THE ECOLOGY OF DIATOM EPIPHYTES OF ZOSTERA sp. IN THE ONKAPARINGA ESTUARY, SOUTH AUSTRALIA (1974 - 1977)

by

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Thesis submitted to the University of Adelaide

for the degree of Doctor of Philosophy

JULY, 1978

CONTENTS

SUMMARY

This thesis reports the results of a series of interconnected studies of diatom periphyte (cells associated with plant substrates) assemblages from the Onkaparinga estuary, South Australia (June 1974 - February 1977). The Onkaparinga is a shallow, coastal plain estuary rather than a deep, drowned valley estuary such as those investigated on the Australian east coast. The estuary includes three general regions, the central of which is delineated by the dominance of a species of the "eelgrass" Zostera (Potamogetonaceae). The Zostera blades serve as substrates for a diverse diatom periphyton flora and these assemblages form the basis of the study.

Limitations of computing space and time meant that only the 95 most common diatom species could be considered for analyses. The remainder of the 254 species so far observed were also considered too uncommon to provide any meaningful addition to the data being considered. Of the 95 species considered, all are illustrated by light or scanning electron micrographs and comments on their taxonomy and ecology are given. In addition, 22 species which may be as yet undescribed are included.

An appraisal of the taxonomy and ecology of the Zostera sp., particularly the role of Zostera blades and the periphyton in assisting silt deposition, is included.

To provide a comparison with studies reported from the northern hemisphere and to place field collections in a temporal framework with respect to the periphyton colonisation sequence, the colonisation sequence was observed using both natural and artificial substrates. The colonisation sequence was seen as a four stage process involving initial colonisation by bacteria and Cocconeis scutellum, colonisation by epiphyte species and the most common motile species, further colonisation by motile species once epiphyte filaments form and finally, emergence of macroscopic algae and sessile animals as obvious parts of the periphyton. The first two

stages occur in the first three days. The epiphytes appear to reach a balance between colonisation, growth and loss somewhere from the fourteenth day onwards. The new substrates provided by the production of new ("juvenile") Zostera blades are likely to be colonised by the periphyton from older blades. The older blades were also considered to be the site for initial colonisation of species new to the assemblage.

The 95 species were analysed on the basis of presence and absence data. Bivariate associative analysis indicated the presence of five nodes containing 64 species, 47 of which were contained in one group and many of those were known to be freshwater species. To elucidate between node relationships, the 64 species were analysed using Factor Analysis. The analysis indicated a curvilinear relationship between the species groups which derived from correlation with salinity and position in the estuary.

Further investigations concentrated upon the epiphyte (attaching) species since they are easy to identify in preserved material, are dominant members of the periphyton but involve few species, and are the only group evolved to live attached to hard substrates. The periphyton was observed to reach maximum cell densities during the winter rather than there being a peak in late autumn and another in early spring as reported from cool to cold temperate climates. Both in the motile and epiphyte (attached) groups, only a few species were observed to be the major contributors to the cell density maxima.

An environmental data base, including temperature, light, salinity and various organic and inorganic compounds, was obtained. This was used to analyse the possible relationships of selected aspects of the periphyton (total cells, total motile cells, total epiphyte cells), individual epiphyte species and the physico-chemical environment. Factor analysis indicated four significant sources of variance in the environmental data. These included the organic or biologically produced variables, a

combination of salinity and position in the estuary, seasonal variance and the inorganic variables. Factor analysis of the environmental data with individual species and bivariate analysis between species and various environmental variables was then carried out. The analyses indicated that there were three groups of species which were related within the groups by their correlations with the environmental variables. The freshwater group were only of importance in very wet winters (e.g. 1974) but, when present, were the most productive. The euryhaline group which dominated the winter assemblages for most of this study were strongly correlated with high levels of inorganic and organic compounds, particularly nitrogenous compounds. In addition, they were apparently able to live in a broad range of salinities and were therefore available to benefit from nutrients entering the estuary with freshwater runoff. The third group was composed of marine species which were correlated with salinity to the exclusion of most other variables.

The same samples were used as a basis for a comparison between using cell densities and species' proportions for analysis of assemblage dynamics. The difference between species' proportions based on viable cells and cleared cells was also investigated. Correlational analyses between environmental variables and species' proportions yielded some questionable results. Interspecific associative analyses also gave variable interpretations when based on species' proportions. Cleared cell studies added further uncertainty by the presence of species which were not part of the living assemblage at the time of sampling.

Finally, suggestions are made regarding the study of hydrological and biological aspects of the estuary which could provide further useful information about the ecology of estuarine diatoms.

DECLARATION

This is to certify that the material contained in this thesis is the work of the author except where otherwise acknowledged and has not been accepted for the award of any other degree or diploma.

David Perry Thomas

ACKNOWLEDGEMENTS

I am indebted to Professor H.B.S. Womersley who allowed me to venture into an area of research about which there is little knowledge in Australia. Once I had overcome some of the initial problems due to lack of familiarity with the subject, he then ensured that I kept my growing enthusiasm for diatom research to within the bounds of my project and frequently has provided useful criticism leading to a clarification of my ideas.

Other members of staff of the Botany Department, University of Adelaide were helpful at various times, particularly Dr G.G. Ganf who introduced me to various aspects of limnology, many of which were of use in the Onkaparinga study. Dr D. Steffensen of the E. & W.S. laboratories at Bolivar, with experience of the Avon-Heathcote estuary in New Zealand, provided me with valuable insight into some of the problems of estuarine research.

Two overseas scientists have been helpful to me by their encouragement, interest in my study, and comments on the research of both themselves and their students. They are Dr F.E. Round from Bristol University, U.K. and Dr C.D. McIntire from Oregon State University, U.S.A.

My parents, Mr and Mrs H.D. Thomas, gave of their time and resources to assist in the carriage and handling of field equipment, and with the rest of my family, have never failed to encourage me at all times.

Finally, this thesis is dedicated to my wife Ruth, without whom this project could not have been attempted and whose support and assistance has been invaluable.

1. GENERAL INTRODUCTION.

1.1. The Onkaparinga estuary.

The Onkaparinga river arises in the Mt Lofty Ranges, east of Adelaide, South Australia, and flows about 60 km south-west through the ranges before entering the Noarlunga basin 35 km south of Adelaide (FIG. 1). With a catchment area of approximately 535 km^2, the Onkaparinga is the next largest permanent river in South Australia after the Murray River[1]. There are two storage reservoirs at present supplied by the Onkaparinga, viz. Mt Bold reservoir (capacity 47,300 megalitres) on the river and Happy Valley reservoir (capacity 12,700 megalitres) supplied from a weir at Clarendon downstream from Mt Bold[1]. These dams reduce the effective catchment area for the Onkaparinga estuary to 88 km^2, much of it in the 500 mm to 660mm zone of annual rainfall (Ward 1966). Major water flow or flooding can only occur after Mt Bold is full and flow occurs over the spillway. In the past this has not occurred until late October or early November, usually requiring two consecutive years with at least 700 mm per annum to adequately fill the reservoir. The increasing population and resultant water demand in the last two decades suggests that the frequency of such flows is likely to diminish with time, regardless of the volume of winter rainfall.

The first Europeans to visit the coastal plain end of the Onkaparinga river in 1839 were displeased to discover that the river was salty where it emerged from the Onkaparinga gorge (Colwell 1972). Later investigation showed that the river was tidal and hence often saline back to the Onkaparinga gorge.

This knowledge was used to good effect a decade later when a flour mill of 2,000 bushels/week capacity was established at Noarlunga and sailing

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1. Hosking, Fargher and Oborn Pty Ltd (1974). "A report on the scientific and engineering aspects of planning proposals for Onkaparinga Estuary Recreation Reserve prepared for the South Australian State Planning Authority". Unpublished. 46 pp. & Appendices.

barges of twenty tons capacity were able to travel up from Port Noarlunga on the spring high tides to deliver grain and backload flour. Small craft plied the estuary more frequently to service the brewery and various other small industries centred in Noarlunga. Smuggling was another aspect of the business life of Port Noarlunga and the Onkaparinga in those early days. The goods mainly came from Kangaroo Island by way of the whalers and sealers and were unloaded up the river to avoid the port authorities (Colwell 1972). When the port facilities nearer to Adelaide were improved, Port Noarlunga went into a decline as Adelaide enticed most of the industry away. For most of the first half of the twentieth century, the Noarlunga region has been a place for holiday-making or retirement.

Until the nineteen-sixties the population of the coastal plain in the Noalunga district was therefore moderately low. The southward expansion of the Adelaide metropolitan area has finally reached this region and industries are once more being attracted to the area. The population increased from 5,492 in 1961 to 28,462 in 1971 (S.A. Yearbook 1973) and is estimated by the South Australian State Planning Office to reach 156,000 by 1991, a twenty-eight fold increase in thirty years. The estuary is therefore looked upon by the S.A. State Planning Authority as a valuable recreational resource. It was this interest in the estuary which stimulated the initial study of the aquatic flora which led to this study.

The Onkaparinga estuary meanders to the sea in a channel cut in Holocene alluvial deposits of various ages (Ward 1966) and is thought to have been laid down by the Onkaparinga when the mouth of the river was much nearer the foothills than it is now, due to a higher relative sea level. The whole is contained within a tectonic basin bounded by faults stemming from the lower Tertiary (Parkin 1969). The Onkaparinga is different from most of the estuaries so far studied in Australia as these are mostly drowned valleys, broad and variable in shape, sometimes contributed to by several rivers (Rochford 1951) and not composed of a river channel cut into the coastal plain. The Onkaparinga also has the distinction of having the largest estuary between

the Glenelg River in south-western Victoria and the Blackwood River in south west Western Australia, a coastline of approximately 5,000 km.

The estuary can be divided into three general zones derived from geological, hydrological and biological considerations. These approximate Rochford's (1951) divisions of fresh, marine and "conflict" zones (see Ch. 5.4).

The first zone, 0-1.7 km downstream from the ford at Noarlunga (FIG. 2), has many of the characteristics of the non-tidal reaches of the river (FIG. 3A,B). One side of the channel follows the slope of the hill down to as much as four metres below the river level. The deeper pools are inter-connected by shallow stony riffles. Reeds fringing the channel provide the only obvious vegetation, as they do upstream, and provide attachment for occasional mats of Enteromorpha compressa (L.) Greville, Cladophora repens? (J.Ag.) Harvey, Spirogyra transeauana Jao and Spirogyra sp. aff. maravillosa Transeau.

The deeps are used for spawning by Black Bream (Acanthopagrus butcherii (Munro)) and Jumping Mullett (Liza argentea Quoy & Gaimard). Otherwise this region is largely defined by the continuous influence of freshwater inflow regardless of the season. Surface salinities seldom exceed 15 p.p.t. of total dissolved salts and the upper pools are occasionally visited by freshwater fish such as Redfin Perch (Perca fluviatillis Linnaeus), Brown Trout (Salmo trutta Linnaeus) and Native Trout (Galaxias attenuatus (Jenyns))[2].

The second section covers the majority of the estuary from 1.7 km to 10.3 km downstream from the Noarlunga ford, thus encompassing the flood plain with the channel broad and shallow (FIGS 4,5). The bends are usually the deepest areas with the bulk of the water flowing in a gutter on the downstream side of the reaches. This is then flanked on the upstream side of the channel by a mud bank extending from 0.5 m to 1 m below mean low water at the gutter to above mean low water level at the edge of the channel. These mud

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2. Branden, K.L., G.G. Petersen & P.A.K. Symons (1974). "The Aquatic Fauna of the Onkaparinga Estuary". Report to the Department of Fisheries, South Australia. (Unpublished) 16 pp & Appendices.

banks are largely colonised by a species of Zostera (FIGS 2,6; Ch.3.). The substratum varies from carbonaceous, anaerobic, fine silts at Noarlunga to sand at Port Noarlunga. It is the distribution of Zostera which characterises this region and delineates the second region from the third by its absence in the third. This middle region is also characterised by the presence of a fauna and flora associated with and reliant upon the Zostera. Sprat of Black Bream, Jumping Mullett, Yellow Eye Mullett (Aldrichetta forsterii (Cuvier & Valenciennes)), Spotted Whiting (Sillago bassensis (Cuvier & Valenciennes)) appear to live most of their lives in this region until they are mature or unless flushed out by freshwater during floods. The adults of these and other local pelagic fish come into the estuary from the sea with the incoming tide and feed in the Zostera beds. Some, such as the Black Bream, feed on the Zostera epiphytes only and others appear to feed omnivorously and include Zostera blade, epiphytes and associated invertebrates in their diets[2]. The salinities here range from less than 1 p.p.t of total dissolved salts during floods to the more usual range of 15 p.p.t. and up to salinities in excess of normal seawater in some of the lower reaches during the summer (often reaching 39 p.p.t.).

The third region extends from 10.3 km downstream to the mouth of the estuary at approximately 11 km downstream from Noarlunga ford. The upstream boundary is marked by a footbridge (FIG. 7A) and the channel shallows generally from this point to less than 1 m below mean low water until it deepens again at the narrow mouth (FIG. 7B). Under the cliffs, the substrate is composed of a red clay which gives way to sand a few metres from the edge of the channel. This region is inundated with normal seawater every day unless there is severe flooding from heavy rains further upstream. The Zostera does not grow here, but whether this is due to continuing high salinities or whether the shallowness of the channel creates currents which are too strong

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2. Branden, K.L., G.G. Petersen & P.A.K. Symons (1974). "The Aquatic Fauna of the Onkaparinga Estuary". Report to the Department of Fisheries, South Australia. (Unpublished) 16 pp & Appendices.

for colonisation is not known. This is in many respects a biological desert in comparison to the upper reaches, both plants and animals being carried through by the current with nothing but shifting sand upon which to settle. The salinities are usually maintained near to those of seawater (36-37 p.p.t.) and this is probably the only region of the estuary to get a complete change of water between each high water.

In common with other South Australian estuaries, the mouth of the Onkaparinga has been blocked from time to time by a sandbar. Such a situation occurs regularly and semipermanently with rivers such as the Inman and Hindmarsh which would have otherwise offered similar environments to the Onkaparinga. A species of Zostera has been collected from both these rivers (Zostera muelleri (?) coll. 9.11.1928, J.B. Cleland (AD) according to den Hartog, 1970) but there has been no evidence of the continued existence of Zostera over the last three years (personal observations). The mouth of the Onkaparinga does not appear to have been blocked since early in the 1960's when for several summers blockage occurred and the water appeared to stagnate. Local residents were inconsistent in their estimates of how frequently this had happened in the past.

In conclusion the Onkaparinga estuary comprises an environment which does not appear to be common elsewhere in Australia. Its topography and largely winter freshwater flow leaves it having more in common with estuaries such as the Kowie estuary in south-eastern South Africa (Giffen 1970) than it does with those of south-eastern Australia where the precipitation is much higher. A comparison between the species described in Chapter 2. and those described by Giffen (1970) shows a marked similarity between the South African estuarine diatom flora and that of the Onkaparinga estuary.

1.2. Aims and history of periphyte research.

1.2.1. Epiphyton or periphyton?

A precise definition of what to call the biocoenoses that develop in association with various types of substrate has eluded aquatic ecologists for more than 50 years.

Many terms have been suggested over the years, mostly of German origin, such as "Nereiden" (Gams 1925), "Aufwuchs" (Seligo 1905), "Bewuchs" (Hentschel 1916) and "Periphyton" (Behning 1928). Cooke (1956) has given a good review of the origins of these terms and it is not proposed to repeat his review here.

English workers and some European workers have preferred to use "benthos" in the general sense (Abdin 1950; Douglas 1958; Lund & Talling 1957; Round 1971) to differentiate such communities from the plankton. In reviewing the terminology, Sládečková (1962) considered that "benthos" was more likely to be interpreted as those communities associated with the bottom, i.e. sediments or rock, and not with substrates generally.

The issue of what terminology to use has been further confused not only by the plethora of terms but by individual authors using particular terms with different implied or defined meanings. For example, "Aufwuchs" can mean communities associated with substrates of various types, as originally intended (Seligo 1905) or more narrowly as communities specifically associated with plant substrates (Naumann 1931). A similar problem arises from the wide use of the term "Periphyton". In the strict sense of the word it should imply organisms associated with plant substrates only, not as originally intended by Behning (1928) and supported by Sládečková (1962) as plants ("phyton") living associated with some undefined substrate. However in the same paper Sládečková (1962) used the groups "epiphyton", "epizoon", "epilithon" and "epipelon" for communities which develop upon plants, animals, rocks and sediment respectively, that is, in the strict sense of the term used.

The epithets "epi-" and "peri-" have been frequently confused partly due to confusion over periphyton and epiphyton. For the purpose of this study

then, it is proposed to use the following terminology.

Periphyton: The community of organisms associated with plant substrates. This includes "epiphyton" and to some extent the "peripelon" (see Ch.4.3.).

Epiphyton: This term is reserved for the organisms which are actually attached to a plant whether by cell to cell contact or by use of a stipe or pad of extruded material.

In a similar manner "peri-" could be used for any community associated with a particular substrate and "epi-" can be retained for those organisms which are actually attached to the substrate, a specialised subgroup of the overall community. In the generalised sense all communities associated with substrates could continue to be called "benthos" as favoured by Round (1971) or, following the lead of Šrámek-Hušek (1946), use the term "periholon" for substrate associated communities and "epiholon" for attaching communities.

1.2.2. Aims of periphyte research.

The first diatoms described were periphyton species (Müller 1773) but the major interest of the early investigators was in the study of plankton species as an integral part of general fisheries research. Most of the early ecological studies were therefore plankton orientated and many of the community concepts were developed with respect to plankton organisation. It was not until the second quarter of the Twentieth Century that attention was focused upon the periphyton and the benthos generally as being worthy of more than just taxonomic investigation (e.g. Phifer 1929; Carter 1932-1933; Ghazzawi 1933; Godward 1934). These authors attempted to correlate species' distributions between samples with broad environmental variations and this approach has changed very little since, except for the advent of multivariate analytical techniques. There have been few investigations of the permanently submerged periphyton assemblages as the majority of reports have dealt with the more easily sampled littoral or eulittoral regions of lakes (e.g. Godward 1937; Brown & Austin 1973), estuaries and coasts (Carter 1932-1933; Ghazzawi 1933; Castenholz 1963,1967; Edsbagge 1965; Evans & Stockner 1972; Hopkins 1964; Hustedt & Aleem 1951; Main & McIntire 1974; McIntire & Overton 1971). The heritage from plankton studies is evident from the two basic conceptual frameworks from which periphyton investigations have been approached.

Taxonomic studies led naturally to investigations of the distributions and co-distributions of species and eventually to interest in the species' structure of different assemblages and how these differ with different environmental conditions. The interest in pollutants of aquatic systems has led to a variety of indices which attempt to "quantify" differences between assemblages. Nearly all rely on the concept of a "healthy" system being that with the maximum variety of genetic information as measured by diversity of genera and species. The community structure approach includes studies of colonisation and succession of selected assemblages but these have usually been carried out upon artificial substrates (e.g. McIntire & Wulff 1969; Aleem 1958;

McIntire & Overton 1971; Brettum 1974; Hendey 1951; Wood 1950,1955). It is likely that the concern over fouling of ships which led to the investigations of Aleem (1958), Wood (1950,1955) and Hendey (1951), together with the development of the "diatometer" to collect periphyton species (Patrick et al. 1954; Patrick & Hohn 1956), has stimulated far more interest in attaching communities than might have otherwise occurred.

The alternative approach to periphyton study is derived from an interest in community or system production and the environmental factors which affect the potential production of any assemblage (Allanson 1973;H.Allen 1971; Hickman 1971; Hickman & Klarer 1974,1975; Mason & Bryant 1975; McIntire 1966; McIntire & Phinney 1965; Newcombe 1949). This approach to aquatic ecology was developed to study plankton, where the majority of production at any time is often provided by only a few species. In periphyton assemblages such a situation is not so common and as many as ten to fifteen species may be "co-dominant". There is therefore always the potential for loss of useful information in the study of production if the species present are not analysed. It is conceivable that two samples containing two different sets of species would give the same estimates of production under two different sets of environmental conditions (see Ch. 6.).

Periphyton, as with other substrate associated assemblages, has been recognised as valuable in monitoring aquatic environments, particularly in shallow and flowing systems. Unlike the plankton, benthic assemblages do not float away with the water but remain to be resampled later. To follow the dynamics of the assemblage does not therefore require the refinding of the body of water first sampled. The ecological disturbance caused by some change in the environment can therefore be monitored at various distances from the source by permanent assemblages which respond to short and long term disturbances, the effects of which might not be picked up by a study of the plankton. The need to monitor and understand the effects of increasing human interference upon aquatic systems has given a sense of urgency to the study of both

natural and polluted waters, with particular reference to the benthic assemblages.

Estuaries have been forced to bear the brunt of much of the world's industrial pollution, recieving pollutants both from upstream and from communities formed on their banks. At the same time, many of the world's estuaries are important in coastal fisheries, either as hatcheries or as the site for the fishery. A few, such as Chesapeake Bay in the U.S.A., support a multi-million dollar fishing industry with a vested interest in keeping the estuary productive.

The estuarine environment is very complex and therefore of interest regarding the ecological adaptations required of the organisms which either live there permanently or for varying periods of time. There is the need to study and understand the dynamics of natural assemblages of species in an estuary, or any other system, before an understanding can be gained of the changes brought about by pollution in one form or another. In addition, the techniques and methods used must produce meaningful results that will not mislead the investigator (see Ch. 6.).

This study contributes to both the understanding of periphyton dynamics in the estuarine environment, as represented by the Onkaparinga estuary, and the value of some of the methods used in research on the diatom periphyton.

1.3. Aims of the project.

This study was organised to investigate various aspects of the diatom periphytes (particularly the epiphytes) of Zostera blades from the sublittoral of the estuary. Samples were collected from June to November, 1974 and from March 1975 to February 1977. The sublittoral was chosen in contrast to the intertidal study of Main & McIntire (1974), and it was recognised that time would not permit investigation of the complex effects of emergence which would be part of an intertidal study. In addition, the method of estimating blade and community age relied on information based on permanently submerged blades.

It was first necessary to observe the seasonal changes in the periphyton assemblages and determine the sampling frequency which could be most informative without being too time consuming. The initial period between sampling was two weeks. This tied in with the samples being taken from blades which had been available for colonisation for two weeks.

Samples were taken while the assemblages were still developing, so that the colonisation sequence through to the "mature" assemblage could be investigated (see Ch. 4.). This was also necessitated by the few reported studies on colonisation by diatoms, particularly of natural substrates. The studies using artificial substrates emphasised the role of plankton as a source of colonising cells. Such a result would be expected due to the lack of alternative sources. The Zostera blade is in close proximity to the other already colonised blades, the plankton, and the peripelon which could move up off the sediments. Only the more mature communities and the plankton were likely to provide a source of new epiphyte species (the basis of most of this study) and were therefore sampled to observe any relationships between the new assemblages and these potential sources of colonising species.

The epiphytes were chosen for close study because they were derived from a few, easily recognisable species which formed a major component of the periphyton. Unlike the motile species, the epiphyte

species had also evolved to be dependent upon solid substrates such as the Zostera blades. Thus the Zostera samples were likely to be representative of the distribution and abundance of epiphyte species. This could not be said of the motile species where sediment samples would probably give a better appraisal of their distributions.

The 14 day old assemblages were then sampled to permit a comparison between various physico-chemical environmental parameters (representing the ambient environment at the time of sampling) and selected aspects of the periphyton, particularly the common epiphyte species (see Ch. 5.). Viable cell densities were chosen as the most convenient biomass estimate. Other aspects, such as total cell volume, would probably have been equally informative, though giving a different bias to various species. The emphasis was to get the most meaningful information from the samples. Further information such as species' proportions in both viable and cleared cell samples, and presence and absence data from cleared cell samples were also obtained. These were then compared with the information derived from viable cell densities to investigate to what extent the type of assemblage indicator affects the implied environmental and interspecific relationships. Such a basic investigation had, apparently, not been reported for diatom samples, despite the wide use of cleared cell proportions as a basis for diatom studies.

Finally, an aspect which is partially recognised in Chapter 2 is the use of the diverse estuarine flora including freshwater and marine species, as the basis for a register of Australian diatoms which includes the previous records (if any), distribution and description of all species observed. This is necessitated by the paucity of publications describing diatoms from the Australasian region. Some descriptions of species from Australian collections can be found in a few European publications (e.g. Castracane 1886; Schmidt et al. 1874-1959). The most intensive studies have been of the fossil diatoms of the Oamaru deposits in New Zealand (Doig 1962a,b; Grove & Sturt 1886, 1887a,b,c; Latour 1888; Reed 1958;

Schrader 1969) and of some of the Australian diatomite deposits (e.g. Crespin 1947; Skvortzow 1937). Marine and estuarine recent diatoms described by the late E.J.F. Wood (Crosby & Wood 1958, 1959; Wood 1961a, b, 1963; Wood et al. 1959) represent the only other studies of note. Wood's collection and slides are not generally available and would require extensive curation if found (Dr S. Jeffrey, pers. comm.). Thus the collections from this and future studies will proceed without acknowledgement to the Wood collection. A duplicate set of taxonomic slides will form series D of the Phycology herbarium, Department of Botany, the University of Adelaide (designated ADU-D).

2. THE TAXA OBSERVED.

2.1. Key to the genera encountered.

Introduction.

The following key includes all genera which have so far been observed in periphyton samples from the Onkaparinga estuary. Those genera included in the ecological study (see Ch. 2.2.) are designated by an asterisk and an alphanumeric index (e.g. G2. Melosira*) which refers to the order of treatment of that genus in chapter 2.2.

The key is dichotomous and relies entirely upon features observable in the light microscope. Use is made of published information using the Scanning Electron Microscope (SEM) in the recognition of Cox's (1975) re-erection of Berkleya Greville emend. Cox but the key uses only those features observable in the light microscope. Amphiprora is allied to Plagiotropis (Tropidoneis) and is not transferred to any of the nitzschioid groups as suggested by Paddock & Sims (1977). This is partly due to the uncertain position of Amphiprora and partly to the canal raphe system of this genus being unobservable in the light microscope.

KEY TO GENERA ENCOUNTERED

1. Cells circular to elliptical with concentric, radial or irregular structure. 2.

1. Cells linear, lanceolate to elliptical or ovate sometimes arcuate or sigmoid, structured relative to a line, radiate, parallel, convergent or irregular. 9.

2. Cells mostly discoid or cylindrical, circular in valve view. 3.

2. Cells approximately rectangular in girdle view, valves elliptical to polygonal. Valves often having elevations, ocelli, pseudo-ocelli, horns or setae. 7.

3. Valve divided into radial sections by alternating elevations and depressions. Actinoptychus

3. Valve not divided into radial secions by alternating elevations and depressions. 4.

4. Cells cylindrical, typically combined to form long or short chains. Valve wall usually thick. G2. Melosira*

4. Cells shortly cylindrical or discoid, solitary or aggregated into loose chains by mucoid strands. Valve wall generally weakly silicified. 5.

5. Cells forming chains by fine mucilaginous filaments or solitary. Valves with an obvious central pore, valve surface finely structured. Thalassiosira

5. Cells mostly solitary, valve surface distinctly structured. 6.

6. Valve with radially ribbed margin and distinct, variously structured central region. G1. Cyclotella*

6. Valve with areolate structure, not with a radially ribbed margin. Coscinodiscus

7. Cells with two long setae per valve, joined by linking at the base of the setae. Chaetoceros

7. Cells with terminal elevations in each of which is developed a pseudo-ocellus. 8.

8. Cells bipolar. Biddulphia

8. Cells tripolar. Triceratium

9. Cells without raphes. 10.

9. Cells with at least one raphe. 23.

10. Cells with conspicuous girdle septa. 11.

10. Cells without septa. 16.

11. Apical axis isopolar. 12.

11. Apical axis heteropolar. 14.

12. Cells with two paired septa, septa undulate. G5. Grammatophora*

12. Cells with numerous septa and numerous girdle bands. 13.

13. Girdle bands strikingly and distinctly structured; some septa formed across the cell. Rhabdonema

13. Girdle bands finely strucutred; septa formed only around the poles of the girdle bands. G10. Striatella*

14. Septa formed only around the apical pole of the valvocopulae. G6. Licmophora*

14. Septa formed across the cell from one side of each valvocopula to the other, not in the pole. 15.

15. Septum bridging the cell once near the apical pole. Licmosphaenia

15. Septum bridging the cell in many places. Climacosphaenia

16. Valves distinguished by strongly developed transapical ribs. 17.

16. Valves without strongly developed transapical ribs. 18.

17. Valve with a broad structureless central area bound at each end by a broad transapical rib. Ribs few. G8. Plagiogramma*

17. Valve without such a central area, ribs many. Diatoma

18. Cells forming flat, stellate colonies; valves with a narrow median axial area. Asterionella

18. Cells not forming such colonies. 19.

19. Apical axis heteropolar, striae broad and apparently not punctured. G7. Opephora*

19. Apical axis isopolar. 20.

20. Cells in girdle view with a distinct pervalvar constriction below the pole. G3. Dimerogramma*

20. Cells without a pervalvar constriction. 21.

21. Cells solitary or at most, with three cells joined together at both poles. G11. Synedra*

21. Cells forming band-like colonies. 22.

22. Valves with transapical rows of large, round areolae. G9. Raphoneis*

22. Valves ornamented differently. G4. Fragilaria*

23. Raphe brief, formed near the poles on each valve, apical axis bowed. Eunotia

23. At least one valve of each cell with a fully developed raphe. 24.

24. Only one valve of each cell with a fully developed raphe, the other valve with an unpunctured axial area or with a rudimentary raphe. 25.

24. Both valves with a developed raphe. 28.

25. Cells usually bent around the apical axis, solitary, with the raphic-valve adjacent to the substrate, never forming stalks and chains. Valve view mostly elliptical. 26.

25. Cells usually bent or reflexed around the transapical axis, solitary or forming foliose or band-like colonies. Valve view mostly linear to lanceolate, rarely elliptical. 27.

26. Cells with a conspicuous inner framework of thick silicate ribs. Campyloneis

26. Cells without such a framework. G13. Cocconeis*

27. Apical axis isopolar. G12. Achnanthes*

27. Apical axis heteropolar, upper valve with a rudimentary raphe. G14. Rhoicosphaenia*

28. Raphe set into the valve surface with the valve wall often thickened on either side of the raphe fissure, not a canal raphe system. Alternatively the raphe may be formed in the apex of a median keel or extension of the valve surface and if so, panduriform in girdle view. 29.

28. Raphe is a "canal raphe system" supported by transapical fibulae, often transapically displaced toward the valve margin, sometimes on a keel or extension of the valve surface or margin. 44.

29. Apical axis or transapical axis or both heteropolar. 30.

29. Both the apical and transapical axis isopolar. 32.

30. Apical axis heteropolar in girdle view. G20. Gomphonema*

30. Apical axis isopolar, transapical axis heteropolar. 31.

31. Apical axis slightly bowed, nearly straight. Cymbella

31. Apical axis prominently bowed. G16. Amphora*

32. Raphe formed on a keel or extension of the valve surface, mostly in the midline of the valve or sigmoid. 33.

32. Raphe formed in the valve surface, valves not distinctly keeled. 34.

33. Raphe formed on a sigmoid keel. G15. Amphiprora*

33. Raphe formed on a straight, median keel. G24. Plagiotropis* (Tropidoneis)

34. Cells with marginal septa on which septal chambers are formed ("loculiferous plates"). G22. Mastogloia*

34. Cells without marginal septa. 35.

35. Apical axis sigmoid. 36.

35. Apical axis not sigmoid (though the raphe may be sigmoid). 37.

36. Raphe fissures veering away from the midline at the central node. Puncta arranged to give the impression of two sets of lines crossing at right angles, one set of which is parallel to the apical axis. G21. Gyrosigma*

36. Raphe fissures formed straight along the midline at the central node. Puncta arranged to give the impression of two sets of lines both set obliquely to the apical axis. G26. Pleurosigma*

37. Cells twisted around the apical axis or raphe more or less sigmoid, obliquely orientated to the valve structure, the raphe of one valve crossing that of the other at an acute angle. Scoliopleura

37. Cells not twisted around the apical axis, raphe generally parallel to the valve structure. 38.

38. Raphe flanked by lateral tubes ("horn-like processes") proceeding from the central nodule to each pole and opening externally via a line of distinct puncta or areolae formed parallel to and near the raphe. G19. Diploneis*

38. Valves without such processes. 39.

39. Valves with a greatly extended central nodule, axial area broader where it surrounds the raphe. Cells usually enclosed in mucoid tubes. G17. Berkleya*

39. Cells not so structured. 40.

40. Valve wall with transapical chambers on the inside, separated by ribs. 41.

40. Valve wall punctate or transversely striate, transapical lines without obvious chambers. 42.

41. Rib interstices (the outer wall of the chamber) hyaline, broad, not obviously punctured. G24. Pinnularia*

41. Rib interstices narrow, finely or coarsely punctate. G27. Trachyneis*

42. Valve with transapical rows of puncta crossed by one or more narrow, lateral, hyaline areas. G18. Caloneis*

42. Valves without such lateral lines. 43.

43. Central area thickened and unpunctured, extended to the valve margin (i.e. a stauros). Stauroneis

43. Central area mostly limited to the centre of the valve. G23. Navicula*

44. Valves with one raphe, often displaced towards the margin. 45.

44. Valves with a raphe formed around both margins. 49.

45. Valves bowed about the pervalar axis or with transapical septa. 46.

45. Valves linear, sigmoid, or ovate to almost circular, raphe often on or near the valve margin. 47.

46. Valves bowed with the raphe formed mostly towards the ventral margin but more or less recurved towards the dorsal margin at the centre. Septa present. G30. Epithemia*

46. Valves bowed with the raphe formed on or near the dorsal margin and slightly recurved towards the ventral margin. Septa absent. G32. Rhopalodia*

47. Cells forming laminar colonies, within which the individuals glide in unison to enable colony movement. Raphe straight following the valve midline. G28. Bacillaria*

47. Cells not forming such colonies, raphe usually displaced towards the margin or totally or partially raised above the valve surface on a median keel. 48.

48. Valves with one side slightly constricted or geniculate near the centre or straight, both raphes formed on the same side of the cell, if one margin constricted than both raphes formed on the unconstricted margin. Hantzschia

48. Valves not so formed, raphes formed on or towards the diagonally opposite margins of the cell or in the valve midline. G31. Nitzschia*

49. Cells saddle-shaped, apical axis of each valve parallel to the transapical axis of the other valve. G29. Campylodiscus*

49. Cells cuneate, ovate to almost circular in valve view with nearly flat valve surfaces, apical axis of each valve in the same line. G33. Surirella*

2.2. Descriptions of and comments on the species.

The number of species investigated here was restricted to one hundred or fewer due to limitations of the computing programs used for data analyses. Such a restriction was useful because the number of taxa actually observed numbered at least two hundred and fifty. Most of these taxa were only observed in one or a few samples and in many cases were represented by one or a few valves in any one sample. To the ecologist these relatively rare species are of interest for the genetic diversity which they represent and hence the potential for change in community structure with environmental variation. However, rare species represent a large source of variance which potentially could render useless many of the mathematical tools developed to analyse the data. To reduce the numbers, presence in six or more samples was taken as the basis for inclusion of any taxon in this investigation. Most of the taxa therefore rejected were species of Navicula and Nitzschia which were likely to be peripelic species having potential distributions quite different to those implied by their occasional appearance in the periphyton. Some of the epiphyte taxa were also omitted due to infrequent occurrence, including marine species such as Climacosphaenia moniligera, Rhabdonema adriaticum, Melosira sulcata, Licmophora ehrenbergii, L. hyalina and Licmosphaenia peragallii in addition to freshwater species of Cymbella and Gomphonema.

The following notes and descriptions are set out in five phylogenetic groups with genera arranged in alphabetical order within each group. The last group is perhaps controversial as it contains both the Nitzschiaceae and Surirellaceae, two groups which at least in part appear to have close phylogenetic origins and are joined here by the common feature of the canal raphe system. Descriptions and terminology follow the outlines suggested in Anonymous (1975) and Hendey (1964). Where possible species' names follow those considered appropriate by van Landingham (1967-) or Mills (1933-1935). The species' order within genera follow their numbering in the analyses and are therefore not necessarily alphabetic.

GROUP 1: The discoid taxa.

G1. CYCLOTELLA Kûtzing 1833

Number of taxa observed: 3

Number of taxa included in study: 1

S1. Cyclotella species 2 (Fig. 8A,B)

1. Frustule.

Outline in girdle view: Rectangular-cylindrical with central undulation of valve face visible.

Length of pervalvar axis: 5-12 µm.

Chloroplasts, protoplast: Chloroplasts small, granular, 15-20 per cell.

Growth habit: Solitary or sometimes in brief chains of two to three cells. Attaches to substrates by extrusion of mucoid strands from the marginal tubes.

2. Girdle.

Shape of bands: Open bands with ligulate copulae.

Areolation or striation of bands: None evident.

Density or number of bands: (3-)4(-5).

3. Valve.

Outline: Circular.

Shape: Slightly convex. central area with a single undulation. Striae formed in depressions between costae.

Diameter: 10-18 µm.

Relative size and shape of areas: Central area takes up half to two thirds the valve diameter and is surrounded by a marginal band of radiate, alveolate striae supported between radiate costae. Valve margin and mantle marked by projections varying in size from spines to granules.

Shape of striae: The central half of each alveolate stria is composed of large punctae and the marginal half composed of very small punctae.

Special features: The central area is ornamented with broad verrucose radiate ridges.

Density of striae: 12-13/10 μm at the margin.

Tubes: Apparently located in most of the costae on the margin, one per costa where present. Structure simple, not a strutted process.

Spines: Located around the margin and mantle, rarely on the valve face. Usually one or at most two longer spines at the marginal end of each alveolus, the rest are smaller (spinules and granules) and scattered.

Shape: Conical, 0.7-0.8 μm long for the main spines, reducing to 0.1-0.5 μm long for the others.

Density: Spines 12-13/10 μm, others 54-60/10 μm.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: An euryhaline taxon found throughout the estuary both in summer and winter. The irregularity of appearance suggests that this is only adventitiously found in the periphyton and is probably planktonic in orgin.
7. Remarks: This appears to be the same as an unnamed species illustrated in Round (1970, plate 8).

G2. MELOSIRA C. Agardh 1824

Number of taxa observed: 4

Number of taxa included in study: 2

Key to taxa studied.

1. Valve face distinctly convex with a circular central area delineated by a collar of fused spines. Valve mantle not differentiated from the face. S2. M. sp.1

1. Valve face virtually flat with no collar. Cell cylindrical. S3. M. varians

S2. Melosira species 1. (Figs 8C,D; 9A,B)

1. Frustule.

Outline in girdle view: Oval-rectangular.

Length of pervalvar axis: 17-31 μm.

Chloroplasts, protoplast: Choloroplasts ovoid, 8-30 per cell.

Growth habit: Colonial. Attached to substrates or other cells by extrusion of a mucilaginous pad from within the collar. In addition to the maintenance of the maternal cingulum which causes cells to be found in pairs, this species forms long chains (sometimes of thousands of cells) by attachment between the central areas of adjacent valves.

2. Girdle.

Shape of bands: Open with ligulate copulae.

Striation of bands: Punctate striae parallel to the pervalvar axis, 65-70/10 μm. Punctae round to elongate in the pervalvar direction.

Band margins unpunctured.

Number of bands: 7-15 in maternal cingulum.

3. Valve.

Outline: Circular.

Shape: Semi-cylindrical.

Diameter: 12-40 μm inversely related to length of pervalvar axis.

Relative size and shape of areas: A narrow collar separates central and marginal areas of the valve and may enclose an area the diameter of which varies from a third of the diameter of large valves to almost the entire diameter of narrower valves.

Shape of areolae: Composed of a loculus occluded externally by a cribrum and internally by a rota. Pentagonal to sexagonal.

Arrangement of areolae: Reticulate.

Density of areolae: 20-43/10 μm at the margin and along a radius.

Labiate processes

Location: Scattered over the valve, most concentrated within the central area, forming a ring parallel to and near the edge of the

valve where it joins to the valvocopula.

Shape: Sessile, forming a slit in the internal wall and opening externally via a very brief tube.

Density: 3-4/10 µm radially in the marginal area.

9-10/10 µm radially in the central area.

Spines

Location: Scattered over the marginal area or absent.

Shape: Varying from small granules to acute, conical spines 1 µm long.

Density: 5-17/10 µm.

4. Reproduction: Auxospores intercalary, autogamous. Derived from the fusion of two out of four, flagellated gametes.
5. Resting spores: Unknown.
6. Ecology and distribution: An euryhaline taxon found in the estuary throughout the year. Maximum numbers are reached when salinities are between 10-20 p.p.t. and the ambient phosphorous and nitrogen levels are high. At such times it often forms a plankton bloom.
7. Remarks: This taxon belongs to the group of Melosira including M. nummuloides, M. varians and M. moniliformis (Crawford 1975a) having the characteristic wall structure. In girdle view species 1 resembles M. arctica, but the auxospores are very different. Alternatively it resembles M. nummuloides except for the broad collar of M. nummuloides and the loculae are not so regularly arranged. M. nummuloides also has the ring of fused spines which form a collar in this taxon and generally appears to be its nearest relative (Crawford 1975b). Specimens have been sent to Dr Crawford and he is yet to decide just what this form is or where it belongs.

S3. Melosira varians C. Agardh 1827:628

van Heurck 1896:441,fig.165,pl.18/611. Hustedt 1930 :240-242,fig.100

Crawford 1971:176-184,figs 1-28;1975a:42,figs 13-15.

(FIG. 9C,D)

Ecology and distribution: A freshwater taxon found when there is continuous freshwater flow into the estuary and then only in the upper reaches. This does not imply that M. varians is a winter species as it will be found after good summer rains and is generally abundant in the reaches upstream of the estuary throughout the year. A cosmopolitan freshwater species.

GROUP 2: The araphic taxa.

G3. DIMEROGRAMMA Ralfs in Pritchard 1861

Number of taxa observed: 1

Number of taxa included in study: 1

S4. Dimerogramma minor (Gregory 1857) Ralfs in Pritchard 1861:790

Hustedt 1959:118,fig.640. Hendey 1964:156,pl.27/12.

Denticula minor Gregory 1857:23,pl.2/35.

(FIG. 10A,B)

Ecology and distribution: A euryhaline taxon with a limited salinity tolerance, generally found in the middle reaches, moving downstream when river flow lowers the middle reach salinities below 15 p.p.t. The upper salinity range appears to about 25 p.p.t. but D. minor has not been observed in large numbers at any time. Associated with Licmophora sp.3 and Plagiogramma staurophorum (see Ch.4.3.). Also recorded from the British Isles, Europe, North America and the Caribbean (McIntire & Moore 1977).

G4. FRAGILARIA Lyngbye 1819

Number of taxa observed: 1

Number of taxa included in study: 1

S5. Fragilaria pinnata Ehrenberg 1841:415,pl.3/6,fig.8

Hustedt 1913 in Schmidt et al.1874-1959:pl.197/47-50,52-54;298/47-68, 70-74. Hustedt 1959:160-162,fig.671a-i. Haworth 1975:74,76,figs 6-13.

(FIG. 10C,D)

Ecology and distribution: A cosmopolitan freshwater taxon found in the upper reaches of the estuary when river flow drops the ambient salinity below 5 p.p.t.

Remarks: This taxon shows a similar variation in morphology to the specimens observed by Haworth (1975) in Scottish glacial sediments. The smallest frustules are of the F. elliptica Schumann type with striae composed of round to linear elliptical punctae and stria density 14/10 µm. Larger valves have progressively more slit shaped perforations in the striae and the stria density decreases to 11/10 µm with an apical axis length of 7-8 µm.

G5. GRAMMATOPHORA Ehrenberg 1839

Number of taxa observed: 2

Number of taxa included in study: 1

S6. Grammatophora oceanica Ehrenberg 1840:159;1854:pl.18/87,19/36,39/2,fig.72 Hustedt 1959:45,fig.573. Hendey 1964:170.

(FIG. 10E-G)

Ecology and distribution: An euryhaline taxon found throughout the estuary except when the river is flowing strongly. Generally found to grow best in the middle reaches of the estuary where the nutrient levels are generally high. On the coast outside the Onkaparinga river and other parts of St Vincent Gulf this species is usually replaced by G. undulata except in very sheltered areas. A cosmopolitan species of temperate waters, recorded from all the continents except the Arctic (McIntire & Moore 1977).

G6. LICMOPHORA C. Agardh 1827

Number of taxa observed: 7

Number of taxa included in study: 3

Key to the taxa studied.

1. Valves linear-cuneate. Valve surface finely striate nearly hyaline. Apical axis 100-190 µm. S7. L. flabellata

1. Valves cuneate, apical axis less than 100 µm, if narrow then coarsely striate, if nearly hyaline then broadly cuneate. 2.

2. Valves broadly cuneate, striae fine almost hyaline. S8. L. sp.3

2. Valves narrow cuneate, striae coarse, obvious. S9. L. sp.4

S7. Licmophora flabellata Carmichael ex C. Agardh 1831:41

van Heurck 1896:342,pl.31/852. Hustedt 1959:58,fig.581. Hendey 1964: 168,pl.26/5.

(FIG. 11A)

Ecology and distribution: An euryhaline taxon with a preference for salinities higher than 15 p.p.t. and usually found in the middle to lower reaches of the estuary.

Remarks: Of interest is the presence of slits (rudimentary labiate processes?) on either side of the pseudoraphe. These have also been noted by Giffen (1970) in his description of L. pfannkucheae, a closely related species (Giffen 1970:278-9,pl.3/41,42). A cosmopolitan species recorded from all the continents except Africa and the Arctic (McIntire & Moore 1977).

S8. Licmophora species 3 (Fig. 11B,C)

1. Frustule.

Outline in girdle view: Cuneate

Length of pervalvar axis: 17-30 μm at apical pole, 4-5 μm at basal pole.

Protoplast, chloroplasts: Chloroplasts numerous, granular, usually clustered in the top two-thirds of the cell.

Growth habit: Forms finely foliose colonies, each cell extruding a long, narrow, mucoid stipe (approx. 100 μm x 3-4 μm) from the basal (narrow) pole.

2. Girdle.

Shape of bands: Open, varying from 2 μm broad at the basal pole to 4-5 μm broad at the apical pole.

Striation of bands: Finely punctate striae directed parallel to the pervalvar axis (56-57/10 μm).

Number of bands: 3 increasing to 5 prior to division.

Septum formation: A marginal septum is formed in the apical pole of the valvocopula and extends 4-5(-8) μm into the cell at the apical pole. From there it tapers toward the margin on either side to form a ridge within 10-12 μm from the apical pole and is present as such on the inner surface of the rest of the band.

3. Valve.

   Outline: Clavate with the basal pole capitate-produced.

   Shape: Convex with an almost flat valvar-plane.

   Dimensions: Apical axis 40-52 μm, transapical axis 7-10 μm.

   Relative size and shape of areas: Striae cover the entire valve surface except for the median axial area (pseudoraphe) which extends from pole to pole and is 0.8 μm broad.

   Shape of striae: Fine punctae formed so close together that they almost form narrow, straight slits.

   Arrangement of striae: Parallel. The striation is sufficiently fine for the valve to appear hyaline in the light microscope.

   Density of striae: 37-38/10 μm.

   Apical pore fields: A series of 10-16 slits in the margin of the basal pole form the Licmophora version of an apical pore field. The slits are 0.5-0.6 μm long and directed parallel to the pervalvar axis.

   Labiate processes

   Location: On one edge of the axial area 1-2 μm from the basal pole.

   Shape: Ovo-triangular, transapically directed. Opens flush with the exterior of the valve. One per valve.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: Marine to euryhaline taxon, usually present when salinities are greater than 20 p.p.t.

S9. Licmophora species 4 (Figs 11D,12A)

1. Frustule.

Outline in girdle view: Cuneate with the valve margin briefly recessed at the apical (broader) pole.

Length of pervalvar axis: 30-42 μm at apical pole, 4-5 μm at basal pole.

Protoplast, chloroplasts: Chloroplasts numerous, granular, clustered in top two-thirds of cell.

Growth habit: Forms finely foliose colonies, each cell extruding a long, narrow mucoid stipe (usually broader in girdle view than in valve view) from the basal pole.

2. Girdle.

Shape of bands: Valvocopula open, linear. Copulae, when present, open, broader at apical pole than at basal pole, usually formed as part of the cell expansion prior to division.

Striation of bands: Pervalvar directed, parallel striae either side of the septum on the valvocopulae and across the breadth of the band on the copulae. Striae 43-44/10 μm.

Number of bands: 3-5.

Septum formation: A marginal septum is formed in the apical pole of the valvocopula and extends 2-3 μm into the cell at the apical pole. From there it tapers toward the margin on either side to form a ridge within 4-5 μm from the apical pole and is present as such around the inner surface of the rest of the band.

3. Valve.

Outline: Clavate with the basal pole narrow, capitate-produced.

Shape: Convex with an almost flat valvar plane.

Dimensions: Apical axis 60-82 μm, transapical axis 7.6-8.3 μm.

Relative size and shape of areas: Striae cover the entire valve surface except the median axial area which extends from pole to pole and is 3.0-3.5 μm broad.

Shape of striae: Composed of a line of apically directed slits (0.45 μm x 0.12 μm).

Arrangement of striae: Parallel.

Special features: Density of striae differs between the two sides of the valve so that the striae vary from alternate at the basal pole to opposite three-quarters of the way along the valve towards the apical pole. Density of slits per stria 57-58/10 μm. Density of striae 15-16/10 μm.

Apical pore fields: A series of 6-7 slits in the margin of the basal pole form the Licmophora version of an apical pore field. The slits are 0.1-0.2 μm long and formed parallel to the pervalvar axis.

Labiate processes

Location: In the centre of the axial area, 1-2 μm from the basal pole and 0.5-1.0 μm from the apical pole.

Shape: Hemispherical with a linear slit directed away from the apical axis.

Density: One at each pole.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: Euryhaline, does occur in water of less than 15 p.p.t. salinity but grows best in the 25-35 p.p.t. range.
7. Remarks: Comparison with electron micrographs of L. ehrenbergi forma grunowii (Okuno in Helmcke & Krieger 1970:vol.7,p.16,pl.669-670) indicate a close affinity with this species by way of the type of stria structure.

G7. OPEPHORA Petit 1888

Number of taxa observed: 1

Number of taxa included in study: 1

S10. Opephora martyi Héribaud 1902:43,pl.8/20

Hustedt 1959:135,fig.654.

(FIG. 12B)

Ecology and distribution: The occurrence of this taxon in the periphyton is very erratic suggesting perhaps a planktonic lifestyle with probably freshwater affinities due to its appearance after the river has been flowing strongly.

G8. PLAGIOGRAMMA Greville 1859

Number of taxa observed: 1

Number of taxa included in study: 1

S11. Plagiogramma staurophorum (Gregory 1857) Heiberg 1863:55

Hustedt 1959:110,fig.635.

Denticula staurophora Gregory 1857:24,pl.2/37.

(FIG. 12C)

Ecology and distribution: A marine to euryhaline taxon often associated with Dimerogramma minor and Licmophora sp.3 (see ch. 4.3.) and usually found in the middle to lower reaches of the estuary. Also recorded in the British Isles, Europe, North America and the Caribbean (McIntire & Moore 1977).

G9. RHAPHONEIS Ehrenberg 1844

Number of taxa observed: 1

Number of taxa included in study: 1

S12. Rhaphoneis surirella (Ehrenberg 1840) Grunow in van Heurck 1880 var. australis (Petit 1877) Grunow in van Heurck 1880: Atlas pl.36/276

van Heurck 1896:330,pl.10/398. Hustedt 1959:174,fig.679d.

R. fasciolata var. australis Petit 1877:vol.3,p.174,pl.4/6.

(FIG. 12D)

Ecology and distribution: A marine to euryhaline taxon occurring in salinities above 20 p.p.t. and therefore collected in the middle to lower reaches of the estuary.

G10. STRIATELLA C. Agardh 1832

Number of taxa observed: 1

Number of taxa included in study: 1

S13. Striatella unipunctata (Lyngbye 1819) C. Agardh 1832:61

Hustedt 1959:32-33,fig.560.

Fragilaria unipunctata Lyngbye 1819:183,pl.62/G.

(FIGS 12E,13A)

Ecology and distribution: A cosmopolitan marine to euryhaline species growing best in salinities of 30 p.p.t. or more.

G11. SYNEDRA Ehrenberg 1830

Number of taxa observed: 6

Number of taxa included in study: 4

Key to included taxa.

1. Valves with two marginal axial areas, no median axial area. S17. S. fulgens

1. Valves with a single median axial area. 2

2. Valves with a large unstructured central area reaching to the margin. S14. S. pulchella var. lacerata

2. Valves without an obvious central area. 3

3. Valves with broad, obvious striae formed near the margin leaving a linear-lanceolate axial area. S15. S. tabulata

3. Valves very finely striate, appearing hyaline in the light microscope, axial area straight and very narrow. S16. S. sp. aff. laevigata

S14. Synedra pulchella (Ralfs ex Kützing 1844) Kützing 1844

var. lacerata Hustedt in Schmidt et al. 1874-1959:pl.300/32,33

Hustedt 1959:192,fig.688c.

(FIG. 13B,C)

Ecology and distribution: A cosmopolitan freshwater taxon only found in the estuary when the river is flowing strongly and the salinity is less than 2 p.p.t. Common in the rest of the Onkaparinga throughout the year.

S15. Synedra tabulata (C. Agardh 1832) Kützing 1844:68,pl.15, figs X,1-3

Hustedt 1959:218-220,fig.710a-d.

Diatoma tabulatum C. Agardh 1832:50.

(FIG. 13D-F)

Ecology and distribution: A genuinely euryhaline taxon found throughout the estuary, throughout the year, regardless of salinity. Grows best in the region between 5 - 15 p.p.t. salinity. Found throughout the world including the Arctic (McIntire & Moore 1977).

Remarks: Fig. 13E illustrates the trend, which is more evident in other estuarine species (see Achnanthes brevipes var. intermedia and Cocconeis scutellum below), of tolerating a range of variation in valve morphology and structure. This is probably due to the minor effects of variation compared to the major evolution of a physiology capable of withstanding great fluctuations of environment.

S16. Synedra sp. aff. laevigata Grunow 1877:166,pl.193/3

Hustedt 1959:213-214,fig.706a-c.

(FIG. 14A,B)

Ecology and distribution: One of the few taxa in this study which can be described as a "summer" species. Generally limited to salinities higher than 25 p.p.t., between January and June, the "rainless" months in this area.

Remarks: This taxon differs from S. laevigata by its finer striae, 54 - 56/10μm instead of the 34 - 38/10μm of the type.

S17. Synedra fulgens (Greville 1827) W. Smith 1853:vol.1,p.74,pl.12/103

Hustedt 1959:228,230,fig.717a.

Exilaria fulgens Greville 1827:vol.5,pl.291

(FIG. 14C-E)

Ecology and distribution: A marine to euryhaline taxon found where salinities exceed 25 p.p.t. Commonly occurs with Striatella unipunctata, Licmophora flabellata and Rhaphoneis surirella var. australis (see ch. 4.3.)

GROUP 3. The monoraphic taxa.

G12. ACHNANTHES Bory 1822

Number of taxa observed: 10

Number of taxa included in study: 4

Key to included taxa.

1. Valves more than 30µm long, linear, axial area on araphic valve excentric, usually formed near the margin. Striae areolate, central area of raphic valve a stauros. S18. A. brevipes var. intermedia

1. Valves less than 30µm long, rostrate-lanceolate, axial area on both valves median, striae punctate, central area of raphic valve not a stauros. 2

2. Axial area of araphic valve linear-lanceolate, central area marked by one slightly short stria. S21. A. species 3

2. Axial area of araphic valve linear, central area marked by more than one short stria. 3

3. Central area of araphic valve formed by three short striae, only on one side of axial area. S19. A. species 1

3. Central area of araphic valve delineated by a broadening of the axial area and an obvious gap between two central striae on one side. S20. A. species 2

S18. Achnanthes brevipes C. Agardh 1824

var. intermedia (Kützing 1833) Cleve 1895:193

Hustedt 1959:425-426,fig.877d,e.

A. intermedia Kützing 1833:48,fig.56.

(FIGS 14F, 15A-E)

Ecology and distribution: A low salinity euryhaline taxon growing well in salinities between 2 p.p.t. and 20 p.p.t. but found in salinities up to

30 p.p.t. The reaction to freshwater or stagnant, eutrophic conditions is to undergo a series of 2 - 3 rapid acytokinetic divisions producing a new pair of valves each time. Each succeeding valve has more of the vela blocked off and the whole structure of the valve becomes more variable (Fig. 15E). It is unknown whether this is a successful strategy for surviving environmental stress, as is the production of resting spores by Chaetoceros species. Most cells seen in this condition are necrotic and it is likely that the strategy might only be successful in the advent of a brief environmental change lasting no more than a tidal cycle (10 - 14 hours).

S19. Achnanthes species 1 (Fig. 16 A-D)

1. Frustule.

   Outline in girdle view: Narrow rectangular, slightly bent at centre.

   Length of pervalvar axis: 1 µm

   Protoplast, chloroplasts: Chloroplast single, H-shaped in each valve and joined in the middle of the cell.

   Growth habit: Solitary, motile.

2. Girdle.

   Shape of bands: Linear.

   Striation of bands: None.

   Number of bands: 1 per valve.

3. Valve.

   Outline: Lanceolate, apex rostrate.

   Shape: Rectangular, valve face slightly convex. Araphic valve with axial area and central area concave.

   Dimensions: Apical axis 14 - 25µm, transapical axis 5.0 - 7.3µm.

   Relative size and shape of areas: Transapical axis heteropolar. The central area scarcely developed to one side of the axial area but taking up one quarter of the valve width on the other side. In the raphic valve, the raphe is developed on the side of the axial area in which the central area is most developed. The central area bounded by 3 or 4 brief striae.

   Shape of striae: Raphic valve striae composed of apically directed slits.

Araphic valve striae composed of three rows of punctae becoming four rows of punctae within 1μm of the margin.

Arrangement: Radiate.

Density of punctae/striae: Raphic valve, 35 - 40 slits/10μm on each stria, 14 - 22 striae/10μm. Araphic valve, 67 punctae/10μm on each stria, 15 - 16 striae/10μm.

Raphe.

Location: To one side of the axial area in the raphic valve.

Structure: At each pole the raphe curves towards the side on which the enlarged central area is found. The terminal fissure changes direction obliquely to curve away towards the opposite margin. At the centre the raphe again curves slightly towards the enlarged central area so that the central pore is just off the main line of the raphe. Central nodule is 0.5 - 0.8μm between central pores. Outer fissure almost straight.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: A freshwater species found commonly in the upper reaches of the estuary and appears to survive salinities up to 10 p.p.t.

S20. Achnanthes species 2 (Figs 17 A-D)

1. Frustule.

   Outline in girdle view: Narrow rectangular, slightly bent at centre.

   Length of pervalvar axis: ca. 0.3μm.

   Protoplast, chloroplasts: Unknown.

   Growth habit: Solitary, motile.

2. Girdle.

   Shape of bands: Linear.

   Striation of bands: None.

   Number of bands: 1 per valve.

3. Valve.

   Outline: Broad-lanceolate, apex rostrate.

   Shape: Mantle brief, valve face flat to slightly convex.

Dimensions: Apical axis 11 - 20μm, transapical axis 4.8 - 8.3μm.

Relative size and shape of areas: Transapical axis heteropolar. One side more inflated than the other. On the less inflated side of the araphic valve there is one central stria which is briefly developed, varying from half the length of other striae to almost nothing. The axial area straight and 0.2 - 0.3μm broad. The raphic valve, almost hyaline in the light microscope, is seen in the SEM to have striae which delineate a large, ovate central area which takes up half the valve width.

Shape of striae: Striae on the araphic valve composed of lines of closely packed punctae (4-5 punctae/line) which are angled away from the apical axis, the angle becoming most obvious midway between the centre and the poles, where the punctal lines are parallel with a line directed from that point to the central nodule.

Arrangement: Radiate.

Density of punctae/striae: Raphic valve, punctae 70 - 71/10μm in each stria, striae 8 - 16/10μm. Araphic valve, punctae 123 - 124/10μm in each stria, striae 8 - 12/10μm.

Raphe.

Location: Along the apical area of the raphic valve.

Structure: Straight, central nodule 0.8 - 0.9μm long.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: A freshwater taxon found in the upper reaches of the estuary unless the river influence extends further downstream.

S21. Achnanthes species 3 (sp. aff. atacamae Hustedt 1927) (Fig. 18 A,B)

1. Frustule.

Outline in girdle view: Linear-rectangular, slightly bent at centre.

Length of pervalvar axis: 0.2 - 0.3μm.

Protoplast: Unknown.

Growth habit: Solitary, motile.

2. Girdle: Unknown.

3. Valve.

Outline: Rhombic, apex cuneate to cuneate sub-rostrate.

Shape: Valve face flat, margin broader at the poles than the centre on the raphic valve. Margin broader at the centre than at the poles on the araphic valve.

Dimensions: Apical axis 24 - 27μm, transapical axis 7 - 8μm.

Relative size and shape of areas: Transapical axis heteropolar. Raphic valve central area developed to one side of the axial area due to one central stria being one-third the length of the rest, and the two flanking striae to the central stria are two-thirds to three-quarters of the length of the rest of the striae. On the other side of the axial area the central area is marked by the central stria being half the length of the rest. One flanking stria may be slightly shorter than the rest. On the araphic valve a small central area is developed on the same side as that of the raphic valve with one central stria being three-quarters of the length of the others. Araphic axial area linear-lanceolate.

Shape of striae: Unknown.

Arrangement: Radial.

Density of striae: 13/10μm.

Raphe.

Location: In the median axial area.

Structure: Straight, central nodule 0.7μm long.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: A freshwater to low salinity euryhaline species with an erratic distribution in samples from the upper reaches of the estuary.

7. Remarks: This taxon is larger than the Peruvian species described by Hustedt (1927, p. 237, pl. 7/1,2), with an apical axis of 24 - 27μm versus 14 - 18μm and transapical axis of 7 - 8μm versus 4 - 5μm. In addition the striae are more broadly spaced (13/10μm versus 14 - 16/10μm)

and the central stria on one side of the araphic valve is always shorter than those around it. These differences probably require at least varietal status for "species 3" and if the minimal variation between other Achnanthes species is taken into account, this taxon could be given specific status.

G13. COCCONEIS Ehrenberg 1838

Number of taxa observed: 9

Number of taxa included in study: 6

Key to taxa studied.

1. Raphe sigmoid. S25. C. pellucida
1. Raphe straight. 2
2. Raphic valve with the central transapical rib broader than the others. S27. C. scutellum var. stauroneiformis
2. Raphic valve without such a distinct rib. 3
3. Araphic valve with areolate striae supported by transapical and apical ribs. S23. C. scutellum
3. Araphic valve with punctate striae or striae formed of fine slits. 4
4. Valves ovoid, distinctly bowed about the apical axis. S24. C. pediculus
4. Valves elliptical, nearly flat. 5
5. Striae 17/10µm, valves elongate elliptical with cuneate apices. S26. C. sp. 4
5. Striae 19/10µm, valves elliptical. S22. C. placentula var. euglypta

S22. Cocconeis placentula Ehrenberg 1838

var. euglypta (Ehrenberg 1854) Grunow 1884:97,pl.1(A)/3

Cleve 1895:170. Hustedt 1959:349,fig.802c.

C. euglypta Ehrenberg 1854:pl.34/6A,fig.2.

(FIG. 18C-F)

Ecology and distribution: A cosmopolitan freshwater species but capable of tolerating salinities up to 15 - 20 p.p.t. and may be found well into the

lower to middle reaches of the estuary.

S23. Cocconeis scutellum Ehrenberg 1838:194,pl.14/8

Schmidt et al. 1874-1959:pl.190/17-21. Cleve 1895:170. van Heurck 1896:286-287,fig.65,pl.8/338. Karsten 1928:271,fig.360a,b. Hustedt 1959:337,fig.790.

(FIGS 19A-E, 20A)

Ecology and distribution: A cosmopolitan euryhaline taxon found both in freshwater and in quiet coastal waters. Recorded throughout the world including the Arctic (McIntire & Moore 1977). Even more variable in frustular architecture than Achnanthes brevipes var. intermedia (see fig. 19 C,D).

S24. Cocconeis pediculus Ehrenberg 1838:194,pl.21/11

Cleve 1895:169. van Heurck 1896:288,pl.8/340. Hustedt 1959:350, fig.804.

(FIG. 20B,C)

Ecology and distribution: The erratic distribution of this taxon in collectons gives no indication of its ecological requirements.

S25. Cocconeis pellucida Grunow in Rabenhorst 1863:21,pl.6/11

Cleve 1895:178. Hustedt 1959:357-359,fig.812

(FIGS 20D,E 21A,B)

Ecology and distribution: A marine to euryhaline taxon found generally in the middle to lower reaches of the estuary where the salinity exceeds 20 p.p.t.

S26. Cocconeis species 4 (sp. aff. placentula var. euglypta (Ehrenberg 1854) Grunow 1884) (Fig. 21 C,D).

Ecology and distribution: A freshwater taxon found more commonly in the middle reaches of the estuary than var. euglypta.

Remarks: This form differs from var. euglypta in the elongate elliptical valve outline with cuneate apices. In addition it has a lower strial density (17/10µm) than var. euglypta (19/10µm) or C. placentula (25/10µm). Possibly an ecotype of var. euglypta.

S27. Cocconeis scutellum Ehrenberg 1838

var. stauroneiformis Rabenhorst 1864:sect.1,p.101.

Cleve 1895:170. van Heurck 1896:287. Hustedt 1959:339, fig.792.

(FIG. 21E-G)

Ecology and distribution: A cosmopolitan marine to euryhaline species common in the lower reaches throughout most of the year, particularly when salinities are in excess of 25 p.p.t.

Remarks: A comparison between figures 21 G and 19 E gives rise to some doubt whether this is a good variety of C. scutellum. The impression gained from the light microscope is that this taxon is a C. scutellum with a broad central transapical rib. However, C. scutellum has loculi occluded by a velum and var. stauroneiformis has loculi occluded by a rota. A close study of the araphic valve would be needed prior to making any change although it would appear that this taxon should be elevated to become a separate species.

G14. RHOICOSPHENIA Grunow 1860

Number of taxa observed: 1

Number of taxa included in study: 1

S28. Rhoicosphenia curvata (Kützing 1833) Grunow 1868:8

Hustedt 1959:430-432,fig.879

Gomphonema curvatum Kützing 1833:39,fig.51.

(FIG. 22A-D)

Ecology and distribution: A cosmopolitan freshwater to euryhaline taxon confined to the upper reaches of the estuary. Grows best in salinities lower than 2 p.p.t.

GROUP 4. The naviculoid taxa.

G15. AMPHIPRORA Ehrenberg 1841

Number of taxa observed: 5

Number of taxa included in study: 2

Key to taxa studied.

1. Valves with keel slightly sigmoid, narrow. Cell straight not contorted about the apical axis. S29. A. sp. 1

1. Valves with keel markedly sigmoid, broad. Cell contorted about the apical axis. S30. A. alata

S29. Amphiprora species 1 (Fig. 23 A)

1. Frustule.

Outline in girdle view: Panduriform-rectangular.

Length of pervalvar axis: 20 - 21µm.

Protoplast, chloroplast: Unknown.

Growth habit: Solitary, motile.

2. Girdle.

Shape of bands: Linear, closed. Valvocopulae 2µm broad, copulae 1.5 - 1.6µm broad.

Striation of bands: Pervalvar directed striae 38 - 39/10µm.

Number of bands: 5

3. Valve.

Outline: Narrow, lanceolate.

Shape: Almost the entire valve forming the keel supporting the raphe.

Dimensions: Apical axis 40 - 56µm, transapical axis 5µm.

Relative size and shape of areas: Most of the valve forms the keel except a small region around the central nodule. There is no central area and the axial area is confined to the apex of the keel.

Shape of striae: Unknown.

Arrangement of striae: Parallel.

Density of striae: 33 - 34/10µm.

Raphe.

Location: In the axial area at the apex of the keel and median to the axial area.

Structure: Maximum extension of the keel occurs within 10µm from the pole after which it narrows towards the valve face at the central nodule. Central nodule narrow, no more than 0.3µm long.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: A freshwater taxon, found only in the upper reaches of the estuary, rarely down as far as the 6km station and then only during periods of strong river flow.

S30. Amphiprora alata (Ehrenberg 1840a) Kützing 1844:107,pl.3/63

Cleve 1894:15. van Heurck 1896:262,fig.52,pl.5/289. Hustedt 1930a: 340,fig.625. Hendey 1964:253,39/14-16.

Navicula alata Ehrenberg 1840a:212.

(FIG. 23B,C)

Ecology and distribution: A freshwater to euryhaline taxon found generally in the upper reaches. Has been found down to the 8km station. A case could be made for a substrate limited distribution but this would require a study of the peripelon.

G16. AMPHORA Ehrenberg 1840

Number of taxa observed: 26

Number of taxa included in study: 8

Key to taxa studied.

1. Valves with semicuneate to semicuneate-obtuse apices. 2
1. Valves with semirostrate-capitate to semicapitate-produced apices. 6
2. Valves with a straight ventral margin. 3
2. Valves with a slightly concave ventral margin. 5
3. Valves apparently hyaline or very finely striate. S36. A. hyalina
3. Valves obviously striate. 4
4. Valves with a broad, straight axial area. S31. A. sp. 1
4. Valves with a narrow, recurved axial area. S34. A. sp. 4
5. Valves less than 20µm long. S36. A. sp. 7
5. Valves more than 25µm long. S38. A. proteus
6. Valves more than 30µm long. S35. A. sp. 5
6. Valves less than 20µm long. 7
7. Valves narrow semilanceolate with semirostrate produced apices, seen as hyaline in the light microscope. S32. A. sp. 2
7. Valves semielliptical with semirostrate-capitate apices, seen as obviously striate in the light microscrope. S33. A. coffeaeformis

S31. Amphora species 1 (Fig. 23 D,E)

1. Frustule.

Outline in girdle view: Truncated linear-rhombic to rhombic-lanceolate.

Length of pervalvar axis: 8.5 - 9.4μm.

Protoplast, chloroplasts: Unknown.

Growth habit: Solitary, motile.

2. Girdle.

Shape of bands: Uniformly broad on the dorsal side and narrowing abruptly at each pole to be uniformly narrow on the ventral side.

Striation of bands: None.

Number of bands: 3

3. Valve.

Outline: Semirhombic.

Shape: Valve face flat, dorsal margin increases in breadth from the poles to a maximum opposite the central nodule.

Dimensions: Apical axis 20 - 48μm, transapical axis 3 - 6μm.

Relative size and shape of areas: The axial area is relatively straight, situated near and parallel to the ventral margin, broadening out towards the ventral margin near the centre of the valve. Width of axial area at poles 0.6μm, width at central nodule 1.3 - 3.0μm depending on cell size.

Shape of striae: Composed of transapically directed slits, 0.3μm long.

Arrangement: Radiate.

Density of punctae/striae: Slits 72/10μm of stria. Striae 17 - 18/10μm.

Raphe.

Location: In the axial area, the terminal pore is on the ventral side of the axial area, the raphe then curves towards the dorsal side of the axial area and back again to the ventral side just prior to the central nodule.

Structure: Central nodule 0.5μm long. Terminal fissure curves towards the dorsal side of the pole.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: A euryhaline taxon found throughout the

estuary throughout the year. Most common in salinities below 25 p.p.t.

7. Remarks: This would appear to be a near relation of the common marine-brackish water species A. angusta Gregory 1857 .

S32. Amphora species 2 (Fig. 24 A,B)

1. Frustule.

Outline in girdle view: Narrow lanceolate with rostrate apices.

Length of pervalvar axis: 7 - 8µm.

Protoplast, chloroplasts: Unknown.

Growth habit: Solitary, motile.

2. Girdle.

Shape of bands: Each valvocopula split into two or three narrow bands on the ventral side and five or six straight bands on the dorsal side. Individual "bandlets" fused at each pole.

Striation of bands: Finely punctate, pervalvar directed striae, 45 - 46/10µm.

Number of bands: Two complex valvocopulae.

3. Valve.

Outline: Semilinear-lanceolate with semicapitate produced apices.

Shape: Valve face flat with the thickly developed axial area forming an outstanding ledge on the ventral margin. Surface of the axial area slopes toward the valve mantle at an angle of 30 - 40° to the valve face.

Dimensions: Apical axis 14 - 31µm, transapical axis 2.5 - 3.2µm.

Relative size and shape of areas: The axial area forms the ventral margin of the valve and has some blind striae formed in its ventral side. The axial area is almost straight on the ventral margin but broadens out dorsally near the central nodule on the dorsal side. The striae are interrupted by a narrow band which is developed parallel to and just in from the dorsal margin. Axial area 0.8µm broad at the poles and 1.7 - 1.8µm broad at the centre.

Shape of striae: Composed of a finely perforated velum covering the spaces between transapical ribs.

Arrangement of striae: Radiate.

Density of striae: 43 - 44/10µm.

Raphe.

Location: In the axial area. The polar nodes are almost on the ventral margin. The raphe then follows the line of the dorsal edge of the axial area to the central nodule remaining 0.8 - 1µm away from the dorsal edge.

Structure: Central nodule 0.3µm long, terminal fissure curves dorsally from the terminal pore to cut the dorsal edge of the axial area.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: Apparently a freshwater to euryhaline taxon but occurs too erratically to allow any definite statement of its ecological preferences.

S33. Amphora coffeaeformis (C. Agardh 1827) Kützing 1844:108,pl.5/37

Schmidt et al. 1874-1959:pl.26/56-58. Hustedt 1930a:345,fig.634. Helmcke & Krieger 1962:vol.1,p.16,pl.76.

Frustulia coffeaeformis C. Agardh 1827:627.

(FIG. 24C)

Ecology and distribution: Part of the freshwater species association but capable of tolerating a wide range of salinities. Distribution generally restricted to the upper 6km of the estuary. A cosmopolitan species recorded from all continents except Asia (McIntire & Moore 1977).

S34. Amphora species 4 (sp. aff. lineolata Ehrenberg 1843:pl.1/3,fig.12)

Schmidt et al. 1874-1959:pl.26/51. van Heurck 1896:138,pl.1/10. Hustedt 1930a:346,fig.636. Cleve-Euler 1953:100,fig.694.

(FIG. 24D,E)

Ecology and distribution: A marine to euryhaline taxon found in the middle to lower reaches of the estuary. Occurs mostly during the dry months of February to June but is present in at least one sample per sampling period during the rest of the year.

Remarks: The type form of A. lineolata is almost rectangular in girdle view and "species 4" has much more inflated valves. This is the only detectable

difference and "species 4" could probably be considered as the local form of this species.

S35. Amphora species 5 (Fig. 25 A)

1. Frustule.

Outline in girdle view: Truncated broad-lanceolate.

Length of pervalvar axis: 10 - 21µm.

Protoplast, chloroplasts: Chloroplast "H"-shaped with two lobes in the dorsal side of each valve.

Growth habit: Solitary, motile or sedentary on colonial diatoms or filamentous algae.

2. Girdle.

Shape of bands: Each valvocopula is narrow and straight on the ventral side but broadens out on the valve edge to become semilanceolate on the dorsal side. Each band splits into 4 - 5 separate bands on the ventral side and 10 - 15 bands on the dorsal side. The bandlets may be fused to each other or free.

Striation of bands: Each "bandlet" has rows of very brief striae composed of 2 - 3 brief apically directed slits. Striae 12/10µm.

Number of bands: One complex valvocopula per valve.

3. Valve.

Outline: Semielliptical with apex capitate produced.

Shape: Semiclavate with the dorsal mantle broad and ventral margin and mantle composed of the thickened axial area.

Dimensions: Apical axis 30 - 64µm, transapical axis 6 - 11.5µm.

Relative size and shape of areas: The axial area is formed by a broad, thickly developed ridge which forms the ventral margin of the valve. There are some briefly developed, blind striae formed on the ventral side of the axial area. All the functional striae are formed dorsally to the axial area. Axial area slightly broader in the region of the central nodule, 2 - 3µm broad.

Shape of striae: Composed of 0.2 - 0.5µm lengths of closely organised, apically directed slits. Each length is separated from the next by a

0.1 - 0.2μm broad apically directed bar.

Arrangement of striae: Radiate.

Density of striae: Dorsal margin 8 - 16/10μm. Ventral margin 13 - 22/10μm.

Raphe.

Location: Median to the axial area, veers towards the ventral margin at the poles and veers towards the dorsal margin at the centre.

Structure: Central nodule 2 - 2.5μm long. Terminal fissure is developed around the pole on the mantle.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: A euryhaline taxon distributed throughout the upper reaches and associative analyses link it with the freshwater taxa.

S36. Amphora hyalina Kützing 1844:108,pl.30/18

Schmidt et al. 1874-1959:pl.26/52-55. Cleve-Euler 1953:100,fig,693. Hendey 1964:265,pl.37/10.

(FIG. 25B)

Ecology and distribution: A marine to euryhaline taxon found in the middle reaches during the dry months and the middle to lower reaches during the wet months of August to December.

S37. Amphora species 7 (Fig. 25C)

1. Frustule.

Outline in girdle view: Not seen.

Growth habit: Solitary, motile.

2. Girdle: Not seen.
3. Valve.

Outline: Semielliptical with the ventral surface slightly concave.

Shape: Valve face slightly convex, ventral mantle scarcely developed, dorsal mantle broadest at the centre.

Dimensions: Apical axis 15 - 18μm, transapical axis 2.9 - 3.2μm.

Relative size and shape of areas: Central area rectangular, longer on

the ventral side than on the dorsal side. Axial area developed ventrally to the raphe, narrow.

Shape of striae: Punctate, narrow.

Arrangement of striae: Radiate dorsally, convergent ventrally.

Density of striae: 21 - 22/10μm.

Raphe.

Location: In the axial area, starting from the terminal pore it curves dorsally before curving back to the central nodule, one-quarter of the valve width from the ventral margin.

Structure: Central nodule 0.2 - 0.3μm long.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: An euryhaline taxon of uncertain affinities due to its erratic distribution in the samples.

S38. Amphora proteus Gregory 1857:518,pl.13/81

Schmidt et al. 1874-1959:pl.27/3. van Heurck 1896:129,pl.24/671. Cleve-Euler 1953:100-101,fig.673b,c.

(FIG. 25D)

Ecology and Distribution: A cosmopolitan marine to euryhaline species growing best in salinities in excess of 25 p.p.t. Recorded from all regions including the Arctic (McIntire & Moore 1977).

G17. BERKLEYA Greville 1827 emend. Cox 1975

Number of taxa observed: 1

Number of taxa included in study: 1

S39. Berkleya rutilans (Trentepohl ex Roth 1806) Grunow 1880:1587

Hustedt 1959:721,fig.1093. Cox 1975:7,figs 31,32.

Conferva rutilans Trentepohl ex Roth 1806:179

(FIG. 26A)

Ecology and distribution: A cosmopolitan euryhaline species of temperate waters. In the Onkaparinga it is found throughout the estuary but grows best in the 20 - 30 p.p.t. salinity range. The tubes in which cells of this taxon live can often smother out the other colonial diatoms particularly

when their numbers reach the order of two million per square centimeter or more.

G18. CALONEIS Cleve in Cleve & Grove 1891

Number of taxa observed: 1

Number of taxa included in study: 1

S40. Caloneis excentrica (Grunow 1860) Boyer 1927:312

Cleve 1894:55.

Navicula excentrica Grunow 1860:545,pl.3/1.

(FIG. 27A)

Ecology and distribution: A freshwater taxon almost restricted to the upper reaches of the estuary. Whether this reflects a nutrient, salinity or substrate demand is unknown.

G19. DIPLONEIS Ehrenberg 1840

Number of taxa observed: 6

Number of taxa included in study: 3

Key to taxa studied.

1. Valve panduriform derived from lanceolate, one end of the valve larger than the other. S41. D. abnormis

1. Valve ovate or rhomboid, not panduriform 2

2. Valve rhombic, striae composed of double rows of punctae. S42. D. smithii var.rhombica

2. Valve broadly elliptical, striae composed of a single row of quadrate areolae. S43. D. ovalis

S41. Diploneis abnormis (Castracane 1886) Thomas comb. nov.*

Navicula abnormis Castracane 1886:27,pl.28/19.

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* Castracane (1886) suggested that this was an "abnormal" form of the normally isopolar Navicula species but having found several valves considered it worth reporting. Van Landingham (1969, p. 1340) considered that Castracane's species was an aberrant form of Diploneis bombus Ehrenberg 1844. The Onkaparinga form of this taxon is certainly a separate species in its own right or at least a variety of D. bombus and not an aberrant form of D. bombus. Hence Castacane's name has been re-applied here.

(FIG. 26B,C)

Ecology and distribution: A freshwater-euryhaline species confined to the upper and middle reaches of the estuary when salinities fall below 15 p.p.t.

S42. Diploneis smithii (Brébisson in W. Smith 1856) Cleve 1894

var. rhombica Mereschkowsky 1902:319,pl.2/19-21

Cleve-Euler 1953:82,fig.654f,g. Hustedt 1959:649,fig.1052a. Hendey 1964:225.

(FIG. 26D)

Ecology and distribution: An uncommon freshwater species found in the upper reaches of the estuary and in the areas of the river upstream of the estuary.

S43. Diploneis ovalis (Hilse in Rabenhorst 1861) Cleve 1891:44,pl.2/13

Cleve 1894:92. Hustedt 1930a:249,fig.390. Hustedt 1959:671-673, fig.1064a-e.

Pinnularia ovalis Hilse in Rabenhorst 1861:No.1025.

(FIG. 32C,D)

Ecology and distribution: A freshwater taxon limited to the upper reaches of the estuary except in times of strong river flow when it can be found occasionally in the middle reaches.

G20. GOMPHONEMA C. Agardh 1824

Number of taxa observed: 7

Number of taxa included in study: 1

S44. Gomphonema constrictum Ehrenberg 1830

var. capitatum (Ehrenberg 1838) Grunow in van Heurck 1880:pl.23/7

van. Heurck 1896:270,pl.7/297. Schmidt et al. 1874-1959:pl.247/12-16, 21,24-25. Hustedt 1930a:377,fig.715. Dawson 1973:414-415,figs 16,19. Okuno in Helmcke & Krieger 1974:vol.9,p.33-34,pl.906.

G. capitatum Ehrenberg 1838:217,pl.18/2.

G. truncatum var. capitatum Patrick & Reimer 1975:119-120,pl.16/4

(FIG. 27B)

Ecology and distribution: A cosmopolitan freshwater species of temperate waters. Found in the Onkaparinga estuary only when the river is flowing

strongly and the ambient salinity is less than 5 p.p.t. Found in the river above the estuary throughout the year.

G21. GYROSIGMA Hassall 1845 emend. Cleve 1894

Number of taxa observed: 5

Number of taxa included in study: 2

Key to taxa studied.

1. Valves with the raphe displaced towards the convex margin for at least the polar quarter. Usually more than 100µm long. S45. G. wansbeckii

1. Valves with the raphe median to displaced towards the concave margin. Usually less than 80µm long. S46. G. eximium

S45. Gyrosigma wansbeckii (Donkin 1858) Cleve 1894:119

Hustedt 1930a:226,fig.340. Hendey 1964:248,pl.35/5.

Pleurosigma wansbeckii Donkin 1858:24,pl.3/7.

(FIG. 27C)

Ecology and distribution: A freshwater, "summer" taxon found in the reaches of the estuary between January and June. It is quite likely that its distribution in the peripelon is wider than occasional appearances in the periphyton would suggest.

S46. Gyrosigma eximium (Thwaites 1848) Boyer 1927:462

Hustedt 1930a:226,fig.339.

Schizonema eximium Thwaites 1848:169,pl.12/F,figs 1-4.

(FIG. 27D)

Ecology and distribution: This appears to be a euryhaline taxon but its presence in periphyton samples has been too erratic for any environmental requirements to be elucidated.

G22. MASTOGLOIA Thwaites in W. Smith 1856

Number of taxa observed: 16

Number of taxa included in study: 4

Key to taxa studied.

1. Valves with a broad central area giving rise to a lateral area on either side of the axial area. 2

1. Valves with a small central area not giving rise to a lateral area. 3

2. Valves with 15 - 30 chambers developed on each side of the valve. Each chamber with an obvious channel developed apically on the marginal surface. S47. M. baldjikiana

2. Valves with 3 - 14 chambers developed on each side of the valve. The central 1 - 6 chambers are obviously larger than the 1 - 4 chambers which are formed on either side. S48. M. pumila

3. Valves with rostrate apices, marginal chambers of even width and divided by an apically directed septum into double chambers. S49. M. sp. 4

3. Valves with subrostrate apices, marginal chambers formed in alternating groups of 3 - 4 broad or narrow chambers, not divided in two by a septum. S50. M. peragallii

S47. Mastogloia baldjikiana Grunow 1893 in Schmidt et al. 1874-1959:pl.188/1,2
sensu Giffen 1970:279,pl.3/43,44
Cleve 1895:158,pl.2/11. Hustedt 1959:550,fig.981.
(FIGS 28A-C, 29A)

Ecology and distribution: An euryhaline taxon found in most of the estuary throughout the year. Grows best in salinities between 20 and 30 p.p.t. Observations have confirmed Giffen's (1970) description of one to two cells forming thick mucilagenous capsules around themselves. These cells have also been observed as solitary and motile. The capsule formation seems to be a defence mechanism against environmental fluctuations and does not imply that this taxon is an epiphyte.

Remarks: The Onkaparinga form is identical to that described by Giffen (1970:pl. 3/43, 44) but differs from descriptions of M. baldjikiana by having the obvious marginal channels leading from the marginal chambers. This is a feature that would surely have been described by either Grunow or Hustedt if it had been present on the European taxon as it implies a close relationship with the section Paradoxae of Mastogloia.

S48. Mastogloia pumila (Grunow in van Heurck 1880) Cleve 1895:157
Hustedt 1959:553,fig.983. Helmcke & Krieger 1963:vol.4,p.23-24,

pl.371-372.

M. braunii var. pumila Grunow in van Heurck 1880:pl.4/23

(FIGS 29B-H, 30A,B)

Ecology and distribution: A freshwater-euryhaline taxon found generally throughout the estuary but growing best in salinities between 5 and 20 p.p.t.

S49. Mastogloia species 4 (Fig. 30 C - E)

1. Frustule.

Outline in girdle view: Rectangular.

Length of pervalvar axis: 5 - 6µm.

Protoplast, chloroplasts: Unknown.

Growth habit: Solitary, motile.

2. Girdle.

Shape of bands: Linear, closed.

Striation of bands: None.

Number of bands: 2

Septum formation: A marginal septum is formed on the edge of the valve and has a row of quadrate chambers developed upon the valvar surface. The septum is developed to the shoulders of the rostrate apex and does not reach the apex. Each chamber is divided in half longitudinally by a fine septum developed parallel to the margin. Chambers 8/10µm, developed to 2µm in from the margin and 1µm wide. The chambers connect to the outer surface through a small channel opening into a shallow trench at the base of the mantle striae.

3. Valve.

Outline: Broad lanceolate with rostrate apices.

Shape: Valve rectangular in section with the valve face slightly convex.

Dimensions: Apical axis 27 - 31µm, transapical axis 12 - 13µm.

Relative size and shape of areas: Axial area very narrow, median. Central area approximately circular, 2 - 3µm in diameter.

Shape of striae: Composed of a single row of small punctae.

Arrangement of striae: Radiate.

Density of punctae/striae: Punctae 30/10μm of stria. Striae 24-27/10μm.

Raphe.

Location: In the median axial area.

Structure: Internal fissure straight, external fissure having a single 3μm long undulation which transfers the fissure to the opposite side of the axial area and back again, otherwise straight. The terminal fissure veers towards the same side of the pole as the undulation. Central nodule 1μm long.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: A marine to euryhaline taxon found in the periphyton between January and May and therefore a "summer" species.

S50. Mastogloia peragallii Cleve 1892:160,pl.23/7

Schmidt et al. 1874-1959:pl.186/39. Hustedt 1959:561-563,fig.994.

(FIG. 31A-C)

Ecology and distribution: A marine to euryhaline taxon found from January to August but most common in salinities of 25 p.p.t. or more. Sometimes found throughout the estuary.

G23. NAVICULA Bory 1822

Number of taxa observed: 54

Number of taxa included in study: 13

Key to taxa studied.

1. Valves with a broad central area extending into a lateral area either side of the axial area. 2

1. Valves without lateral areas. 4

2. Valves more than 100μm long. S57. N. lyra

2. Valves less than 80μm long. 3

3. Valves less than 20μm long with two lateral areas on either side of the axial area. S51. N. dissipata

3. Valves generally more than 20μm long, one lateral area either side of the axial area, lateral area thickened internally. S63. N. opuntioides

4. Valves with obviously punctate striae. 5

4. Valves with broad striae (seen to be composed of apically directed slits in the SEM). 7

4. Valves hyaline, linear-lanceolate. S62. N. ostrearia

5. Valves less than 25µm long. S60. N. pseudincerta

5. Valves longer than 30µm. 6

6. Valves with striae 10 - 11/10µm evenly spaced. S52. N. marina

6. Valves with striae 14/10µm more widely spaced opposite the central area than near the poles. S55. N. digitulus

7. Valves with radiate striae. 8

7. Valves with some striae not radiate. 10

8. Valves less than 20µm long. S60. N. pseudincerta

8. Valves longer than 30µm. 9

9. Valves with a linear axial area and rhombic to circular central area. S53. N. ramosissima

9. Valves with a linear-lanceolate axial area and no obvious central area. S56. N. yarrensis

10. Striae radiate except for a group of 3 -5 central striae which are parallel and surrounded by the nearest radiate striae. S58. N. digitoradiata

10. Valves with non-radiate striae near the poles. 11

11. Valves with striae parallel near the pole. S61. N. sp. 31

11. Valves with striae varying from radiate at the centre to parallel to convergent near the poles. S54. N. avenacea

S51. Navicula dissipata Hustedt 1936 in Schmidt et al. 1874-1959:pl.403/7-8
Hendey 1964:214,pl.37/7. Hustedt 1966:549-550,fig.1587.

(FIG. 32A,B)

Ecology and distribution: A freshwater taxon abundant in the estuary in times of continuous river flow such as experienced July to October 1974. Usually limited to the upper reaches of the estuary.

S52. Navicula marina Ralfs in Pritchard 1861:903

Hendey 1964:207,pl.31/1-3. Hustedt 1966:705-707,fig.1697

(FIG. 33A)

Ecology and distribution: A freshwater to euryhaline taxon found in the upper and middle reaches throughout the year.

S53. Navicula ramosissima (C. Agardh 1824) Cleve 1895:26

van Heurck 1896:232,pl.5/244. Hustedt 1934 in Schmidt et al. 1874-1959:pl.393/8,9. Hendey 1964:194,pl.30/9.

Schizonema ramosissimum C. Agardh 1824:11.

(FIG. 33B-D)

Ecology and distribution: An euryhaline taxon found throughout the year, growing best in salinities greater than 15 p.p.t. A cosmopolitan temperate brackish and marine water form (McIntire & Moore 1977).

S54. Navicula avenacea (Brébisson in Brébisson & Godey 1835) Cleve 1895:15

Grunow 1880:34. Cleve-Euler 1953:151-152,fig.807

Cymbella avenacea Brébisson in Brébisson & Godey 1835:50,pl.7

(FIG. 34A,B)

Ecology and distribution: A freshwater taxon limited in its penetration into the estuary to the upper reaches.

S55. Navicula digitulus Hustedt 1943:162,figs 26-30

Cleve-Euler 1953:175,fig.865A. Hustedt 1966:252,fig.1378.

(FIG. 34C)

Ecology and distribution: A tube-dwelling marine to euryhaline taxon found in most of the estuary where salinities exceed 15 p.p.t.

S56. Navicula yarrensis Grunow 1876 in Schmidt et al. 1874-1959:pl.46/1-6

Cleve 1895:69.

(FIG. 34D)

Ecology and distribution: A freshwater to euryhaline taxon found in the upper and middle reaches of the estuary.

Remarks: This taxon is indicative of one of the major difficulties faced in using cleared cells as a basis for ecological investigation. Large and obvious though the cells are, no living cells have been seen in three years of investigating periphyton fresh samples but only empty frustules. This

and other problems are referred to in chapter 6.

S57. Navicula lyra Ehrenberg 1841:419,pl.1/1,fig.9a

Schmidt et al. 1874-1959:pl.2/16,129/11-14. Wood 1961a:680,pl.52/79. Hendey 1964:209,pl.33/2. Hustedt 1966:500-502,fig.1548.

(FIG. 34E)

Ecology and distribution: A cosmopolitan freshwater to euryhaline taxon found in both arctic and temperate waters (McIntire & Moore 1977). In the Onkaparinga it is found mainly in the upper reaches of the estuary and in the peripelon of the reaches above the estuary.

Remarks: Wood (1961a, p. 680, pl. 52/79) described the rhombic form illustrated here (Fig. 34 E) as "N. lyra var.". Observations from the Onkaparinga suggest that the rhombic form is a variant of the broad-lanceolate type form and that it is possible to find cells that are intermediate in shape between these two extremes. Thus Wood's (1961a) unnamed variety may be treated as a synonym of N. lyra.

S58. Navicula digitoradiata (Gregory 1856) Ralfs in Pritchard 1861:904

van Heurck 1896:184,pl.3/130. Hustedt 1930a:301,fig.518. Hendey 1964:202,pl.29/8,9. Helmcke & Krieger 1961:vol.3,p.27,pl.292. Pinnularia digitoradiata Gregory 1856:9,pl.1/32.

(FIG. 34F)

Ecology and distribution: An euryhaline taxon growing best in 15 - 30 p.p.t. salinities. Reported from both arctic and temperate waters (McIntire & Moore 1977).

S59. Navicula species 26 (Fig. 34 G)

1. Frustule.

Outline in girdle view: Rectangular.

Length of pervalvar axis: 0.5 - 1.0µm.

Protoplast, chloroplasts: Unknown.

Growth habit: Solitary, motile.

2. Girdle: Not seen.

3. Valve.

Outline: Lanceolate with broad-cuneate apices.

Shape: Valve face flat, mantle narrow, linear. Rectangular in section.

Dimensions: Apical axis 18 - 21.5µm, transapical axis 19 - 20µm.

Relative size and shape of areas: Axial area narrow-lanceolate, 0.9 - 1µm broad near the centre. Central area circular to rhombic, 3.4 - 3.5µm broad, pierced on one side by the central stria which is developed to the edge of the central nodule.

Shape of striae: Linear, punctate.

Arrangement: Radiate.

Density of striae: 28/10µm. Most widely spaced opposite the central nodule.

Raphe.

Location: Median to the axial area.

Structure: Straight, central nodule 0.4 - 0.5µm long.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: This taxon only appeared in the periphyton between April and August but in such an erratic way that no estimate of its environmental requirements could be attempted.

S60. Navicula pseudincerta Giffen 1970:285-286,pl.4/60-62

(FIG. 34H)

Ecology and distribution: An euryhaline taxon restricted to the cooler months of April to November but apparently capable of growing well in a wide range of salinities from 10 - 30 p.p.t.

S61. Navicula species 31 (Fig. 35 A)

1. Frustule.

Outline in girdle view: Rectangular.

Length of pervalvar axis: 4 - 5µm.

Protoplast, chloroplasts: Unknown.

Growth habit: Solitary, motile.

2. Girdle: Unknown.
3. Valve.

Outline: Lanceolate with obtuse apices.

Shape: Valve face slightly convex.

Dimensions: Apical axis 40 - 84µm, transapical axis 7 - 15µm.

Relative size and shape of areas: Axial area narrow, linear, slightly curved near the poles. Central area broad, circular, diameter 2.5 - 6.5µm, delineated by 2 - 4 striae.

Shape of striae: Composed of a single line of apically directed slits.

Arrangement: Radiate in the centre to parallel near the poles.

Density of slits/striae: Slits 35/10µm of stria. Striae 7 - 15/10µm depending upon the length of the valve, to form a constant 60 - 64 striae along the length of the whole cell.

Raphe.

Location: To one side of the axial area.

Structure: External fissure straight, curving to the other side of the axial area near the pole, the terminal fissure recurving back again. Central nodule 1.4 - 1.6µm long.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: A freshwater taxon found only occasionally in the estuary.
7. Remarks: Wood (1961a p. 680, pl. 52/77) misidentified this taxon as N. vulpina Kützing, a taxon with a long, irregularly shaped, central area and striae becoming convergent near the poles not parallel as in this taxon.

S62. Navicula ostrearia (Gaillon 1820) Bory 1827:474

Hendey 1964:187. Hustedt 1966:36,fig.1192a.

Vibrio ostrearius Gaillon 1820:93.

(FIG. 35B)

Ecology and distribution: A marine to euryhaline taxon found only occasionally in the periphyton and then when salinities are in excess of 25 p.p.t.

S63. Navicula opuntioides Simonsen 1959:79,pl.12/1

Hustedt 1966:470,fig.1528a,b.

(FIG. 35C)

Ecology and distribution: A marine to euryhaline form growing best in the nutrient enriched waters found in the middle reaches from August to November where salinities were in excess of 20 p.p.t.

G24. PINNULARIA Ehrenberg 1840

Number of taxa observed: 1

Number of taxa included in study: 1

S64. Pinnularia borealis Ehrenberg 1841:420,pl.1/2,fig.6,pl.4/1,fig.5
Schmidt et al. 1874-1959:pl.45/19,20. van Heurck 1896:170,pl.2/77.
Hustedt 1930a:326,fig.597.

(FIG. 35D)

Ecology and distribution: A freshwater taxon rarely found down as far as the middle reaches of the estuary.

G25. PLAGIOTROPIS Pfitzer 1871

Number of taxa observed: 3

Number of taxa included in study: 1

S65. Plagiotropis lepidoptera (Gregory 1856) Reimer in Patrick & Reimer 1975:8
Cleve 1894:25. Hendey 1964:256,pl.36/2,4.
Amphiprora lepidoptera Gregory 1856-1857:76,pl.1/39.

(FIG. 36A)

Ecology and distribution: A marine taxon rarely penetrating the estuary above the lower reaches.

G26. PLEUROSIGMA W. Smith 1852

Number of taxa observed: 6

Number of taxa included in study: 3

Key to included taxa.

1. Valves almost linear, raphe straight for most of its length, apices broad. S67. P. rigidum

1. Valves markedly sigmoid, raphe sigmoid tending towards the convex margin of the valve, apices narrow. 2

2. Valves narrow, tapering gradually towards the poles, raphe fissures overlapping at the centre. S66. P. sp. 2

2. P.T.O.

2. Valves broad, tapering rapidly towards the poles, raphe fissures straight at the centre, scarcely developed into the central area.

S68. P. sp. 5

S66. Pleurosigma species 2 (Fig. 36 B-D)

1. Frustule.

Outline in girdle view: Narrow-rectangular, tapering slightly towards the poles.

Length of pervalvar axis: 5 - 6µm.

Protoplast, chloroplasts: Chloroplast "H"-shaped in each valve, lobes ribbon-like, irregular.

Growth habit: Solitary, motile.

2. Girdle: Not seen.

3. Valve.

Outline: Narrow, lanceolate-sigmoid.

Shape: Valve mantle very narrow, valve face sloping up towards the raphe on either side.

Dimensions: Apical axis 180 - 215µm, transapical axis 17 - 18µm.

Relative size and shape of areas: Axial area narrow, developing excentrically towards the convex margin as it approaches the poles, at no point parallel to the valve margin. Central area small, oval, 1.3µm broad.

Shape of striae: Composed of "X"-shaped loculi opening externally through an apically directed slit and internally through a rota.

Arrangement: Decussate and parallel. Angle of decussate striae approximately 60^{o}.

Density of loculae/striae: Decussate striae 22/10µm with loculi 17/10µm of stria. Parallel striae 20/10µm with loculi 18/10µm of stria.

Raphe.

Location: Median to the axial area.

Structure: External fissure veers at the central area towards the concave margin, each fissure overlapping the other at the centre. Central node narrow, 0.2µm between central pores. At each pole the

terminal fissure curves around towards the concave margin and ends directed back down the cell and parallel to the concave margin.

4. Reproduction: Unknown.
5. Resting spores: Unknown.
6. Ecology and distribution: A freshwater to euryhaline taxon rarely found downstream from the upper reaches of estuary.
7. Remarks: This taxon has a superficial resemblance to P. decorum W. Smith but the striae are more acutely angled and closer together. The most significant feature is the overlapping of the raphe fissures at the centre, a feature generally associated with species of Gyrosigma Hassall.

S67. Pleurosigma rigidum W. Smith 1853:64,pl.20/198

van Heurck 1896:251-252,pl.6/265.

(FIG. 37 A-C)

Ecology and distribution: A marine to euryhaline taxon very common in all reaches of the estuary except when salinities become variable and drop below 10 p.p.t.

S68. Pleurosigma species 5 (Fig. 37 D,E)

1. Frustule.

   Outline in girdle view: Narrow, rectangular.

   Length of pervalvar axis: 1.5 - 2µm.

   Protoplast, chloroplasts: Unknown.

   Growth habit: Solitary, motile.

2. Girdle: Not seen.
3. Valve.

   Outline: Lanceolate-sigmoid.

   Shape: Valve face sloping up slightly to the raphe on each side.

   Dimensions: Apical axis 128 - 140µm, transapical axis 13 - 14µm.

   Relative size and shape of areas: Axial area narrow, parallel to the valve margins near the centre, becoming increasingly excentric towards the poles as it approaches the convex margin of the valve. Central area small, elliptical, 1.5µm wide.

Shape of striae: Formed of a single row of punctae.

Arrangement: Both decussate and parallel.

Density of punctae/striae: Decussate striae 19/10μm composed of punctae 17/10μm of stria. Parallel striae 10/10μm composed of punctae 18/10μm.

Raphe.

Location: Median to the axial area.

Structure: External fissure enters the central area straight. Central nodule 1 - 2μm long. Terminal fissure veers towards the concave margin, briefly developed.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: An euryhaline taxon present in the estuary throughout the year except when salinities are reduced below 10 p.p.t.

G27. TRACHYNEIS Cleve 1894

Number of taxa observed: 1

Number of taxa included in study: 1

S69. Trachyneis aspera (Ehrenberg 1841) Cleve 1894:191

van Heurck 1896:205,pl.4/165. Hendey 1964:236,pl.29/13.

Stauroptera aspera Ehrenberg 1841:pl.1/1,figs 1-2,pl.2/6.

(FIG. 37F)

Ecology and distribution: A marine to euryhaline taxon commonly occurring in the middle reaches of the estuary particularly when salinities are above 25 p.p.t. A cosmopolitan temperate water species (McIntire & Moore 1977).

GROUP 5. The nizschioid taxa.

G28. BACILLARIA Gmelin in Linnaeus 1788

Number of taxa observed: 1

Number of taxa included in study: 1

S70. Bacillaria paradoxa Gmelin in Linnaeus 1788:3903

van Heurck 1896:292,pl.16/518. Hustedt 1930a:396,fig.755.

(FIG. 38A)

Ecology and distribution: A cosmopolitan temperate freshwater to euryhaline taxon (McIntire & Moore 1977). Found in the Onkaparinga river in

salinities up to 25 p.p.t. but growing best in salinities below 10 p.p.t.

G29. CAMPYLODISCUS

Number of taxa observed: 5

Number of taxa included in study: 3

Key to included taxa.

1. Valves having three concentric rings of large-areolate, radiate striae. S72. C. daemelianus

1. Valves without areolate striae. 2

2. Valves with radiate costae developed from a median rib. Costae opposite. S73. C. ralfsii

2. Valves with radiate costae developed from a lateral rib. Median and two lateral ribs present. Costae alternate, developed through the median to the opposing lateral rib, forming a median region with twice as many costae as the marginal regions. S71. C. incertus

S71. Campylodiscus incertus Schmidt 1875 in Schmidt et al. 1874-1959: pl.15/13-15

(FIG.38B,C)

Ecology and distribution: A freshwater taxon confined to the upper reaches of the estuary and to the reaches upstream of the estuary.

S72. Campylodiscus daemelianus Grunow 1874 in Schmidt et al. 1874-1959: Probeheft fig.4

Schmidt et al. 1874-1959:pl.54/1,2.

(FIG. 38D)

Ecology and distribution: A freshwater to euryhaline taxon found in salinities up to 20 p.p.t. though restricted in distribution to the upper reaches of the estuary.

S73. Campylodiscus ralfsii W. Smith 1853:30,pl.30/257

Schmidt et al. 1874-1959:pl.14/1-3. van Heurck 1896:376,pl.32/869. Cleve-Euler 1952:127,fig.1576.

(FIG. 38E)

Ecology and distribution: A freshwater to euryhaline taxon restricted to salinities less than 20 p.p.t. and the middle and upper reaches of the estuary.

Remarks: The Onkaparinga form varies from the type by the presence of brief rows of 1-4 intercostal granules positioned halfway between the median rib and the margin.

G30. EPITHEMIA Brébisson in Brébisson & Godey 1838

Number of taxa observed: 3

Number of taxa included in study: 1

S74. Epithemia zebra (Ehrenberg 1833) Kützing 1844

var. saxonica (Kützing 1844) Grunow 1862:328,pl.6/6

Fricke 1904 in Schmidt et al. 1874-1959:pl.525/3-14. Hustedt 1930a: 385,fig.730. Cleve-Euler 1952:37,fig.1409i,k.

Epithemia saxonica Kützing 1844:35,pl.5/15.

(FIG. 39A,B)

Ecology and distribution: A freshwater to euryhaline taxon found in the upper to middle reaches of the estuary particularly when salinities are below 15 p.p.t.

G31. NITZSCHIA Hassall 1845

Number of taxa observed: 35

Number of taxa included in study: 16

Key to included taxa.

1. Raphe median to the valve, valves oblong with broad, acute apices. Raphe supported on a narrow, linear keel. S90. N. distans

1. Raphe excentric, formed on and parallel to the margin. 2

1. Raphe excentric, formed near the margin, recurved towards the centre near the central nodule. 13

2. Cells linear-rectangular in girdle view. 3

2. Cells in girdle view linear to rectangular becoming sigmoid towards the poles. 9

3. Valve panduriform-lanceolate. 4

3. Valve lanceolate. 6

4. Valve face transapically undulate, 10-30 μm long, no longitudinal hyaline area opposite the raphe.

S76. N. constricta

4. Valve face flat, longer than 30 μm with a longitudinal hyaline area opposite the raphe. 5

5. Valve 60-70 μm long, striae 15/10 μm. S86. N. acuminata

5. Valve 35-50 μm long, striae 19/10 μm. S87. N. apiculata

6. Valve face transapically undulate. 7

6. Valve face flat. 8

7. Valve broad-lanceolate with rostrate apices.

S77. N. punctata

7. Valve lanceolate with acute apices. S78. N. fusoides

8. Valve narrow-lanceolate with acute, produced apices.

S79. N. fonticola

8. Valve narrow-lanceolate. S80. N. liebethrutii

9. Valve linear with acute apices. S89. N. sp.34

9. Valve sigmoid towards the apices. 10

10. Valve linear-sigmoid, 350-450 μm long.

S82. N. sp.12

10. Valve linear-lanceolate to oblong, sigmoid, less than 200 μm long. 11

11. Valve linear-lanceolate, sigmoid with acute produced apices.

S85. N. sigma var. rigida

11. Valve oblong becoming sigmoid at the apices. 12

12. Valve with rostrate apices, 40-70 μm long.

S83. N. clausii

12. Valve with acute apices, 100-200 μm long.

S84. N. sigma

13. Valve linear-lanceolate, sigmoid, apices slightly rostrate, 100-200 μm long. S75. N. vidovichii

13. Valve oblong, sigmoid at the apices. 14

14. Valve with rostrate apices, 50-100 μm long. S81. N. obtusa var. scalpelliformis

14. Valve with truncated, acute apices, 120-160 μm long. S88. N. obtusa

S75. Nitzschia vidovichii Grunow 1921 in Schmidt et al. 1874-1959: pl.336/29-31

(FIG. 39C,D)

Ecology and distribution: A euryhaline, tube-forming taxon found throughout the estuary, except where the salinity falls below 10 p.p.t. With Berkleya rutilans the most common motile form in the periphyton.

Remarks: Mills (1934:1241) indicated that this is a variety of N. obtusa W. Smith 1853 but does not mention it in the list of N. obtusa varieties (p.1223).

S76. Nitzschia constricta Ralfs in Pritchard 1861:780

Grunow 1862:567. Cleve & Grunow 1879:71. Schmidt et al. 1874-1959: pl.333/18.

(FIG. 39E,F)

Ecology and distribution: A freshwater taxon limited in distribution to the upper reaches of the estuary.

S77. Nitzschia punctata (W. Smith 1853) Grunow in Cleve & Grunow 1879:68

van Heurck 1896:384,pl.15/491. Hendey 1964:278,pl.39/261.

Triblionella punctata W. Smith 1853:36,pl.30/261.

(FIG. 39G)

Ecology and distribution: A freshwater taxon confined to the upper reaches of the estuary.

S78. Nitzschia fusoides Ehrlich 1975:269,pl.3/17-20

(FIG. 40A)

Ecology and distribution: A freshwater to euryhaline taxon found in salinities up to 30 p.p.t. but most common in lower salinities.

S79. Nitzschia fonticola Grunow in Cleve & Grunow 1879:97

van Heurck 1880-1885:pl.69/15-20. Schmidt et al. 1874-1959:pl.348/60-72. van Heurck 1896:402,pl.17/557. Hustedt 1930a: 415,fig.800.

(FIG. 40B)

Ecology and distribution: Apparently a freshwater to euryhaline taxon but its distribution in the periphyton is too erratic to make any prediction about environmental requirements.

S80. Nitzschia leibethrutii Grunow in Cleve & Grunow 1879:98

Schmidt et al. 1874-1959:pl.348/84-87.

(FIG. 40C)

Ecology and distribution: A freshwater to euryhaline taxon found throughout the estuary but growing best in the upper reaches.

S81. Nitzschia obtusa W. Smith 1853

var. scalpelliformis Grunow in Cleve & Grunow 1879:92

van Heurck 1896:397-398,pl.16/538. Schmidt et al. 1874-1959:pl.336/22-24. Hustedt 1930a:422,fig.8176.

(FIG. 40D)

Ecology and distribution:An euryhaline taxon found throughout the estuary when the salinities are below 30 p.p.t.

S82. Nitzschia species 12. (Fig. 40E-H)

1. Frustule.

Outline in girdle view: Linear-sigmoid.

Length of pervalvar axis: 2-3 μm.

Protoplast, chloroplasts: Unknown.

Growth habit: Solitary, motile.

2. Girdle.

Shape of bands: Linear-sigmoid, very narrow.

Striation of bands: None.

Number of bands: 2

3. Valve.

Outline: Linear-sigmoid, tapering gradually from the centre towards the poles.

Shape: Valve face flat sloping up towards the marginal raphe. Valve mantle broader on the side with the raphe than the non-raphe side.

Dimensions: Apical axis 350-480 µm, transapical axis 6-7 µm.

Relative size and shape of areas: Axial area excentric, developed on the margin, narrow. Central area absent.

Shape of striae: Composed of a single line of small poroid areolae, each occluded by a velum.

Arrangement: Parallel.

Density of striae: 38-39/10 µm.

Raphe

Location: Raised on a brief keel on the valve margin.

Structure: A canal raphe system. Fibulae evenly spaced, 8/10 µm.

No obvious central nodule.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: A freshwater taxon limited in distribution to the upper reaches of the estuary.

S83. Nitzschia clausii Hantzsch 1853 in Rabenhorst 1848-1860 according to Pankow 1976:298

Schmidt et al. 1874-1959:pl.336/7-11. Hustedt 1930a:421,fig.814.

(FIG. 41A)

Ecology and distribution: Apparently a freshwater taxon but has appeared too erratically in periphyton samples for its environmental requirements to be estimated.

S84. Nitzschia sigma (Kützing 1844) W. Smith 1853:39,pl.13/108

Ralfs in Pritchard 1861:781,pl.4/21. van Heurck 1896:396,pl.16/531. Schmidt et al. 1874-1959:pl.236/1. Hustedt 1930a:420,fig.813.

Synedra sigma Kützing 1844:67,pl.30/14.

(FIG. 41B)

Ecology and distribution: A freshwater taxon restricted to the river and reaches of the estuary.

S85. Nitzschia sigma (Kützing 1844) W. Smith 1853

var. rigida (Kützing 1844) Grunow 1878:119

van Heurck 1896:393,pl.16/533. Schmidt et al. 1874-1959:pl.336/6.

Amphipleura rigida Kützing 1844:1041,pl.4/30.

(FIG. 41C,D)

Ecology and distribution: A marine to euryhaline taxon which appears to grow best in the higher nutrient levels experienced between September and January, particularly in the middle reaches.

S86. Nitzschia acuminata (W. Smith 1853) Grunow in Cleve & Grunow 1879:73

van Heurck 1896:388,pl.15/506. Schmidt et al. 1874-1959:pl.331/4,5. Hustedt 1930a:401,fig.764.

Triblionella acuminata W. Smith 1853:36,pl.10/77.

(FIG. 41F)

Ecology and distribution: A freshwater taxon restricted to the river and the upper reaches of the estuary.

S87. Nitzschia apiculata (Gregory 1857) Grunow in Cleve & Grunow 1879:73

van Heurck 1896:387,pl.15/505. Schmidt et al. 1874-1959:pl.331/14,15. Hustedt 1930a:401,fig.765. Hendey 1951:72,pl.16/4. Helmcke & Kreiger 1962:vol.1,p.18,pl.88.

Triblionella apiculata Gregory 1857:79,pl.1/43.

(FIG. 41E)

Ecology and distribution: A freshwater to euryhaline taxon capable of living in salinities up to 20 p.p.t. Generally restricted to the middle and upper reaches of the estuary.

S88. Nitzschia obtusa W. Smith 1853:39,pl.13/109 van Heurck 1896:397,pl.16/538. Schmidt et al. 1874-1959:pl.336/20,21, 352/6,7. Hustedt 1930a:422,fig.817a. Hendey 1964:282.

(FIG. 42A)

Ecology and distribution: A freshwater taxon rarely found downstream of the upper reaches of the estuary.

S89. Nitzschia species 34 (Fig. 42B,C)

1. Frustule.

   Outline in girdle view: Linear rectangular, becoming sigmoid towards the apices.

   Length of pervalvar axis: 2-3 µm.

   Protoplast, chloroplasts: Unknown.

   Growth habit: Solitary, motile.

2. Girdle.

   Shape of bands: Narrow, linear, sigmoid towards the apices.

   Striation of bands: None.

   Number of bands: 2

3. Valve.

   Outline: Linear lanceolate.

   Shape: Valve surface flat.

   Dimensions: Apical axis 140-165 µm, transapical axis 10-11 µm.

   Relative size and shape of areas: Axial area excentric, developed on the margin, narrow. Central area absent.

   Shape of striae: Composed of a single line of small poroid aveolae each occluded by a velum.

   Arrangement: Parallel.

   Density of striae: 15-16/10 µm.

   Raphe

   Location: On a brief keel developed in the axial area.

   Structure: A canal raphe system. Fibulae evenly spaced, 5/10 µm.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: A freshwater taxon found in the estuary between September and November.

S90. Nitzschia distans Gregory 1857:530,pl.14/103

van Heurck 1896:394,pl.33/878.

(FIG. 42D,E)

Ecology and distribution: A freshwater taxon mostly limited to the upper reaches of the estuary.

G32. RHOPALODIA O. Müller 1895

Number of taxa observed: 5

Number of taxa included in study: 2

Key to included taxa.

1. Valve semicircular with acute produced apices, less than 20 µm long, structure fine, no obvious striae. S91. R. gibberula var. producta

1. Valve semicircular, more than 20 µm long, with obvious areolate striae. S92. R. musculus

S91. Rhopalodia gibberula (Ehrenberg 1843) O. Müller 1895

var. producta (Grunow 1862) O. Müller 1899:290

van Heurck 1896:297,pl.9/361.

Epithemia producta Grunow 1862:330,pl.6/9.

(FIG. 42F,G)

Ecology and distribution: A freshwater taxon rarely found downstream from the upper reaches of the estuary.

S92. Rhopalodia musculus (Kützing 1844) O. Müller 1899:278

Schmidt et al. 1874-1959:pl.254/1-11. Hustedt 1930a:392,fig.745. Helmcke & Krieger 1962:vol.1,p.17,pl.82-83. Patrick & Reimer 1975:191, pl.28/5.

Epithemia musculus Kützing 1844:33,pl.30/6.

(FIG. 43A)

Ecology and distribution: An euryhaline taxon found throughout the estuary throughout the year.

G33. SURIRELLA Turpin 1828

Number of taxa observed: 9

Number of taxa included in study: 3

Key to included taxa.

1. Valve obovate-lanceolate. S94. S. ovalis
1. Valve cuneate. 2
2. Valve broadly cuneate, almost circular. S93. S. sp.2
2. Valve cuneate. S95. S. ovata

S93. Surirella species 2 (Fig. 43B,C)

1. Frustule.

   Outline in girdle view: Rectangular, broader at the cingulum than the margin.

   Length of pervalvar axis: 10-12 µm.

   Protoplast, chloroplasts etc.: Two large plate-like chloroplasts, one in each valve.

2. Girdle: Not seen due to characteristic build-up of detritus on the cingulum which survives acid clearing.

3. Valve.

   Outline: Broadly cuneate, almost circular.

   Shape: Valve face very irregular due to external costae. Margin concave with the marginal raphe transapically produced from the mantle edge of the margin.

   Dimensions: Apical axis 30-37 µm, transapical axis 26-29 µm.

   Relative size and shape of areas: Axial area formed around the entire margin on the mantle edge of the margin. Central area absent.

   Areolae/striae: Absent.

Raphe

Location: Formed on the mantle edge of the margin, around the entire margin.

Structure: Canal raphe system. Fibulae 18-19/10 μm, evenly distributed. Both polar nodules at the more acute end of the valve.

Special structures: Costae formed both internally and externally on the valve, radiate from a central pair of ribs. Costae formed in groups of one to four (3 groups/10 μm), overlapping in the centre with the costae from the other side of the raphe (11-14/10 μm). Costae typically with granulate apices.

4. Reproduction: Unknown.

5. Resting spores: Unknown.

6. Ecology and distribution: A freshwater to euryhaline species being found in salinities up to 30 p.p.t. though most prevalent in less than 10 p.p.t.

S94. Surirella ovalis Brébisson 1838:17

van Heurck 1896:373,pl.13/585. Hustedt 1930a:441,fig.860-861. Pankow 1976:315-316,fig.675,pl.21/2.

(FIG. 43D)

Ecology and distribution: A freshwater to euryhaline taxon found in most reaches throughout the year though never very common.

S95. Surirella ovata Kützing 1844:62,pl.7/1-4

Schmidt et al. 1874-1959:pl.23/49-55. Hustedt 1930a:442,fig.863-864.

(FIG. 43E)

Ecology and distribution: A freshwater taxon found only in the upper reaches of the estuary.

3. THE SUBSTRATE: ZOSTERA sp.

3.1. Comments on Taxonomy and Distribution.

The Zostera found in the Onkaparinga estuary was collected and identified as Z. muelleri Irmisch ex Aschers, by Dr Hj. Eichler for the State Herbarium of South Australia (Eichler, Dec.-1956, AD 95906001). This specimen, along with others given this name, was observed by Dr den Hartog prior to the publication of his monograph on sea-grasses of the world (den Hartog 1970) and Eichler's identification was apparently accepted without comment. Prior to and during this study of the Onkaparinga estuary, Zostera samples were collected from various parts of the estuary including vegetative shoots (Inns & Thomas, Sept.-1973, ADU A43891; FIG. 44) and reproductive shoots (Thomas, Dec.-1975, ADU A46712; FIG. 45).

Investigation of these samples and the herbarium specimen collected by Eichler indicates that there is one species of Zostera in the estuary and that it is the same species as collected by Eichler. If this form is identified using den Hartog's key to the subgenus Zosterella (Aschers.) Ostenfeld (den Hartog 1970:64) the Onkaparinga form is Z. capicornii Aschers. due to the presence of two groups of two to three roots per node. Observation of the seed indicates that this species is neither Z. muelleri nor Z. capricornii as the seed is smooth with 80-90 fine logitudinal striae (FIG. 46) and not ribbed as are the seeds of the other species. In addition, TABLE 3.1. indicates that the Onkaparinga form is generally larger than either Z. muelleri or Z. capricornii. In all other features than those mentioned in TABLE 3.1., the Onkaparinga form is the same as Z. muelleri and this fact may be the cause of its misidentification.

One other specimen in the State Herbarium of South Australia, collected by J.B. Cleland from the mouth of the Coorong in South Australia (Cleland, Mar.-1925, AD 97236142), appears to be the same species. This species may now be limited to the Onkaparinga estuary.

TABLE 3.1.

	Z. muelleri*	Z. capricornii*	Zostera sp.
Rhizome diameter (mm)	0.5 - 1.5	0.7 - 2	1 - 2.5
Roots/node	2	2 groups	2 groups of 2-3
Internode distance (mm)	4 - 31	4 - 40	10 - 35
Leaf sheath length (cm)	1.5 - 11	2 - 10	2 - 30
Leaf blade length (cm)	5 - 30	7 - 50	5 - 200+
Leaf blade width (mm)	1 - 2	2 - 5	1.5 - 4
Accessory bundles	(3-) 4 - 6	3 - 7	4 - 6
Generative shoot axis (cm)	1 - 50	1 - 30	40 - 300
No. of spathes	1 - 4 or more	numerous	4 or more
Seed test	20 ribs	16 ribs	smooth, 80 - 90 striae

TABLE 3.1. Comparison of major differences between Z. muelleri and the Onkaparinga form, and with Z. capricornii.
(* after den Hartog 1970:81-85, 87-90)

In the other estuaries so far investigated in South Australia (i.e. those of the Gawler, Port, Inman and Hindmarsh rivers), either no Zostera occurs or there are occasional patches of Heterozostera tasmanica (or Z. mucronata in the Port river). The one exception to this is an isolated clump of Z. muelleri in West Lakes, an artificial marine lake system formed from a coastal swamp which was part of the Port River. It was from this area that the only clearly identifiable specimen of Z. muelleri in the State Herbarium was collected (Tate, Jan. 1883, AD 96404345).

It has already been mentioned (Ch.1.1. and FIG. 2) that within the Onkaparinga estuary the Zostera covers almost all available mud banks from 1.7-10.4 km downstream from the ford at Noarlunga and from the lower eulittoral to 2.5 m below mean low water. Within the usual salinity range the apex will produce a new blade every two to three weeks throughout the year. The Zostera will grow in salinities down to 3-5 p.p.t. but tends to

shed its leaf blades when kept in salinities below 3 p.p.t. for longer than 2-3 days. If the low salinity conditions continue, aquarium studies have shown that the rhizome eventually dies off (see Ch. 3.2.). The Zostera starts to flower in late September though the major flowering usually does not occur until mid-November. Flowering is only prolific by plants living in the 7 km to 10.4 km region and at or below mean low water. Seed setting usually occurs from late December to January but a very small proportion of plants actually produce seed, the generative shoot either being washed out to sea or decomposing before the seeds mature.

In conclusion, it would appear that the form of Zostera occurring in the Onkaparinga estuary is probably an undescribed species and for the purposes of this thesis it will be referred to as Zostera sp.

3.2. *Zostera* as a substrate.

The study of natural populations of attaching diatoms has always been restricted by the difficulty of providing clean substrates. This is particularly important if a study of colonisation is to be attempted, or if the production of individual species or the community generally is to be estimated. Previously there have been two basic approaches to overcoming this problem, either by cleaning an already colonised substrate or by providing an artificial substrate such as a glass slide (Patrick *et al*. 1954). How "natural" a community is which develops on the broad, smooth and rigid surface of a glass slide is open to question as little is known of the substrate requirements of the various species. Certainly the evidence of Prowse (1959), McRoy & Goering (1974) and Harlin (1975) indicates that nutrients leak from the blades of some aquatic plants and these compounds would provide a different chemical environment around the plant than that around a glass slide.

It is surprising that there appear to be no studies using newly produced blades of aquatic plants as substrates for colonisation, even though there have been various studies describing the periphyton of the plant (e.g. Reyez-Vasquez 1970; Kita & Harada 1962; Main & McIntire 1974; Sullivan 1977) and Sieburth & Thomas (1973) used the principle of time being equivalent to distance with mature blades without attempting to put an age on the stages observed. Species of the Potamogetonaceae would be particularly useful due to the basal meristem of the blades and the presence of various species throughout the range from freshwater to marine environments. Such a study requires that the blade growth rate of the plants be determined and its potential variance estimated. Once this information is available the "host" plant becomes a potentially valuable research tool.

It has already been mentioned (Ch.3.1.) that the *Zostera* found in the Onkaparinga estuary produces new blades throughout the year. The first part of the new blade's growth and elongation occurs within the sheath of the next most mature blade. The new blade is therefore readily visible and available for colonisation as it appears out of the top of the sheath. At this point it is about half way through the linear growth phase

which will continue for another two to three weeks (FIG. 47). By either collecting the tips of blades of different lengths or sampling at intervals along the length of individual blades, the change of community structure with time can be observed (see Ch. 4.2.). When all the blades at the apex of the rhizome (usually four to six) are taken into account, communities up to three months old can be observed. After six to eight weeks the blade starts to die and by 12 weeks the periphyte community is largely a self supporting mass of intertwined filaments with little physical support from the rapidly decomposing blade. Finally the blade and periphyton mass breaks away from the plant near the base and either sinks to the bottom or is carried away by the current.

The use of Zostera blades as a source of natural substrates led directly to the development of a new artificial substrate which would simulate the Zostera in its reaction to water movement. The best material was found to be narrow strips cut from 3cm broad, flat, polythene tubing. This plastic was found to have the same buoyancy as the Zostera blades and, in the estuary, had a similar life span, eventually being weighed down by periphyton and detritus and sinking to the bottom. Human interference with artificial substrates placed in the estuary meant that use of this method was largely restricted to aquarium studies. Early experimentation indicated a factor which must be taken into account when using artificial substrates. It was noticed that broad strips of plastic had a dense growth of attaching species developed within 1-2 mm of the edge. Further investigations using substrates of different widths indicated an inverse relationship between substrate width and the overall density of attaching cells (FIGS 48A & 49). Such a trend was noted by Patrick (1968) who indicated that diatometer slides developed denser aggregations of cells if the slides were turned side on to the direction of water flow. A study using artificial substrates shows differing community structures with respect to the ratio of motile species (slightly affected by substrate width) to attaching species (greatly affected by substrate width) unless designed to emulate the shape of a natural substrate for comparison or, as intended by the diatometer, they are

standardised (see FIG. 48B). The physical cause for the substrate width effect would appear to be due to simple hydrodynamics. A flat surface placed in the current forces the medium to flow out and around it and usually leaves a "dead area" towards the centre with some eddying. There is a similar, though less marked, effect upon the downstream face. Since most of the attaching species are non-motile, and transported passively through the water, they are most likely to have first contact with the substrate near the edges. Eddies may then pick up some cells to colonise the central area. The water movement effect upon effective nutrient concentrations (Munk & Riley 1952) would tend to give the cells growing near the edge of the substrate a higher nutrient concentration than those near the centre. This last effect is likely to lead to the motile species also remaining near the substrate edge and this is what is observed to occur (FIG. 49C).

Observations on substrates of various widths show that a substrate of 5 mm or less in width will give an even cover of attaching forms and avoid creating a bias in favour of the motile species. Zostera blades fall well within this size range. Zostera therefore provides useful natural substrate which is likely to give regular and comparable results in a study of periphyton communities in that part of the estuary in which the Zostera is found. The main problem with its use (as indicated by FIG. 47) is the effect of temperature and to a lesser extent salinity on the growth rate of blades. This requires some art on the part of the investigator when sampling to collect blades of approximately the right age, a two week old (ex sheath) blade being 0.4-0.6 of the length of the mature blades, with a potential error of plus or minus one day in age estimation. Such an error of less than 10% was found in duplicate periphyton samples and is probably mostly due to the difficulty in estimating the age of the blade except when periphyton density is very low.

3.3. *Zostera* and the future of the Onkaparinga estuary.

In chapter 3.2. it was mentioned that not only periphyton builds up on *Zostera* blades but so does silt and detritus. This feature will be discussed again in chapter 4.3. with respect to the periphyton development but it is also of major importance to the *Zostera* community and the estuary in general and will be discussed here in that context.

Silt entrapment around the *Zostera* blade occurs as a direct result of the formation of filaments of epiphyte species around the blade. Silt, once trapped, is bound into the community by a network of filaments and the tubes of various tube-dwelling species. By the end of the blade's life it may have twenty to fifty times its mass in periphyton and silt built up around it. This mass then sinks to the bottom or is carried away. In this manner, with the aid of the flocculating effect of increasing salinity, most of the silt entering the estuary is removed from the water and transferred with some silicate (diatom frustules) to the bottom. This leads to an increase in the bottom level with time and is sufficiently rapid to be noticeable over the course of a few years. Under normal conditions winter floods would wash most of a year's build-up out to sea and scour the channels so that the general tidal movement of water will keep the estuary relatively clear and navigable for small craft for most of the year.

The building of upstream dams to catch the winter river flow changes this picture, particularly when the water demand is sufficiently high so that the dams rarely fill to the point of overflowing. The winter floods through the estuary then become less frequent and the build-up of new sediment is allowed to remain long enough to be stabilised by the growth of plants over the top of it. This not only applies to the mud banks but also to the channels. Once the *Zostera* successfully colonises the bare channels it becomes increasingly difficult for later floods to scour it out. In addition the long *Zostera* blades tend to increase the drag on water movement to further reduce any scouring effect that the tidal currents may have had.

In chapter 1.1. it was mentioned that barges navigated the

estuary up to Noarlunga during the latter half of the nineteenth century. A century later much of the estuary is so shallow that it becomes difficult to navigate a small aluminium dinghy the full length due to shallows covered with Zostera. Increasing population demand on the waters of the Onkaparinga suggests a bleak future for the estuary if present trends continue. It is a quirk of fate that at a time when the local population is looking towards the estuary for development as a recreation resource, their presence is contributing to turning the estuary into a tidal swamp. This is one case where the engineering answer of dredging the channel may well be the best solution for the estuary, the Zostera community and the recreational fishery which depends on it.

4. COLONISATION OF THE SUBSTRATE.

4.1. Introduction.

Interest in the colonisation sequence on various substrates developed from studies aimed at reducing fouling on ships. Studies on fouling organisms, which usually form similar communities to those on natural substrates, were initiated to look at benthic communities generally with particular importance placed on those formed on artificial substrates. This was particularly the case in the post-World War 2 period with research being carried out in the United Kingdom (Hendey 1951), United States of America (Aleem 1958) and Australasia (Wood 1950,1955; Skerman 1956). These studies showed an initial colonisation of bacteria, followed by diatoms, and later, larger algae and animals. An early study by Zobell & Allen (1935) indicated that a primary film of bacteria was necessary for colonisation to proceed on inert substrates. Sieburth & Thomas (1973) investigated the importance of bacteria and diatoms in the colonisation of blades of Zostera. Prior to this study, investigation of Zostera periphyton had been limited to species composition and seasonal abundance (Brown 1962[1]; Kita & Harada 1962; Main & McIntire 1974; Marsh 1970[2]; Sullivan 1977), and no attempt had apparently been made to examine the assemblages in the Scanning Electron Microscope.

Sieburth & Thomas (1973) investigated Zostera blades at various stages of colonisation and observed that bacterial colonisation was minimal and not a prerequisite for diatom colonisation, in contrast to the earlier work of Zobell & Allen (1935). In addition they observed that Cocconeis scutellum Ehrenberg was the first to colonise the Zostera and this species formed a continuous "crust" on the blade surface before other species colonised the surface of Cocconeis cells. The purpose of this part of the present study was to determine to what extent the observations of Sieburth & Thomas (1973) applied to colonisation of Zostera blades in the Onkaparinga and if possible to put a time scale on the sequence.

1. Brown, C.L. (1962). On the ecology of Aufwuchs on Zostera marina (in Charleston Pond, Rhode Island). M.Sc. Thesis, Univ. of Rhode Island, R.I.
2. Marsh, G.A. (1970). A seasonal study of Zostera epibiota in the York River, Virginia. Ph.D. Thesis, College of William & Mary, Williamsburg, Va. 167 pp.

4.2. Studies of the colonisation sequence.

4.2.1. The initial colonisation.

In this study both Zostera blades and their polythene equivalent were used to observe the colonisation sequence. Zostera blades of known age were sampled from various stations in the estuary, measured, and 1 cm lengths were removed at various distances along the blade. These lengths were gently placed in distilled water to remove excess salts and then dried at room temperature in a vaccuum dessicator. The dried blade pieces were mounted on a coverslip with a silver suspension and placed on an aluminium stub, plated with gold-paladium and observed in the Scanning Electron Microscope (SEM), a Seimens Autoscan.

The polythene strips of various widths (1.5-16 mm) were placed in laboratory aquaria in which Zostera was growing at various salinity and temperature conditions. Pieces of polythene strip could therefore be removed at various stages to allow the colonisation sequence to be conveniently observed. Lengths (1 cm) of polythene strip were removed at intervals of 3, 7 and 14 days, stained with Aniline blue-HCL and mounted in 50% Karo (containing phenol as a preservative) on a glass slide. The slides were then observed with direct light using a Leitz SM-LUX laboratory microscope.

Colonisation of the Zostera at the 2 km station was initiated by coccoid bacteria, Cocconeis scutellum and C. placentula var. euglypta (FIG. 50A). This was also observed by Sieburth & Thomas (1973), but the rest of the sequence is somewhat different in the Onkaparinga estuary. Rather than the formation of a continuous layer of Cocconeis, the next stage, which becomes marked after 3 days, is the rapid colonisation by the more common of the epiphyte species and a build-up of some detritus (FIG. 50B,C). After about 7 days the epiphyte colonies are well established and detritus covers large areas of the blade surface (FIG. 50D). It is at this stage that the non-Cocconeis motile species begin to reach a cell density equivalent to that of the epiphyte species and the number of motile species begins to

increase. The number of motile species appears to slowly increase for the rest of the "life" of the assemblage but the majority of the attaching species are already present at this stage (see Ch. 4.2.2.). After 14 days the motile species, particularly the tube forming ones, and some of the epiphyte species which have a colony form which enables them to grow well away from the blade surface, begin to numerically dominate the assemblage. Many of the cells growing near the blade surface become buried in the silt and detritus, all of which is held together by further colonisation of the surface crust and the network of tubes formed by the tube dwelling species.

At the 10 km station the sequence was similar with the exception that Cocconeis pellucida replaced C. placentula var. euglypta (FIG. 51B,C) and there was not much silt deposition. This is probably due to the low silt loading of the water by the time it reaches the 10 km station, most of the silt having been removed further upstream. The density of periphyte cover is often lower at the seaward end of the estuary with the exception of blooms of the tube dwelling Berkleya rutilans and the growth of macroscopic algae such as Myrionema magnusii (Sauvageau) Loiseaux.

In general the colonisation of Zostera blades can be divided into four stages.

1. Initial colonisation of bacteria and Cocconeis species, either by a large number of colonising cells which continue to arrive for the first 7 days or by a few colonising cells which divide rapidly on the new substrate. The plankton was observed to have very low densities of viable diatoms (less than 1000 cells/litre) which suggests rapid growth from a few colonising cells is the more likely strategy.
2. Within one to two days, colonisation by common epiphyte cells starts. These cannot spread themselves over the surface as the Cocconeis species can and therefore tend to grow in clumps or colonies where the colonising cell first attached to the substrate. The epiphyte colonies would appear to reduce the water velocity near the blade,

and this has the dual effect of assisting silt deposition and providing a relatively sheltered environment for motile cells to colonise the surface without being carried away by the current. This is also the stage that fungal and macro-algal spores colonise the blade.

3. After 7 days the motile species begin to become numerically dominant as the blade surface begins to build up sufficient sediment to appear similar to the mud flat on which the Zostera grows. Many of the epiphytes which live only near the blade surface and the Cocconeis species tend to die, presumably due to being buried in the silt and detritus, or being shaded by the filamentous species.
4. After 14 days, periphytic and epiphytic animals tend to become associated with the assemblage. Those observed are protozoans and other detrital feeders (e.g. copepods and rotifers) with mouth parts too small to feed on any but the smallest diatoms. At this stage, also, the epiphytic diatoms appear to reach a balance between growth, colonisation and loss due to death, predation and cells being carried off by the current (see Ch. 4.2.2.). Any macro-algae present tend to produce vertical filaments at this stage and become more obvious.

This sequence can be delayed by a sudden change in temperature, as observed in aquarium studies using polythene strips. Aquaria used in Zostera growth studies were set up with water collected from the 2 km and 10 km stations respectively and were placed in controlled temperature rooms of 12°C and 20°C. The effect of temperatures which approximate winter and summer conditions could then be observed with respect to species found in either end of the estuary.

At 20°C there was little difference in colonisation between the two sets of attaching assemblages (FIG. 52) except for the presence or absence of a few species. In the 12°C aquaria the colonisation of the strips by

diatoms was much slower (FIG. 53) for both aquaria, and Cocconeis scutellum was the dominant diatom coloniser. This was observed with species which were originally derived from temperatures in the estuary of approximately 20°C.

Different species are often involved in the assemblages, depending on the ambient salinities, but those species which occur in both summer and winter assemblages appear to become acclimated to a particular temperature regime and do not survive a rapid change. It is likely that some members of these populations can live in some temperatures better than others and when such conditions are present those cells then outgrow the other cells to form the majority of the new population. The population then appears to become acclimated to that temperature. This principle is likely to apply to other environmental conditions such as salinity and may explain the wide salinity "tolerance" of Cocconeis scutellum and other euryhaline species. Thus a population can be thought of as having a tolerance to environmental change even if this is not true for individuals within the population.

Referring again to Cocconeis scutellum, a sample collected from the 6 km station in November 1975 is of relevance to the observations of Sieburth & Thomas (1973). Lack of rain and a series of low tides had left this region of the Onkaparinga in a near stagnant condition. Cocconeis scutellum had colonised the Zostera blades and, lacking any competition, had formed a crust covering the entire blade, after which the cells had all died. Some epiphytes had colonised the surface of the crust and had also died. The samples observed by Sieburth & Thomas had come from a brackish marsh which may provide conditions almost as extreme as those noted above, but not sufficiently severe to kill the Cocconeis nor to prevent colonisation by other species. The controlling factors appear to be the relative colonisation and growth rates of Cocconeis and the epiphyte species.

4.2.2. The juvenile and mature blade communities.

To study the next stage of the development of the periphyton assemblage and to gain some insight into a possible source of colonising species,

the 14 day assemblages growing on juvenile Zostera blades were compared with the next most mature blade assemblages from the same plant. These more mature blades were estimated to have assemblages aged between 25 and 30 days. Samples were scraped, shaken vigorously to break up the colonies and give random dispersal, and the living cells (those with intact cytoplasm) were counted in a Haemocytometer and referred back to the area of the sampled piece of blade to give an estimate of cell density. The dominant interest was in the epiphyte species which form the basis of this study but motile species were also noted. Samples were collected every three weeks from June 1976 to February 1977.

The epiphyte species composition and total cell densities (FIGS 54-57) show the two sets of assemblages (14 and 25-30 days) to have almost identical species' structures at any given time. For the non-motile epiphyte species there can only be two species' pools from which cells can be derived for colonising a substrate, i.e. the plankton or mature epiphyte assemblages. Observations on the plankton showed it to be very poor in epiphyte species and that the epiphytes sink out of suspension in a few minutes in the low current velocities experienced generally in the Onkaparinga. This indicates that the likely source of epiphyte colonising cells would be previously colonised blades near the juvenile blade. The system of blade production ensures that the juvenile blade is surrounded by more mature blades and is usually within a few centimetres of them, if not actually touching. The juvenile blade therefore tends to be colonised by those epiphyte species which are growing well on the more mature blades. It is likely to be a bi-directional flow of cells and if the interchange is sufficiently frequent the common species would be expected to be found in the same proportions regardless of the age of the assemblage, as indicated by the observations made here. The more mature assemblages do have an important role in providing conditions which aid in colonisation by species new to the assemblage, the cells of which may be carried adventitiously in the plankton.

This nearness to and potential interchange with assemblages of

various ages may be very different from the dynamics of assemblages developed on hard substrates such as glass slides. Continuous colonisation of the assemblage (not necessarily the Zostera blade surface) partially explains why the living species found on mature blades may not reflect the species composition that would have been found on the blade several weeks earlier. This is particularly so in an estuary when environmental fluctuations may lead to a rapid reduction in the number of living cells in the assemblage. The "mature" assemblage may therefore have species in it which have been colonising the assemblage only for as long as they have been colonising the "juvenile" assemblage. That this is so is indicated by the total cell densities. When the environment has been relatively stable for a few weeks, the mature blade is usually found to carry higher densities of epiphytes than the juvenile blades because the assemblage had been colonised and growing longer on the older blade. Alternatively, when the environment has been unstable, epiphyte densities tend to be very similar and low because the species now forming the living assemblage may not have been growing for very long on either juvenile or mature blades. Both may actually be young assemblages regardless of blade age.

4.3. The attaching species as a part of the periphyton.

In chapter 3.3. and again in this chapter, it has been emphasised that one of the side effects of colonisation by attaching species is the formation of filaments which extend out into the water. These filaments increase the likelihood that both silt and planktonic cells will be trapped and hence added to the assemblage. Both aspects are apparently important to the periphyton. The entrapment of a new species which may be better suited to a recently changed environment is necessary if the periphyton is going to continue to exist, as it will survive when other species die off. In chapter 5.2. it will be shown that the periphyton assemblage recovers very slowly when the epiphytes are greatly reduced in numbers and remains species poor for several weeks after the epiphytes begin to return. With respect to the motile species which can theoretically (and probably do) move up from the mud along the blades, there is the added dimension in their apparent requirement for a silt layer over the Zostera blade. The maximum number of motile species can usually be found in the upper reaches of the estuary (FIG. 58) regardless of the ambient salinity. Some of these species are known to be freshwater species, others have been found in various parts of the estuary but only consistently in the upper reaches.

An associative analysis was carried out using the local program "LANGE 3" which calculates the correlation coefficients for each pair of species on the basis of presence and absence data. LANGE 3 was run with presence and absence data for the ninety five species described in chapter 2.2. from juvenile blade samples collected between March 18, 1976 and February 16, 1977 from all four sampling stations. The results indicated the presence of five groups which were clearly defined at a level of probability of less than 0.001 (FIG. 59) but become less well defined by the presence of common species at lower confidence limits. Fifty percent of the species (47 species) either formed or were loosely associated with one group. Many of these Group I species are common freshwater forms but others can be found in a wide range of salinities. It would appear that

Group I is an association of which the members have only their presence in the upper reaches in common. This does not imply only a freshwater association because there are other gradients in the estuary than just salinity, one of which is the amount of silt which builds up on the Zostera blades. An intensive study of both peripelon and periphyton would therefore be needed to gain insight into the individual requirements of each of these species.

The complexity of Group I compared to the other four groups is best indicated by a factor analysis of the presence and absence data for the species which form the groups. The data was analysed using the FACTOR subroutine of the Statistical Package for the Social Sciences, Version 7 and the inter-variable relationships with respect to the first three factors illustrated by FIGURE 60. The variance in the data was sufficiently complex that eighteen of the factors were significant (Eigenvalues greater than 1.0) but the first three factors adequately separate the five groups derived from LANGE 3 (see also FIG. 59). The first factor is inversely related to distance down the estuary (though not significantly so) but the other components show no obvious relationship to any of the measured environmental parameters.

In conclusion, the colonisation of Zostera blades is a very complex process which probably relies to some extent on unmeasurable or unknown parameters and can therefore only be described in the most general terms with reliance on largely circumstantial evidence. This uncertainty is likely to increase with the age of the assemblage as the interactions in the assemblage become more complex.

5. ENVIRONMENTAL INFLUENCE ON COMMUNITY DEVELOPMENT

5.1. Introduction.

An estuary provides one of the most interesting and yet most difficult environments to be studied. The major logistical problem involves trying to measure or estimate the diurnal fluctuations due to tidal ebb and flow, how these fit into the spring to neap cycles and how it all fits into an overall seasonal variation. There is the further complication that cycles of wet and dry years occur to distort otherwise annual cycles (see Ch.5.2.).

In a study such as this, the diurnal variation can only be observed for isolated instances as the estuary is too heavily populated to leave continuous recorders unguarded. A compromise was reached by spending the two days prior to each sampling date making observations on the tidal cycle, one day each at the 2 km and 10 km stations. The variation in river level was recorded with the aid of a gauge post placed in the water. Salinity and temperature at the level of the Zostera blades was measured with an AUTOLAB Hamon Temperature/Salinity bridge Model 602. Photosynthetically active light input was measured at blade level with a LI-COR (Model LI-185) quantum sensor (when available). Oxygen concentration, as percent saturation, was measured with an Electronic Instruments Ltd. Dissolved Oxygen Meter, Model 1510 (subject to malfunctions) and converted to a concentration by an equation the derivation of which can be found in APPENDIX A. Current velocity was measured by a 24×24cm aluminium drogue and by a General Oceanics Model 2031 Digital Flowmeter with a low velocity propeller.

These studies were backed up by observations and water samples taken at each sampling station at the time of sampling the Zostera. Salinity and temperature profiles were taken for the water column from surface to sediment over the Zostera beds. Water samples were taken at the Noarlunga ford (to monitor the input from the river) and at the surface and near the sediment over the Zostera beds at each sampling station. These water samples were then analysed at the Bolivar laboratories of the South Australian

Engineering and Water Supply Department for the following:

1. Total Dissolved Solids (TDS)
2. pH
3. Nitrite (NO_2)
4. Nitrate (NO_3)
5. Ammonia (NH_3)
6. Total Kjeldahl Nitrogen (TKN)
7. Soluble Phosphate (PO_4S)
8. Total Phosphate
9. Silicon Dioxide (SiO_2)
10. Total Organic Carbon (TOC)
11. Total Carbon

From these the following variables were also derived:

12. Total Organic Nitrogen (TON): TKN less the inorganic compounds NO_2, NO_3 and NH_3.
13. Particulate Phosphate (PO_4P): Total Phosphate less PO_4S.
14. Total Inorganic Carbon (TIC): Total Carbon less TOC (see also APPENDIX C).

Total dissolved solids (or salinity) has already been shown in both field studies (Karentz & McIntire 1977; Main & McIntire 1974) and laboratory studies (Admiraal 1977b; Martin 1970[1]; Wulff & McIntire 1972) to be an important factor in the distribution of estuarine diatoms. McIntire (1973), using four variables (mean salinity, mean salinity range, mean temperature and mean emergence time) and Principle Components Analysis, showed that salinity was the most important variable in determining the distribution of winter diatom assemblages in the intertidal zone of Yaquina estuary, Oregon. McIntire's (1973) analysis is likely to have been biased by the probable covariance of the first three variables, and the few variables considered (see Ch. 5.3.3.). This does not detract from the result that salinity is an important variable but does leave the question unanswered of its importance, relative to other environmental variables.

pH was included largely for its effect upon which form of inorganic carbon would be available to the plant community. Both river and seawater were found to be equally alkaline, varying generally between 7.9 and 8.5 with extremes of 7.7 and 9.1 being recorded. These measurements were taken in the

1. Martin, J.V. 1970 : Salinity as a factor controlling the distribution of benthic estuarine diatoms. Ph.D. Thesis, Oregon State University, Corvallis, Oregon, U.S.A.

laboratory several hours after sampling and show a more extreme range about a mean of 8.3 than the few in situ measurements would indicate is normal for the estuarine waters.

The rest of the assays were included to cover the general range of nitrogen, phosphorous, silicon and carbon sources (Bates 1976; Carpenter 1970; Confer 1972; Faust & Correll 1975; Ferguson et al. 1976; Holmes 1966; Lewin 1961) without going into the complex study of vitamins, micro-nutrients and trace elements which have been shown to be necessary for the growth of some diatoms (e.g. Carlucci & Bowes 1972; Droop 1955; Jeffrey & Carpenter 1974).

Daily rainfall figures for Mt Bold reservoir were investigated as a possible aid in estimating river flow but were found to be of little value, providing no information that was not already evident from the salinity data. This hydrological aspect of the study will be returned to in Chapter 7.

The oxygen readings were similarly uninformative with the daily range varying from 10-20% to 120% saturation, and sometimes well in excess of 200%, at which bubbles formed. Lack of faith in the accuracy of the oxygen electrode after it had been immersed for several hours led to the discarding of the results on the assumption that oxygen would not become limiting at a low concentration due to the shallowness of the estuary, and if high concentrations were limiting, the oxygen meter was incapable of measuring them.

In general the concept behind this section of the study was to obtain a broad, stable environmental data base which would maintain its structure when combined with periphyton data for multivariate analyses. To derive the maximum information out of such analyses it was necessary to have available the maximum number of environmental variables that could be measured within the limits of available time and analytical resources and are likely to have some bearing upon the distribution of periphyton species. The physico-chemical environment was considered to be the principle determinant factor in population and community dynamics, in agreement with Kinne (1967). The biological envi-

ronment of extracellular substances, competition for light, predation, etc. was considered to be a minor factor compared to the physico-chemical environment, as well as being very difficult to quantify. A secondary objective was to avoid, as much as possible, the potential bias, such as that already mentioned with respect to McIntire (1973), by considering too few environmental variables.

Multivariate analytical techniques have been used, with apparent success, in terrestrial plant ecology for some time (e.g. Ivimey-Cook & Proctor 1967; Lambert & Williams 1962; Lange 1968; Noy-Meir 1971,1974). Aquatic plant ecologists have been slower to adopt these techniques but the studies in which they have been used (Allen 1967,1971; Karentz & McIntire 1977; McIntire 1973; Ricard 1977; Symons 1970) show that extra, useful information can be extracted from the otherwise complex ecological data which so often results from aquatic ecological research. In this study, Factor Analysis has been found to be useful in the extraction of information from large amounts of data and forms the basis for most of Chapter 5.3. Another "popular" multivariate analytical technique was investigated, vis. Canonical Correlation. However, this required that one set of variables should be independent and too few of the environmental variables could be realistically placed in such a category. The analysis was therefore not used.

5.2. The implications of seasonal and spacial distributions.

The ecology of assemblages of attaching diatoms from estuaries have, until now, been studied in cool to cold temperate climates (Bacon & Taylor 1976; Hargraves 1965[1]; Martin 1970[2]; Welch et al. 1972). Such assemblages are characteristically limited by low temperatures and low light during the winter and have a late spring to summer maximum in cell densities. The Onkaparinga estuary is situated in a warm temperate climate and water temperatures rarely drop below 11°C in the winter. What effect this climate would have on the seasonal dynamics of the periphyte assemblages was unknown and worthy of investigation.

A study of the juvenile blade (14 day) epiphytes was initiated in June, 1974 as part of work towards a B.Sc. (Honours) degree. This was an opportune time to start because the winter of 1974 was particularly wet (the last before commencement of the drought of 1975-8) and variations in species' distributions were more marked in 1974 than they were in the period between 1975 and 1977 covered by this study.

Juvenile blade tips from at least ten plants were sampled initially every two weeks (June to November, 1974; March, 1975 to March, 1976) and later, every three weeks (March, 1976 to February, 1977. The sampling stations (2, 6, 8 and 10km downstream from Noarlunga ford) were chosen because of the presence of extensive Zostera beds (not present at the 4km station) and gave samples which were representative of periphyton distribution in the estuary. The samples were preserved in 4% Formalin and seawater, the periphyton then being scraped off the blade, shaken vigorously to break up colonies, and concentrated down to a known volume for counting under the microscope using a Haemocytometer. The surface area of each blade from which the periphyton had been scraped was measured so that cell densities could be estimated. Diatom

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1. Hargraves, P.E. 1965: On the seasonal changes in plant periphyton in a salinity gradient. M.Sc. Thesis, University of Rhode Island, Rhode Island, U.S.A.

2. Martin, J.V. 1970: Salinity as a factor controlling the distribution of benthic estuarine diatoms. Ph.D. Thesis, Oregon State University, Corvallis, Oregon, U.S.A.

cells which still had intact cell contents were defined as having been viable at the time of sampling. Viable cell densities were estimated for epiphyte species from all samples collected. Due to difficulties in identifying viable motile cells these were not studied until March 1976 when they were included as an estimate of total motile cell density.

The total epiphyte cell densities and the proportion of each species in each sample are shown in FIGS 61-72. These results show a peak in epiphyte production from late Autumn to early Spring. There is an apparent inverse relationship between ambient salinity and cell densities which probably reflects a positive correlation with freshwater input. In addition, a comparison between the 1974 data (FIGS 61,64,67 & 70) and the 1976/7 data (FIGS 63, 66,69 & 72) shows a decline in the height of the peaks since 1974 which is probably a direct effect of the drought. Most of the nutrient input into the estuary is derived from runoff after rain (see Ch.5.4.) as the local seawater has low nutrient levels. For example, both nitrate and soluble phosphate are usually present in concentrations below 0.02 mg/l at the seaward end of the estuary and are often in the region of 0.5 mg/l in the upper reaches.

The low precipitation rates for 1975 and particularly 1976 have had two major effects upon the epiphyte assemblages. An important effect is the reduced nutrient input into the estuary so that the potential growth rates are reduced. Linked with this is the reduction in the length of time during which parts of the estuary have low salinity, high nutrient conditions. The euryhaline species (Melosira sp.1, Synedra tabulata and Achnanthes brevipes var. intermedia) and freshwater species (Synedra pulchella var. lacerata and Gomphonema constrictum var. capitatum) have apparently evolved to exploit these conditions as indicated by their domination of the winter peak assemblages (FIGS 61-72). Not only the epiphytes grow best during the winter but also some of the motile (tube forming) species, particularly Berkleya rutilans, Nitzschia vidovichii and N. sigma var. rigida, form the base of winter peaks in motile cell densities (FIGS 73,74).

Comparison of the variation of dominant epiphyte species' proportions with respect to distribution down the estuary (FIGS 61-72, 75 - Winter, 76 - Summer) indicate that there are three basic groups of epiphyte species. The first group could be potentially divided into two groups, one containing the freshwater species (listed above) which generally appear at the top end of the estuary during a wet winter (FIG. 75A), and the other, a euryhaline group of species which grow best at the top end of the estuary during relatively dry winters (FIG. 75B,C) but are common throughout. During the summer (FIG. 76) these freshwater-euryhaline species tend to be limited to the upper reaches, although two (Melosira sp.1 and Synedra tabulata) generally occur throughout in low densities. The second group contains euryhaline species, with limited tolerances, which are found in the 6-8 km region during the summer (FIG. 76) but tend to almost disappear during the winter. This group comprises Grammatophora oceanica, Licmophora sp.3 and the much rarer species Plagiogramma staurophorum and Dimeregramma minor. The third group is nearly absent during the winter but may penetrate all the way up the estuary during the summer. These are marine-euryhaline species which attain their maximum densities at the lower end of the estuary and include Licmophora flabellata, Synedra fulgens, Rhaphoneis surirella var. australis and Striatella unipunctata.

From the species' correlation matrix (FIG. 59) it can be seen that the first group has species belonging to GROUP I of the matrix plus those species which are so common that they cannot be segregated into any group from presence and absence data (i.e. Melosira sp.1, Synedra tabulata and Achnanthes brevipes var. intermedia). The second group corresponds with GROUP V of the matrix.

Data containing limited information, such as the presence and absence data referred to here, can therefore assist with the interpretation of species' abundance data by providing basic groupings which can then be looked at more closely. Even with a relatively dry winter, such as 1976, species from each group show distributions characteristics of the group as

described above (FIGS 77-79). To get more information out of the data, however, it becomes necessary to use one or more of the techniques of multivariate analysis as well as bivariate analysis.

5.3. Correlational analyses.

5.3.1. Structure of the environmental data.

In Chapter 5.1. it was stated that one of the objects of the sampling program was to provide a broad data base of environmental variables which would not be too disturbed if species or assemblage data was added for a combined analysis. It was therefore necessary to analyse the environmental data to discover how the variables related to each other. The most convenient method to investigate between-variable relationships is to calculate a set of common factors which make up various aspects of the entire data set, i.e. a Factor Analysis. Each variable contributes to a greater or lesser extent to each factor and variables having a strong covariance will usually cluster together with respect to those factors over which they have greatest influence. In addition, the factor axes may be rotated mathematically to aid in the delineation of the various variable clusters.

The analysis was carried out with the aid of FACTOR, a program which is part of the Statistical Package for Social Sciences (SPSS) software attached to the Adelaide University Cyber 173 Computer. The general practice in the use of such analyses is to consider as significant only those factors which have eigenvalues of 1.0 or greater, and this convention will be applied here to the unrotated factors. Rotation of axes, where used, is the VARIMAX orthogonal rotation of FACTOR using data normalised by the method of Kaiser (1963).

Thirteen variables were analysed, both as a data set by themselves and as a data set related to distance down the estuary. The variables included were:

1. TDS (Total dissolved solids)
2. pH
3. NH3
4. NO2
5. NO3
6. TON (Total organic nitrogen)
7. PO4S (Soluble phosphate)
8. PO4P (Particulate phosphate)
9. TIC (Total inorganic carbon)
10. TOC (Total organic carbon)
11. SILOX (Silicon oxides)
12. TEMP (Temperature)
13. QUANT (Total daily quantum input)

The analysis indicated that there were four significant factors contributing to the data variance. With the addition of the distance variable (DIST), the four factors accounted for 76.9% of the variance. VARIMAX rotation of the factor axes gave the situation illustrated in FIGURE 80 (see also TABLE 5.1; FIG. 81). From the graphs it is evident that there are four groups of variables, in five clusters, which contribute significantly to each of the four factors respectively.

The first factor is largely composed of variance related to the biologically derived variables TON, PO4P, NH3, TOC and pH. Observations indicated that these variables would be correlated with a phytoplankton bloom consisting of a dinoflagellate (Pyrodinium sp.), a species of Euglena and several small flagellates. These variables are therefore likely to be contributed to by the plankton (including diatoms, bacteria and various animal species in addition to the flagellates already mentioned) rather than necessarily being major components of the chemical environment to which species will react. It is not known what proportions of TOC and TON are bound up in biological material and what proportions are dissolved in the water and potentially available as nutrient resources for the periphyton.

The second factor is mostly contributed to by two inversely correlated sets of variables based on position in the estuary. One cluster of variables is related to freshwater input into the estuary, the most important of which are TIC and SILOX. Both TIC and SILOX diminish in concentration down the estuary, TIC diminishes due to the precipitation of excess carbonate upon mixing with saline waters and SILOX is probably reduced by absorption by diatoms. At the opposite pole of FACTOR 2 is the cluster of DIST and TDS.

The third factor effectively represents the temporal aspects of the data with the summer maximum variables (TEMP and QUANT) directed towards one pole and the winter maximum variables (e.g. NO3) directed towards the opposite pole.

	FACTOR			
	1	2	3	4
TON	.90	.12	-.07	.13
PO4P	.81	.18	-.08	-.04
NH3	.70	.37	-.24	.12
TOC	.62	.31	.07	-.12
pH	.61	-.13	-.46	.25
SILOX	.21	.50	-.30	.17
TIC	.19	.88	-.12	.05
NO3	.08	.10	-.42	.49
NO2	.03	-.02	-.27	.94
PO4S	.03	.07	.08	.69
DIST	-.09	-.92	-.18	.10
QUANT	-.09	-.24	.91	-.14
TEMP	-.11	-.03	.95	-.04
TDS	-.23	-.63	.21	-.02
%Variance	36.58	18.25	12.25	9.72
Eigenvalue	4.63	2.31	1.55	1.23

TABLE 5.1 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables. Dominant variables of each factor are underlined.

The fourth factor is mostly derived from the variance of the inorganic nutrients, nitrate (NO3), nitrite (NO2) and soluble orthophosphate (PO4S). The concentrations of these three compounds were highest in the samples from the 6 km and 8 km stations (FIGS 82-84). This was apparently due to input from a small creek, approximately 5 km downstream from Noarlunga ford (FIG. 2), which was draining nutrient rich water from the land on the northern side of the estuary. Apparently the Noarlunga meatworks, banned from emptying sewage into the Onkaparinga, had been spraying it onto pastures as a fertiliser (Dr D.A. Steffensen, pers. comm.). The excess water was finding its way into the creek where it was found to be nourishing a dense bloom of an Euglena species. The effects of this input were noticeable 3 km upstream on the high tide (FIG. 85) and about the same distance downstream on the low tide. This aspect therefore breaks up what would otherwise have been a system of environmental variables which vary constantly along the estuary. One of the functions of factor analysis is to assist in delineating the variation due to such disturbances to the system being studied. In this case the grouping of variables is also shown up by bivariate analysis. The correlation coefficients (FIG. 81) show significant between-variable correlations (0.4 or more) within the clusters delineated by FACTOR.

In conclusion, the period from March 18, 1976 to February 16, 1977 covered a year of below average rainfall for the catchment of the Onkaparinga river. Even so, there was enough rain for incoming freshwater to vary the chemistry of the estuary sufficiently for correlation analyses to be considered worthwhile. The variables included provide a robust data base which should not be markedly affected by the addition of another variable representing some aspect of the periphyton. In a general way, the contribution of the position in the estuary, season, organic and inorganic variables, to the variance of selected aspects of periphyton assemblages can therefore be estimated.

If this was a non-flowing system such as a lake, maximum cell densities would lead to a depletion of available nutrients. In a flowing

system such as the estuary during winter, such a depletion would be unlikely to occur due to the cells not being in a body of water long enough to remove all the nutrients, though the concentrations are likely to diminish towards the seaward end of the estuary. Thus direct correlations are likely to be useful in elucidating the environmental circumstances which contribute to maximum cell densities and will be treated as such here.

5.3.2. Correlations between periphyton and the environment.

The periphytic diatoms are represented by the variable TOTCELL which is composed of the total density of viable diatom cells for each sample. In chapter 5.2. it was shown that the maximum epiphyte and motile cell densities occurred during the winter. In the factor analysis this variable would be expected to contribute to the opposite pole from TEMP and QUANT on the seasonal factor. As the maxima of epiphytes and motile cells occurred at opposite ends of the estuary, TOTCELL would not be expected to contribute much variance to the distance factor. The analysis shows (TABLE 5.2) that the seasonality of the TOTCELL variance is so marked that it causes the seasonal factor to replace the distance factor as FACTOR 2. On both factors TOTCELL is negatively related to salinity (see also FIG. 86), but the scattergram of TDS versus TOTCELL (FIG. 87) shows how little low-salinity information is available to back this up. Alternatively the inverse relationship of TOTCELL with TEMP (FIG. 88) and QUANT (FIG. 89) indicates a strong inverse correlation. This on its own is not very informative as most of the nutrients are also inversely correlated with TEMP and QUANT (FIG. 86) and may well be over-riding any effects of low temperature and light. With respect to TOTCELL the most important nutrient variables appear to be nitrite, nitrate and ammonia. However, the presence of high cell densities at times of low concentration of one or other of these compounds poses the question of whether all of the nutrients are required for maximum cell densities or do some of the components of the periphyton grow better in some nutrients than in others?

	FACTOR			
	1	2	3	4
TON	.90	.10	.13	.14
PO4P	.81	.08	.18	-.04
NH3	.69	.26	.37	.09
TOC	.62	-.06	.34	-.13
pH	.60	.46	-.12	.25
SILOX	.20	.30	.50	.14
TIC	.20	.12	.86	.03
TOTCELL	.17	.57	.10	.23
NO3	.07	.44	.09	.47
PO4S	.03	-.05	.06	.70
NO2	.02	.35	-.02	.93
QUANT	-.07	-.92	-.23	-.09
DIST	-.09	.16	-.92	.00
TEMP	-.10	-.95	.00	.01
TDS	-.22	-.20	-.66	-.03
%Variance	36.16	18.49	11.27	8.99
Eigenvalue	4.91	2.51	1.53	1.22

TABLE 5.2 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus total viable cell densities.
Dominant variables of each factor are underlined.

The next stage in the analysis was to break the total cell densities down into the epiphyte (TOTATT) and motile (TOTUNAT) species. Factor analyses of these two variables (TABLES 5.3 & 5.4) indicated the differences that can be hidden by a conglomerate grouping such as TOTCELL.

TOTATT contributes strongly to FACTOR 1 with the organic variables. A far more intensive study than was possible here would be required to determine whether the epiphytes contributed to, merely correlated with, or are stimulated to grow by aspects of the organic variables (see also Ch. 7).

TOTATT, as also indicated by figures 61-72, is inversely related to distance down the estuary and therefore contributes to the TIC/SILOX pole of FACTOR 2. The strongest relationship is the inverse correlation of TOTATT with TDS which probably indicates a requirement for salinites below normal seawater. This could equally well be partially due to the input of nutrients which are also inversely related to salinity and positively correlated with TOTATT. The inorganic variables of FACTOR 4 positively covary with TOTATT. Most of this appears to be due to the correlation of TOTATT with both NO2 and NO3.

By comparison (TABLE 5.4), the motile cell variable TOTUNAT only strongly covaries with the temporal axis (FACTOR 3) in a manner which implies maximum cell densities during the winter. TOTUNAT has a negative correlation with the organic variables of FACTOR 1 (FIG. 86) and shows a lower correlation with the inorganic variables (FACTOR4) than TOTATT. By observation much of the variance of TOTUNAT would appear to be due to fluctuations in cell densities of two of the tube forming species, Berkleya rutilans and Nitzschia vidovichii. Both these species bloomed at various times in late autumn and early winter and mostly in the middle to lower reaches.

TOTATT and TOTUNAT are still conglomerate groupings, like TOTCELL, reflecting the reactions of a variety of species, each potentially having a unique set of environmental requirements for optimum growth. TOTATT was therefore divided into its component species to investigate whether species' level analyses would be more informative. For example, from figures 61-72

	FACTOR			
	1	2	3	4
TON	.91	.12	.07	.13
PO4P	.81	.18	.08	-.04
NH3	.70	.37	.24	.12
TOC	.61	.30	-.08	-.12
pH	.60	-.13	.46	.25
TOTATT	.47	.46	.38	.21
SILOX	.20	.49	.29	.16
TIC	.19	.86	.11	.04
NO3	.08	.09	.42	.48
NO2	.03	-.01	.28	.96
PO4S	.03	.08	-.08	.68
DIST	-.09	-.93	.18	.00
QUANT	-.09	-.24	-.90	-.13
TEMP	-.11	-.03	-.96	-.04
TDS	-.24	-.66	-.22	-.02
%Variance	38.54	16.92	11.36	9.08
Eigenvalue	5.26	2.31	1.55	1.24

TABLE 5.3 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus total epiphyte viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.90	.13	.05	.13
PO4P	.82	.19	.02	-.04
NH3	.71	.39	.19	.09
pH	.63	-.09	.44	.25
TOC	.60	.33	-.10	-.13
SILOX	.21	.52	.27	.14
TIC	.20	.89	.05	.03
NO3	.09	.12	.43	.47
NO2	.04	.00	.35	.92
PO4S	.03	.05	-.05	.70
TOTUNAT	-.04	-.12	.50	.16
DIST	-.08	-.89	.22	-.00
QUANT	-.11	-.29	-.91	-.09
TEMP	-.15	-.07	-.94	.00
TDS	-.22	-.66	-.14	-.03
%Variance	34.56	19.39	11.32	9.03
Eigenvalue	4.67	2.62	1.53	1.22

TABLE 5.4 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus total unattached viable cell densities. Dominant variables of each factor are underlined.

it was evident that three species dominated the upper reaches during the periods when maximum cell densities were recorded. These species (Melosira sp.1, Synedra tabulata and Achnanthes brevipes var. intermedia) must therefore respond differently to the winter conditions than some of the others and should be distinguished from the other species by a combination of multivariate and bivariate analyses.

The most obvious relationship between the three epiphyte species which make up the winter cell density maxima is that they can each be characterised as truly euryhaline and will be found almost throughout the estuary throughout the year. These species therefore have a selective advantage over species which are restricted in their environmental tolerances to a narrow salinity range. Factor analysis (TABLES 5.5-5.7) indicates that each of these species is probably exploiting different aspects of the estuarine environment. SYNTAB covaries most strongly with the organic and inorganic variables and has the highest correlation with the winter end of the temporal axis (FACTOR 3). Alternatively, ABREV has so much variance related to position in the estuary that it causes the distance factor to be elevated to FACTOR 1. Bivariate analysis (FIGURE 86) backs up what is indicated by the factor analysis. MELSP1 and ABREV have more in common with each other than either have with SYNTAB. MELSP1 shows a stronger positive or negative correlation with all variables, except SILOX, than does ABREV. It is significant that several of the peaks of ABREV cell densities coincide with peaks in silicon oxide concentrations. Achnanthes brevipes var. intermedia has large, solidly constructed cell walls and there may be a requirement for high concentrations of silicon oxides to allow a rapid production of new cell walls which must coincide with a rapid growth rate. Melosira sp.1 is less likely to require the same concentrations of silicon oxides as the cells are smaller and the cell walls much finer than A. brevipes var. intermedia.

The overall impression gained from the analyses is as follows. MELSP1 and ABREV require moderately high levels of nutrients; the most important apparently are nitrogenous compounds. Alternatively SYNTAB grows

	FACTOR			
	1	2	3	4
TON	.91	.15	.07	.13
PO4P	.80	.18	.07	-.04
NH3	.70	.39	.23	.12
TOC	.61	.31	-.08	-.12
pH	.60	-.11	.46	.25
MELSP1	.36	.50	.29	.15
SILOX	.20	.48	-.28	.16
TIC	.18	.87	.10	.04
NO3	.07	.10	.41	.49
NO2	.03	-.00	.27	.95
PO4S	.03	.08	-.08	.69
DIST	-.07	-.93	.19	.01
QUANT	-.09	-.26	-.91	-.13
TEMP	-.11	-.05	-.95	-.04
TDS	-.23	-.67	-.21	-.01
%Variance	37.39	17.01	11.51	9.09
Eigenvalue	5.10	2.32	1.57	1.24

TABLE 5.5 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Melosira sp.1 viable cell densities.
Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.91	.12	.06	.12
PO4P	.83	18	.08	-.04
NH3	.70	.36	.23	.11
pH	.61	-.13	.45	.24
TOC	.60	.31	-.08	-.13
SYNTAB	.43	.18	.32	.27
SILOX	.22	.50	.30	.17
TIC	.18	.87	.12	.04
NO3	.09	.09	.42	.49
NO2	.05	-.03	.28	.96
PO4S	.02	.07	-.08	.67
DIST	-.09	-.92	.17	-.00
QUANT	-.10	-.22	-.89	-.13
TEMP	-.12	-.02	-.96	-.04
TDS	-.26	-.64	-.22	-.03
%Variance	36.72	17.11	11.46	9.11
Eigenvalue	5.00	2.33	1.56	1.24

TABLE 5.7 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Synedra tabulata viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TIC	.86	.17	.09	.04
SILOX	.52	.19	.28	.17
ABREV	.50	.23	.16	.08
NH3	.41	.69	.23	.12
TOC	.32	.61	-.08	-.12
PO4P	.21	.81	.08	-.04
TON	.14	.90	.06	.13
NO3	.12	.07	.42	.49
PO4S	.07	.03	-.09	.69
NO2	.00	.03	.27	.94
TEMP	-.06	.11	-.95	-.04
pH	-.09	.61	.46	.25
QUANT	-.26	-.08	-.89	-.13
TDS	-.68	-.21	-.20	-.01
DIST	-.91	-.06	.21	.01
%Variance	36.32	17.20	11.59	9.08
Eigenvalue	4.92	2.33	1.57	1.23

TABLE 5.6 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Achnanthes brevipes var. intermedia viable cell densities.

Dominant variables of each factor are underlined.

better in high nutrient, eutrophic situations again with emphasis on the importance of nitrogenous compounds. The long intervals between samples and the variety of compounds potentially contained in some of the variables prevents any finer interpretation of the analyses.

The correlation with a nitrogenous nutrient source is also evident in another species, vis. Plagiogramma staurophorum (PLAG). This species has not been observed to reach cell densities of more than a few thousand per square centimetre and these, as implied by both factor analysis (TABLE 5.8) and the correlation coefficients (FIG. 86), only occurred at the same time as peak concentrations of nitrite (NO2) were measured. If this does imply reliance on nitrite as a nitrogen source then P. staurophorum is probably barely surviving in the waters of the Onkaparinga where nitrite concentrations have been rarely measured above .01 mg/l.

The remaining species were all thought to be marine to marine-euryhaline, based on their distributions and as delineated by presence and absence data (see Ch.4.3.). The marine-euryhaline species, Grammatophora oceanica (GRAMOC; TABLE 5.12), Licmophora sp.3 (LIC3; TABLE 5.14) and Licmophora sp.4 (LIC4; TABLE 5.11) are difficult to dissociate from the marine species Licmophora flabellata (LICFLAB; TABLE 5.9), Striatella unipunctata (STRIAT; TABLE 5.15), Synedra fulgens (SYNFULG; TABLE 5.13) and Synedra laevigata (SYNLAEV; TABLE 5.10). All these species vary from the winter species by their low or negative correlations with the nutrient variables and their positive correlations with salinity and distance. Both SYNLAEV and GRAMOC are positively correlated with both TEMP and QUANT which may be due to a response to temperature and/or light or some aspect of the environment not accounted for here which is also correlated with light.

The analytical techniques used in this study are therefore useful in sorting out the covariation of aspects of the environment with selected aspects of the assemblages being studied. Such techniques are only as good as the information upon which they are based. If another three to seven years were available for this study it would be logical to proceed to examine sites for

	FACTOR			
	1	2	3	4
TON	.89	12	.08	.16
PO4P	.82	.18	.07	.01
NH3	.69	.37	.25	.12
TOC	.62	.30	-.08	-.08
pH	.59	-.13	.48	.24
SILOX	.21	.50	.30	.20
TIC	.19	.88	.13	.02
PLAG	.11	.02	-.04	.44
NO3	.06	.10	.46	.45
PO4S	-.00	.07	-.03	.68
NO2	-.02	-.02	.34	.94
DIST	-.09	-.92	.18	-.01
QUANT	-.09	-.24	-.92	-.06
TEMP	-.11	-.03	-.94	.02
TDS	-.24	-.63	-.21	-.02
%Variance	34.53	17.30	11.46	10.20
Eigenvalue	4.67	2.34	1.55	1.38

TABLE 5.8 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Plagiogramma staurophorum viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.91	.09	-.07	.14
PO4P	.81	.16	-.08	-.03
NH3	.71	.34	-.25	.12
TOC	.64	.26	.05	-.14
pH	.61	-.18	-.45	.26
SILOX	.23	.48	-.33	.16
TIC	.22	.87	-.17	.02
NO3	.07	.09	-.42	.49
PO4S	.03	.09	.07	.67
NO2	.02	.00	-.26	.95
LICFLAB	.00	-.32	-.06	-.07
QUANT	-.11	-.17	.92	-.13
TEMP	-.12	.03	.95	-.05
DIST	-.13	-.91	-.12	.04
TDS	-.26	-.62	.25	.00
%Variance	34.43	17.29	11.82	9.16
Eigenvalue	4.66	2.34	1.60	1.24

TABLE 5.9 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Licmophora flabellata viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.90	.12	-.04	.12
PO4P	.81	.17	-.08	-.05
NH3	.71	.35	-.21	.14
pH	.63	-.16	-.39	.31
TOC	.62	.30	.08	-.12
SILOX	.23	.48	-.30	.20
TIC	.20	.86	-.15	.06
NO3	.09	.08	-.39	.52
NO2	.04	-.02	-.22	.89
PO4S	.03	.08	.19	.76
SYNLAEV	.01	-.17	.35	.13
DIST	-.09	-.93	-.12	.03
QUANT	-.13	-.18	.89	-.22
TEMP	-.15	.03	.93	-.13
TDS	-.24	-.63	.25	-.03
%Variance	34.81	17.07	11.70	9.91
Eigenvalue	4.67	2.29	1.57	1.33

TABLE 5.10 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Synedra laevigata viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.91	.07	-.07	.13
PO4P	.82	.13	-.09	-.04
NH3	.72	.32	-.25	.12
TOC	.63	.28	.06	-.12
pH	.60	-.18	-.45	.26
SILOX	.24	.48	-.32	.17
TIC	.24	.85	-.15	.04
NO3	.08	.08	-.43	.49
PO4S	.03	.08	.08	.69
NO2	.02	-.01	-.27	.95
LIC4	.01	-.16	-.01	-.01
QUANT	-.10	-.20	.92	-.13
TEMP	-.11	.01	.95	-.04
DIST	-.14	-.92	-.14	.01
TDS	-.27	-.62	.23	-.01
%Variance	34.23	17.11	11.58	9.07
Eigenvalue	4.64	2.32	1.57	1.23

TABLE 5.11 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Licmophora sp.4 viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.89	.13	-.10	.15
PO4P	.84	.17	-.01	-.12
NH3	.71	.36	-.16	.02
TOC	.62	.33	.00	-.05
pH	.61	-.13	-.49	.28
SILOX	.22	.48	-.26	.12
TIC	.19	.87	-.07	-.01
NO3	.08	.07	-.31	.36
NO2	.04	-.02	-.25	.79
PO4S	.02	.09	.06	.83
GRAMOC	-.02	-.19	.19	-.02
DIST	-.08	-.94	-.13	-.02
QUANT	-.08	-.23	.93	-.11
TEMP	-.12	-.02	.91	-.00
TDS	-.23	-.64	.24	-.03
%Variance	34.33	16.98	11.66	9.33
Eigenvalue	4.71	2.33	1.60	1.28

TABLE 5.12 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Grammatophora oceanica viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.90	.10	-.07	.13
PO4P	.82	.17	-.08	-.04
NH3	.71	.35	-.23	.13
TOC	.62	.30	.08	-.11
pH	.61	-.16	-.46	.25
SILOX	.22	.50	-.29	.19
TIC	.21	.85	-.10	.09
NO3	.08	.07	-.42	.50
NO2	.03	-.05	-.28	.92
PO4S	.03	.04	.08	.70
SYNFULG	-.01	-.21	.03	.06
QUANT	-.09	-.25	.90	-.14
TEMP	-.11	-.05	.95	-.04
DIST	-.11	-.93	-.20	-.04
TDS	-.25	-.63	.20	-.05
%Variance	34.45	17.19	11.56	9.11
Eigenvalue	4.65	2.32	1.56	1.23

TABLE 5.13 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Synedra fulgens viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.89	.12	-.10	.15
PO4P	.84	.17	-.02	-.13
NH3	.71	.36	-.18	.02
TOC	.62	.31	.01	-.03
pH	.61	-.16	-.48	.27
SILOX	.22	.49	-.30	.13
TIC	.20	.86	-.12	.00
NO3	.08	.10	-.33	.31
NO2	.04	-.01	-.26	.72
PO4S	.03	.07	.05	.89
LIC3	-.01	-.29	-.15	.05
DIST	-.09	-.93	-.12	-.04
QUANT	-.09	-.21	.94	-.10
TEMP	-.12	.00	.93	.01
TDS	-.23	-.63	.25	-.04
%Variance	34.08	17.30	11.77	9.45
Eigenvalue	4.69	2.38	1.62	1.30

TABLE 5.14 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Licmophora sp.3 viable cell densities. Dominant variables of each factor are underlined.

	FACTOR			
	1	2	3	4
TON	.90	.08	-.07	.14
PO4P	.82	.15	-.08	-.03
NH3	.71	.32	-.26	.12
TOC	.64	.27	.05	-.13
pH	.61	-.20	-.45	.26
SILOX	.24	.47	-.33	.16
TIC	.23	.85	-.18	.03
NO3	.08	.08	-.42	.49
PO4S	.03	.08	.07	.67
NO2	.02	-.01	-.26	.96
STRIAT	.01	-.32	-.06	-.04
QUANT	-.11	-.16	.93	-.13
TEMP	-.12	.04	.94	-.05
DIST	-.13	-.92	-.11	.02
TDS	-.26	-.63	.25	-.01
%Variance	34.39	17.38	11.83	9.10
Eigenvalue	4.65	2.35	1.60	1.23

TABLE 5.15 Eigenvalues, eigenvectors and the percentage of variability associated with the first four VARIMAX rotated factors for environmental variables plus Striatella unipunctata viable cell densities. Dominant variables of each factor are underlined.

short, intensively sampled periods which would be backed up by culture studies to further delineate which correlations have a causative basis and which are coincidental (see Ch. 7). Taking the long intervals between samples into account, the clustering of environmental variables into the groupings indicated by factor analysis, gives an insight into the basic structures of the estuarine environment which would otherwise have been difficult and time consuming to achieve.

The results do indicate that variables other than just salinity and temperature can and probably do account for much of the variation in the assemblage structure of estuarine epiphytic diatoms. To what extent any one variable or set of variables influences individual species or whole assemblages could only be ascertained by investigating the diatom flora of several estuaries with varying freshwater inputs. It may well be observed that in conditions which provide much greater river flow than experienced during the course of this study, the measured variables would differ in their contributions to the variation of epiphyte assemblage structure.

5.4. Overview of environmental influence in the Onkaparinga estuary.

The epiphytic diatoms can be seen to belong to three broad groupings, the environmental requirements of which overlap to some extent. The freshwater group require a continuous flow of freshwater into the estuary before they can become established. That is, they require a relatively stable environment. The species of the marine group also require a relatively stable environment, but one of high salinity and form the species of GROUPS II-V (FIG. 60). The marine species will rarely be found alive in salinities below 25 p.p.t. Between these two groups is a small group of euryhaline species which thrive in unstable conditions. Unlike the other two groups, the euryhaline species can apparently grow well at any salinity as long as the nutrient concentrations are adequate for growth. These species have therefore evolved to survive in Rochford's (1951) zone of "conflict" between the relative stability of the fresh- and seawaters. Thus the euryhaline species (Melosira sp.1, Synedra tabulata and Achnanthes brevipes var. intermedia) commonly dominate the winter assemblages, particularly in the upper reaches where the environment is least stable.

There is a second zone of instability associated with the input from the creek midway down the estuary, the effect of which is evident in most salinity profiles (FIG. 90). Here the higher salinities allow some of the marine species, particularly Grammatophora oceanica and Synedra laevigata to grow in the relatively high concentrations of inorganic nutrients which are associated with the second zone.

In Chapter 4.2.1. it was suggested with respect to Cocconeis scutellum that a population may have within it races which may have differing environmental requirements. That this may also be so for at least one of the euryhaline species, vis. Melosira sp.1, was suggested by the results of several series of batch cultures containing similar concentrations of inorganic nutrients but varying in salinity. These cultures were unsuccessful in that they became a survival test rather than providing conditions for growth. However, in each series Melosira sp.1 showed a bimodal distribution

of cell densities. One mode was in the 10-12 p.p.t. region (as were the single modes of Synedra tabulata and Achnanthes brevipes var. intermedia) and a second in the 30-33 p.p.t. region. For Melosira sp.1 at least, there may be present in any assemblage a combination of two physiological races, the relative proportions of which may depend upon the ambient salinity of the surrounding medium. It remains for some careful culture studies to elucidate further what may be a very interesting aspect of estuarine diatom ecology.

While the euryhaline species may live in a low competition environment due to the inherent variability of that environment, they are not the most productive of the assemblages. This can be seen from comparing figures 61-72. The most productive epiphyte assemblages are those formed by the freshwater species when the river is flowing continually without actually flooding the estuary. During such periods, Synedra pulchella var. lacerata, various species of Gomphonema (particularly G. constrictum var. capitatum) and Melosira varians, form very dense epiphyte assemblages.

After the winter bloom conditions cease, there is frequently a brief period when the epiphyte cell densities fall away, almost to zero. This was particularly noticeable during November in 1974 and 1975. The apparent cause is the slow upstream migration of the marine species after the retreat of the freshwater and euryhaline species at the cessation of winter and early spring rains. During and just after such periods, the species' composition of periphyton samples can vary greatly and appears to be indicative of the role of chance in the distribution of species and not necessarily that of the ambient environment. The net seaward flow of the estuarine waters, together with the slow upstream movement on the incoming tide, are likely to be important factors in the distribution of epiphyte species, particularly the marine species.

One of the sources of variance in analysing species' distributions versus environmental parameters may be a matter of geographic isolation. Though a particular species may be capable of growing well in the prevailing

environment at some upstream station, the upstream drift is not fast enough to get the species to that site and for it to colonise and grow, before the environment changes again. By contrast, the downstream movement of species is very fast. Within a week of Synedra pulchella var. lacerata becoming established at the 2 km station in 1974, it was also well established at the 10 km station.

There are various aspects of the estuarine environment which are therefore difficult to quantify or otherwise take into account. Those that have been investigated here are only indicative of long term trends without the useful background knowledge of what the short term variations may be. Even so, this study has helped to establish the basic techniques by which long or short term trends can be analysed, even in a highly variable system such as an estuary.

6. COMPARISON OF EPIPHYTE RESEARCH TECHNIQUES.

The emphasis of this study has been on describing epiphytic diatom assemblages in terms of viable cell densities. These give a record of which species were living in the assemblage at the time of sampling, their relative numerical importance with respect to other species in the assemblage and, perhaps most importantly, they enable a direct comparison with other samples. A major drawback to the widespread use of this technique is the problem of taxonomic identification of species using whole cells. This is particularly so with many species of Navicula and related genera. The epiphytic species too, sometimes require very careful observation before an identification can be made.

The study of living or preserved cells was considered worth persevering with to provide realistic data on species' responses to their environment and, secondarily, to enable a comparison between this technique and the commonly used techniques based on cleared cells.

The majority of diatom investigations have relied upon cleared cell counts as the basis for analysis (e.g. Amspoker 1975; Bacon & Taylor 1976; Castenholz 1960; Main & McIntire 1974; McIntire 1968 ; Patrick 1971; Sullivan 1977; Wulff & McIntire1972). Alternative approaches have emphasised aspects of the whole assemblage, such as chlorophyl α (e.g. Admiraal 1977a,c; Welch et al. 1972), or have studied living or preserved cells but expressed the results in terms of species' preportions in the assemblage (e.g. Cattaneo et al. 1975) or some subjective order of abundance (e.g. Aleem 1950, 1958; McIntire & Wulff 1969). Very few investigations have estimated cell densities as an estimate of biomass (e.g. Brettum 1974; Karentz & McIntire 1977; Patrick 1968; Potter et al. 1975; Reisen & Spencer 1970; Reyez-Vasquez 1970).

With regard to community parameters such as chlorophyl α, dry weight, etc., the analyses of total viable cell densities (TOTCELL), total epiphyte cell densities (TOTATT) and the comments pertaining to them (Ch. 5.3.) are of relevance here. These variables, which are contributed to by many species,

and different groups of species at different times and places, are too complex for community level estimates of biomass to be very meaningful. Such estimates are probably more useful in the situations for which they were developed (e.g. lakes, reservoirs or open ocean) where the community may contain few abundant species and the biomass estimate approaches that of the dominant species.

In a situation such as an estuary it is therefore necessary to use some species level estimate of abundance. As mentioned above, this has commonly been orientated towards the individual sample with the proportion of a species being estimated relative to the other species in the sample. Such an approach is virtually unavoidable when using cleared cells, but is certainly avoidable when using living or preserved material. The species proportion method has one serious drawback in providing no reliable comparison between samples of differing cell densities. For example, TABLE 6.1 illustrates the potential problem in intersample comparisons using species proportions.

	Species A	Species B
Sample 1		
Density (cells/cm^2)	1500	4500
Proportion	.25	.75
Sample 2		
Density (cells/cm^2)	1500	500
Proportion	.75	.25
Sample 3		
Density (cells/cm^2)	250	750
Proportion	.25	.75

TABLE 6.1 Hypothetical variations of two species in three different samples.

On a proportional basis, species B would be assumed to have grown better in the environment pertaining to sample 1 than it did with respect to sample 2, and correctly so. However, species A would be assumed to have

grown better in the sample 2 environment than in the sample 1 environment and that is unlikely to be correct. Similarly samples 1 and 3 would be characterised as identical and yet neither species actually grew as well in the environment of sample 3 as that of sample 1.

A further dimension is added by the use of cleared cells, that of species being present which were not living in the assemblage at the time of sampling. These species may have lived in the assemblage earlier or may have been caught by the assemblage as the cells swept past in the plankton. This is particularly obvious when freshwater species occur in downstream cleared cell samples and had not been observed as having been alive at the time of sampling. Nor is the cleared cell count necessarily indicative of the history of the assemblage as some species are more likely to lose their dead cells from the assemblage than others. For example, Melosira sp.1 forms such robust colonies that the first twenty or more cells nearest the substrate may be long dead and decomposed but the intercellular pads and the cell walls still maintain the attachment. Alternatively, many of the motile species have a far more tenuous hold on the assemblage and are more likely to be lost when they die. These various effects would be expected to become more significant with assemblage age, particularly if a changeable environment is encouraging various groups of species at different times.

To further investigate the effects of studying assemblages using species' proportions, and the differences between cleared cell and viable cell counts, the samples used for the viable cell counts were cleared in concentrated nitric acid for 12 hours at 60^{o}C (Crawford 1971). After dilution in distilled water, the samples were eventually transferred to pure ethanol to avoid the fungal contamination which had destroyed several earlier samples. Cleared cells were eventually dried onto cover glasses and mounted in CAEDEX resin (MERCK), a form of Canada balsam. A slide was made representing each sample, scanned in the light microscope to note all species, and finally, 500-700 epiphyte cells were counted according to species in a transect or several transects across the centre of the cover glass.

Apart from nine species which had not been counted in the preserved material and were not sufficiently common in the cleared material to be significant, the cleared cell proportions were much the same as the viable cell proportions. The only noticeable trend was that the species which dominated the viable cell counts for any sample tended to become even more prominant in the cleared cell counts.

The correlation coefficients with environmental variables (FIGS 86, 91 & 92) do show some very important differences between analysis on the basis of cell densities (FIG. 86) and proportions (FIGS 91,92), and between viable cell proportions (FIG. 91) and cleared cell proportions (FIG. 92). For example, Synedra tabulata is shown to be inversely correlated with salinity (-.46) and very positively correlated with the organic and inorganic variables (e.g. TON:.49; NH3:.44; NO2:.43) when analysed using cell densities. When analysed as a proportion of the assemblage, whether cleared or viable cells, these correlations drop to insignificance.

The interpretation of species' associations is made more difficult by using proportionate representation instead of cell densities. This was indicated by comparison of samples 1 & 2 of TABLE 6.1 above. Species that co-occur should be more positively correlated than species that do not co-occur. On the basis of proportional representation, if a species reaches a high density relative to the other species in a sample, regardless of whether all densities are low or high, that species automatically achieves the dominant proportion and the others are given minor shares. If in another assemblage a second species grows well then the positions may be reversed. These two species then show up as being negatively correlated on the basis of species proportions. Such a situation can be observed by referring to the positive correlation constellations (FIG. 93) and species association matrices (FIGS 94-96) for the epiphyte species. Commonly co-occurring species such as Achnanthes brevipes var. intermedia and Melosira sp.1 positively correlate with respect to viable cell densities (.35; FIG. 94) but negatively correlate with respect to viable cell proportions (-.11; FIG. 95) and cleared cell pro-

portions (-.06; FIG. 96). Alternatively, species whose distributions partially overlap, such as Grammatophora oceanica and Striatella unipunctata, have stronger positive correlations from proportional representation than cell densities.

It is, therefore, difficult to perceive that reliable, consistent information can be derived from the use of species proportions as a basis for data analysis. This is particularly true of cleared cell proportions for the reasons already stated above. However, a whole range of information statistics has been made use of in studies based on cleared cell data. Given the potential for misinformation present in cleared cell counts, the value of results obtained from such statistics, even a simple index such as "S", the number of species, is open to doubt.

In conclusion, the evidence presented here indicates that, wherever possible, some quantitative measure of viable cell abundance should be estimated in preference to species proportions based on cleared cells as an index of assemblage dynamics.

7. SUGGESTIONS FOR FURTHER INVESTIGATION

One of the major problems to be encountered in a research project such as this, perhaps more so in an estuary than anywhere else, is to obtain representative environmental data. The data used in this thesis was considered representative of seasonal variations in the environmental variables and it did correlate with the seasonal changes of species' data.

Early in the project it was recognised that a detailed knowledge of the estuarine hydrology was necessary before the variability of the seasonal data could be understood. Towards this goal, tidal predictions, records from a tidal recorder owned by the Engineering and Water Supply Department of S.A. (dismantled in late 1975 by the Department), and observations of variation in salinity, temperature and light over various tidal cycles at various points in the estuary were collected and analysed. The intention was to obtain sufficient background information to encourage a hydrologist to derive a model of the estuarine hydrology, or to modify one of the computer models of Harleman & Lee (1969) with a view to adding correlated variables at a later stage. Such a model would have allowed the short term variability to be taken into account. This was not successful and the only reward was a good general appreciation of some of the gross factors evident in the hydrology of the Onkaparinga estuary. With a system as complex as an estuary, a computer based mathematical model of its hydrology would still seem to be a necessary adjunct to any intensive study of estuarine ecology.

The complete diatom flora of the estuary needs to be studied using similar methods to those applied here but at more sampling stations. The inter-relationships between the planktonic, peripelic and periphytic assemblages are yet to be determined for an estuary but are potentially interesting from the point of view of assemblage dynamics if results are achieved similar to those of Clark & Runnels (1975) in freshwater ponds. The nearest investigation comprised the studies published on the diatom assemblages of the Yaquina estuary in Oregon. The periphyton (Main & McIntire 1974), peripelon

(Amspoker 1975) and plankton (Karentz & McIntire 1977) have each been investigated, the studies of Amspoker and Karentz being contemporaneous (Dr C.D. McIntire, pers. comm.). The one drawback to these studies is the reliance on cleared cells as a basis for analysis (see Ch. 6.), although Karentz & McIntire (1977) also estimated plankton concentrations.

Once an overall study has been achieved, the next step would be to study intensively several selected sites during periods of importance, e.g. the effects of the mid-estuary creek upon the diatom assemblages or the effects of runoff from heavy rainfall. In this way, individual aspects of the system can be better understood and eventually contribute to a model of the estuary which could assist in its management. In addition, biological interactions such as herbivory could be investigated. For example, the diatoms are known to form an important part of the diet of some of the pelagic fish (see Ch.1.1.). Gut contents of various fish indicated that the peripelon (or the assemblages on old Zostera blades), was the major source of food for the fish as the predominant species eaten by the fish were the motile diatoms and there were few epiphytes present.

Finally, the estuary is an extremely valuable starting point for taxonomic or floristic studies of the diatoms of any region. Apart from the euryhaline species, twelve months of sampling will also bring the taxonomist in contact with the major freshwater and marine species, and, as this study has, will provide a very solid basis for any regional flora. In addition, the wide range of ecological conditions will usually allow several species of any genus to be collected and their different environmental requirements estimated.

APPENDIX A: A new equation for estimating oxygen saturation in saline waters.

The requirement for accurate estimates of oxygen saturation in natural waters, saline or not, is derived from the two approaches to oxygen measurement. Most oxygen probes provide a measure of percent saturation which needs to be converted to a concentration for comparison with other samples. Alternatively, direct measurement of oxygen concentration needs to be referred to the theoretical concentration at saturation to determine to what extent the sample varies from the same water free from physical, chemical or biological disturbance.

The variation of oxygen concentration in saturated waters of various salinities and temperatures has been determined by various methods and these have been reviewed by Green & Carritt (1967). The results are usually published as a table of concentrations, with or without a formula from which they were derived. In the last of a series of papers on the determination of oxygen solubility (Carpenter 1965; Carritt & Carpenter 1966; Carpenter 1966), Green & Carritt (1967) published tables of saturated oxygen concentrations for waters ranging in temperature from 0-35^{o}C in 1^{o}C intervals and 0-30 p.p.t. chlorinity in 2 p.p.t. intervals. Anyone wishing to determine values between those given in the tables were left to use two cumbersome equations, one giving a Bunsen coefficient (α) and the other, the vapour pressure (P_{vap}) which were then combined to calculate the saturated solubility of oxygen (S) as a function of temperature and chlorinity.

The equations were expressed as follows:

$$\alpha.10^{3} = \exp\{(-7.424 + \frac{4417}{T} - 2.927.\ln T + 0.04238\ T) -$$

$$-Cl.(-0.1288 + \frac{53.44}{T} - 0.04442.\ln T + 7.145\ .10^{-4}\ T)\}$$

$$P_{vap} = \{(1 - 9.701\ .10^{-4} Cl)\}.\exp\{18.1973(1 - \frac{373.16}{T}) +$$

$$+3.1813\ .10^{-7}\ (1 - \exp[26.1205(1 - \frac{T}{373.16})]) -$$

$$-1.8726\ .10^{-2}(1 - \exp[8.03945(1 - \frac{373.16}{T})]) +$$

$$+5.02802\ .\ln(\frac{373.16}{T})\}$$

$$S = 0.2094(10^{-3}\alpha).(1 - P_{vap})$$

where T is the absolute temperature, Cl is the chlorinity in parts per thousand (Cl = (salinity - 0.03)/1.805) and P_{vap} is in atmospheres.

Not only are these equations cumbersome but, as printed, do not give the values in the table derived from them.

A new equation was required which would duplicate the results without being too extravagant with computing time. This was derived by formulating the equation for the surface represented by the data with respect to temperature (^{o}C) and chlorinity. The equations were derived with the aid of POLYANNA, a curve-fitting program which is part of the soft ware of the Adelaide Unversity Cyber 173 computer and was designed by Mr. C. Marlin of the Computing Science Department.

The equation derived is as follows:

$$\text{Oxygen concentration } (\mu\text{g-at/l}) = e^{C-S}$$

where $C = (6.8233 - 2.728\times10^{-2}T - 2.9369\times10^{-4}T^{2} + 1.6768\times10^{-4}T^{3} - 2.7275\times10^{-5}T^{4} + 2.3549\times10^{-6}T^{5} - 1.1094\times10^{-7}T^{6} + 2.6913\times10^{-9}T^{7} - 2.6313\times10^{-11}T^{8})$

$$S = (0.012807 - 1.6412\times10^{-4}T + 2.6854\times10^{-6}T^{2})\times Cl$$

The equation was tested over the entire range of values covered by the table (Table II of Green & Carritt 1967) from which it was derived. The results duplicated the table exactly when the numbers were rounded off. This equation is therefore put forward as an alternative which, though not derived from thermodynamic theoretical considerations, is relatively uncomplicated and very easy to program for using any programmable calculator.

APPENDIX B:- Index to included taxa.

APPENDIX C

Tables of environmental data supplied by the E.&W.S.

Environmental data from surface water samples taken at the 2km station

Date	T.D.S. (mg/l)	pH	NH_3 (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	TKN (mg/l)	TON (mg/l)	PO_4sol (mg/l)	PO_4tot (mg/l)	PO_4part (mg/l)	TOC (mg/l)	TC (mg/l)	TIC (mg/l)	SiO_2 (mg/l)
180376	37000	7.9	.09	.03	-	2.96	2.84	.090	.214	.124	3	52	49	2
080476	37000	8.3	.03	.02	<.01	2.27	2.22	.086	.125	.039	8	58	50	1
290476	33000	8.0	.09	<.01	<.01	1.19	1.10	.058	.117	.059	25	80	55	4
200576	32000	7.9	.11	.01	<.01	1.73	1.62	.090	.102	.012	5	62	57	4
100676	19000	8.0	.43	.10	.01	.53	0	.036	.046	.010	4	64	60	3
010776	17000	8.5	.06	.01	<.01	1.09	1.02	.004	.082	.078	9	61	52	3
220776	19000	8.5	.28	<.01	<.01	5.45	5.17	.014	1.050	1.036	9	63	54	5
120876	20000	8.3	.08	.02	.02	1.48	1.36	.089	.134	.045	26	70	49	2
020976	18000	9.1	.67	.03	<.01	46.90	46.20	.052	1.900	1.848	52	108	56	5
230976	19000	8.3	.08	<.01	<.01	1.98	1.90	.020	.150	.130	9	54	45	3
141076	9600	7.9	.07	.01	<.01	2.24	2.16	.090	.096	.006	16	61	45	5
041176	19000	8.2	.08	<.01	<.01	1.49	1.41	.053	.256	.203	2	41	39	4
251176	31000	7.9	.11	.01	<.01	.76	.64	.031	.100	.069	4	44	40	<1
161276	35000	7.7	.16	.01	.01	.67	.49	.036	.160	.124	9	54	45	5
060177	35000	8.0	.12	.01	<.01	.91	.78	.038	.122	.084	14	60	46	1
270177	34000	8.1	.12	.01	<.01	1.03	.90	.150	.210	.060	8	45	37	1
160277	31000	8.2	.07	<.01	<.01	1.62	1.54	.297	.360	.063	10	50	40	5

Environmental data from surface water samples taken at the 6km station

Date	T.D.S. (mg/l)	pH	NH_3 (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	TKN (mg/l)	TON (mg/l)	PO_4sol (mg/l)	PO_4tot (mg/l)	PO_4part (mg/l)	TOC (mg/l)	TC (mg/l)	TIC (mg/l)	SiO_2 (mg/l)
180376	39000	8.1	.16	.02	-	1.19	1.0	.165	.254	.089	13	50	37	3
080476	38000	8.3	.30	.33	.09	-	-	.280	-	-	2	48	46	2
290476	38000	8.3	.15	<.01	<.01	2.24	2.09	.104	.218	.114	15	56	41	4
200576	36000	8.1	.13	.01	<.01	1.13	.99	.091	.130	.039	6	53	47	6
100676	29000	8.3	.13	.54	.12	.72	0	.187	.220	.033	6	55	49	5
010776	31000	8.6	.19	.21	.04	1.88	1.44	.118	.207	.089	4	41	37	3
220776	30000	8.6	.47	.42	.05	10.90	9.96	.047	1.590	1.543	6	58	52	5
120876	30000	8.5	.15	.29	.22	12.25	11.59	.260	.480	.220	3	39	36	5
020976	32000	8.4	.06	.04	.03	2.73	2.60	.022	.083	.061	2	35	33	2
230976	28000	8.4	.31	.19	.04	1.82	1.28	.027	.029	.002	8	46	38	3
141076	22000	8.3	.09	<.01	<.01	.77	.68	.095	.224	.129	19	59	40	3
041176	22000	8.1	.09	.02	<.01	1.33	1.22	.083	.144	.061	1	41	40	4
251176	34000	8.0	.09	.02	<.01	.26	.15	.081	.110	.029	1	41	40	1
161276	36000	8.0	.10	.01	<.01	.50	.39	.092	.200	.108	6	47	41	4
060177	36000	8.0	.08	.01	<.01	.73	.64	.119	.160	.041	12	56	44	1
270177	32000	8.3	.13	.02	<.01	.82	.67	.190	.250	.060	8	40	32	1
160277	30000	8.3	.17	<.01	<.01	2.61	2.44	.149	.735	.586	17	55	38	4

Environmental data from surface water samples taken at the 8km station

Date	T.D.S. (mg/l)	pH	NH_3 (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	TKN (mg/l)	TON (mg/l)	PO_4sol (mg/l)	PO_4tot (mg/l)	PO_4part (mg/l)	TOC (mg/l)	TC (mg/l)	TIC (mg/l)	SiO_2 (mg/l)
180376	40000	8.1	.10	.01	-	1.18	1.07	.044	.064	.020	1	32	32	2
080476	39000	8.3	.10	.04	.01	.53	.58	.120	.129	.009	3	40	37	2
290476	39000	8.3	.11	.01	.01	1.33	1.22	.052	.097	.045	14	45	31	2
200576	37000	8.3	.12	.01	.01	1.27	1.15	.056	.088	.032	6	48	42	5
100676	30000	8.4	.13	.36	.07	.56	0	.113	.136	.023	3	51	48	2
010776	32000	8.5	.25	.35	.06	1.16	.50	.174	.207	.033	6	43	37	3
220776	39000	8.3	.06	.01	.01	1.33	1.25	.025	.037	.012	2	30	28	2
120876	33000	8.5	.12	.04	.21	12.25	11.88	.410	.480	.070	3	40	37	2
020976	38000	8.2	.04	.01	.01	1.80	1.75	.018	.110	.092	1	29	28	1
230976	32000	8.4	.17	.06	.02	.40	.15	.150	.250	.100	11	44	33	2
141076	34000	8.3	.02	.01	.01	.29	.27	.032	.074	.042	9	39	30	1
041176	28000	8.1	.09	.01	.01	.48	.38	.065	.119	.054	1	37	36	2
251176	39000	8.1	.06	.01	.01	.10	.04	.017	.030	.013	2	33	31	1
161276	39000	8.0	.06	.01	.01	.43	.37	.037	.090	.053	6	42	36	3
060177	39000	8.1	.04	.01	.01	.46	.41	.033	.062	.029	11	45	34	1
270177	34000	8.2	.08	.01	.01	1.31	1.22	.130	.210	.080	5	39	34	1
160277	35000	8.3	.08	.01	.01	1.31	1.22	.220	.250	.030	8	41	33	2

Environmental data from surface water samples taken at the 10km station

Date	T.D.S. (mg/l)	pH	NH_3 (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	TKN (mg/l)	TON (mg/l)	PO_4sol (mg/l)	PO_4tot (mg/l)	PO_4part (mg/l)	TOC (mg/l)	TC (mg/l)	TIC (mg/l)	SiO_2 (mg/l)
180376	40000	8.2	.04	.01	-	2.73	2.68	.020	.084	.064	12	37	25	1
080476	39000	8.4	.09	.01	.01	2.73	2.63	.090	.182	.092	3	37	34	2
290476	39000	8.2	.12	.01	.01	1.07	.95	.033	.095	.062	12	40	28	3
200576	38000	8.3	.12	.01	.01	1.07	.95	.022	.085	.063	3	39	36	3
100676	36000	8.2	.07	.17	.03	.46	.19	.057	.058	.001	4	40	36	3
010776	34000	8.6	.07	.16	.03	1.52	1.29	.079	.150	.071	8	39	31	2
220776	39000	8.1	.06	.01	.01	1.80	1.74	.007	.027	.020	3	30	27	1
120876	35000	8.6	.12	.01	.02	3.20	3.06	.200	.226	.026	3	37	34	2
020976	38000	8.2	.03	.01	.01	1.56	1.53	.009	.013	.004	1	29	28	1
230976	35000	8.3	.08	.02	.01	.48	.38	.084	.140	.056	8	39	31	1
141076	38000	8.3	.02	.01	.01	.16	.14	.015	.054	.039	10	35	25	1
041176	32000	8.2	.03	.01	.01	1.30	1.27	.046	.087	.041	1	35	34	1
251176	39000	8.1	.04	.01	.01	.23	.19	.005	.027	.022	1	30	29	1
161276	39000	8.1	.07	.01	.01	.40	.33	.009	.059	.050	7	39	32	4
060177	40000	8.2	.02	.01	.01	.55	.52	.002	.014	.013	10	38	28	1
270177	37000	8.1	.06	.01	.01	1.40	1.33	.033	.880	.877	5	37	32	1
160277	40000	8.0	.04	.01	.01	1.31	1.27	.011	.063	.052	1	30	29	1

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FIGURE 1

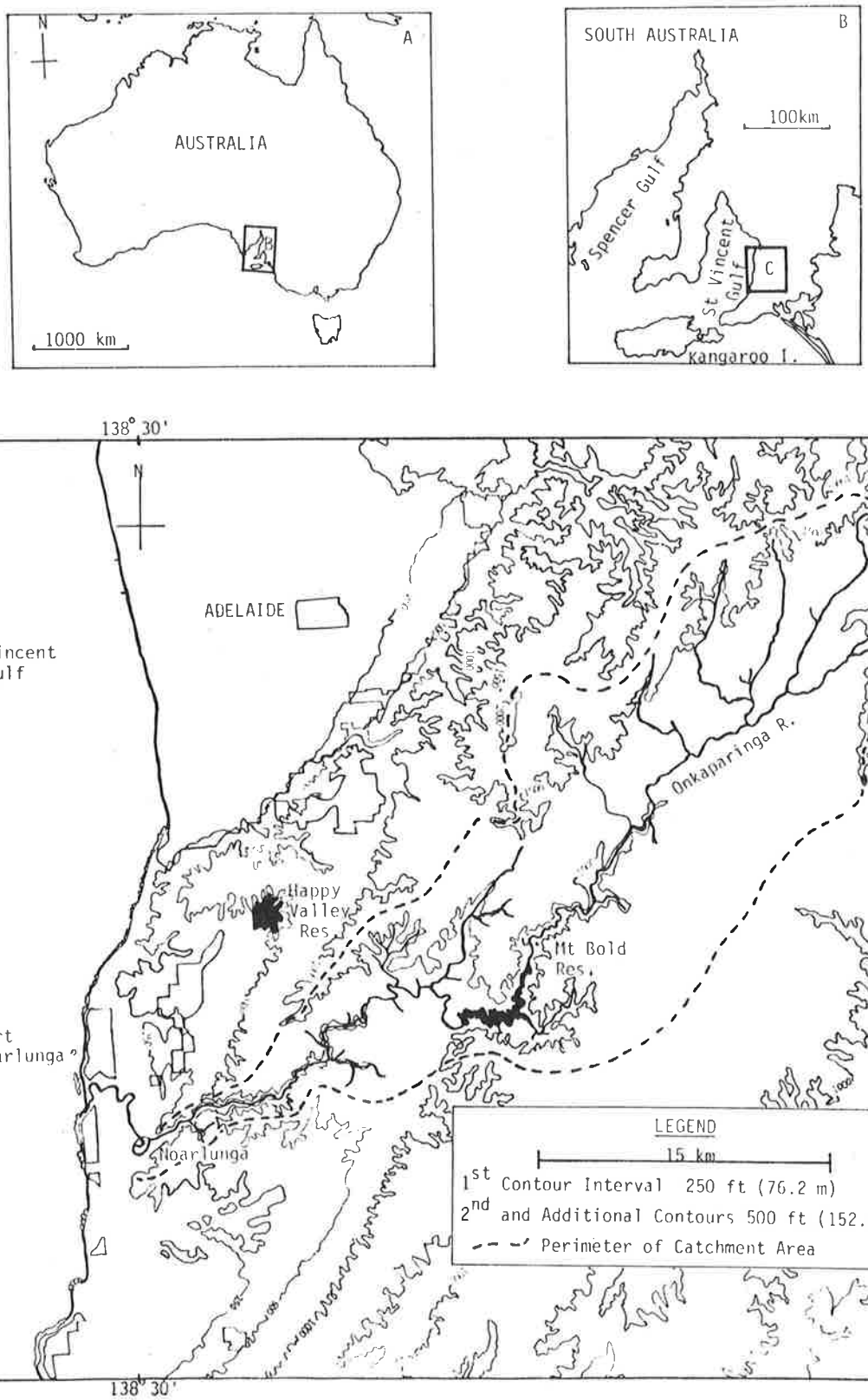

A
N
AUSTRALIA
1000 km
B
SOUTH AUSTRALIA
100km
Spencer Gulf
St Vincent Gulf
C
Kangaroo I.
138° 30'
C
N
ADELAIDE
St Vincent Gulf
Onkaparinga R.
Happy Valley Res.
Mt Bold Res.
Port Noarlunga
Noarlunga
LEGEND
15 km
1st Contour Interval 250 ft (76.2 m)
2nd and Additional Contours 500 ft (152.4 m)
Perimeter of Catchment Area
138° 30'

FIGURE 2

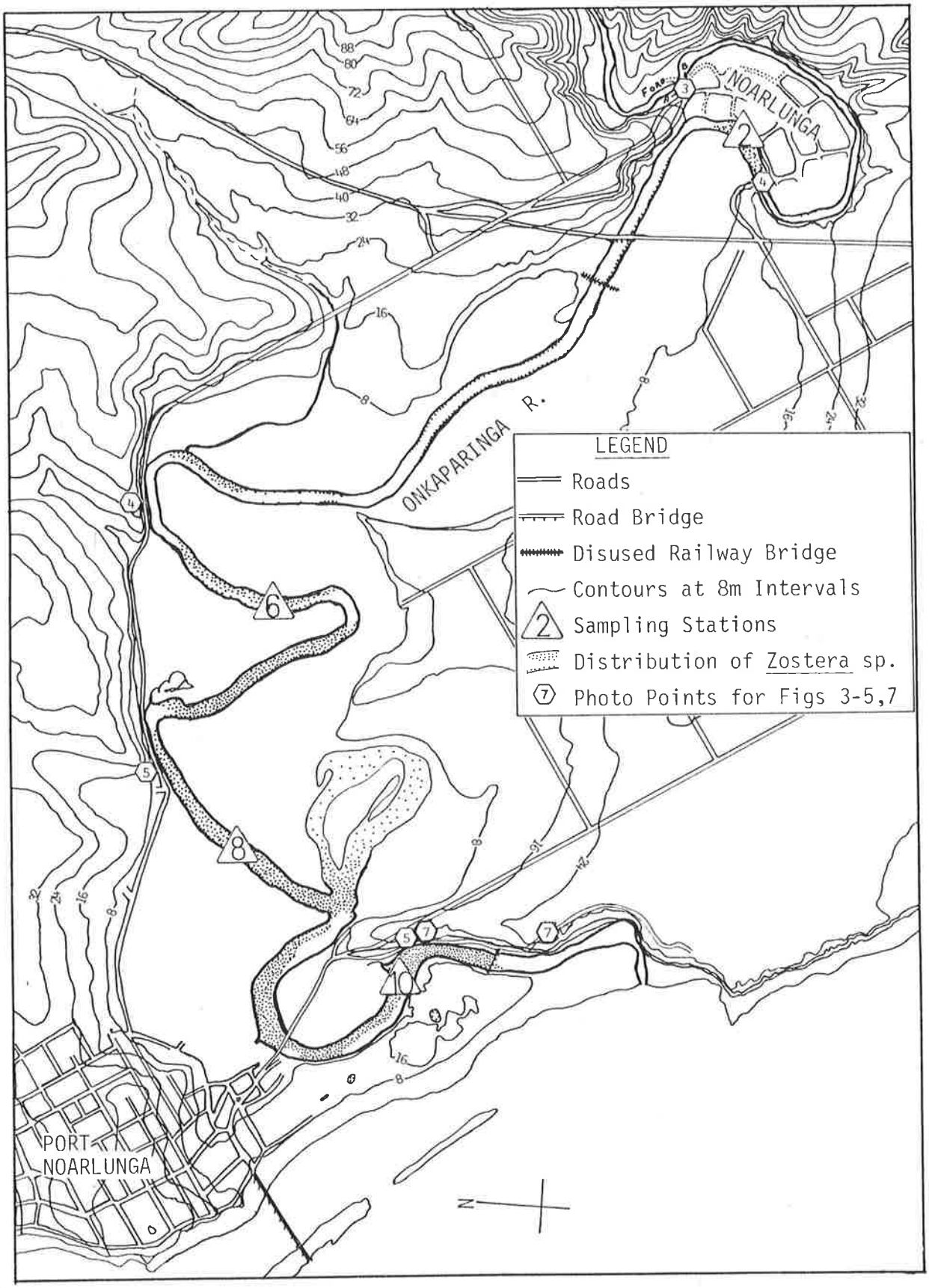

NOARLUNGA
ONKAPARINGA R.
PORT NOARLUNGA
LEGEND
Roads
Road Bridge
Disused Railway Bridge
Contours at 8m Intervals
Sampling Stations
Distribution of Zostera sp.
Photo Points for Figs 3-5,7
N

FIGURE 3

A. The ford at Noarlunga after the channel had been deepened, 20-II-1977.Background shows the Onkaparinga valley winding upstream from left to right.

B. View downstream from the ford at Noarlunga. Note shallow riffle and the steep sides to the left side banks.

FIGURE 3

A

B

FIGURE 4

A. View downstream towards the 2 km station marked by the arrow.

B. View downstream towards the 6 km station marked by the arrow.

FIGURE 4

A

B

FIGURE 5

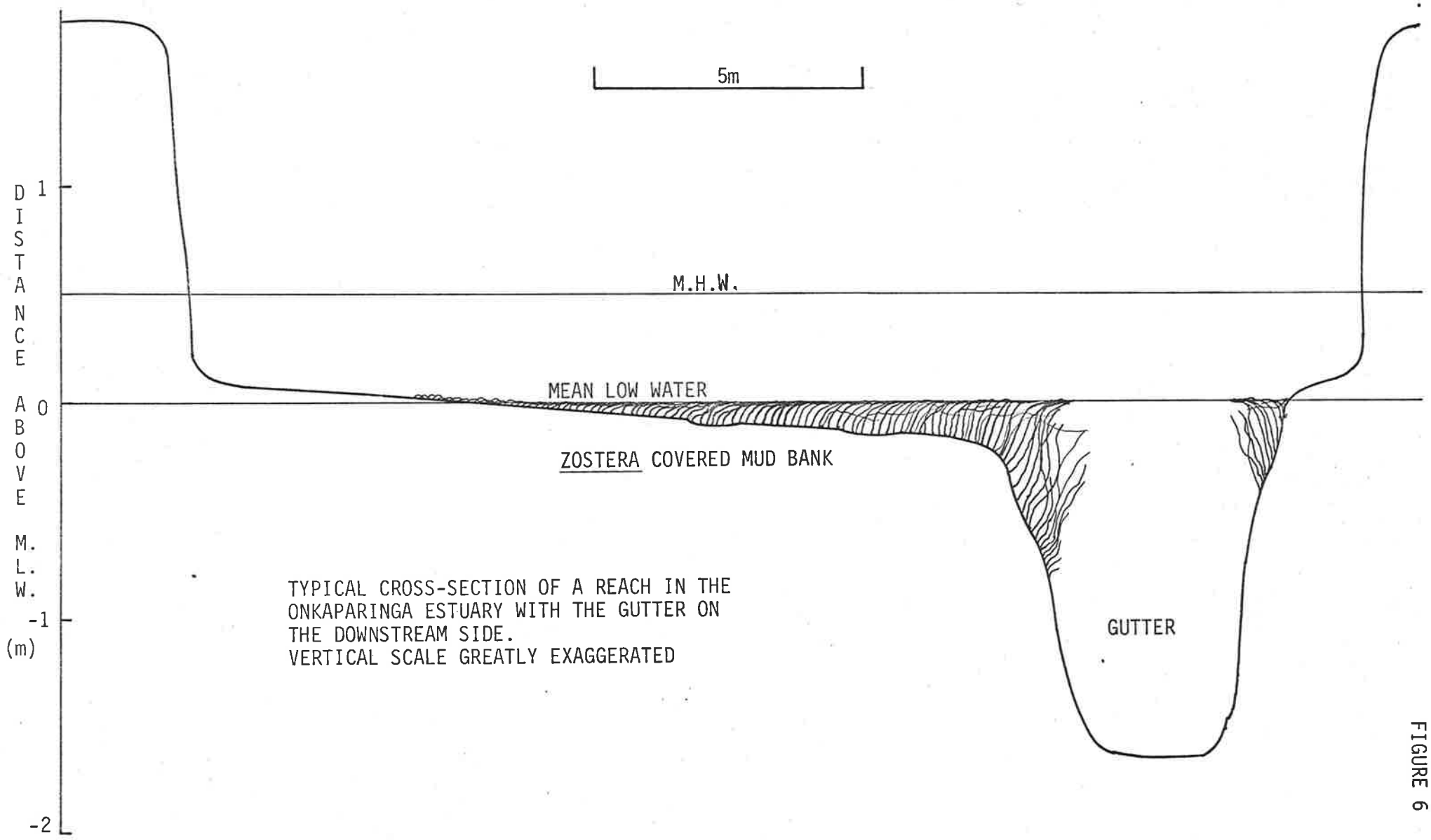
A. View downstream towards the 8 km station marked by the arrow.

B. View upstream towards the 10 km station marked by the arrow.

FIGURE 5

A

B



TYPICAL CROSS-SECTION OF A REACH IN THE ONKAPARINGA ESTUARY WITH THE GUTTER ON THE DOWNSTREAM SIDE.
VERTICAL SCALE GREATLY EXAGGERATED

FIGURE 6

FIGURE 7

A. View downstream towards the footbridge marking the seaward extent of the *Zostera* distribution.

B. View downstream towards the narrow mouth of the Onkaparinga river.

FIGURE 7

A

B

FIGURE 8

Cyclotella species 2

A. Valve view (SEM).

B. Oblique view of frustule (SEM).

Melosira species 1

C. Oblique view of valve with spinules (SEM).

D. Close view of external surface of valve with external openings of labiate processes and collar (SEM).

FIGURE 8

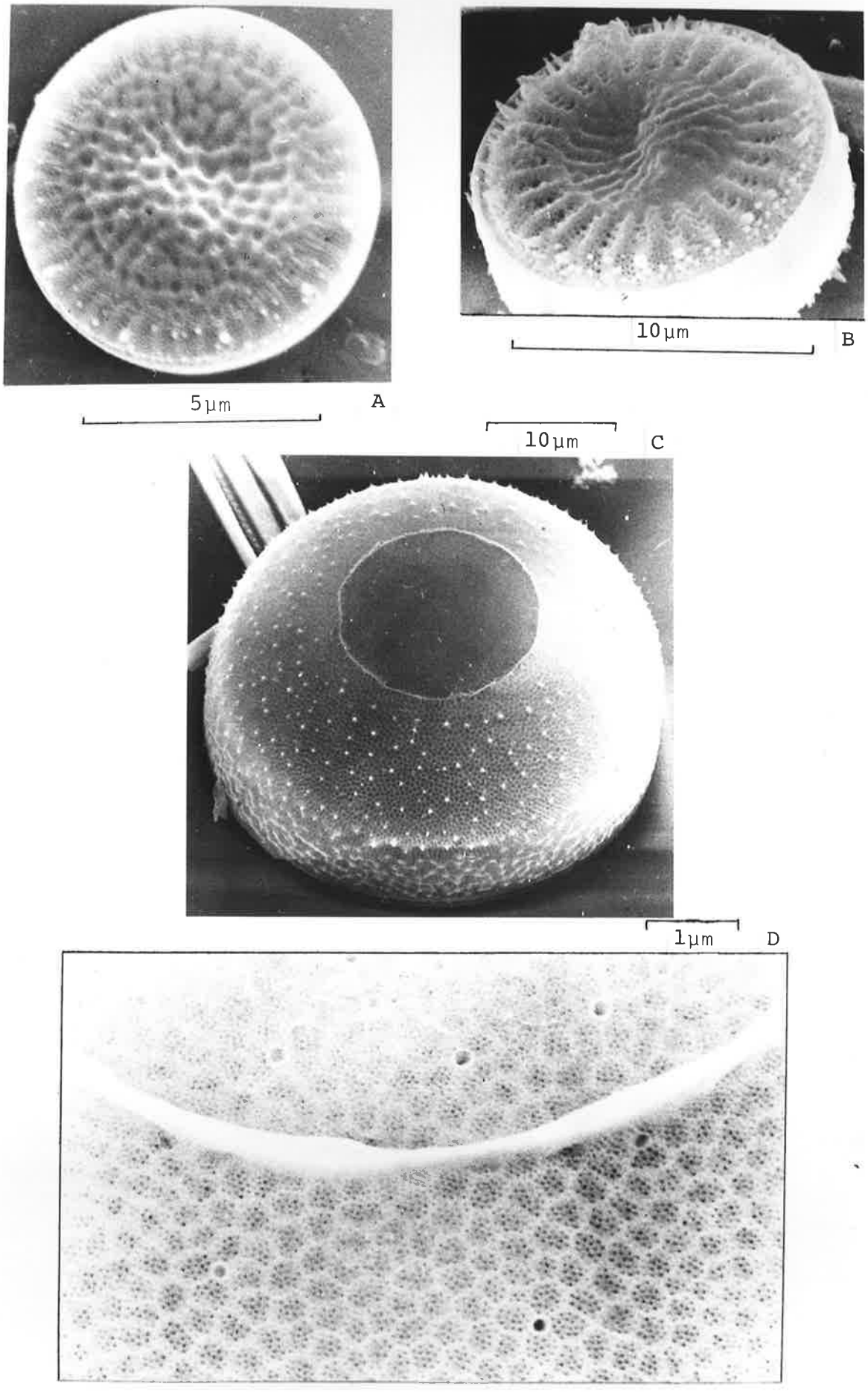


FIGURE 9

Melosira species 1

A. Girdle view of cingulum (SEM).

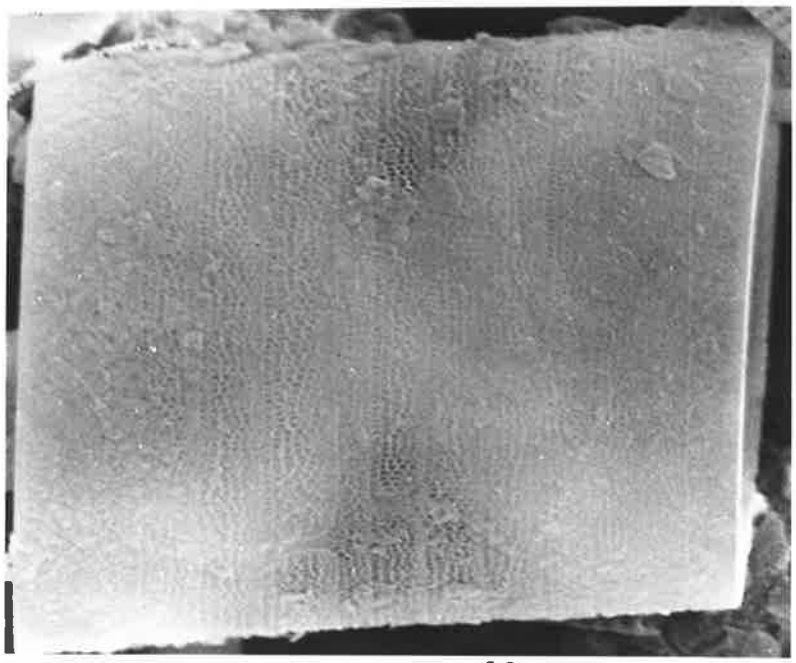
B. Girdle view of form variation with diameter (LM).

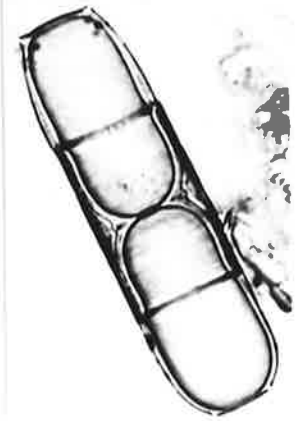
Melosira varians C. Agardh

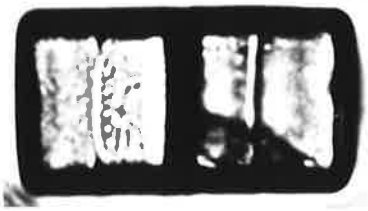
C. Girdle view (LM).

D. Valve view (SEM).

FIGURE 9







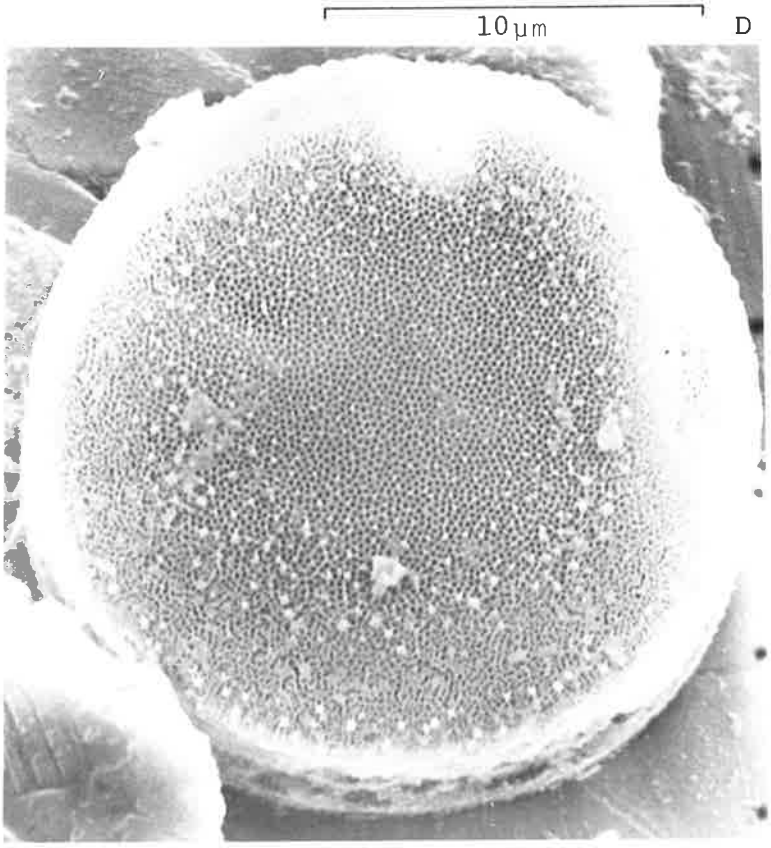


FIGURE 10

Dimerogramma minor (Gregory) Ralfs

A. Valve view (LM).

B. Girdle view (LM).

Fragilaria pinnata Ehrenberg

C. Valve view (SEM).

D. Oblique view (SEM).

Grammatophora oceanica Ehrenberg

E. Girdle view showing septum form (LM).

F. Girdle view showing surface detail (SEM).

G. Valve view (LM).

FIGURE 10

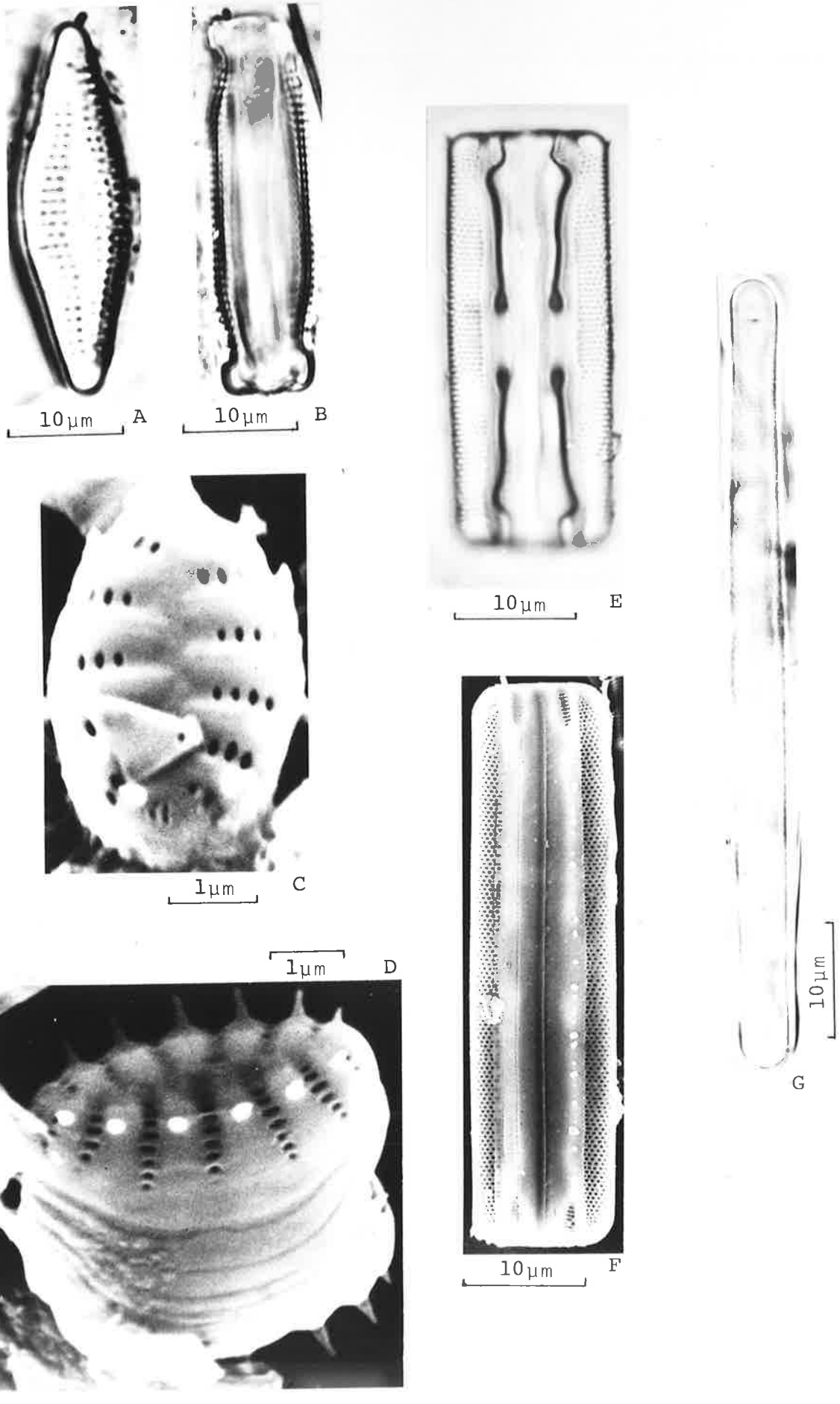


FIGURE 11

Licmophora flabellata (Carmichael) ex C. Agardh

A. Valve view showing the basal polar slits and slits either side of the axial area (SEM). (The figure of the apical third of the valve is transposed to the upper right hand edge of the rest of the figure)

Licmophora species 3

B. Oblique view of valve (SEM).

C. Internal valve view showing septum formation and basal labiate process (SEM).

Licmophora species 4

D. Girdle view (LM).

FIGURE 11

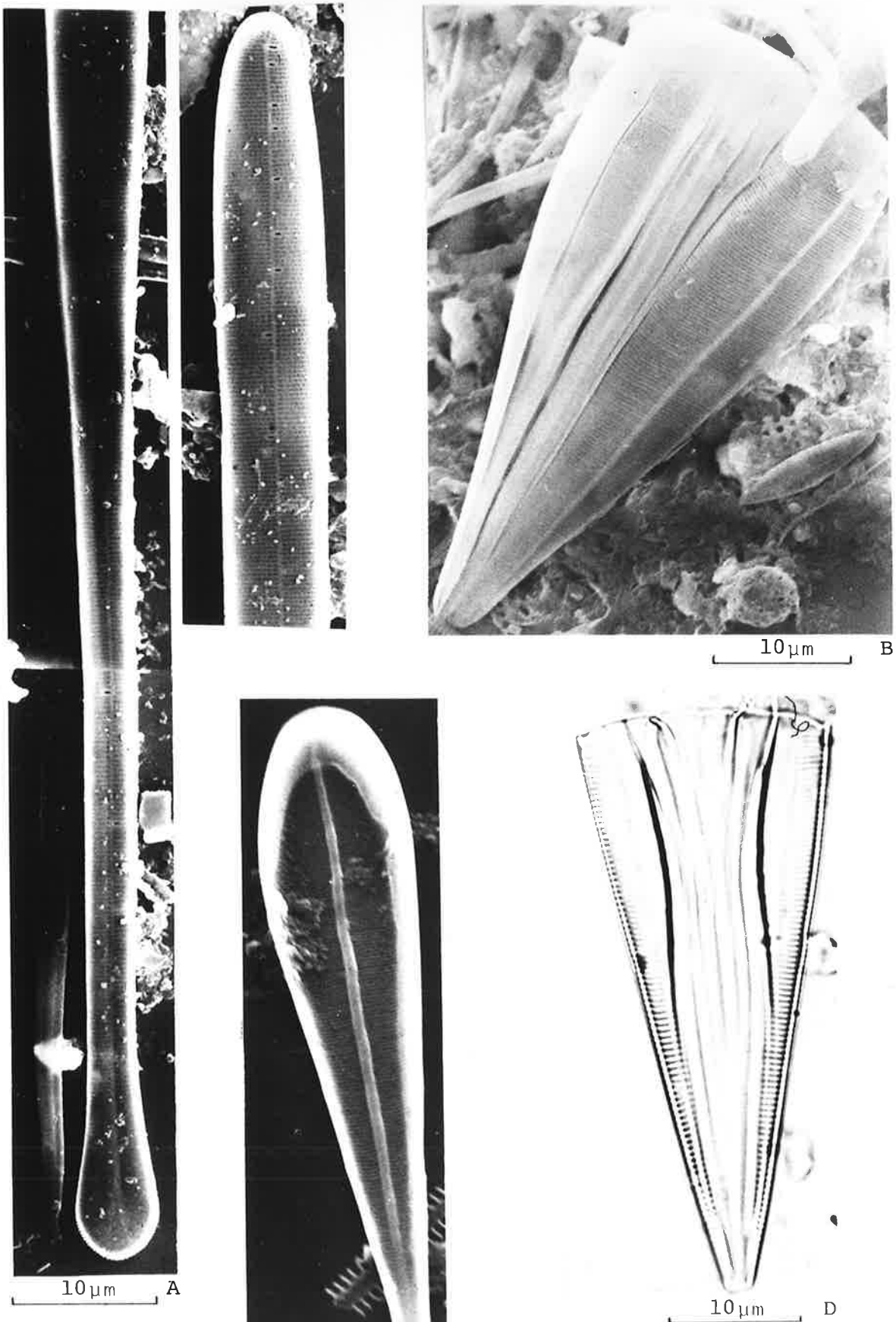


FIGURE 12

Licmophora species 4

A. Valve view and valvocopulae showing external openings of apical and basal labiate processes (SEM).

Opephora martyi Heribaud

B. Valve view (LM).

Plagiogramma staurophoram (Gregory) Heiberg

C. Valve view (LM).

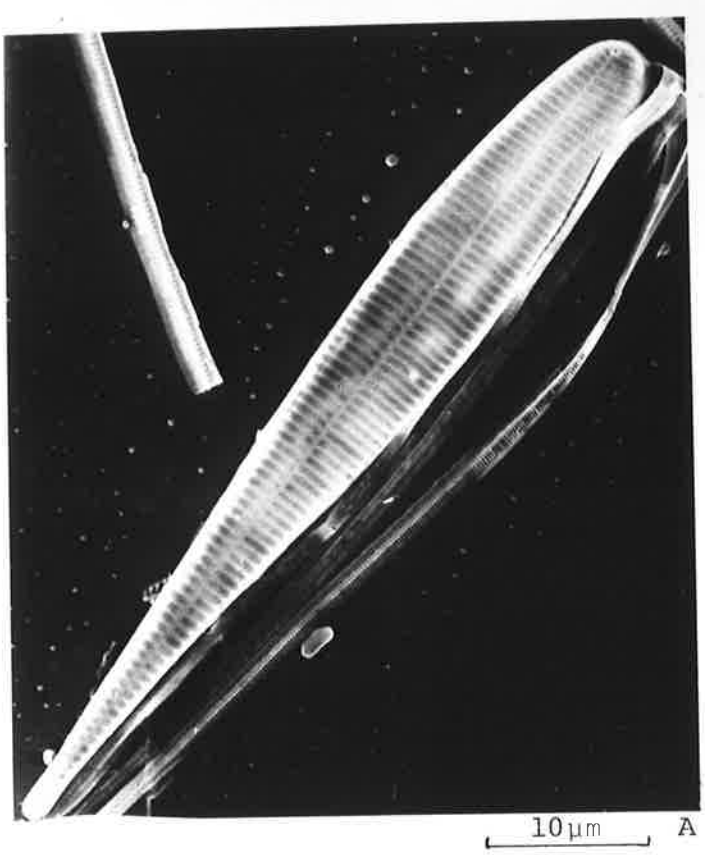
Rhaponeis surirella var. australis (Petit) Grunow in van Heurck

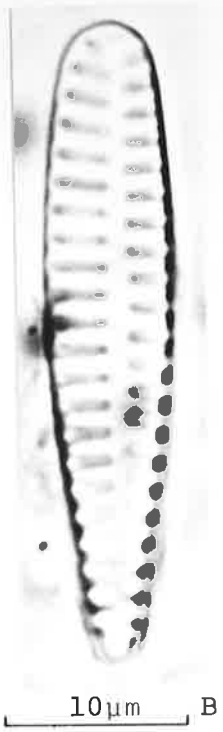
D. Valve view (LM).

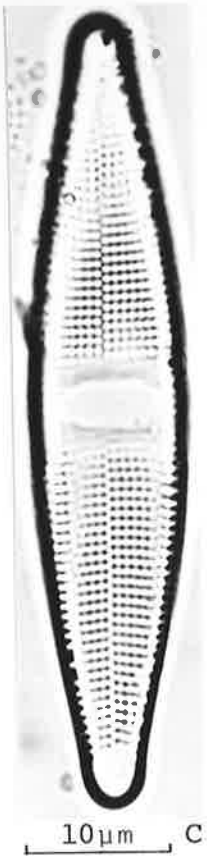
Striatella unipunctata (Lyngbye) C. Agardh

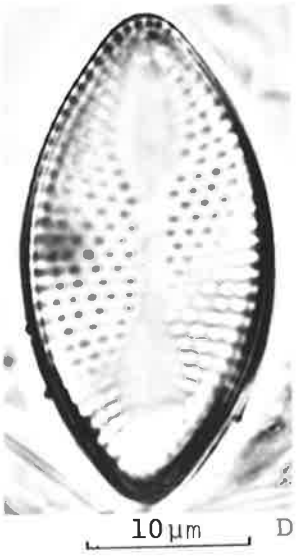
E. Girdle view (SEM).

FIGURE 12









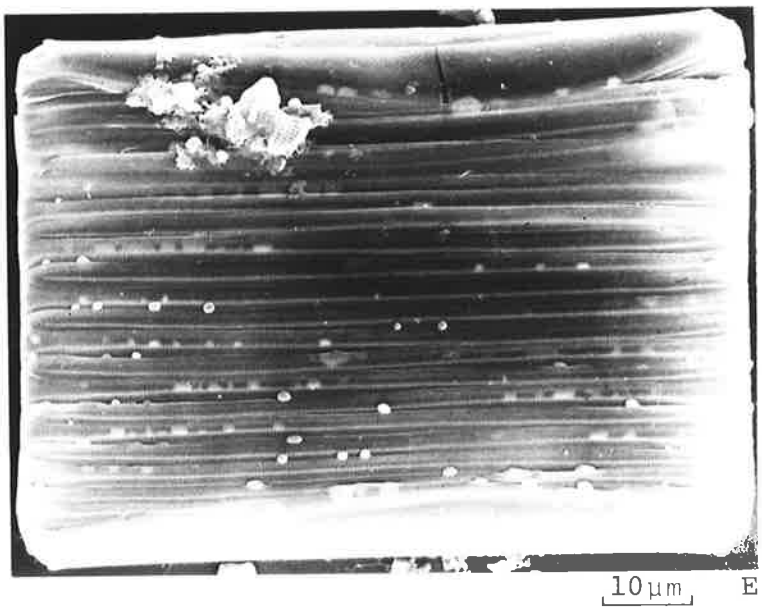


FIGURE 13

Striatella unipunctata (Lyngbye) C.Agardh

A. Valve view with copulae showing polar septum (SEM).

Synedra pulchella var. lacerata Hustedt in Schmidt et al.

B. Valve view of full size valve (LM).

C. Valve view of small valve (LM).

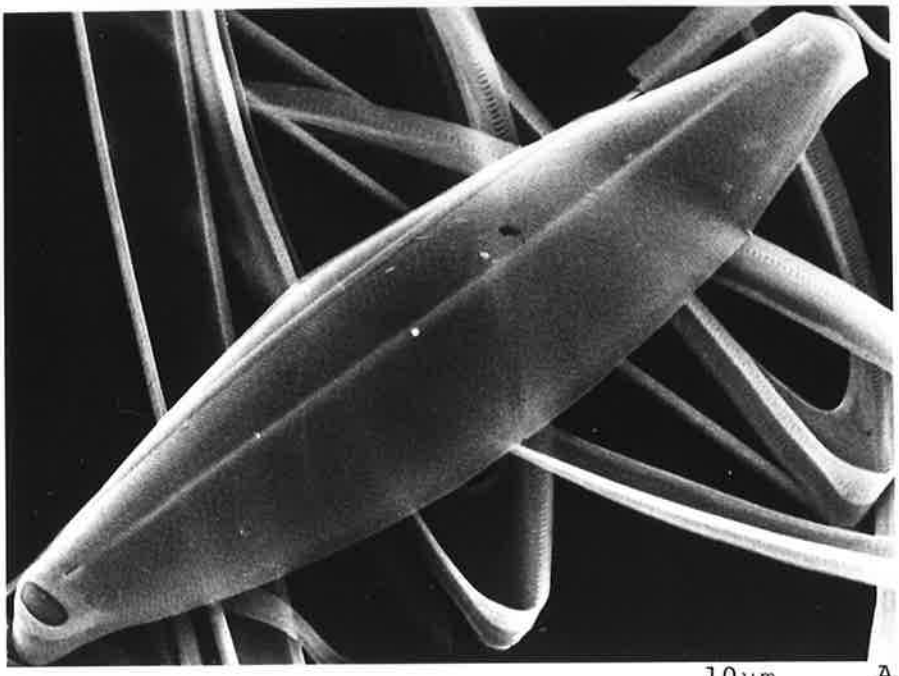
Synedra tabulata (C.Agardh) Kützing

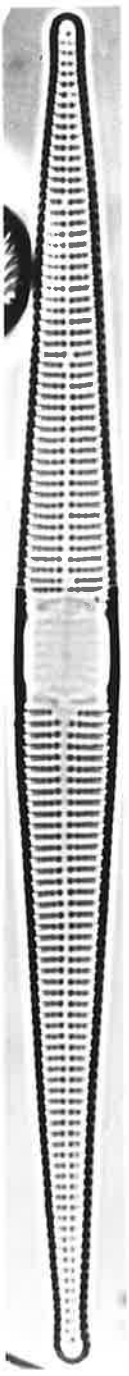
D. Close up of valve pole showing structure of striae, external opening of labiate process and ocellus with porelli (SEM).

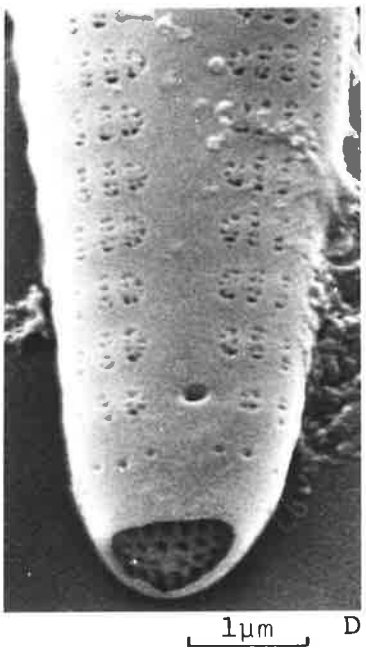
E. Valve view showing abnormality of stria formation (LM).

F. Valve view (LM).

FIGURE 13







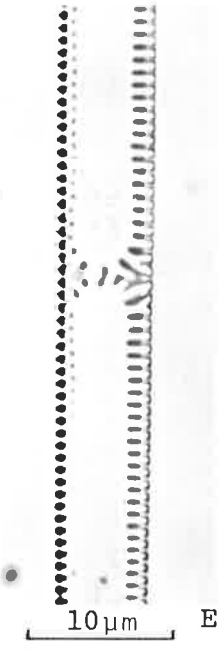


FIGURE 14

Synedra sp. aff. laevigata Grunow

A. Valve view (LM).

B. Close view of valve pole showing external opening of labiate process and ocellus with porelli (SEM).

Synedra fulgens (Greville) W. Smith

C. Valve view (LM).

D. Mid-valve view showing lateral axial areas (SEM).

E. Close view of valve pole (SEM).

Achnanthes brevipes var. intermedia (Kützing) Cleve

F. Girdle view of dividing cell (LM).

FIGURE 14

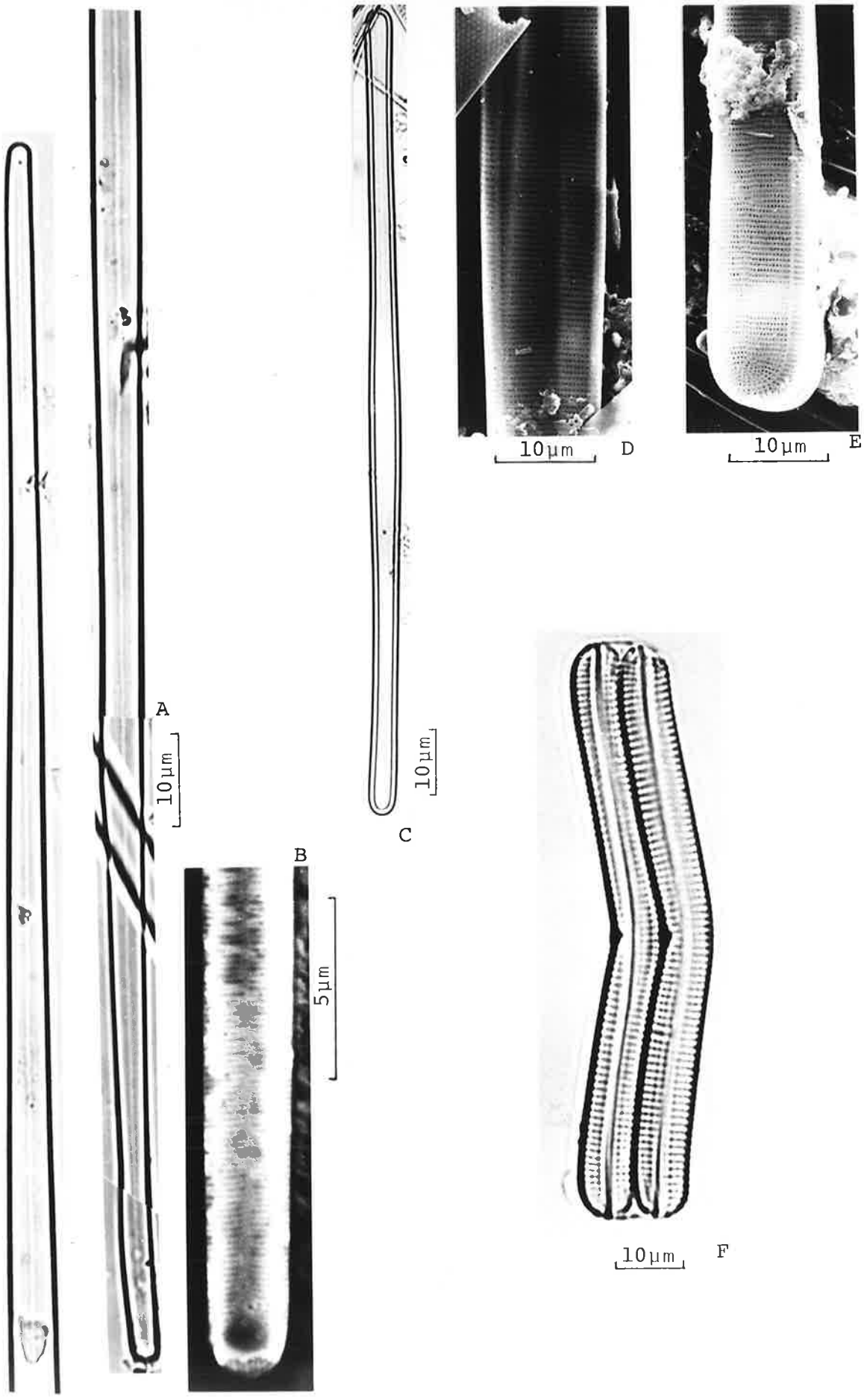


FIGURE 15

Achnanthes brevipes var. *intermedia* (Kützing) Cleve

A. Raphic valve view (SEM).

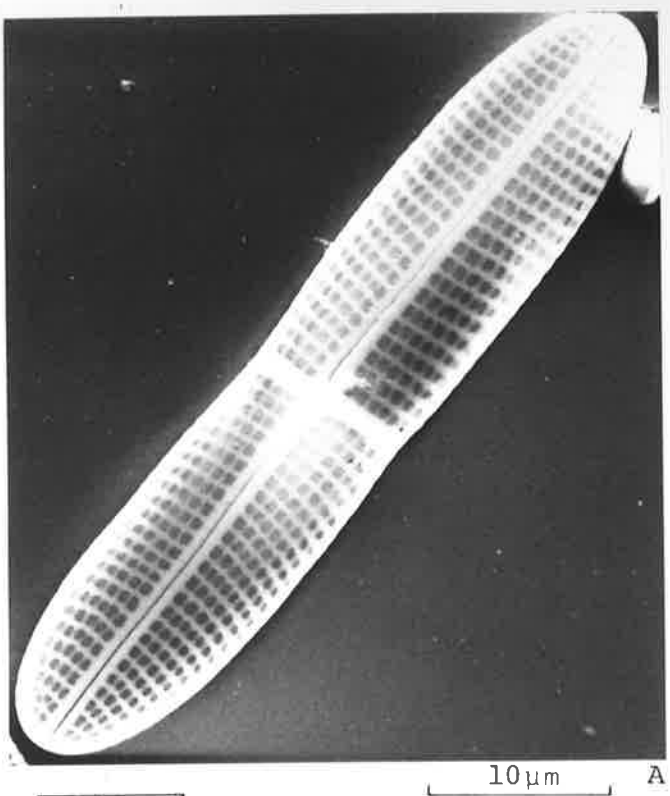
B. Close view of central area of raphic valve showing the form of cribrum occluding each areola (SEM).

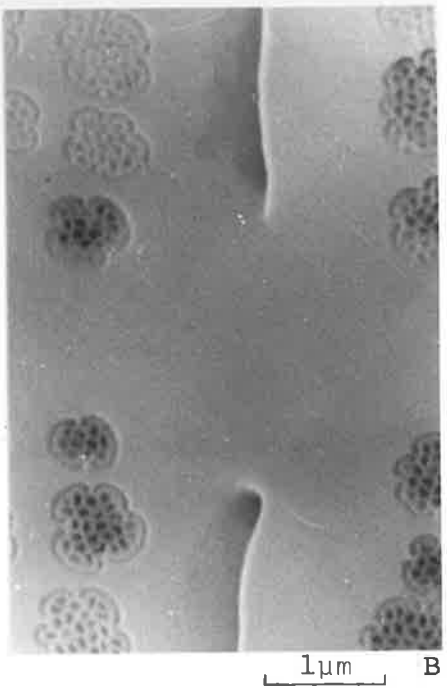
C. Araphic valve view (SEM).

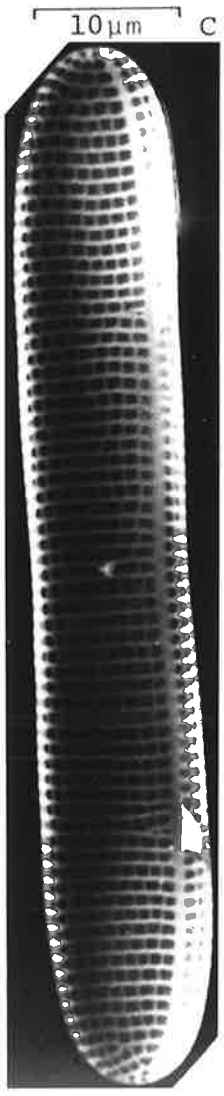
D. Abnormal araphic valve resulting from unfavourable environmental conditions (SEM).

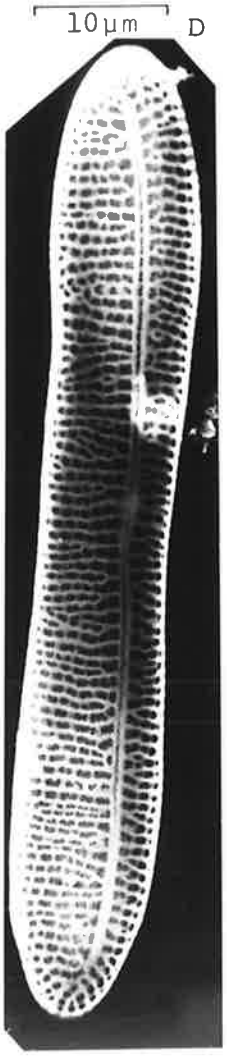
E. Oblique view of central region showing areolate valvocopulae (SEM).

FIGURE 15









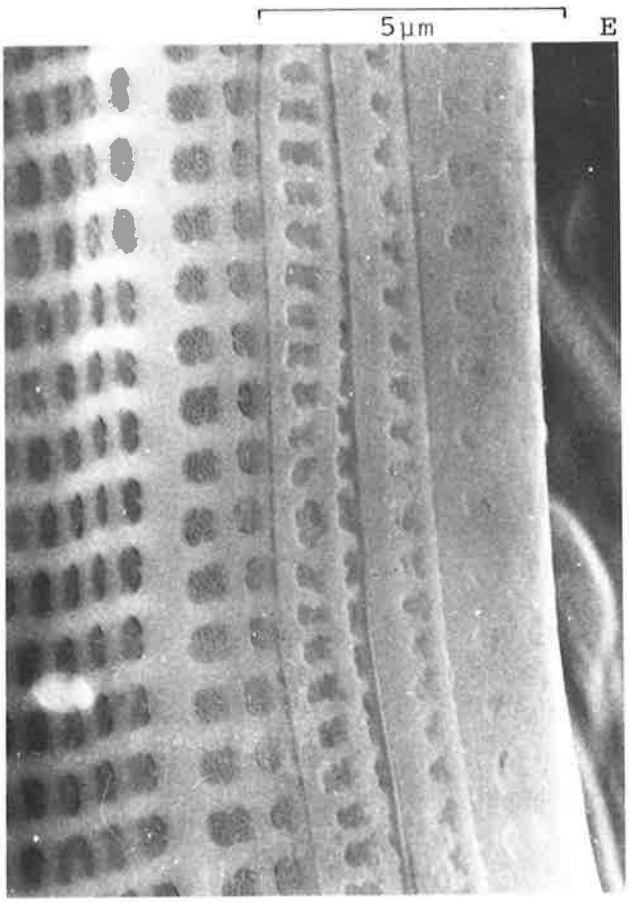


FIGURE 16

Achnanthes species 1

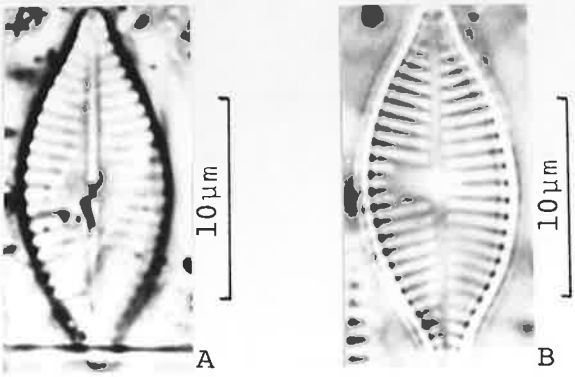
A. Raphic valve view (LM).

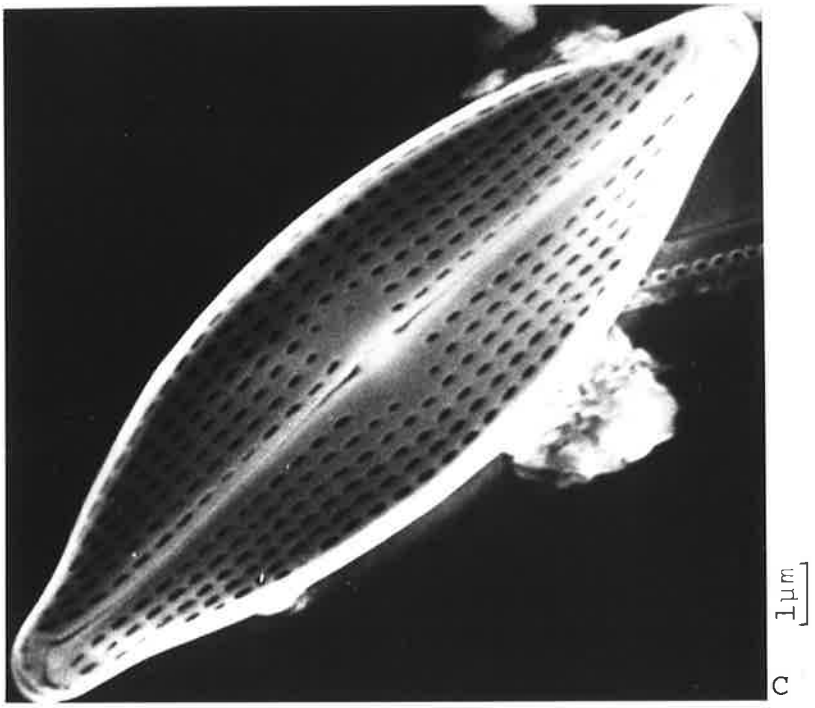
B. Araphic valve view (LM).

C. Raphic valve view (SEM).

D. Araphic valve, oblique view (SEM).

FIGURE 16





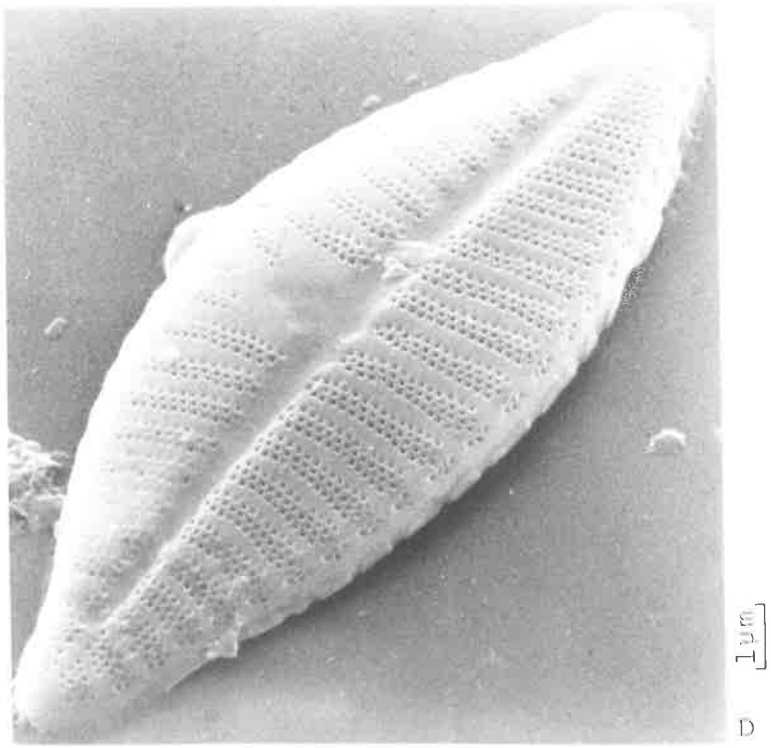


FIGURE 17

Achnanthes species 2

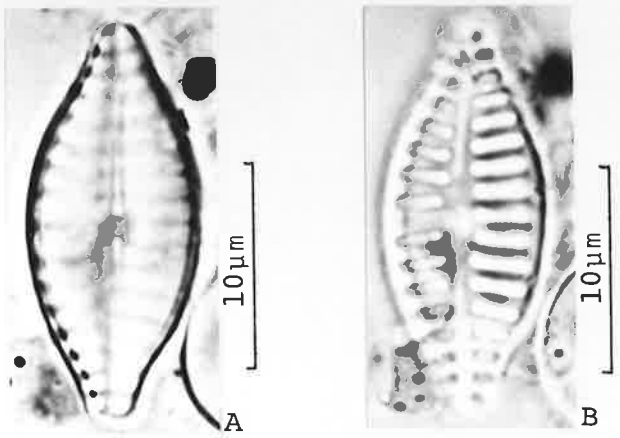
A. Raphic valve view (LM).

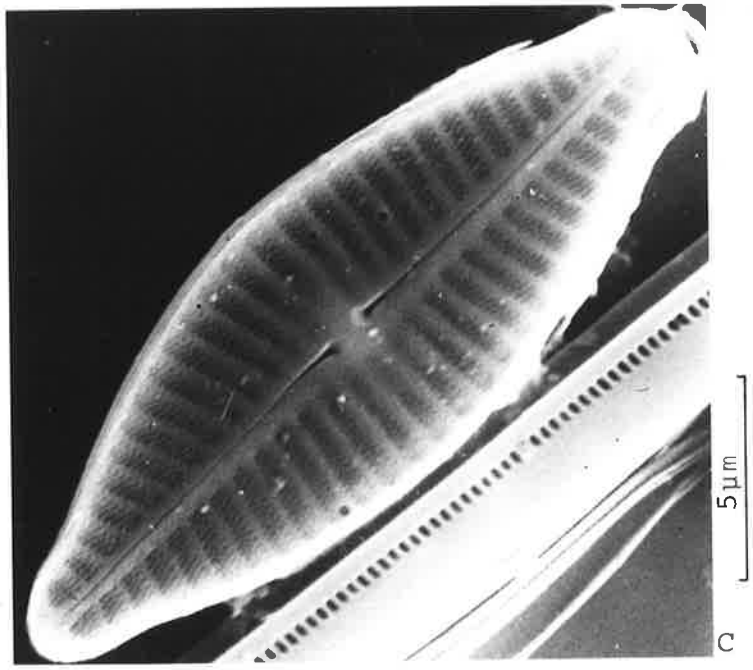
B. Araphic valve view (LM).

C. Raphic valve view (SEM).

D. Araphic valve view (SEM).

FIGURE 17





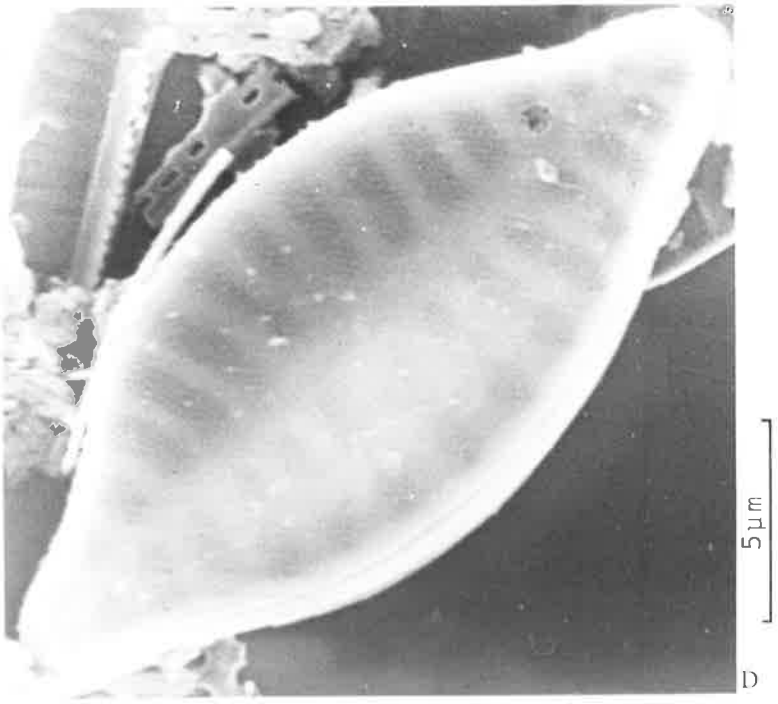


FIGURE 18

Achnanthes species 3

A. Raphic valve view (LM).

B. Araphic valve view (LM).

Cocconeis placentula var. euglypta (Ehrenberg) Grunow

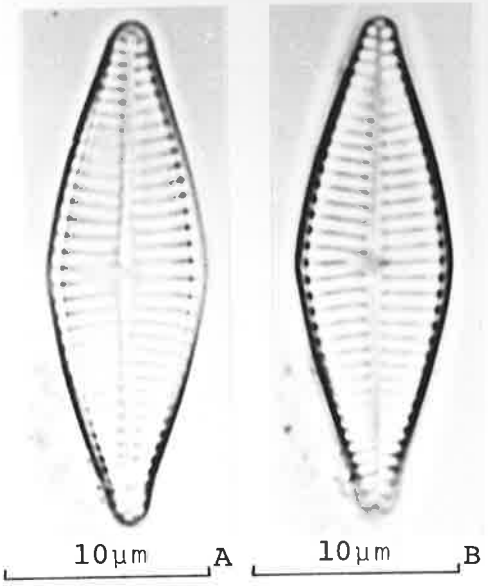
C. Raphic valve view (LM).

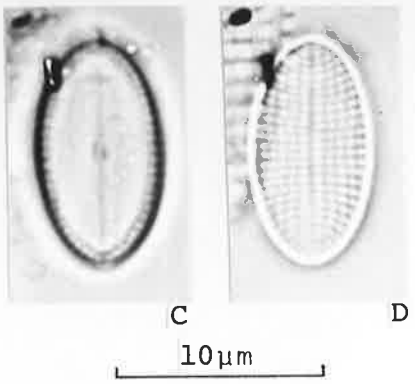
D. Araphic valve view (LM).

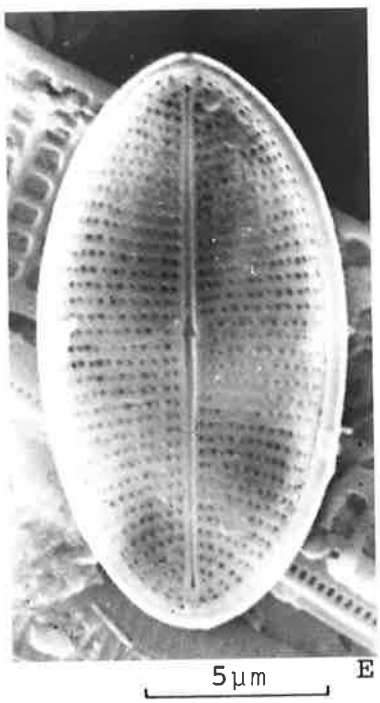
E. Raphic valve view showing structure of striae (SEM).

F. Araphic valve view showing structure of striae (SEM).

FIGURE 18







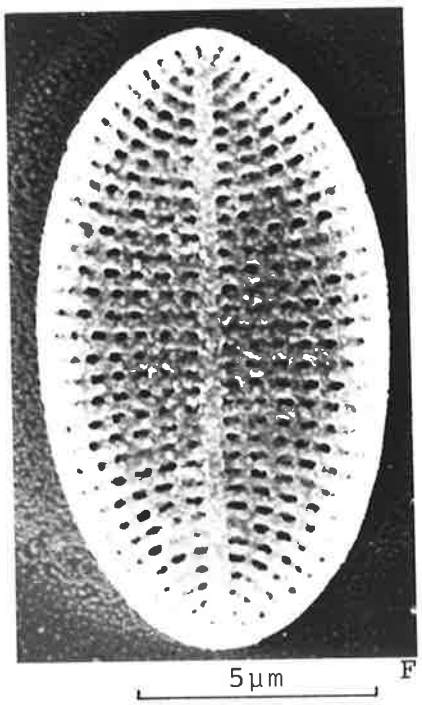


FIGURE 19

Cocconeis scutellum Ehrenberg

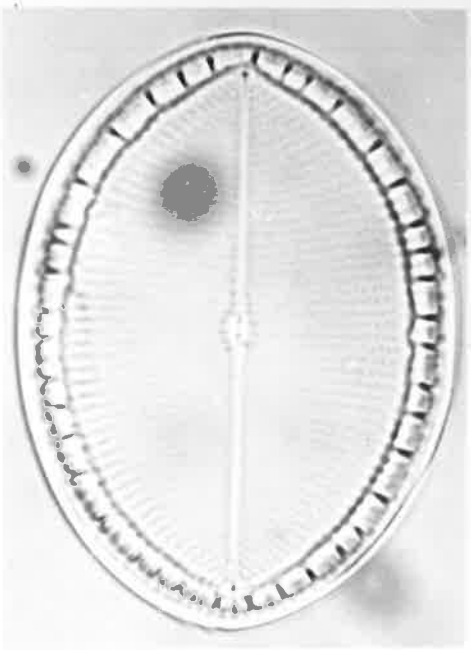
A. Raphic valve of full size frustule (LM).

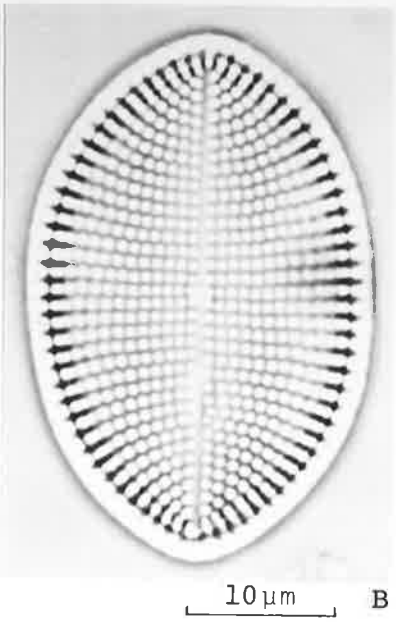
B. Araphic valve of full size frustule (LM).

C,D. Abnormal araphic valves indicative of potential plasticity in valve structure in unfavourable environmental conditions (LM).

E. Raphic valve showing structure of striae, small valve (SEM).

FIGURE 19





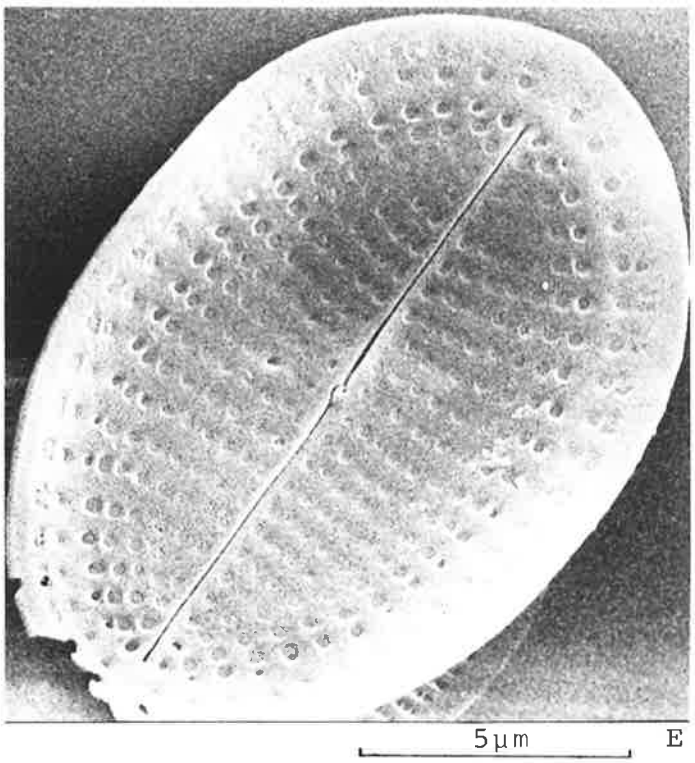


FIGURE 20

Cocconeis scutellum Ehrenberg

A. Araphic valve view showing structure of striae (SEM).

Cocconeis pediculus Ehrenberg

B. Raphic valve view (LM).

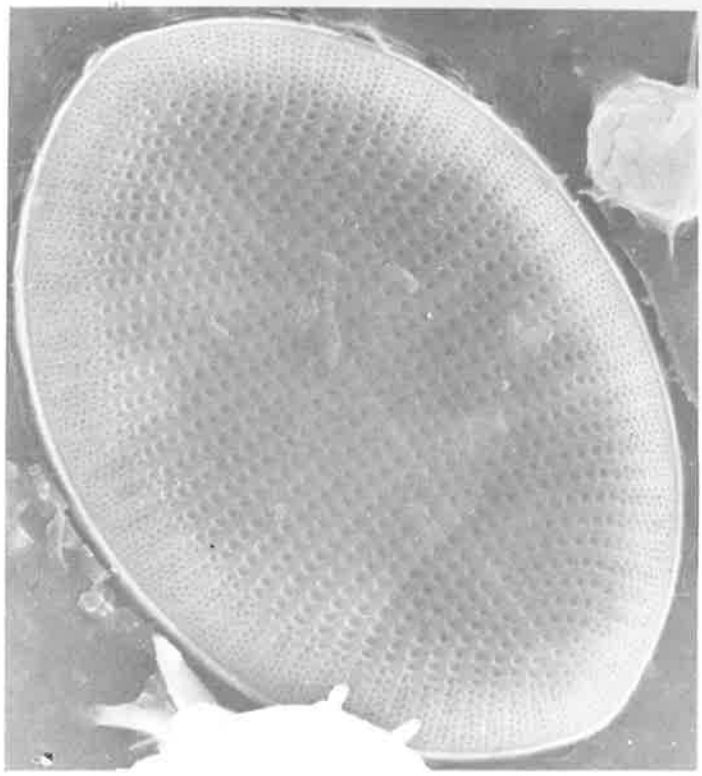
C. Araphic valve view (LM).

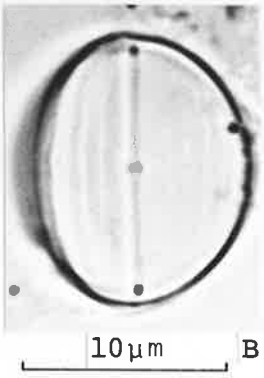
Cocconeis pellucida Grunow in Rabenhorst

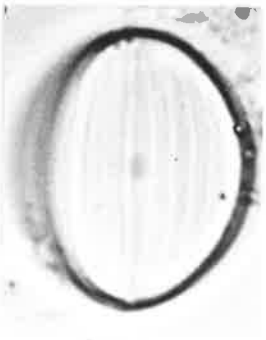
D. Raphic valve view (SEM).

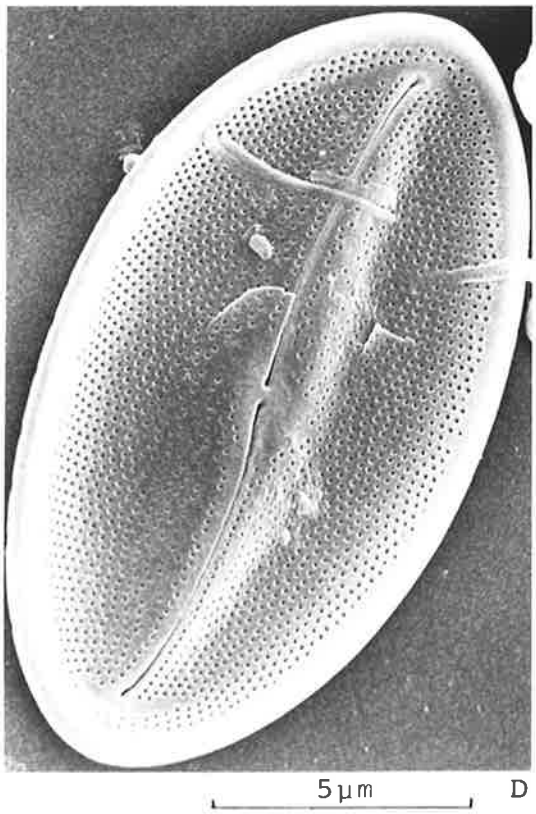
E. Araphic valve, oblique view (SEM).

FIGURE 20









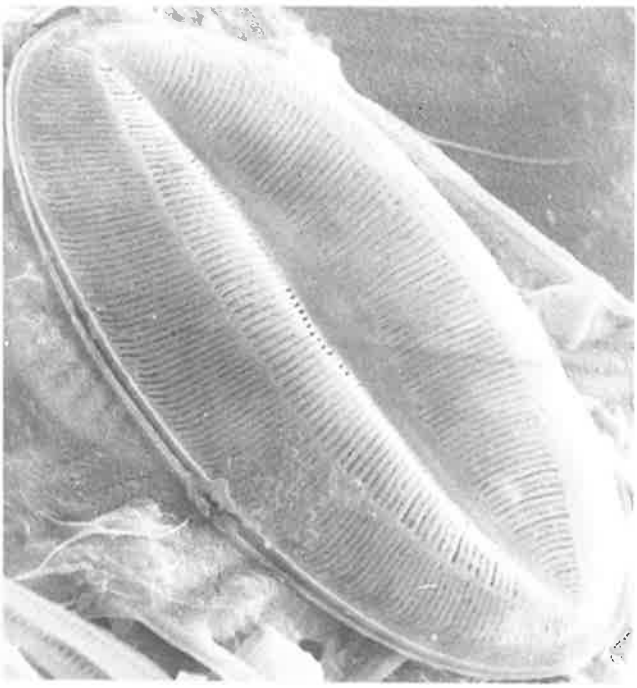


FIGURE 21

Cocconeis pellucida Grunow *in* Rabenhorst

A. Raphic valve (LM).

B. Araphic valve (LM).

Cocconeis species 4

C. Raphic valve view (LM).

D. Araphic valve view (LM).

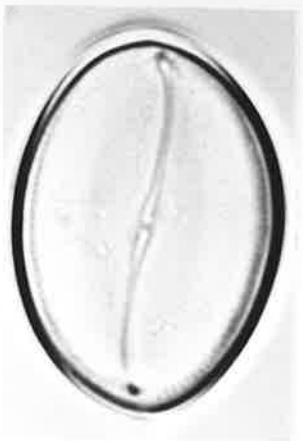
Cocconeis scutellum var. *stauroneiformis* Rabenhorst

E. Raphic valve view (LM).

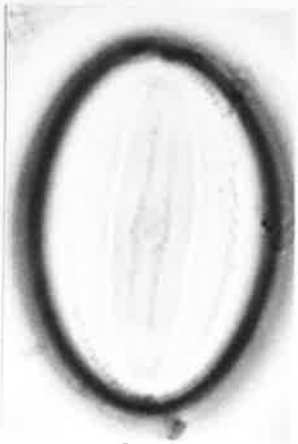
F. Araphic valve view (LM).

G. Raphic valve, oblique view showing structure of striae (SEM).

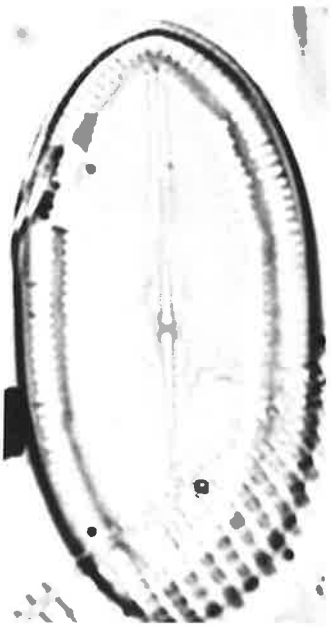
FIGURE 21



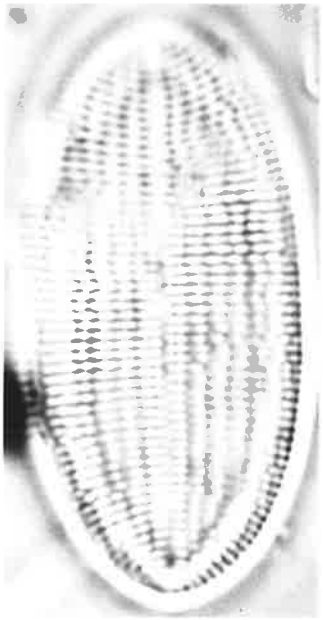
10µm A



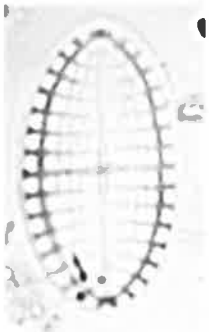
10µm B



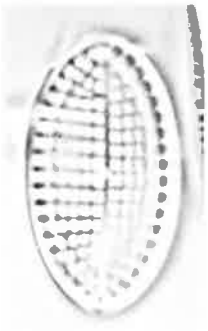
10µm C



10µm D



10µm E



10µm F

5µm G

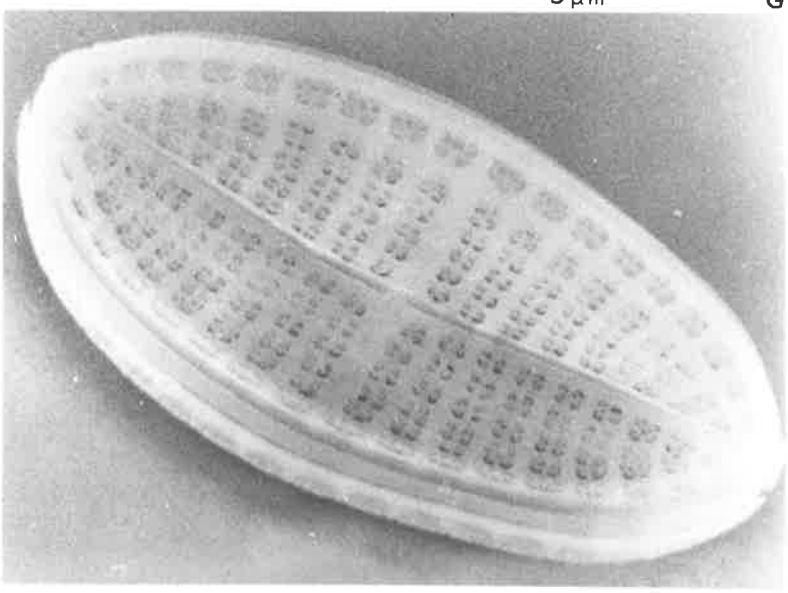


FIGURE 22

Rhoicosphaenia curvata (Kützing) Grunow

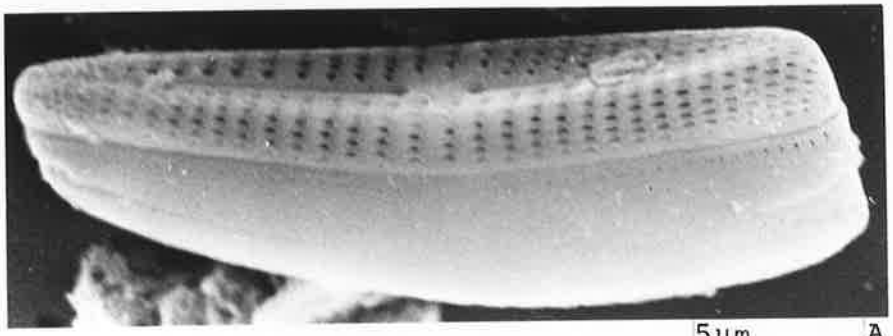
A. Raphic valve, oblique view (SEM).

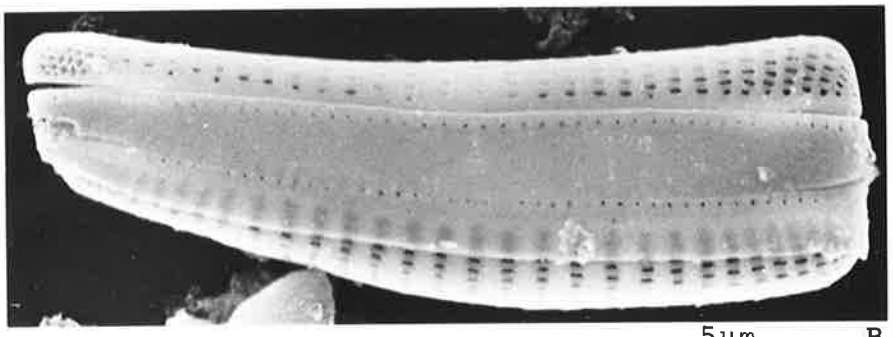
B. Girdle view showing the apical pore field at the basal pole of each valve (SEM).

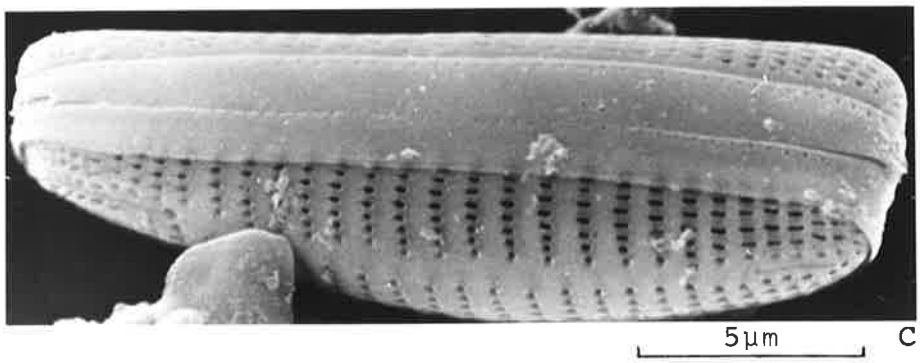
C. "Araphic" valve, oblique view showing rudimentary raphe fissures (SEM).

D. Girdle view showing extent of septa (LM).

FIGURE 22







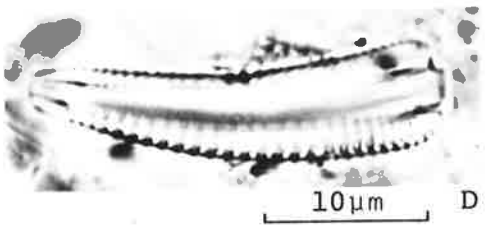


FIGURE 23

Amphiprora species 1

A. Girdle view (SEM).

Amphiprora alata (Ehrenberg) Kützing

B. Valve view (LM).

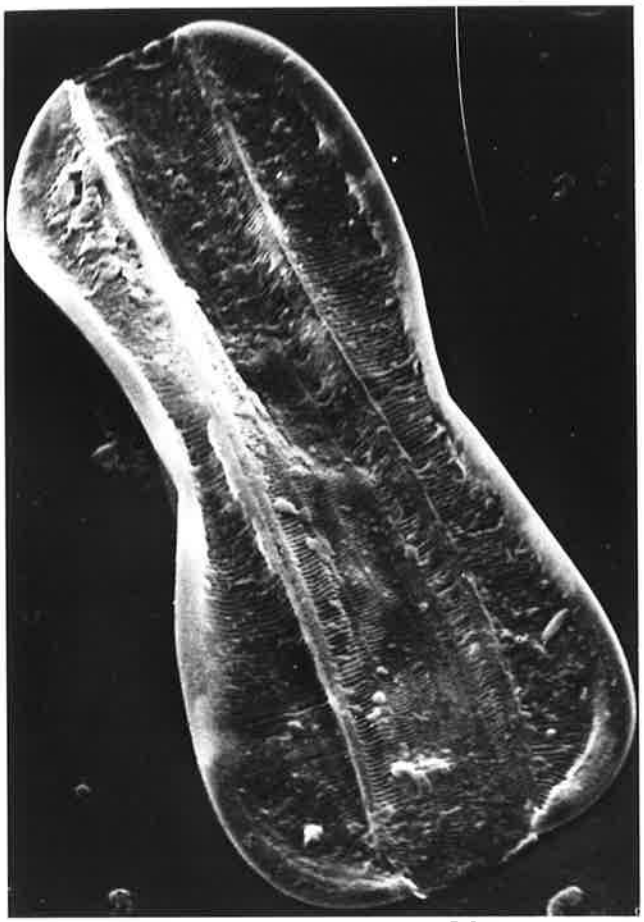
C. Girdle view (LM).

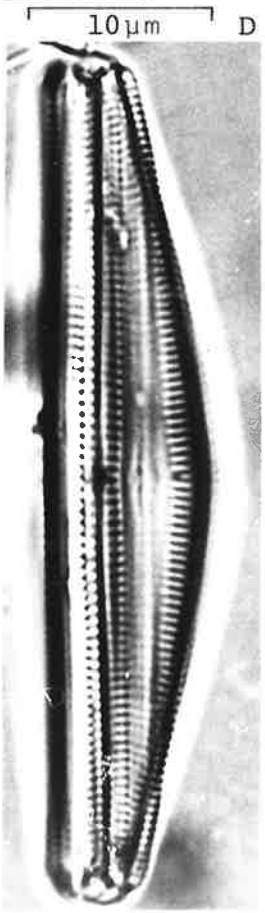
Amphora species 1

D. Valve view of large frustule (LM).

E. Girdle and valve view of small frustule (SEM).

FIGURE 23





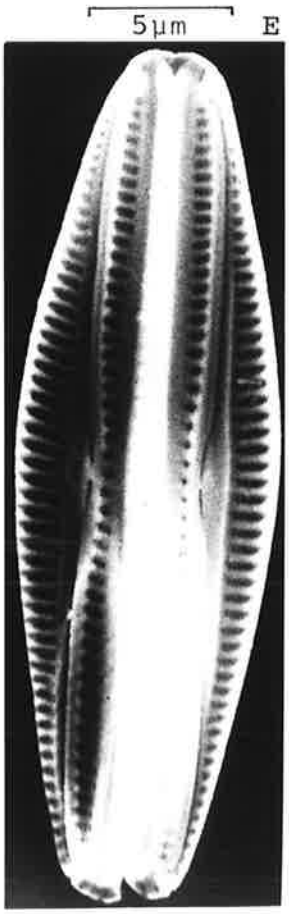


FIGURE 24

Amphora species 2

A. Valve view (SEM).

B. Girdle and valve view of dividing cell (SEM).

Amphora coffeaeformis (C. Agardh) Kützing

C. Oblique valve view (SEM).

Amphora species 4

D. Valve view (LM).

E. Girdle view showing complex valvocopulae (SEM).

FIGURE 24

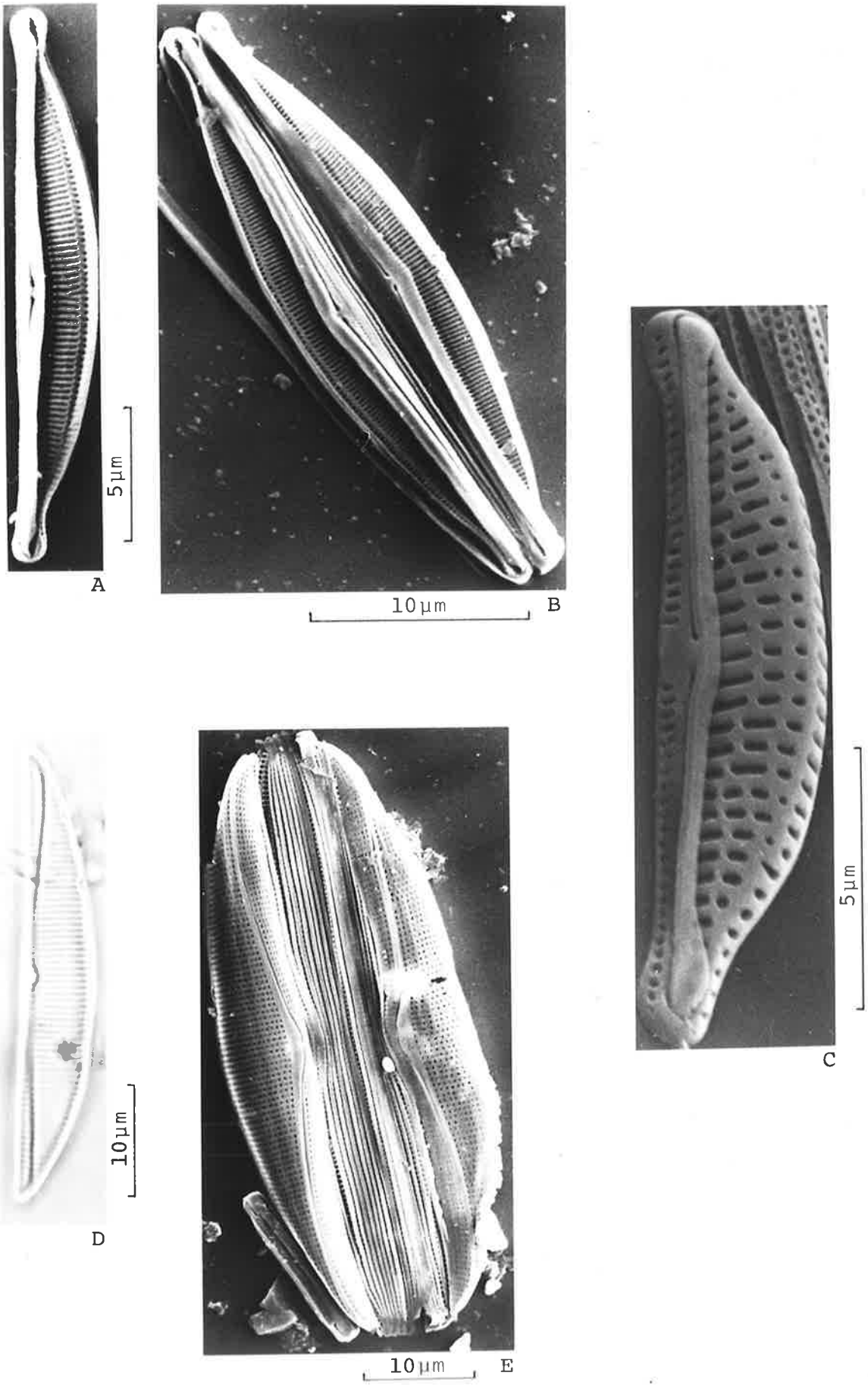


FIGURE 25

Amphora species 5

A. Valve and girdle view showing complex valvocopulae (SEM).

Amphora hyalina Kützing

B. Valve view (LM).

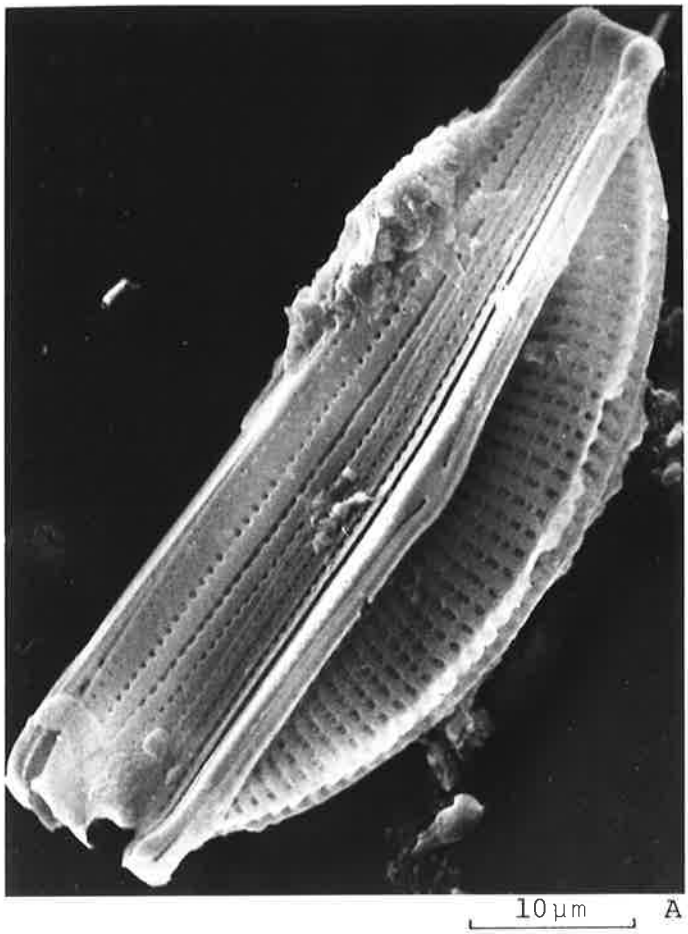
Amphora species 7

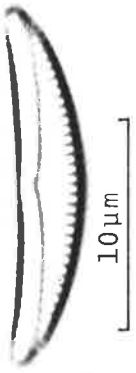
C. Valve view (LM).

Amphora proteus Gregory

D. Valve view (SEM).

FIGURE 25





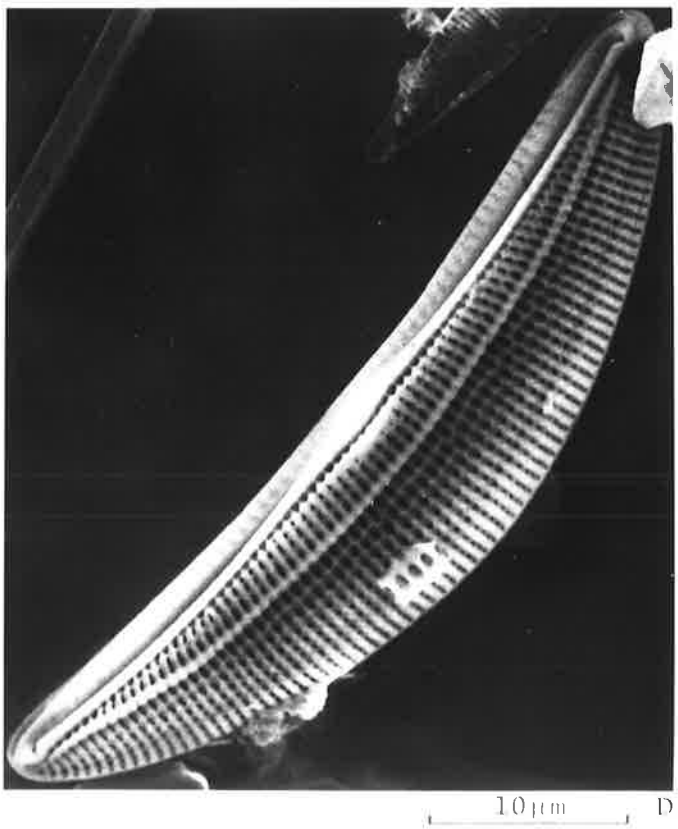


FIGURE 26

Berkleya rutilans (Trentepohl *ex* Roth) Grunow

A. Valve and girdle view (SEM).

Diploneis abnormis (Castracane) Thomas comb. nov.

B. Valve view showing surface details (SEM).

C. Valve view (LM).

Diploneis smithii var. *rhombica* Mereschkowsky

D. Valve view (LM).

FIGURE 26

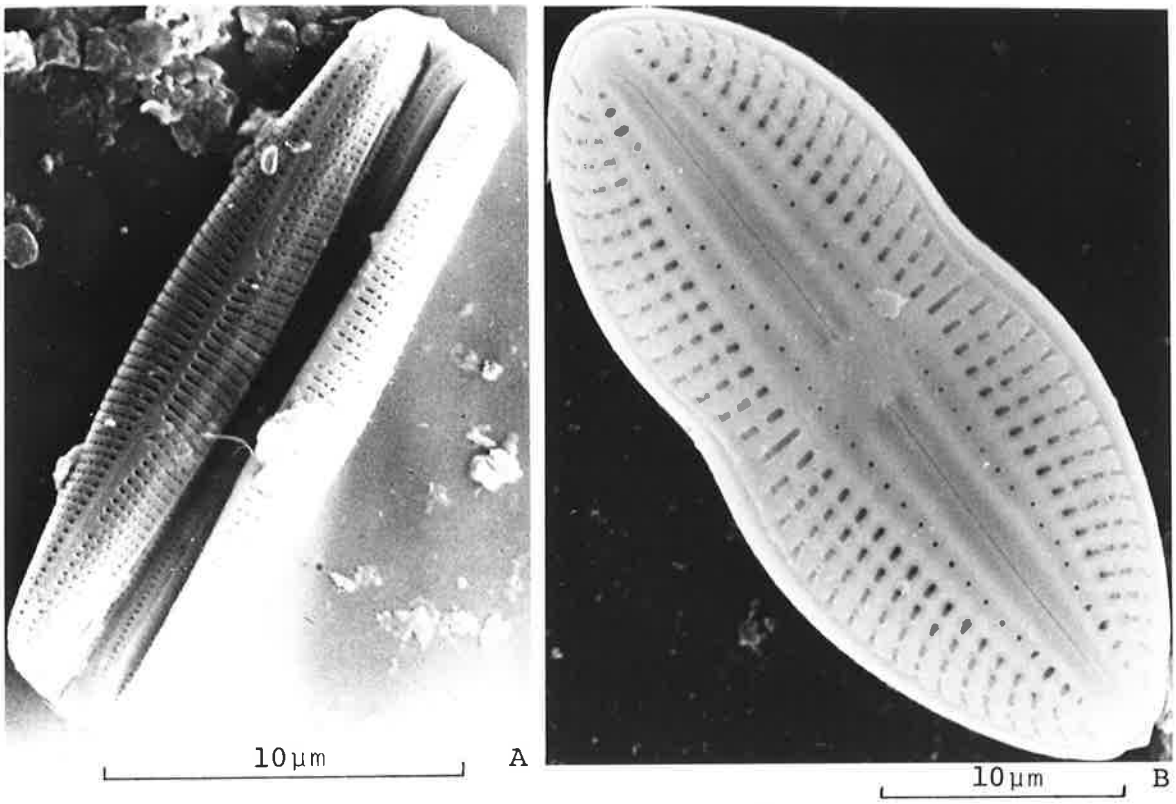


FIGURE 27

Caloneis excentrica (Grunow) Boyer

A. Valve view (LM).

Gomphonema constrictum var. capitatum (Ehrenberg) Grunow

B. Valve view (SEM).

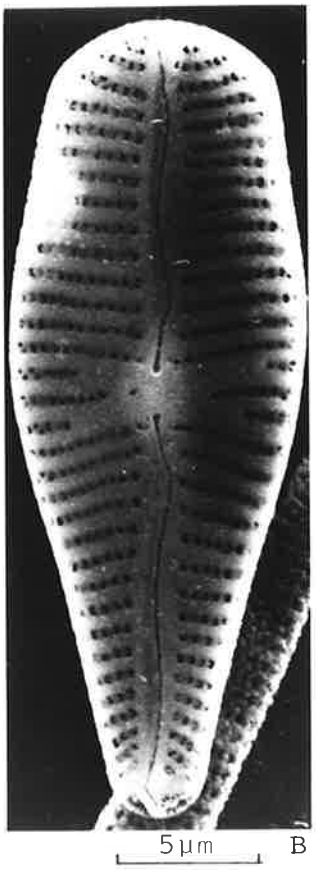
Gyrosigma wansbeckii (Donkin) Cleve

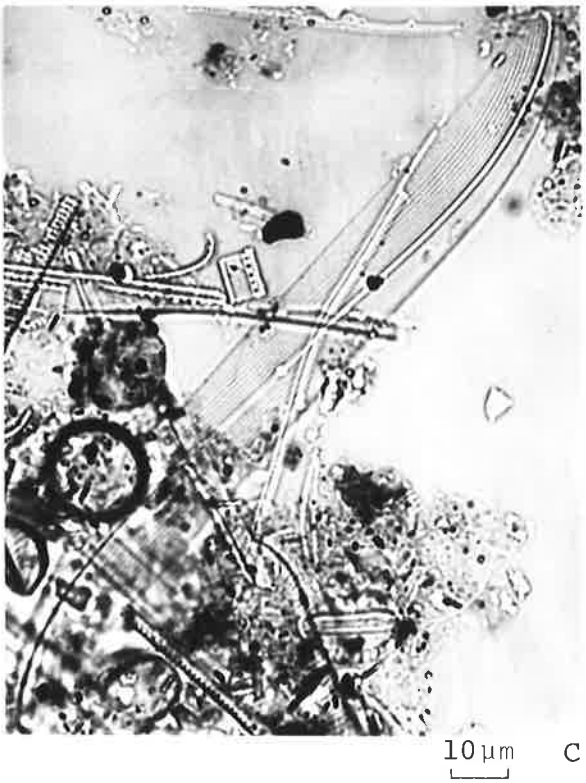
C. Valve view (LM).

Gyrosigma eximium (Thwaites) Boyer

D. Oblique valve view (SEM).

FIGURE 27





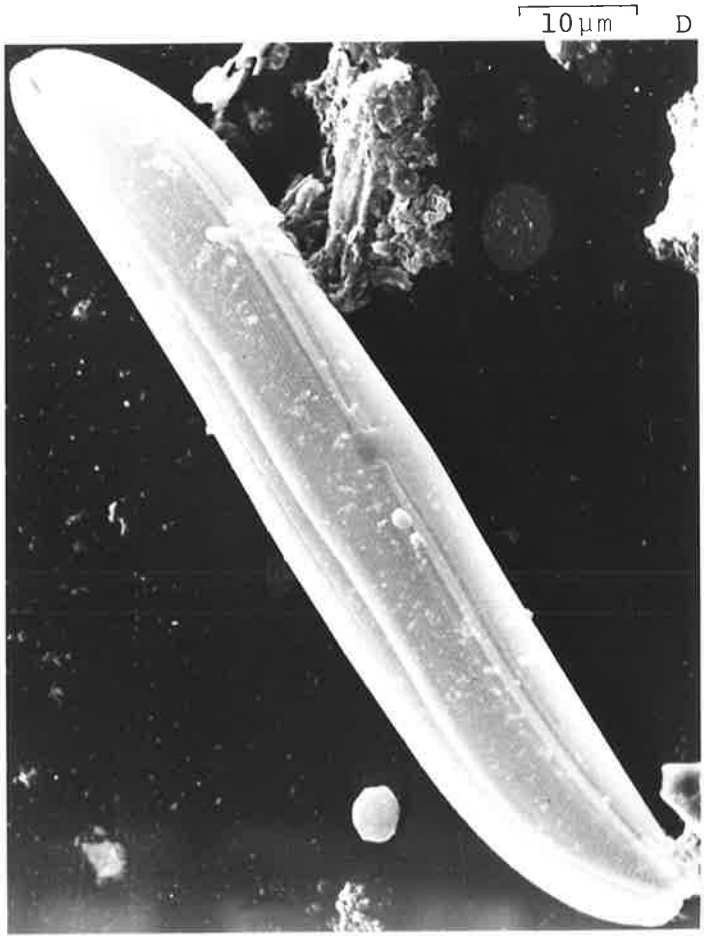


FIGURE 28

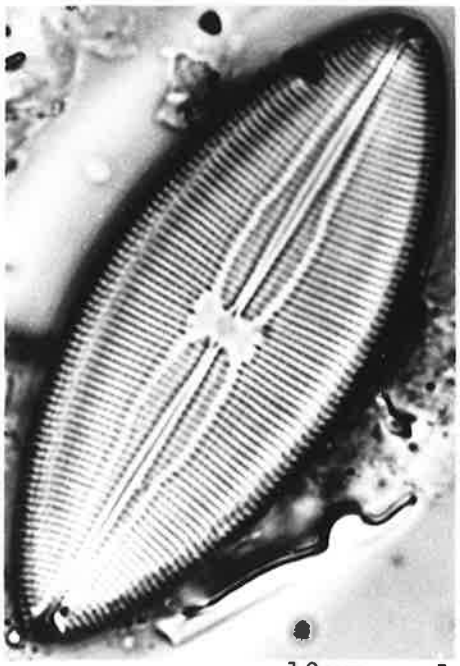
Mastogloia baldjikiana Grunow in Schmidt et al.

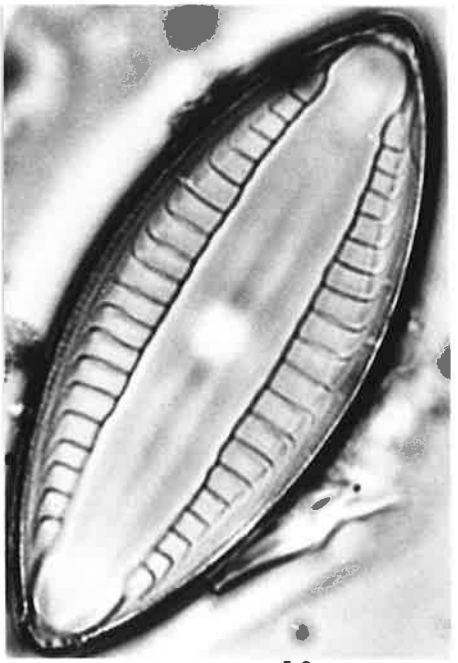
A. Valve view (LM).

B. Valve view showing septal chambers (LM).

C. Valve view showing surface details (SEM).

FIGURE 28





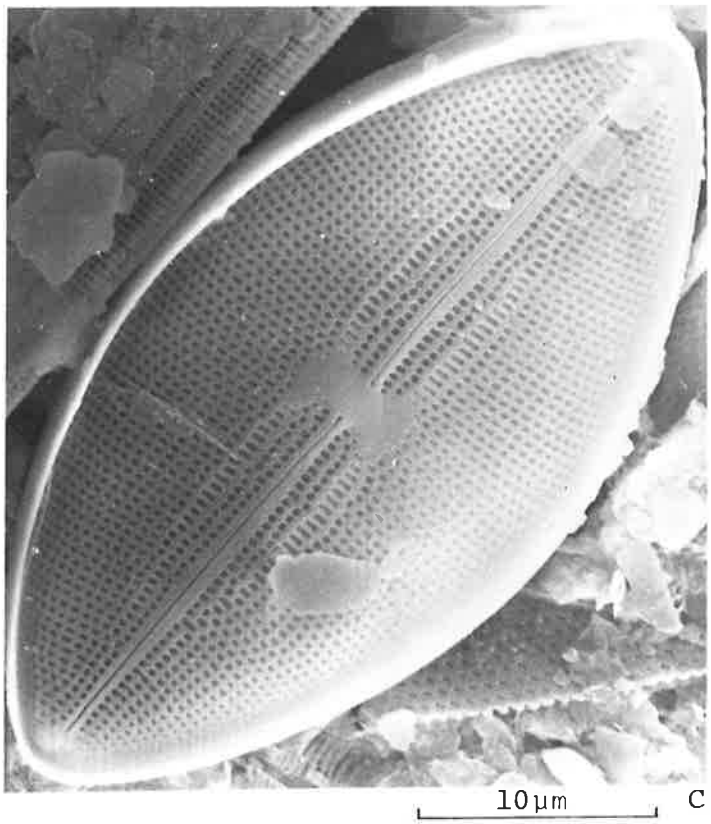


FIGURE 29

Mastogloia baldjikiana Grunow in Schmidt et al.

A. Valve view showing internal details including septal chambers (SEM).

Mastogloia pumila (Grunow in van Heurck) Cleve

B. Valve view of small form (LM).

C. Valve view of small form showing arrangement of large and small septal chambers (LM).

D. Valve view of medium size form (LM).

E. Valve view of medium form showing arrangement of large and small septal chambers (LM).

F. Valve view of large size form (LM).

G. Valve view of large form showing arrangment of large and small septal chambers (LM).

H. Valve and girdle views showing external details including the external openings of the septal chambers (SEM).

FIGURE 29

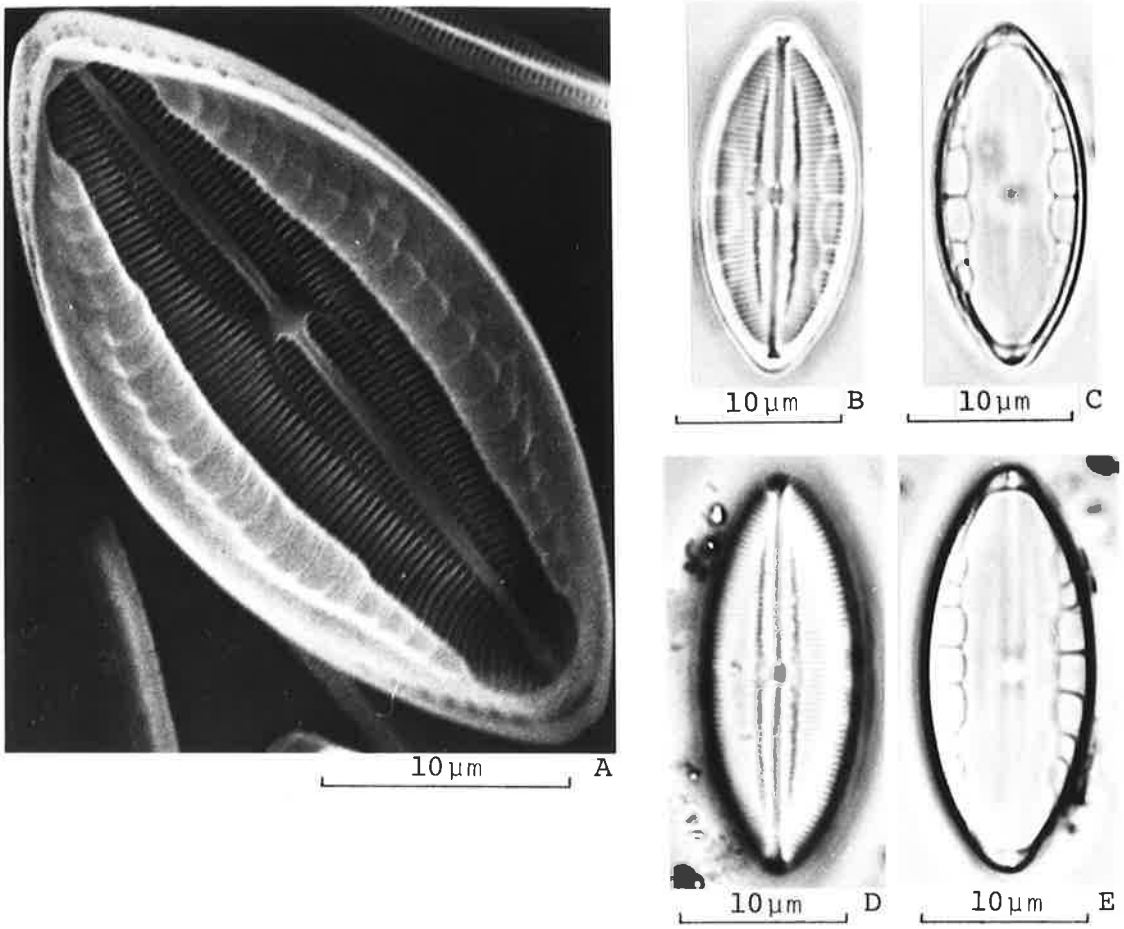


FIGURE 30

Mastogloia pumila (Grunow *in* van Heurck) Cleve

A. Valve view of small form showing internal details (SEM).

B. Valve view of large form showing internal details (SEM).

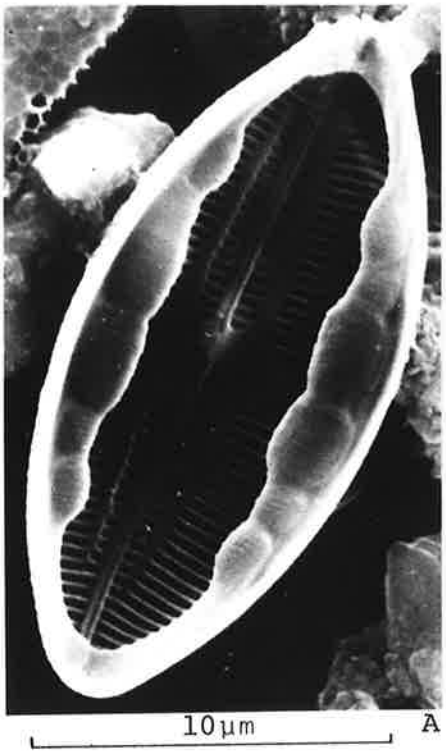
Mastogloia species 4

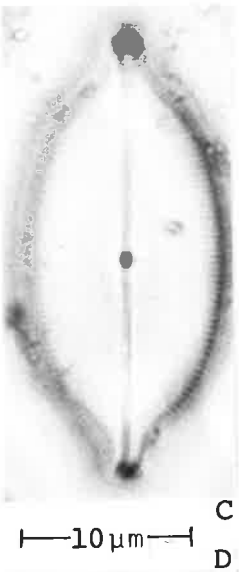
C. Valve view (LM).

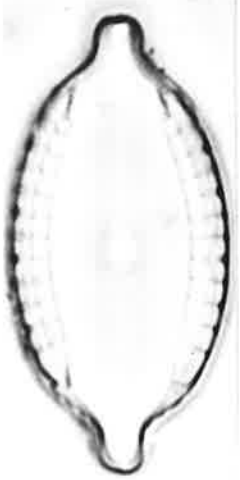
D. Valve view showing arrangement of septal chambers (LM).

E. Valve view showing surface details (SEM).

FIGURE 30







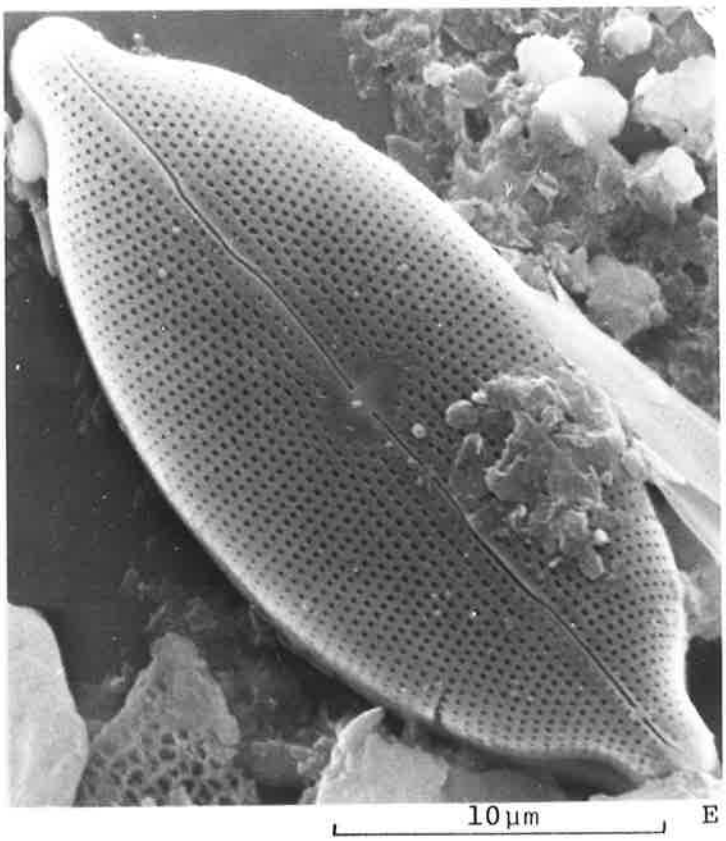


FIGURE 31

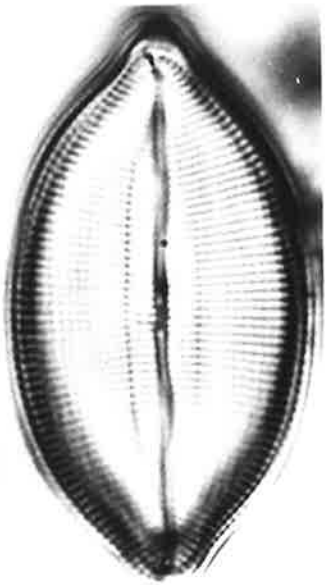
Mastogloia peragallii Cleve

A. Valve view (LM).

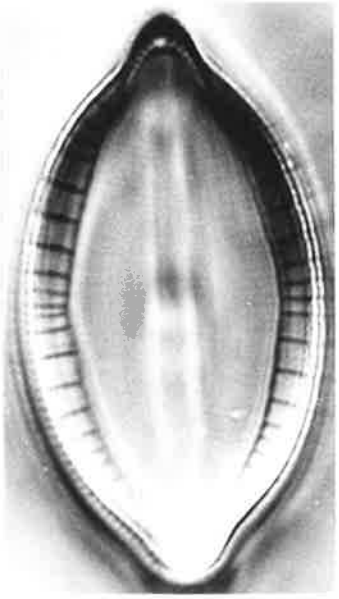
B. Valve view showing arrangement of septal chambers (LM).

C. Oblique valve view showing surface details, including the external openings of the septal chambers (SEM).

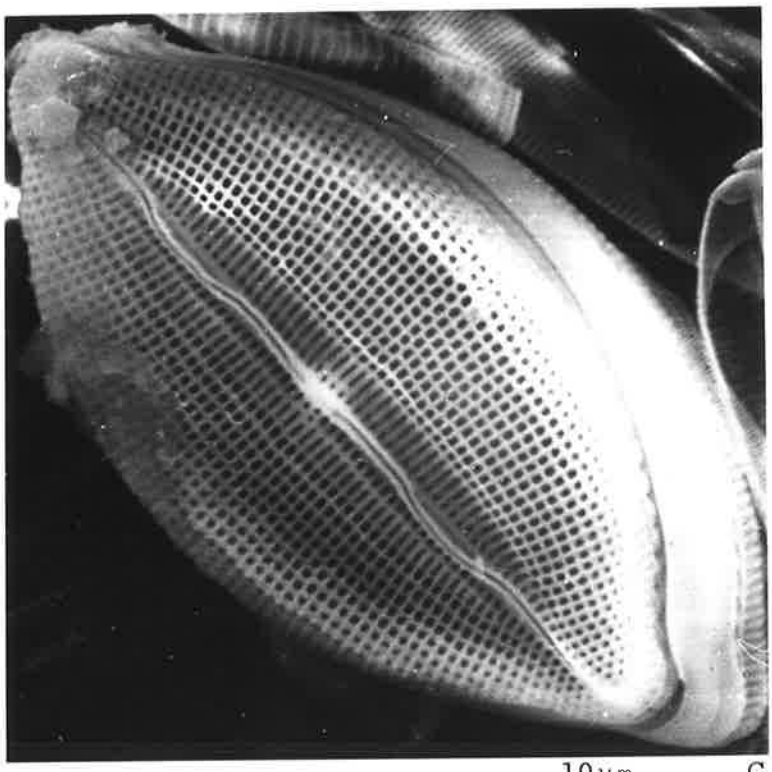
FIGURE 31



10 µm A



10 µm B



10 µm C

FIGURE 32

Navicula dissipata Hustedt *in* Schmidt *et al.*

A. Valve view (LM).

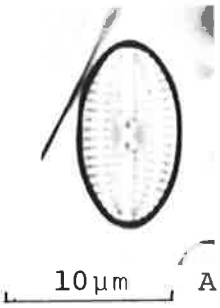
B. Oblique valve view showing surface details (SEM).

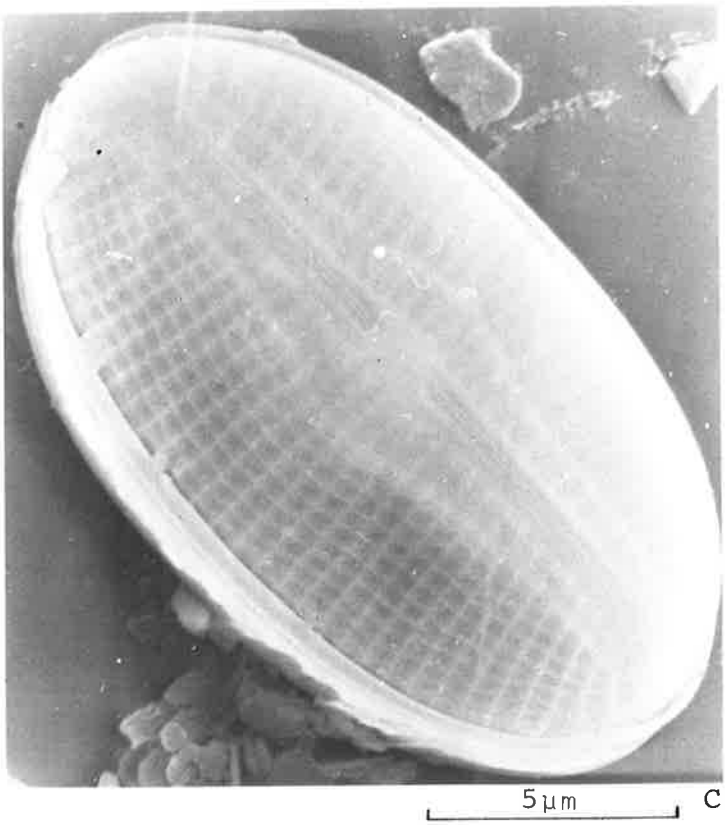
Diploneis ovalis (Hilse *in* Rabenhorst) Cleve

C. Oblique valve view showing surface details (SEM).

D. Valve view of large size form (LM).

FIGURE 32





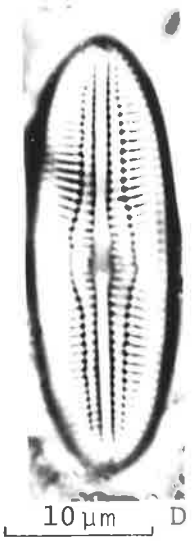


FIGURE 33

Navicula marina Ralfs in Pritchard

A. Valve view (LM).

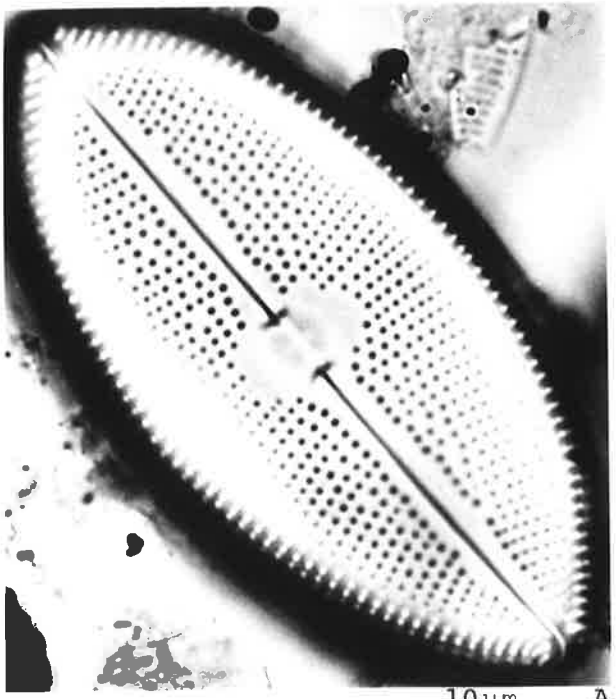
Navicula ramosissima(C.Agardh) Cleve

B. Valve view (LM).

C. Oblique valve view showing surface details (SEM).

D. Close view of valve pole (SEM).

FIGURE 33



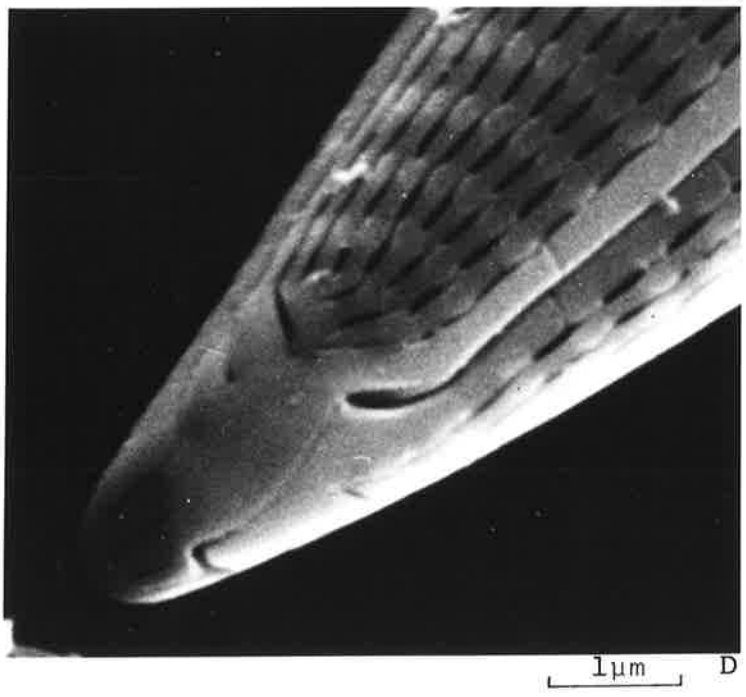


FIGURE 34

Navicula avenacea (Brébisson) Cleve

A. Valve view (LM).

B. Valve view showing structure of striae (SEM).

Navicula digitulus Hustedt

C. Valve view (LM).

Navicula yarrensis Grunow in Schmidt et al.

D. Valve view (LM).

Navicula lyra Ehrenberg

E. Valve view (LM).

Navicula digitoradiata (Gregory) Ralfs in Pritchard

F. valve view (LM).

Navicula species 26

G. Valve view (LM).

Navicula pseudincerta Giffen

H. Valve view showing structure of striae (SEM).

FIGURE 34

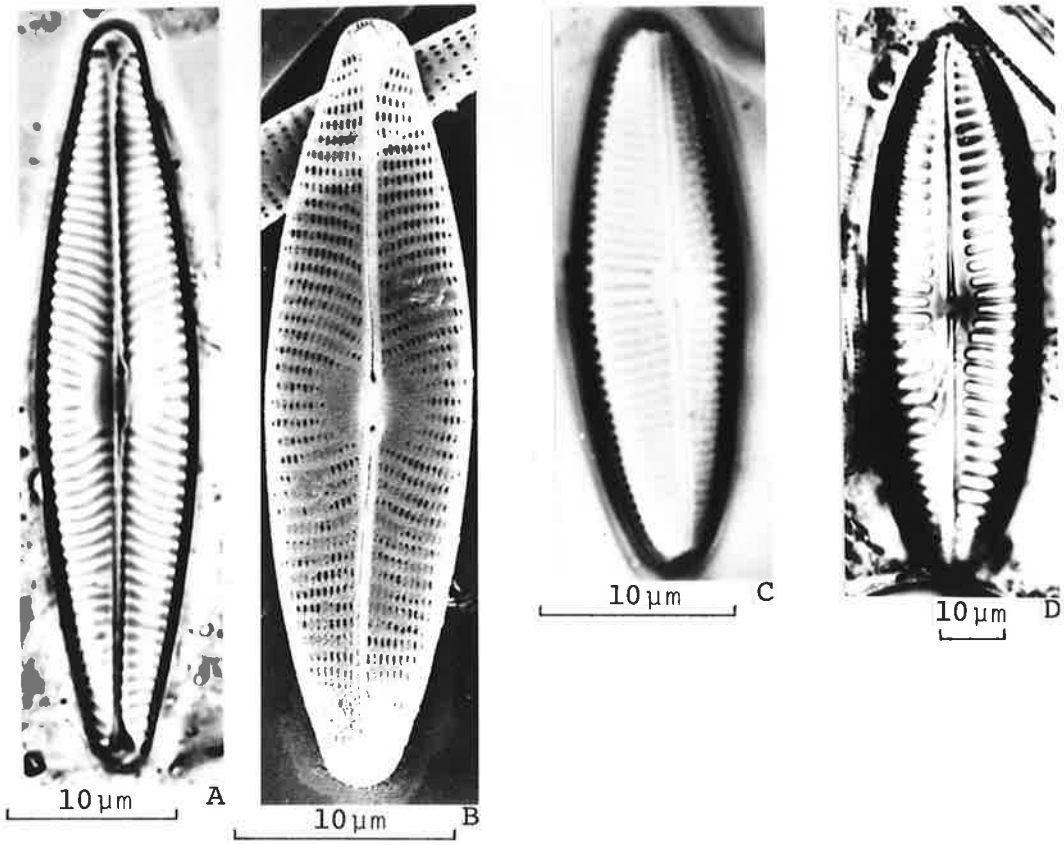


FIGURE 35

Navicula species 31

A. Valve view showing structure of striae (SEM).

Navicula ostrearia (Gaillon) Bory

B. Valve view (LM).

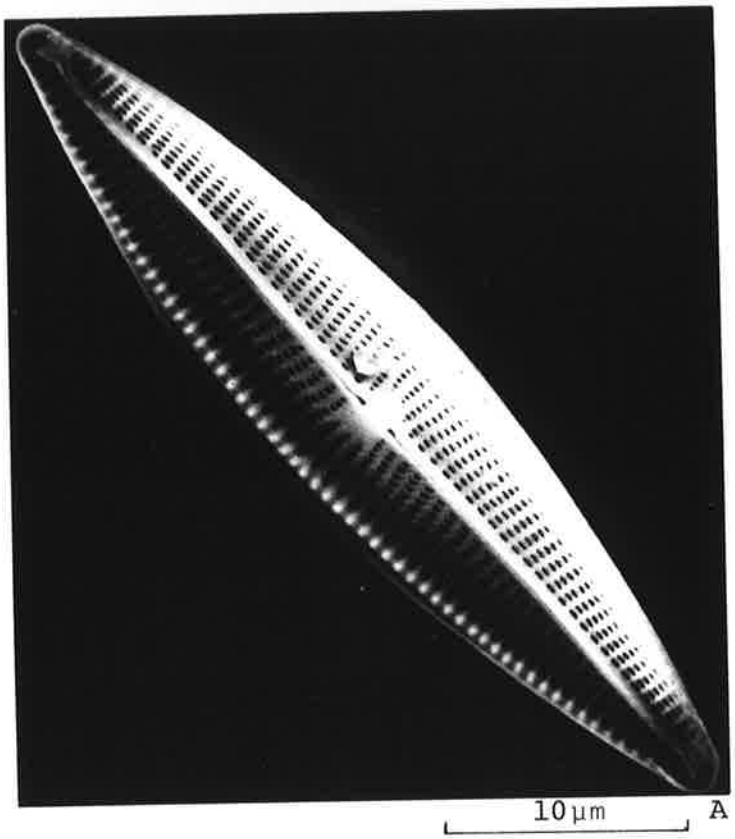
Navicula opuntioides Simonsen

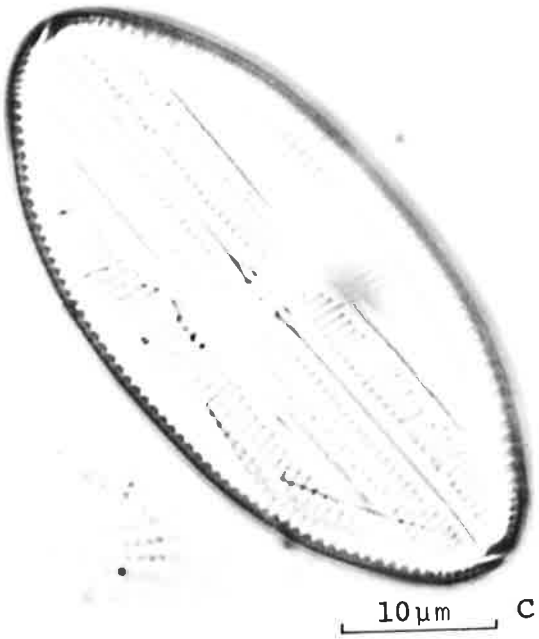
C. Valve view (LM).

Pinnularia borealis Ehrenberg

D. Valve view (LM).

FIGURE 35





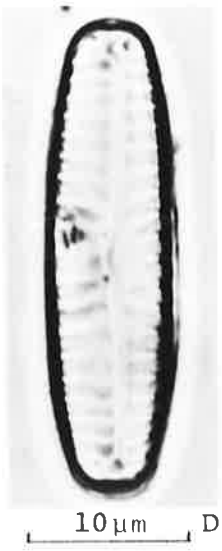


FIGURE 36

Plagiotropis lepidoptera (Gregory) Reimer *in* Patrick & Reimer

A. Girdle view (LM).

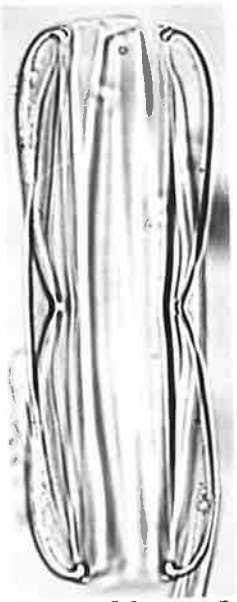
Pleurosigma species 2

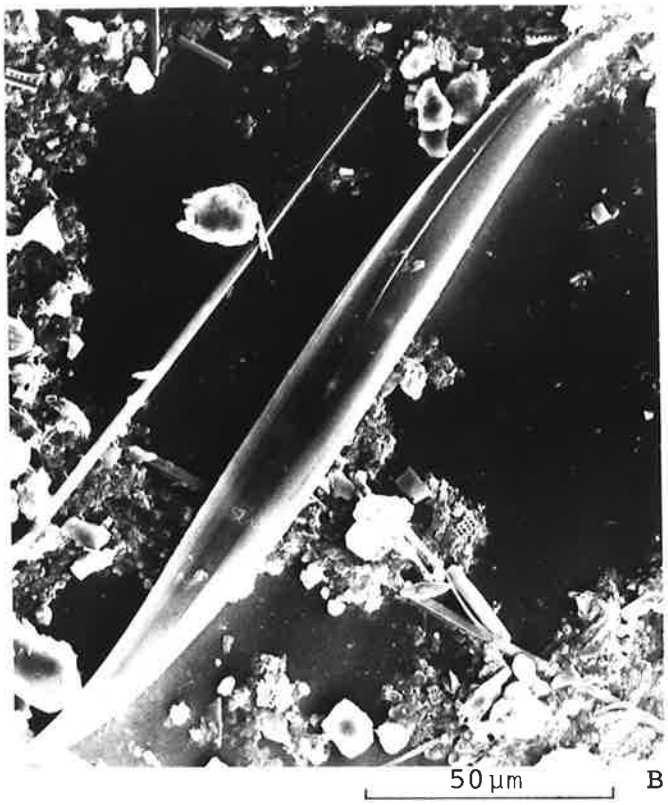
B. Valve view showing valve outline and position (SEM).

C. Close view of central region showing overlapping raphe fissures and distribution of loculate striae (SEM).

D. Close view of valve pole showing curved raphe fissure (SEM).

FIGURE 36





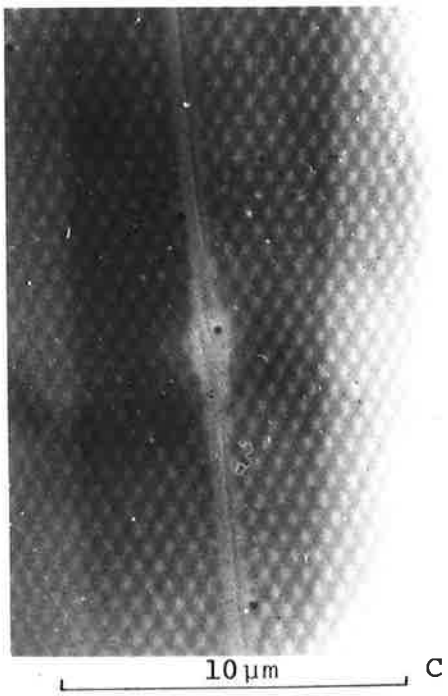


FIGURE 37

Pleurosigma rigidum W. Smith

A. Valve view showing valve outline and position of raphe (LM).

B. Close view of central region showing central area and distribution of punctae.

C. Close view of valve pole showing typical triangulate terminal nodule.

Pleurosigma species 5

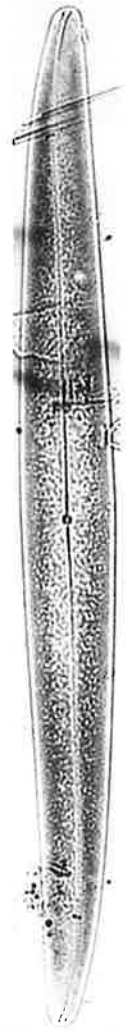
D. Valve view showing valve outline and position of raphe (LM).

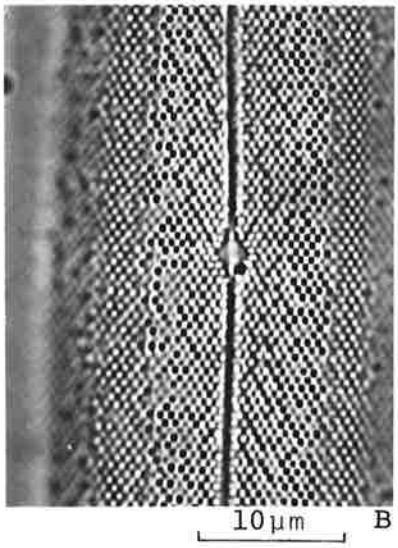
E. Close view of central region showing central area and distribution of punctae (LM).

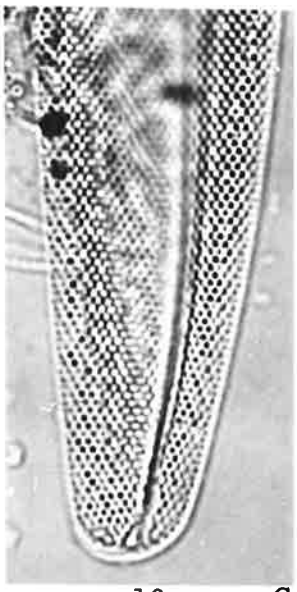
Trachyneis aspera (Ehrenberg) Cleve

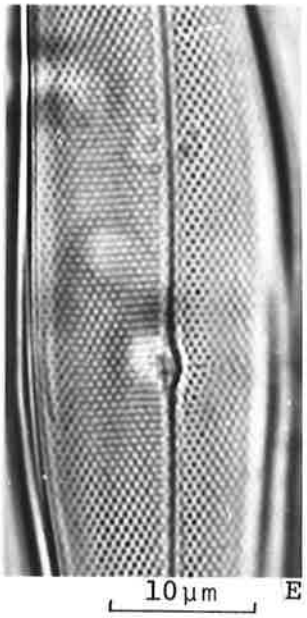
F. Valve view (LM).

FIGURE 37









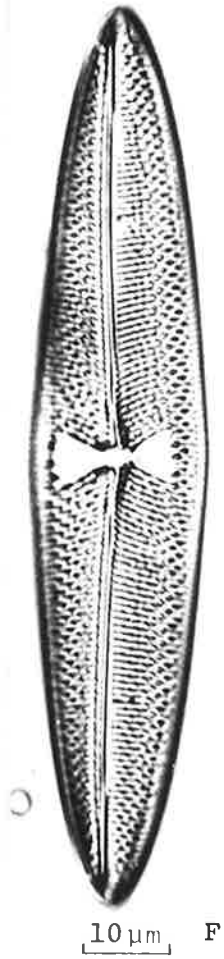


FIGURE 38

Bacillaria paradoxa Gmelin *in* Linnaeus

A. Oblique valve view showing internal details including uneven distribution of fibulae (SEM).

Campylodiscus incertus Schmidt *in* Schmidt *et al.*

B. Valve view (LM).

C. Oblique view showing girdle bands and marginal canal raphe system (SEM).

Campylodiscus daemelianus Grunow *in* Schmidt *et al.*

D. Oblique view showing surface detail and marginal canal raphe system (SEM).

Campylodiscus ralfsii W. Smith

E. Valve view (LM).

FIGURE 38

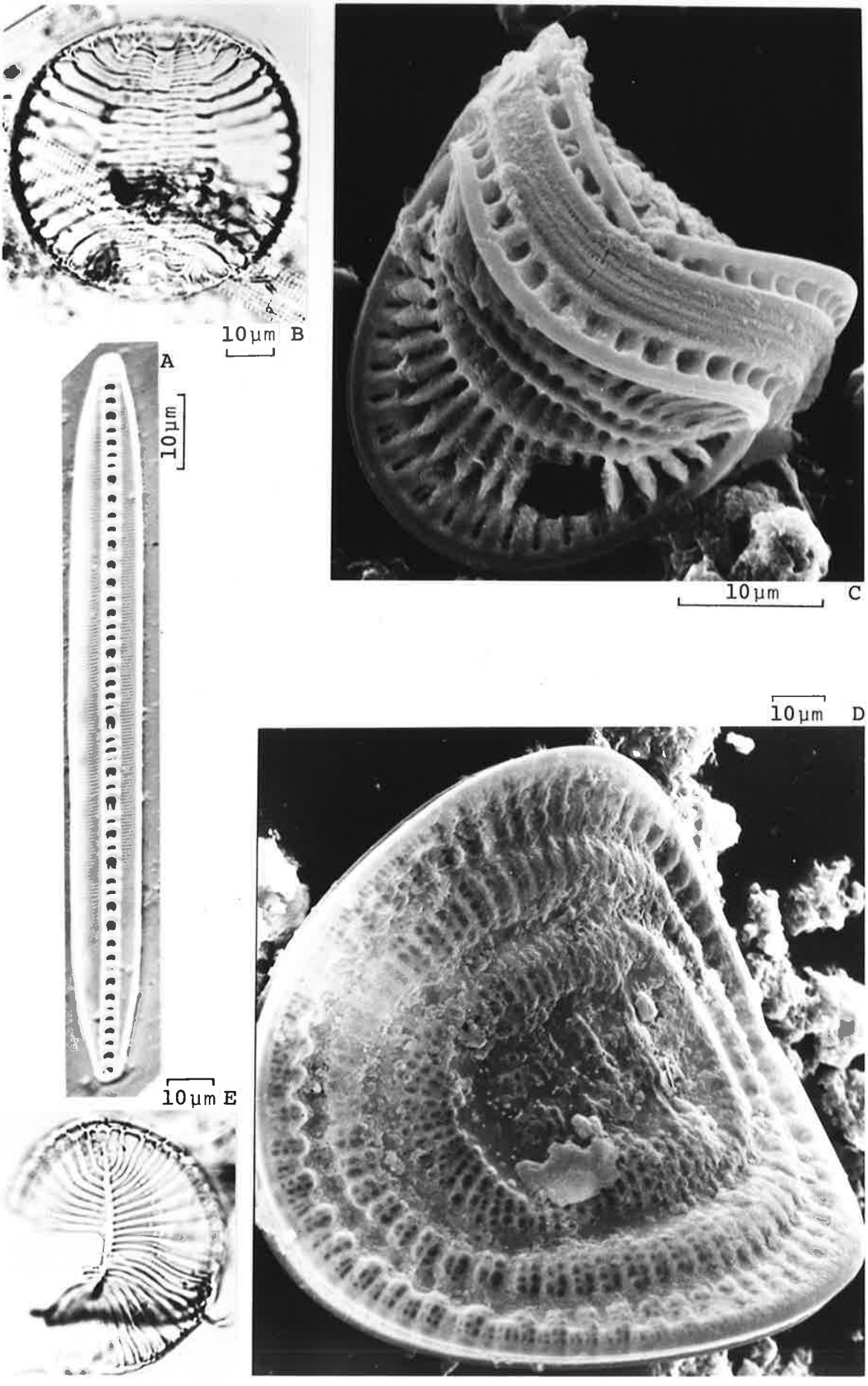


FIGURE 39

Epithemia zebra var. saxonica (Kützing) Grunow

A. Valve view showing position of raphe and arrangement of striae and costae(LM).

B. Valve view showing septum formation (LM).

Nitzschia vidovichii Grunow in Schmidt et al.

C. Girdle view (LM).

D. Valve view (SEM).

Nitzschia constricta Ralfs in Pritchard

E. Oblique view showing distribution of large poroid areolae and marginal raphe on external surface (SEM).

F. Oblique view showing internal valve including distribution of fibulae and the cribra occluding the poroid areolae (SEM).

Nitzschia punctata (W. Smith) Grunow in Cleve & Grunow

G. Valve view (LM).

FIGURE 39

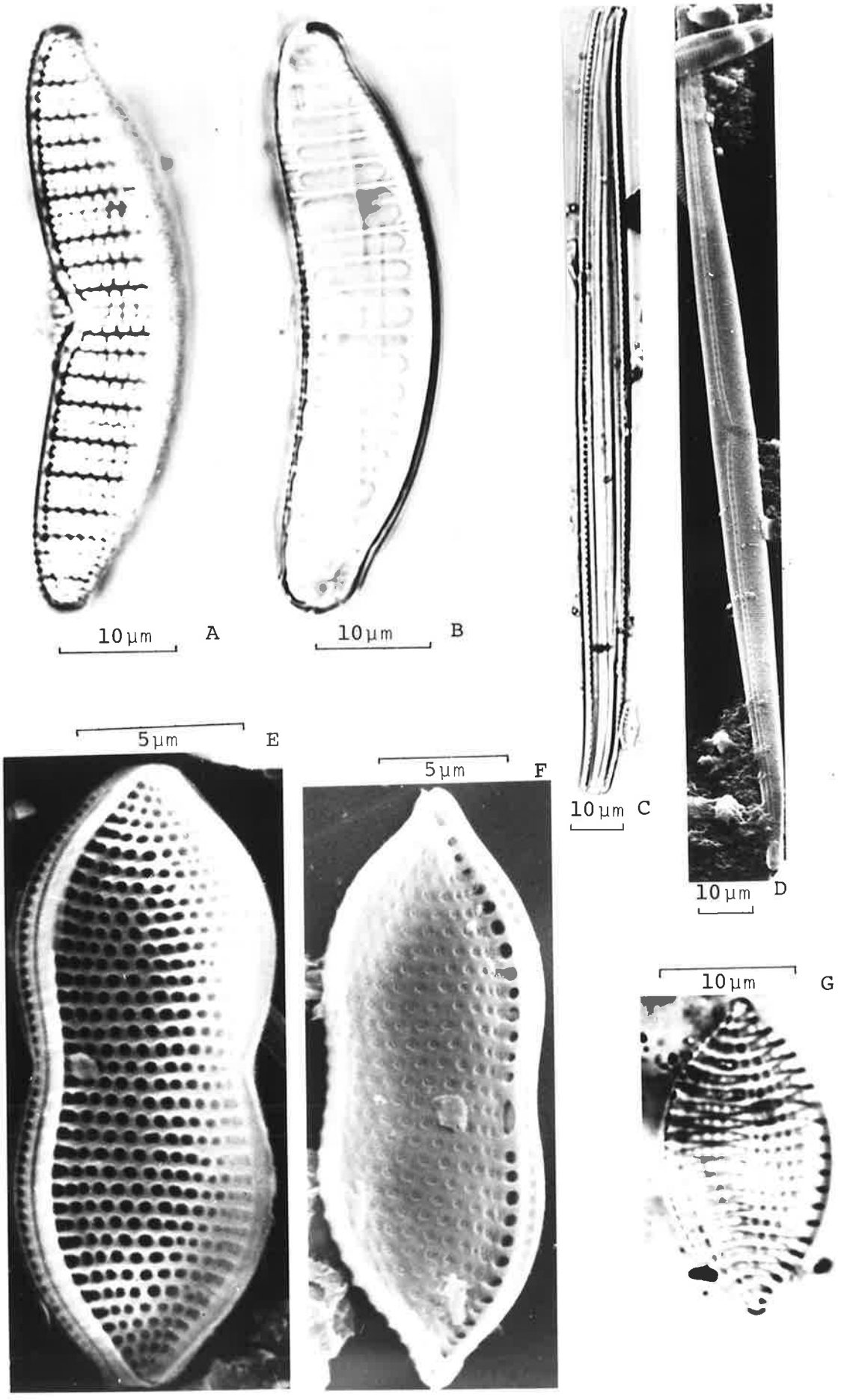


FIGURE 40

Nitzschia fusoides Ehrlich

A. Valve view (LM).

Nitzschia fonticola Grunow in Cleve & Grunow

B. Valve view (LM).

Nitzschia liebethrutii Grunow in Cleve & Grunow

C. Valve view (LM).

Nitzschia obtusa var. scalpelliformis Grunow in Cleve & Grunow

D. Valve view (LM).

Nitzschia species 12

E-H Valve view (LM).

FIGURE 40

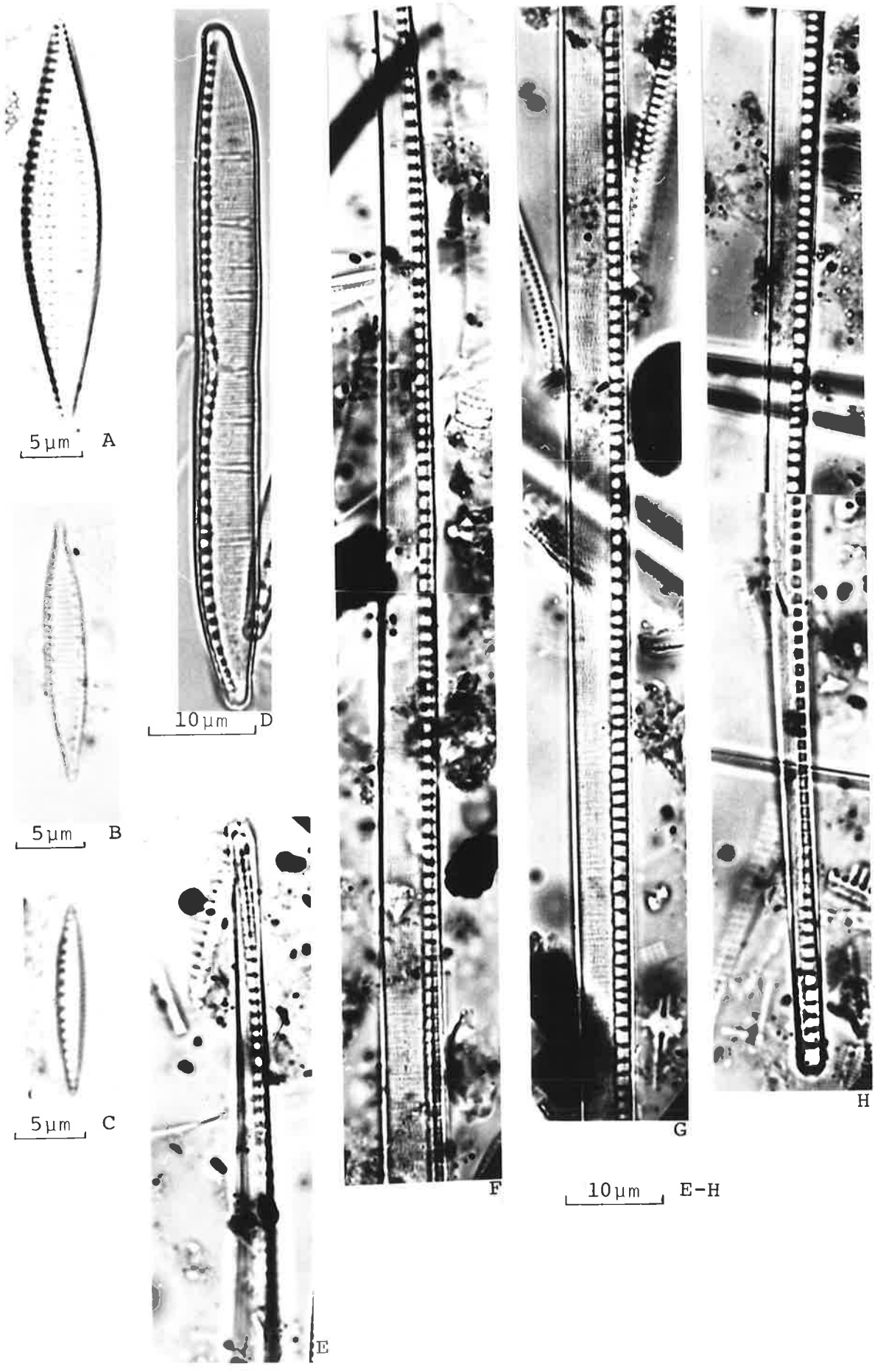


FIGURE 41

Nitzschia clausii Hantzsch in Rabenhorst

A. Valve view (LM).

Nitschia sigma (Kützing) W. Smith

B. Valve view (LM).

Nitzschia sigma var. rigida (Kützing) Grunow.

C. Valve view showing valve outline and raphe position (LM).

D. Close view of central region showing distribution of striae and fibulae (LM).

Nitzschia apiculata (Gregory) Grunow in Cleve & Grunow

E. Valve view (LM).

Nitzschia acuminata (W. Smith) Grunow in Cleve & Grunow

F. Valve view (LM).

FIGURE 41

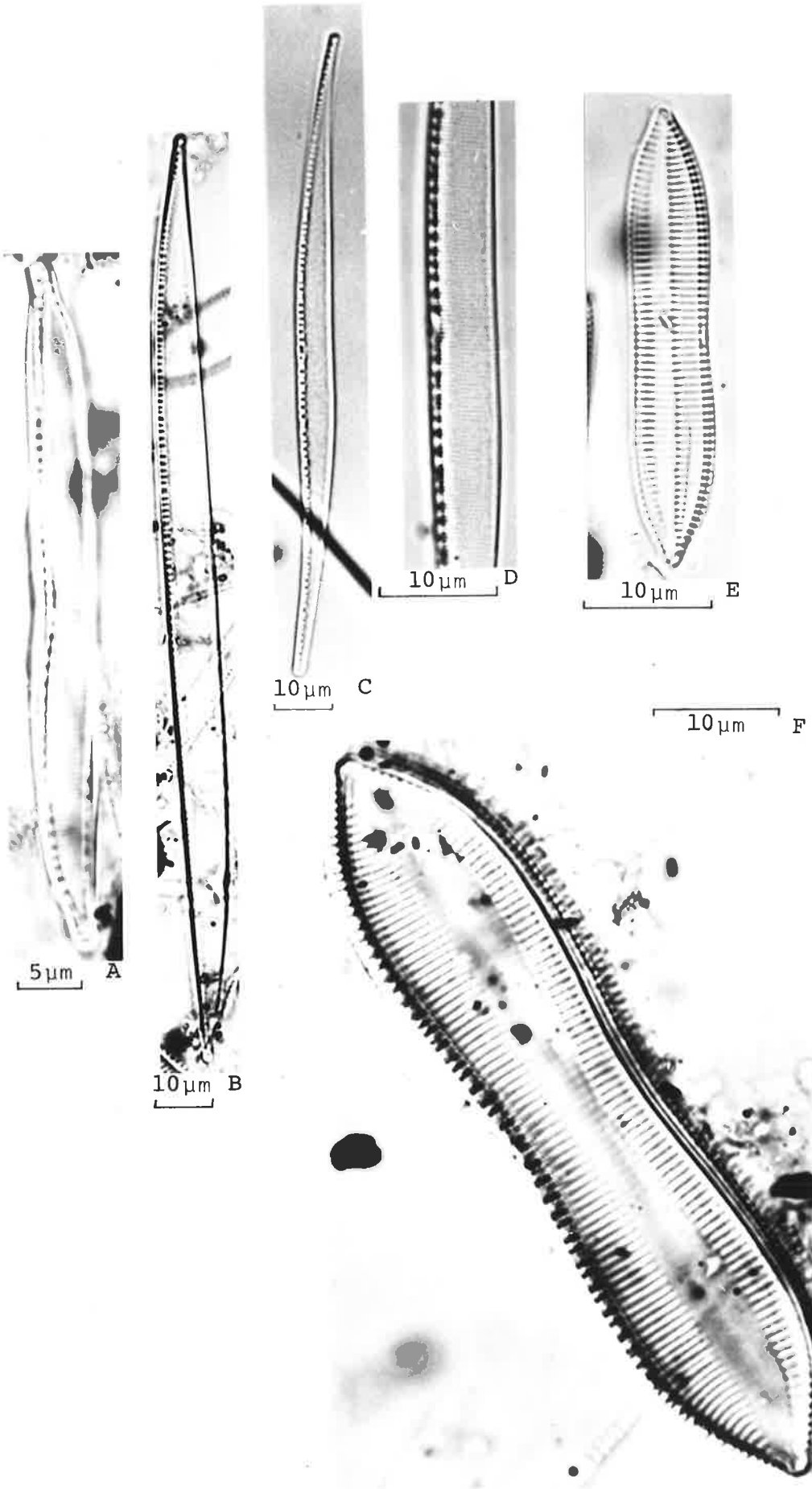


FIGURE 42

Nitzschia obtusa W. Smith

A. Valve view (SEM).

Nitzschia species 34

B. Valve view showing valve outline and position of raphe (LM).

C. Close view of central region showing distribution of striae and fibulae (LM).

Nitzschia distans Gregory

D. Valve view (LM).

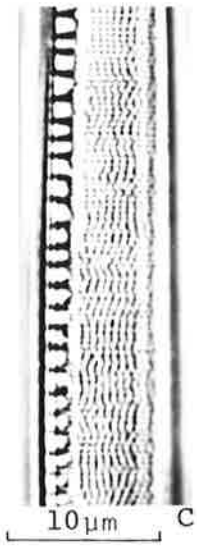
E. Girdle view (LM).

Rhopalodia gibberula var. producta (Grunow) O. Müller

F. Valve view (LM).

G. Oblique view showing surface details (SEM).

FIGURE 42



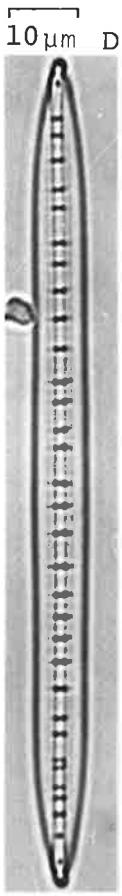


FIGURE 43

Rhopalodia musculus (Kützing) O. Müller

A. Valve view showing poroid areolae with cribra (SEM).

Surirella species 2

B. Valve view (LM).

C. Valve view showing surface details (SEM).

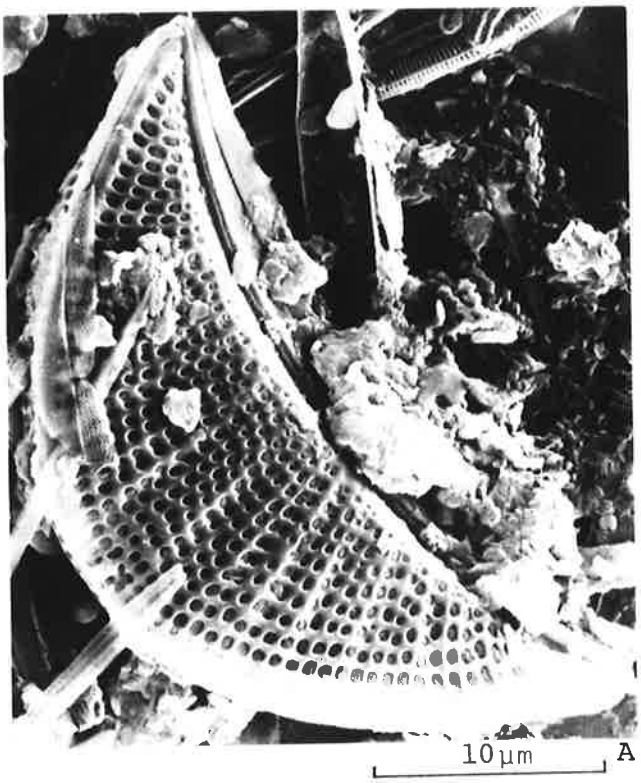
Surirella ovalis Brébisson

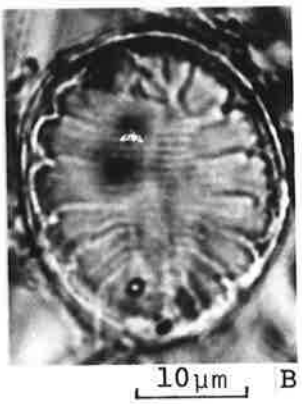
D. Valve view (LM).

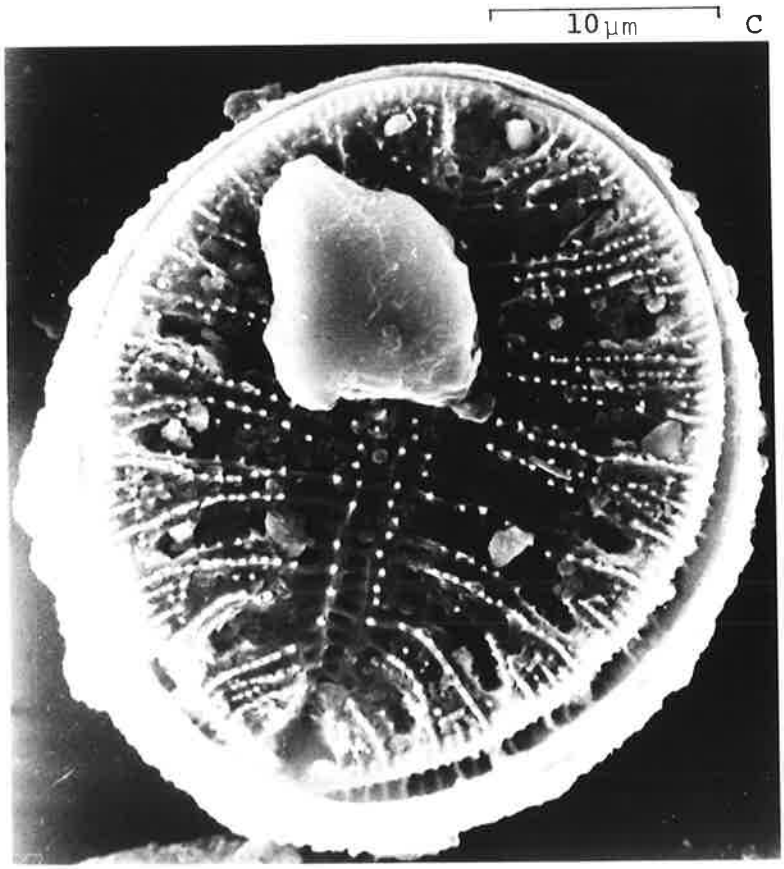
Surirella ovata Kützing

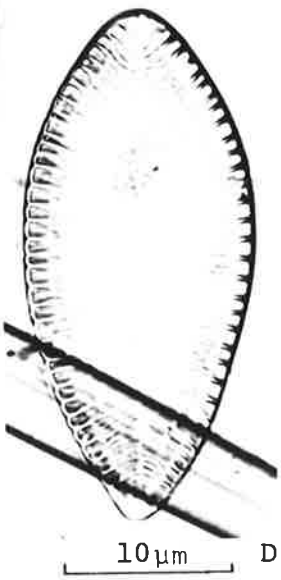
E. Valve view (LM).

FIGURE 43









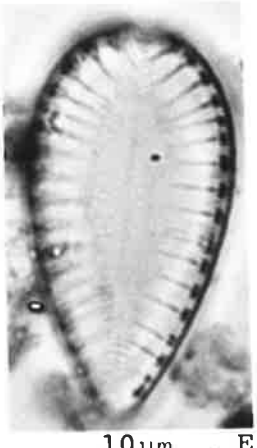
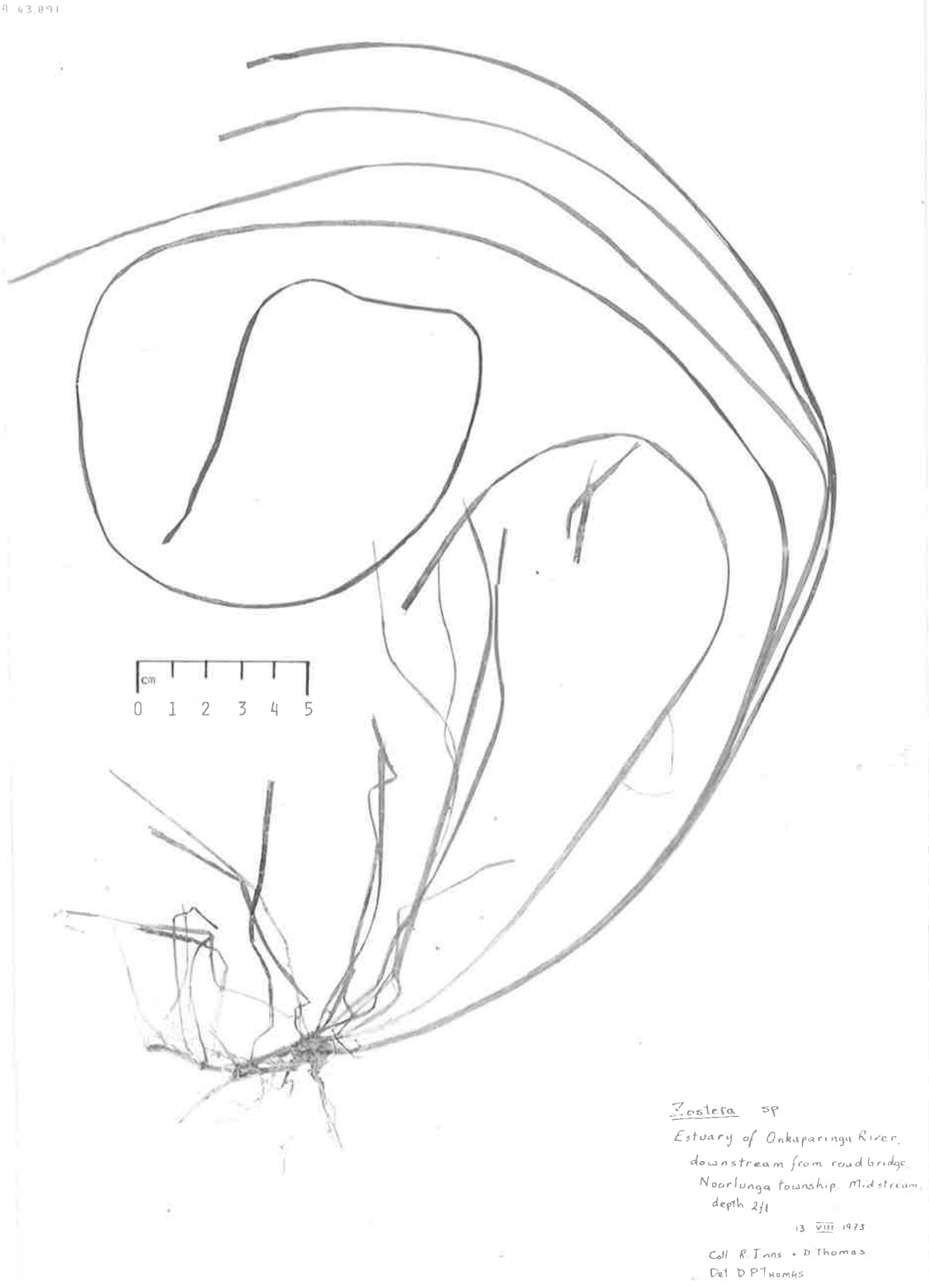


FIGURE 44

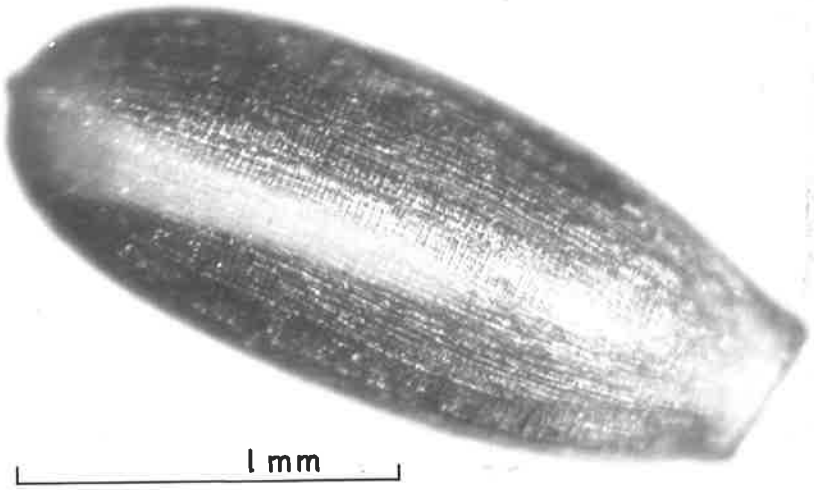


Zostera sp
Estuary of Onkaparinga River,
downstream from road bridge
Noarlunga township. Mid stream
depth 2/1
13 VIII 1973
Coll R Inns + D Thomas
Det D P Thomas

FIGURE 45


A46712
cm
0 1 2 3 4 5
Zostera sp.
Estuary of the Onkaparinga R.
Noarlunga District, South Australia
10km downstream from Noarlunga ford,
near sandhill at Port Noarlunga.
Edge of channel, ca. 25cm. Below MLW
coll. & det. D THOMAS
11-XII-75

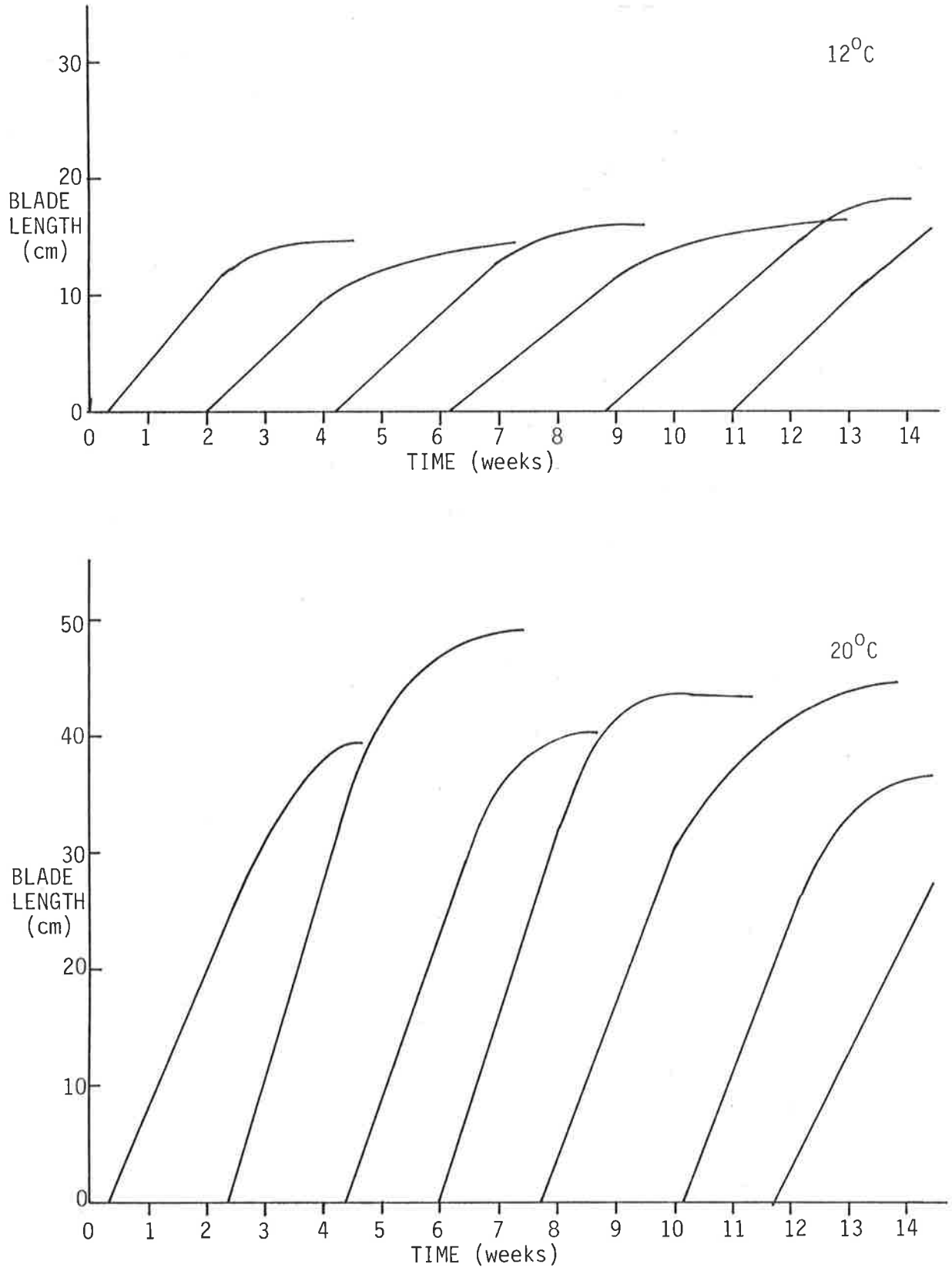
FIGURE 46



Seed of Zostera sp. collected in the Onkaparinga estuary at 10km station, January, 1976.

FIGURE 47

GRAPH OF BLADE LENGTH FROM SHEATH vs TIME FOR SUCCESSIVE BLADES FROM TWO TYPICAL SHOOT APICES GROWING AT DIFFERENT TEMPERATURES



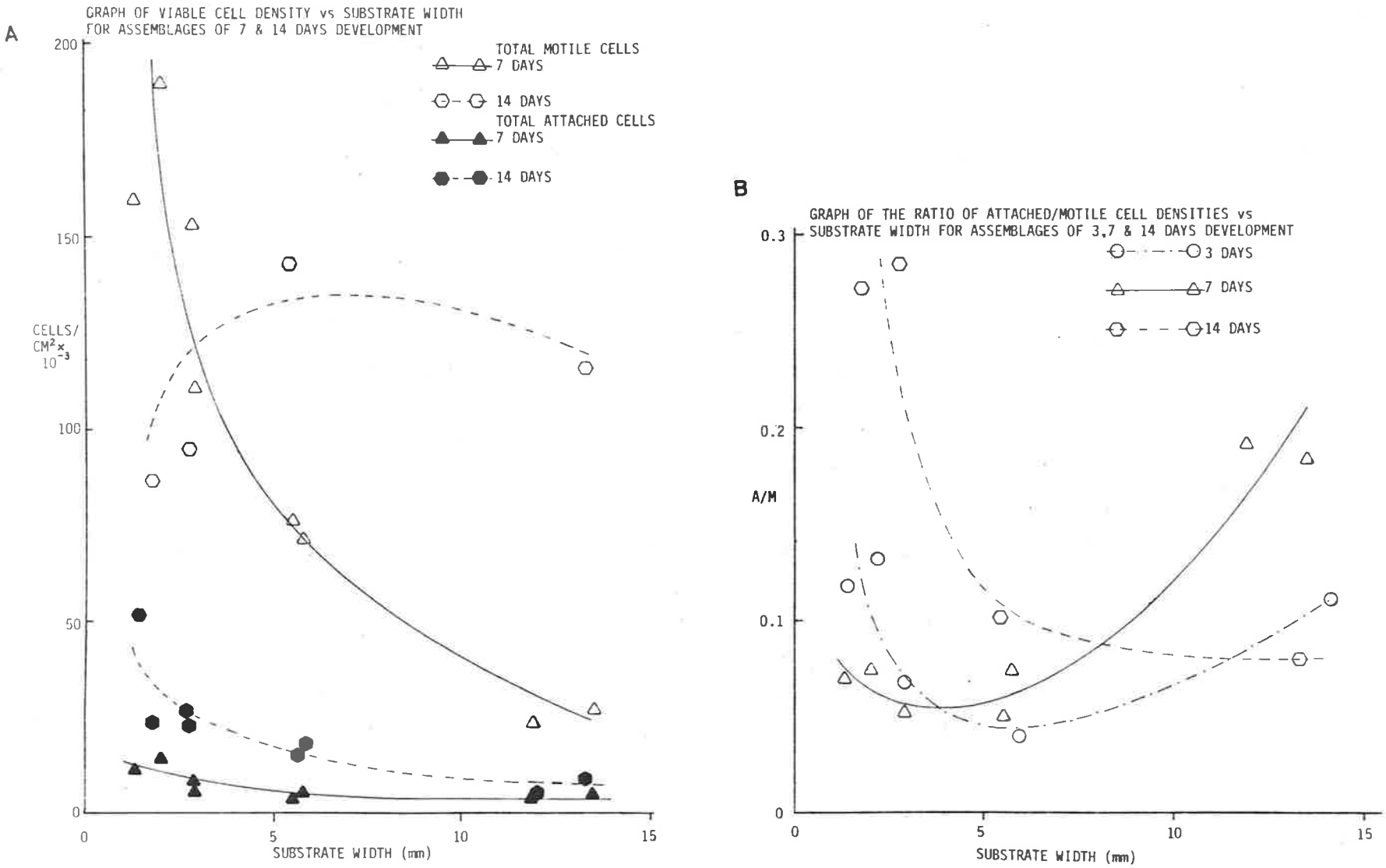

A
GRAPH OF VIABLE CELL DENSITY vs SUBSTRATE WIDTH
FOR ASSEMBLAGES OF 7 & 14 DAYS DEVELOPMENT
TOTAL MOTILE CELLS
7 DAYS
14 DAYS
TOTAL ATTACHED CELLS
7 DAYS
14 DAYS
CELLS/
CM2 x
10-3
200
150
100
50
0
0
5
10
15
SUBSTRATE WIDTH (mm)
B
GRAPH OF THE RATIO OF ATTACHED/MOTILE CELL DENSITIES vs
SUBSTRATE WIDTH FOR ASSEMBLAGES OF 3,7 & 14 DAYS DEVELOPMENT
3 DAYS
7 DAYS
14 DAYS
A/M
0.3
0.2
0.1
0
0
5
10
15
SUBSTRATE WIDTH (mm)

FIGURE 48

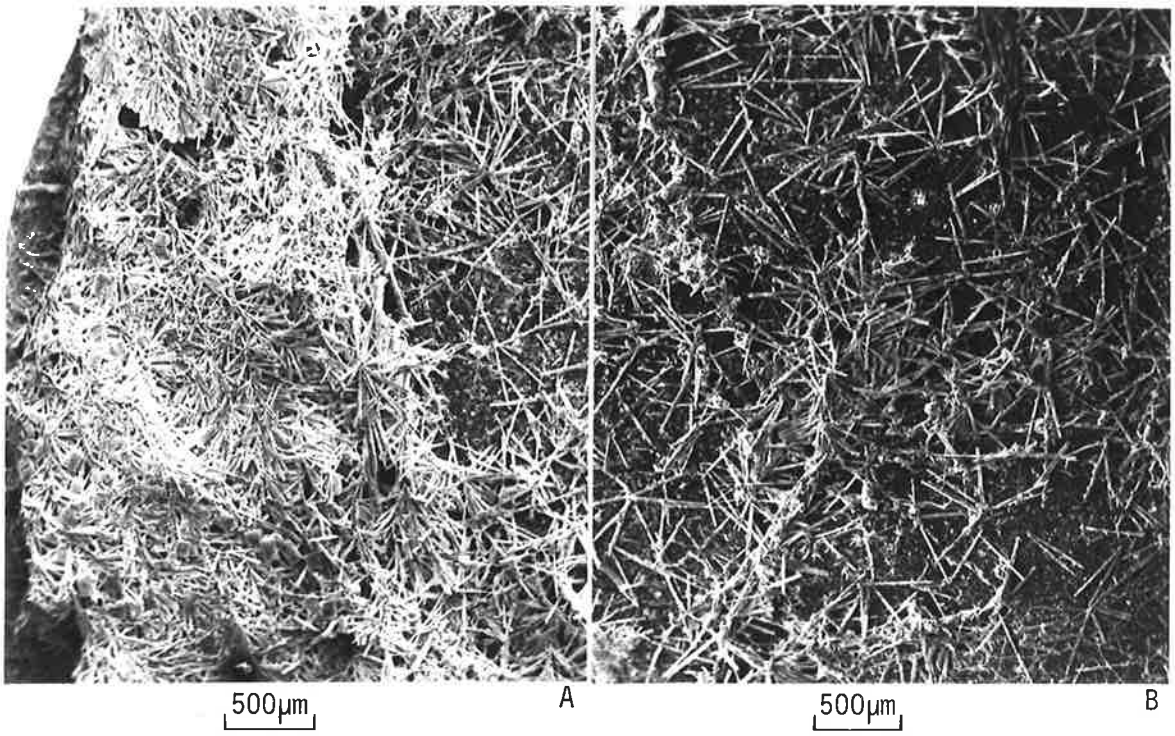
FIGURE 49

A. Left hand edge of 15 mm broad artificial substrate to show concentration of attaching cells near edge (SEM).

B. Centre of the same artificial substrate to show lower cell densities (SEM).

C. Edge of 14 mm broad artificial substrate after 7 days in culture to show concentration of Cocconeis cells, as well as attaching cells, near the edge.

FIGURE 49



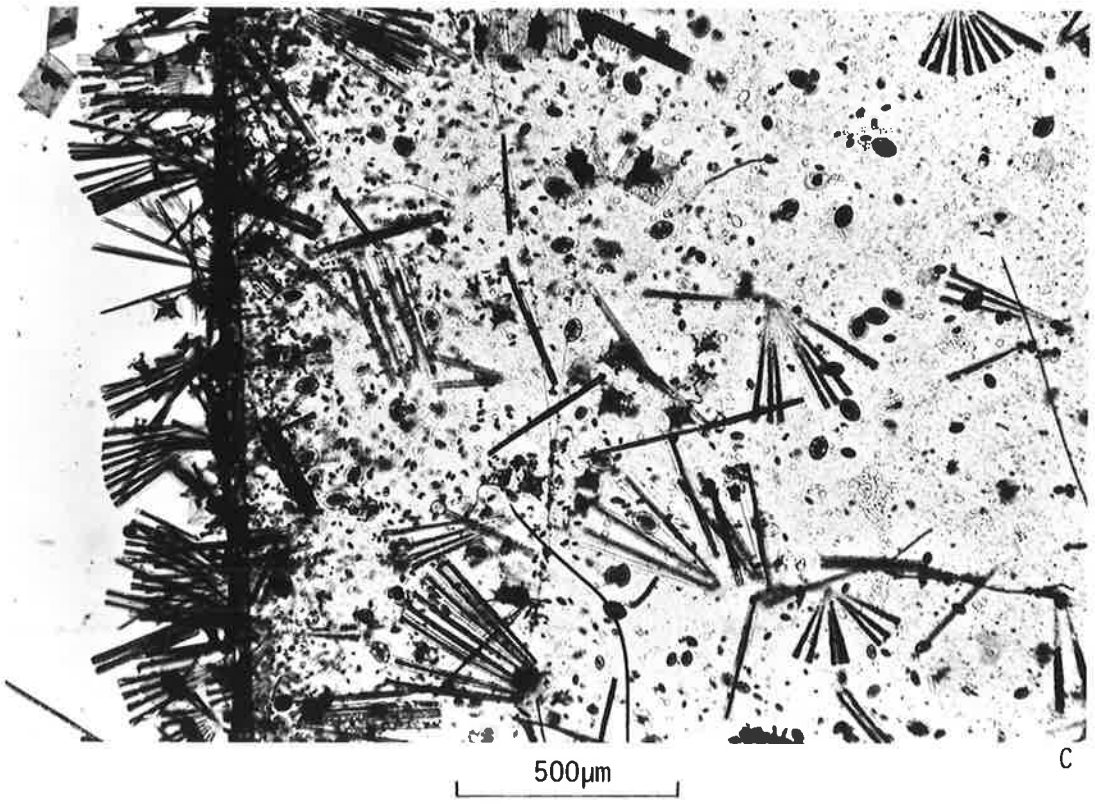


FIGURE 50

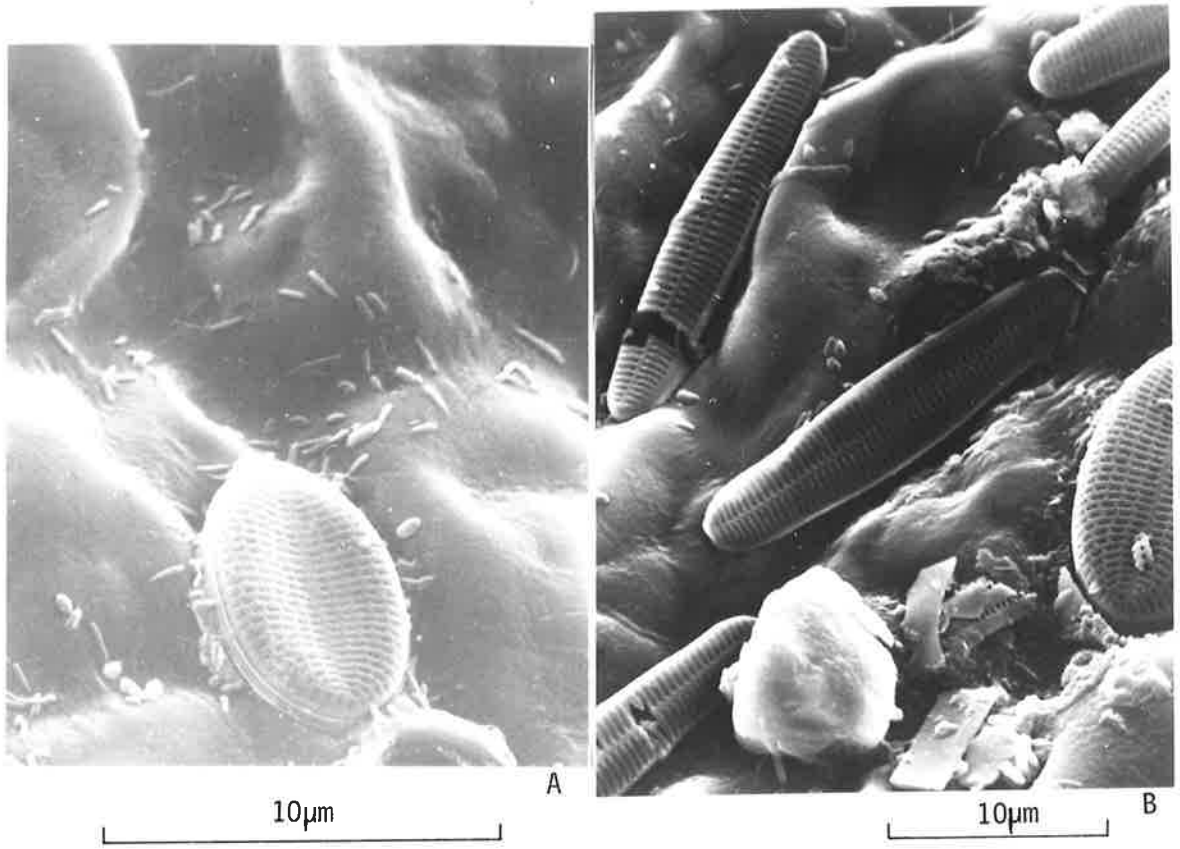
A. Zostera blade surface after 1 day exposure at 2 km station. Note coccoid bacteria and Cocconeis placentula var. euglypta (SEM).

B. Zostera blade surface after 3 days exposure at 2 km station. Note presence of epiphyte species and some detritus (SEM).

C. Zostera blade surface after 5 days exposure at 2 km station. Note presence of variety of epiphyte species and a few motile species. Also clumps of detritus forming near the points of attachment between epiphytes and the blade surface (SEM).

D. Zostera blade surface after 8 days exposure at 2 km station. Note formation of crust containing silt, detritus and periphyton cells (SEM).

FIGURE 50



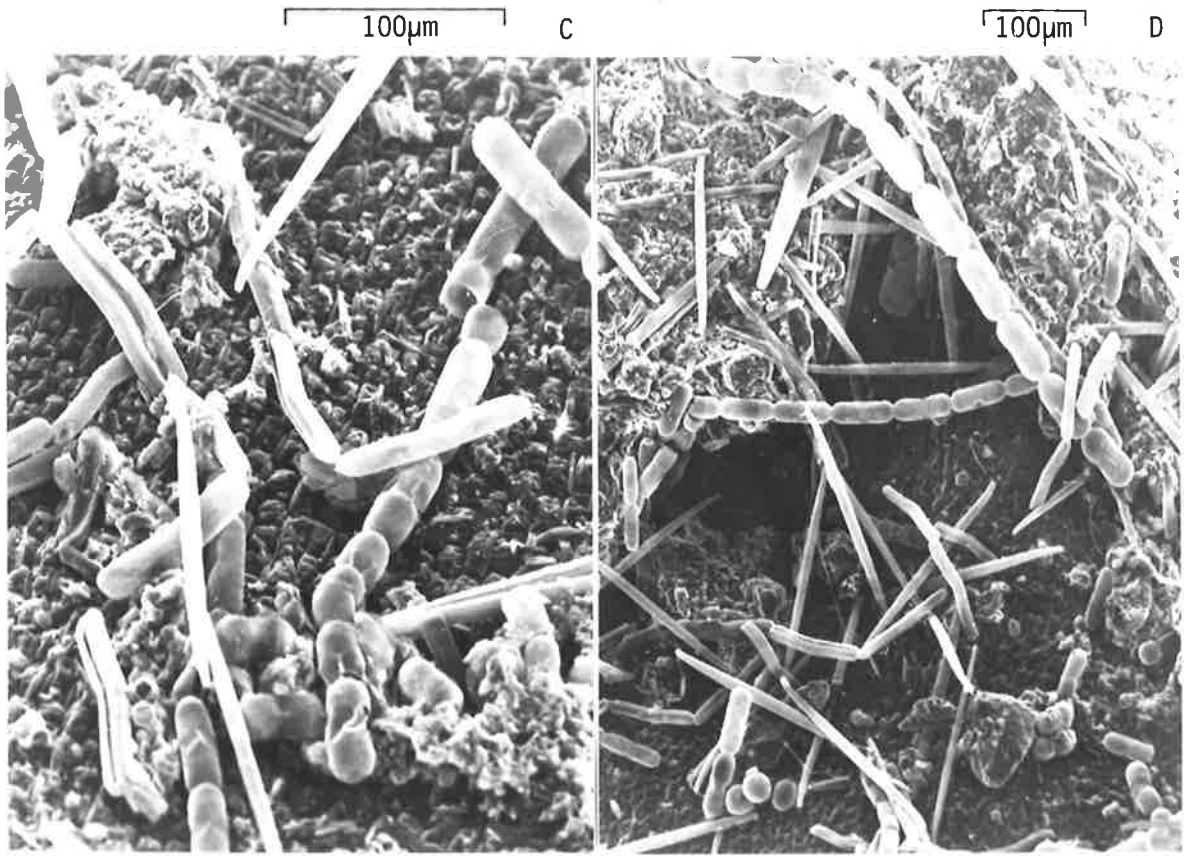


FIGURE 51

A. Zostera blade surface after 14 days exposure at 2 km station. Blade cells totally obscured by a dense mass of periphyton cells, silt and detritus. Note majority of cells on the surface are of motile species (SEM).

B. Zostera blade surface after 3 days exposure at 10 km station. Note presence of Cocconeis pellucida with C. scutellum (SEM).

C. Zostera blade surface after 7 days exposure at 10 km station. Note low density of epiphyte cells and predominance of Cocconeis cells (SEM).

FIGURE 51

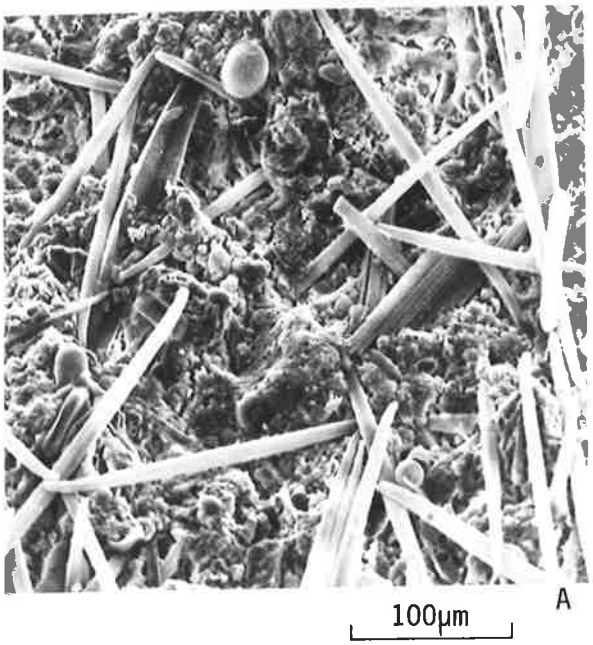


FIGURE 52

Artificial substrate surfaces after incubation in water from either the 2 km or 10 km stations kept at 20°C. Salinities 30.5 p.p.t. and 34.2 p.p.t. respectively.

A. 2 km water, 3 days incubation (LM).

B. 10 km water, 3 days incubation (LM).

C. 2 km water, 7 days incubation (LM).

D. 10 km water, 7 days incubation (LM).

E. 2 km water, 14 days incubation (LM).

F. 10 km water, 14 days incubation (LM).

FIGURE 52

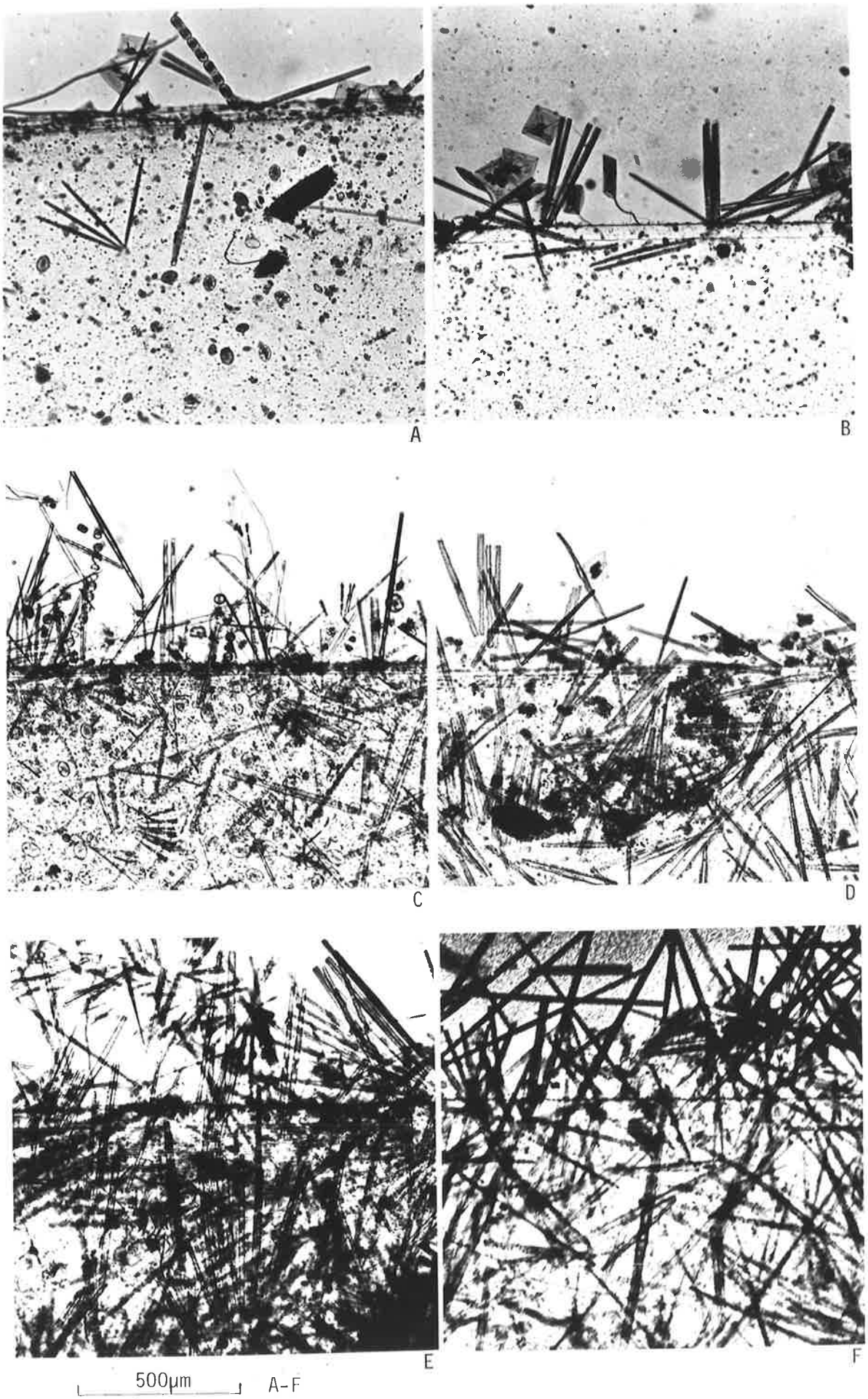


FIGURE 53

Artificial substrate surfaces after incubation in water from either the 2 km or 10 km stations kept at 12°C. Salinities 30.5 p.p.t. and 34.2 p.p.t. respectively.

A. 2 km water, 3 days incubation (LM).

B. 10 km water, 3 days incubation (LM).

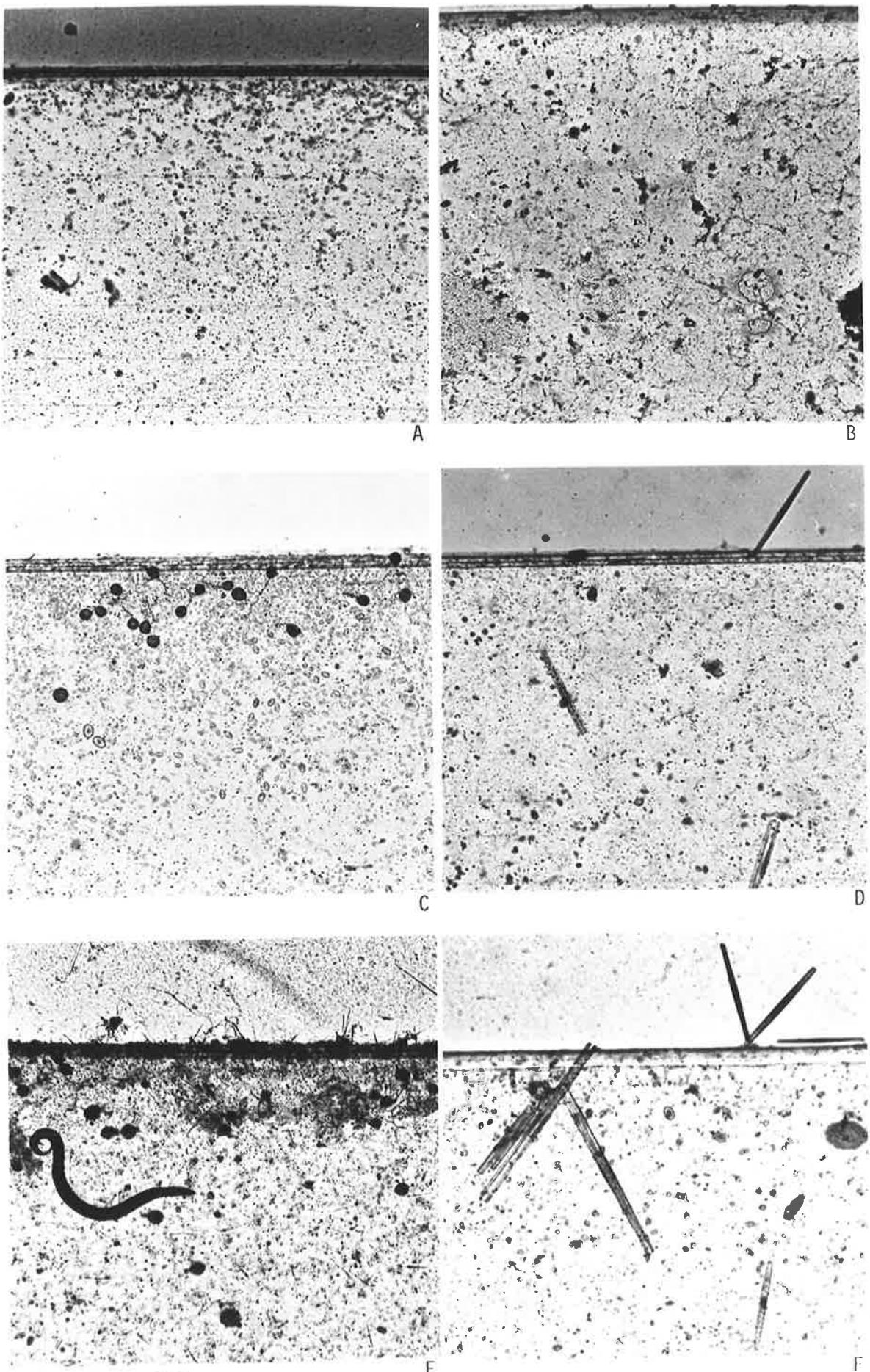
C. 2 km water, 7 days incubation (LM).

D. 10 km water, 7 days incubation (LM).

E. 2 km water, 14 days incubation (LM).

F. 10 km water, 14 days incubation (LM).

FIGURE 53



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

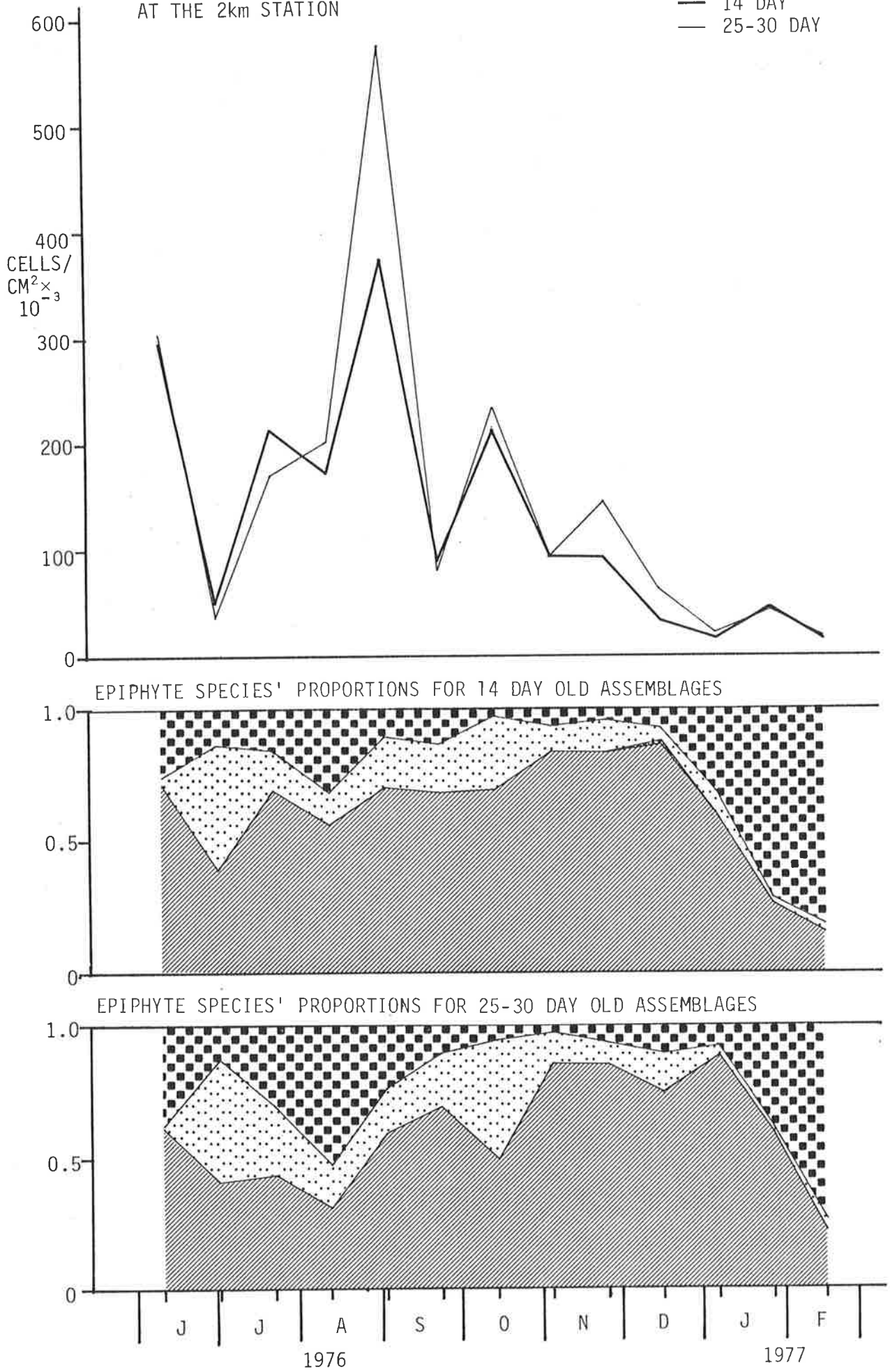
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 54

GRAPH OF TOTAL EPIPHYTE CELL DENSITY vs TIME FOR 14 & 25-30 DAY OLD ASSEMBLAGES AT THE 2km STATION



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

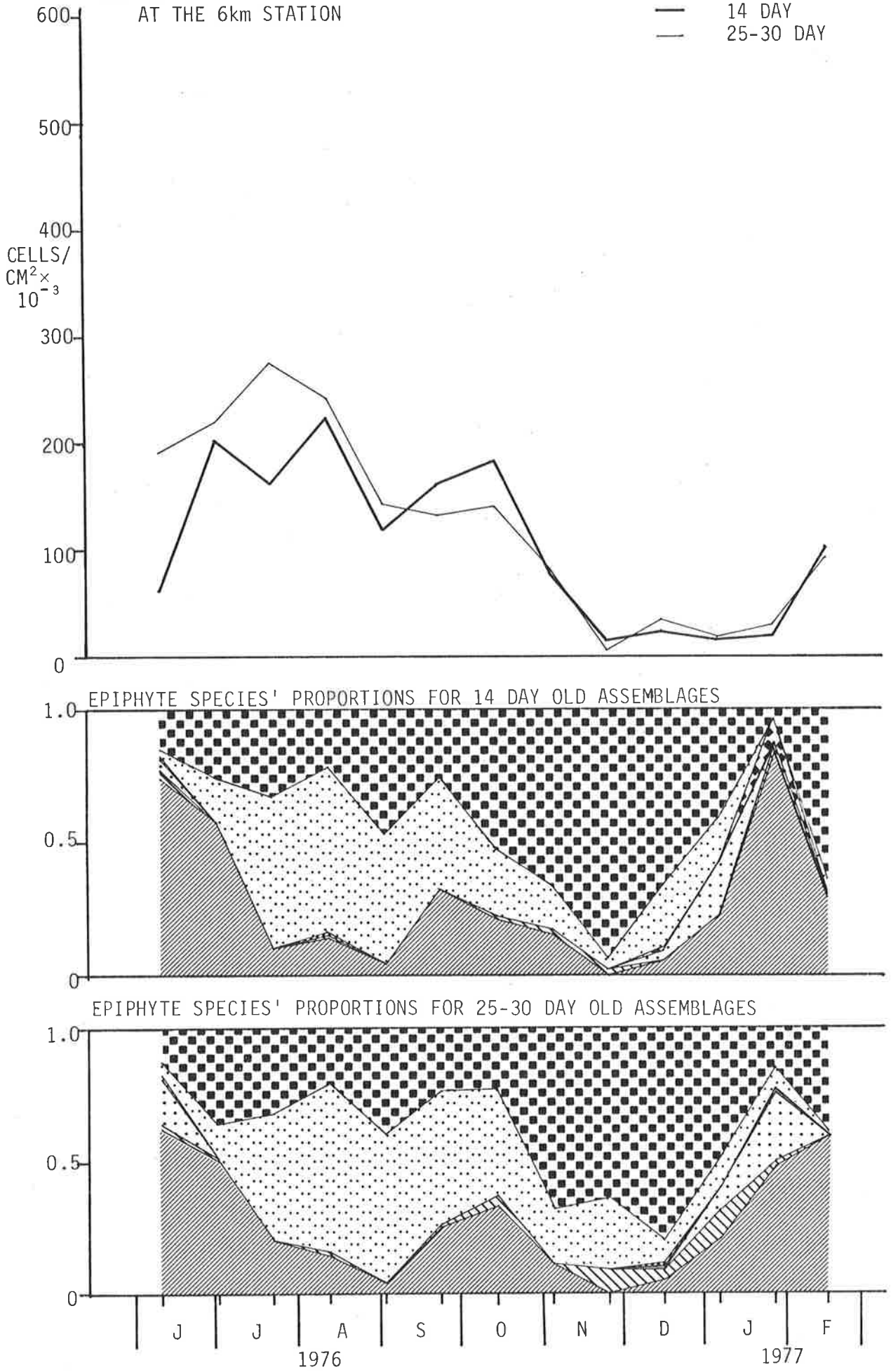
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

GRAPH OF TOTAL EPIPHYTE CELL DENSITY vs TIME FOR 14 & 25-30 DAY OLD ASSEMBLAGES AT THE 6km STATION

FIGURE 55



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

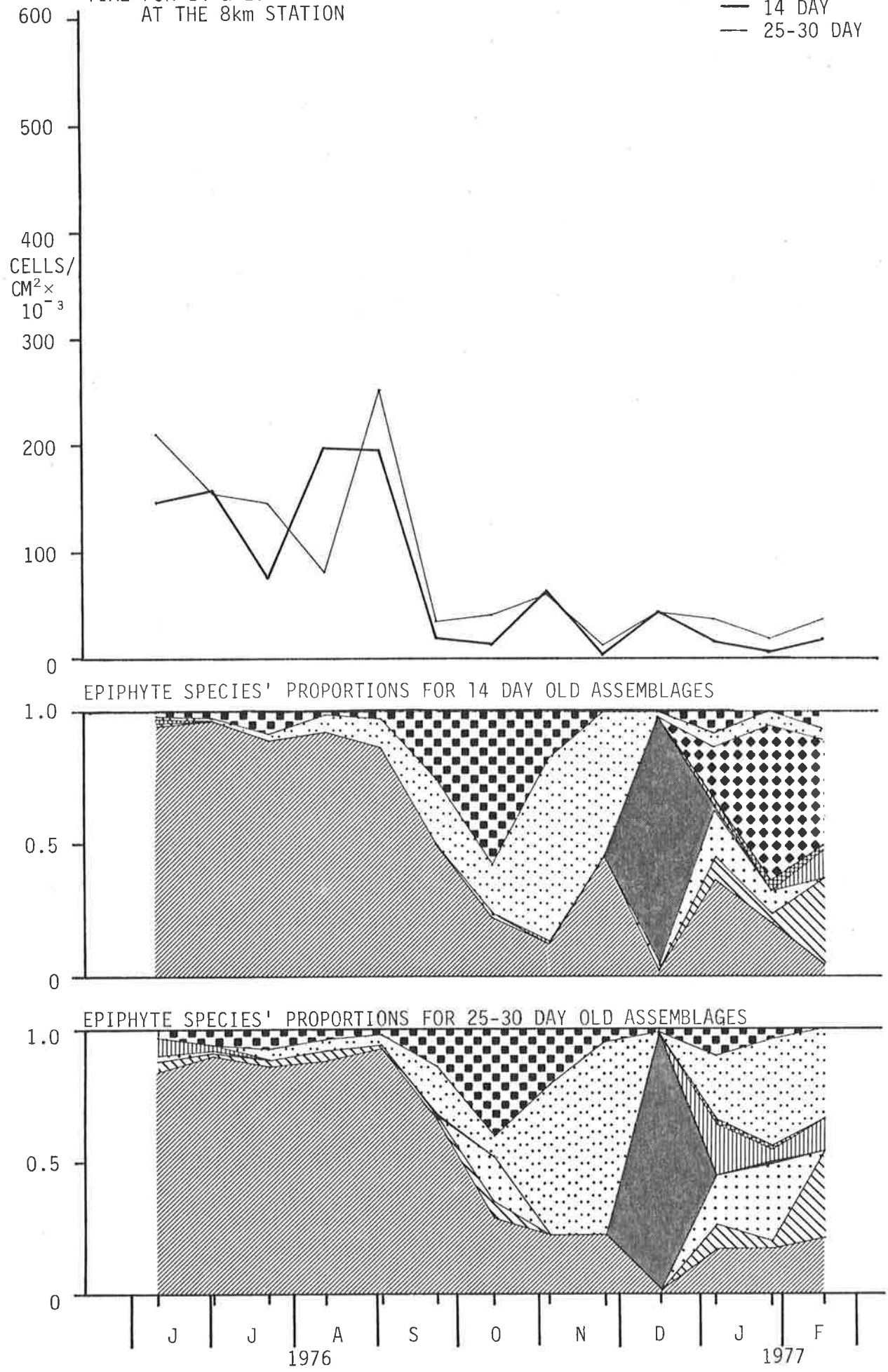
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 56

GRAPH OF TOTAL EPIPHYTE CELL DENSITY vs TIME FOR 14 & 25-30 DAY OLD ASSEMBLAGES AT THE 8km STATION



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

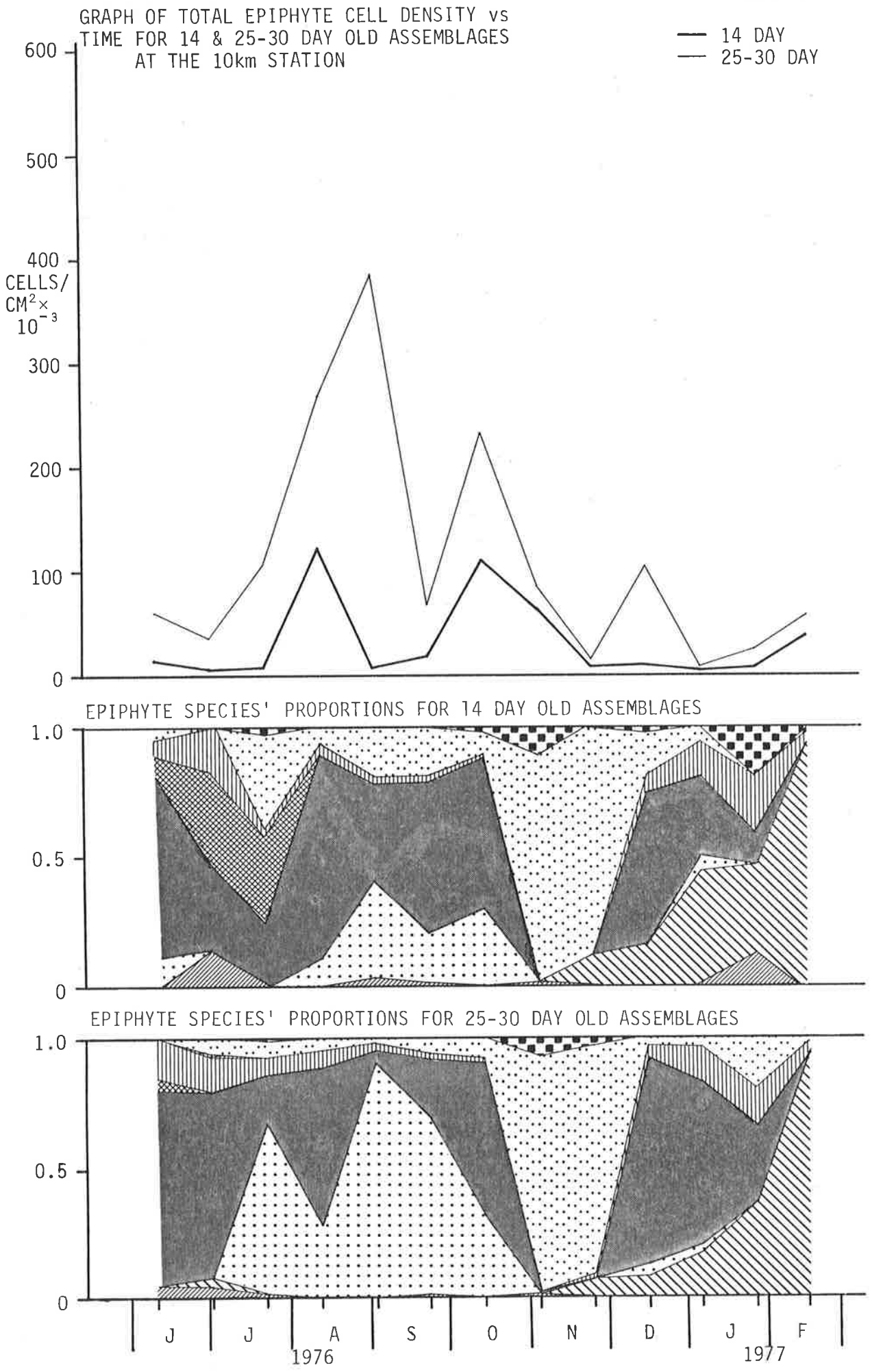
S. tabulata

Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 57


GRAPH OF TOTAL EPIPHYTE CELL DENSITY vs TIME FOR 14 & 25-30 DAY OLD ASSEMBLAGES AT THE 10km STATION
14 DAY
25-30 DAY
600
500
400
CELLS/ CM^2 × 10^{-3}
300
200
100
0
EPIPHYTE SPECIES' PROPORTIONS FOR 14 DAY OLD ASSEMBLAGES
1.0
0.5
0
EPIPHYTE SPECIES' PROPORTIONS FOR 25-30 DAY OLD ASSEMBLAGES
1.0
0.5
0
J
J
A
S
O
N
D
J
F
1976
1977

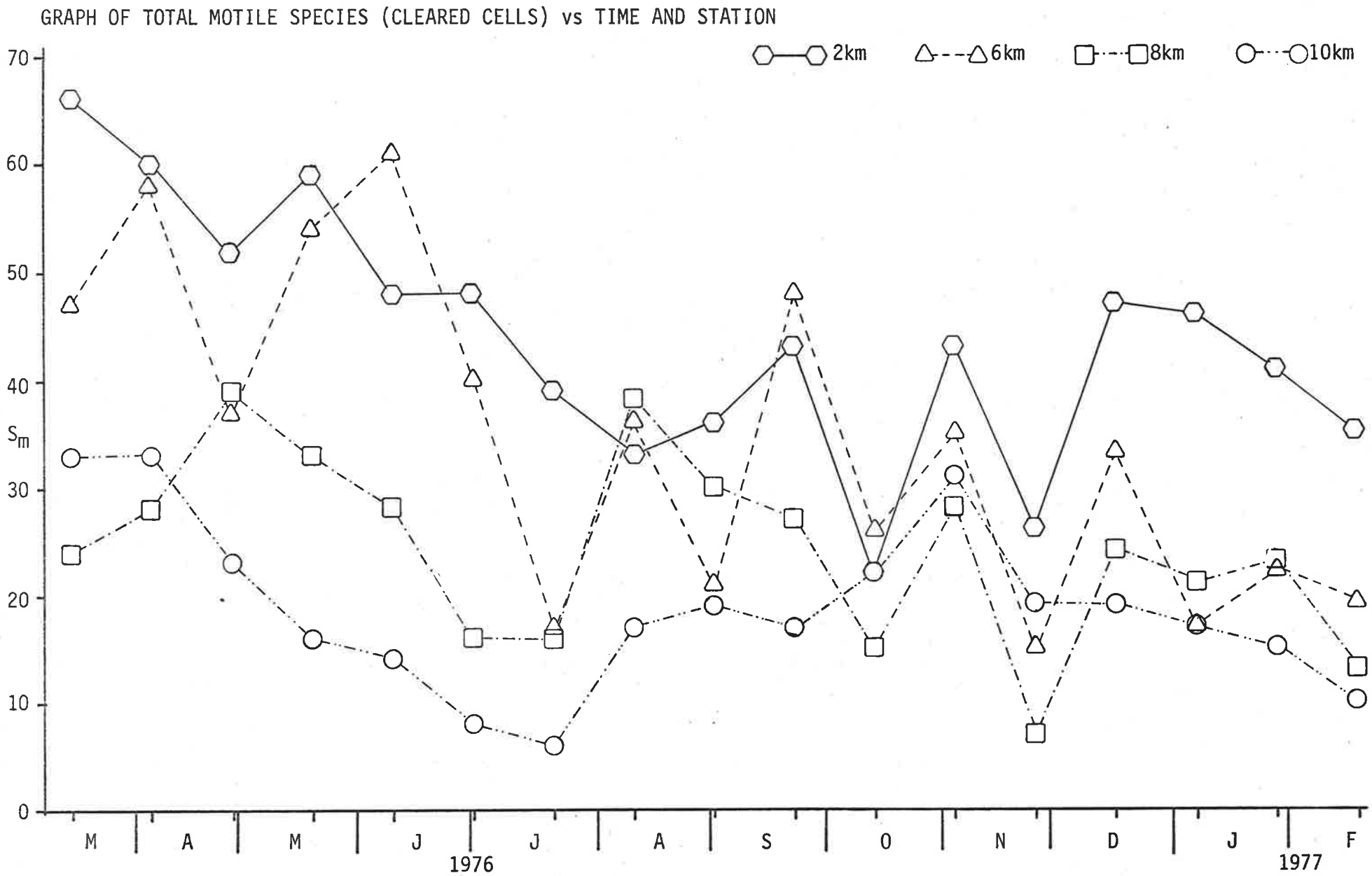

GRAPH OF TOTAL MOTILE SPECIES (CLEARED CELLS) vs TIME AND STATION
2km
6km
8km
10km
70
60
50
40
30
20
10
0
Sm
M
A
M
J
J
A
S
O
N
D
J
F
1976
1977

FIGURE 58

FIGURE 59

No.	Species
3	Melosira varians
4	Dimerogramma minor
5	Fragilaria pinnata
7	Licmophora flabellata
8	L. species 3
11	Plagiogramma staurophorum
12	Rhaphoneis surirella var. australis
13	Striatella unipunctata
14	Synedra pulchella var. lacerata
16	S. laevigata
17	S. fulgens
19	Achnanthes species 1
20	A. species 2
22	Cocconeis placentula var. euglypta
25	C. pellucida
26	C. species 4
27	C. scutellum var. stauroneiformis
28	Rhoicosphaenia curvata
29	Amphiprora species 1
30	A. alata
33	A. coffeaeformis
34	A. species 4
35	A. species 5
36	A. hyalina
38	A. proteus
39	Berkleya rutilans
40	Caloneis excentrica
41	Diploneis abnormis
42	D. smithii var. rhombica
43	D. ovalis
44	Gomphonema constrictum var. capitatum
45	Gyrosigma wansbeckii
47	Mastogloia baldjikiana
48	M. pumila
49	M. species 4
50	M. peragallii
52	Navicula marina
54	N. avenacea
56	N. yarrensis
57	N. lyra
60	N. pseudincerta
64	Pinnularia borealis
66	Pleurosigma species 2
68	P. species 5
70	Bacillaria paradoxa
71	Campylodiscus incertus
72	C. daemelianus
73	C. ralfsii
74	Epithemia zebra var. saxonica
76	Nitzschia constricta
77	N. punctata
78	N. fusoides
79	N. fonticola
80	N. leibethrutii
82	N. species 12
84	N. sigma
86	N. acuminata
87	N. apiculata
90	N. distans
91	Rhopalodia gibberula var. producta
92	R. musculus
93	Surirella species 2
94	S. ovalis

FIGURE 59

CORRELATION MATRIX OF THE 64 MOST SIGNIFICANT SPECIES' CORRELATIONS ACCORDING TO "LANGE3", FROM THE 95 MOST COMMON SPECIES

KEY:

Code	Range
0=	P>0.05
1=	0.05 >P>0.01
2=	10^{-2} >P> 10^{-3}
3=	10^{-3} >P> 10^{-5}
4=	10^{-5} >P> 10^{-9}
5=	10^{-9} >P> 10^{-17}
6=	10^{-17} >P> 10^{-33}

GROUP II, GROUP III, GROUP IV, GROUP V

	68	39	34	25	11	4	8	16	50	49	27	36	12	13	7
39	-1
34	0	3
25	-3	3	2
11	0	0	0	0
4	0	0	0	0	4
8	0	1	0	0	0	3
16	0	0	1	0	0	0	0
50	0	0	0	2	1	0	0	2
49	0	0	0	0	0	0	0	4	3
27	0	0	0	0	0	0	1	0	0	0
36	0	0	0	0	0	1	1	0	0	0	0
12	0	0	0	0	0	0	1	0	0	0	1	1
13	0	0	0	0	0	0	1	0	0	0	1	2	2
7	0	0	0	1	1	0	1	0	0	0	0	3	1	3
17	0	0	0	0	1	0	1	0	0	0	2	1	6	3	2

GROUP I

	3	5	14	19	20	22	28	29	30	33	38	40	41	42	43	45	48	52	54	56	57	60	64	66
5	1
14	0	5
19	2	3	2
20	2	2	2	1
22	0	1	0	1	1
28	3	4	2	4	2	0
29	2	2	2	2	0	0	2
30	1	3	3	2	0	0	2	2
33	0	1	1	0	2	3	1	0	0
38	0	0	0	0	0	1	0	0	2	0
40	0	0	0	0	0	0	0	0	2	0	0
41	1	1	0	3	0	0	1	1	4	0	4	3
42	0	0	0	0	0	0	0	0	3	0	0	3	1
43	1	1	0	3	0	1	1	1	4	0	2	2	5	1
45	4	1	0	1	2	0	2	2	1	0	0	1	2	0	2
48	0	0	1	2	0	1	0	0	0	1	0	0	0	0	1	1
52	1	2	1	4	2	0	5	1	4	2	1	1	3	0	1	2	0
54	1	2	3	0	1	0	2	1	1	3	0	0	1	0	2	2	0	1
56	0	1	1	2	1	3	2	0	4	2	3	2	4	1	2	0	0	6	0
57	1	0	1	1	3	0	1	0	2	0	0	2	3	1	4	2	0	2	0	3
60	2	3	3	2	2	0	1	1	5	1	0	1	3	2	4	2	0	1	3	2	3
64	0	1	1	1	0	1	0	3	2	2	0	0	2	0	4	1	0	2	1	2	1	2
66	2	1	1	1	1	0	2	3	1	1	1	0	2	0	2	4	0	3	3	3	0	1	2
70	1	3	4	3	2	0	3	1	1	0	0	0	1	1	2	1	1	1	1	0	3	1	2	2
71	2	1	2	4	0	0	1	1	2	0	0	2	2	2	4	2	1	3	2	2	4	3	2	2
72	2	1	0	3	0	0	2	0	3	0	0	1	5	0	2	1	0	6	0	5	1	0	3	1
73	0	0	0	1	0	0	0	0	4	0	2	2	6	1	3	0	0	3	0	4	3	2	4	0
74	2	4	1	3	1	0	3	0	3	0	0	1	4	2	2	0	0	3	0	4	3	3	0	1
76	2	0	1	1	0	0	0	0	3	1	4	2	5	1	4	3	3	3	1	3	4	2	0	2
77	2	5	2	2	4	0	3	2	4	0	0	0	2	0	2	2	0	3	2	3	1	2	1	2
78	3	2	3	6	1	0	3	3	3	0	1	1	3	0	4	2	3	3	2	2	3	5	2	0
80	2	3	3	2	0	0	3	2	2	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0
82	0	1	2	0	0	0	0	2	1	0	1	1	0	0	0	2	0	0	2	0	1	3	1	2
84	0	0	1	0	0	2	0	0	3	2	3	2	2	0	2	0	0	1	3	4	1	2	2	0
86	2	2	0	0	1	0	0	1	4	1	0	0	1	2	2	3	0	2	0	2	2	4	2	0
87	0	1	0	3	0	3	0	0	3	0	2	0	3	0	2	0	0	2	0	6	2	0	2	0
91	2	3	3	2	0	1	0	2	4	0	0	0	1	0	2	0	2	0	0	3	2	3	1	0
92	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	3	2	0	1	3	1	0	0
26	3	0	0	1	1	0	2	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
35	0	0	0	2	1	0	1	0	0	0	0	0	1	0	1	2	3	0	0	0	1	0	0	0
44	3	1	0	1	1	0	1	0	2	0	0	0	0	0	2	1	0	0	0	0	1	1	0	0
47	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0
79	0	2	2	2	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2
90	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0
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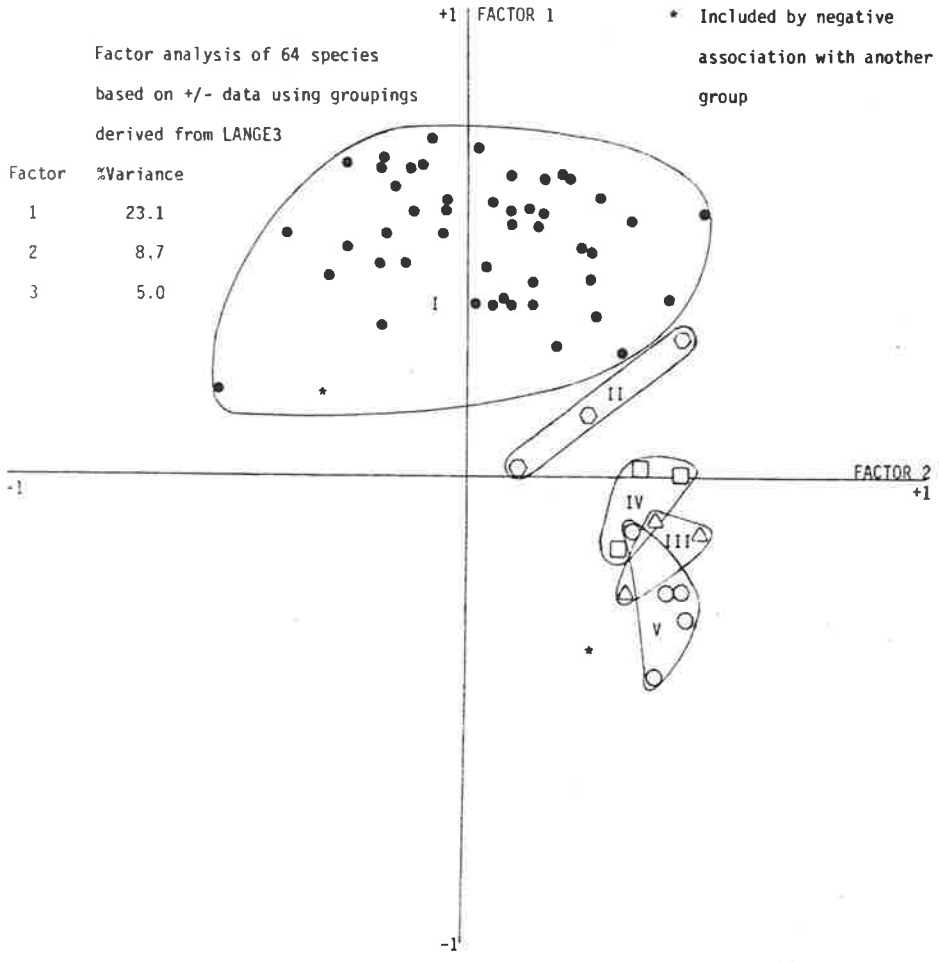
94	0	0	0	1	0	0	0	1	2	0	0	0	0	0	0	0	0	2	0	1	0	0	2	0
68	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
39	2	1	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
27	0	0	0	0	0	0	0	0	-1	0	0	-1	-4	0	-2	0	0	0	-1	-1	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	-2	-1	0	0	0	0	-1	-1	0	0
17	0	0	0	0	0	0	0	0	-2	0	-2	0	-1	-1	-2	-1	0	0	-1	0	0	-1	0	0

	70	71	72	73	74	76	77	78	80	82	84	86	87	91	92	26	35	44	47	79	90	93	94
71	5
72	0	0
73	0	0	3
74	3	4	3	3
76	1	3	1	2	1
77	2	3	2	0	3	2
78	2	4	0	2	3	3	3
80	2	0	0	0	1	0	1	3
82	0	1	0	0	0	3	0	2	0
84	0	2	0	2	0	3	0	2	0	1
86	0	3	4	1	2	1	2	2	0	1	1
87	2	2	3	3	3	0	2	1	0	0	2	0
91	3	3	0	1	1	2	1	3	2	0	1	1	2
92	0	0	0	1	1	3	0	2	1	0	0	0	0	2
26	0	0	0	0	2	0	0	1	2	0	0	1	0	1	0
35	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0
44	0	0	1	0	1	1	0	1	0	0	0	1	0	1	0	2	0
47	0	0	2	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
79	3	0	0	0	0	0	0	0	0	0	0	0	1	2	0	2	0	0	0
90	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0
93	0	0	2	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	3	0	0
94	0	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
39	2	0	0	0	2	0	0	0	1	0	0	0	0	0	0	2	0	0	0	2	-1	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	0
11	0	0	0	0	0	0	0	0	0	0	-2	0	0	0	0	0	0	0	0	0	-1	0	0
4	0	0	0	0	0	-2	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	-1	0	0
8	0	0	0	0	0	-1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0
27	0	-1	-2	0	0	-1	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	-1	-1	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	-2	0	0	0	-1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	-1	0	0
13	0	0	0	0	-1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	-2	0	0
7	0	-1	0	0	0	-1	0	0	0	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0
17	-1	-3	0	0	0	-3	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0


Factor analysis of 64 species
based on +/- data using groupings
derived from LANGE3
Factor %Variance
1 23.1
2 8.7
3 5.0
* Included by negative association with another group
+1
FACTOR 1
FACTOR 2
-1
+1
-1
I
II
III
IV
V

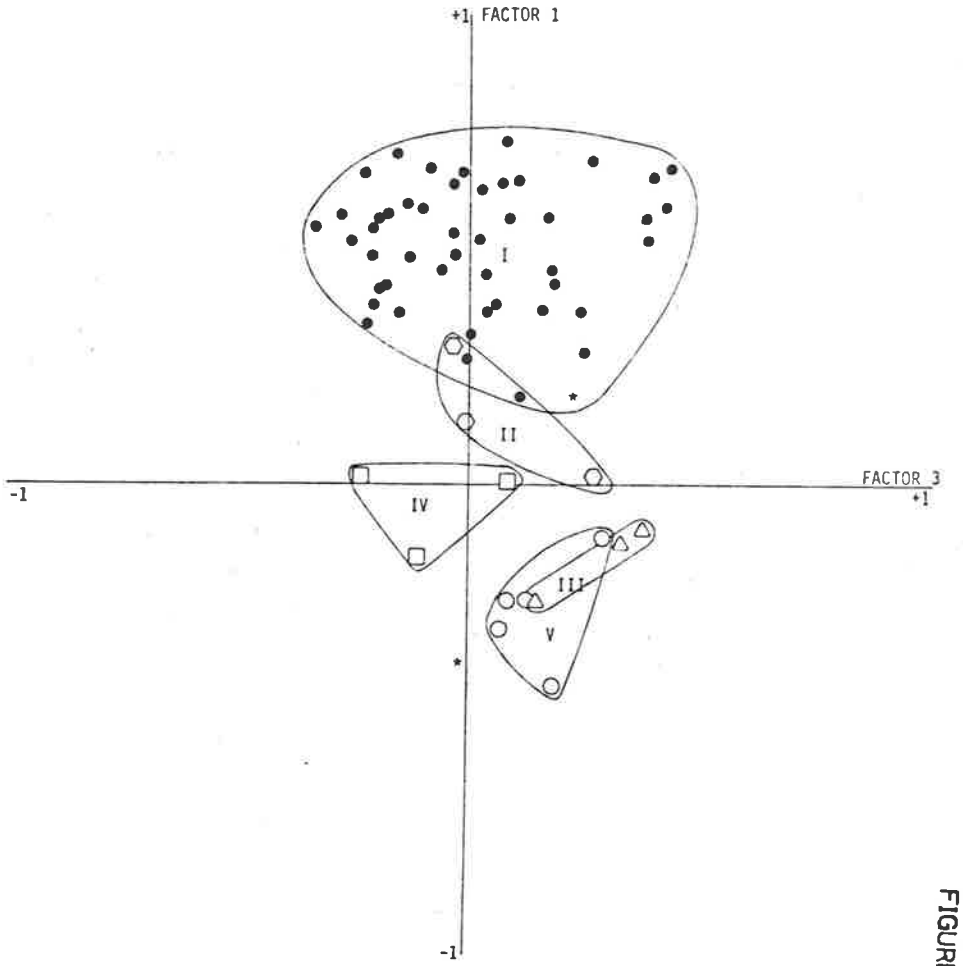

+1
FACTOR 1
FACTOR 3
-1
+1
-1
I
II
III
IV
V

FIGURE 60

KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

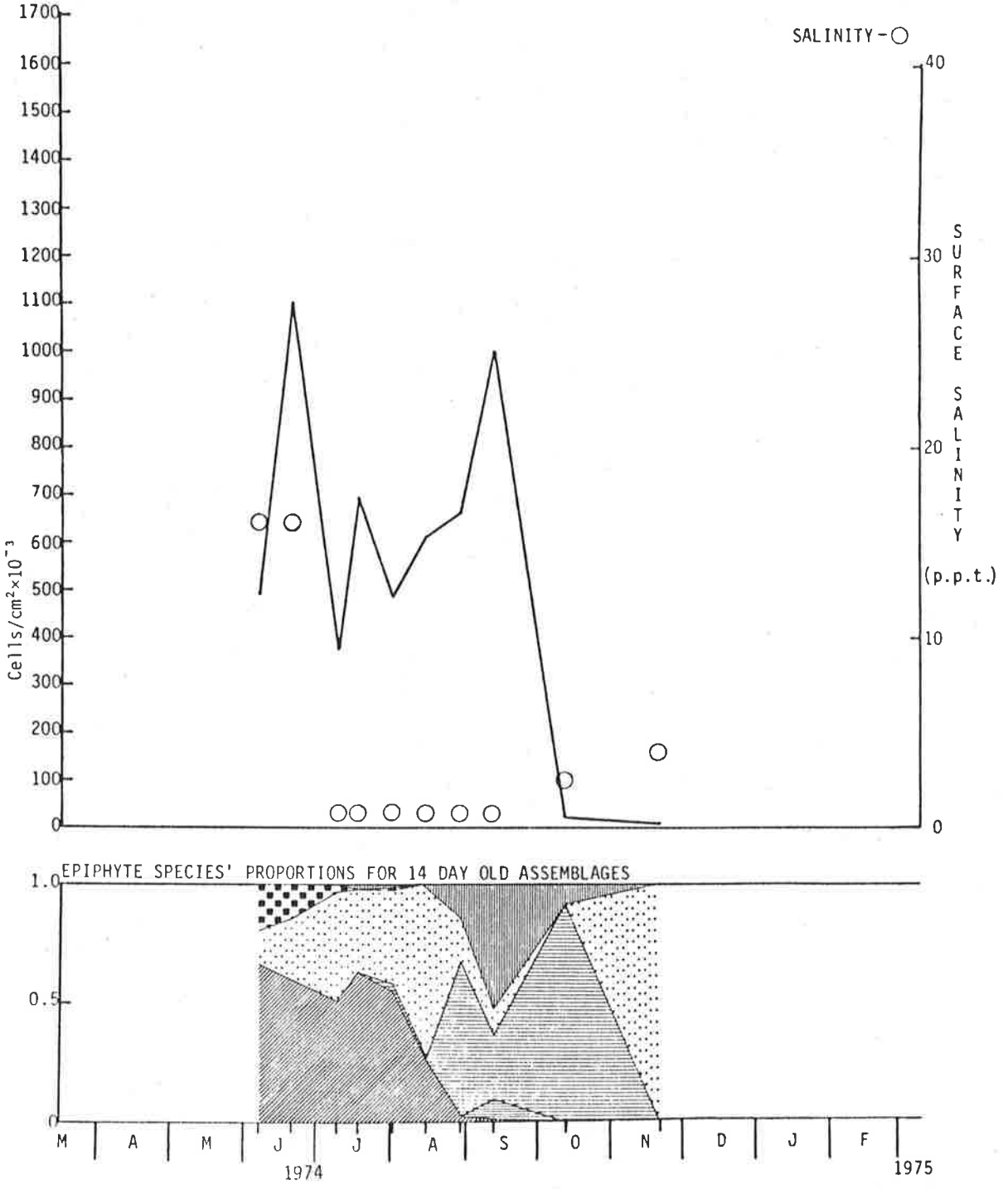
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 61

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 2km STATION, 1974, FOR 14 DAY ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. *lacerata*

S. tabulata

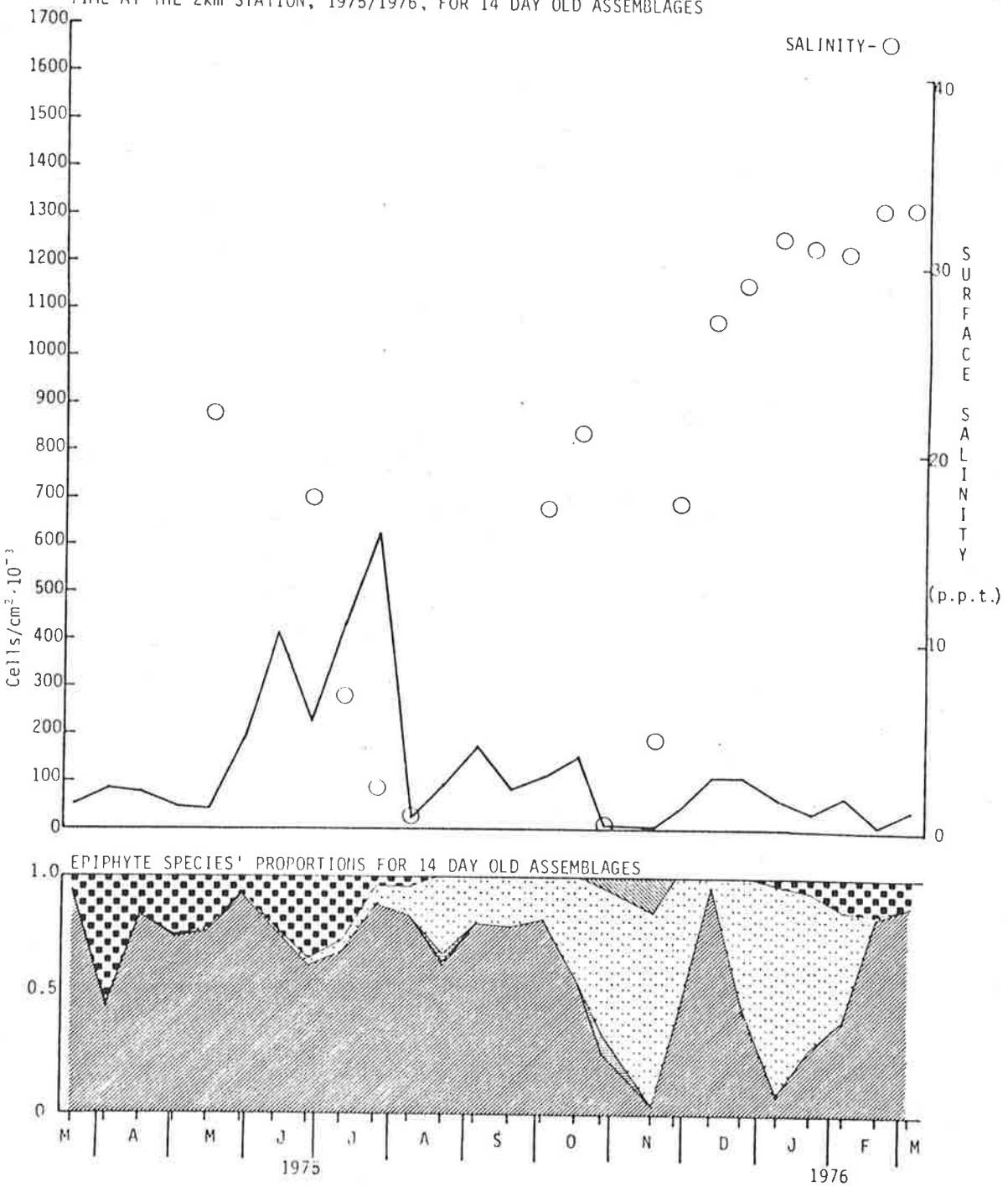
Achnanthes brevipes var. *intermedia*

Rhoicosphaenia curvata

Gomphonema constrictum var. *capitatum*

FIGURE 62

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 2km STATION, 1975/1976, FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

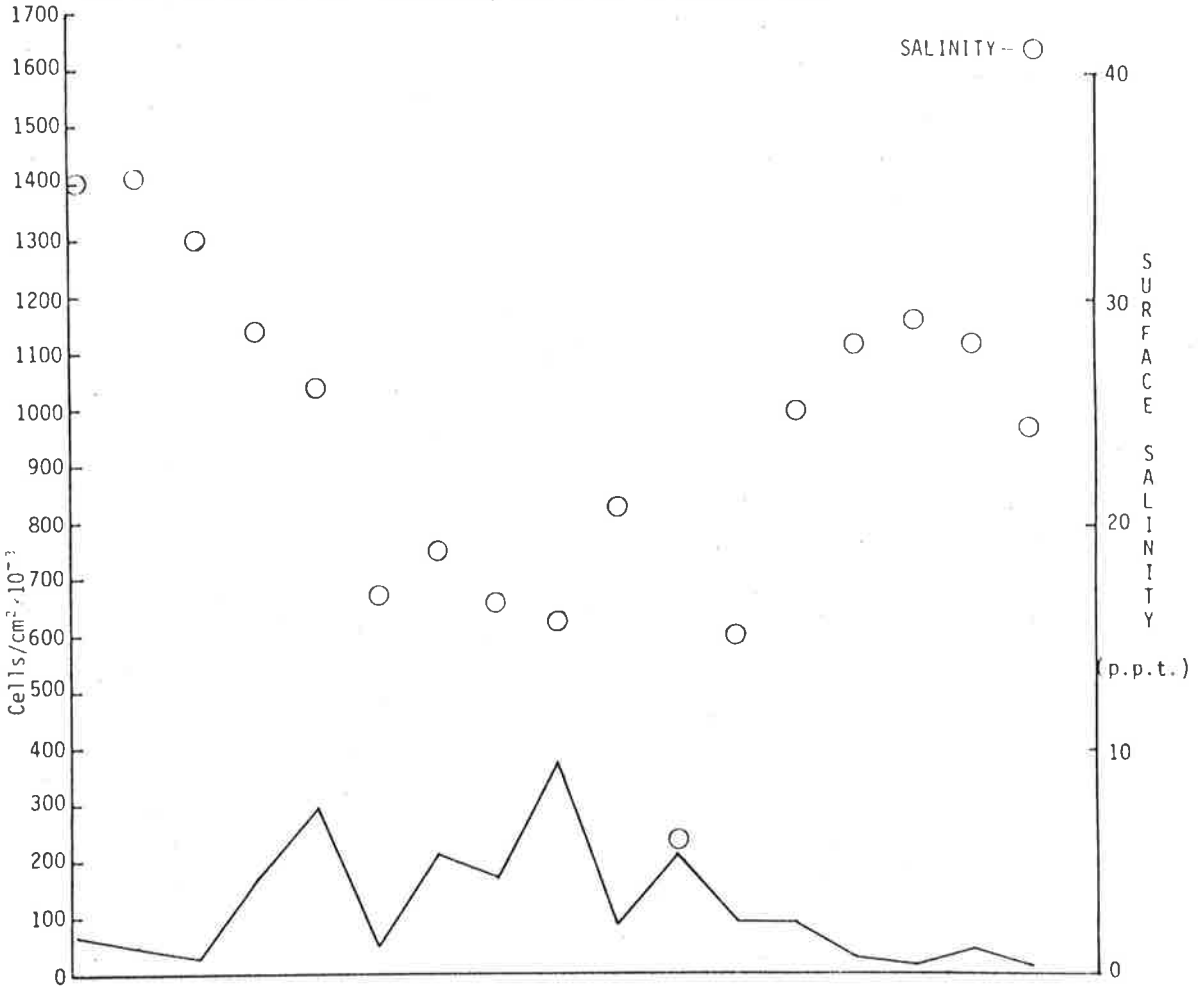
Achnanthes brevipes var. intermedia

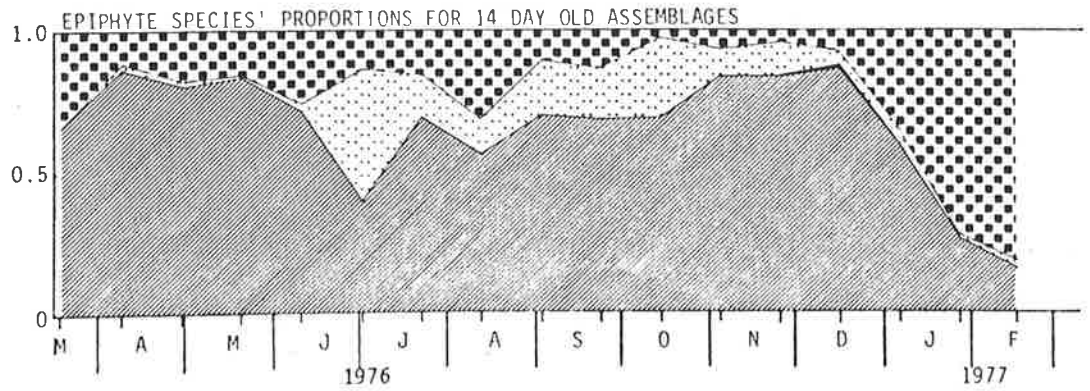
Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 63

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SUFACE SALINITY vs TIME AT THE 2km STATION, 1976/1977, FOR 14 DAY OLD ASSEMBLAGES





KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

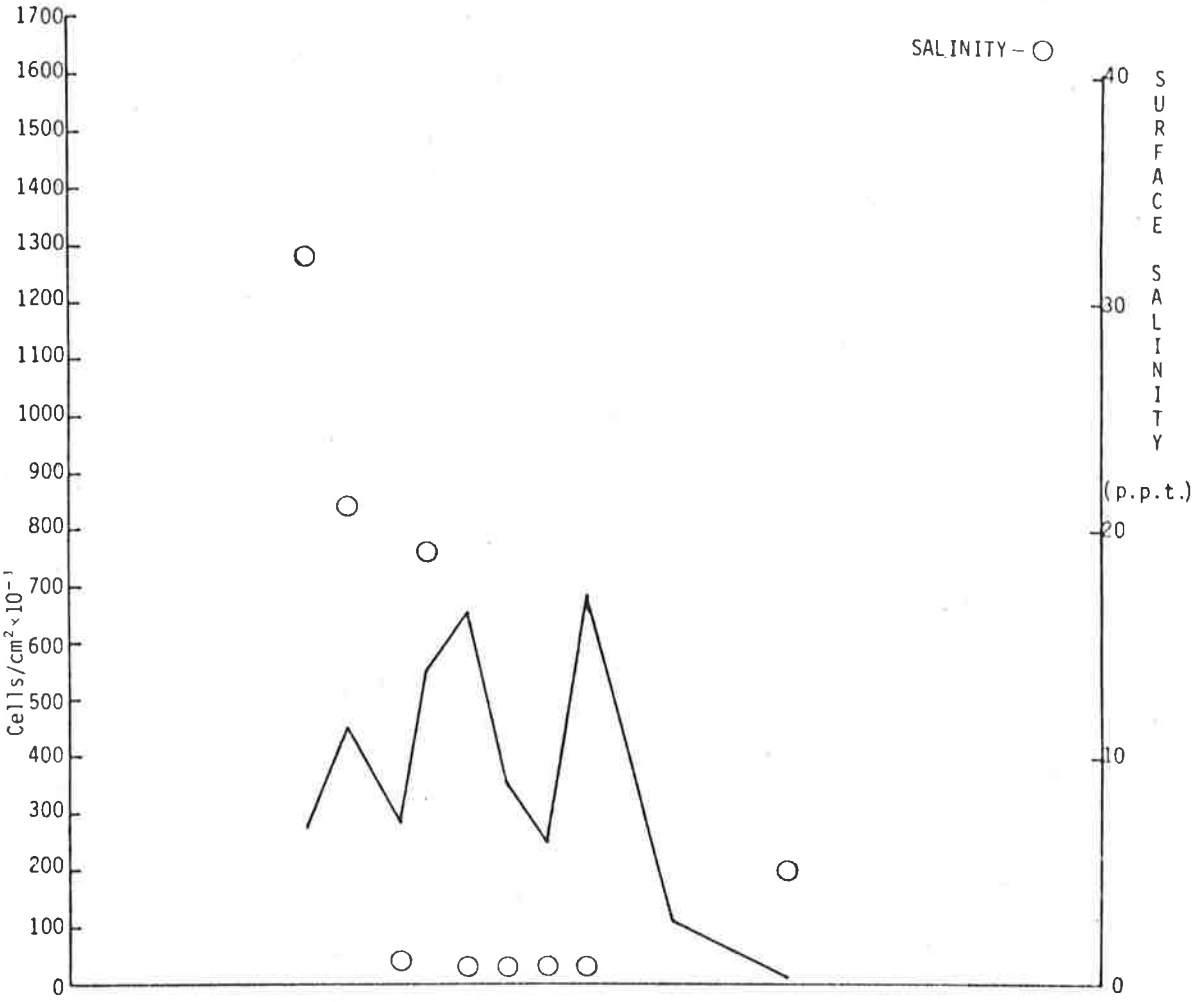
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

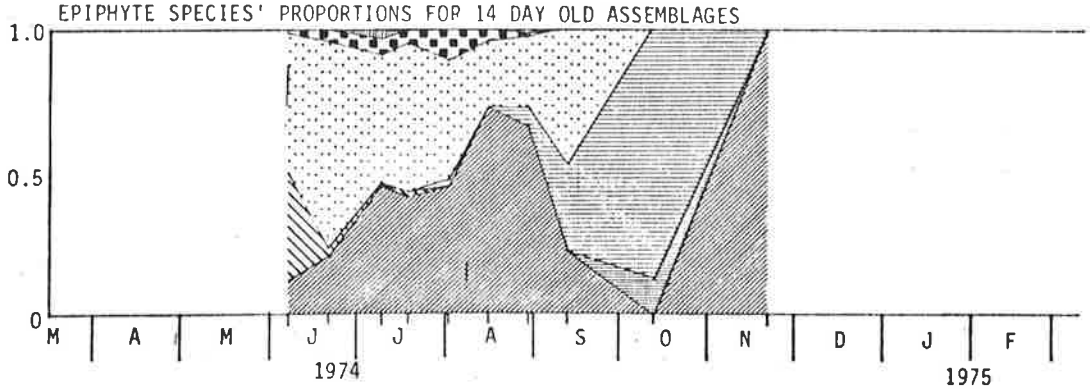
Gomphonema constrictum var. capitatum

FIGURE 64

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 6km STATION, 1974, FOR 14 DAY OLD ASSEMBLAGES



EPIPHYTE SPECIES' PROPORTIONS FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

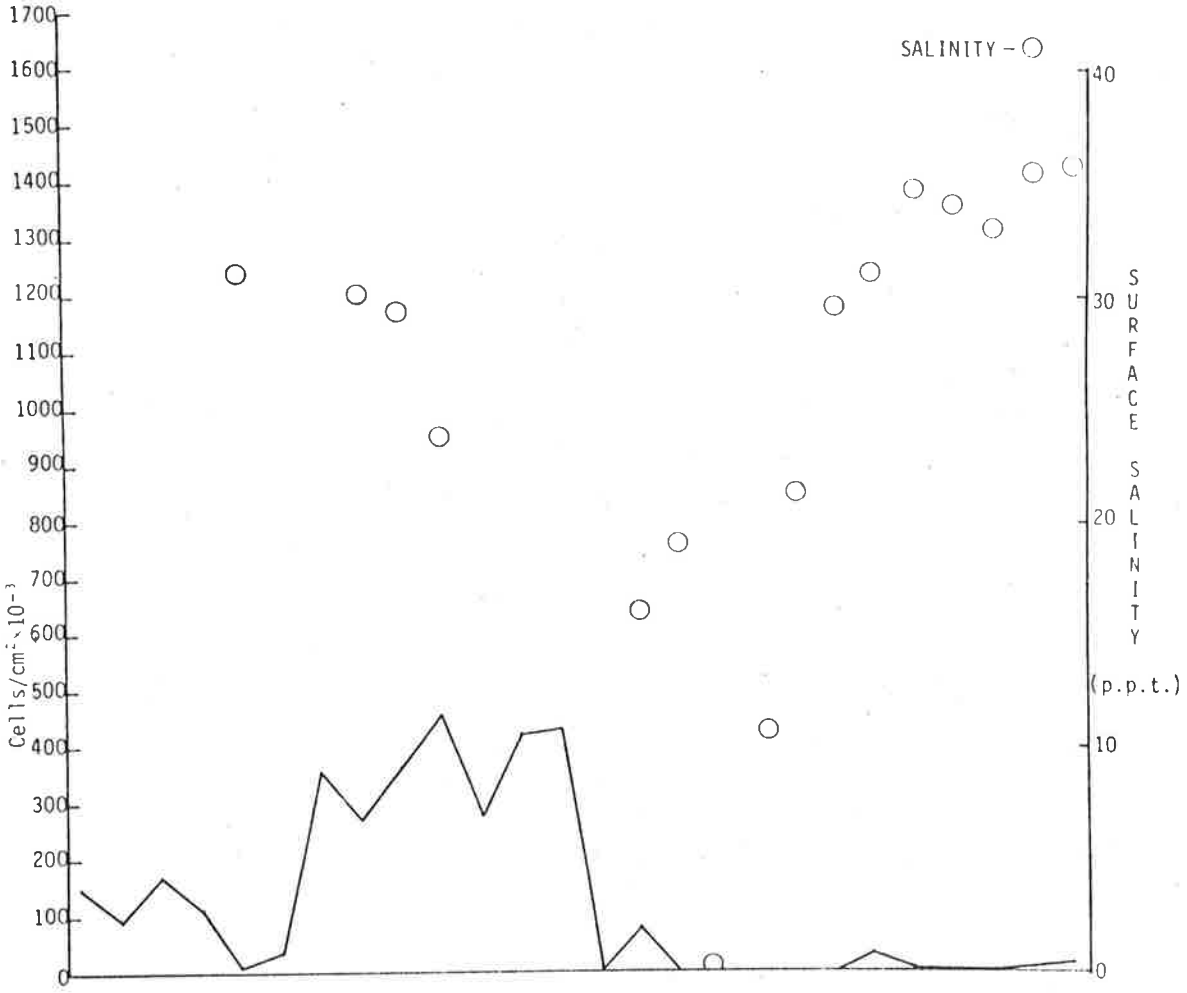
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

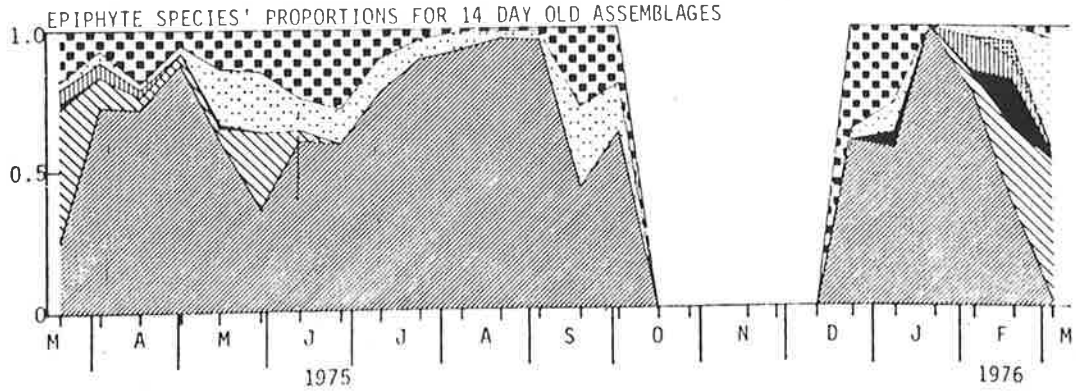
Gomphonema constrictum var. capitatum

FIGURE 65

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 6km STATION, 1975/1976, FOR 14 DAY OLD ASSEMBLAGES



EPIPHYTE SPECIES' PROPORTIONS FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. *lacerata*

S. tabulata

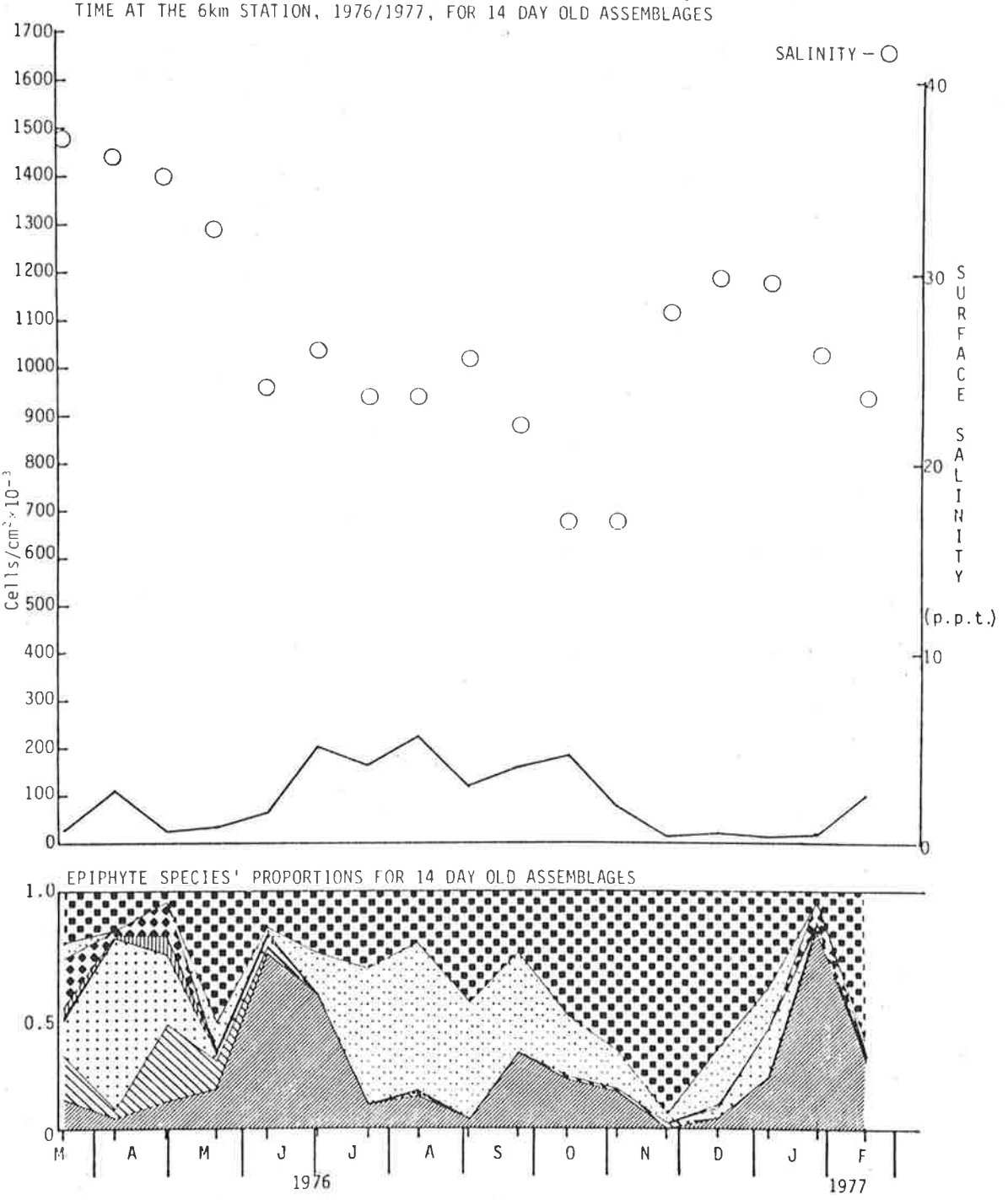
Achnanthes brevipes var. *intermedia*

Rhoicosphaenia curvata

Gomphonema constrictum var. *capitatum*

FIGURE 66

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 6km STATION, 1976/1977, FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. *lacerata*

S. tabulata

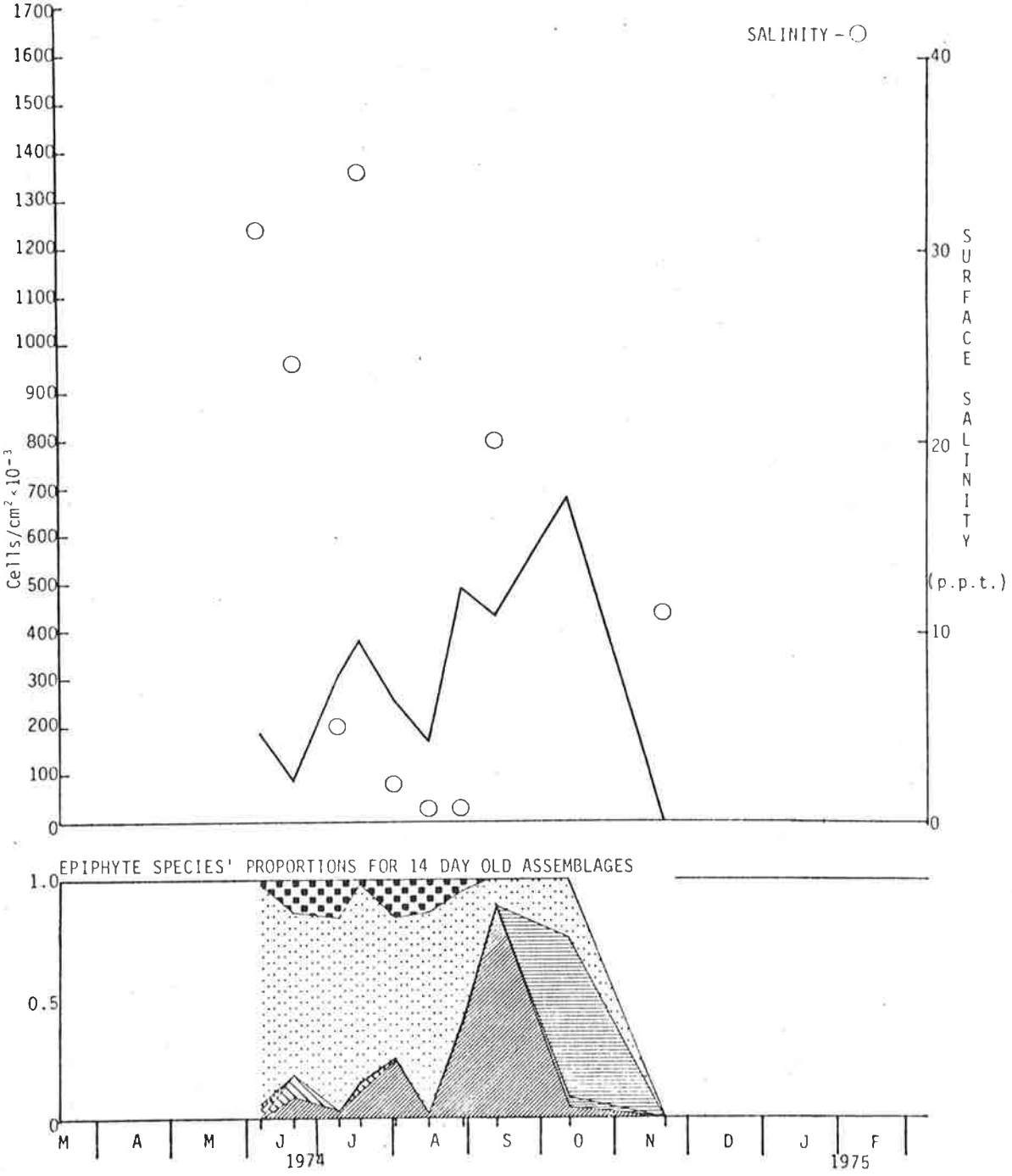
Achnanthes brevipes var. *intermedia*

Rhoicosphaenia curvata

Gomphonema constrictum var. *capitatum*

FIGURE 67

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 8km STATION, 1974, FOR 14 DAY ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

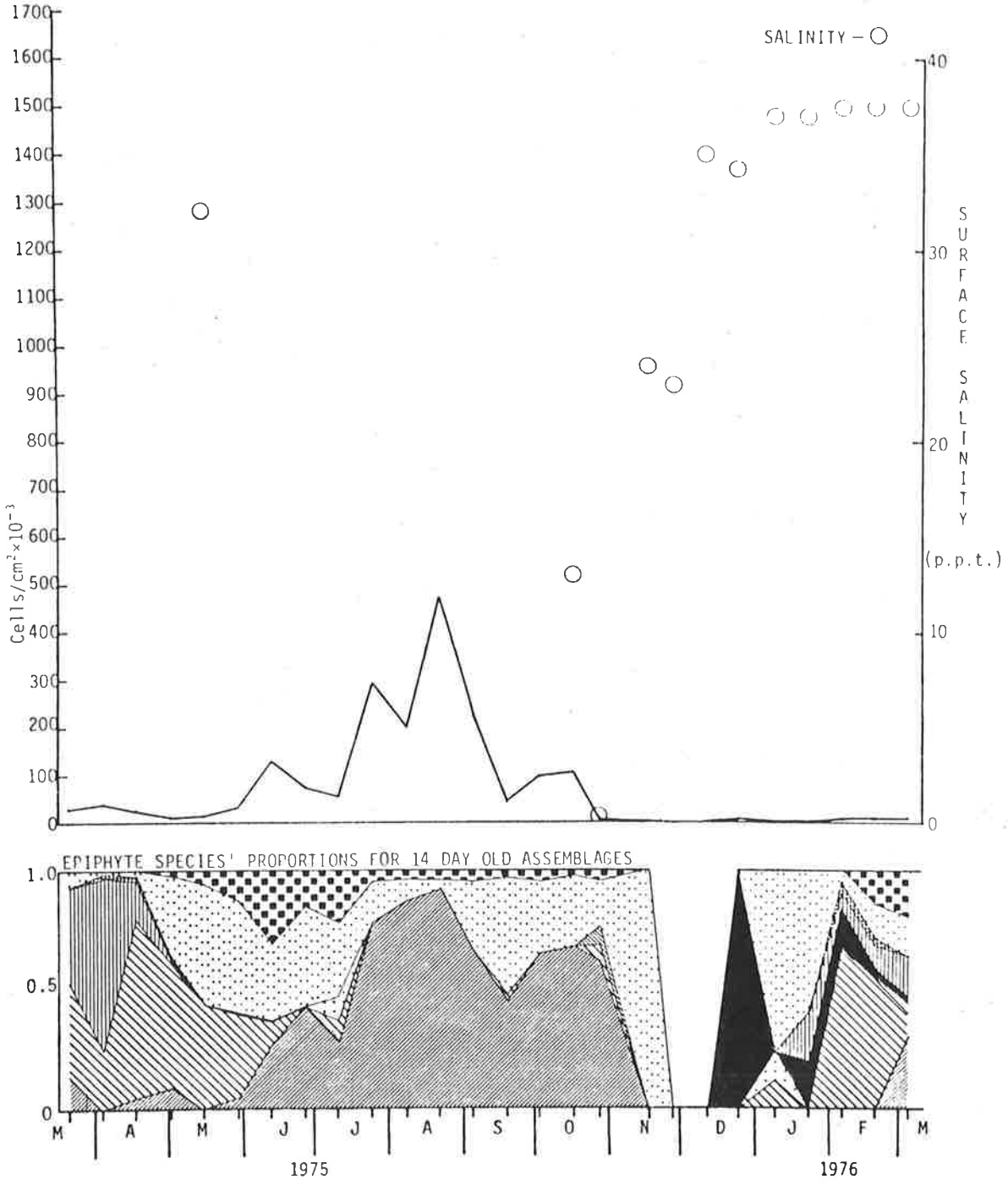
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 68

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 8km STATION, 1975/1976, FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4.

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

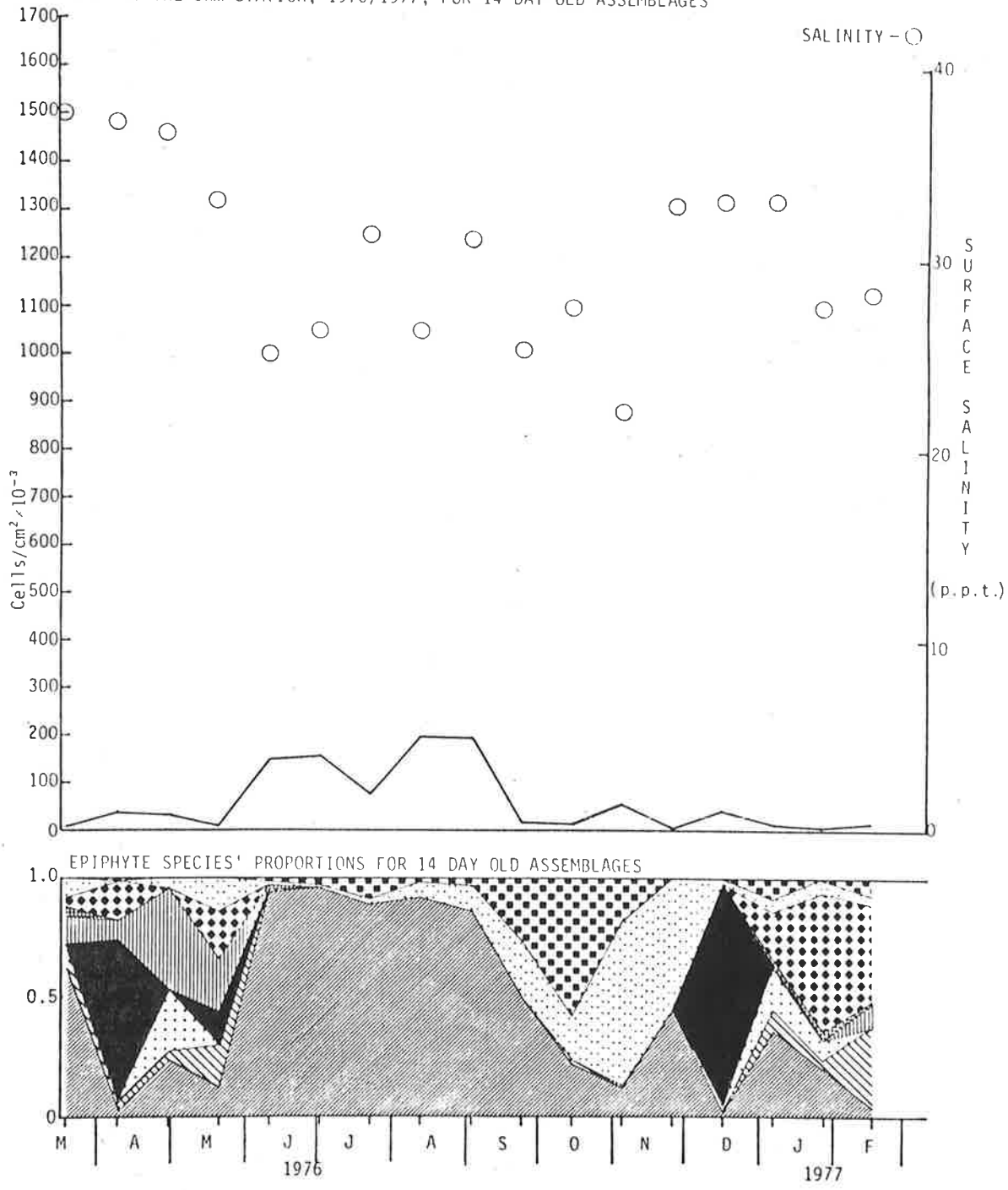
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 69

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 8km STATION, 1976/1977, FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. *lacerata*

S. tabulata

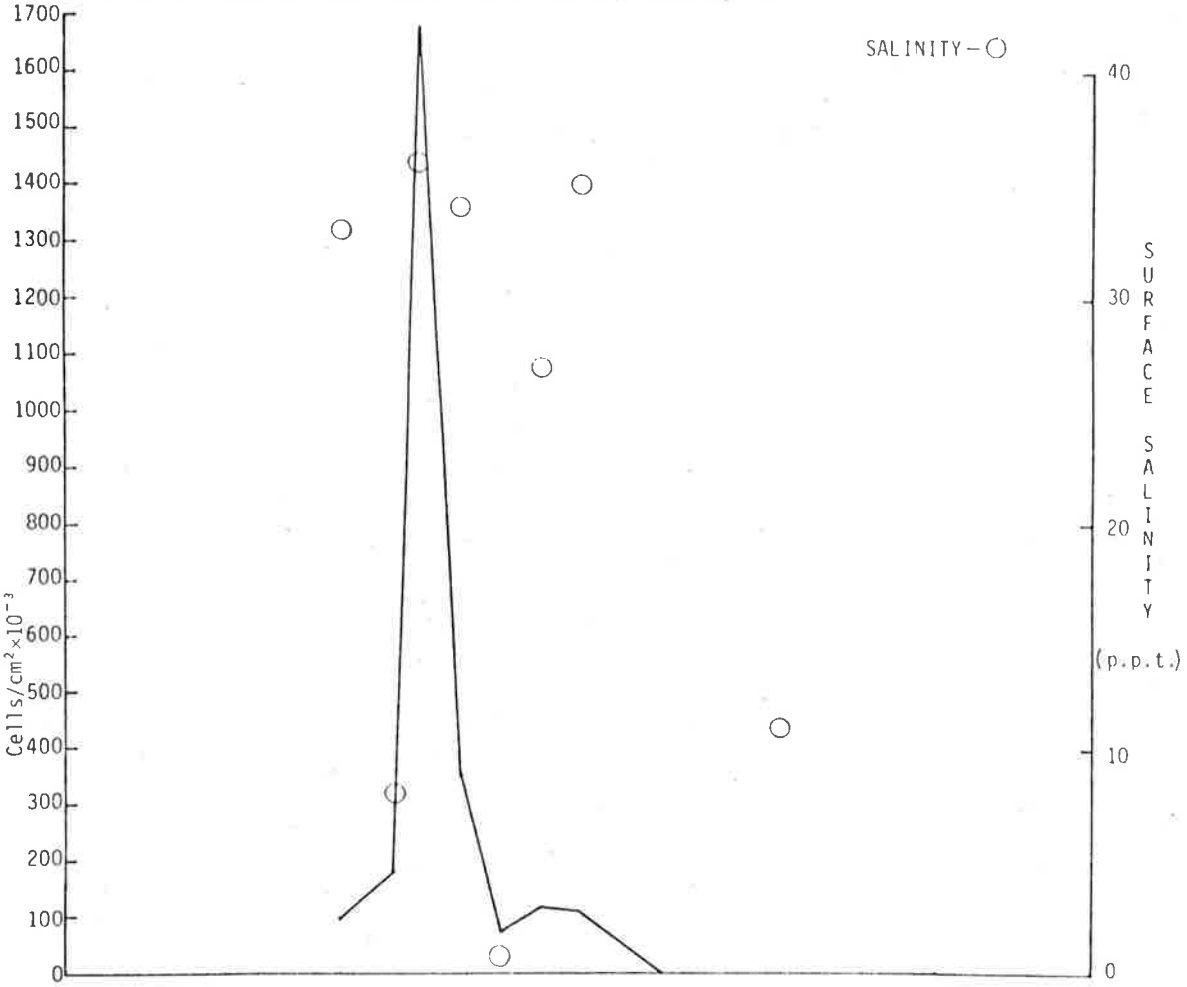
Achnanthes brevipes var. *intermedia*

Rhoicosphaenia curvata

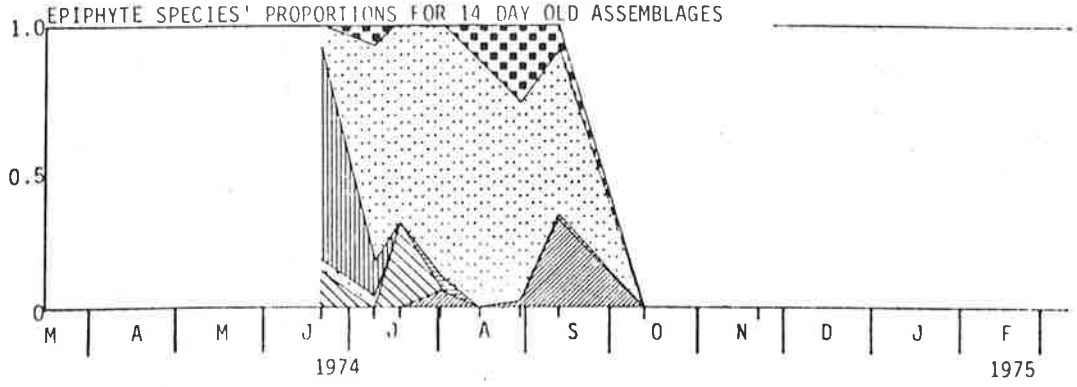
Gomphonema constrictum var. *capitatum*

FIGURE 70

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 10km STATION, 1974, FOR 14 DAY OLD ASSEMBLAGES



EPIPHYTE SPECIES' PROPORTIONS FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

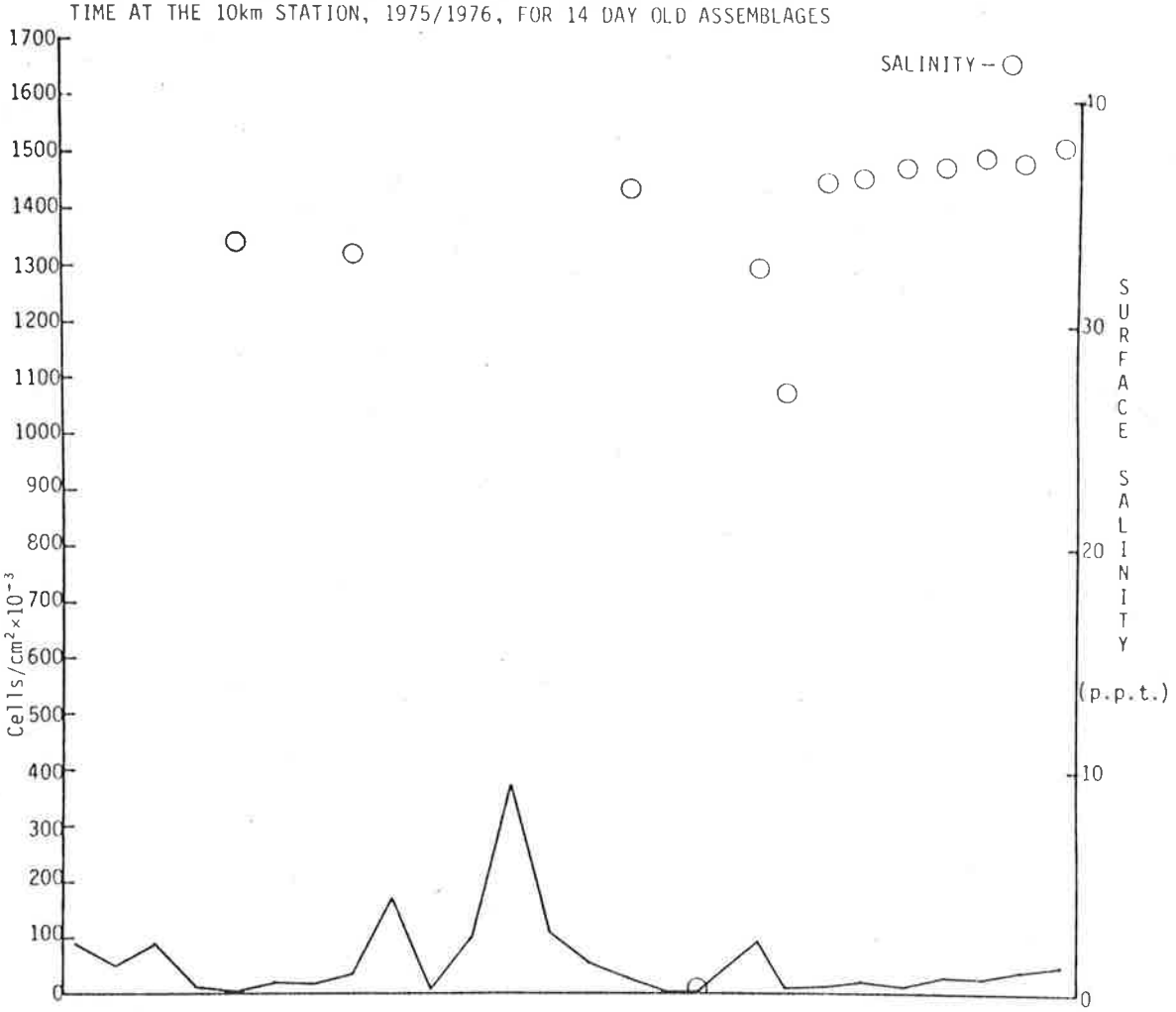
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

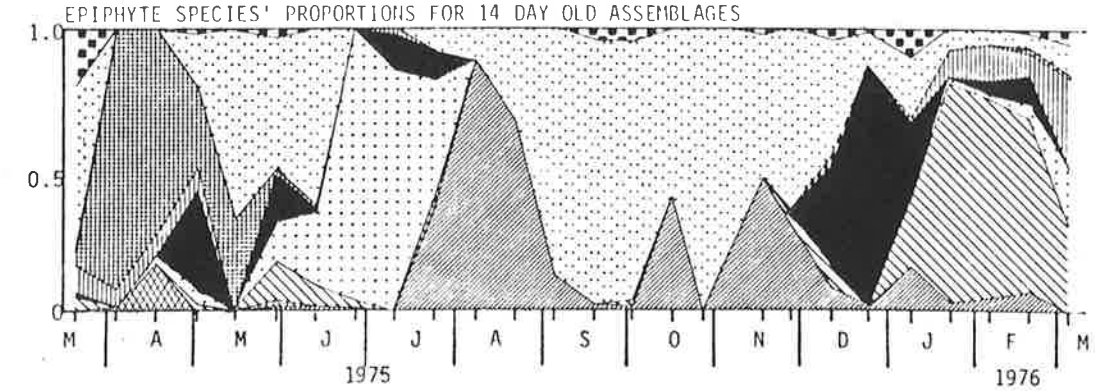
Gomphonema constrictum var. capitatum

FIGURE 71

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 10km STATION, 1975/1976, FOR 14 DAY OLD ASSEMBLAGES



EPIPHYTE SPECIES' PROPORTIONS FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 72

GRAPH OF TOTAL EPIPHYTE CELL DENSITY AND SURFACE SALINITY vs TIME AT THE 10km STATION, 1976/1977, FOR 14 DAY OLD ASSEMBLAGES

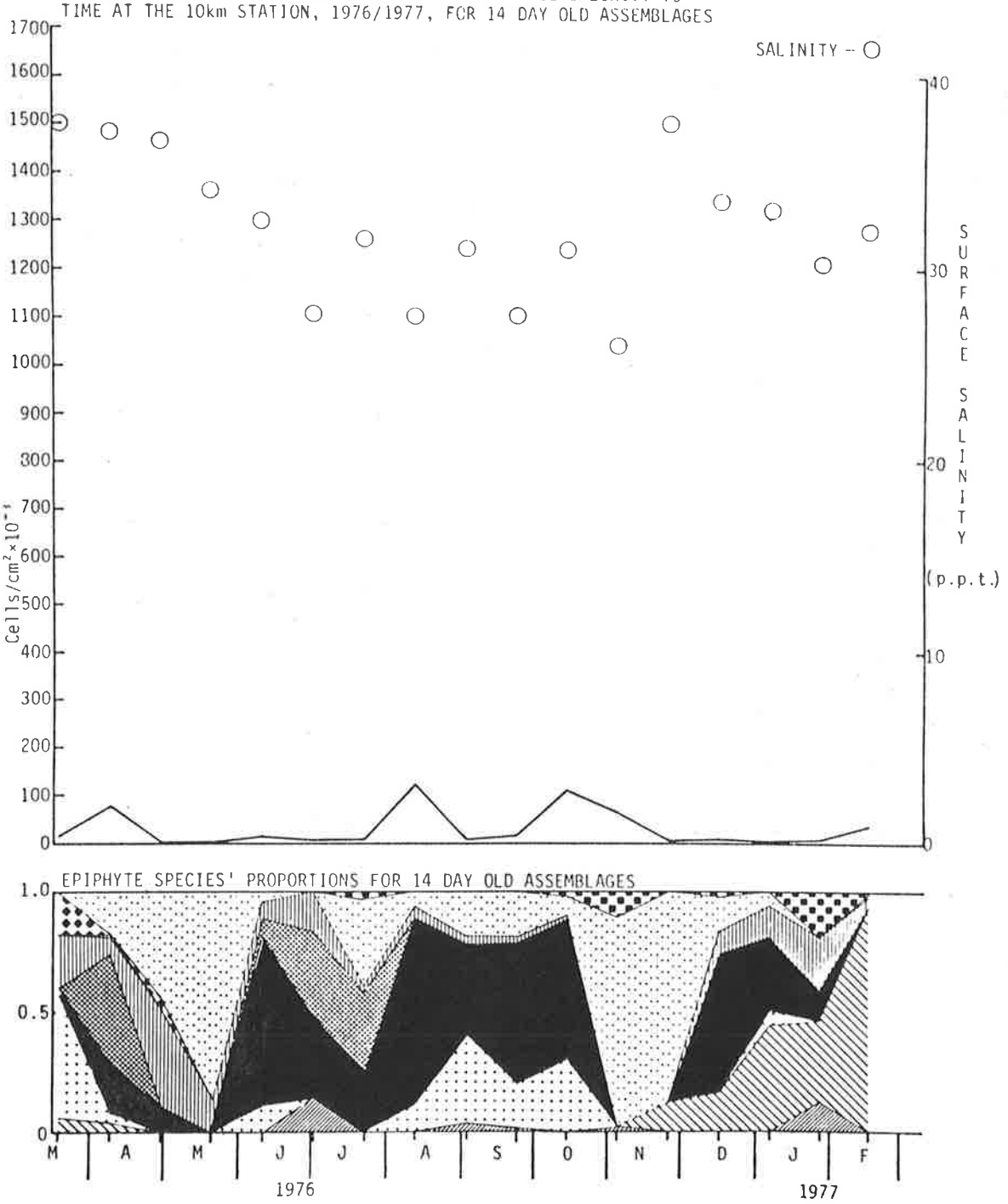


FIGURE 73

GRAPH OF TOTAL MOTILE CELL DENSITIES vs
TIME AND STATION FOR 14 DAY OLD ASSEMBLAGES

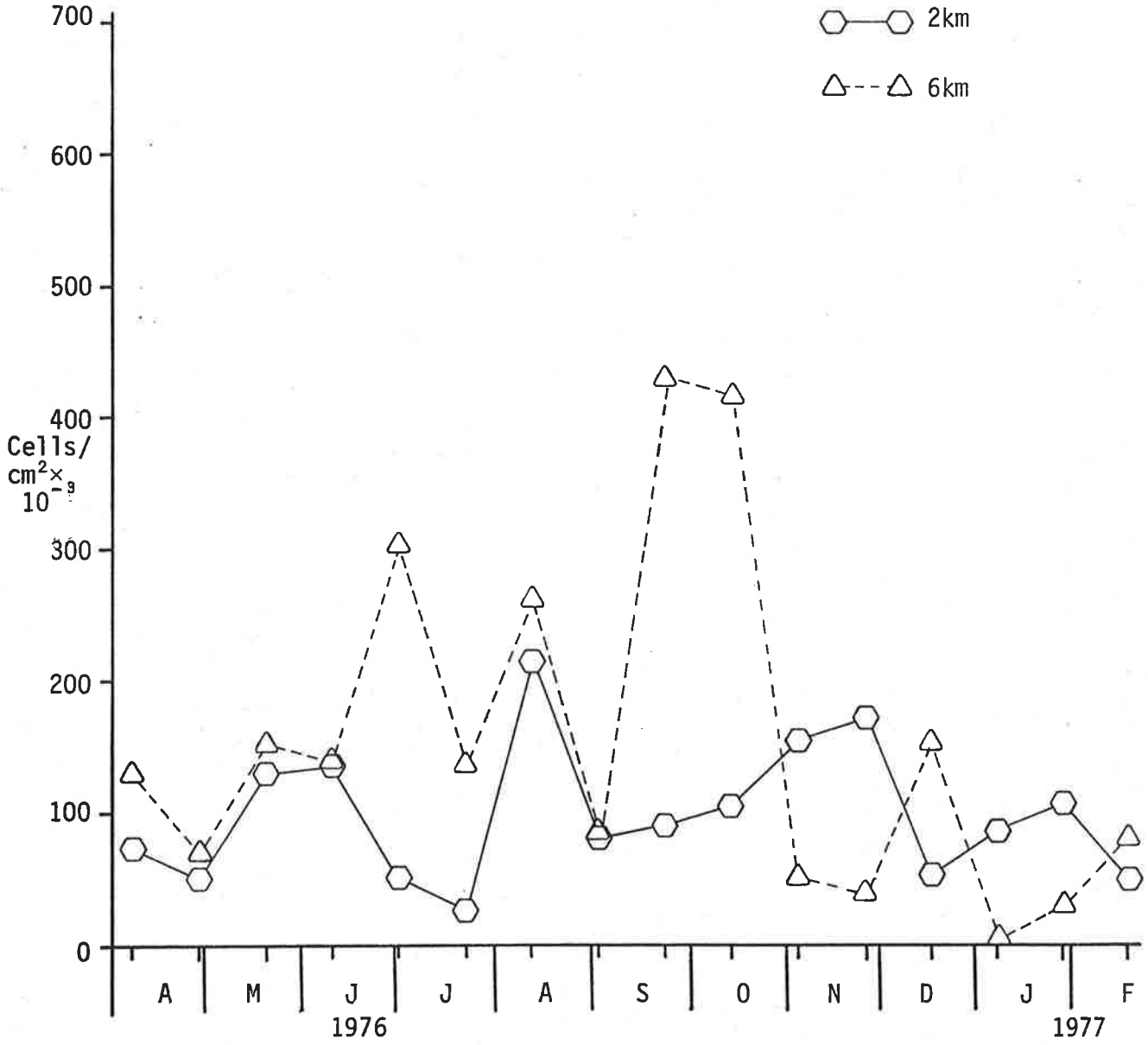
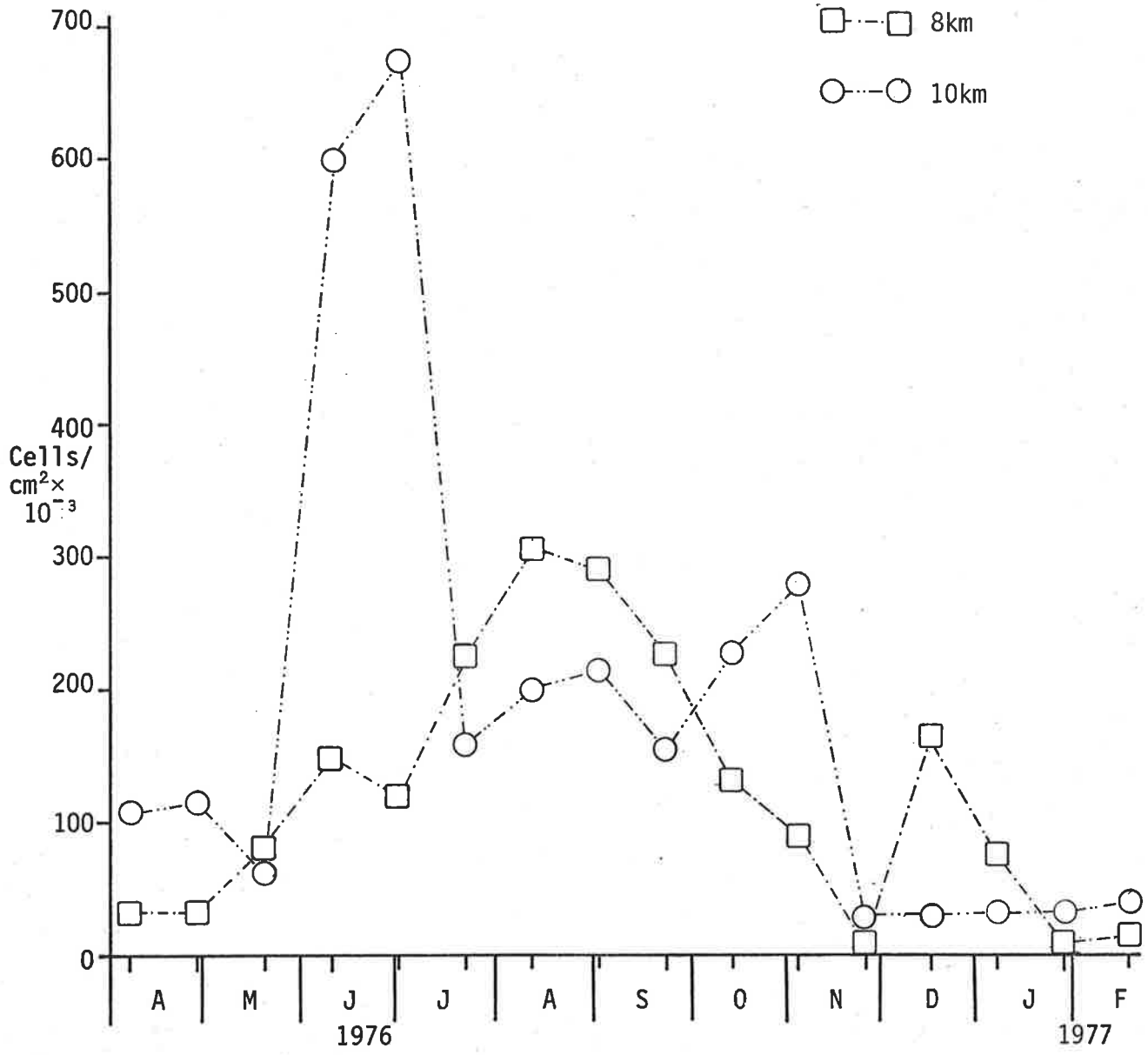


FIGURE 74

GRAPH OF TOTAL MOTILE CELL DENSITIES vs
TIME AND STATION FOR 14 DAY OLD ASSEMBLAGES



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

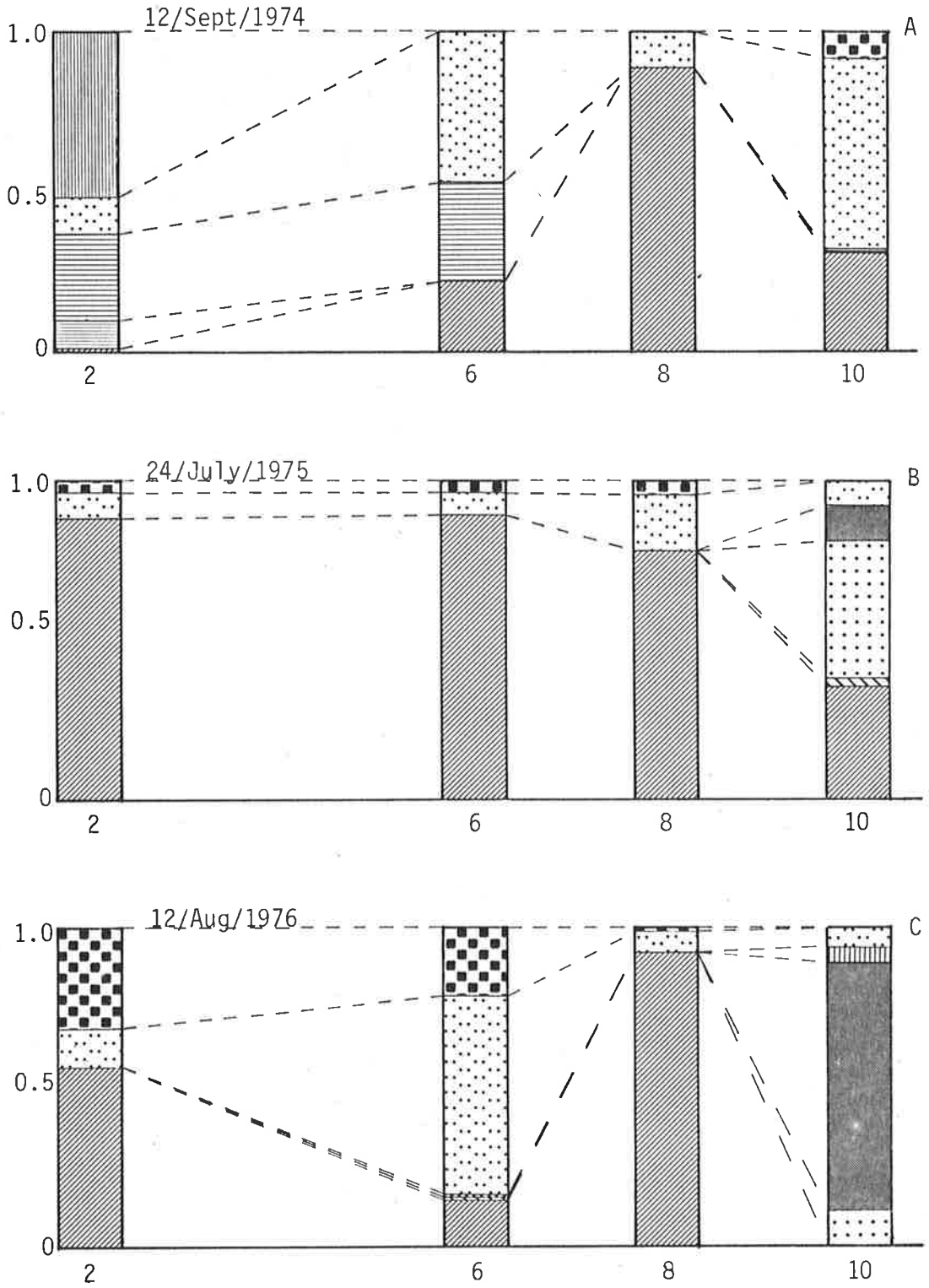
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 75

VARIATION OF SPECIES' PROPORTIONS AT SAMPLING STATIONS DURING WINTER



KEY

Melosira sp. 1

M. varians

Climacosphaenia moniligera

Grammatophora oceanica

Licmophora flabellata

L. sp. 3

L. sp. 4

Plagiogramma staurophorum

Striatella unipunctata

Synedra flabellata

S. laevigata

S. pulchella var. lacerata

S. tabulata

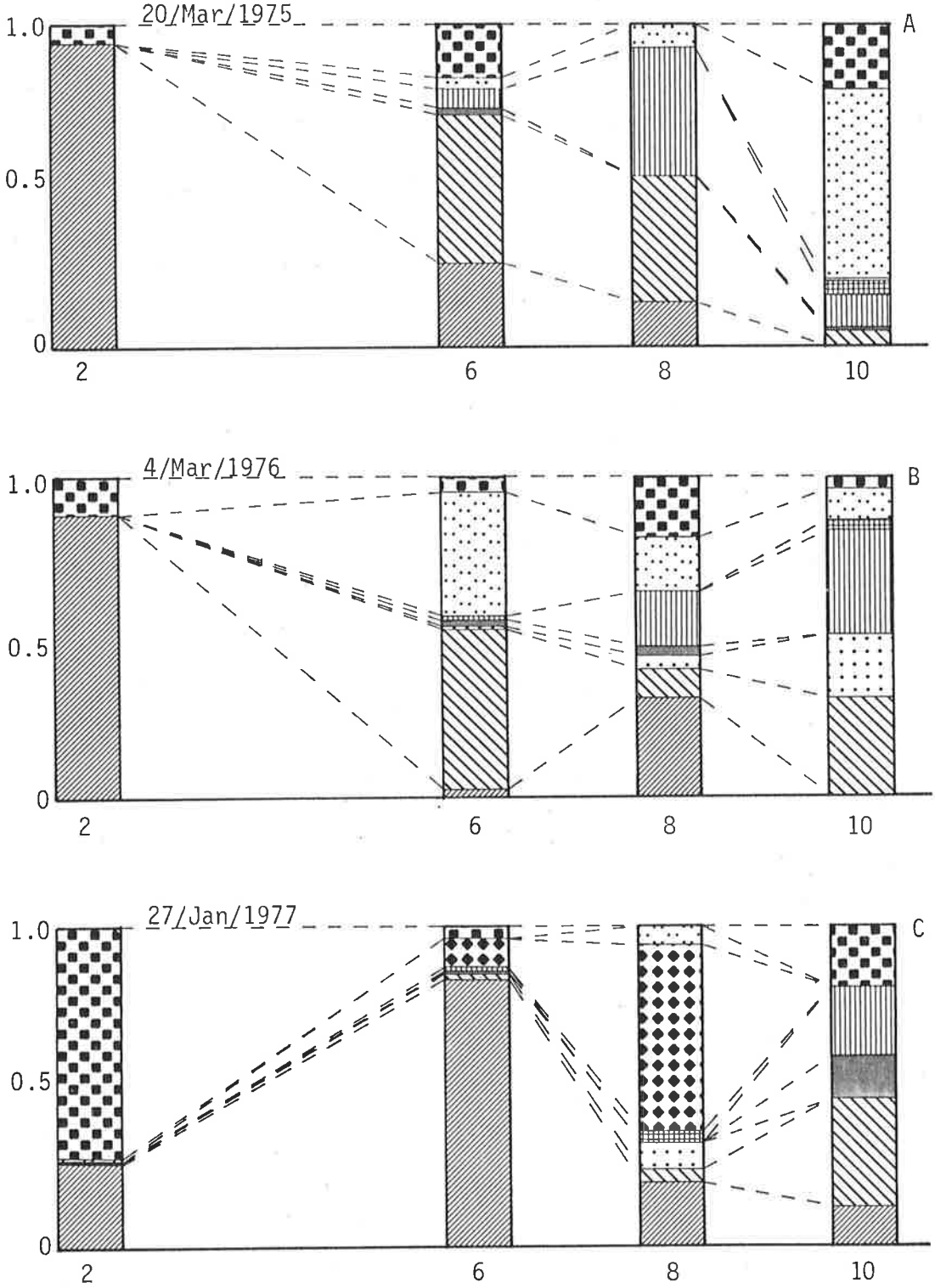
Achnanthes brevipes var. intermedia

Rhoicosphaenia curvata

Gomphonema constrictum var. capitatum

FIGURE 76

VARIATION OF SPECIES' PROPORTIONS AT SAMPLING STATIONS DURING SUMMER



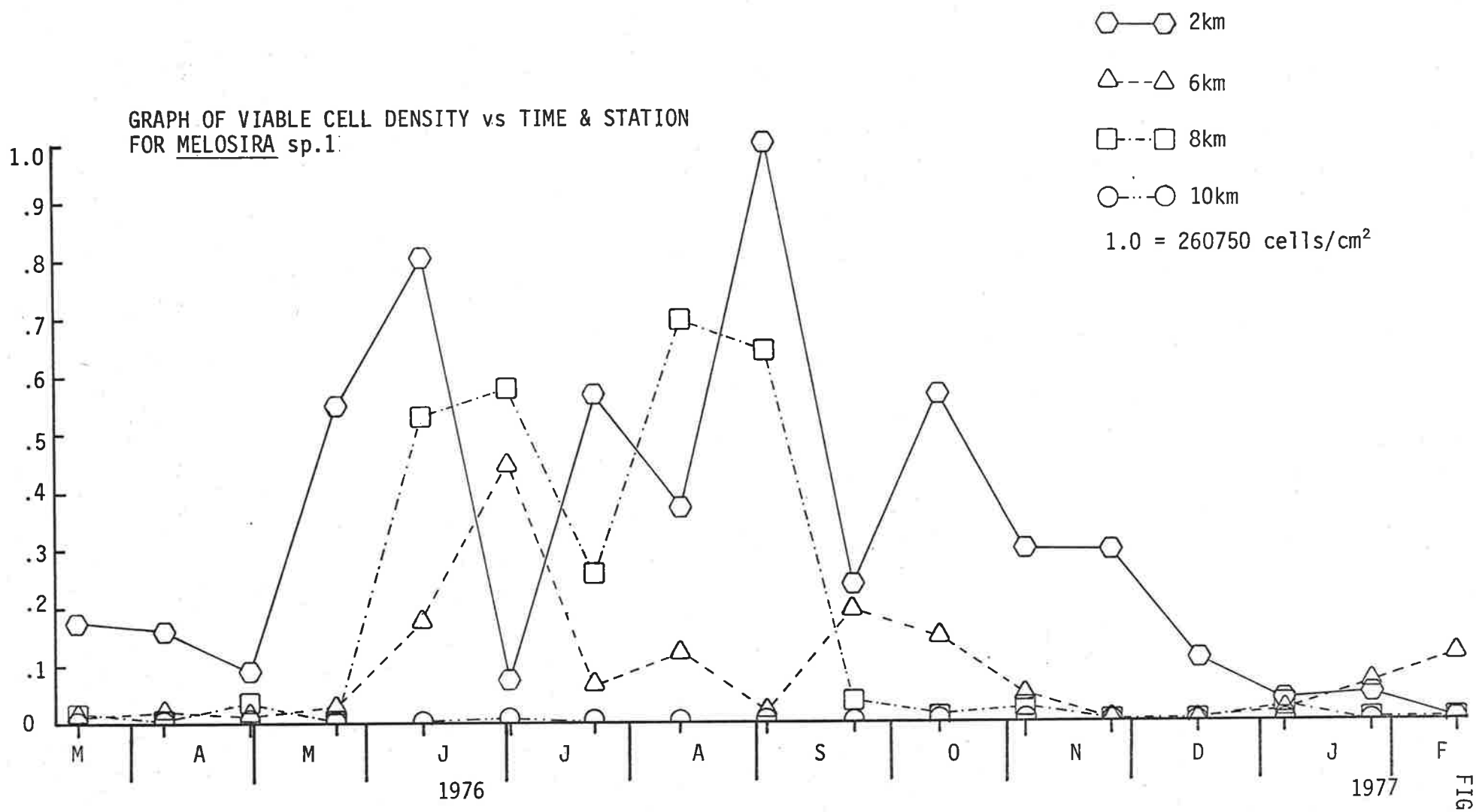

GRAPH OF VIABLE CELL DENSITY vs TIME & STATION
FOR MELOSIRA sp.1
2km
6km
8km
10km
1.0 = 260750 cells/cm²
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
M
A
M
J
J
A
S
O
N
D
J
F
1976
1977

FIGURE 77

GRAPH OF VIABLE CELL DENSITY vs TIME & STATION
FOR GRAMMATOPHORA OCEANICA

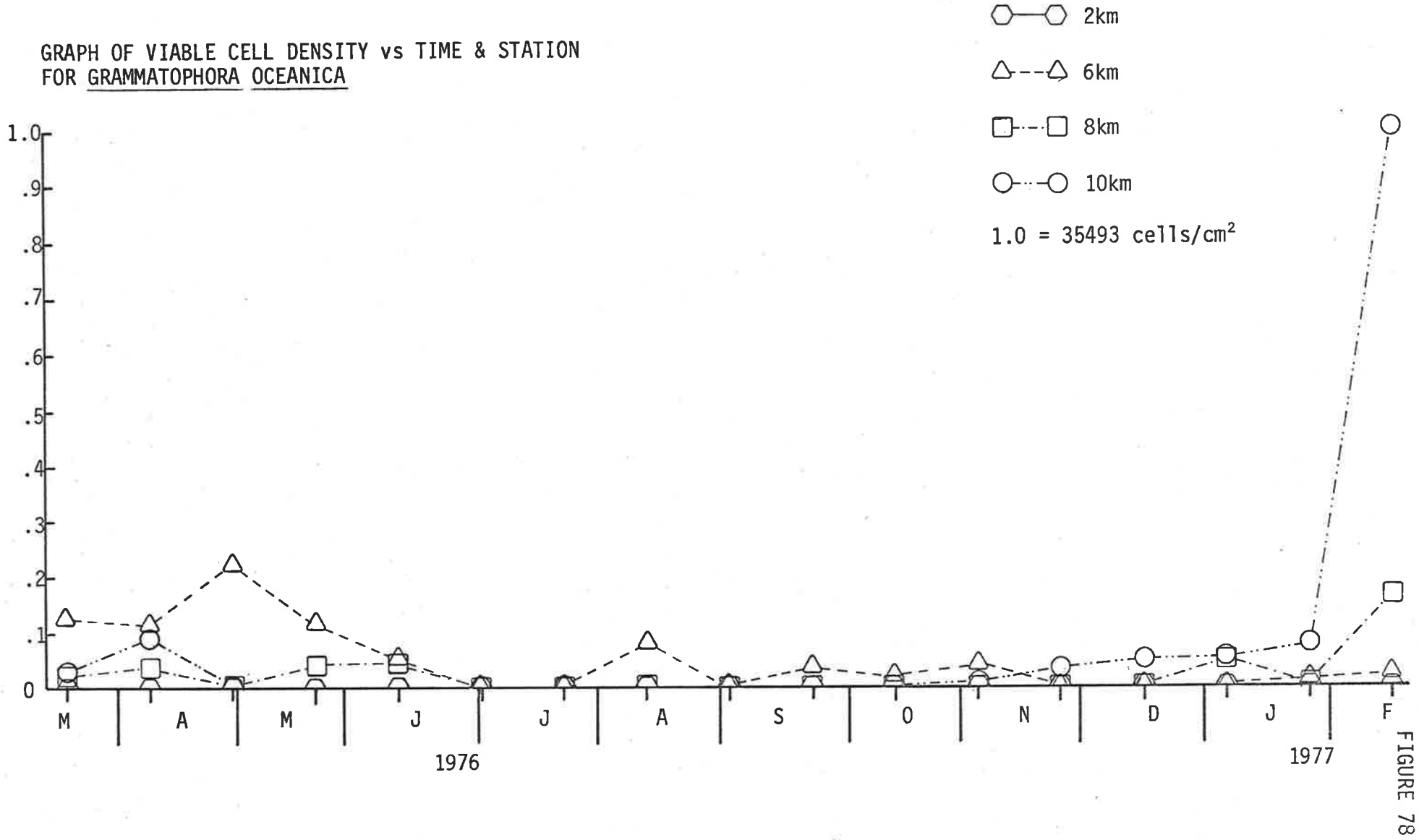


FIGURE 78

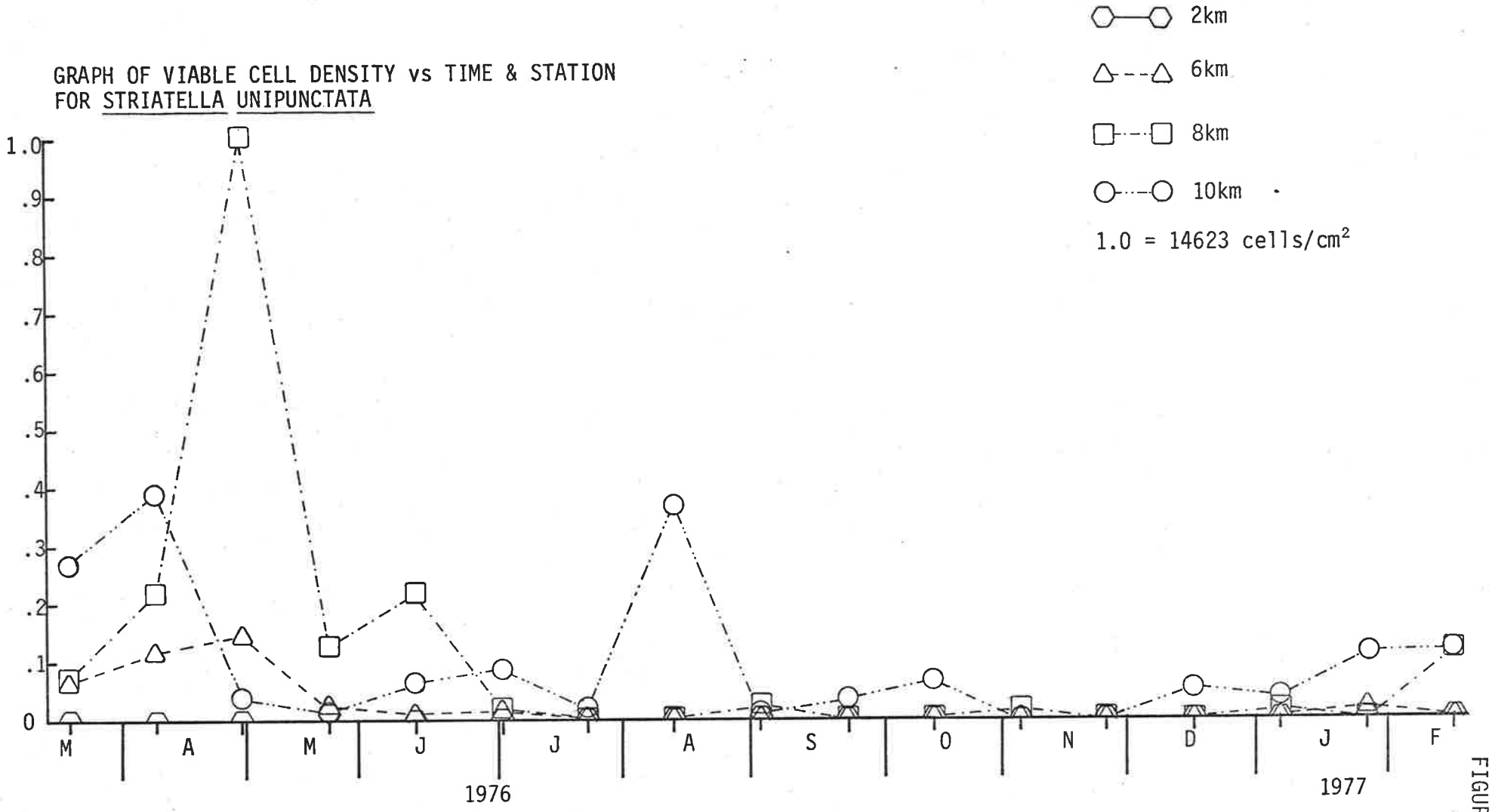
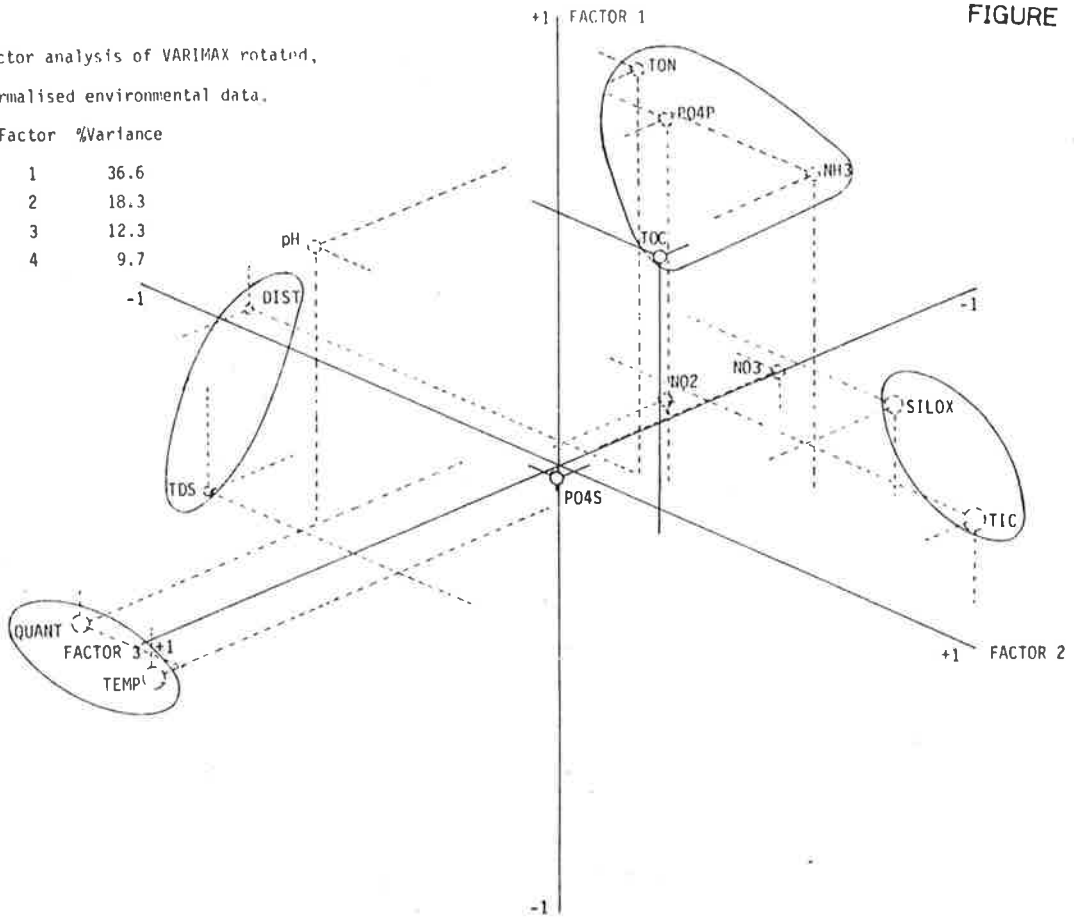

GRAPH OF VIABLE CELL DENSITY vs TIME & STATION
FOR STRIATELLA UNIPUNCTATA
2km
6km
8km
10km
1.0 = 14623 cells/cm²
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
M
A
M
J
J
A
S
O
N
D
J
F
1976
1977

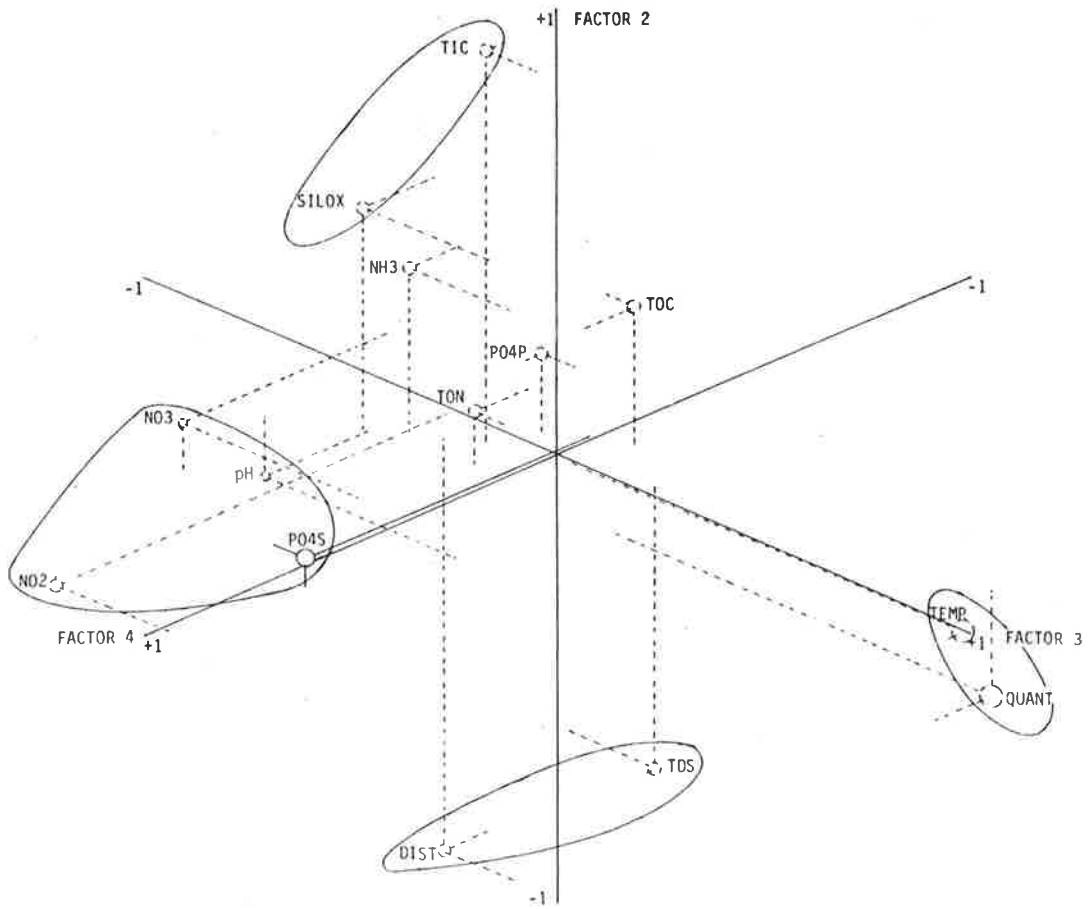
FIGURE 79

FIGURE 80

Factor analysis of VARIMAX rotated, normalised environmental data.

Factor	%Variance
1	36.6
2	18.3
3	12.3
4	9.7





TDS	.62												
TIC	-.79	-.58											
SILOX	-.38	-.43	.53										
TEMP	-.13	.25	-.16	-.35									
QUANT	-.09	.38	-.32	-.43	.89								
TON	-.20	-.29	.28	.28	-.20	-.22							
PO4P	-.20	-.31	.35	.31	-.17	-.11	.75						
TOC	-.37	-.35	.35	.26	-.01	-.08	.63	.49					
NH3	-.33	-.38	.54	.43	-.28	-.34	.69	.72	.44				
pH	.14	-.23	.02	.17	-.51	-.52	.59	.49	.32	.48			
NO2	.04	-.04	.08	.21	-.33	-.36	.22	.02	-.14	.20	.33		
NO3	.02	-.11	.25	.27	-.37	-.42	.08	.17	-.14	.41	.35	.63	
PO4S	-.10	-.03	.11	.16	.06	-.03	.13	-.08	-.02	.13	.24	.65	.32
	DIST	TDS	TIC	SILOX	TEMP	QUANT	TON	PO4P	TOC	NH3	pH	NO2	NO3

CORRELATION MATRIX FOR

ENVIRONMENTAL DATA

SEE CH. 5.3.

FIGURE 81

FIGURES 82-84

SCATTERGRAMS to illustrate the scatter of values obtained for selected environmental variables with respect to the sampling station.

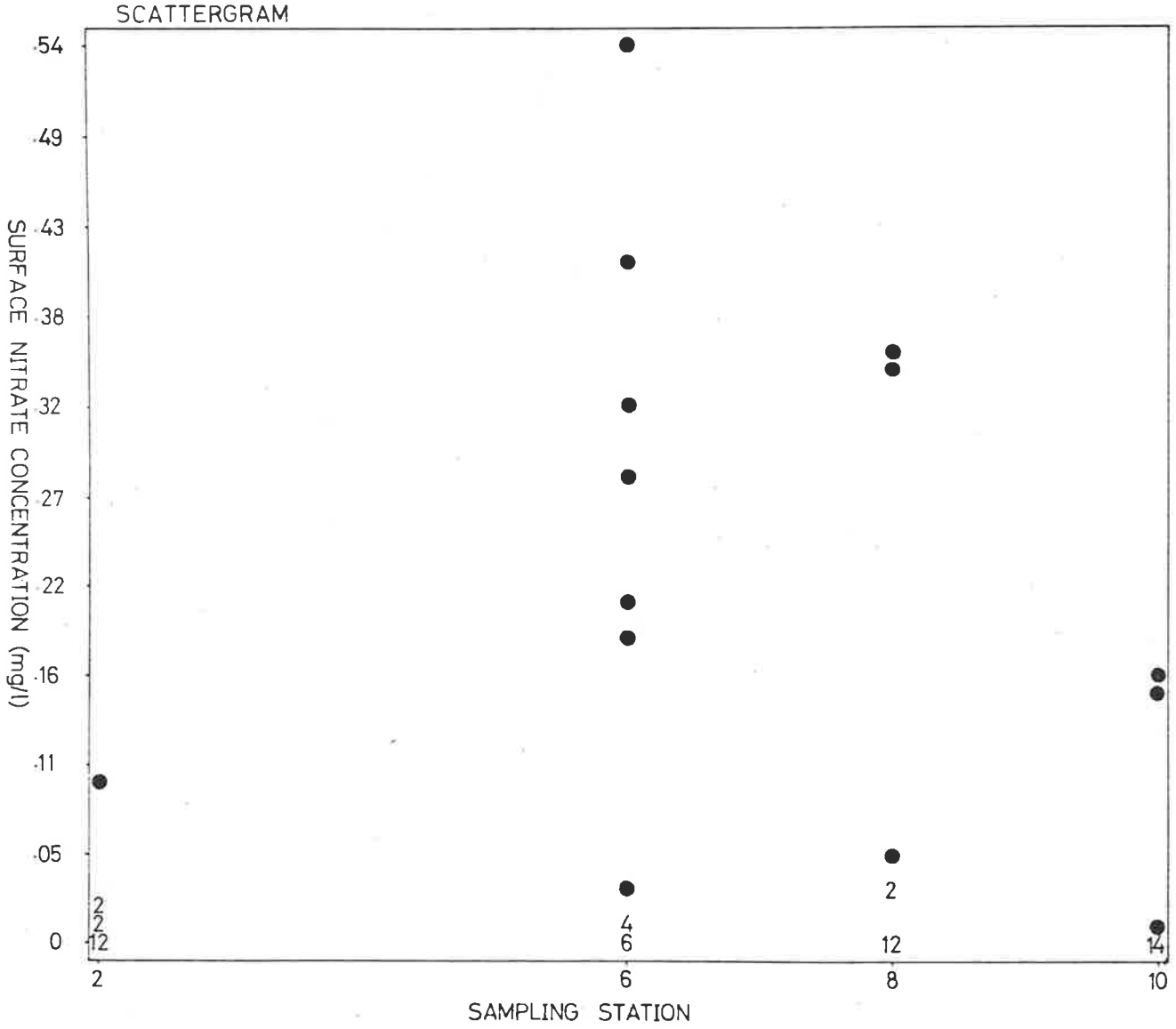

SCATTERGRAM
.54
.49
.43
.38
.32
.27
.22
.16
.11
.05
0
SURFACE NITRATE CONCENTRATION (mg/l)
2
2
12
4
6
2
12
14
2
6
8
10
SAMPLING STATION

FIGURE 82

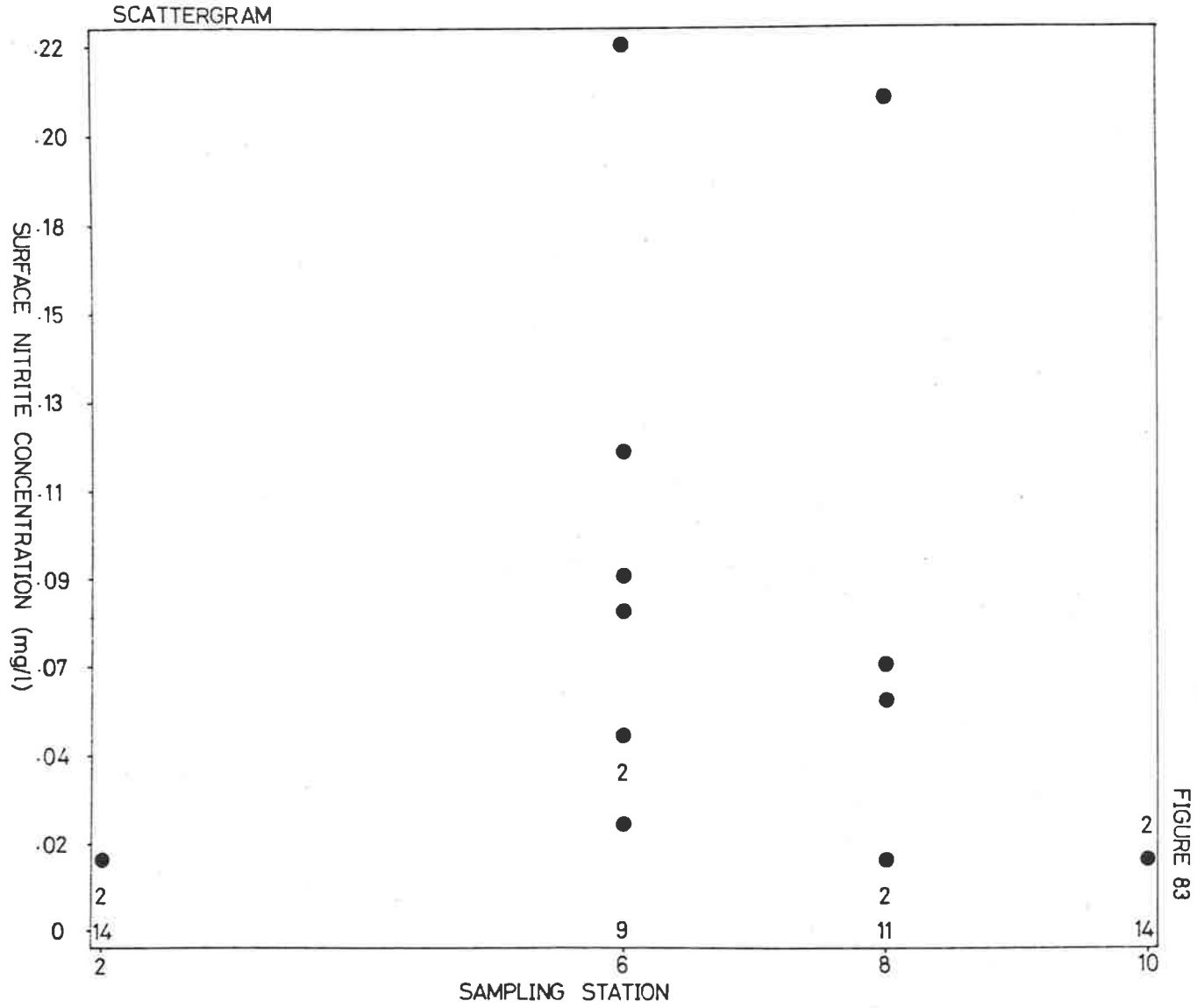

SCATTERGRAM
.22
.20
.18
.15
.13
.11
.09
.07
.04
.02
0
SURFACE NITRITE CONCENTRATION (mg/l)
2
14
9
2
11
2
14
2
6
8
10
SAMPLING STATION

FIGURE 83

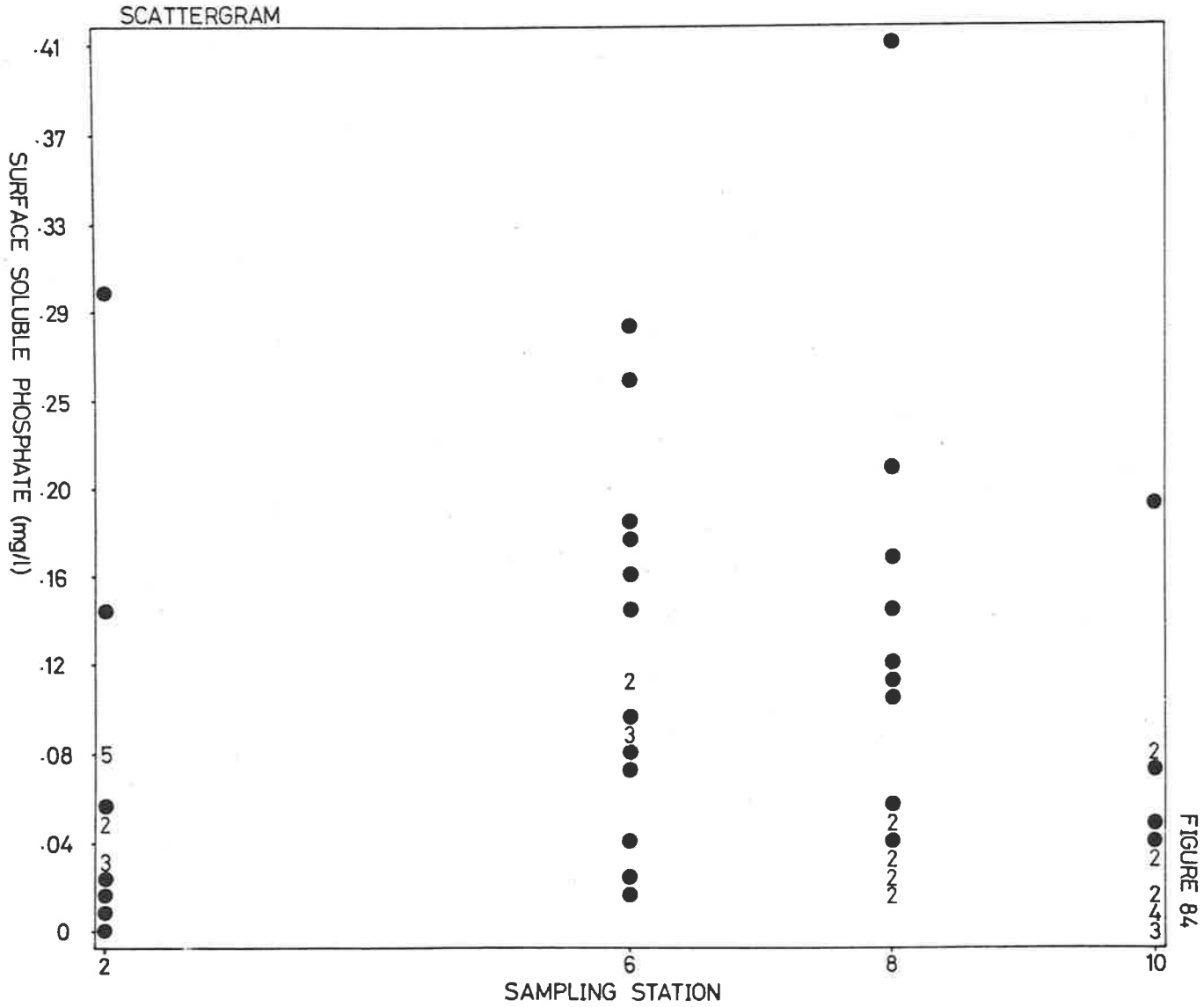

SCATTERGRAM
SURFACE SOLUBLE PHOSPHATE (mg/l)
.41
.37
.33
.29
.25
.20
.16
.12
.08
.04
0
2
6
8
10
SAMPLING STATION

FIGURE 84

Distance from Noarlunga ford (km)	1.7	5.6	8	10
TDS (g/l)	29	11	37	40
NH3 (mg/l)	.22	3.25	.13	.03
NO3 (mg/l)	.30	3.35	.04	.02
NO2 (mg/l)	.04	.28	.02	<.01
TON (mg/l)	.89	27.12	.49	.36
PO4S (mg/l)	.077	1.390	.032	.011
PO4P (mg/l)	.137	.870	.063	.016
Detergent (mg/l)	.04	.11	.02	<.01
TOC (mg/l)	7	40	14	3
B.O.D. (mg/l)	4	10	2	1
pH	8.0	7.8	8.1	8.0
Suspended solids (mg/l)	34	720	19	42
Total coliform bacteria (/100ml)	42000	81000	260	530
Total E. coli (/100ml)	42000	77000	260	430

Results of surface water analyses taken at high tide on 23/5/1977 by an officer of the Engineering and Water Supply Department.

	DIST	TDS	SILOX	TIC	TEMP	QUANT	PO4P	TON	NH3	TOC	pH	NO3	NO2	PO4S
TOTCELL	-.04	-.35	.23	.11	-.55	-.59	.13	.28	.32	.11	.42	.35	.42	.14
TOTATT	-.41	.64	.36	.48	-.46	-.52	.45	.58	.65	.33	.44	.30	.34	.16
TOTUNAT	.20	-.05	.07	-.16	-.44	-.44	-.12	.00	.00	-.07	.27	.27	.31	.08
MELSP1	-.45	-.57	.26	.51	-.37	-.47	-.34	.50	.56	.31	.29	.22	.25	.14
ABREV	-.41	-.54	.34	.42	-.19	-.27	.33	.23	.47	.24	.21	.20	.14	.07
SYNTAB	-.18	-.46	.34	.19	-.38	-.33	.45	.49	.44	.17	.42	.34	.43	.07
PLAG	-.03	-.07	.23	-.03	.02	.01	.14	.15	.07	.05	.14	.15	.41	.29
SYNLAEV	.14	.25	-.13	-.15	.29	.30	-.10	-.07	-.06	.02	-.01	-.12	-.02	.22
LIC4	.17	.12	-.04	-.08	.01	.03	-.03	.00	-.04	-.08	.10	-.03	-.05	.00
GRAMOC	.19	.20	-.06	-.15	.17	.21	-.05	-.03	-.08	-.09	-.12	-.04	-.00	-.04
SYNFULG	.22	.15	-.13	-.10	.08	.08	-.07	-.04	-.07	-.13	.11	.07	-.02	.04
LICFLAB	.27	.22	-.15	-.27	-.06	-.04	-.10	-.06	-.14	.06	.10	-.08	-.05	-.04
LIC3	.28	.17	-.10	-.20	-.13	-.05	-.09	-.04	-.10	-.09	.16	-.10	-.05	.07
STRIAT	.29	.27	-.10	-.22	-.04	-.06	-.08	-.05	-.07	.01	.14	-.05	-.06	.01

Correlation coefficients for viable cell densities versus environmental variables.

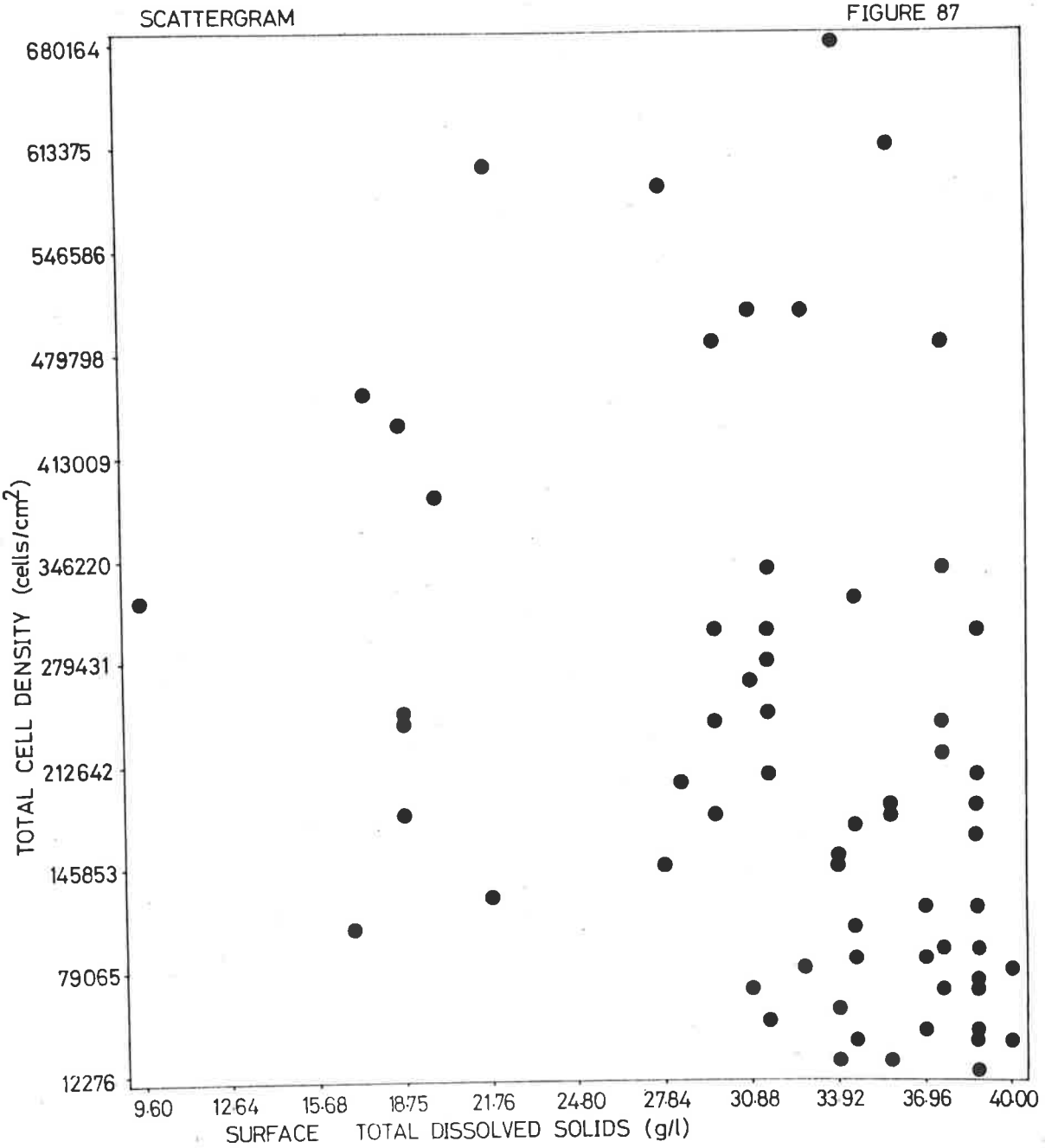
FIGURE 86

FIGURES 87-89

SCATTERGRAMS to illustrate the scatter of Total Cell Densities with respect to selected environmental variables.

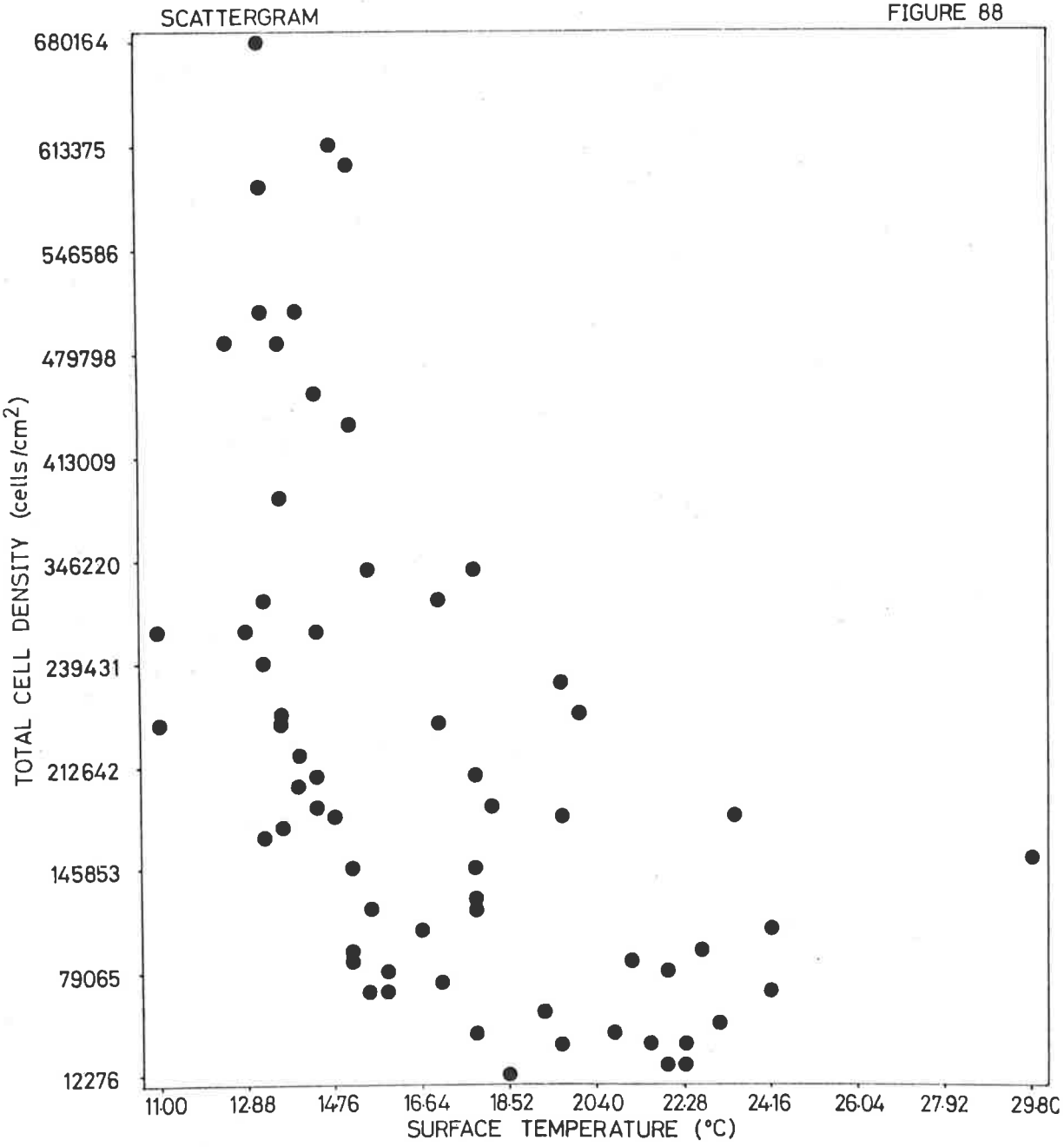
SCATTERGRAM

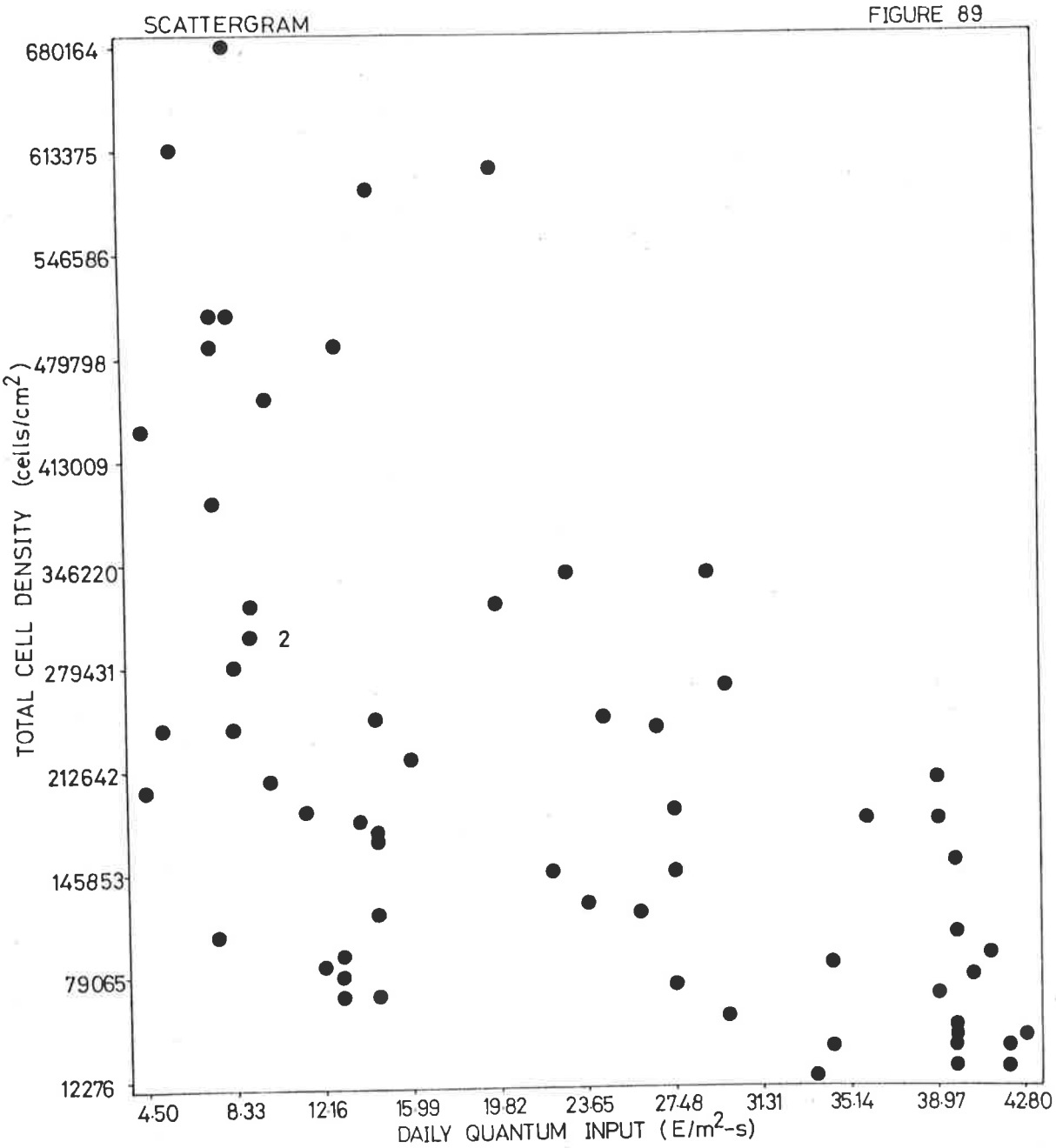
FIGURE 87



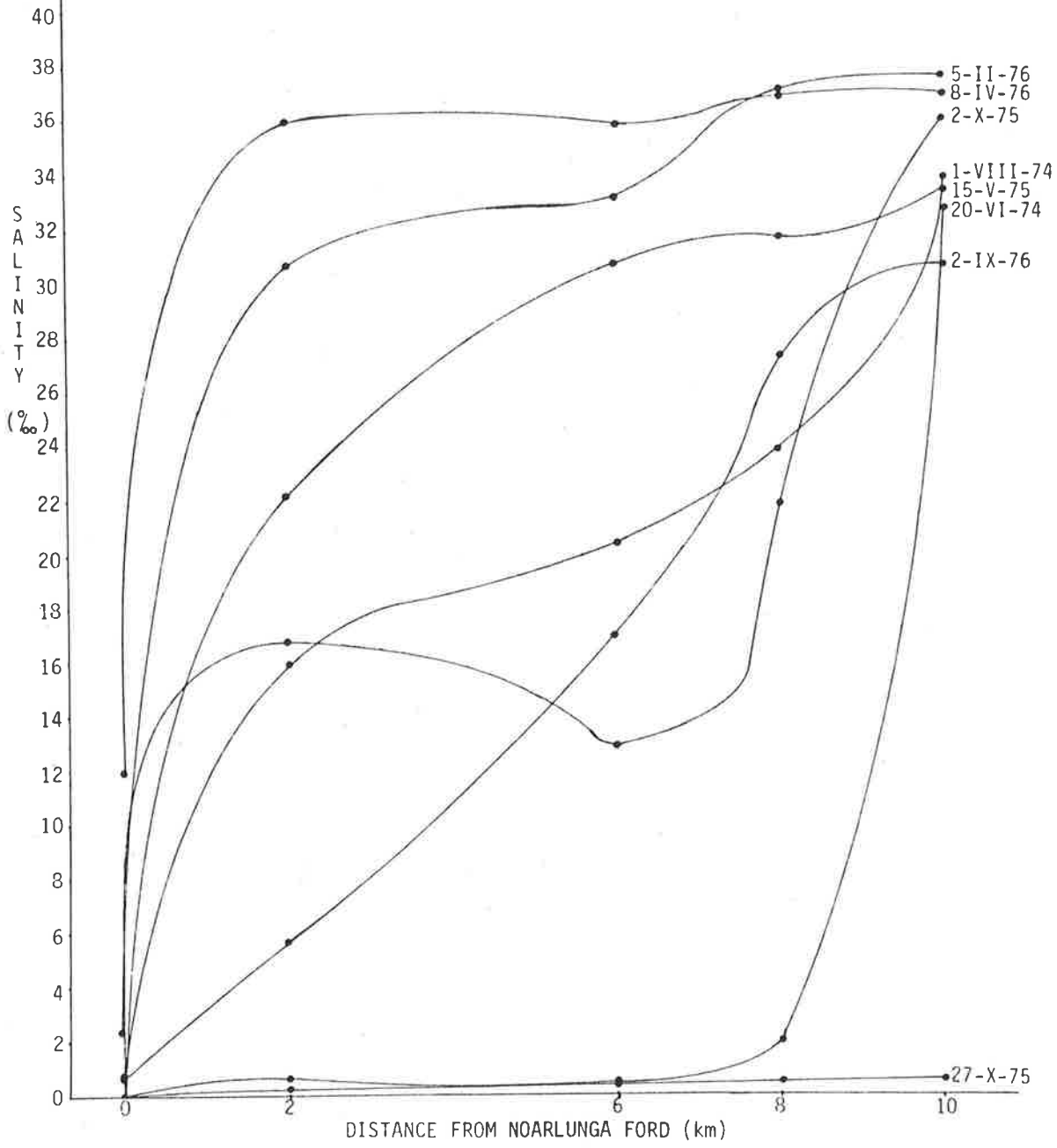
SCATTERGRAM

FIGURE 88




SCATTERGRAM
FIGURE 89
680164
613375
546586
479798
413009
346220
279431
212642
145853
79065
12276
TOTAL CELL DENSITY (cells/cm^2)
2
4·50
8·33
12·16
15·99
19·82
23·65
27·48
31·31
35·14
38·97
42·80
DAILY QUANTUM INPUT (E/m^2-s)

SURFACE SALINITY GRADIENTS IN THE ONKAPARINGA ESTUARY: 1974-1976 FIGURE 90



	DIST	TDS	SILOX	TIC	TEMP	QUANT	PO4P	TON	NH3	TOC	pH	NO3	NO2	PO4S
MELSP1	-.60	-.40	.12	.49	-.12	-.26	.07	.15	.25	.15	.00	.21	.18	.15
ABREV	-.39	-.22	.20	.26	.24	.15	.08	-.04	.08	.08	-.14	-.03	-.06	.21
PLAG	-.03	-.07	.22	-.03	.03	.02	.14	.14	.07	.05	.13	.15	.40	.28
SYNLAEV	.15	.19	-.18	-.16	.32	.32	-.08	-.06	-.08	.02	-.01	-.13	-.07	.19
SYNFULG	.16	.15	-.20	-.16	.26	.26	-.07	-.04	-.08	-.12	-.03	-.06	-.08	.05
SYNTAB	.20	-.11	.04	-.12	-.23	-.14	.08	.07	.04	-.17	.12	.03	.07	-.22
LIC4	.23	.19	-.06	-.15	-.09	-.04	-.08	-.04	-.08	-.12	.12	.01	-.03	.00
GRAMOC	.29	.30	-.16	-.24	.28	.36	-.02	-.07	-.16	-.07	-.15	-.13	-.10	-.11
LICFLAB	.32	.32	-.24	-.33	.07	.07	-.13	-.07	-.19	.09	-.01	-.12	-.09	-.11
STRIAT	.42	.37	-.06	-.34	-.00	-.02	-.04	-.08	-.11	.04	.04	-.12	-.13	-.19
LIC3	.45	.28	-.09	-.32	-.16	-.01	-.12	-.09	-.20	-.10	.04	-.08	-.09	-.13

Correlation coefficients for viable cell proportions versus environmental variables.

FIGURE 91

	DIST	TDS	SILOX	TIC	TEMP	QUANT	PO4P	TON	NH3	TOC	pH	NO3	NO2	PO4S
MELSP1	-.58	-.40	.13	.48	-.05	-.19	.11	.16	.23	.21	.03	.18	.17	.18
ABREV	-.49	-.19	.14	.33	.35	.22	-.03	-.09	.04	.10	-.26	-.12	-.11	.18
FRAG	-.23	-.13	.04	.32	-.16	-.12	.19	.02	.06	-.01	.16	.06	-.01	-.05
MELVAR	-.15	.02	.34	.11	.08	.03	-.05	-.03	-.03	.00	-.07	-.07	-.07	.26
GOMCAP	-.14	-.13	.20	.05	.03	-.01	-.02	-.04	-.04	-.12	-.03	-.07	-.07	-.01
OPEPH	-.09	.08	.07	.10	.08	.13	-.03	-.04	-.06	-.03	-.11	-.06	-.06	.02
RHOIC	-.02	.22	.26	.09	.05	.09	-.07	-.08	-.01	-.06	-.23	-.13	-.08	-.05
SYNPUL	-.02	-.07	.20	.15	-.10	-.17	-.04	-.05	.01	-.03	.04	.55	.31	.17
RHAPH	.11	.11	-.01	-.05	.01	.15	-.07	-.07	-.07	-.12	-.09	-.06	-.06	-.02
CLIMAC	.14	.11	.12	-.09	.02	.17	-.03	-.04	-.05	-.01	-.07	-.06	-.05	-.12
SYNLAEV	.14	.19	-.15	-.13	.22	.25	-.09	-.07	-.07	-.05	.01	-.11	-.10	.17
DIMER	.16	.20	.15	-.04	.04	-.03	-.07	-.07	-.02	-.02	-.08	-.03	.02	-.03
SYNTAB	.21	-.11	.03	-.16	-.32	-.17	.12	.08	.07	-.19	.15	.14	.15	-.19
LIC4	.27	.19	-.07	-.18	-.10	-.05	-.07	-.02	-.09	-.12	.13	-.01	-.05	-.03
PLAG	.27	.21	.04	-.18	-.00	.04	.05	-.09	-.03	.01	-.07	-.14	-.08	-.05
SYNFULG	.29	.23	-.02	-.15	.14	.16	-.08	-.08	-.11	-.10	-.01	-.11	-.13	-.02
STRIAT	.31	.30	.07	-.25	-.02	-.05	-.10	-.06	-.06	.04	.01	-.13	-.12	-.17
LICFLAB	.34	.26	-.20	-.34	-.04	-.02	-.11	-.06	-.19	.03	.01	-.10	-.11	-.16
GRAMOC	.36	.36	-.18	-.30	.29	.39	.00	-.09	-.18	-.08	-.16	-.17	-.13	-.15
LIC3	.43	.24	-.09	-.30	-.21	-.13	-.12	-.07	-.16	-.12	.12	-.05	-.06	-.05

FIGURE 92

Correlation coefficients for cleared cell proportions versus environmental variables.

FIGURE 93

A. Species' constellation based on correlation coefficients of viable cell densities.

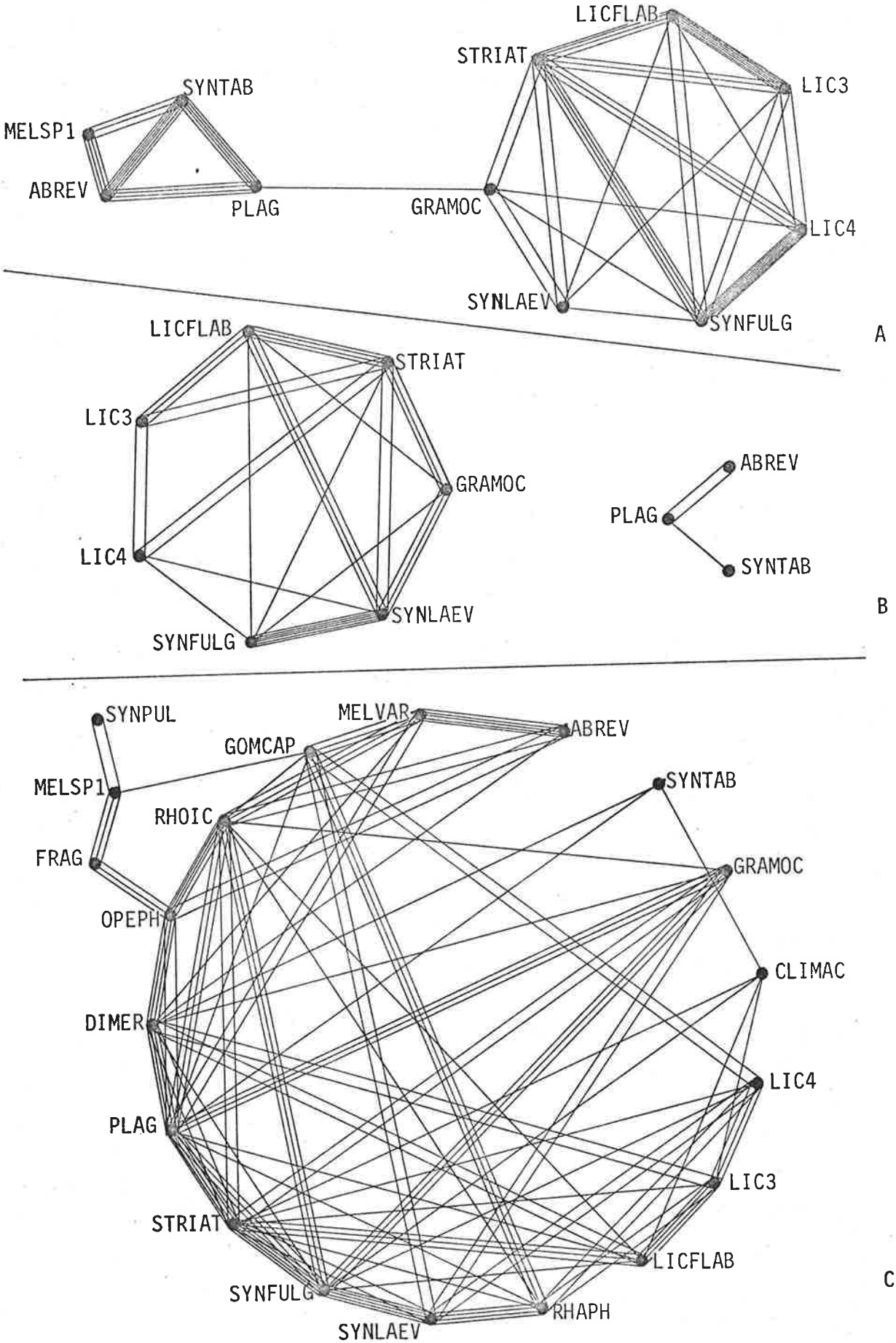
B. Species' constellation based on correlation coefficients of viable cell proportions.

C. Species' constellation based on correlation coefficients of cleared cell proportions.

KEY

ABREV	Achnanthes brevipes var. intermedia
CLIMAC	Climacosphaenia moniligera
DIMER	Dimeregramma minor
FRAG	Fragilaria pinnata
GOMCAP	Gomphonema constrictum var. capitatum
GRAMOC	Grammatophora oceanica
LICFLAB	Licmophora flabellata
LIC3	L. sp.3
LIC4	L. sp.4
MELSP1	Melosira sp.1
MELVAR	M. varians
OPEPH	Opephora martyi
PLAG	Plagiogramma staurophorum
RHAPH	Rhaphoneis surirella var. australis
RHOIC	Rhoicosphaenia curvata
STRIAT	Striatella unipunctata
SYNFULG	Synedra fulgens
SYNLAEV	S. laevigata
SYNPUL	S. pulchella var. lacerata
SYNTAB	S. tabulata

FIGURE 93


LICFLAB
STRIAT
LIC3
SYNTAB
MELSP1
ABREV
PLAG
GRAMOC
LIC4
SYNLAEV
SYNFULG
A
LICFLAB
STRIAT
LIC3
GRAMOC
LIC4
SYNLAEV
SYNFULG
ABREV
PLAG
SYNTAB
B
SYNPUL
MELVAR
ABREV
GOMCAP
MELSP1
SYNTAB
RHOIC
FRAG
GRAMOC
OPEPH
CLIMAC
DIMER
LIC4
PLAG
LIC3
STRIAT
LICFLAB
SYNFULG
RHAPH
SYNLAEV
C

ABREV	.35									
SYNTAB	.26	.53								
PLAG	-.02	.34	.41							
SYNLAEV	-.22	-.22	-.19	-.07						
LIC4	-.09	-.10	-.01	-.03	-.05					
GRAMOC	-.15	-.11	-.07	.02	.19	.04				
SYNFULG	-.04	-.17	-.08	-.05	.10	.80	.05			
LICFLAB	-.18	-.18	-.11	-.06	.07	.03	-.01	.17		
LIC3	-.17	-.17	-.09	-.05	.01	.01	-.06	.13	.69	
STRIAT	-.16	-.24	-.16	-.07	.17	.29	.13	.32	.37	.26
	MELSP1	ABREV	SYNTAB	PLAG	SYNLAEV	LIC4	GRAMOC	SYNFULG	LICFLAB	LIC3

Correlation coefficients for species' associations based on viable cell densities.

FIGURE 94

ABREV	-.11									
PLAG	-.07	.19								
SYNLAEV	-.19	-.19	-.02							
SYNFULG	-.02	-.19	-.04	.60						
SYNTAB	-.31	-.05	.10	-.20	-.12					
LIC4	-.23	-.19	-.04	.07	.02	-.08				
GRAMOC	-.30	-.17	-.06	.21	.06	-.18	-.06			
LICFLAB	-.33	-.22	-.08	.22	.07	-.20	-.07	.05		
STRIAT	-.33	-.32	-.08	.12	.06	-.05	.13	.20	.30	
LIC3	-.42	-.32	-.08	-.13	-.05	-.14	.11	-.01	.27	.11
	MELSP1	ABREV	PLAG	SYNLAEV	SYNFULG	SYNTAB	LIC4	GRAMOC	LICFLAB	STRIAT

Correlation coefficients for species' associations based on viable cell proportions.

FIGURE 95

ABREV	-.06														
FRAG	.26	-.05													
MELVAR	-.07	.42	-.04												
GOMCAP	.10	-.02	-.04	.26											
OPEPH	-.06	.20	.22	-.03	-.03										
RHOIC	-.12	.16	-.04	.23	.09	.45									
SYNPUL	.19	-.06	-.03	-.02	-.03	-.02	-.05								
RHAPH	-.13	-.12	-.04	-.04	.23	-.03	.03	-.03							
CLIMAC	-.13	-.08	-.03	-.02	-.03	-.02	-.05	-.02	-.03						
SYNLAEV	-.13	-.19	-.07	-.05	.18	-.05	-.05	-.04	.33	-.04					
DIMER	-.26	.03	-.06	.02	-.02	.42	.33	-.04	-.06	-.04	-.03				
SYNTAB	-.40	-.07	-.09	-.12	-.11	-.01	-.05	-.08	-.02	.07	-.23	.04			
LIC4	-.28	-.22	-.05	-.04	.09	-.04	-.10	-.03	.17	-.03	.12	-.03	-.04		
PLAG	-.23	-.06	-.09	.13	.03	.16	.28	-.05	.05	-.05	-.07	.33	.05	-.09	
SYNFULG	-.20	-.26	-.05	-.05	-.07	-.02	.29	-.05	-.00	.10	.48	.07	-.15	.01	
STRIAT	-.27	-.28	-.07	-.06	-.03	-.06	.14	-.03	.01	.10	.12	.11	-.13	.08	
LICFLAB	-.33	-.24	-.07	-.05	-.06	-.05	.03	-.02	-.07	.02	-.03	.17	-.08	-.03	
GRAMOC	-.31	-.17	-.09	-.04	-.03	-.00	.06	-.05	-.00	.15	.20	.09	-.22	-.06	
LIC3	-.40	-.33	-.08	-.07	-.08	-.06	-.03	-.05	.19	.08	-.12	.14	-.01	.27	
	MELSP1	ABREV	FRAG	MELVAR	GOMCAP	OPEPH	RHOIC	SYNPUL	RHAPH	CLIMAC	SYNLAEV	DIMER	SYNTAB	LIC4	

SYNFULG	.22				
STRIAT	.43	.47			
LICFLAB	.03	.05	.21		
GRAMOC	.26	.28	.19	-.01	
LIC3	-.03	-.01	.01	.36	-.07
	PLAG	SYNFULG	STRIAT	LICFLAB	GRAMOC

Correlation coefficients for species' associations based on cleared cell proportions.

FIGURE 96