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Peripheral vegetation of Peel Inlet and Harvey Estuary, Western Australia

by D. J. Backshall and P. B. Bridgewater

School of Environmental and Life Sciences, Murdoch University, Murdoch, W.A. 6153

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Abstract

Fifteen vegetation units, distinguished by differences in the floristic composition of vascular plant species, have been recognised from the Peel Inlet-Harvey Estuary system, Western Australia. Analysis of the epontic diatom flora within units confirms their integrity. The spatial distribution of these vascular-plant communities around the estuarine system appears to be controlled by the substrate summer salinity values, together with the vertical distance from the high water mark. Evidence from aerial photographs extending back 23 years suggests that dynamic processes are less important than these spatial controls in determining community distribution. Exceptions to this occur only when sudden major geomorphic changes force concomitant vegetation changes.

Introduction

During 1977-78 an investigation was undertaken of the peripheral vegetation and associated diatom flora of the Peel Inlet-Harvey Estuary System, Western Australia. This estuarine system comprises two large shallow basins of 65 km^2 (Peel Inlet) and 50 km^2 (Harvey Estuary), joined to the sea by a 5 km inlet channel. The basins are connected to each other by a narrow channel, which cut through a broad, barely submerged marginal shelf. The sedimentology of the area has been described by Logan and Brown (1975). This survey was confined to the tidal marsh environment of both Peel Inlet and Harvey Estuary.

Ecological studies of Western Australian vegetation have shown considerable methodological variation, from empirical analysis of transects (e.g. Sauer 1964), classifications based on dominant strata using a range of criteria (Gardner 1942, Speck 1952, Beard and Webb 1974) to recent implementation of numerical methods utilising floristic information (Havel 1975). This paper outlines the application of the Zurich-Montpellier (Z-M) method as a practical technique utilising floristic attributes. Additionally, the paper evaluates the results from this technique with independently gathered environmental data and data obtained from diatom sampling.

Theoretical implications of Z-M phytosociology have been discussed by Bridgewater (1971), Westoff and van der Maarel (1973) and Muller-Dombois and Ellenberg (1974). These references contain the most detailed accounts of the techniques available in the English language, and it is not proposed to discuss them further in this paper.

Methods

At each of eighteen sites (Fig. 1) two or three transects were laid from the high water mark to the edge of the sandy beach ridge. These sites were considered to represent the least disturbed examples of a variety of soil and vegetational types. Soils of the estuary fringe are referrable to three soil systems—Bassendean and Spearwood Dune systems and Pinjarra Plain soil system (McArthur and Bettenay 1960). Site selection was made by field reconnaissance, coupled with use of colour aerial photography taken in 1976 by the Western Australian Lands Department. The transects comprised regularly spaced relevés (samples) one metre square and spaced 5 or 10 m apart, depending on the abruptness of vegetation change. A total of 747 relevés were collected from the estuaries. Species cover-abundance were recorded for each relevé using the Braun-Blanquet scale (Bridgewater 1971). A set of computer programs was used to print tables of species and relevés for each transect. These tables were then examined, and 'potential differential species' (PDS) noted. The initial choice of PDS is made from species having an apparently clumped distribution, with usually $< 60\%$ presence in the group of relevés forming the transect. Selection of PDS was facilitated using a computer program, which incorporates numerical methods as outlined by Ceska and Roemer (1971). Groups of relevés with similar PDS were then extracted from the transect raw tables and entered into a presence table (Table 1).

Each column in Table 1 represents thus the sum of a number of relevés from the estuary, with the frequency of species presence in these relevés recorded as a percentage class (I-V). Table 1 allows the structuring of a classification for the tidal marsh vegetation (Table 2). As only one locality was surveyed, it is inappropriate to utilise the standard Z-M system of nomenclature. Accordingly, the system of naming the vegetation units follows that of Bridgewater (1974). For ease of reference all specific names are derived from Blackall and Grieve (1974) and Grieve & Blackall (1975).

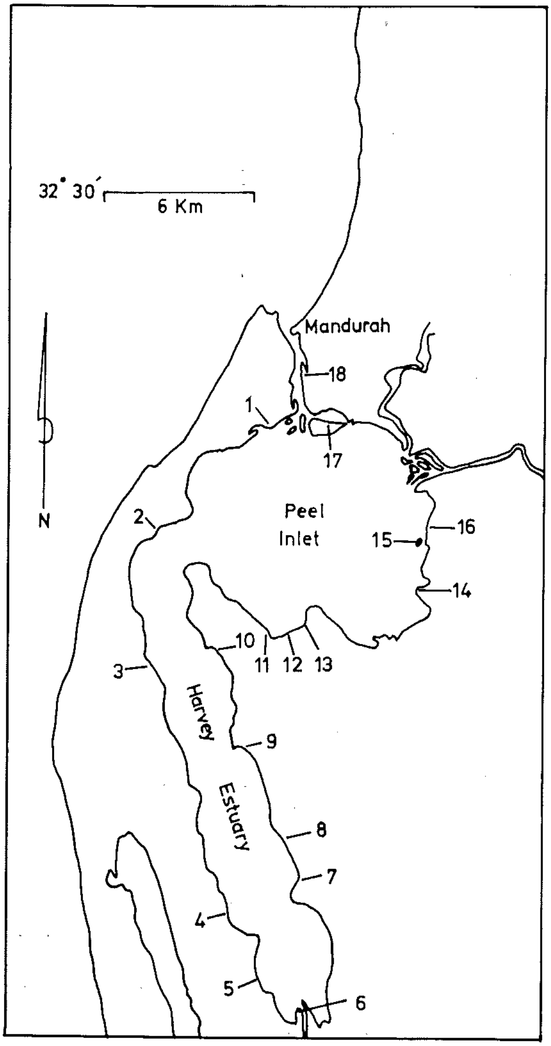

Figure 1.—Location map of Peel Inlet—Harvey Estuary showing sites of transect analysis.

Vegetation ecology

The fifteen vegetation units derived from the classification (Table 2), augmented by all diatom species (Table 3), were subjected to Principal Axes Ordination (van der Maarel 1969). This technique allows a choice of reference stands which will establish the extremes of a gradient instead of emphasizing differences within the groups.

The ordination (Fig. 2) is accompanied by selected substrate information. Summer salinity values were derived from soil samples obtained from the top 10 cm of the soil profile. These were collected during March from all transects, and analysed as a 1:5 soil water extract using a P66 digital chlorodometer. Total ions were measured as a 1:5 soil water extract using a Sproule electronic conductivity meter. This analysis was performed in August. Data were obtained from four replicate sites for each vegetation group.

The Y axis of the ordination appears to relate strongly to salinity, with hypersaline relevés at the positive end and slightly brackish relevés at the negative. The relationship of relevés along the X axis is less easily discernable, but approximates to a littoral—beach ridge sequence.

Vegetation distribution and dynamics

Peripheral vegetation of an estuary is influenced by marked variations in substrate conditions in both space and time. Horizontal distance from the littoral zone and vertical distance from a fluctuating water table are two important factors superimposed on other influences. Environmental factors may occur either as a mosaic, or as an attenuating gradient, depending upon local conditions. An understanding of the spatial relationships of vegetation with these environmental factors may help in elucidating temporal processes operating within estuarine vegetation. Figure 3 shows the distribution of physical features, vegetation units and salinity regimes along a hypothetical transect from water edge to established dunes.

Distribution of the *Arthrocnemum* complex component communities reflect both spatial and temporal sequences which are readily observed in numerous salt marshes of the area. The *Arthrocnemum bidens* community develops on the less saline rims of salt marsh concavities, but progrades into the *Triglochin mucronata* community at lower levels. In the more saline centres of the concavities, *A. halocnemoides* occurs as a single species, or in extreme environments, a bare pan develops. Where the concavities are less saline, perhaps as a result of more effective ground water or tidal flushing the *Salicornia quinqueflora* community occurs. Sedimentation of the concavity and subsequent reduction of flushing implies a maturation of the system through time. Where the concavity is linked to the estuary, the *Arthrocnemum* complex merges with the *Salicornia* complex.

Beeftink (1962) found the salinity units of the Venice system useful in environmentally classifying saltmarsh communities. This system provides a classification of saline waters into three broad categories—euhaline, with a range of 1.65-2.2% chlorinity, polyhaline, with a range of 1.0-1.65% chlorinity, and mesohaline, with a range of 0.3-1.0% chlorinity. Vegetation units 1-3 (*Arthrocnemum* complex) are euhaline, using this terminology, while the *Triglochin mucronata* and *Salicornia quinqueflora* communities (units 4 and 5) are polyhaline, with all other communities being mesohaline.

Many communities clearly respond to spatial features, such as the salinity changes described above, rather than temporal factors. Nevertheless, due to the dynamic nature of shorelines in this region, it is possible to infer some successional relationships between communities. Inference may be given a factual basis by comparison of old aerial photographs with recent runs. In this study aerial photographs from 1957 allowed a time scale to be placed on some successional processes.

Initial development of tidal marshes can be linked to emergence of spits or sandbars. Sedimentation often continues until the bar is joined to the shore by one extremity (Chapman 1938). Once sufficient

Table 1.

Presence table for important species in the 15 vegetation units

Vegetation units (see Table 2)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Arthrocnemum halocnemoides	V	V	V	V	I	+	....	....	....	....	II	II	....	....	....
Salicornia quinqueflora	....	I	V	II	V	V	V	IV	V	....	III	....	....	....	....
Suaeda australis	....	....	....	....	I	V	I	+	III	+	III	....	II	....	....
Juncus maritimus	....	....	....	....	....	III	IV	V	....	III	I	....	V	....	....
Machaerina juncea	....	....	....	....	....	....	I	+	V	III	....	....	....	....	....
Melaleuca raphiophylla	....	....	....	....	I	II	....	....	IV	III	....	....	....	....	....
Schoenus fasicularis	....	....	....	....	....	....	....	....	I	IV	....	....	....	....	....
Apium prostratum	....	....	....	....	....	....	....	....	....	IV	....	....	....	....	....
Sporobolus virginicus	....	+	....	....	III	I	I	+	....	IV	IV	....	I	....	V
Atriplex paludosa	....	....	....	....	....	I	....	....	I	....	V	V	....	....	....
Parapholis incurva	II	....	....	....	+	....	....	....	....	....	II	....	....	V	V
Cotula coronopifolia	....	....	....	....	....	....	....	....	....	....	....	....	....	V	IV
Arthrocnemum bidens	V	+	....	....	....	I	....	....	....	....	....	....	....	III	III
Triglochin mucronata	....	+	+	V	....	....	....	....	....	....	....	....	....	....	....
Gahnia trifida	....	....	....	....	....	+	V	+	II	+	....	....	....	....	....
Frankenia pauciflora	I	I	I	II	+	....	....	....	....	....	IV	....	....	I	....
Atriplex hastata	....	....	....	....	+	I	....	....	....	+	+	V	II	II	....
Polypogon monspeliensis	....	+	....	....	+	I	....	....	III	II	....	V	....	V	....
Angianthus preissianus	I	I	....	III	+	....	....	....	....	....	....	....	....	....	IV
Casuarina obesa	I	....	....	III	II	....	I	I	....	....	....	....	....	I	I
Hordeum hystrix	....	+	....	III	....	....	....	....	....	+	....	....	....	II	....
Melaleuca cuticularis	....	....	+	....	+	I	II	III	III	....	II	....	I	....	....
Samolus juncea	....	....	+	III	....	+	....	III	II	II	....	....	....	....	....

Note: I = species occurred between 0-19% of relevés taken.
II = species occurred between 20-39% of relevés taken.
III = species occurred between 40-59% of relevés taken.
IV = species occurred between 60-79% of relevés taken.
V = species occurred between 80-100% of relevés taken.
\+ = species occurred in only one relevé taken.

N.B. Species which occurred in less than 5 of the total relevés are not included in this table.

protection is afforded, the pioneer community appears to be the *Salicornia quinqueflora* community, often with *S. quinqueflora* as the only species represented. As the surface is stabilised, and raised a little by silt accumulation, the *Salicornia* community is replaced by the *Salicornia-Suaeda australis* community. A tidal marsh of these two communities now exists north of Heron Point, Harvey Estuary. That this marsh has developed within 20 years is established by comparison of aerial photographs for 1957 and 1976.

Marshes colonised by *Arthrocnemum* species are more saline, tend to be completely summer dry and certainly have a better developed soil profile than the early colonising spits and sandbars. It seems likely that the *Arthrocnemum* community represents a stable environment, which could be regarded as climax vegetation. Most of the communities identified appear more correlated with estuarine and fluvial processes, rather than the base soil system. Exceptions to this appear to be the *Salicornia-Machaerina* and *Schoenus-Sporobolus* communities which are apparently confined to shores of the Spearwood Dune system.

Diatom communities

Little work has been done in Australia on the diatom flora of estuaries and salt marshes, with Wood (1964) being the most significant contribution. Diatoms form an important part of the food chain in estuaries, with some species also useful as environmental indicators. Associations of distinct diatom communities with terrestrial and macro-algal communities in salt marshes and estuaries have been noted by Carter (1948), Round (1960) and Chapman (1962).

Table 2.

Classification of vegetation units

I. *Arthrocnemum halocnemoides* complex
    1. *Arthrocnemum bidens* community
    2. *A. halocnemoides* community
    3. *Salicornia quinqueflora* community
    4. *Triglochin mucronata* community

II. *Salicornia quinqueflora* complex
    5. *S. quinqueflora* community

III. *Salicornia quinqueflora—Suaeda australis* complex
    6. *Suaeda australis* community

IV. *Juncus maritimus—Salicornia quinqueflora* complex
    7. *Gahnia trifida* community
    8. *Juncus maritimus—Salicornia quinqueflora* community

V. *Salicornia quinqueflora—Machaerina juncea* complex
    9. *Salicornia quinqueflora—Machaerina juncea* community

VI. *Schoenus fasicularis—Sporobolus virginicus* complex
    10. *Schoenus fasicularis—Sporobolus virginicus* community

VII. *Atriplex paludosa* complex
    11. *Frankenia pauciflora* community
    12. *Atriplex hastata* community

VIII. *Juncus maritimus* complex
    13. *Juncus maritimus* community

IX. *Cotula coronopifolia—Parapholis incurva* complex
    14. *Polypogon monspeliensis* community
    15. *Sporobolus virginicus—Angianthus preissianus* community

Vegetation units denoted by arabic numerals refer to the numbered columns in Table 1.

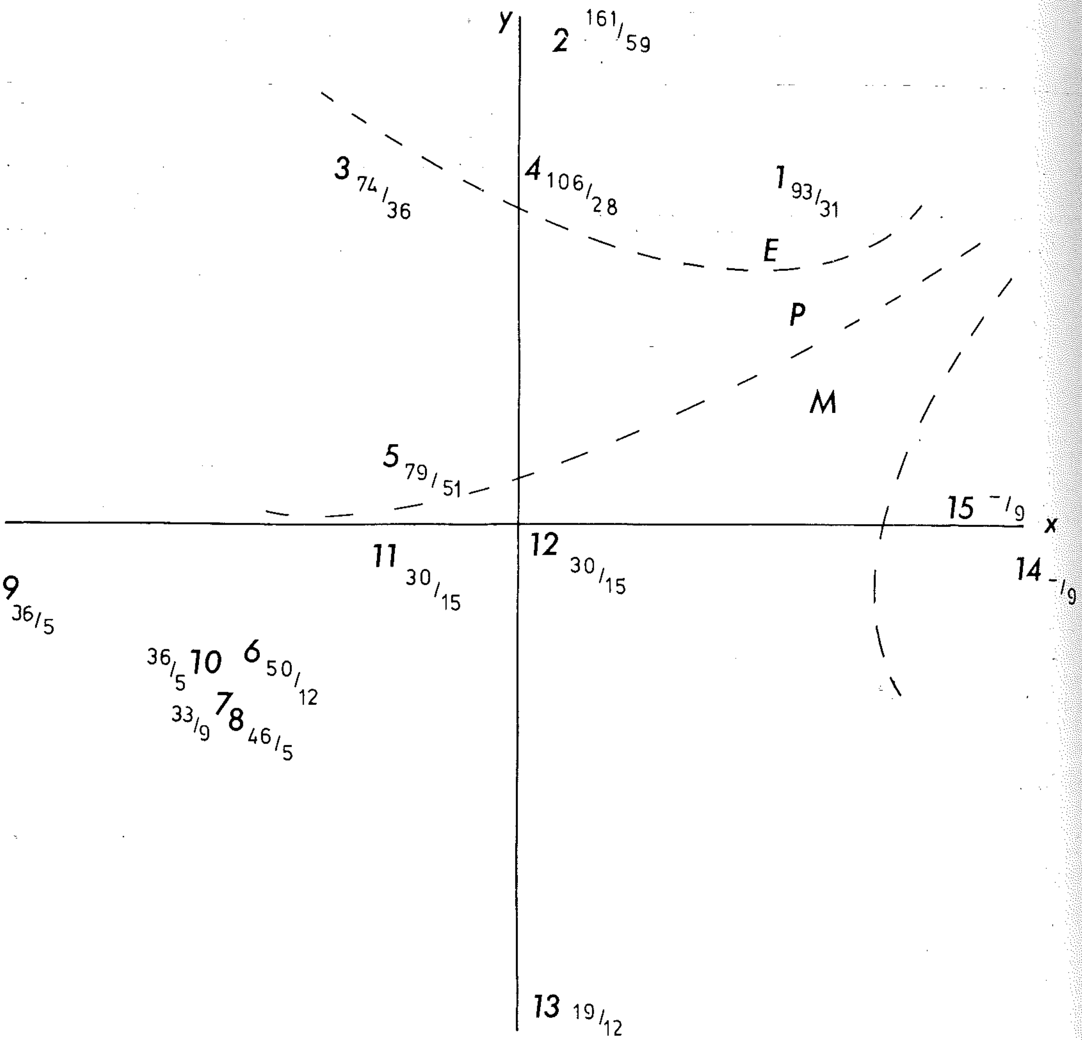

Figure 2.—Principal Axes Ordination of the 15 vegetation units. Figures in bold type represent vegetation units. (see Table 2). Figures in lighter type represent values for chlorinity and total ions (Meq. L-1/μMhos x 10-2). Dashed lines define salinity, where E equals euhaline, P equals polyhaline and M equals mesohaline.

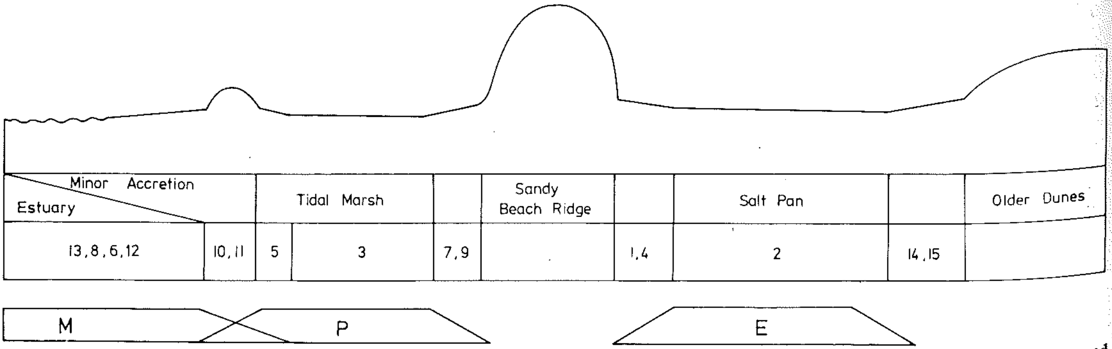

Figure 3.—Schematic diagram of important physical features of the peripheral estuarine environment, vegetation units and salinity types along a hypothetical transect. Figures denote the vegetation units, while the salinity types are indicated thus: M equals mesohaline, P equals polyhaline, E equals euhaline.

Diatom communities and floristically defined vascular plant communities may well be affected by different environmental conditions. Aleem (1950), however, showed that benthic diatoms seldom penetrate deeper than 2 mm into the marsh surface. Diatoms form a micro-habitat of mucilage on the surface of salt marshes in the Peel-Harvey system, so they could be buffered to some extent from the high salinity levels in the soils of the mature marshes. Planktonic forms may also be temporarily deposited in benthic conditions, and, if sampled, could conceivably affect the results obtained. With these caveats in mind, an analysis of diatoms found in each of the 15 vegetation units was attempted.

Four widely distributed replicate sites were chosen for each of the vegetation units noted in Table 2. Soil surface scrapings from each site were cultured in petri dishes in the laboratory. A sterilised solution of sugar and yeast extract was applied as required, to keep the scrapings moist for a period of three weeks before being examined. In this way, species dormant in the soil were encouraged to become active and more readily observed.

Table 3.

Diatom species located in vegetation units

Vegetation units (see Table 2)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Achnanthes longipes Agardh	+	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mastoglia ignorata Hust.	+	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Amphora javanica A.S.	+	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Navicula marina Ralfs in Pritchard	+	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cocconeis speciosa Gregory	+	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nitzchia sp. 6	....	+	....	....	....	....	....	....	....	....	....	....	....	....	....
N. longissima (de Brebisson ex Kutz) Ralfs in Pritchard	....	+	....	....	....	....	....	....	....	....	....	....	....	....	....
Diploneis crabro Ehr.	....	+	....	....	....	....	....	....	....	....	....	....	....	....	....
Nitzchia subvitrea Hust.	...	....	....	+	....	....	....	....	....	....	....	....	....	....	....
Diploneis sp. 1	....	....	....	+	....	....	....	....	....	....	....	....	....	....	....
Nitzchia vitrea Norm.	....	....	....	....	+	....	....	....	....	....	....	....	....	....	....
Cymbella subturgida Hust.	....	....	....	....	+	....	....	....	....	....	....	....	....	....	....
Navicula sp. 1	....	....	....	....	+	....	....	....	....	....	....	....	....	....	....
Cocconeis distans A.S.	....	....	....	....	+	....	....	....	....	....	....	....	....	....	....
Nitzchia sigma var. *rigida* Grun. ex Van Heurck	....	....	....	....	+	....	....	....	....	....	....	....	....	....	....
Achnanthes sp. 2	....	....	....	....	+	....	....	....	....	....	....	....	....	....	....
Amphiprora angustata Hendey	....	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Achnanthes sp. 3	....	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Opephora sp. 1	....	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Synedra sp. 1	....	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Anomoenis sp. 1	....	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Genus A	....	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Plagiogramma sp. 1	....	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Nitzchia closterium (Ehr.) Wm. Smith	....	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Amphora gigantea Grun. in A.S.	....	....	....	....	....	....	....	....	+	+	....	....	....	....	....
Genus B	....	....	....	....	....	....	....	....	....	....	+	+	....	....	....
Mastoglia sp. 2	....	....	....	....	....	....	....	....	....	....	+	+	....	....	....
M. pseudoparadoxia Hust.	....	....	....	....	....	....	....	....	....	....	+	+	....	....	....
Navicula sp. 2	....	....	....	....	....	....	....	....	....	....	+	+	....	....	....
N. vulpina Kutz.	....	....	....	....	....	....	....	....	....	....	....	....	+	....	....
Fragillaria sp. 1	....	....	....	....	....	....	....	....	....	....	....	....	+	....	....
Nitzchia gracilis Hantz.	....	....	....	....	....	....	....	....	....	....	....	....	+	....	....
N. sp. 4	....	....	....	....	....	....	....	....	....	....	....	....	+	....	....
Diploneis smithii (de Brebisson) Cleve	....	....	+	+	....	....	....	....	....	....	....	....	....	....	....
Nitzchia sp. 1	....	....	+	+	....	....	....	....	....	....	....	....	....	....	....
Navicula elegans Wm. Smith	....	....	+	+	....	+	....	+	....	....	....	....	....	....	....
Nitzchia brebissonii Wm. Smith	+	....	....	....	+	....	....	....	....	....	....	....	....	....	....
N. sp. 5	+	....	....	....	+	+	....	....	....	....	....	....	....	....	....
Amphora proteus Gregory	+	....	....	....	+	+	....	....	....	....	....	....	....	....	....
Achnanthes brevipes Agardh	....	....	....	....	+	+	....	....	....	....	....	....	....	....	....
Amphora macilenta Gregory	....	....	....	....	+	+	....	....	....	....	....	....	....	....	....
Cocconeis scutellum Ehr.	....	....	....	....	+	+	....	....	....	....	+	+	....	....	....
Thalassothrix sp. 1	....	....	....	....	+	+	....	....	....	....	+	+	....	....	....
Cocconeis debesi Hust.	....	....	....	....	....	+	....	....	....	....	+	+	....	....	....
Epithemia sp. 1	....	....	....	....	....	+	....	....	....	....	+	+	....	....	....
Cocconeis apiculata A.S.	....	....	....	....	....	+	....	....	....	....	+	+	....	....	....
Navicula sp. 3	....	....	....	+	+	....	....	....	....	....	+	+	....	....	....
Nitzchia compressa (Bail.) Boyer	+	....	....	+	....	+	....	....	....	+	+	+	....	....	....
Pleurosigma strigosum Wm. Smith	....	+	....	+	+	....	....	....	....	....	+	+	....	....	....
Epithemica sp. 2	....	....	....	....	....	+	....	....	....	....	+	+	+	+	+
Achnanthes sp. 1	....	....	....	....	....	....	....	....	....	....	....	....	+	+	+
Grammatophora macilenta Wm. Smith	+	....	....	+	+	....	....	....	....	....	....	....	....	+	+
Pinnularia legumen Ehr.	+	....	....	....	+	+	....	....	....	....	....	....	....	....	....
P. splendida Hust.	+	....	....	....	....	+	+	....	....	....	....	....	....	....	....
Cocconeis placentula Ehr.	+	....	....	....	....	+	....	....	....	....	....	....	....	....	....
Navicula lyra var. *elliptica* A.S.	+	....	+	+	+	+	+	....	....	....	+	+	....	....	....
Pinnularia ambigua Cleve	+	....	+	+	....	....	+	+	....	....	+	+	....	....	....
Amphora graeffii (Grun.) Cl.	+	+	....	+	....	+	....	+	....	....	....	....	....	....	....
A. sp. 2	....	+	+	....	....	+	+	+	....	....	....	....	....	....	....
Nitzchia sp. 2	....	+	+	....	....	....	+	....	....	....	....	....	....	....	....
N. sp. 3	....	....	....	+	+	....	....	+	....	....	....	....	....	....	....
Melosira sp. 1	....	....	....	....	....	+	....	+	....	....	....	....	....	....	....
Cymbella yarransis A.S.Cl.	+	....	....	+	....	....	....	....	....	....	....	....	....	....	....
Genus C	+	....	....	....	....	....	....	+	....	....	....	....	....	....	....
Cocconeis sp. 1	....	....	+	....	....	+	....	....	....	....	....	....	....	....	....
Grammatophora marina (Lyngb.) Kutz	....	....	....	+	....	+	....	....	....	....	....	....	....	....	....

Where species identification was not possible a code name was used. Descriptions and drawings of unidentified diatoms may be found in Backshall (1977), or copies may be acquired from the authors. Identification of species was achieved using the following works: Crosby and Wood (1959), Wood *et al.* (1959), Wood (1961a, 1961b, 1963) and Hendey (1964).

The distribution of diatoms (Table 3) shows that more than 50% of the species were unique to individual vegetation units, although approximately half of these were accounted for by groups 1, 5, and 6. Unique species present in groups 2 and 4 add justification for distinguishing these vegetation units. Groups 10, 11, 14, 15 are, however, distinguished only by their paucity of diatom flora. This is probably a reflection of long periods of surface desiccation on these more elevated sites. *Nitzchia compressa, Cocconeis placentula, Pinnularia legumen* and *P. splendida* indicate some affinity between groups 1 and 6. The *Arthrocnemum bidens* community (group 1) is typically found on the emerging fringes of salt marsh concavities, while *Salicornia-Suaeda* community (group 6) occupies a similar zone on the emerging banks of the estuaries. The suggested similarities may be because the communities occupy sites of regular water fluctuation while differences in salinity of these 2 habitats appear to be reflected by differences in the diatom flora of the communities. Similarly, although the *Salicornia-Suaeda* community and the *Salicornia quinqueflora* community may have unique species of diatoms, a clear relationship between them is indicated by the common presence of *Amphora proteus, Nitzchia* sp. 5, *Cocconeis scutellum, Achnanthes brevipes, Amphora macilenta* and *Thalassiothrix* sp. 1. Both vascular-plant communities are found at similar elevations above high water mark, but with different soil salinities.

The overall distribution of diatom species is similar to that reported by Round (1960) with many species exhibiting a strong preference for different habitats, while others demonstrate a wider tolerance. Lack of the common planktonic genera *Rhizosolenia, Chaetocerous* and *Coscinodiscus* would seem to confirm that the species encountered are indicative of surface changes, rather than planktonic drift-ins.

Interaction of peripheral and submerged vegetation

One of the major environmental problems in the Peel-Harvey system is high productivity of the alga *Cladophora.* During winter storms massive amounts of algal material are deposited on shorelines, often with severe results on the *Juncus maritimus* complex. Massive deposition can cause death or debilitation of the *Juncus* and consequent erosion. Colonisation of the large masses of *Cladophora* is often effected by *Atriplex* spp. and *Suaeda australis.* This latter species commonly colonises organic deposits, e.g. *Zostera* deposits at Westernport Bay, Victoria.

At some points on the shores of Peel Inlet *Scirpus maritimus* appears to also colonise areas of light *Cladophora* deposition. There appears to be a competitive interaction between *S. maritimus* and *J. maritimus* on these sites which warrants further investigation. Degradation of the established *Juncus maritimus* community will inevitably result in shoreline regression, and consequent build-up of silt in other sites.

This effect is another problem associated with the occurrence of *Cladophora* mats. Regeneration of the shoreline appears rapid in regions where the *Salicornia quinqueflora—Suaeda australis* community occurs (i.e. in areas where shoreline stabilization is proceeding naturally), but is lacking on the eastern shore of Peel Inlet. The introduction of colonising species (e.g. *Suaeda australis, Atriplex hastata*), into freshly deposited *Cladophora* mats could be a useful management tool in preventing erosion, and aiding rapid assimilation of the *Cladophora.*

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