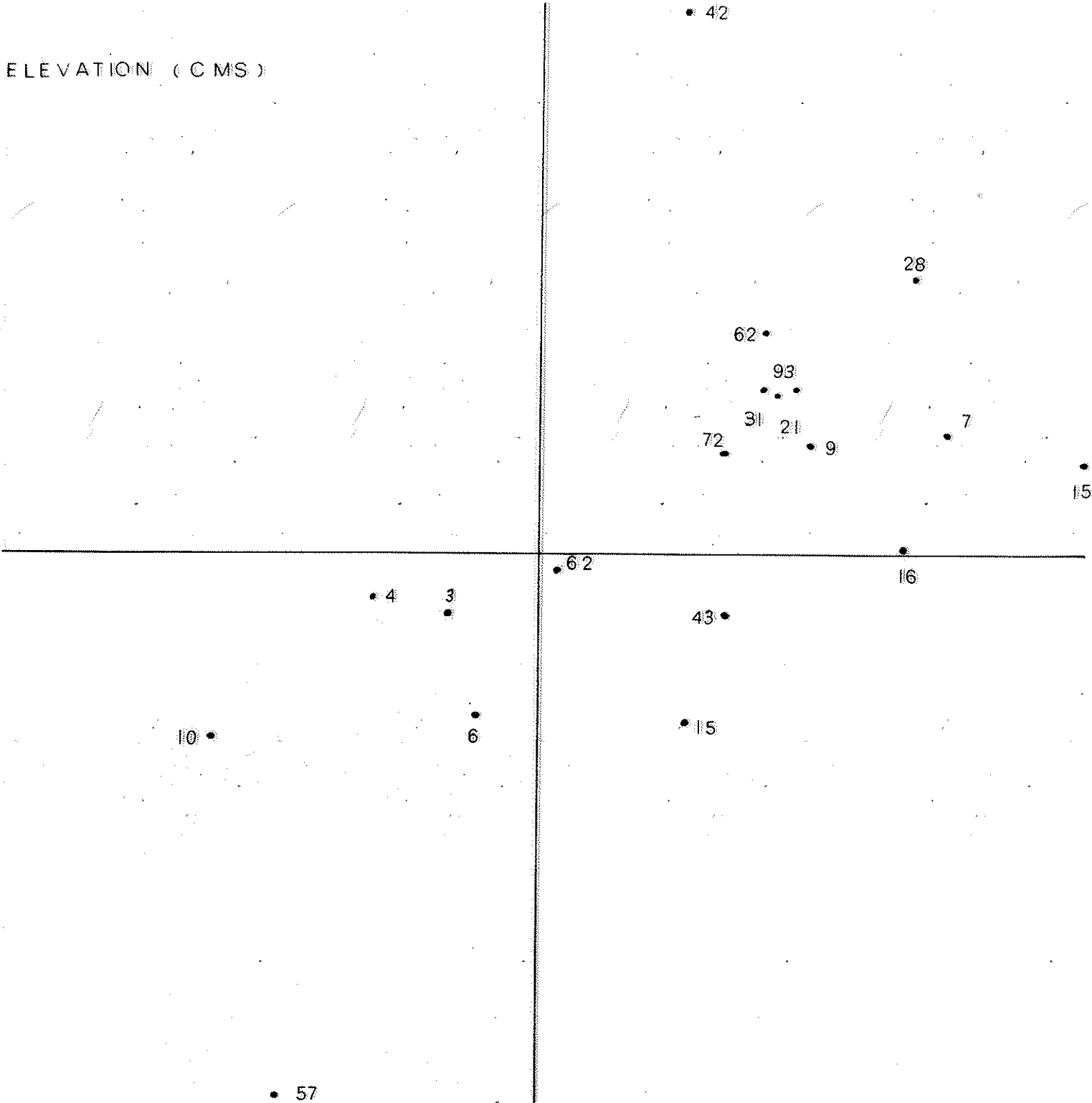
MOISTURE REGIME

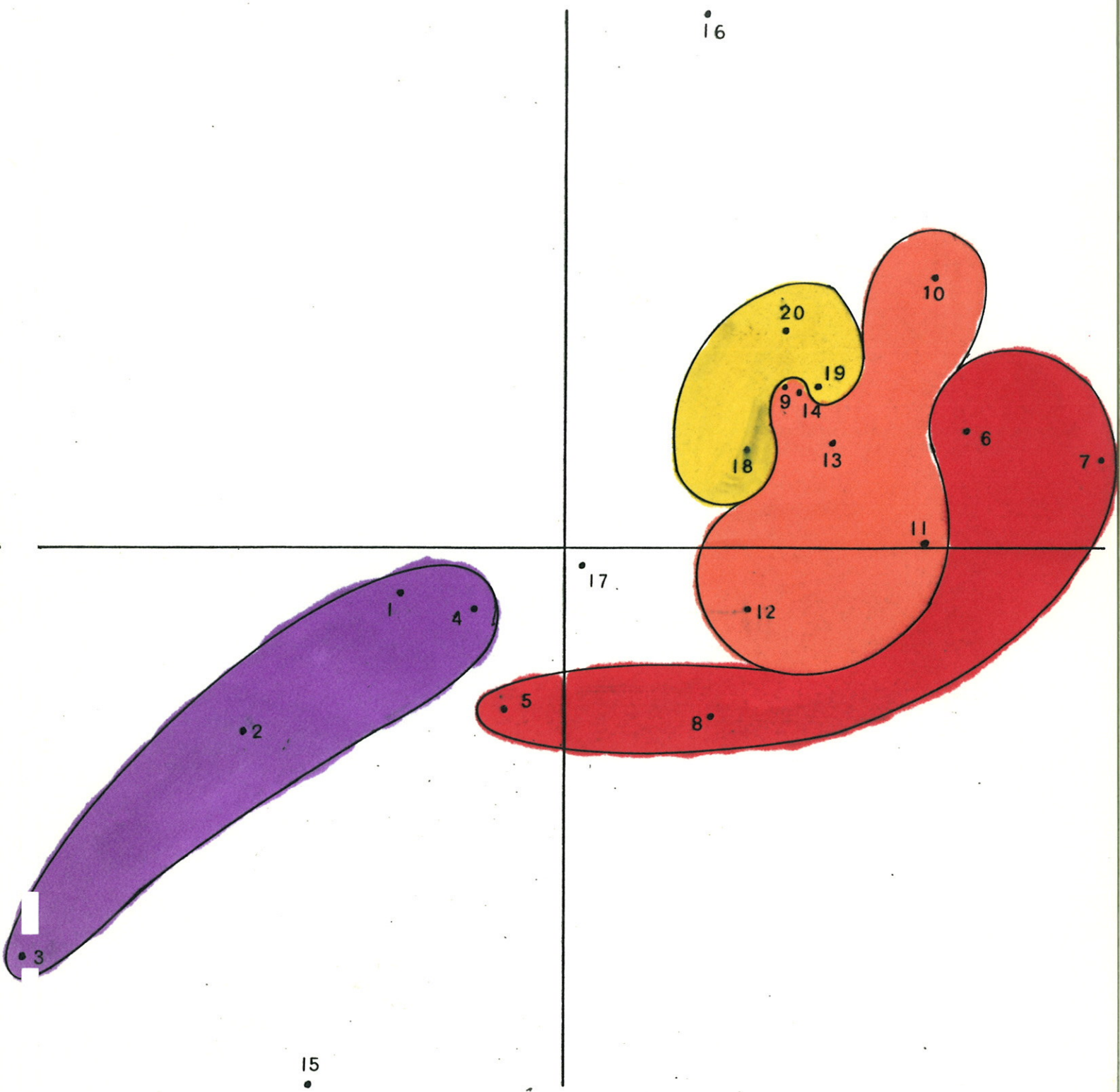


DRAINAGE REGIME



ELEVATION (CMS)





(e) Drainage regime -- this is a function of topography and soil profile, e.g., sandy but shallow A horizon overlying impervious clay on a low flat may dry out in summer, but remain waterlogged all winter, thus drainage regime is poor. This was assessed during soil profile analysis in September, normally end of winter.

G = good

M = medium

P = poor

V = variable

(f) Primary Profile form (PPF) -- (Appendix IV)

D = duplex

U = uniform

G = gradational

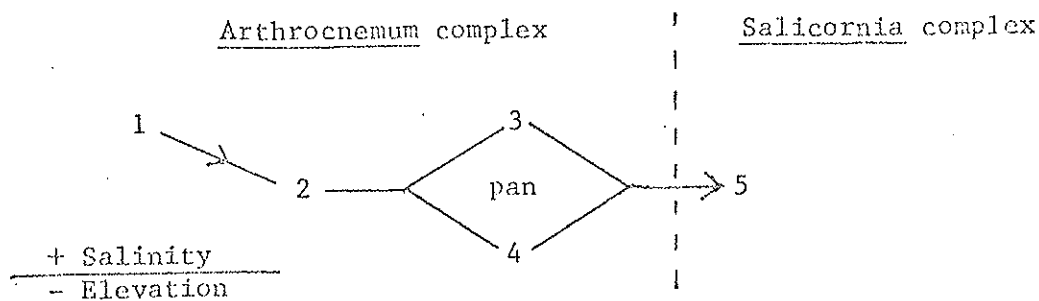
V = variable

6.4 Discussion. A feature of the ordination is the folding of the L. carphoides complex over the J. maritimus complex. This is likely to reflect the high Beta diversity between the marsh and ridge vegetation which is indicated in the heterogeneity graphs (Section 5). The ordination is interpreted more easily by taking each complex separately.

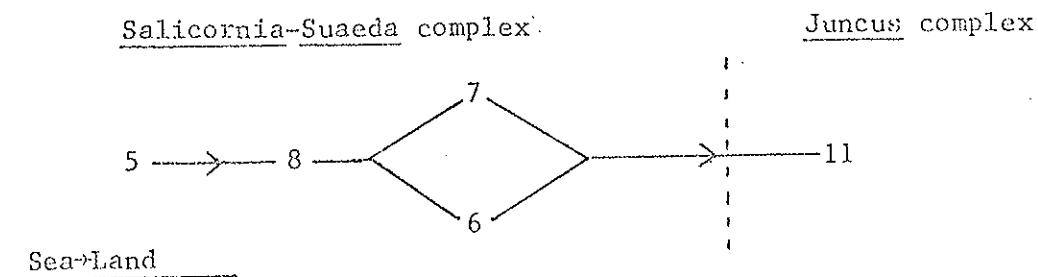
(a) The Arthrocnemum complex (-x, -y) forms a gradient commonly observed in the field. Approaching the origin, overlays indicate a positive salinity and negative elevation trend which indicate a succession from the edges of a salt marsh concavity to the centre, where either Halocnemoides single species (group 3) or bare ground occurs. In less mature (and less saline) concavities, Halocnemoides-Salicornia communities replace group 3. Where the concavity is connected to the estuary, the succession moves abruptly into a Salicornia community, usually group 5.

The complex shows a preference for well developed, duplex soils, and seems to fall into the euhaline zone proposed by Beetsink (1962).

The succession can be summarised as:



(b) The relationships of the Salicornia-Suaeda complex are not so readily discerned in the field and allow for heuristic interpretation of the ordination. The sequence of groups 5 → 8 → 7 is often observed along the transects (see also Figure 3), with group 5 often at the marine extremity. Group 8 is differentiated by group 7 by Atriplex paludosa. The data indicates a preference for soil profile development for this group, but it is not distinguished by other data. Alternatively it is restricted to near the shore zone for ecological reasons not investigated. The Salicornia-Suaeda group (6) has an observable preference for lower elevations, and this is reflected in the data. Apart from this the complex seems to be positioned along a sea-land gradient, not related to the environmental variables ordinated. The group is typically connected to the Juncus complex by the Juncus-Suaeda group (11).



(c) The gradients that have attenuated the interstand distances of the previous complexes did not scatter the Juncus complex. The groups occur as a cluster between the Salicornia-Suaeda and L. carphoides complexes. This is the position that they occupy in the overall sea-land

sequence of the peripheral vegetation, with the exception of group 13. This commonly occurs on the submerged marginal shelf, and because of the nature of the sampling, only the landward extreme (mainly lake swamp verges) were surveyed in the transects, so the data should be viewed in this context.

For the complex, the data reflects the intermediate zone it occupies. The substrate is typically mesohaline, on moderate elevations and has variable soils. A preference is shown for moisture with the exception of group 12, which as previously mentioned is the most elevated group and joins this complex with the extreme L. carphoides complex.

(d) L. carphoides complex. The overlays show that this complex ends salinity (-ve), elevation (+ve) and soil profile development (uniform → duplex, -ve) gradients for the four complexes. The clustering is to be expected considering the within-group uniformity of the overlaid data and the soil description tables (Appendix VIII).

UC 1.2 soils are quartose sands with uniform coarse-textured profiles showing little pedologic organization apart from some accumulation of organic matter at the surface. The soils are highly permeable and well drained, which accounts for the low conductivity and salinity readings. Phosphorus, nitrogen and zinc are common deficiencies (Northcote, 1975). Insight into the distribution of these groups around the estuary would require separate beach ridge analysis for both vegetation and substrate.

(e) Segregated units. Group 17 is differentiated by exotic herbaceous species, and is most commonly found on the disturbed slopes of beach ridges. As such it could be analogous to the "outlier" stands of Bray and Curtis (1957).

Group 15 is typically located on mounds or banks of salt marshes, and is not recognisably part of any sea-land gradient.

Group 16 is mainly confined to Western Harvey Estuary, generally well back from the shoreline. The surface soil is usually dry in summer,

although Melaleuca raphiophylla would be expected to have access to the water table at these elevations. As the soil is also low in salinity, neither vegetation or substrate seem to integrate with the marsh-beach ridge sequence around the estuaries.

7. Vegetation Ecology and Dynamics

7.1 Salt marsh ontogeny

The limited duration of this study necessitated a schema of temporal processes of marsh vegetation to be an extrapolation of spatial arrangements outlined in section 6.4. However, with the various types of salt marsh formation being fairly well documented (Yapp, 1917; Chapman, 1938, 1960) stages of development can be recognised in the field. In addition, comparison of recent aerial photographs (E.P.A. Proj. R51, WA 1609C) with a 1957 air survey (Lands and Surveys, WA 343), can place a time scale on some of these processes.

Extensive marsh development in this system was typically initiated by the emergence of a spit or sandbar some distance offshore on the shallow marginal shelf. Developing bars can be seen on the windward shores of Eastern Harvey estuary, and northern and eastern Peel estuary. Sedimentation of offshore bars typically continues until linked to the shore by one extremity (Chapman, 1938). Figure 7 shows the development of an offshore sandbar which had been exposed by an exceptionally low tide.



Figure 7.

Once sufficient protection from wave action is afforded, Salicornia sward development can commence. This may proceed until the marsh surface is raised sufficiently to suit Suaeda establishment.



Figure 8. A Salicornia-Suaeda community behind a small ridge just north of Herron Point, Harvey Estuary is shown. Aerial photographs indicate this to be marsh formed since 1957.



Figure 9. Similar marsh further north which is evident in the 1957 survey. Here a well-formed beach ridge has been colonised by

Juncus maritimus, Scirpus nodosis, and a few Melaleuca cuticularis (not shown). A factor in ridge formation in this area is the exposure of the marginal shelf for long periods during summer, allowing translocation of loose sand by wind.



Figure 10. A more mature marsh, looking from the centre towards a well-developed ridge. A Juncus-Samolus fringe is replaced by a Salicornia-Arthrocnemum community towards the centre. Arthrocnemum and Suaeda occur with low cover abundance.



Figure 11. This represents the successional climax of marsh formation in this area. Arthrocnemum bidens and Triglochin spp. are common on the fringes, with A. halocnemoides having high cover-abundance towards the centre. The lowest, most submerged areas are often left as bare pans.

From the environmental data ^{en}prested in section 6.3 it can be seen that the mature marshes are more saline, drier in summer, and have a more developed profile. Samples for analysis were taken from the A horizon, which is usually a medium or heavy clay overlying sand. Chapman (1960) and Beeftink (1966) have stated that during tidal submergence there is little penetration of tidal waters into marsh soils because of retention of aeration of the surface layer. The impervious tendencies of surface clays may be accentuated by a coating of mucilage laid down by diatom populations during winter and spring. Under these conditions a certain salinity equilibrium could be maintained on a mature marsh. Salt deposited on the surface by evaporation of tidal waters in late spring-early summer would probably be flushed from the marsh by autumn and winter rains. Clarke and Hannon (1970) showed there was little evidence of leaching of salinity down through the profile in Sydney salt

marshes. A detailed study of the soilwater-plant relationships would provide a better understanding of the successional status of the mature marsh communities in this system.

7.2 Shoreline Recession

The effects of Cladophora deposition has been mentioned in section 5.2. Halophila ovalis and Chaetomorpha spp. are seen to contribute to detritus deposition along upper Harvey Estuary shorelines. The high productivity of Cladophora is a unique characteristic of this estuarine system, and is currently a focal point of the E.P.A. study. A consequence of deposition is the destruction of the Juncus zone allowing waves to erode the beach ridges. This can be particularly severe during winter, when the roots of the fringing Melaleuca and Casuarina trees are undermined and exposed. The annuals, Suaeda australis, Salicornia quinqueflora and Scirpus maritimus colonise the deposition zone in spring, often forming an unnatural (and temporary) association with Casuarina obesa (Figure 12a). The status of the vegetation fringing the waters of the system can be classified into three categories of disturbance:

Zone 1. Most severely disturbed (Figure 12a, b). In this zone Juncus is severely reduced, with detritus deposition reaching the tree zone. Uprooted trees are common.



Figure 12a.



Figure 12b.

Zone 2. Moderately disturbed (Figure 13). Deposition is restricted to the Juncus zone; some destruction evident. Only Melaleucas growing right at the water's edge are affected.



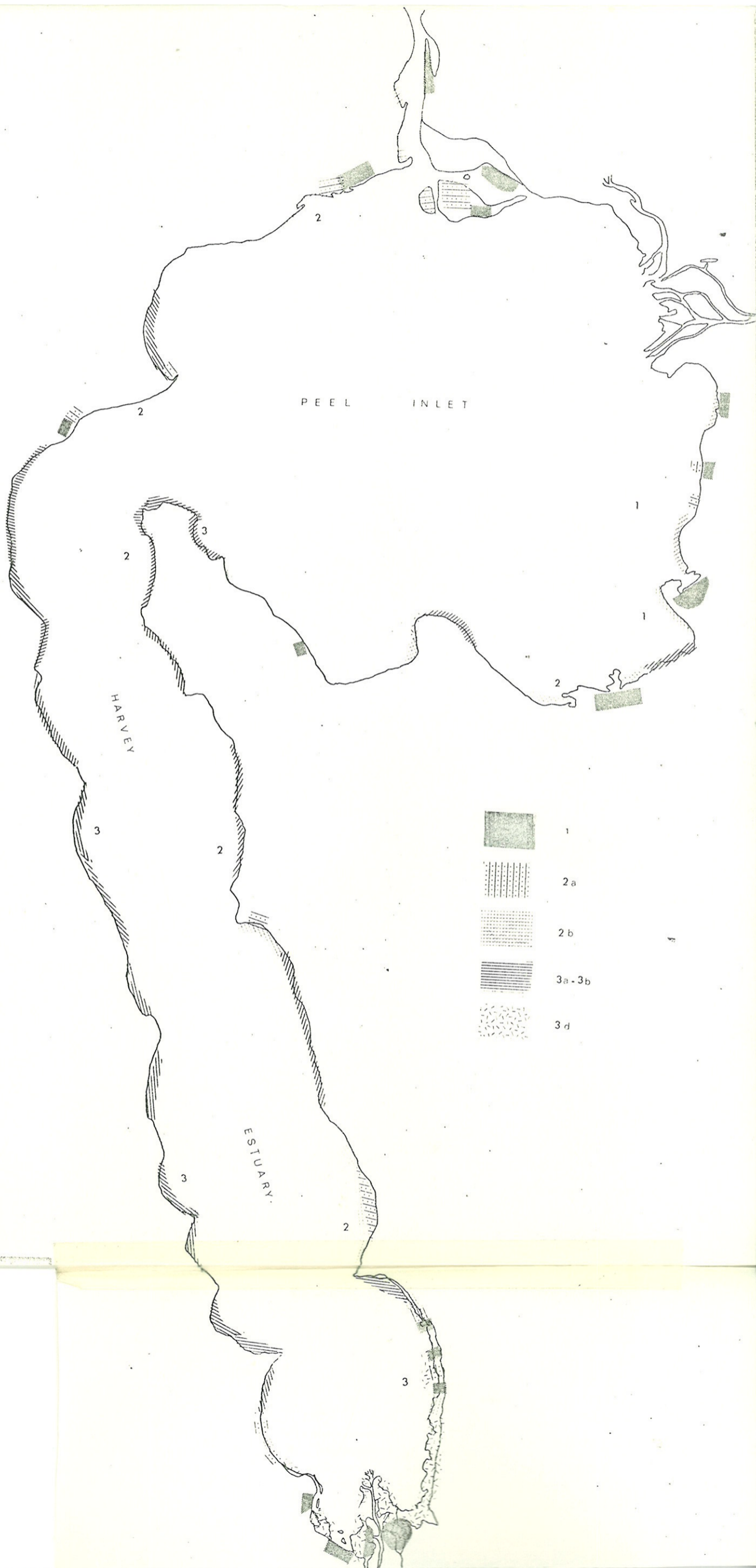
FIG 13

Zone 3. Undisturbed (Figure 14). Melaleuca-Juncus zone healthy.



Figure 14.

The distribution of zones 1-3 are shown on Figure 15, along with the major marsh complexes and communities previously described.



7.3 Some autecological observations

The spring germination of Scirpus maritimus was appreciably more widespread than stands observed the previous summer. Although often in direct competition with Juncus, aided by detritus deposition, it often formed a definite seaward zonation on protected areas (drains and rivers), demonstrating a better tolerance to submergence under certain circumstances. Conversely it can thrive on a substrate where a shallow A horizon overlying impervious hardpan combined with long periods of emergence has excluded establishment of Juncus.



Figure 16. Detritus plus access to sufficient lateral seepage during the growing season allowed establishment of Scirpus maritimus at Thompson Bay.

Watsonia bulbilifera is another exotic species becoming well established around the periphery. As indicated by its status in the community classification (Appendix VI) its relationship to other beach ridge vegetation is not yet clear. It is thought to be an invading species, its establishment possibly being aided by frequent fires creating disturbed zones in the area.



Figure 17. A dense sward of W. bulbilifera is shown. Dead Jacksonia and Viminaria are evident.

The two species Scirpus maritimus and Watsonia bulbilifera are the most noticeable indicators of dynamic changes occurring in the peripheral vegetation around the system.

7.4 General influences on the peripheral vegetation

The intrusion of species common in the surrounding vegetation unit into the transitional zone has been discussed in section 2.2. A general distribution of more developed marsh unit stands is shown in Figure 15.

The distribution of the Juncus-Melaleuca (3a) and Juncus-Suaeda (3b) communities seem to predominate on the shores of the Spearwood Dune system (described in section 2.1). Coincidentally these areas are also less affected by weed deposition.

The best developments of typical Juncus community (3d) are found on the Bassendean shores of lower Harvey estuary; however this also could be a reflection of the influence of the Harvey River. The relationships of the Arthrocnemum complex with substrate has been

previously discussed (Chapter VI) and was considered to be influenced principally by estuarine processes.

It could be concluded from a consideration of the distribution of surrounding vegetation and soils presented in Chapter II, and subsequent analysis of the peripheral vegetation, that it is only the Spearwood system that has a noticeable influence on the marsh vegetation. Along the shores of the older soil systems, it is the estuarine and fluvial influences which predominate.

8. Epontic and benthic diatom flora

8.1 Introduction

Very little work has been done in Australia on the diatom flora of estuaries and salt marshes, the most significant contribution being that of Fergusson-Wood (1964). Diatoms form an important part of the food chain in estuaries, and some species are also useful as environmental indicators. Another aspect of diatom ecology is a tendency to form coincidental associations with terrestrial and macro-algal communities in salt marshes and estuaries (Carter, 1948; Round, 1960; Chapman, 1962). It was considered worthwhile to see if similar tendencies were evident in the Peel-Harvey estuarine system, and to see if further ecological information could be derived from a knowledge of their species distributions.

When relating diatom and floristic communities it should be appreciated that each are affected by different sets of environmental conditions. Australian epontic species are mainly epiphytic (Fergusson-Wood, 1964), so they will be obviously less influenced by the substrate than their host plant. Also Aleem (1950) showed that benthic diatoms seldom penetrate deeper than 2mm into the marsh surface. Diatoms form a micro-habitat of mucilage on the surface of salt marshes in the Peel-Harvey system, so they could be buffered to some extent from the high salinity levels in the soils of the mature marshes.

8.2 Methods

Because of the complexity of factors operating on the diatom communities, it was decided that presence-absence data would be appropriate for this study. Soil surfaces scrapings were collected at the time of soil analysis (section 3.2). Using the key to the flora (Appendix III) four replicates were collected from each plant group and were cultured in petri dishes in the laboratory. A sterilised solution of sugar and yeast extract was applied to the soil surface to keep it continually

moist. The samples were then left for at least three weeks before being examined. In this way, species that were dominant in the soil would become active and become more readily observed. Identification of species was derived from Ingram Hendey (1964), Ferguson Wood (1959, 1961, 1963) and Crosby and Wood (1958).

8.3 Results and discussion

8.3.1 Relationships with plant groups. The distribution of species (Table IV) shows that more than half were unique to individual plant groups, although approximately 50% of these were accounted for by groups 3, 5, and 6. Groups 1 and 11 also have a high proportion of unique species, and could be considered as habitats that may be differentiated on the basis of their diatom composition. However groups 12, 14, 16, 18, 19, and 20 are distinguished mainly by their paucity of diatom flora. This is probably a reflection of long periods of surface dessication on these most elevated sites.

Plant groups 4, 7, and 8 have been classified as subcommunities (see Table III) and this status seems to be reflected in Table IV by their respective lack of unique diatom flora. Interestingly Navicula elegans, Mitzchia sp. 1 and Diploneis smithii seem to indicate a relationship between the Arthrocnemum-Triglochin community (group 2) and the Arthrocnemum-Salicornia community (group 4). These two groups are often found close together ecologically, with group 4 being inundated more frequently by tides. Generally, those groups receiving the most influence from the estuary have the greatest diversity of diatom species.

In the distribution table, Nitzchia compressa, Cocconeis placentula, Pinnularia legumen and P. splendida seem to indicate a relationship between groups 3 and 7. The Arthrocnemum halocnemoides-A. bidens community (group 3) is typically found on the emerging fringes of mature salt marsh concavities, while Salicornia-Juncus-Suaeda communities

TABLE IV

Group No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	20*
NITZCHIA SP. 6	+																	
NITZCHIA LONGISSIMA	+																	
DIPLONEIS CRABO	+																	
ACHNANTHES LONGIPES			+															
MASTOGLIA IGNORATA			+															
AMPHORA JAVANICA			+															
NAVICULA MARINA			+															
COCCONEIS SPECIOSUM			+															
NITZCHIA SUBVITRIA				+														
NITZCHIA VITRIA					+													
CYMBELLA STURGIDA					+													
NAVICULA SP. 1					+													
DIPLONEIS DISTANS					+													
NITZCHIA SIGMA VAR RIGIDA					+													
ACHNANTHES SP. 2					+													
AMPHIPRORA ANGUSTATA						+												
ACHNANTHES SP. 3						+												
OPEPHORA SP. 1						+												
SYNEDRA SP. 1						+												
ANOMOENIS SP. 1						+												
SP. 3						+												
PLAGIOGRAMMA SP. 1						+												
NITZCHIA CLOSTERIUM						+												
AMPHORA SP. 1								+										
MASTOGLIA SP. 2								+										
MASTOGLIA PSUEDOPARADOXIA								+										
NAVICULA VULPINA											+							
FRAGILLARIA SP. 1											+							
NITZCHIA GRACILIS											+							
NITZCHIA SP. 4											+							
AMPHORA GIGANTEA														+				
SP. 2																		+
HANTZCHIA AMPHIOXES																		+
SP. 4																		+
FRAGILLARIA SP. 2																		+
NAVICULAR ELIPTICA		+	+	+	+		+	+		+								+
PINNULARIA AMBIGUA		+	+	+				+	+	+								+
AMPHORA GRAEFFII	+		+	+		+			+									
PLEUROSIGMA STRIGOSUM	+			+	+			+										
AMPHORA SP. 2	+	+				+			+	+			+					+
NITZCHIA SP. 2	+	+								+			+					
NITZCHIA COMPRESSA			+	+			+	+						+				
COCCONEIS PLACENTULA			+			+	+							+				
PINNULARIA LEGUMEN			+		+		+											
PINNULARIA SPLENDIDA			+				+			+								
COCCONEIS SP. 1	+						+											
NAVICULA ELEGANS	+		+				+		+									
NITZCHIA SP. 1	+		+				+		+									
DIPLONEIS SMITHII	+		+															
GAMOTOPHORA MACILENTA			+	+	+										+			
CYMBELLA YARRENSIS			+	+									+					
AMPHORA PROTEUS			+		+	+												
NITZCHIA SP. 5			+		+	+												
DIPLONEIS SP. 1				+									+					
GOMATOPHORA MARINA				+		+												
SP. 1			+							+								
COCCONEIS SCUTELLUM				+	+		+											
NAVICULA SP. 3				+	+			+										
NITZCHIA SP. 3				+	+				+									
NITZCHIA BREBISSEONII			+		+													
ACHNANTHES BREVIPES					+	+												
AMPHORA MACILENTA					+	+												
THALASSIOTHRIX SP. 1					+	+		+										+
COCCONEIS APICULATA					+			+										
EPITHEMIA SP. 1						+		+										
COCCONEIS DEBESI						+		+										
EPITHEMIA SP. 2						+	+	+		+				+	+	+		
MELOSIRA SP. 1						+			+				+					
NAVICULA SP. 2								+					+					
ACHNANTHES SP. 1											+				+			

* Groups 18 and 19: No data

(group 7) occupy a similar zone on the emerging banks of the estuaries. Although the differences in salinity could be reflected by the unique diatom assemblage of group 3, the habitats could be similar in other respects important to microflora.

Similarly, although groups 5 and 6 have unique diatom flora, a relationship in habitat is indicated by Amphora proteus, Nitzschia sp. 5, Achnanthes brevipes, Amphora macilenta and Thalassiothrix sp. 1. Like groups 3 and 7, these two groups are found at very similar elevations above height tide (see overlays, section 6.3).

The overall distribution of species is similar to that reported by Round (1960) in that while many species have a strong preference for different habitats, others demonstrate a wider range of tolerance. In this study, the diatom distribution strongly reflects the floristic classification described in section 4.3.

8.3.2 Ecological significance of species. The species identified in this study are also common in the Swan-Canning River estuarine system (Johns, pers. comm.) This is not surprising, considering the proximity of the two systems, and that both are situated in the Swan Coastal Plain. There is considerably less comparison to be made with English marsh flora, with Diploneis smithii being the only common species in Carter's (1948) survey. This occurred in the upper marsh Glyceria and Juncetum zones. There were no species in common with the salt marshes on the River Dee (Round, 1960). All of the identified species have been recorded from Eastern States and New Zealand estuaries, by Fergusson Wood, but little ecological information is supplied.

Notable in their absence are the common planktonic genera Rhizosolenia spp. Chaetoceros sp. and Coscinodiscus spp. This indicates that the species shown are likely to be true sedentary communities and not artifacts of planktonic deposition.

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APPENDIX I

Key to vegetation map -- common species in dominant strata

- A -- Arthrocnemum halocnemoides
- Ac -- Acacia spp.
- Ag -- Agonis flexuosa
- As -- Astartea fascicularis
- Ba -- Baekea grandifolia
- B -- Banksia spp.
- Ca -- Casuarina spp.
- E -- Eucalyptus rudis
- H -- Hakea spp.
- J (Woodland) -- Jarrah (Eucalyptus marginata)
- J (Sedgeland) -- Juncus maritimus
- Jk -- Jacksonia spp.
- K -- Kunzea ericifolia
- L -- Lepidosperma spp.
- M -- Marri (Eucalyptus calophylla)
- m -- Melaleuca spp.
- N -- Nuytisa floribunda
- R -- Regelia ciliata
- S -- Salicornia quinqueflora
- Tu -- Tuart (Eucalyptus gomphocephala)
- Ty -- Typha sp.
- X -- Xanthorrhoea preisii
- F -- farmland
- Res-- residential

APPENDIX II

Prevailing Wind Data

The graphs are derived from wind data supplied by the Bureau of Meteorology, Western Australia. The recordings were taken 0900 and 1500 hours daily over a period of five years, 1971-1976. Only wind speeds > 10 km/hr were included in the graphs.

A -- period January to April

B -- May to August

C -- September to December

N = north

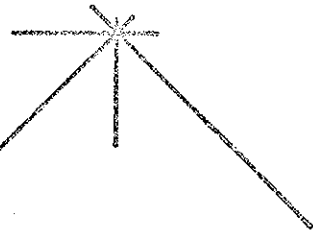
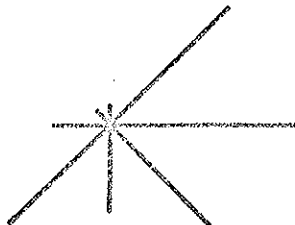
Scale = 1mm = 1 observation

N

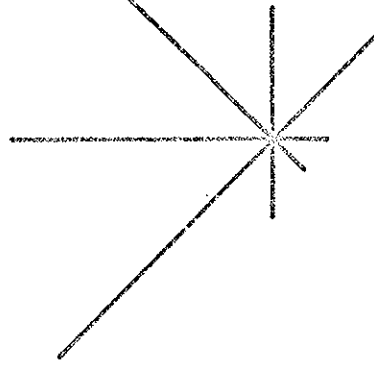
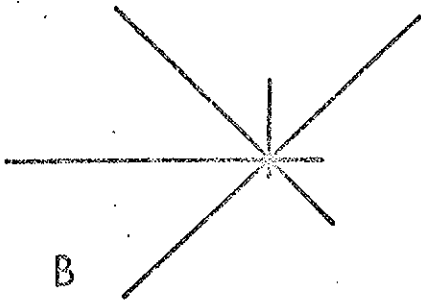
A M

P M

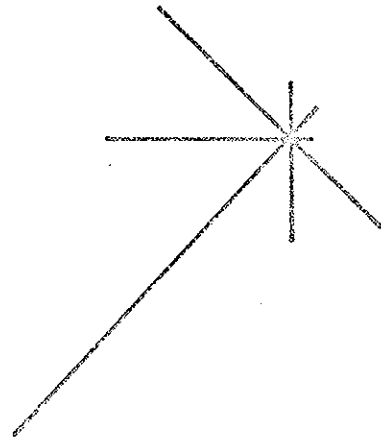
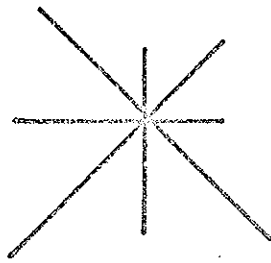
A



B



C



APPENDIX III

Key to vegetation communities of the Peel/Harvey estuarine system

Note: The key should be used with a 1m² quadrat. Disturbed areas and edges of obvious zonation should be avoided. Best period for sampling is late spring, summer, and early autumn.

1. Arthrocnemum halocnemoides present as significant shrub layer (> 30% canopy cover) - - - - - 2
 Not as above - - - - - 5
2. A. halocnemoides (> 30% cover) with Triglochin mucronata - - Group II
T. mucronata not present - - - - - 3
3. A. halocnemoides (> 30% cover) with A. bidens - - - - - Group III
A. bidens not present - - - - - 4
4. A. halocnemoides with Salicornia quinqueflora (together > 50% cover) - - - - - Group IV
A. halocnemoides as single species (> 50% cover) - - - - - Group I
5. S. quinqueflora present - - - - - 6
S. quinqueflora absent - - - - - 11
6. S. quinqueflora with Juncus maritimus - - - - -
Suaeda australis and Atriplex paludosa - - - - - Group VIII
 Not as above - - - - - 7
7. S. quinqueflora with J. maritimus and S. australis - - - - Group VII
 Not as above - - - - - 8
8. S. quinqueflora with J. maritimus and Samolus junceus - - - Group IX
 Not as above - - - - - 9
9. S. quinqueflora with J. Maritimus and Gahnia trifida - - - - Group X
 Not as above - - - - - 10
10. S. quinqueflora with Suaeda australis (together > 50% cover) Group VI
S. quinqueflora as a single species (> 50% cover) - - - - - Group V
11. Juncus maritimus present as significant sward (> 30% cover)- 12

- T. maritimus absent - - - - - 15
12. J. maritimus with Suaeda australis (> 50% cover) - - - - - Group XI
S. australis absent - - - - - 13
13. J. maritimus with Sporobobolus virginicus (> 50% cover) - - - - - Group XII*
S. virginicus absent - - - - - 14
14. J. maritimus with Melaleuca raphiophylla - - - - - Group XIV
J. maritimus as single species (> 50% cover) - - - - - Group XIII
15. Stands having at least three of the following species,
or two with >50% cover:
S. virginicus, Parapholus sp., Cotula coronifolia
Angianthus preissianus - - - - - Group XV
Not as above - - - - - 16
16. Stands having at least three of the following species
present, or two with >50% cover:
Lepidosperma striatum, Machaerina junceum,
M. raphiophylla, Gahnia trifida - - - - - Group XVI
Not as above - - - - - 17
17. Stands with at least three of the following species
present: Briza maxima, Hyperchoeris radicata,
Ehrharta sp., Silene gallica, Hordeum histrix - - - - - Group XVII
Not as above - - - - - 18
18. Stands with at least three of the following species
present, or any two (except Macromitrium archerii)
with >50% cover: Lepidosperma carphoides, Jacksonia
sternbergiana, Thysanthus dichotomus, Macromitrium
archerii - - - - - Group XVIII
Not as above - - - - - 19
19. Kunzea ericifolia present, with L. carphoides and/or
M. archerii - - - - - Group XIX
20. L. carphoides with Watsonia sp. (> 30%) - - - - - Group XX

APPENDIX IV

Determination of Primary Profile Form

When the soil profile has been described the horizons can be named according to the definitions outlined in Northcote (1974). The modern, or upper solum becomes evident and classification begins with determining the primary profile form (PPF). Definition of these forms will aid interpretation of the soil data ordination and tables.

1. Uniform primary profile forms (A) -- soil profiles dominated by the mineral fraction with small (if any) texture differences throughout, such that no clearly defined texture boundaries are to be found in the solum except for possible surface crusts < 2.5 cm thick. The texture range throughout the solum is not more than equivalent to that which can be included within the span of one texture group (e.g., texture group: sandy clay → silty clay → light clay → light medium clay).

2. Gradational primary profile forms (G) -- soil profiles dominated by the mineral fraction and showing increasingly finer (more clayey) texture grades on passing down the solum. The boundaries between horizons are usually gradual or diffuse, and the texture difference between consecutive horizons is less than 1.5 texture groups. The range of texture through the solum must exceed the equivalent of the span of a texture group.

e.g., sand → loamy sand → sandy loam (→ sandy clay loam).

3. Duplex primary profile form (D) -- soil profiles dominated by the mineral fraction with a texture contrast of $>1\frac{1}{2}$ texture groups between A and B horizons. Boundaries are clear to sharp. The distance from the bottom of the A horizons to the top of the main B horizon occurs over a vertical interval of < 10 cm, except where sequioxidic layers (laterite) occur between the A and B horizons.

APPENDIX V

Zurich-Montpellier Sorting Program

This program is useful for identifying PDS before manual handsorting of the "raw" table data. The program detects species/releve coincidences and is based on a strategy devised by Ceska and Roemer (1971). The same data cards used in the Table-Sort Program can be used. It initially searches for all those species which occur in 15 to 70% of the releves under consideration. Species which fall between these arbitrary limits are those most likely to be conspicuous in group formation.

The PDS with the greatest number of occurrences is selected and all the releves in which it occurs are found. The remaining PDS are scanned and those which occur in at least 50% of these releves are selected. If none can be found, then the original species is printed out as a single species, and is not considered further in the analysis. The PDS with the next highest number of occurrences is then selected, and the process is repeated until all the PDS are rejected or a suitable species group is found. When groups are found, then the releves involved are then scanned to ensure that each releve contains at least 50% of the selected PDS. Those that do not contain 50% are rejected. If satisfactory, the single species (if any) PDS group and releves are printed out, and the process repeated.

Data from each site was processed separately, and the list of PDS obtained resembled the species list shown on Table II, section 4.2, with the addition of Hamiandra liantha (site 10), Sonchus asper (site 13), Apium australe (site 4), Scirpus maritimus (site 11), Juncus bufonius (site 11) and Trigonella suavissima (site 4).

APPENDIX VI

List of Vegetation Units (de Smidt's classification)

1. Arthrocnemum complex

1a. Arthrocnemum community (Typical)

Identifying species. A. halocnemoides

1a. Arthrocnemum -- Salicornia variant

Differential species. Salicornia quinqueflora

1b. Arthrocnemum -- Triglochin community

Differential species. Triglochin mucronata

1c. Arthrocnemum community

Differential species. Arthrocnemum bidens

2. Salicornia complex

2a. Salicornia community

Identifying species. Salicornia quinqueflora

2b. Salicornia -- Suaeda community (Typical)

Identifying species. Salicornia quinqueflora

Suaeda australia

2b.1. Juncus subcommunity

Differential species. Juncus maritimus

2b.2. Atriplex subcommunity

Differential species. Atriplex paludosa

3. Juncus complex

Identifying species. Juncus maritimus

3a. Juncus -- Melaleuca community

Identifying species. Juncus maritimus

Melaleuca raphiophylla

3b. Juncus -- Suaeda community

Identifying species. Suaeda australis

3c. Juncus -- Sporobolus community.

Identifying species. Sporobolus virginicus

3d. Juncus community (Typical)

Identifying species. Juncus maritimus

3d.1. Samolus -- Salicornia subcommunity

Differential species. Samolus junceus

Salicornia quinqueflora

3d.2. Gahnia -- Salicornia subcommunity

Differential species. Gahnia trifida

Salicornia quinqueflora

4. Lepidosperma complex

Identifying species. Lepidosperma carphoides

4a. Lepidosperma -- Jacksonia -- Thysanotus -- Macromitrium community

Identifying species. L. carphoides

T. dichotomus

J. sternbergiana

M. archerii

4b. Lepidosperma -- Kunzea -- Macromitrium community

Identifying species. L. carphoides

K. ericifolia

M. archerii

4c. Lepidosperma -- Watsonia fragment

Differential species. Watsonia bulbifera

Segregated units

5. Sporobolus -- Parapholus -- Cotula -- Angianthus community

Identifying species. S. virginicus

C. coronopifolia

A. preissianus

Parapholus sp.

6. Lepidosperma --- Melaleuca -- Machaerina --- Gahnia community

Identifying species. L. striatum

M. raphiophylla

Machaerina junceum

Gahnia trifida

7. Briza -- Hyperchoeris --- Ehrharta --- Silene --- Hordeum community

Identifying species. Briza maxima

Hyperchoeris radicata

Ehrharta sp.

Silene gallica

Hordeum histrix

APPENDIX VII

Transect data species list -- encoded species plus occasionals

- | | |
|---|---|
| <p><u>Cycadoceae</u></p> <p>1. <u>Macrozamia reidii</u></p> <p><u>Cupressaceae</u></p> <p>2. <u>Actinostrobus pyramidalis</u></p> <p><u>Scheuchzeriaceae</u></p> <p>3. <u>Triglochin calcitrapa</u></p> <p>4. <u>T. centrocarpa</u></p> <p>5. <u>T. mucronata</u></p> <p>6. <u>T. striata</u></p> <p><u>Gramineae</u></p> <p>7. <u>Argrostis</u> sp. 1</p> <p>8. <u>Aira caryophylla</u></p> <p>9. <u>Avena</u> sp. 1</p> <p>10. <u>Briza maxima</u></p> <p>11. <u>Bromus madritensis</u></p> <p>12. <u>Bromus</u> sp. 1</p> <p>13. <u>Cynodon actylon</u></p> <p>14. <u>Distichlis</u> sp. 1</p> <p>15. <u>Ehrhata calycina</u></p> <p>16. <u>Gastridium</u> Sp. 1</p> <p>17. <u>Holcus lanatus</u></p> <p>18. <u>Hordeum histrix</u></p> <p>19. <u>Hordeum</u> sp. 1</p> <p>20. <u>Parapholus</u> sp. 1</p> <p>- <u>Spinifex longifolia</u></p> <p>20. <u>Sporobolus virginicus</u></p> <p><u>Stipa</u> sp. 1</p> | <p><u>Cyperaceae</u></p> <p>21. <u>Lepidosperma carphoides</u></p> <p>- <u>L. gladiatum</u></p> <p>22. <u>L. longitudinale</u></p> <p>23. <u>L. striatum</u></p> <p>29. <u>Shoenus nitens</u></p> <p>30. <u>Shoenus</u> sp. 1</p> <p>31. <u>Machaerina junceum</u></p> <p>32. <u>Gahnia trifida</u></p> <p>33. <u>Scirpus nodosis</u></p> <p>34. <u>Scirpus maritimus</u></p> <p><u>Restionaceae</u></p> <p>24. <u>Leptocarpus aristatus</u></p> <p><u>L. canus</u></p> <p><u>L. coangustatus</u></p> <p>25. <u>L. tenax</u></p> <p>26. <u>Lepyrodia muirii</u></p> <p>27. <u>Lyginia tenax</u></p> <p><u>Centrolepideae</u></p> <p>35. <u>Centrolepis</u> sp. 1</p> <p><u>Phylodraceae</u></p> <p>36. <u>Phylydrella pygmaea</u></p> <p><u>Juncaceae</u></p> <p>37. <u>Juncus bufonius</u></p> <p>38. <u>J. capitus</u></p> <p>39. <u>J. maritimus</u></p> <p>- <u>J. pallidus</u></p> |
|---|---|

- Liliaceae
40. Thysanotus dichotomus
41. Trycoryne elatior
- Xanthorrhoeaceae
42. Xanthorrhoea preisii
- Haemodoraceae
43. Conostylus aurea
- Iridaceae
44. Pattersonia occidentalis
45. Romulea rosea
- Casuarinaceae
46. Casuarina obesa
- Proteaceae
47. Banksia grandis
- B. illicifolia
48. B. littoralis
- Hakea lissocarpha
- H. marginata
49. H. scoparia
50. H. varia
- Stirlingia latifolia
- Loranthaceae
- Nuytsia floribunda
- Polygonaceae
51. Rumex crispus
52. R. polygonum
53. Rumex sp.
- Chenopodaceae
54. Arthrocnemum bidens
55. A. halocnemoides
56. A. "syncarpum" P.G. Wilson INED.
57. A. "undulatum" P.G. Wilson INED.
- Atriplex cinera
58. A. pastata
59. A. paludosa
- Rhagodia baccata
60. Salicornia quinqueflora
61. Suaeda australis
- Aizoaceae
62. Carpobrotus aequilaterale
- Caryophyllaceae
63. Cerastium glomeratum
64. Silene gallica
- Spergularia arvensis
- S. nibra
- Lauraceae
- Cassytha sp. 1
- Cruciferae
65. Raphanus raphanistrum
- Pittosporaceae
66. Sollya fusiformes
- Mimosaceae
67. Acacia cyanophylla
- A. cyclops
68. A. pulchella
- Xylomelum angustifolium
- Papilionaceae
- Jampholobium tormentosa

- Hardenbergia comptonia
- 69. Jacksonia purcellata
- 70. J. sternbergiana
- 71. Trigonella suavissima
- 72. Viminaria junceum
- Geraniaceae
- Pelagonium capitum
- Oxidaceae
- 73. Oxalis pes-caprae
- Myrtaceae
- Agonis flexuosa
- 74. Baekea grandifolia
- Calothamnus quadrifus
- 75. Eucalyptus gomphocephala
- 76. E. rudis
- Hypocalymma angustifolium
- 77. Kunzea ericifolia
- K. micrantha
- 78. Melaleuca cuticularis
- 79. M. hamulosa
- M. heugelii
- M. incana
- 80. M. leptoclada
- M. lanceolata
- M. nematophylla
- 81. M. raphiophylla
- 82. M. teretifolia
- 83. Regelia ciliata
- Frankeniaceae
- 84. Frankenia pauciflora
- Lythraceae
- Lythrum lissopifolia
- Goodenaceae
- 85. Dampiera sp.1
- Apiaceae
- 86. Apium australe
- 87. Centelle asiatica
- Primulaceae
- 88. Anagallis foemina
- 89. Samolus junceus
- 90. S. repens
- Plumbaginaceae
- Limonium salicorniaceae
- Convulvulaceae
- 91. Wilsonia backhousei
- 92. W. humilis
- Lamiaceae
- 93. Hemiandra leianthus
- Orobanchaceae
- 94. Orobanche sp. 1
- Plantaginaceae
- Plantago lanceolata
- Rubiaceae
- Opercularia vaginata
- Dipsaceae
- 95. Dischisma arenarium
- Stylidaceae
- Stylidium sp. 1
- Asteraceae
- 96. Angianthus cunninghamii

100. A. tennellus
101. Aster subtulatus
102. Brachycome perpusilla
- Conyza bonanensis
103. C. canadensis
104. Cotula coronopifolia
- Ghaphalium candidissimum
- Helichrysum cordatum
105. Hyperchoeris radicata
106. Silylium marianum
107. Sonchus asper
108. Watsonia bulbilifera Mathews and Bolus.
121. Ursinia anthemoides
- 109-119 herbaceous exotics (incidentals)
- Orthotricaceae
120. Macromitrium archeri Mitt. in Hook.

APPENDIX VIII

Soil A Horizon Description and Analysis

Group No.	Colour (Moist)		Value/ Chroma	Texture	Ph	CaCO ₃	Depth (CM)	Drainage Regime	Conductivity Mean (Mohms)	P.P.F.
	Code	Description								
1	10yr 2/1 / 10yr 3/3	Black / Dark Brown	1 - 5	Clay-Loam / Heavy Clay	6.5 / 6.9	a	2 / 18	Fair / Poor	5875	D- (x2) DY 4.53 DG 3.5
2	10yr 2/1 / 10yr 3/3	Black / Dark Brown	1 - 5	Clay-Loam / Sand	6.8 / 7.4	a / c	2 / 10	Good / Poor	2772	D (x2) Dd 3.53 DG 3.5
3	10yr 4/1 / 10yr 3/2	Dark Grey / Very Dark Greyish brown	1 - 2	Clay-Loam / Sand	6.8 / 7.0	a	1 / 10	Fair / Poor	3050	D (x2) DG 4.12 DG 2.62
4	25yN3 / 10yr 2/2	Very dark grey / Very dark brown	1 - 2	Loam / Light Clay	6.5 / 7.9	a / b	4 / 10	Fair / Poor	3625	D (x2) DG 3.5 (x2)
5	10yr 3/1 / 10yr 4/3	Very dark grey / Dark Brown	1 - 5	Clay-Loam / Sand	6.4 / 7.0	a / D	5 / 10	Good / Poor	5122	D (x3) Uc 1.21

Group No.	Colour (Moist)		Value / Chroma	Texture	Ph	CaCO ₃	Depth (CM)	Drainage Regime	Conductivity Mean (µohms)	P.P.F.
	Code	Description								
11	10yr 2/1 / 2.5y 8/2	Black / White	1 / 3	Heavy clay / Sand	7.5 / 6.6	a	8 / 40	Good / Poor	1242	D Dd 3.53 Uc 1.21 Uc 1.11
12	2.5y N8	White	3	Sand	7.6 / 7.7	a	↓	Good	41	Uc 1.11 Uc 1.21 (x3)
13	10yr 2/1 / 2.5y 7/2	Black / Light Grey	1 / 3	Heavy clay / Sand	6.6 / 7.7	a	3 / 30	Poor	3050	D (x2) *
14	10yr 3/1 / 10yr 6/6	Black / Brownish Yellow	1 / 4	Loamy clay / Sand	6.9 / 8.5	a / b	1 / 5	Good / Poor	462	D (x2) Uc 1.11 Gn 1.82
15	10yr 3/1 / 10yr 3/3	Very dark grey / Dark brown	1 / 5	Clay Loam / Sand	7.2 / 8/2	a / b	1 / 20	Good / Fair	910	Uc 1.21 Dd 3.52 Uc 1.22 Uc 1.11

* Submerged soils

Group No.	Colour (Moist)		Value / Chroma	Texture	Ph	CaCo ₃	Depth (CM)	Drainage Regime	Conductivity Mean (μohms)	P.P.F.
	Code	Description								
16	2.5y N2	Black	1	Heavy clay / sand	6.9	a	1	Poor	387	D Dd 3.51 Dy 4.53 Uc 1.13
	2.5 N3	Very dark grey			8.5	D	17	Good		
17	10yr 4/2	Dark grey-brown	2	Loamy sand / sand	6.6	a	3	Good	281	Uc 1.11 Uc 1.22 Uc 1.21 (x2)
	10yr 7/1	Light grey	3		8.7	b	↓			
18	10yr 4/1	Dark Grey	2	Sand	7.4	a	8	Good	38	Uc 1.21 (x4)
	2.5y 8/0	White	3		7.7		↓			
19	10yr 3/2	Very Dark Grey-Brown	1	Sand	7.2	a	14	Good	67	Uc 1.21 (x3) Uc 1.23
	10yr 7/1	Light Grey	3		7.8		↓			
20	10yr 5/3	Brown	1	Sand	7.2	a	8	Good	82	Uc 1.21 (x2) Uc 1.23 (x2)
	10yr 3/2	Very dark Grey Brown	2		7.6		↓			

APPENDIX IX

Description of unidentified diatom species

NITZCHIA sp. 1 (Plate 1, figure 1)

Cells solitary, valve margins linear, oblong, apices obliquely cuneate. Striae distinct on margins, slightly constricted at the center, axial area broad, hyaline. Striae 10 per 10 μ
Length 100 μ

NITZCHIA sp. 2 (Plate 1, figure 2)

Cells solitary, in valve view slightly panduriform. Striae restricted to margin, 3 per 10 μ , slight gap near central area. Two chromatophores, disc shaped, one towards each end. Apex broadly rounded
Length 75 μ

THALLASIOTHRIX sp. 1 (Plate 1, figure 3)

Cells solitary, in valve view narrow linear, oblong, ends truncated. Distinct marginal striae, 6-7 per 10 μ , central area hyaline.
Length 250 μ

NITZCHIA sp. 3. (Plate 1, figure 4)

Cells solitary, narrowly lanceolate, apices acute. Striae on margins indistinct, 11 per 10 μ . Central area hyaline. Two oblong chromatophores.
Length 90 μ

SP. 1 (Plate 1, figure 5)

Cells solitary, in valve view narrowly lanceolate, apices sub-rostrate. Axial area linear, narrow, raphae indistinct. Valve surface finely striate, 13-16 per 10 μ , transverse.
Length 90 μ

NAVICULAR sp 2

(Plate 1, figure 6)

Cells solitary, narrowly lanceolate, apices sub-rostrate. Axial area linear, narrow, raphae indistinct. Valve finely striate 13-16 per 10μ , transverse.

Length 90μ

NAVICULA sp. 3.

(Plate 1, figure 7)

Cells solitary, valve view broadly lanceolate to narrowly rhombic-lanceolate, apices broadly rounded. Well defined raphae, central area mostly hyaline septa. Striae punctate, well defined, radiate, 7 per 10μ .

Length 90μ

ACHNANTHES sp.1

(Plate 1, figure 8)

Cells solitary, frustules in valve view broadly elliptical, broadly rounded extremities. Frustule in girdle view arcuate. Lower (ventral) valve central area dilated to form a broad stria, interrupting definite radiate striae (30).

Length 50μ

FRAGILARIA sp.1

(Plate 1, figure 9)

Cells solitary, in valve view panduriform, apices rostrate, produced, striae fine, continuous, more distinct at margins.

Length 45μ

AMPHORA sp. 1

(Plate 1, figure 10)

Paired frustules elliptical, broad, truncate. Solitary valves lunate, ventral margin slightly concave, raphae biarcuate.

Central nodule distinct, transverse.

Length 50μ

NAVICULA sp. 1

(Plate 1, figure 11)

Cells solitary, in valve view narrowly lanceolate, apices slightly capitate, produced. Raphae distinct, linear, axial area narrow. Striae finely punctate, septum narrow, hyaline.

Length 70 μ

ACHNANTHES sp. 2

(Plate 1, figure 12)

Cells solitary; frustule in ventral valve view elliptical, raphae distinct, continuous, striae punctate, 3-4 per 10 μ . Puncta in 6 rows from axial area to margin.

Length 120 μ

EPITHEMIA sp. 1

(Plate 2, figure 1)

Cells solitary, valve view arcuate, surface rounded. Costae distinct (10) striae fine.

Length 185 μ

EPITHEMIA sp. 2

(Plate 2, figure 2)

Cells solitary, valve arcuate, almost semi-elliptical, with slightly concave ventral margin. Costae not pronounced, striae radiate, 4-6 per 10 μ .

Length 75 μ

COCCONEIS sp. 1

(Plate 2, figure 3)

Cells solitary, in valve view elliptical, ends bluntly rounded, striae radiate, interrupted by two hyaline, arcuate rows. Axial area widest at center, raphae narrow, septum

distant.

Length 55 μ

NITZCHIA sp. 4.

(Plate 2, figure 4)

Cells solitary, sides nearly parallel in middle, sigmoid towards ends, apices obliquely cuneate. Oblong striae (100) on margins, axial area wide, hyaline, raphae obscure.

Length 180-200 μ

AMPHORA sp 2

(Plate 2, figure 5)

Cells solitary, valves with arcuate dorsal and concave ventral margins ends slightly capitate, raphae almost straight, striae fine.

Length 50 μ

MASTOGLIA sp. 1

(Plate 2, figure 6)

Cells solitary, valve view broadly elliptical, apices rostrate. Marginal septum comprises 10 loculii continuing to apices, radiate. Valve surface divided by 6 definite striae. Axial area narrow, raphae linear.

Length 90 μ

SP. 2

(Plate 2, figure 7)

Cells solitary, valve view lanceolate, axial area narrow, linear, raphae indistinct. Striae radiate, 3 per 10 μ .

Length 30 μ

MELOSIRA sp. 1

(Plate 2, figure 8)

Cells colonial, in chains. Valves cylindrical, surface finely punctate, radiating, irregular.

Diameter 35 μ

OPEPHORA sp. 1

(Plate 2, figure 9)

Cells solitary, valves elliptical, striae coarse, punctate, in 8 rows, separated by definite hyaline space.

Length 15 μ

ANOMAENIS sp. 1

(Plate 2, figure 10)

Cells solitary, valve narrowly elliptical, apices capitulate.

Striae very fine, transverse, raphae linear, narrow.

Length 40 μ

SP. 3

(Plate 2, figure 11)

Cells solitary, valve view lanceolate, apices rostrate. Raphae indistinct, linear, striae radiate, punctate, 8 per 10 μ .

Length 15 μ

PLAGIOGRAMMA sp. 1

(Plate 2, figure 12)

Cells solitary, frustules in girdle view (shown) almost rectangular, valve view near lanceolate. Intercalary band, ends, hyaline. Striae (15) interrupted by transverse hyaline bands.

Length 20 μ

NITZCHIA sp. 5.

(Plate 2, figure 13)

Cells solitary, valve view narrowly sigmoid, axial area hyaline with two oblong chromatophores toward each end. Fine punctate

on margins, raphae indistinct.

Length 40 μ

NITZCHIA sp. 6.

(Plate 2, figure 14)

Cells solitary, free, valve margins almost linear, apex obliquely cuneate. Axial area broad, hyaline. Fine striae on margins.

Length 90 μ

SYNEDRA sp. 1

(Plate 2, figure 15).

Cells free, valve view narrowly linear lanceolate, apices acute. Striae fine, 7 per 10 μ , transverse, axial area a fine hyaline space.

Length 75 μ

ACHNANTHES sp. 3.

(Plate 3, figure 1)

Cells solitary girdle view semi-lanceolate, semi-panduriform. Surface distinctly punctate.

Length. 70 μ

SP. 4

(Plate 3, figure 2)

Cells solitary, valve view elliptical, valve surface rounded, raphae fine, radiate, axial area narrow.

Length. 30 μ

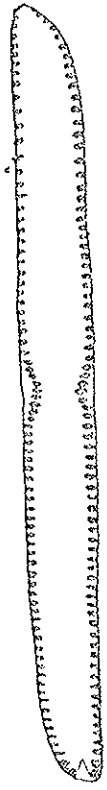
FRAGILARIA sp. 2.

(Plate 3, figure 3, A,B,)

Cells solitary, valve view (b) narrow panduriform, apices slightly capitate produced, striae fine, transverse. Girdle view (a) rectangular, largely hyaline.

Length 200 μ

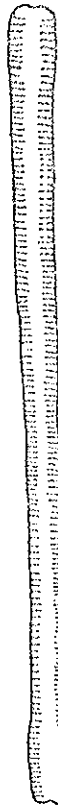
PLATE I



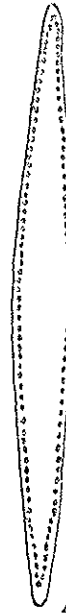
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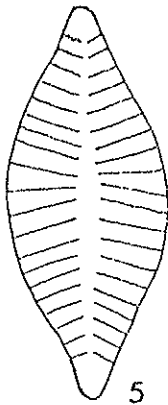
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3



4



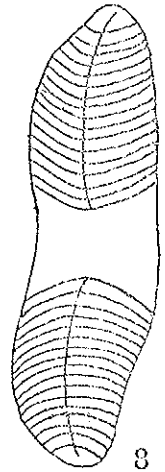
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6



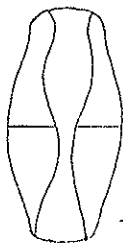
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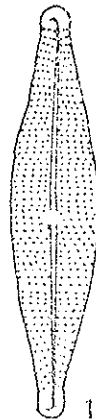
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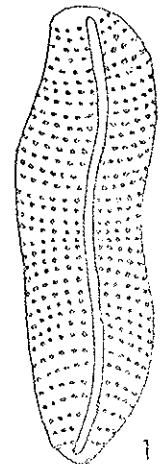
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10



11



12

PLATE II

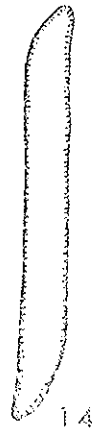
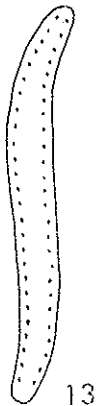
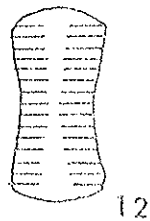
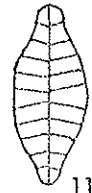
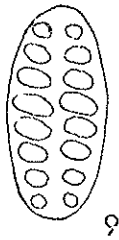
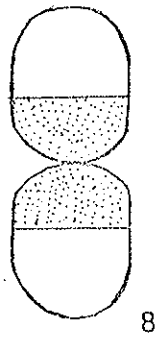
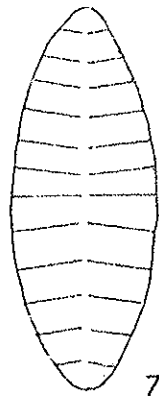
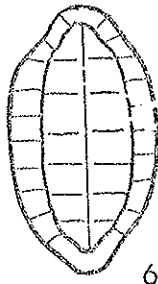
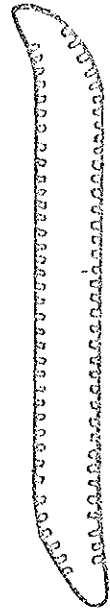
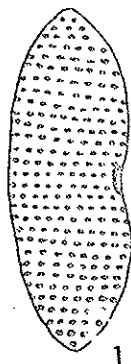
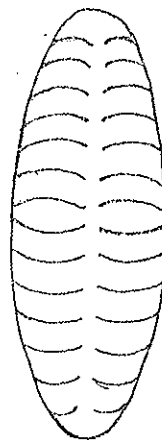


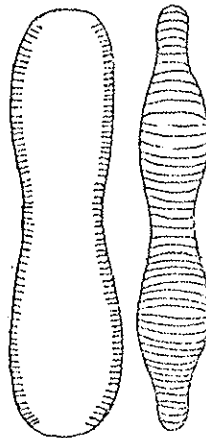
PLATE III



1



2



3 a

b

APPENDIX

Species list - Bacillariophyceae.

ACHNATHACEAE

- Achnanthes brevipes Ag.
A. longipes Ag.
Cocconeis apiculata As.
C. debesi HUST.
C. placentula Ehr.
C. scutellum Ehr.
C. speciosum gregory.
Cymbella sturgida HUST.
C. yarrensii (Schmidt) Cleve.

BACILLARIACEAE

- Hantzchia amphioxes (Ehr) Grun
Nitzschia brebissonii W. Sm.
N. closterium (Ehr) W.S.
N. compressa (Bail) Boyer.
N. gracilis HANTZ.
N. longissima (Breb) Raphs.
N. sigma var rigida. Grunow ex Van Heurck.
N. subvitrea HUST
N. vitrea Norm.

CYMBELLACEAE.

- Amphora. gigantea grun in A.S.
A. graeffii (grun) C.L.
A. javanica A.S.

A. proteus. Greg.

A. macilenta. Greg.

FRAGILARIACEAE

Gamatophora macilenta W. Sm.

G. marina (Lyngb.) Kutz.

NAVICULACEAE.

Amphiprora. angustata. HEND.

Diploneis crabo. Ehrenburg.

D. distans A.S.

D. Smithii (breb) d.

Mastoglia ignorata HUST

M. pseudoparadoxia HUST.

Navicula elegans W.M. Smith.

N. eliptica W.M. Smith.

N. marina. Raphs in Pritchard.

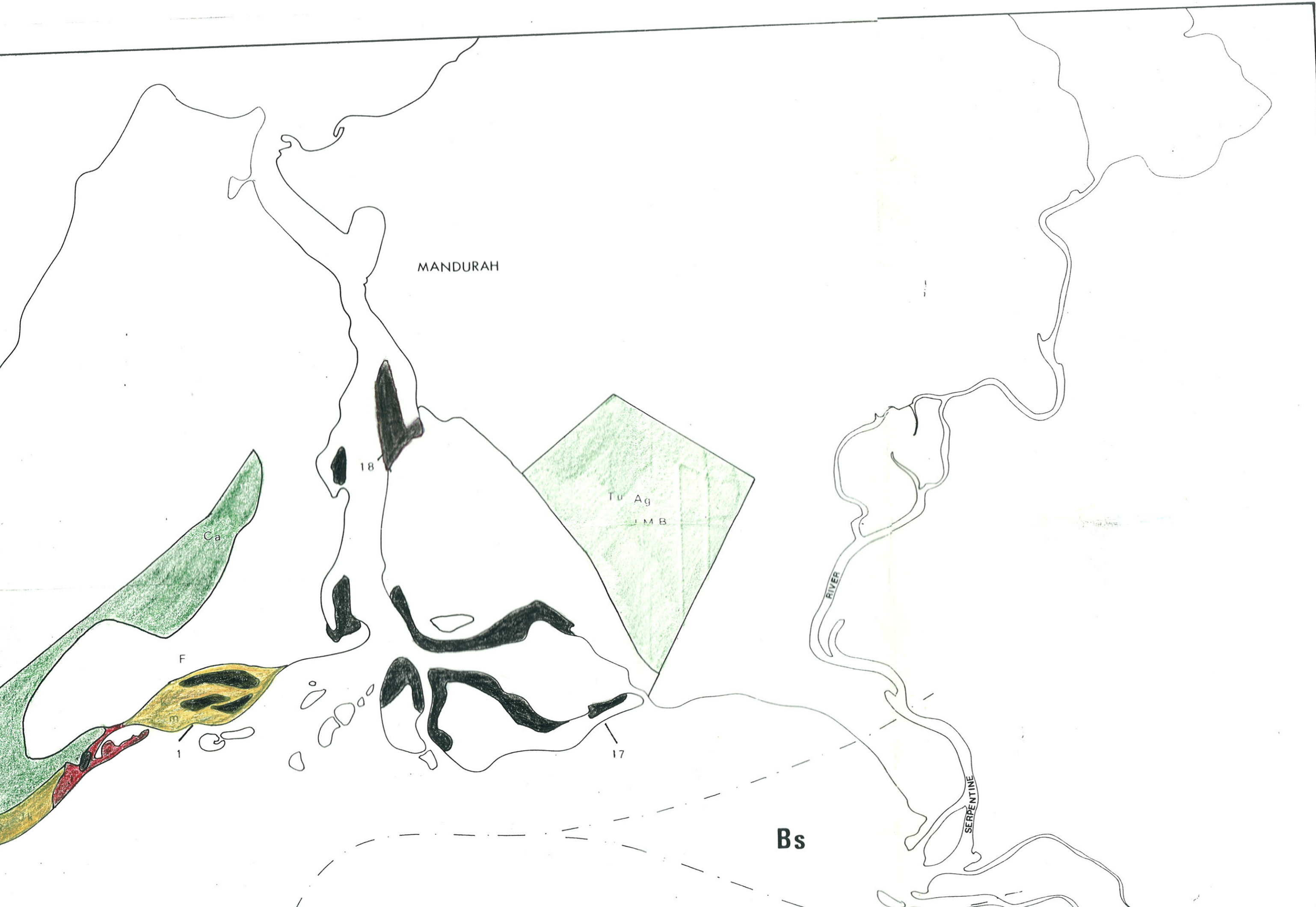
N. vulpina Kutz.

Pinnularia ambigua cleve.

P. legumen. E.Hr.

P. splendida HUST.

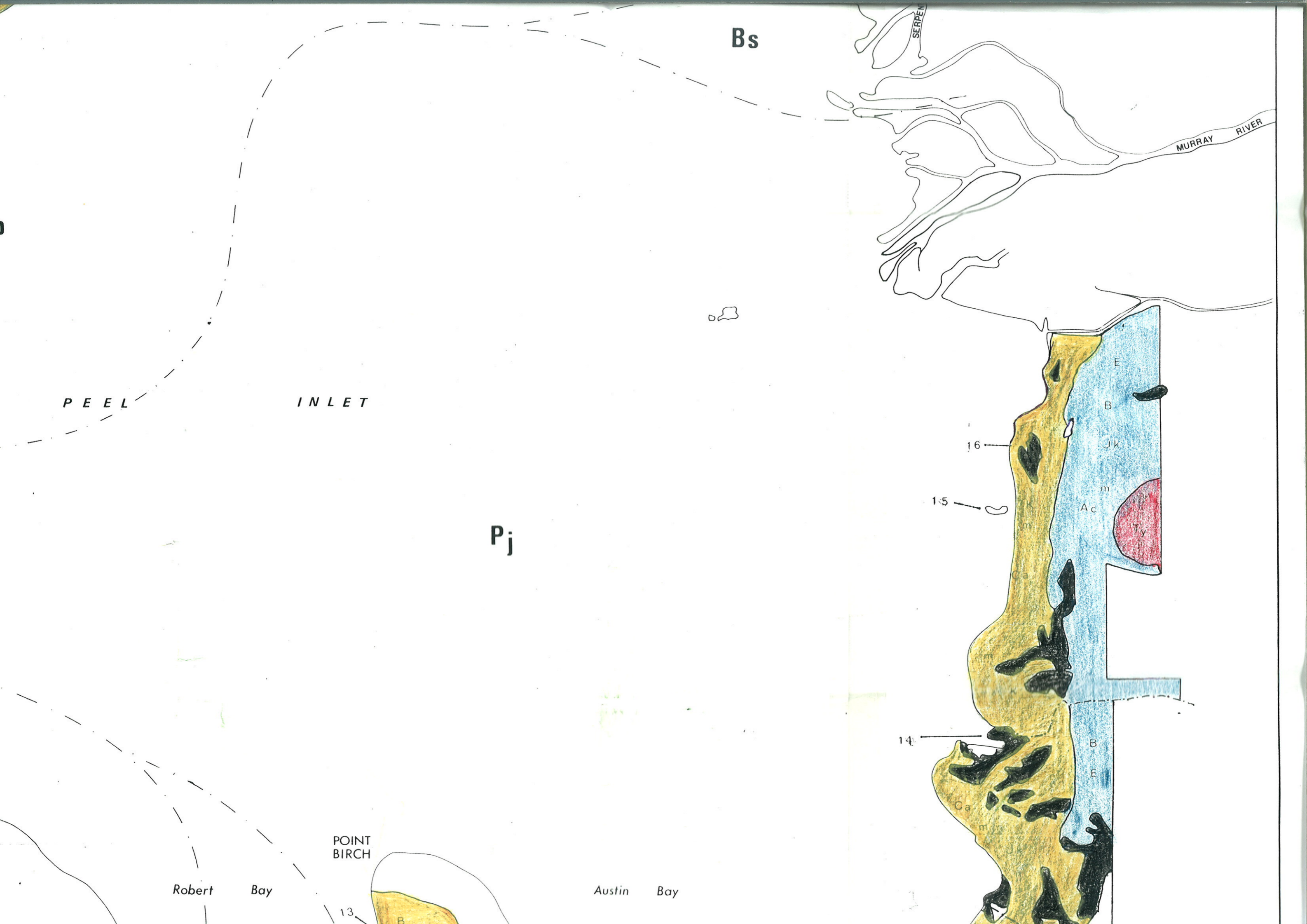
Pleurosigma strigosum W.M. Smith.



I N D I A N

O C E A N





Bs

SERPEN

MURRAY RIVER

PEEL

INLET

Pj

16

15

E
B
Jk
m
Ac
Ty

14

POINT BIRCH

Robert Bay

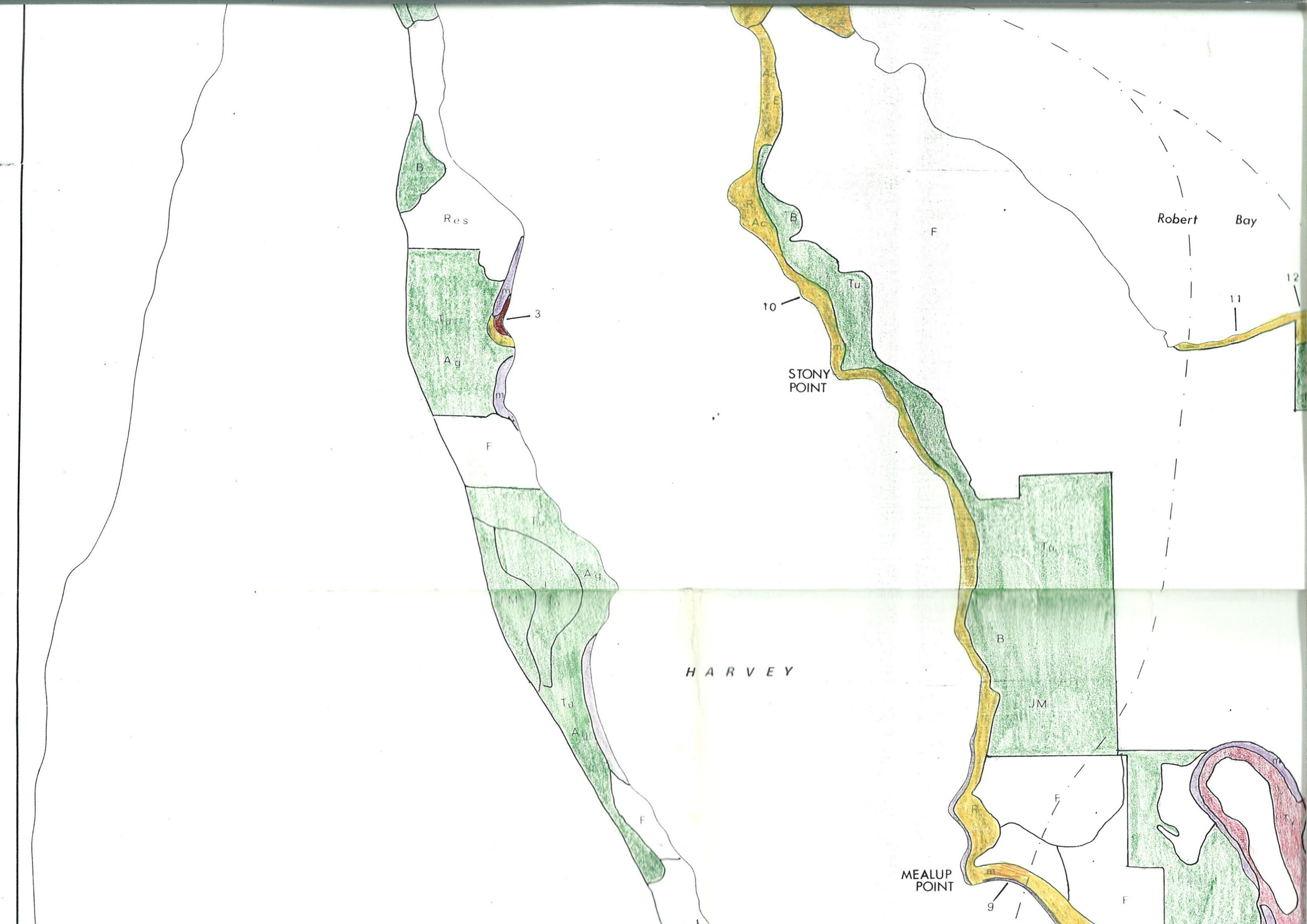
Austin Bay

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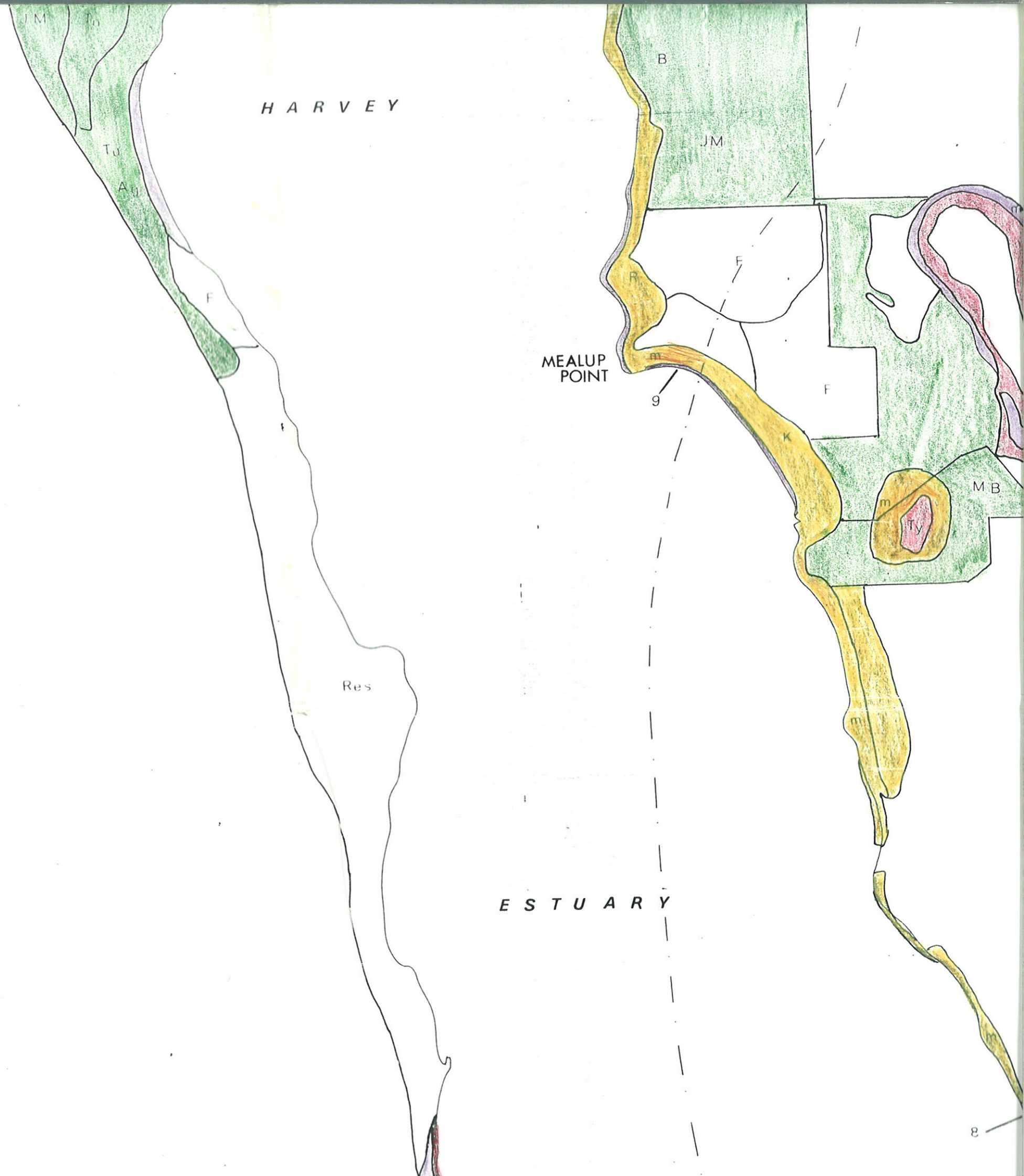
B









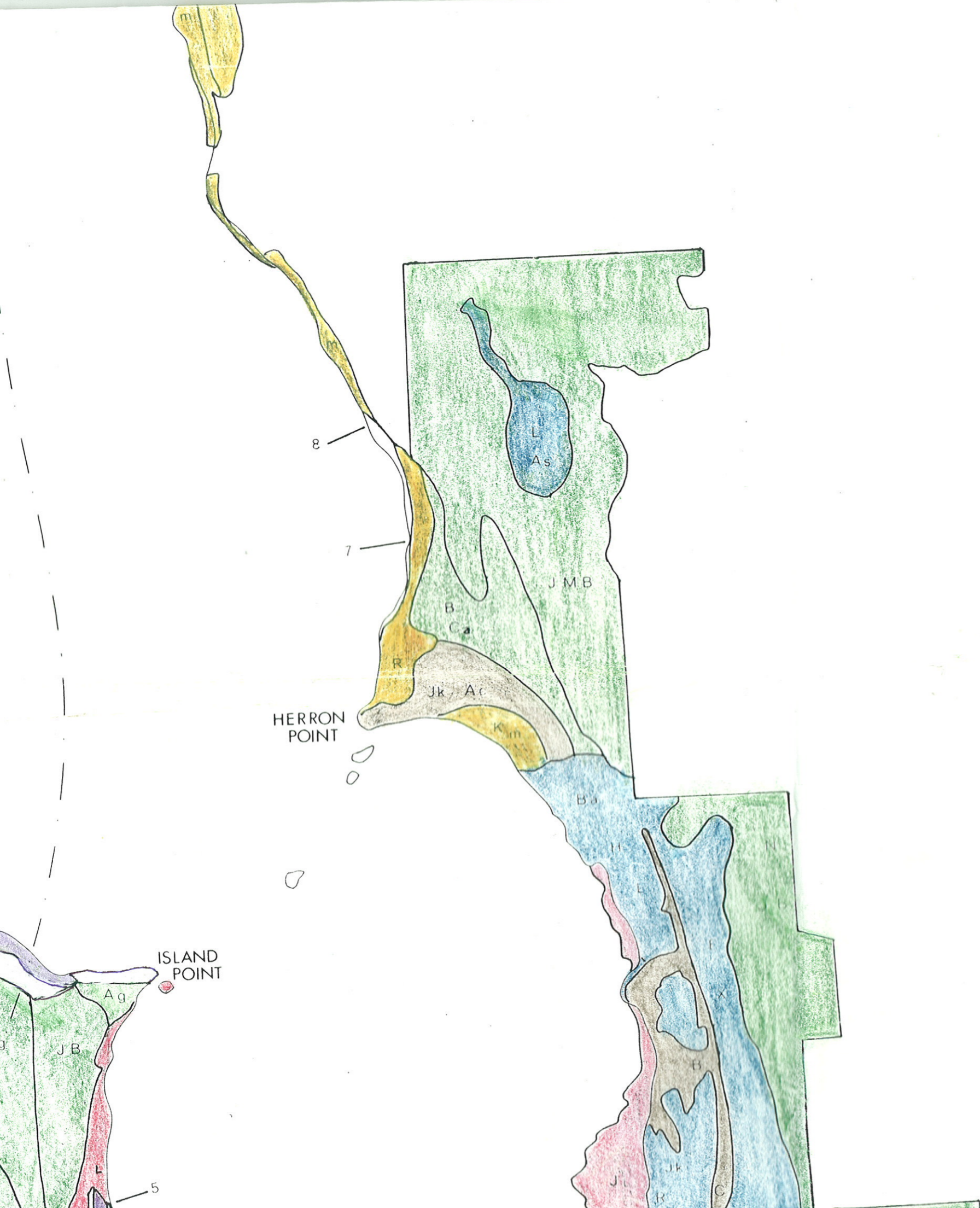


H A R V E Y

MEALUP POINT

E S T U A R Y

Res



ESTUARY

8

7

HERRON POINT

ISLAND POINT

5

m

F

m

4

A g

F

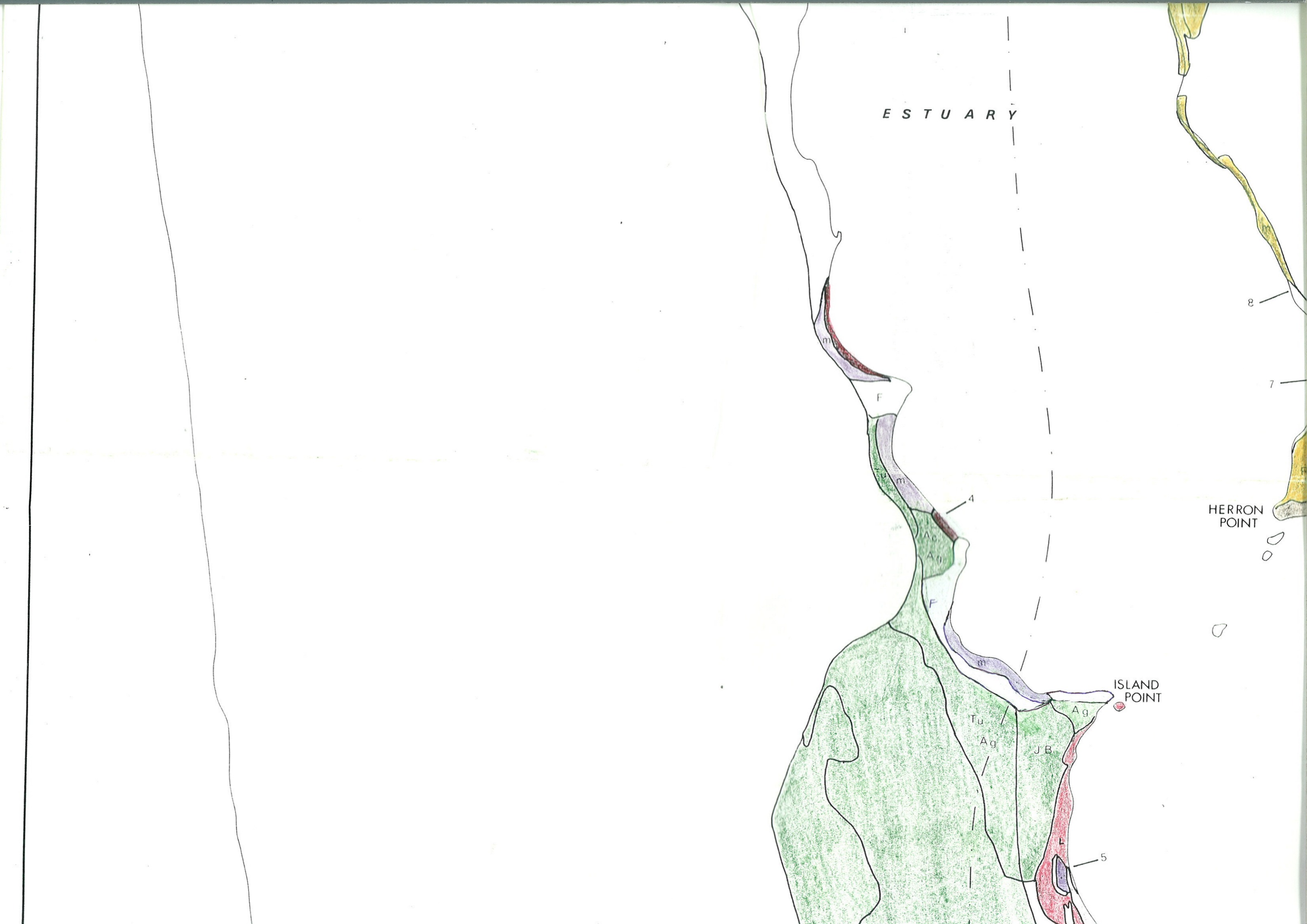
Tu

A g








J B

A g

L





	LOW CLOSED FOREST
	WOODLAND
	LOW OPEN WOODLAND
	LOW OPEN WOODLAND + CLOSED HEATH
	CLOSED SCRUB
	OPEN HEATH
	SEDGELAND
Sp	SPEARWOOD DUNE SYSTEM
Bs	BASSELIDEAN DUNE SYSTEM
Pj	PIJARRA PLAIN SOILS

