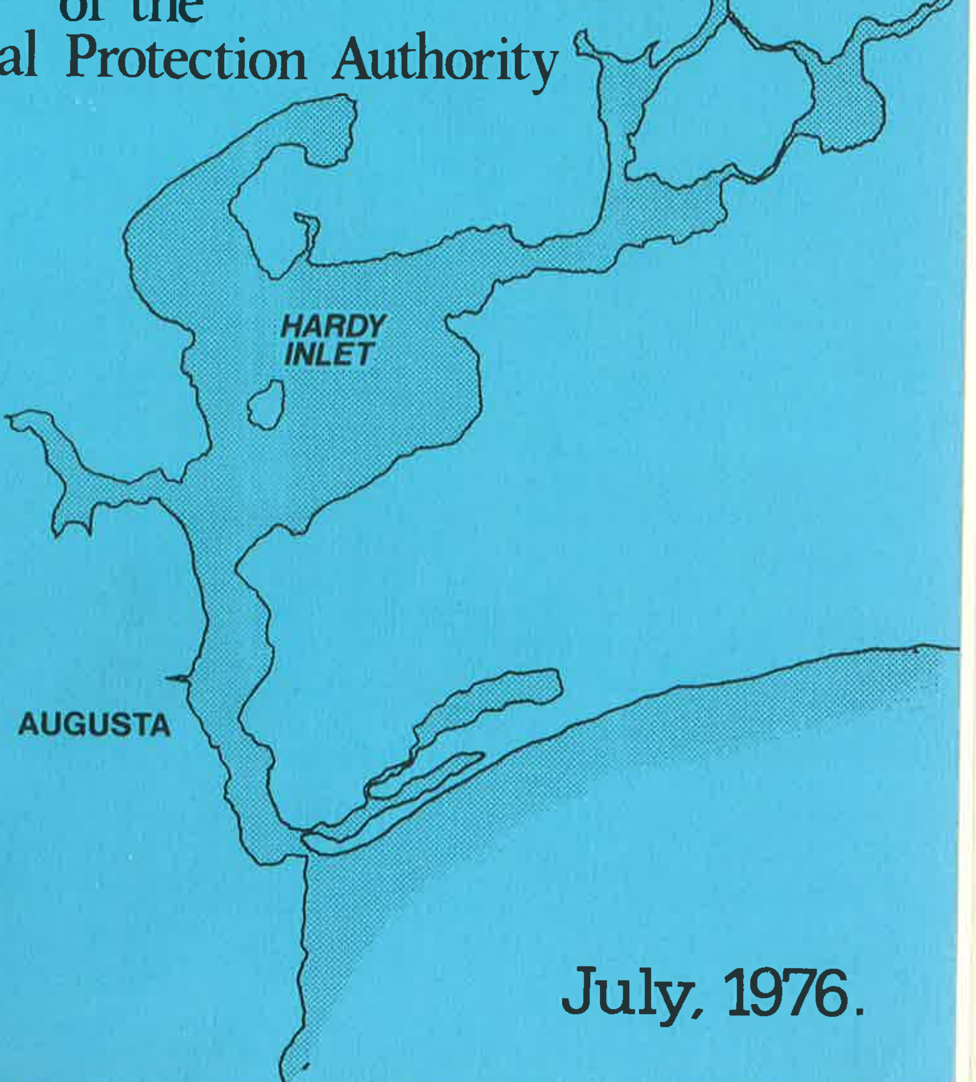
Technical Report 3

PRELIMINARY REPORT ON BOTANICAL
STUDIES OF THE BLACKWOOD RIVER ESTUARY

ENVIRONMENTAL STUDY OF THE BLACKWOOD RIVER ESTUARY

a report to the
Estuarine and Marine Advisory Committee
of the
Environmental Protection Authority



July, 1976.

An environmental study of the Blackwood River Estuary

Preliminary report of botanical studies

R.A. Congdon and A.J. McComb

These notes summarise the results to date, and provide a partial review of background literature. Some of the results will be fully interpretable only when further information is available, and so a detailed discussion of the data is not included at this time.

THE VEGETATION OF THE WATER

INTRODUCTION

Benthic plants

The distribution of benthic plants is governed by the tolerance of each species to salinity, exposure and water currents; by requirements for nutrients, substrate and light and by plant dispersal and colonization mechanisms.

As light is essential for photosynthesis, the quality, quantity and duration of light is important in determining plant distribution. Light transmission decreases with depth and the light undergoes characteristic changes in spectral composition; these properties are affected by the quantities of dissolved and suspended material. In turbid waters the blue region of the spectrum is characteristically decreased, whilst in weed beds both the red and blue wavelengths are reduced to give predominantly green; the red and blue wavelengths are those involved in photosynthesis. In general, benthic plants are eliminated when the full light intensity falls below some 5% of the light at the surface (e.g. Odum 1971) and detailed distribution studies should establish this figure more accurately for the Blackwood River Estuary.

Benthic macroscopic algae

Superficial examination suggested that the macroscopic algae are not a major component (as biomass) in the Estuary, but records have been taken of major species. A preliminary survey carried out by Allender in February and August 1966 served as a guide. Allender (1974) concluded that the macroscopic algae flora is very depauperate compared with other estuarine floras he examined in south western Australia and attributed this to brevity of the summer saline phase and lack of solid substrates.

Benthic angiosperms

It was clear that this group is a most important component of the estuarine flora, and it is convenient to review some relevant productivity data from the literature. *Ruppia maritima* is common in the Estuary and is a cosmopolitan species. Nixon and Oviatt (1974) studied the rates of respiration and photosynthesis of plants of this species in North America, in terms of oxygen, in relation to light intensity and temperature. Controlled environmental studies were carried out and field studies using plastic domes corrected for plankton metabolism and sediment respiration. *Ruppia* was found to become quickly light saturated under field conditions. *Ruppia* biomass was sampled by means of a grab, but reliable estimates were difficult to obtain because of the patchy distribution of the plants; this means that production measurements obtained by the dome method are equally difficult to extrapolate to meaningful field measurements.

Measurements of midsummer metabolism in two eelgrass (Zostera marina) ecosystems were made by Nixon and Oviatt (1972) and Suda (1974). Nixon and Oviatt reported standing crops from a pond and a tidal river of 65 and 67 g (dry wt).m^{-2}. Respiration was found to exceed photosynthesis, so that there was no nett production of the systems as a whole. Since this was in midsummer, when light intensities would not be limiting, senescence of the plants or high temperature may have been responsible. Suda (1974) found that in July oxygen metabolism was in equilibrium, but in August the oxygen production was relatively high, probably because of an increase in epiphytes. Odum (1963) measured productivity in turtle grass beds (Thalassia testudinum and Diplanthera wrightii) in Redfish Bay, Texas, before and after the dredging of an intracoastal channel. Moderate values of 2 to 8 g $O_2.m^{-2}.day^{-1}$ were observed in the spring of 1959 following a period of shading by turbid waters, but exceptionally high values of 12 to 38 g $O_2.m^{-2}$ day^{-1} were recorded the following spring in those areas not smothered with silt. Chlorophyll A in 1959 averaged 0.03 $g.m^{-2}$ but increased to 0.68 $g.m^{-2}$ the following summer. Increased nutrient levels was the only suggested cause.

Of the benthic plant communities in Lake Macquarie, N.S.W., Wood (1959) regarded the seagrass communities as biologically most important. Epiphytes were abundant and used extensively as a food source by phytophagous fish and other fauna. Two species of Zostera (Z. capricorni and Z. muelleri) were dominant and were voraciously consumed by black swans. Zostera muelleri had a minimum density in late summer and regenerated in autumn. *Ruppia maritima* occurred in backwaters and broke away at the end of summer. The seagrasses indicated areas of great bacteriological activity. *Zostera* has been found to produce reducing substances whilst *Ruppia* does not, and Wood suggests that this may influence their relative distribution.

Benthic diatoms

These are common in the superficial sediment layers of the Blackwood. Moul and Mason (1957), who studied the diatom populations on sand and mudflats at Woods Hole, Massachusetts found in the surface 2.5 cm from 9,000 cells $.mm^{-3}$ in June to 570 cells $.mm^{-3}$ in August. Few diatoms occurred below 6 cm. The mud-diatom communities surface on exposure at low tide and migrate below the surface just before the arrival of the incoming tide (e.g. Hopkins, 1966 ; Faure-Fremiet, 1951; Callòme and Debyser, 1954). Taylor and Palmer (1963) and Taylor(1964) collected diatoms in nylon bolting cloth when they migrated to the surface as the tide receded, made up cultures, and measured photosynthesis with ^{14}C-Na_2CO_3. The diatoms were very efficient at low light intensities 35% of the maximum photosynthetic rate being attained at 0.75 cal. cm^{-2}. hr^{-1} (approximately 1% summer mid-day solar radiation). The maximum rate occurred at about 14% summer mid-day sunlight (12 cal.cm^{-2}hr.) and there was 10% inhibition at full summer mid-day sunlight(75 cal.$cm^{-2}hr^{-1}$) (cf. *Coscinodiscus* below). Ten percent of light could penetrate a layer of oxidized surface sand 1.5mm deep. This suggested that at noon on a cloudless midsummer day cells as deep as 3mm are above their compensation level, while those from 2mm to the surface are able to photosynthesize at 90% or

better of their maximum rate.
Jenkin (1937) examined the oxygen production by the diatom Coscinodiscus excentricus in relation to light intensity. This diatom has been identified in samples from the Blackwood River estuary (see below). She found a gradual inhibition at light intensities greater than 1.8 $cal.cm^{-2}.hr^{-1}$ and systrophe (clumping of chloroplasts) was induced at 9.6 $cal.cm^{-2}.hr^{-1}$. The compensation point occurred at 0.13 $cal.cm^{-2}.hr^{-1}$.

The production of the microscopic benthic algae in the intertidal zone of salt marshes in Georgia have been examined by Pomeroy (1959) who notes that although pennate diatoms of many genera were dominant, green flagellates, dinoflagellates and blue-greens were also present. Using oxygen changes measured under dark and light belljars, Pomeroy estimated an annual gross production of 200 cal. m^{-2} for these intertidal algae, which would account for one-third of the total annual primary production including the fringing vegetation (Odum. 1971). He suggested that the algae would be inhibited by high light intensities. The manner in which he arrived at his optimal range (32.7 - 279 lux) is suspect as it was derived from the data of Ryther (1956) who studied pelagic phytoplankton.

In summary, it appears that diatoms are able to produce at very low light intensities, and might make a significant contribution to gross production. It is not clear whether diatoms are much inhibited by high light intensities but variation between species is likely and mixed populations will be affected differently.

Planktonic algae

It became clear from preliminary sampling that the contribution of plankton to productivity is small and this topic has therefore received relatively little attention in the project to date. Rochford (1951) suggested that the maximum development of the marine influences in Australian estuaries in summer would preclude vernal plankton bursts, since summer fixation and turnover of nutrients is low. He also suggested that vertical turbulence and low phosphate levels would permit little or no phytoplankton production except in estuaries which are almost neritic.

It seemed likely that maximum phytoplankton production in the Blackwood River estuary would be in spring, when the river flow is ebbing and turbidity is decreasing. The nutrients, light and temperature would be favourable, but the nutrients would decrease as the marine influence is extended (see below).

General

The work described in the following section was concerned with the collection, identification, distribution and in some instances, biomass of these planktonic and benthic species.

METHODS

Distribution of benthic plants

The broad distribution of benthic species was mapped using field observations and collections, and from specimens collected by members of the Department of Fisheries and Fauna benthic team. Filamentous algae were fixed in formalin, stained in dilute gentian violet and permanently mounted in karo prior to identification (Allender 1967). Some fish gut samples were examined for plant material.

Phytoplankton

As the phytoplankton stocks in the estuary are low and the area large, conventional routine sampling and counting were not carried out. Phytoplankton were collected by taking a surface sample of approximately 5 litres; 5 to 10 ml of formalin was added to this, and plankton allowed to settle overnight. The supernatent was then siphoned off, and the concentrate studied. Some zooplankton hauls collected with a plankton net were also examined.

Samples were collected in September and October 1974, and February 1975. October samples were collected from Swan Lakes and the Deadwater, which were found to be highly productive in terms of benthic plants (see below) and where turbidity and turbulence are low.

Biomass studies

Biomass (standing crop) measurements were made of *Zostera mucronata* in Seine Bay, *Ruppia maritima* in Swan Lakes, and *Chara vulgaris* in East Swan Lakes.

A tin tube, square in section (23cm x 23cm) was placed over a representative patch of weed and all of the enclosed plant material removed by hand. Special care was taken to collect root and rhizome material, by digging large pieces of sediment out by hand and rinsing to expose the plant material; simple pulling of the fronds did not recover the roots. Five samples of each species were collected, bulked in a plastic bag and sealed.

Within 6 hrs. the weed was sorted to remove foreign material such as adhering sediment, mussels and algae. Epiphytes were only abundant on the *Zostera*; these were small, they did not appear to contribute significantly to the weight, and were not removed. The material was blotted dry, weighed, dried to constant weight (72 hrs.) at 80 ^{o}C, and dry weight determined.

RESULTS AND DISCUSSION

Benthic angiosperms

The distribution of the benthic angiosperms is shown (with the charophyte Lamprothamnium papulosum) in Figure 1. Ruppia maritima - this seagrass occurs in the Deadwater, the Swan Lakes and from Point Ellis to at least Alexandra Bridge, where Allender recorded it in February 1966, and Hodgkin (pers. comm.) in 1975. The species is the most widespread and in greatest abundance of the benthic plants. Ruppia occurs in a salinity range of 0.2 to 60.0% (Aston 1973) and this tolerance is undoubtedly one of the major factors favouring its wide distribution in this estuary. Standing crop measurements were taken of a dense patch in Swan Lakes in October, and results are in Table 1. The dry weight figure of 0.37kg.m^{-2}may be compared with the data of Nixon and Oviatt (1974) who found 0.05 to 1.46 kg. (dry wt) m^{-2} of Ruppia maritima during the Northern Hemisphere summer.

Most of the Ruppia growing in the estuary is found in less than I metre of water. This is probably due to the light factor, although substrate cannot yet be ignored. During the winter phase the water coming down the two rivers is turbid. The Blackwood River contains much suspended matter, while the Scott River contains mainly dissolved material. The effect of this

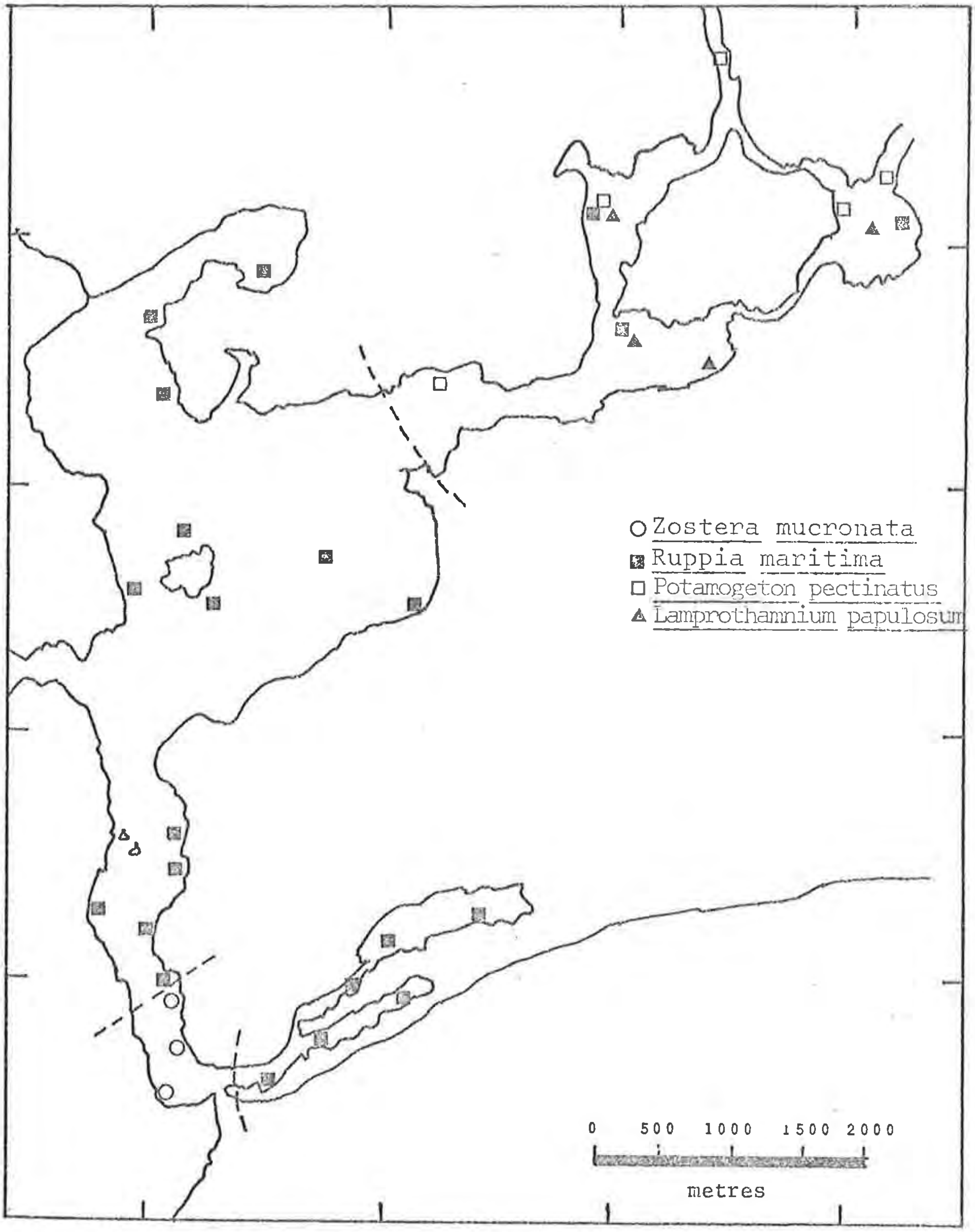


Fig.1. The distribution of the major benthic plant species of the Blackwood River Estuary.

TABLE 1

STANDING CROP MEASUREMENTS FOR BENTHIC PLANTS

(October 1974)

Species	Location	Fresh weight ($Kg.m^{-2}$)	Dry weight ($Kg.m^{-2}$)
Zostera mucronata	Seine Bay	0.05	0.01
Ruppia maritima	Swan Lakes	1.89	0.33
Chara vulgaris	East Swan Lakes	1.72	0.45

turbidity on light transmission is illustrated by Secchi disk transparency readings (Table 2). The Secchi transparency at Point Dalton (station 90) in May, the summer phase, was at 3.5 metres. This reading was reduced to 1.0 metre at the same station in July, during the winter phase. For the well studied Wisconsin Lakes, the Secchi reading represents the zone of light penetration down to about 5% of the solar radiation reading at the surface, and the 5% level marks the lower limit of the major photosynthetic zone (Odum 1971). Thus the transmission of light through the water column is reduced seasonally, and may affect plant distribution for winter-growing species. No seedlings of *Ruppia* have yet been found in the estuary, but much young vegetative growth has been observed, arising from rhizomes in winter. Growth continues in spring and at least early summer.

Other species:- *Zostera mucronata* is found on shoals south of Point Ellis and its shoots are covered with small epiphytes. New shoots appeared in October and are probably rapidly covered in epiphytes (Wood 1959; Odum 1971). *Zostera* occurs on coarse sediments of marine origin and although it prefers saline water shoots persist throughout the year. The plant is scattered and a biomass estimate based on five samples taken in October was 0.01 Kg. (dry wt) m^{-2} within the community (Table 1). For communities of *Zostera marina* in America, Nixon and Oviatt (1972), found 0.06 to 0.07 Kg. (dry wt).m^{-2} and Suda (1972) 0.07 Kg. (dry wt).m^{-2} for shoots and 0.09 for roots. *Zostera* is clearly less abundant than *Ruppia* and achieves a lower biomass density.

TABLE 2

LIGHT PENETRATION AS SECCHI DISC DETERMINATIONS

Date	No. of determinations	Mean depth to which disc was visible (m)
May 1974	9	2.7 ± 0.16
July 1974	3	1.0
August 1974	3	1.0
February 1975	2	3.4

Potamogeton pectinatus (fennel pondweed) has been collected at station 83 in the south, to station 150 in the Blackwood River and station 115 in the Scott River. Unlike freshwater forms of Potamogeton pectinatus, it has very narrow leaves and leaf sheaths, making confusion with Ruppia relatively easy. P. pectinatus is reported to survive in a salinity range of 0.5 to 8.0‰ (Aston 1973), consistent with its narrow distribution in the Blackwood. Germinating seeds of Potamogeton were collected from station 111 in May and young seedlings from station 150 in July. In February 1975 large amounts of dead Potamogeton were found near stations 150 and 105. It is suggested that this species behaves as an annual in the Blackwood, dying off under high salinity conditions and regenerating from seed when the salinity falls.

Allender (1974) recorded Halophila ovalis (Sea Wrack) from near station 16 in February 1966. This species is known to prefer marine conditions, and would only flourish in water near sea-water salinity. It has not been recorded in the current study, but little sampling has yet been done in summer.

The ponds on Point Pedder contain brackish water (11‰ October 1974) and Ruppia maritima and the alga Lamprothamnium papulosum occur there. The East Swan Lakes contain fresh, alkaline water (pH=9.6, October 1974) and support a rich growth of benthic plants. The alga Chara vulgaris is the most abundant species, forming a very dense population (see standing crop measurement, Table 1). Potamogeton pectinatus, Cotula coronopifolia, Haloragis brownii, Potamogeton ochreatus, Ranunculus muricatus, and Triglochin procera also occur.

Macroscopic algae

Table 3 lists the macro-algae collected from the estuary and shows their seasonal distribution.

The green algae are the most euryhaline-widely distributed-and have the greatest number of species. The number of species of browns increased in summer, but the reds remained approximately constant.

Rhizoclonium a euryhaline species, appears to be the dominant alga in the estuary and occurs throughout the year. Large amounts of this species were noticed in October particularly in the Deadwater, and a local fisherman commented that this is an annual occurrence. It was found to form extensive algal mats amongst fringing rushes. Cladophora was not found in great quantity.

Table 3 shows that stenohaline and euryhaline species are present. Of those which appear stenohaline, Acetabularia peniculus, Pterocladia Lucida, Spyridia sp., Cytoseira trinodis, Dictyota furcellata, Sphacelaria furcingenia and Calothrix sp. would be polyhaline preferring high salinities. Mougeotia sp. and Spirogyra sp. are oligohaline while Monostroma oxyspermum, Achrochaetium radicans,Lyngbya sp. and Rivularia sp. may also fall into this class. Definitely euryhaline species include Chaetomorpha linum, Enteromorpha ahlneriana, Rhizoclonium riparium, Chondria tenuissima, Gracilaria verrucosa, Polysiphonia sp. and Ectocarpus sp.

Acetabularia peniculus is known to overwinter in the estuary using cyst formation. Cockle shells collected

Table 3

MACROSCOPIC ALGAE RECORDED FROM THE ESTUARY, WITH SEASONAL OCCURRENCE

Species	Collection sites, indicated by sampling station numbers 3						
	February	March	May	July	August	September	October
Chlorphyceae							
Acetabularia peniculus (R.Br) Solms-Laubach[2]	16	13					
Chaetomorpha linum (Muller) Kutzing[2]	93		02	13	01,20,70,95,135		
C.valida (H & H) J.Ag.							
Cladophora sp.[2]	00,20,38,70.				01		
Enteromorpha ahlneriana[3]	00,16,20,38,70				00,01,11,12,15,49,95,135		12
Monostroma oxyspermum (Kutzing) Doty (formerly *Ulvaria oxysperma*)[2]					05,38,49,70,95		
Mougeotia sp.						90,110,165.	
Rhizoclonium riparium (Roth) Harvey[2]	00,16,20,38				00,11,12,25,70,95,135		12
Sirogyra sp.[2]	180					90,110,165	
Ulothrix sp.[2]	00				00,38,49,95.		

Table 3 (cont'd)

Table 3 (cont'd)

Species	February	March	May	July	August	September	October
	Collection sites, indicated by sampling station number 3						
PHAEOPHYCEAE							
Cytoseira trinodis (J.Ag.)[2]	00,70						
Hormophysa triquetra (L) Kuetz			111				
Ectocarpus siliculosus[2]	70			11,49			
Dictyota furcellata[2]	70,93						
Sphacelaria furcingena[2]	00,70						
RHODOPHYCEAE							
Chondria tenuissima (Goodenough & Woodward) C. Agardh[2]	16,20,70		35,61,63,85		15,49,70		
Gracilaria verrucosa (Hudson)[00] Papenfuss[2]			02	02	11,12,38,49		12
Polysiphonia sp.[2]	oo,16,20,38,70,93		19		70		
Pterocladia lucida (R.Br.) J. Agardh	00						
Achrochaetium radians[2]					00,11,15,38,70		
Spyridia sp.[2]	00,16,20						
CYANOPHYCEAE							
Calothrix sp.[1]	70.90	13					
Lyngbya sp.[2]					49,38,70		
Rivularia sp.[1]							
CHAROPHYCEAE							
Chara vulgaris L							
Lamprothamnium papulosum							

1 Species also recorded by Allender. 2 Species recorded by Allender, but not seen in the present study.
3.Collections by B. Allender, R.A. Congdon, E.P. Hodgkin, J. Wallace

from station 13 in August, when placed in saline nutrient solution yielded a growth of *Acetabularia* (P. Collins, pers. comm.). *Pterocladia lucida* and *Dictyota furcellata* are well known marine forms and probably invade the estuary each summer from the ocean.

Two species of the Charales are present. *Lamprothamnium papulosum* occurs on shallow sediments around Molloy Island, having been collected from stations 93, 95, 98, 108, and 115 (Fig.1). It occurs widely in brackish waters but no species in the Charales is known to tolerate more than 2/3 sea water (about 24‰) (Wood and Imahori 1965). As mentioned above, *Chara vulgaris* occurs in East Swan Lakes.

Phytoplankton

Records of phytoplankton are given in Table 4. Phytoplankton densities were low in all samples compared with those found in freshwater eutrophic situations, and were dominated by diatoms and desmids. Genera included *Melosira*, *Coscinodiscus* and *Chaetoceros*. A large proportion of pennate diatoms were present. The green filamentous algae *Spirogyra* and *Mougeotia* occurred in some samples; these are freshwater species.

Chaetoceros was in relative high abundance, a taxon found by Wood (1959) in the phytoplankton rich waters of Lake Macquarie. This is a marine genus.

TABLE 4

PHYTOPLANKTON SPECIES COLLECTED FROM THE ESTUARY

Locality	Sampling site and date	Phytoplankton present
Point Irwin	Plankton net (24/9/74)	Spirogyra, Melosira, Coscinodiscus, Chaetoceros Mougeotia and pennate diatoms
	Bulk water (24/9/74)	Melosira, desmid, pennate diatoms.
	Bulk water (9/2/75)	Chaetoceros, Coscinodiscus, pennate diatoms.
Deadwater	Plankton net (24/9/74)	Chaetoceros, Melosira, desmid and pennate diatoms.
	Bulk water (24/10/74)	Chaetoceros, pennate diatoms.
Blackwood,165	Plankton net (29/9/74)	Spirogyra, Mougeotia, pennate diatoms, and a filamentous blue-green.
Scott, NW channel	Bulkwater (24/9/74)	Mougeotia, Melosira, Closterium (?) and pennate diatoms.
Swan Lakes	Bulkwater (24/10/74)	Melosira, Chaetoceros, and pennate diatoms.

Fish gut samples

The guts of fish netted in March and May 1974 were examined for plant material (Table 5). Nine species had consumed vegetative material and it can be readily seen that *Ruppia* was extensively consumed by these animals and must be an important component of the food chain. Plant material consumed included *Ruppia*, *Lamprothamnium*, *Chondria*, *Rivularia*, *Polysiphonia*, diatoms, epiphytic algae and detritus from various macrophytes.

THE FRINGING VEGETATION

Introduction

The fringing vegetation must be considered as part of the estuary, as it contributes organic matter to the aquatic system, and colonizes shoaling sediments. Odum (1971) notes that estuaries are highly productive and that (for the United States) the amount of organic carbon which they produce per unit area each year is comparable with tropical and subtropical forests. The fringing vegetation is included in this estimate, as at least in the United States,this is the dominant primary producer for the estuary ecosystem. (Pomeroy et al 1965; Udell et al 1969; Nixon and Oviatt 1974).

TABLE 5

PLANT MATERIAL IN FISH GUT SAMPLES

Fish Species	Plant Material
Leatherjacket (3)[2]	*Ruppia*, epiphytes, diatoms, *Chondria*
Schnapper (1)	*Ruppia*, epiphytes
Black Bream (8)	*Ruppia*, epiphytes, diatoms, *Chondria*, *Polysiphonia*, *Lamprothamnium*, *Rhizoclonium*
Yellow eye Mullet (4)	*Ruppia*, epiphytes, diatoms, *Rhizoclonium* *Polysiphonia*
Trumpeter (6)	*Ruppia*, diatoms, *Rhizoclonium*
Silver Bream (1)	*Rhizoclonium*, diatoms
Blowfish (1)	*Ruppia*, diatoms
Skipjack (1)	*Ruppia*
Garfish (1)	*Ruppia*

[2] no. of fish examined.

This vegetation provides a gradient between the aquatic and terrestrial environments; substances passing from one environment to the other can be subjected to a partial filtration by this vegetation. Nutrients and sediments in run-off and leachates from the land may be absorbed in quantity by the fringing vegetation, thus reducing the amount reaching the open water (Anon. 1974). Estuarine water is "filtered" in the reverse direction both daily (tidal) and seasonally.

The topography of the shoreline governs the extent and form of the fringing vegetation in the first instance. For example, Clarke and Hannon (1969) found that very small changes in microtopography determine the zonation in Sydney mangrove and salt marshes. Where the estuary flows through a steep-sided river channel, the fringing vegetation cannot develop to the same extent as on the gentle slopes of a lagoonal area.

Physical, chemical and biotic factors are also related to the zonation of vegetation. For example, as one moves from the water's edge one might expect to find gradients in waterlogging, salinity, soil organic matter, pH, shading and the concentration of inorganic nutrients, although there is very little information in the literature concerning such gradients. The present chapter is concerned with documenting the fringing vegetation, and changes in the substratum are dealt with in a subsequent section.

METHODS

Distribution

General surveys have been made of the distribution of plant communities of the estuary using aerial photographs and analysis on the ground. The species fringing the open water were recorded between each consecutive pair of sampling stations from station 00 to Warner Glen Bridge (station 210).

Transects were made through representative areas of shore communities, and soil samples taken from the transects for examination of the substratum. A tape was laid at right angles to the water through the communities, and the presence or absence of each species recorded in metre segments. Heights and cover were determined, and profile diagrams prepared.

Biomass

As a preliminary study, the standing crop of *Juncus maritimus* growing on a sand ridge on Point Pedder was estimated in October. Plant material was harvested from a 50 x 50 cm quadrat, separated into "aboveground live" and "aboveground dead" and fresh weights taken. Below ground material was separated into "below ground apparent live" and "below ground apparent dead", and below ground fibrous". This below ground material required washing, and was dried in the sun for 1 hour before weighing. The material was then dried at 80°C for 72 hours and dry weights determined.

RESULTS AND DISCUSSION

The distribution of the fringing plant species along the Blackwood River Estuary shows a pattern which is almost certainly related to salinity tolerance (Table 6). *Juncus maritimus* and *Machaerina juncea* occur throughout the estuary and are particularly common in the lagoonal area; this suggests a high salinity tolerance. *M. juncea* generally occurs scattered with *Juncus* but away from the water's edge. Near station 110, in the Scott River basin and further up the estuary this species occurs in large stands in the water. *Gahnia trifida* was only seen below station 170, it occurs under the paperbark woodland and on the steeper banks of the river, seldom close to the water. The other species occur north of station 170, indicating a low salinity tolerance. The sedge *Cyperus* was only seen north of station 190, indicating a distinct preference for freshwater.

Marsh vegetation

Three main types of marsh vegetation occur on the gentle sloping shores of the lower estuary (Fig. 2). A species list is given in Appendix I.

Salicornia marsh - this occurs on the southern shore of the Deadwater and is particularly developed near the mouth. The principal plant is *Salicornia australis*, and *Samolus repens* is common. The *Salicornia* marsh also occurs on Thomas Island, interspersed with *Juncus* marsh. It is developed on an inorganic substratum of high salinity, though quantitative determinations of these parameters have not yet been made.

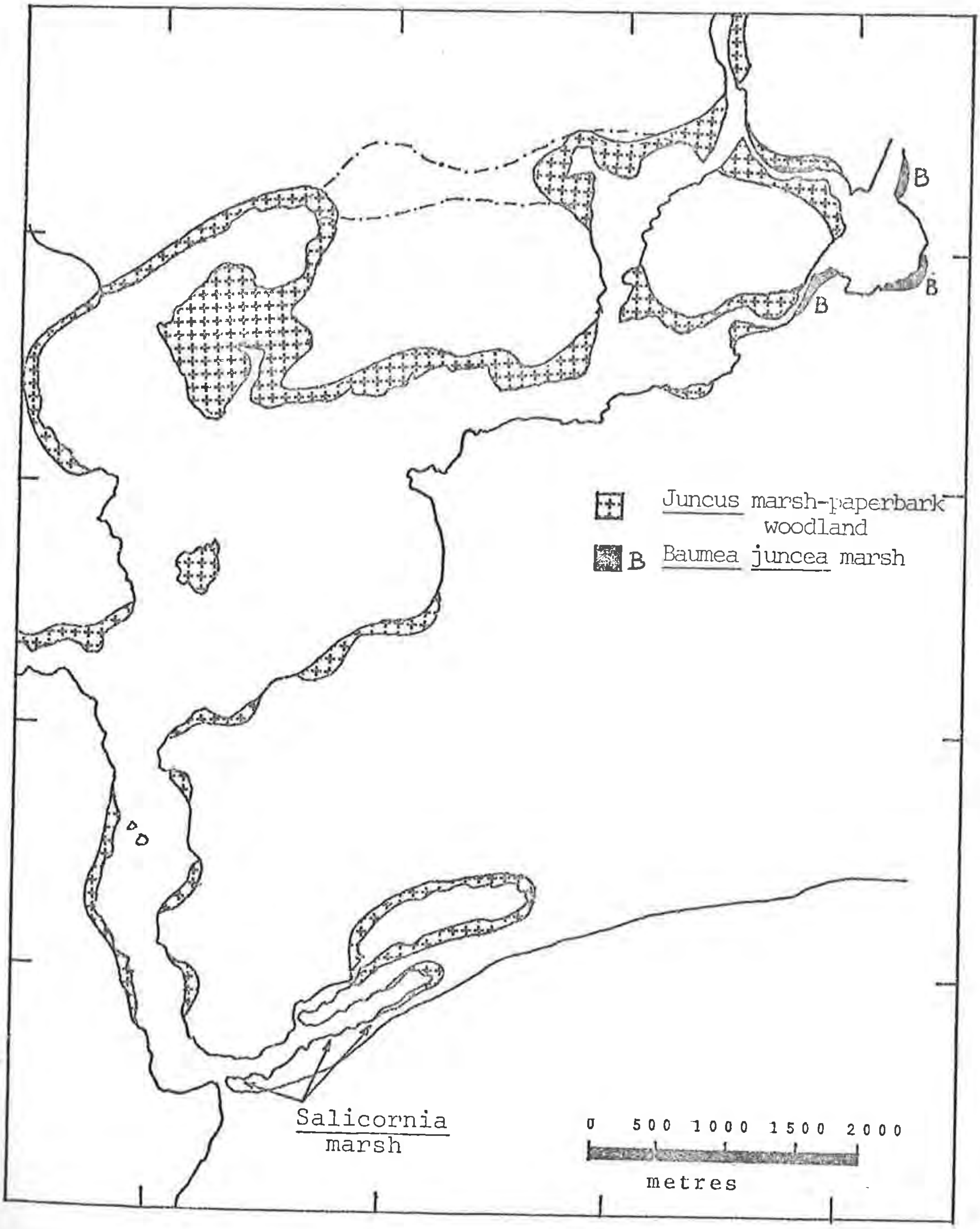


Fig.2. Major areas of wetland vegetation. (not strictly to scale).

Distribution of Plant Species Fringing the Blackwood River Estuary

Species	Sample Station								
	0-100	-140	-150	-160	-170	-180	-190	-200	-210
Juncus maritimus	+	+	+					+	
Machaerina juncea	+	+	+	+	+	+	+	+	+
Gahnia trifida	+	+	+	+	+				
Baumea articulata			+		+	+			
Lepidosperma gladiatum						+	+	+	+
Lepidosperma sp.						+	+	+	+
Anigozanthos flavidus							+	+	+
Cyperus								+	+

Machaerina marsh - This occurs in the Scott River basin on the eastern side of Molloy Island, and along the Scott River. In general morphology and behaviour in invading open water *Machaerina juncea* is similar to *Juncus maritimus* (see below) but appears to prefer less saline water.

Juncus marsh - The greater part of the shore line is fringed with *Juncus* marsh, dominated by *Juncus maritimus* (shore rush)(Fig. 2 and 3). It often occurs in almost pure stands, but other species do occur, and the most prominent of these are *Machaerina juncea*, *Scripus nodosus* and *Samolus repens*.

The marsh clearly advances into the estuary from the shore, young, vigorously growing rhizomes progressing at right angles from the fringing vegetation in most of the shallow areas examined (Fig 4). An exception is the eastern fringe of Point Pedder where some exposure and regression of rhizomes is occurring because of sand erosion; a sand ridge has been built up parallel to the shore. This is probably a minor and transient set-back to the general advance of the vegetation, as to the north of the transect line there is an ancient minor dune, heavily vegetated, some 40 m from the present edge of the estuary. On the small new dune there is the sedge *Scirpus nodosus*, a dominant species of the major coastal dunes. Small, shallow bays in the Point Pedder region are being encroached upon by the rush and are apparently becoming isolated from the main estuary. Other ponds in the mosaic of vegetation

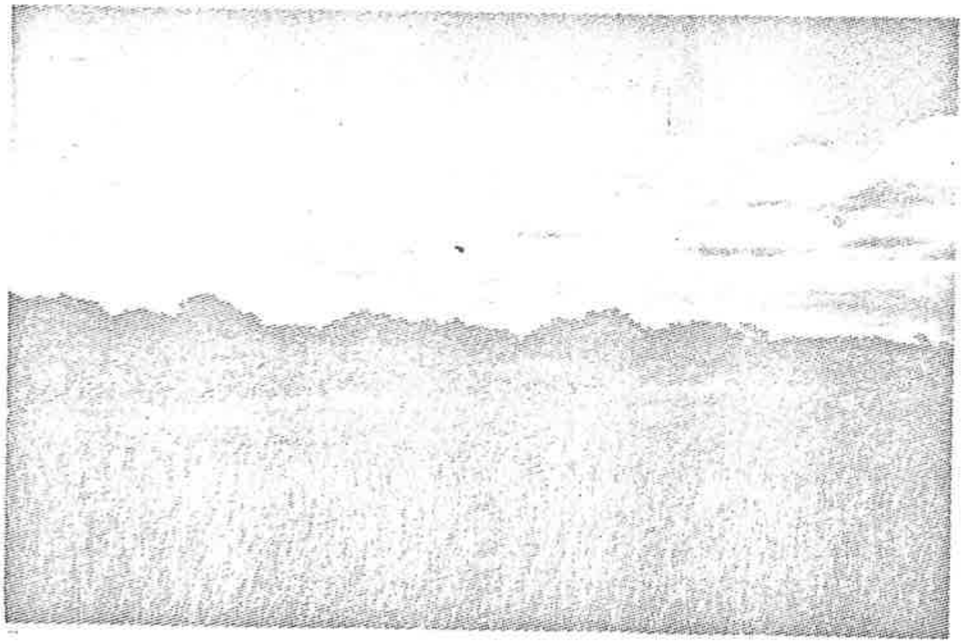


Fig. 3. Juncus marsh at Point Pedder with paperbark forest in the background.

Fig. 4. Propagation of *Juncus maritimus* by rhizome and seedlings.

at Point Pedder were apparently occluded in this way.

If the water is sufficiently shallow, *Juncus* seedlings can become established; these have been observed on areas which are exposed at low tide. Clark and Hannon (1970) found that seed of this species germinated in 20% sea water (about 7‰ NaCl) but not pure sea water, and Congdon (unpublished) found that seed gave 54% germination in 6‰ NaCl after 20 days at 20°C, The seed survives soaking in sea water, germinates in water up to 4 mm deep, and requires light for germination. Thus the seed probably germinates, and seedlings become established, while the surface water of the estuary is fresh. The seedlings have been observed to survive in the Point Pedder region for more than a year, despite seasonal fluctuations in submergence and water currents, and so may build up stands as sand and debris accumulate and the rush clumps expand in area.

In summary, the marsh actively invades shallow water from the margins and, as a less important mechanism of colonization, by the establishment of seedlings in shallow water. It will be appreciated that by impeding current flow and filtering water, the marsh has an important role to play in the stabilisation of water-borne sediment. Behind the fringe of *Juncus* marsh a paperbark woodland is typically established dominated by *Melaleuca cuticularis* and, less commonly, *Melaleuca raphiophylla* (Figs.5 and 6).

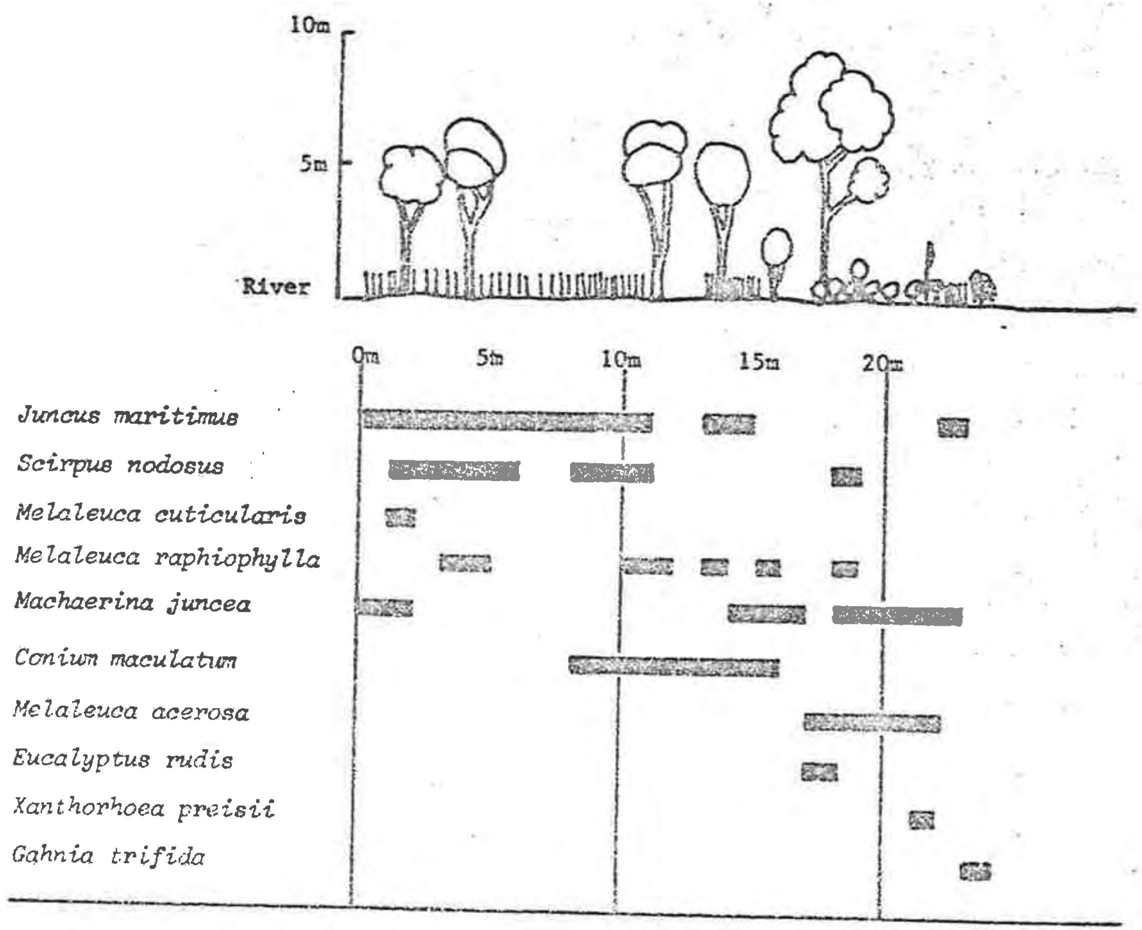


Fig. 5. Vegetation profile diagram - near station 95.

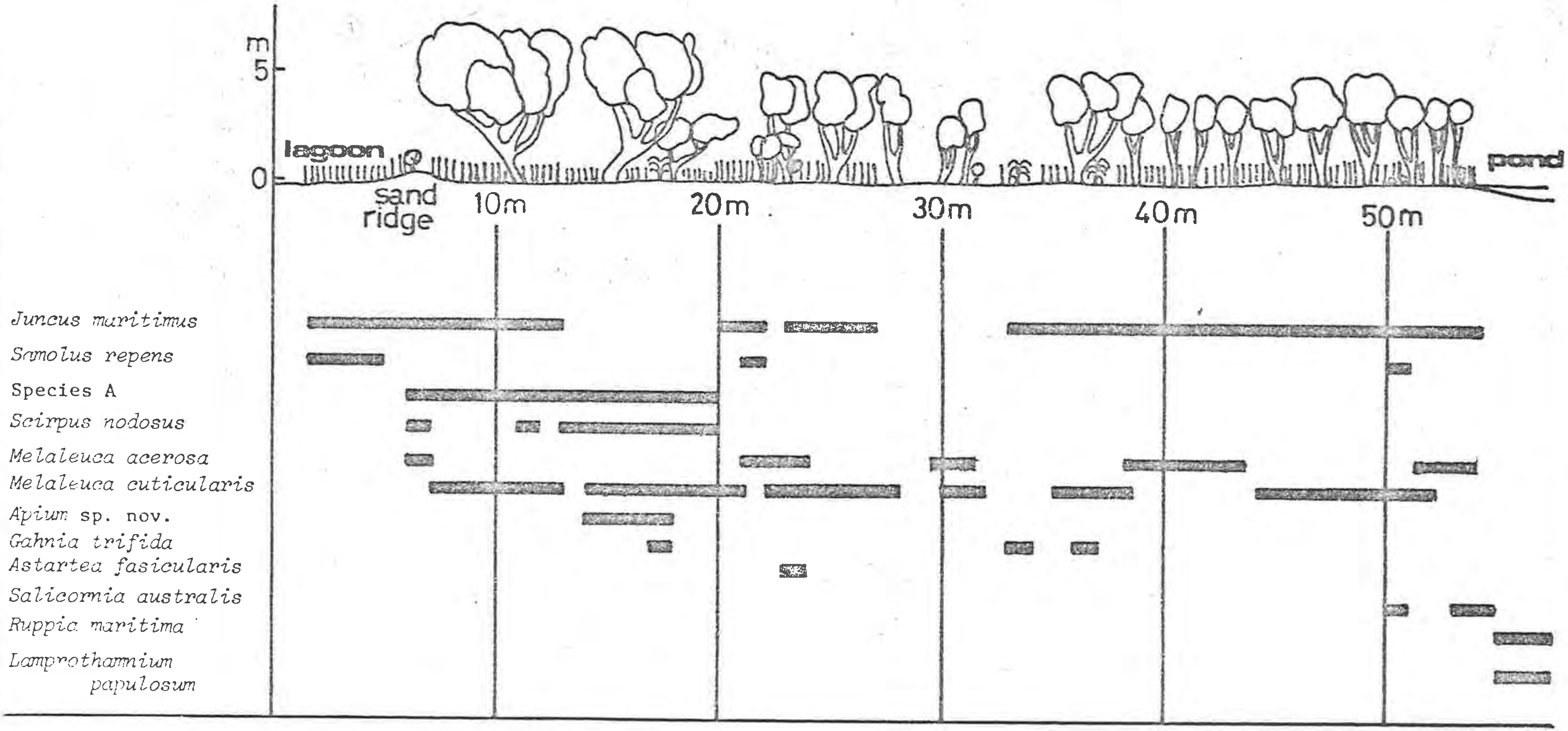


Fig. 6. Vegetation profile diagram - Point Pedder.

Where the marsh is extensive and the slope gentle (e.g. Point Pedder, parts of West Bay and Molloy Island) a Melaleuca "carr" occurs, consisting of isolated Melaleuca seedlings representing pioneers in a succession of marsh to paperbark woodland. This carr is less well seen where the topography is more steep and the successional zones therefore narrow. Where the banks of the river are steep, there may occur a fringe of Juncus with scattered Melaleuca trees, which apparently collapse into the river as the Juncus layer on which Melaleuca becomes established is poorly secured to the substratum.

Mature Melaleuca trees are generally some 7 m tall, with spreading crowns. The canopy is dense, and greatly reduces light penetration. This, together perhaps with leaf fall, leads to a marked decrease in the density of Juncus, which is virtually eliminated. Small herbs and occasional clumps of Gahnia trifida occur. Among the herbs, Conium maculatum is most common and other species, including Anagallis arvensis, Apium sp. nov. and Centella asiatica occur. The zonation of the paper barks is possibly related to the stability as well as the type of substrate. The trees have very shallow root systems and occur in waterlogged, peaty soils subject to settling and erosion. Established stands occur in areas least susceptible to disturbance.

The transition between paperbark woodland and jarrah forest is usually marked by a zone of Melaleuca acerosa, a shrub to 4m. A generalised zonation profile is presented in Figure 7 to illustrate the main points. The zonation from open water to paperbark woodland reflects temporal succession but the transition from paperbark woodland to jarrah forest is obscure and will not be pursued in the present study.

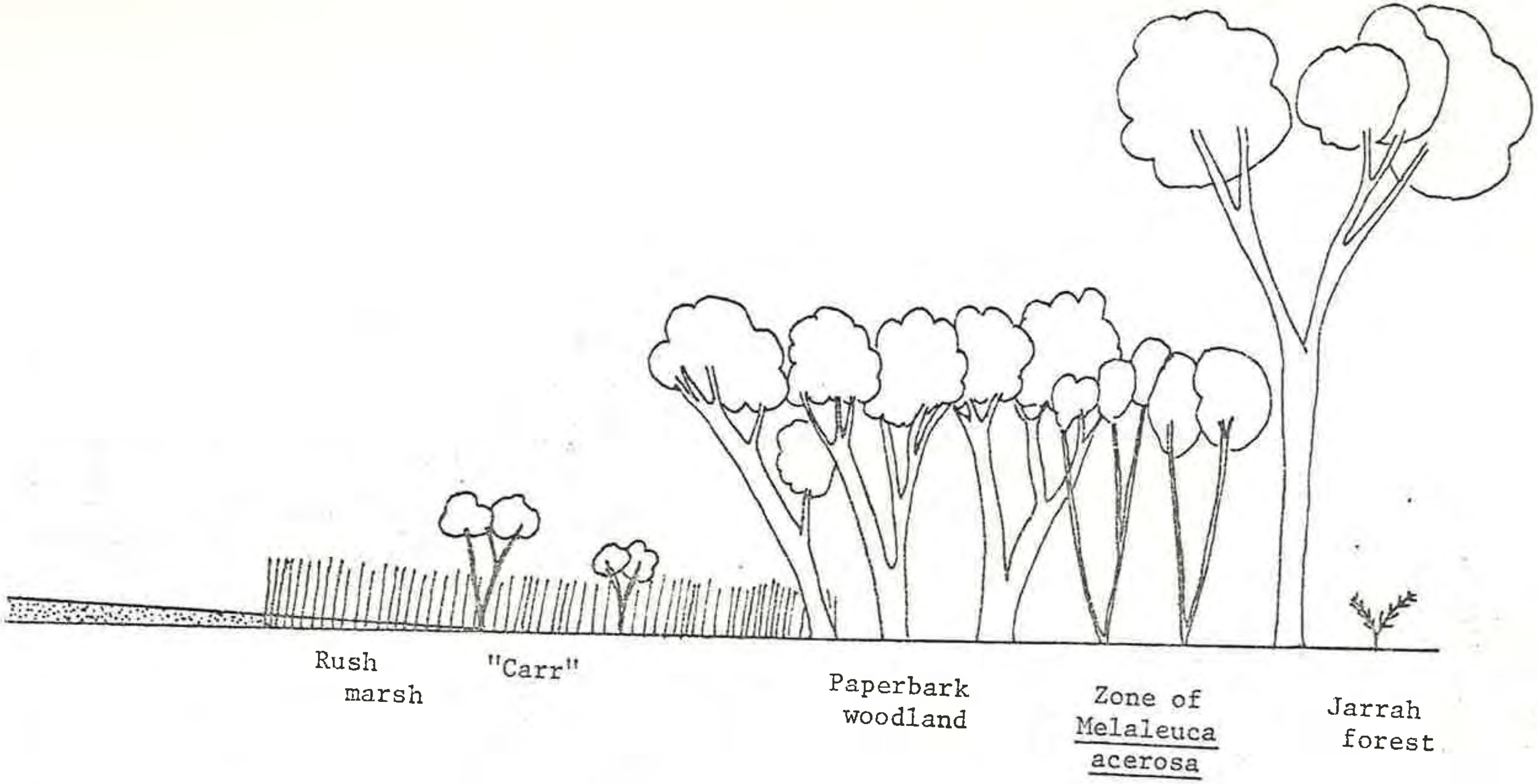


Fig. 7. Generalized zonation profile.

Biomass

Table 7 contains some standing crop measurements for *Juncus maritimus* growing on a Point Pedder sandridge. It can be seen that the below ground dead component is comparatively large, and probably reflects the gradual piling up of sand burying the rhizomes in this region. The corresponding aboveground dead would be gradually removed by tidal action or soil formation. The amount of aboveground dead is comparable with the aboveground live, suggesting that this component is significant and may be an important source of detritus to the estuary as well as peat to the shore succession. A comparison of Table 1 and 7 standing crop figures emphasises the high productivity of the fringing vegetation. The role of fringing vegetation in supplying detritus to an estuary has been well established in the Northern Hemisphere where grasses are dominant (e.g. Udell et al 1969, Nixon and Oviatt 1974).

The total aboveground dry weight of 2.15 $kg.m^{-2}$ is higher than total aboveground dry weights of 0.84 to 1.29 $kg.m^{-2}$ obtained for *Spartina alterniflora* at the end of its growing season (Nixon and Oviatt, 1973; Teal 1962).

Table 7

Standing Crop Measurements for Juncus Maritimus Growing on Point Pedder Sand Ridge (24/10/1974)

	Fresh Weight	Dry Weight
Aboveground Live	2.48 $kg.m^{-2}$	1.28 $kg.m^{-2}$
Aboveground Dead	2.36	0.87
Total Aboveground	4.84	2.15
Belowground Live	2.96	1.09
Belowground Dead	4.27	1.61
Belowground Fibrous	0.95	0.35
Total Belowground	8.19	3.06
Total live[1]	5.44	2.37
Total dead[1]	6.63	2.48

[1] excludes fibrous material

NUTRIENTS AND SALINITY

Introduction

In this chapter we are concerned with the nutrient status of the open water, sediments, and fringing plant communities. Useful reviews of the large literature on nutrient cycling in estuaries may be found in Likens (1972) and Kramer and Allen (1972). A few of the more pertinent papers are mentioned here.

Sediments

The marine sediment profile is shown in Fig.8 (Fenchel 1969). In Hardy Inlet the profile generally consists of very thin oxidized and redox discontinuity zones, of the order of 5 mm. The reduced zone is very black and, if penetrated at low tide, releases a very noticeable odour of hydrogen sulphide gas. Biggs (1967) attributes the colour of black sediments to hydrotroilite (FeS_nH_2O) - an amorphous ferrous sulphide; and grey sediments to pyrite (FeS_2). The organic matter content of Australian estuarine muds ranges from 0 to 26% with a mean of 14% (Baas Becking, 1969).

According to Odum (1971) the bulk of the benthic fauna occurs in the oxidized zone, while chemosynthetic bacteria and nematodes occur in the redox discontinuity zone. The reduced zone is inhabited by anaerobic bacteria, protozoa and nematodes. The burrows of macrofauna and the roots of seagrasses and marsh vegetation extend into this zone.

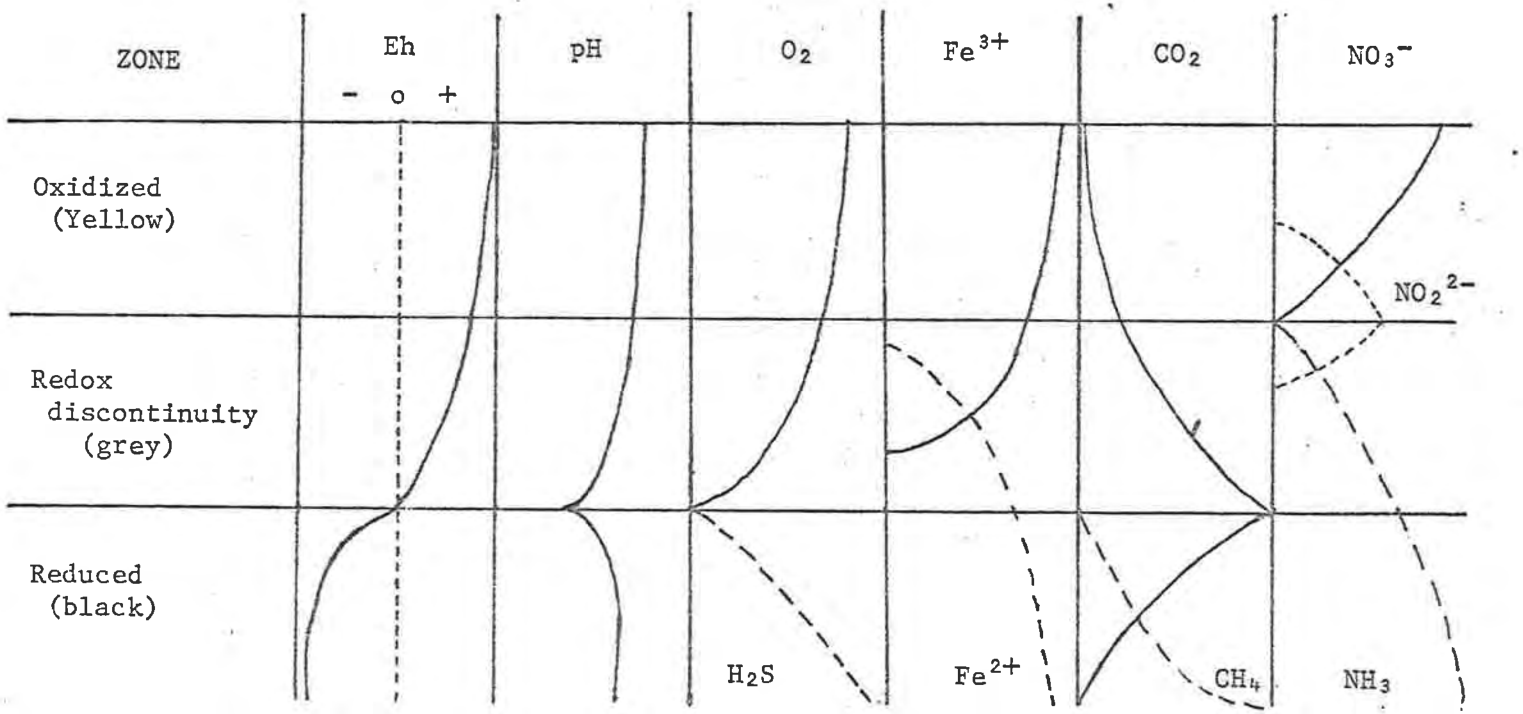


Fig. 8. Marine Sediment profile (Fenchel, 1969).

Nitrogen

Nitrate and ammonia are the forms of nitrogen normally taken up by plants, and there is some evidence that ammonia is preferred by phytoplankton; if necessary the form of nitrogen can be assessed by assaying for nitrate reductase, which is only present when nitrate is being assimilated (Brezonik 1972; Harvey 1940). Mortimer (1941-2) suggests that ammonia can be liberated by anaerobic sediments into the water column, aided by water movement.

Zostera marina can take up nitrogen compounds and inorganic carbon through the roots, as shown by isotope studies in the laboratory (McRoy and Barsdate 1970; McRoy and Goering 1974; McRoy et al 1972). The isotopically labelled compounds were transferred to epiphytes by leakage from the leaves. There is evidence for a similar transfer of labelled phosphorus (see below), and other evidence for plant uptake of nutrients from sediments is given by Bristow and Whitcombe (1971), and Waisel and Shapira (1971). It is therefore likely that seagrasses in general obtain nutrients from the sediments through their roots, as do terrestrial angiosperms. Brooks et al (1971) have demonstrated nitrogen-fixation in the sediments of the Waccasassa estuary, Florida, using the acetylene reduction method. They found fixation rates of 0.64 to 6.0 ng $N.hr^{-1}$. Fixation occurred below 2 cm, and not in the upper 2 cm of flocculent, unconsolidated sediment. A Clostridium-like species was isolated from the sediments.

Goering and Parker (1972) also used the acetylene-reduction method to demonstrate nitrogen fixation by algal epiphytes on four species of seagrass, including Ruppia maritima.

Calothrix was probably responsible.

Patriquin and Knowles (1972) found high rates of acetylene-reduction in the rhizosphere sediments of four genera of seagrasses, including *Zostera marina*. The nitrogen-fixing bacteria in the rhizosphere sediments were 50 to 300 times more abundant than in the non-rhizosphere sediments. Nitrogen fixation has also been demonstrated in the rhizospheres of two species of emergent freshwater macrophytes (Bristow 1974).

Phosphorus

Phosphorus may well be the limiting nutrient in natural waters in southwestern Australia, because of its low concentration in soils, and because of nitrogen fixation (see above) when levels of available nitrogen are low. Of the two, phosphorus is therefore the nutrient which should be afforded more attention.

Sediments are a source of phosphorus for the water column. Kramer (1972) states that the adsorption and desorption of phosphorus from sediments is controlled by the oxidation-reduction potential, pH, concentration of calcium, and the degree of agitation of sediment in the water. Mortimer (1971) concluded that as long as the concentration of oxygen at the sediment surface is greater than 2 mg/litre, there is no release of nutrients; below 2 mg O_2/litre phosphorus, ammonia and silica are released if present.

McRoy and Barsdate (1970) showed that Zostera marina can take up labelled phosphorus through the roots as well as through the leaves under laboratory conditions. In the field they injected labelled P 7cm below the sediment surface in a Zostera bed in the lower intertidal, and uptake by the roots occurred. McRoy et al (1972) showed that the rates of phosphorus uptake and loss, by both the leaves and roots of Zostera, were dependent on the orthophosphate concentration of the liquid medium in which they were placed. They estimated that 41% of the phosphorus lost from an eelgrass ecosystem was exported from the lagoon to the sea, corresponding with 3,000 kg of phosphorus per day in the ecosystem they studied.

Harlin (1973) showed transfer of labelled P and C from Zostera marina to certain algal epiphytes.

Pomeroy et al (1965) studied phosphorus exchange in freshly collected core samples and suspensions of estuary surface sediments using ^{32}P as a tracer. Two mechanism were apparent- one chemico-physical involving clay minerals and the other biological, involving microbial uptake. Biological exchange was trivial in undisturbed sediments but as significant as the chemico-physical exchange in suspended sediments. That is, micro-organisms build up a pool of phosphorus below the sediment surface, and if the sediment is disturbed this biological phosphorus will be exchanged with dissolved phosphorus in the water. The rates of exchange and the exchange capacity of the sediments are large enough to be significant ecologically. Thus sediment may act as a buffer for phosphorus in the water column, and disturbing a sediment may be of ecological importance.

Laboratory studies have shown that the ability of silts to adsorb phosphorus is correlated with the amount of iron relative to the amount of organic matter present. Organic matter depressed phosphate adsorption and suspended silts adsorbed 80 to 90% of the phosphate in solutions of 0.55 to 2.55 mg.P per litre (Jitts, 1959).

Three phosphorus fractions can be distinguished. Interstitial phosphorus is readily extracted and is that in the water of the interstices surrounding the sediment particles; it is in equilibrium with the phosphorus in the water column and the adsorbed phosphorus. The interstitial and adsorbed phosphorus are probably available to the roots of a benthic angiosperm, as in terrestrial plants an ion-exchange mechanism functions in uptake of adsorbed phosphorus. Interstitial phosphorus has a higher concentration in coarser sediments, because silts adsorb it more readily (Rochford, 1951). The level is therefore expected to be highest in marine sediments. The reverse is to be expected for adsorbed phosphorus. The third fraction is chemically combined phosphorus, usually measured with the other two as "total phosphorus". Exchange with this phosphorus is slow, and it is not readily available for plant growth.

There is exchange between phosphorus in the water and plankton, and Lean (1973) reports the excretion of an organic phosphorus compound by the plankton in lake water. This results in the extracellular formation of a colloidal substance, and much of the non-particulate phosphorus in the lake he studied was in this form. Chu (1946) has demonstrated that some phytoplankton can use organic phosphorus direct.

PREVIOUS STUDIES OF NUTRIENTS IN THE BLACKWOOD RIVER ESTUARY

Analyses were made of samples from the Blackwood River estuary south of Alexandra Bridge on a number of occasions between 1945 and 1952 (Rochford 1953; Rochford and Spencer 1953). Chlorinity, oxygen, phosphate and nitrate were recorded from 1945, and pH from 1949. Oxygen readings through the years for a number of stations ranged between 0.00 and 7.05 mg O_2 per litre as determined by Winkler titration. The range for pH was 6.74 to 8.39; phosphate from 0 to 25 μg PO_4-P per litre; and nitrate from 0 to 760 μg NO_3-N per litre.

Bottom deposits from the Blackwood River estuary were analysed in 1951 (Rochford 1953). Samples containing silt in the highest fraction were selected from each station. Only material which passed through a 0.2 mm sieve was used for the analyses except in the case of interstitial phosphate, where the mud *in toto* was used. Samples were collected in May and October and the ranges for stations south of station 130 are presented in Table 8. There are no significant seasonal changes, but it should be noted that samples collected in October were not necessarily from identical locations to those collected in May.

Table 8

Ranges of components in bottom muds from Blackwood River Estuary (1951) for stations south of No. 130. (Rochford 1953)

	Interstitial phosphorus (μg/g)	Adsorbed phosphorus (μg/g)	Total phosphorus (μg/g)	Organic carbon (mg/g)	Total nitrogen (mg/g)
May	0-3	0-45	135-370	28-50	1.3-3.4
October	0-3	0-97	300-500	21-52	0.5-4.3

MATERIALS AND METHODS

Open Water

Where possible nutrients were analysed using standard methods adopted by C.S.I.R.O. for marine chemistry (Major et al 1972).

Dissolved orthophosphate was determined by the single solution method with iodine-impregnation for preservation of samples. Total phosphorus was also determined by this method after perchloric acid digestion. Aliquots of 100 ml were used for each analysis.

In the determination of organic nitrogen, 100 ml of water was digested using copper sulphate as a catalyst (Anon. 1955) after boiling off the ammonia in the presence of a buffer to maintain alkaline conditions. The acid digest was made alkaline, ammonia distilled off, and 50 ml aliquots analysed by the Solorzano method for ammonia (Major et al 1972).

Dissolved oxygen was determined in the field with a Beckman Field Lab Oxygen Analyzer (Beckman Instruments, Inc., Fullerton, California). pH was determined in the field using a BpH Electrometer (N.L. Jones, Melbourne) until October, a portable Metrohm pH meter was used subsequently (E488 Metrohm Ltd., Herisau, Switzerland). Conductivity was measured with a conductivity meter (Type MC1 Mk IV, Electronic Switchgear Ltd., London) in the field, or with a Metrohm Conductometer (E382, Metrohm Ltd., Herisau, Switzerland) in the laboratory. Conductivity was converted to salinity using standard curves derived from Thomas, et al (1934).

Chloride was measured with a Clinical Chloride Titrator (Model 4-4415, American Instrument Company, Silver Spring, Maryland) using 0.2 ml sample. Calcium, magnesium, sodium and potassium were determined by atomic absorption spectrophotometry (Model AA6, Varian Techtron Pty.Ltd., Springvale, Victoria,). Because of the high concentration of these elements in seawater, they were determined direct without preservation techniques or other pretreatment. Some dilution was necessary for summer samples. An artificial seawater matrix was used for standards, and the methods are described in Parker (1972).

Carbonate-bicarbonate was determined by the alkalinity method (Anon. 1955) soon after collection of the samples.

Nitrate was assayed by the strychnidine method on 5 ml aliquots, and replicated at least 3 times as described by Major et al (1972).

Sediments beneath open water

Duplicate sediment samples were collected from areas where plant communities were present, using a corer (7 cm diameter). They were sealed in soil tins. Details of the sediment collection sites and depths are shown in Table 14.

Loss on ignition was determined on one of each pair of samples using a muffle furnace at 650°C. Interstitial, adsorbed and total phosphorus were determined using methods described by Rochford (1951) but total sediment was used, whereas Rochford only examined the silt fraction. Organic nitrogen was analysed on a sediment suspension as for the water analysis, except that a copper selenium mercury catalyst was used (17.3g $CuSo_4$, 2.6g HgO, 1g Se, 116.7 Na_2SO_4).

Substratum of fringing plant communities

The substratum was examined along the two transects described previously (Figs. 5 and 6). Soil samples were collected at the surface and 30 cm depth, at regular intervals along each transect. Where the water table was accessible the dissolved oxygen content and specific conductance was measured *in situ*. Soil samples were examined for water content, loss on ignition, pH and specific conductance in the laboratory. Soil pH was determined using a 1:2.5 soil-water suspension as described by Chapman and Pratt (1961), and soil conductivity using a 1:2 soil-water suspension as described by Hanna (1964).

Soil samples from the transect at Point Pedder were analysed for nutrient content. Inorganic phosphorus was determined by agitating 0.2 g of soil in 100 ml of deionized water and analysing by the single solution method (Major et al 1972). Total phosphorus was determined after digestion of 0.5 g of soil by the repeated addition of 0.3 ml perchloric acid and 2 ml of concentrated sulphuric acid and evaporating until a clear residue was obtained. To this was added 100 ml of deionized water; after standing overnight an aliquot was diluted, neutralized and analysed by the single solution method. Nitrogen was determined on 2.00 g of dried soil by Kjeldahl digestion, followed by the distillation of an aliquot in a Markham still, collection of ammonia in boric-acid-indicator solution, and subsequent titration against dilute HCl.

Plant communities

Plant material of *Ruppia*, *Zostera*, *Chara* and *Juncus* from the biomass studies was ground in a Wiley mill and analysed for phosphorus and nitrogen content. Phosphorus was determined in 0.5 g of plant material, and nitrogen on 0.2 g of plant material, using the methods described above for substrate analyses.

RESULTS AND DISCUSSION

Open water

Acidity: pH readings for a number of stations from July to October have ranged from 6.68 to 8.30 (Table 9). The estuary is generally alkaline and only water from the Scott River has been slightly acid. The range agrees well with that recorded by Rochford (1953), over 8 years, of 6.74 to 8.39. The form of inorganic carbon in the water is bicarbonate, as the pH does not reach a high enough level for carbonate and hydroxide alkalinity to be present. Alkalinity titrations performed in October illustrate this (Table 10). In comparison, the water in East Swan Lakes had a pH of 9.60 and carbonate was present.

Oxygen: Oxygen is present in the surface waters and at 3 m throughout the year (Table 11). The levels are quite high, even at 3 m when the river is stratified in the summer phase (Fig. 9, 10 and Table 11). Oxygen depletion at night has not been studied so far, but the readings in May were taken along the estuary from 0710 to 1530 hours, and there was no obvious trend during the course of the day. This is consistent with the observation of lack of phytoplankton in the estuary. Presumably the levels are high primarily because of the large surface area/volume of the water. Depletion at greater depths may be expected.

Nutrients and salinity: Results of water analyses are presented in Table 12, Appendix 2, and figures 11 - 14. Water samples were analysed from a number of stations in May (summer phase) and July and August (winter phase), and therefore suggest the seasonal extremes to which the estuary is subjected. There may be a brief period of high nutrient flow-through at the time of commencement of runoff from the winter rains.

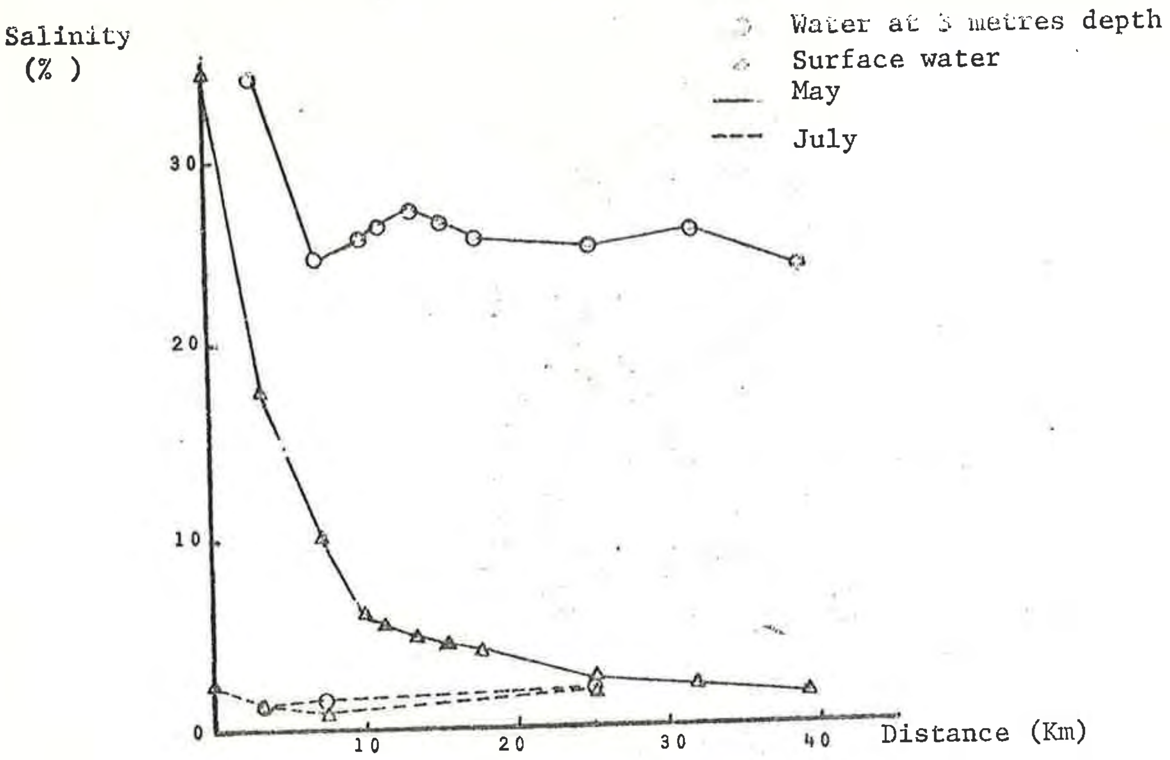


Fig. 9. Salinity changes in the estuary.

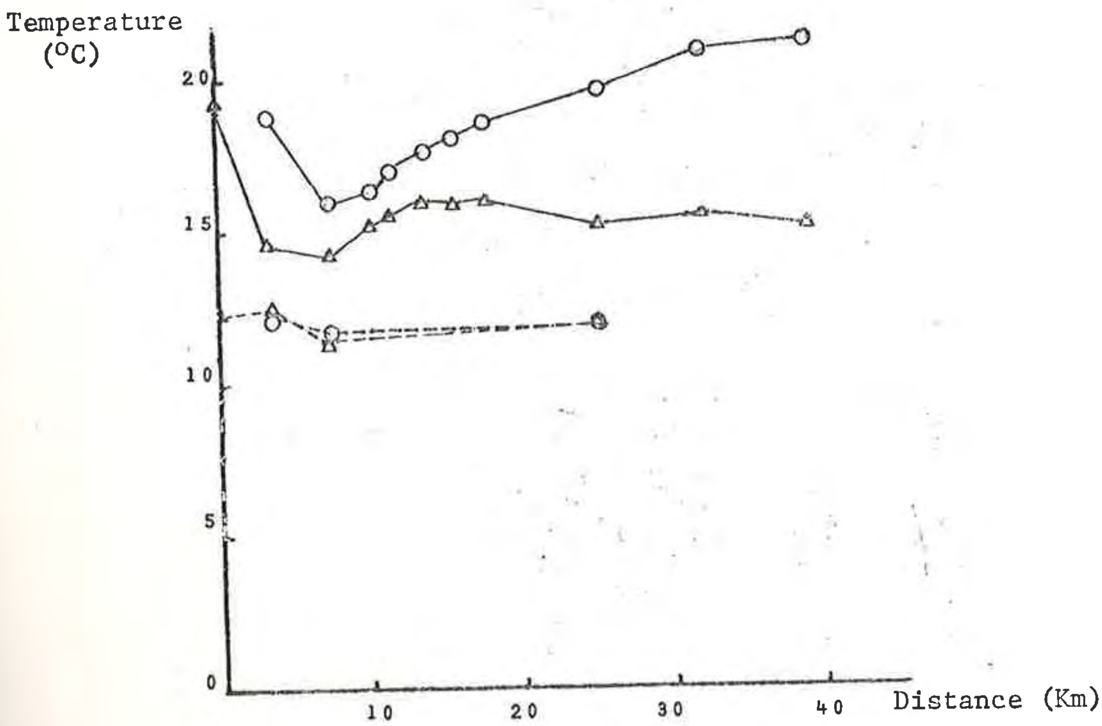


Fig.10. Temperature changes in the estuary.

Table 9

pH Readings

Date	No. of readings	Station	Mean pH (standard error)
July 1974	6	0-180	7.5(0.12)
August 1974	7	0-135	7.4(0.08)
October 1974	1	20	8.3(-)

Table 10

Alkalinity determinations
(October 1974)

Location	pH	Alkalinity (mg $CaCo_3/1$) Total	Carbonate	Bicarbonate
Riverside cottages	8.30	81	0	81
East Swan lakes	9.60	127	72	55

Table 11

Dissolved oxygen determinations

Data are in mg/l, and standard errors are in brackets

Time of Year	No. of Samples	Stations sampled	Oxygen levels	
			Surface water	3m
May (Summer phase)	10	00-210	11.1(0.4)	10.6(0.6)
July (Winter phase)	5	00-180	12.9(0.4)	13.4(0.6)

Table 12

Nutrient analyses of surface waters from selected stations
(Full data are in Appendix 2)

Station	Salinity (‰)		Inorganic phosphorus (μg/l)		Organic phosphorus (μg/l)		Organic Nitrogen (μg/l)		Nitrate Nitrogen (μg/l)
	May	July	May	July	May	July	May	July	July
Mouth	35.3	2.1	0	6.5	0	31.5	20	214	231
Pt. Irwin	17.8	1.2	1.5	8.0	9.5	17.0	152	226	238
Pt. Dalton	10.0	1.0	0	14.0	14.0	12.0	192	273	221
Old Alexander Bridge	2.4	1.8	3.0	9.5	0	43.0	81	445	312
Warner Glen	1.5	1.8	4.5	11.0	0	-	82	-	-

In May, when the salinity range for the sampling locations was high, 1.5 (at the surface upstream) to 35.33‰, inorganic phosphorus varied between 0 and 5 μg/l; total phosphorus between 0 and 14 μg P/l; and organic nitrogen between 20 and 213 μg N/l. In July the salinity of the sampling locations varied between 1.0 and 17.8‰. The ranges for inorganic phosphorus, total phosphorus and organic nitrogen were 2.0 to 14.0 μg P/l., 6.5 to 72.0 μg P/l and 214 to 458 μg N/l respectively. The range for nitrate was 101 to 312 μg N/l.

In August the salinity range was low, 0 to 1.2‰. Inorganic phosphorus was 3.0 to 11.0 μg P/l., total phosphorus was 13.0 to 34.0 μg P/l., organic nitrogen was 221 to 362 μg N/l and nitrate was 0 to 73 μg N/l. Samples collected in February 1975 contained 1.5 to 18 μg NO_3-N/l.

The nutrient levels in seawater are very low, and increase as the water is diluted with river water. Thus, levels of nutrients are much higher during the winter phase than the summer phase. (See also Rochford 1953; Rochford and Spencer 1953). The levels are, however, quote low when compared with those in eutrophic aquatic systems (e.g. for Lake Joondalup - Inorg. P 0-64 μg P/l, total P 10 - 202 μg P/l, Org. N 0.9 - 4.5 mg/l).

In general the cation ratios agree with those of seawater except for the lower values of potassium in July and August. This is apparently due to this element being more readily leached from soil than the other major cations. This is suggested by the August results (Figs.11-14). Land adjacent to North Arm was cleared early in 1974. Potassium in water from the North Arm was in a relatively higher ratio to the other cations when compared with the water coming from the Blackwood and Scott rivers.

CHANGES IN METALLIC CATIONS - AUGUST 1974.

Fig.11: Sodium

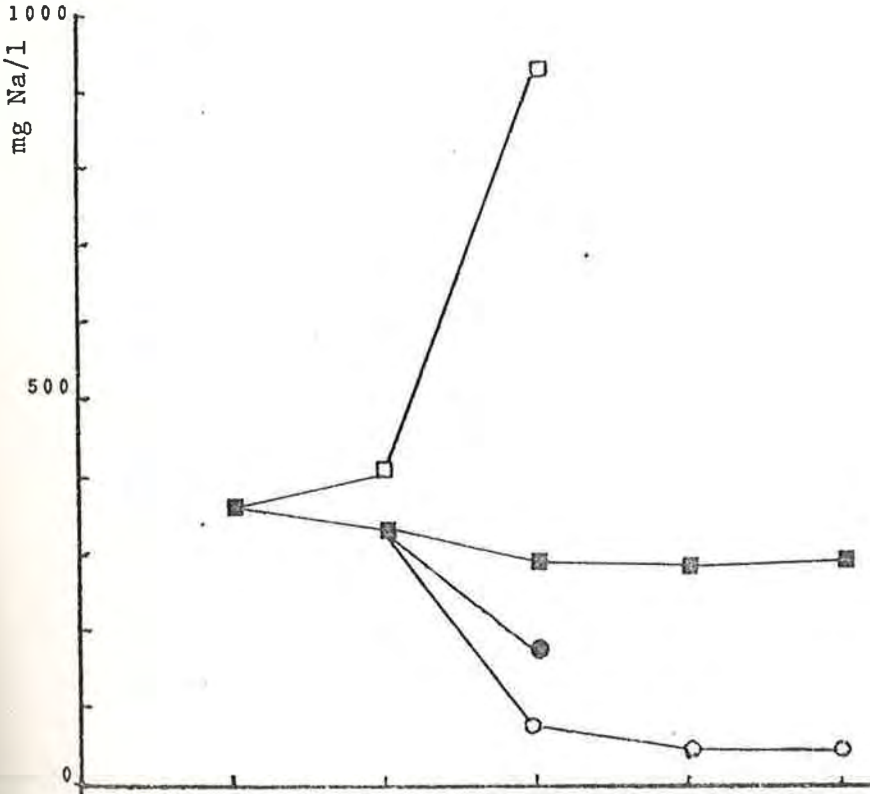


Fig.12: Calcium

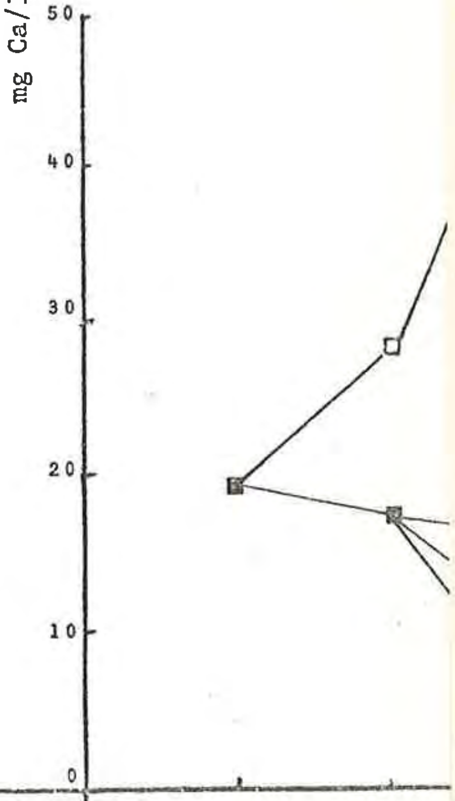


Fig.13: Potassium

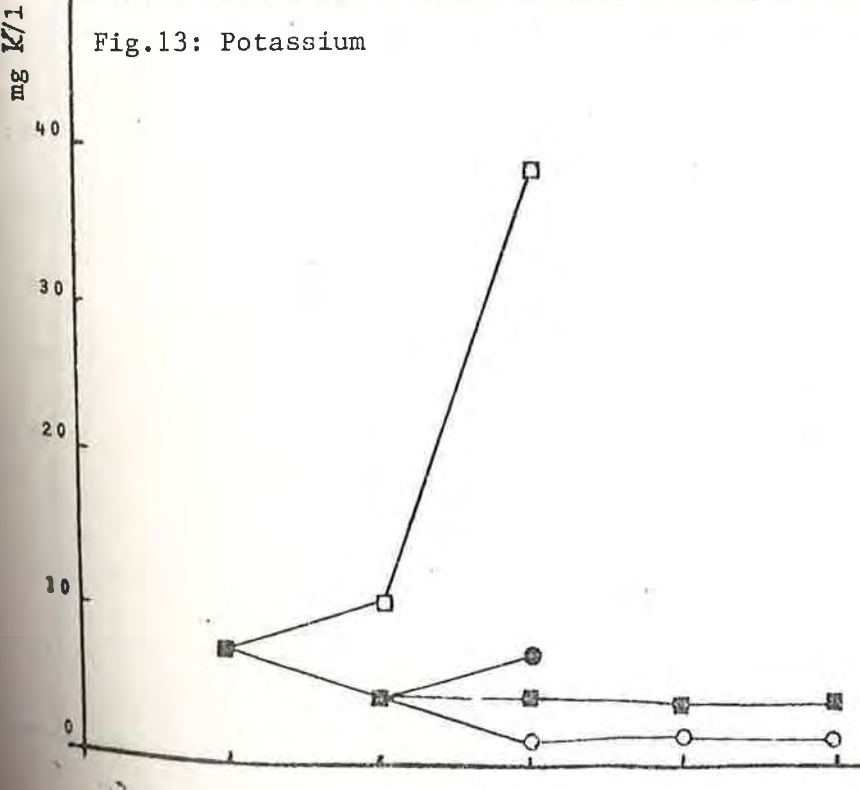
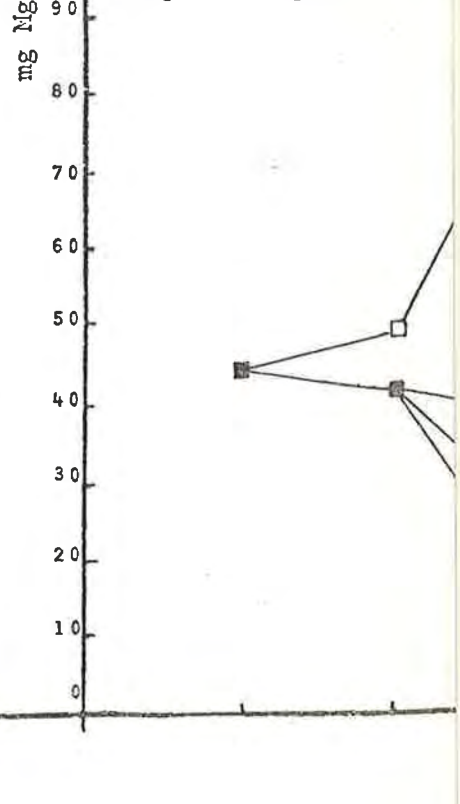


Fig.14: Magnesium



IN METALLIC CATIONS - AUGUST 1974.

Fig.12: Calcium

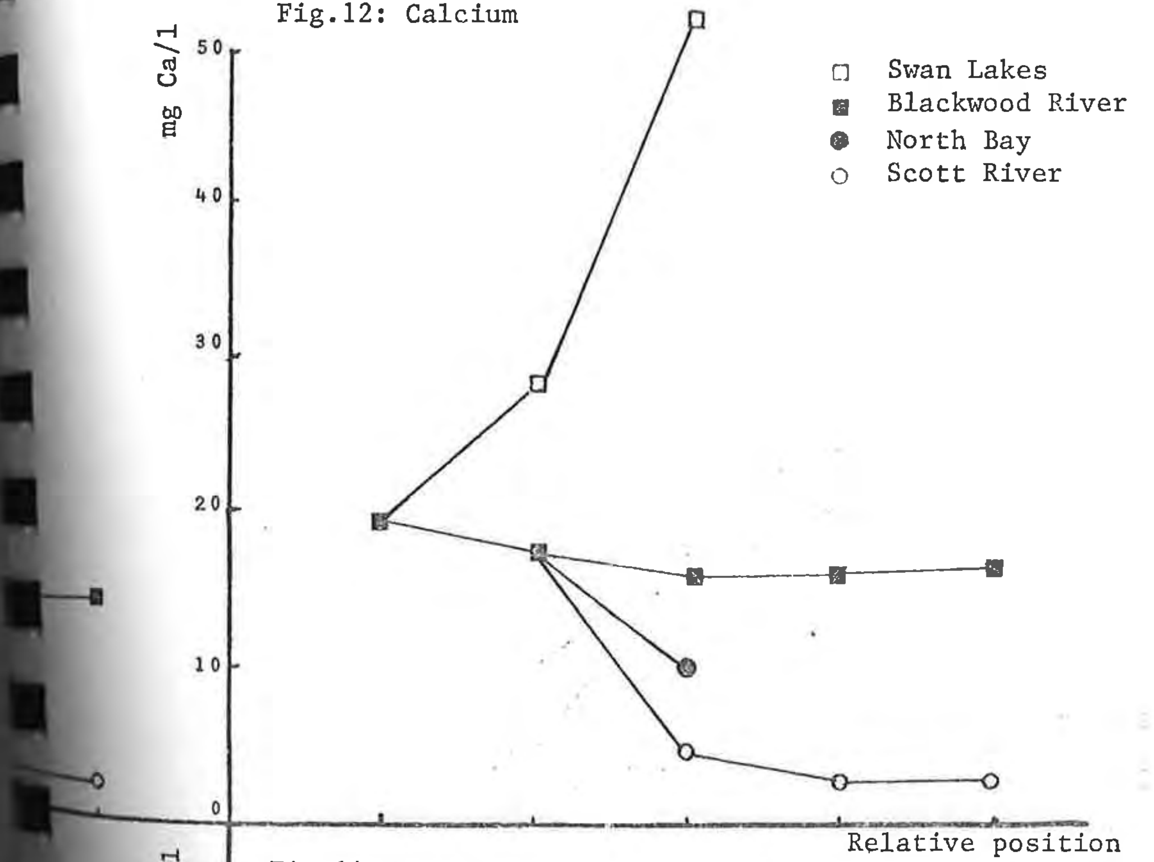
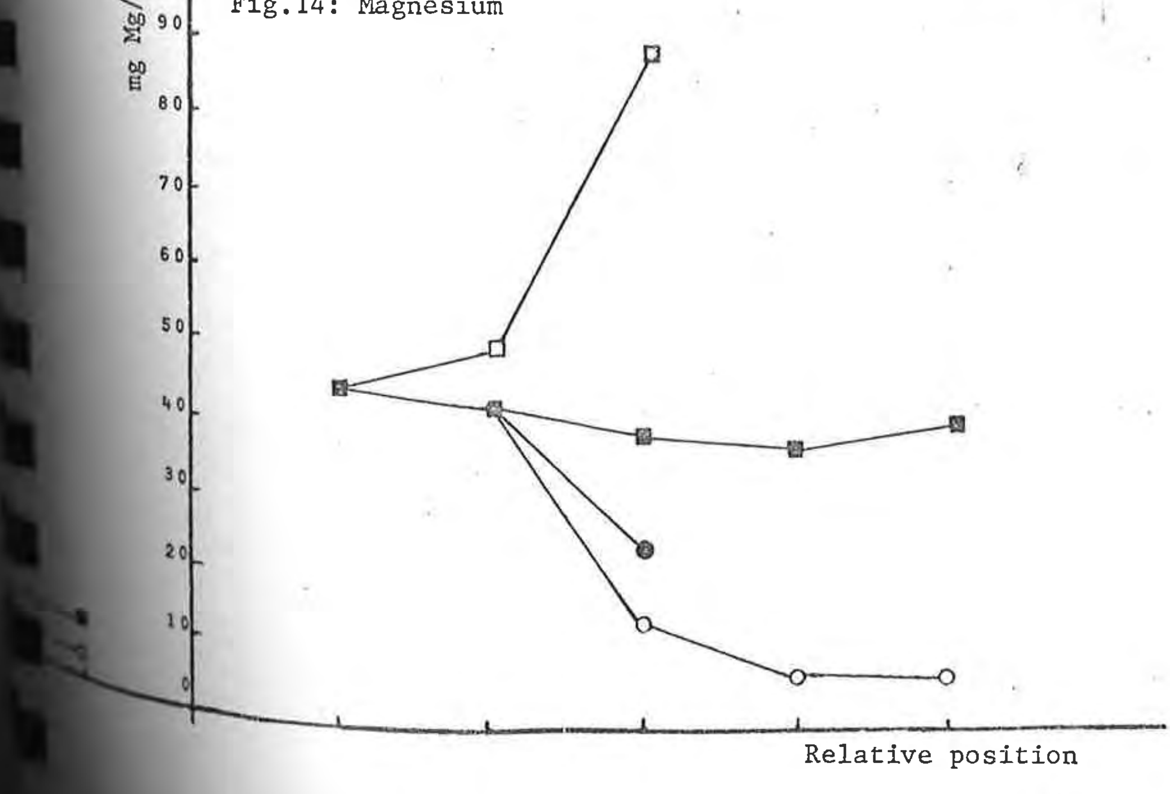


Fig.14: Magnesium



Cation concentrations increased with distance up the Blackwood River in July, and is due to increasing dilution of the rather saline water coming down the river by tributaries and other drainage carrying fresher water. The levels obtained in August show that the Scott River carries fresher water than the Blackwood (Table 13). For example at station 93, just south of Molloy Island, two streams of water are indentifiable. These samples were collected within 5 metres of each other. Sample 93' had a higher concentration of cations than sample 93" indicating that the water in the former was from the Blackwood, and the latter from the Scott. This is also shown in the nitrate results, but the levels of phosphorus and organic nitrogen in the Scott River samples were comparatively high.

General - Phosphate did not exceed 14.0μg P/l in the samples analysed. Since Rochford (1953) found concentrations up to 25.0μg P/l, there is no evidence to suggest an increase in the nutrients coming down the Blackwood River. Phosphorus is in low concentrations, and if the level is increased then eutrophication problems could occur. During the winter when phosphorus is at its maximum level, the river flow is high and most of it must flow through to the sea. Spring-time is critical, since the river flow is slacking while the P level is still high compared with summer levels, and conditions are favourable for photosynthesis.

Table 13

Comparison of waters of the Blackwood and Scott Rivers. (August 1974)

		Blackwood	Scott
Sodium	(mg/l)	290	40
Potassium	(mg/l)	4	1
Calcium	(mg/l)	17	3
Magnesium	(mg/l)	40	7
Chloride	(mg/l)	500	100
Nitrate	(μg/l)	80	3
Organic N	(μg/l)	223	221
Phosphate P	(μg/l)	8	8
Organic P	(μg/l)	20	5

Sediment analyses

The results are presented in Table 14. The highest values for interstitial phosphorus, total phosphorus and organic nitrogen occurred in Swan Lakes, where the grey flocculent sediment is thought to contain a large amount of swan faecal material. Disregarding these values, those obtained for interstitial phosphorus and total phosphorus cover a greater range than the values obtained by Rochford (1952) and this could be partially attributed to the difference in the sampling methods. Coarser particles under plant communities would include detritus, which would raise the total phosphorus level.

The samples from Swan Lakes had the highest percentage loss on ignition indicating higher organic matter contents. The high value obtained for station 12 is not expected as the sediments are coarse and sandy (marine in origin). The loss on ignition figures are within the range of 0 to 26% organic matter content given by Baas Becking (1959) for Australian estuarine muds except for the high value obtained at station 04, where flocculent faecal material was dominant.

Levels of phosphorus and organic nitrogen, expressed per gram of dry sediment, are higher than the values obtained for the water column, expressed per litre, at the same sampling location. Even in August, which is in the winter period of high nutrient levels in the water, the sediments are a richer potential source of nutrients (Table 14).

Table 14

Sediment analysis data
(August 1974)

Station	water depth (cm)	Interstitial phosphorus (µg/g d.wt.)	Adsorbed phosphorus (µg/g d.wt.)	Total phosphorus (µg/g d.wt)	Organic nitrogen (mg/g d.wt.)	Loss on ignition (% d.wt)	Nutrient Status of water: Total P (µg/1)	Nutrient Status of water: Organic N (mg/1)	Description of Community
04	67	113.3	20.0	360.8	7.87	48.56	-	-	Sparse *Ruppia*; grey sediment = light, flocculent.
Swan Lakes									
05.5	35	118.3	3.3	1280.8	3.77	19.57	27.0	0.31	Dense *Ruppia*; grey coarse sediment.
12	30	70.9	5.9	865.0	0.64	17.32	34.0	0.27	Sparse *Zostera mucronata*; coarse sandy sediment.
North of Thomas Is.	50	69.1	0.5	577.5	1.96	1.86	-	-	Scattered *Ruppia*; coarse sediments - oxidized yellow over black.
78	50	18.8	9.1	236.1	1.73	5.50	-	-	Sparse *Ruppia*; black gelatinous mud.
93	50	89.1	11.6	88.3	1.25	1.84	-	-	Sparse *Ruppia* and *Lamprothamnium*; coarse mineral sands - grey.
95	43	28.6	11.7	144.4	2.09	3.21	25.0	0.31	*Potamogeton* and *Lamprothamnium*; moderately coarse sediment.
105	113	12.6	1.5	56.9	1.41	9.07	21.0	0.31	*Ruppia*; fine black gelatinous sediment.
135	73	44.6	97.2	397.3	1.74	7.33	28.0	0.22	*Potamogeton*; coarse sandy sediment with fine organic particles.

Substratum of fringing vegetation

Tables 15 and 16 show the results of soil analyses along the two transect lines of Figs. 5 and 6. Salinity (specific conductivity) decreased with distance from the estuary in the shore transect, consistent with drainage of fresh water from the shore towards the estuary. At the Point Pedder transect, there was an increase from 10 to 50 m related to the high salinity of the pond as compared with the estuary (11‰ compared with 6‰, or 15 μmhos cm^{-1} compared with 7.91).

Dissolved oxygen readings from soil water in the shore transect decreased with distance, related to depth of watertable and soil respiration. Soil pH decreased with distance in both transects, consistent with increasing levels of organic matter in the form of peat.

Soil nutrients were determined for the Point Pedder transect. Inorganic phosphorus, total phosphorus and nitrogen were found to increase with distance from the estuary. The phosphorus source for the Juncus communities would be the inorganic phosphorus (interstitial and adsorbed) of the sediments, which is converted to organic phosphorus by the plant. On seasonal senescence and decomposition of plant parts, some phosphorus would be released, but much would be retained by these perennial plants. Any further phosphorus arriving at the substratum would also be available for trapping by the plants. Thus the general level of phosphorus is built up.

Table 15

Soil analysis data for shore transect near Station 95[1]. (4.7.1974)

Distance from river (m)	Specific Conduct-ance ($k\Omega^{-1}.cm^{-1}$)	Dissolved Oxygen[2] (ppm)	pH	Water Content (%)	Loss on ignition[3] (%)	Depth t water table[4] (cm)
5	5.68	8.2	5.94	271.2	28.6	-10
10	8.06	6.6	5.78	158.4	18.0	-6
15	4.58	6.0	5.78	149.6	23.95	1
20	1.53	1.5	5.50	137.8	24.2	5
25	0.55	-	5.62	103.8	15.15	15

1 Shown in Fig. 5.

2 Measured <u>in situ</u> where water table accessible.

3 As per cent of dry weight.

4 -ve indicates water above surface

Table 16

Soil analysis data for Point Pedder transect near Station 73[1]

Distance from Estuary (m)	Depth of Sample	Specific Conductance ($k\Omega^{-1}.cm^{-1}$)	Dissolved Oxygen[2] (ppm)	pH	Depth to water table (cm)	Ortho-phosphate phosphorus (μg/g)	Total phosphorus (μg/g)	Kjeldahl nitrogen (μg/g)	Sediment appearance
0[3]	surface	2.44	11.0	6.02	0	$25x10^{-1}$	$326x10^{-1}$	250	yellow-grey, inorganic
5	surface	0.03		6.07	100	12	154	240	yellow, sandy
10	surface	0.15	2.5 at 60cm	5.83	60	2	282	330	yellow, inorganic
10	30 cm	1.08		6.02	-	12	320	220	white-grey, inorganic
15	surface	0.27		6.18	45	207	1292	650	white-black, some organic
15	30 cm	0.93		6.36	-	2	330	120	white, inorganic
20	surface	0.47		5.96	-	155	1672	670	white-black more organic
30	surface	0.95		5.78	-	175	3560	1520	black, very organic
40	surface	1.65		5.53	28	157	2788	3220	white-black, some organic
50	surface	11.83		5.63	5	482	3376	10590	black, mainly organic
55	surface	15.00	12.3	-	0				

1 Shown in Fig. 3.

2 Measured <u>in situ</u> where water table accessible.

3 Bottom sediment exposed at very low tide.

Plant Communities

Levels of phosphorus and nitrogen in plant material are shown in Table 17. Contents are relatively high in the benthic plants, which have little sclerenchymatous tissue. In *Juncus* it can be seen that the dead above-ground material contains some 20% of the phosphorus, and almost 40% of the nitrogen, of the live material, suggesting that 80% of the phosphorous and 60% of the nitrogen are translocated from the senescing tissue to the remainder of the plant. The proportions are very similar for rhizome material. The figures for the roots suggest poorer translocation but it must be remembered that there is great difficulty involved in deciding between living and dead roots.

It is a simple matter to multiply these figures up using the biomass data of Tables 1 and 7, to give the figures of Table 18, and the relatively large amount of P and N present in *Juncus* communities is readily apparent. When further data is available concerning sediment density, plant distribution, and variation between sites and seasons, it will be possible to compute the total amounts of N and P in the vegetation. In the case of the benthic plants, much of the plant growth is seasonal - indeed *Potamogeton* behaves as an annual - and so the bulk of the nutrients are accumulated during a season's growth. If the plants take up P only from the sediments, the loss from the sediments should be readily detected.

Table 17

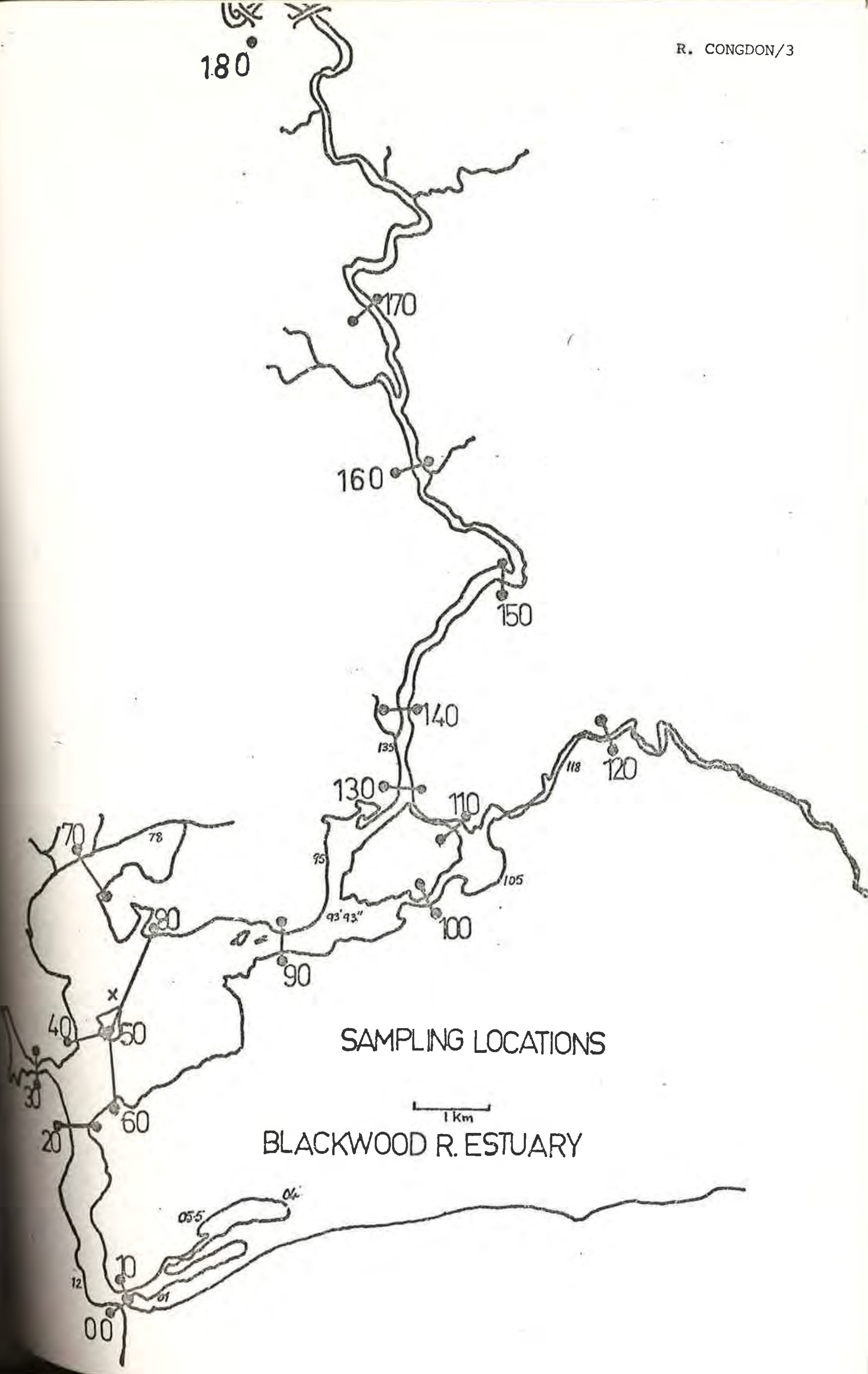
Nutrient levels in plant material
(October 1974)

		Total phosphorus (mg/g)	Organic Nitrogen (mg/g)
Ruppia maritima	aboveground	1.6	13.9
	belowground	2.1	10.3
Zostera mucronata	total	1.7	15.2
Chara vulgaris	total	0.9	7.3
Juncus maritimus			
	aboveground live	0.6	11.0
	aboveground dead	0.1	4.2
	rhizome live	0.6	9.3
	rhizome dead	0.1	4.6
	roots live	0.2	2.3
	roots dead	0.1	2.5
	fibrous material	0.2	3.8

Table 18

N and P in plant material,
calculated on a per area basis

	P (g/m^2)	N (g/m^2)
Ruppia	6.1×10^{-1}	4.0
Chara	3.9	3.3
Zostera	0.2	0.2
Juncus	15.1	31.2



SAMPLING LOCATIONS

BLACKWOOD R. ESTUARY

Station	Time	Depth (m)	Sal. (‰)	Temp. (°C)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (g/l)	NH_3 (μg/l)	Org.N (μg/l)	Inorg.P (μg/l)	Total P (μg/l)
00	0710	S	35.3	19.1	10840	400	387	1230	21.4	7.5	20	0	0
20	0745	S	17.8	14.5	8520	295	306	932	19.8	17.0	152	1.5	11.0
		3	34.3	18.8	10420	284	370	1177	22.6	0	36	0	11.0
90	0810	S	10.0	14.2	3645	89	117	210	6.7	23.0	192	0	14.0
		3	24.5	15.8	6530	223	228	692	16.4	3.5	157	4.5	9.0
130	0845	S	5.9	15.2	1770	38	71	155	3.1	25.0	207	5.0	7.0
		3	25.6	16.3	6670	232	247	785	15.6	-	-	-	-
140	0915	S	5.4	15.6	1330	36	66	130	3.2	-	-	-	-
		3	26.3	17.0	7270	264	268	873	18.2	-	-	-	-
150	1015	S	4.8	16.0	1020	36	62	133	2.9	-	-	-	-
		3	27.1	17.7	7720	286	282	931	14.4	-	-	-	-
160	1050	S	4.4	15.9	980	33	58	128	2.5	-	-	-	-
		3	26.5	18.0	7450	271	271	815	15.0	-	-	-	-
170	1140	S	4.0	16.1	745	30	52	91	2.3	77.0	127	4.0	3.0
		3	25.6	18.5	6570	252	254	781	15.0	-	-	-	-
180	1230	S	2.4	15.2	400	20	38	44	1.0	51.0	81	3.0	0
		3	25.1	19.6	5070	238	247	712	12.5	-	-	-	-
200	1350	S	2.1	15.4	150	16	34	22	0.8	33.0	67	2.0	0
		3	25.9	20.8	6830	238	263	802	17.2	-	-	-	-
210	1530	S	1.5	15.2	200	17	29	3	0.6	21.0	82	4.5	1.0
		3	23.8	21.2	6320	220	248	740	14.0	260.5	213	1.5	3.0
Darradup Bridge		S	-	-	470	18	47	21	0.8	-	-	-	-

July 1974 (3.7.1974 - 5.7.1974)

Station	Time	Depth (m)	Sal. (‰)	Temp. (°C)	Na (mg/1)	K (mg/1)	Ca (mg/1)	Mg (mg/1)	Cl (g/1)
01	1530	S	17.8	13.0	6280	241	242	796	12.1
00	1700	S	2.1	12.3	600	20	28	90	1.2
20	1400	S	1.2	12.4	368	9	17	55	0.6
		3	1.2	12.3	358	9	17	55	0.7
80-	1330	S	1.1	11.8	295	7	16	46	0.6
		3	1.1	11.6	300	7	17	47	0.5
90	1030	S	1.0	11.5	276	5	16	44	0.5
		3	1.3	11.7	350	9	18	60	0.7
180	1000	S	1.8	11.8	445	5	39	113	1.0
		3	1.8	11.8	445	5	39	114	1.0
210		S	-	-	472	5	42	124	1.1

July 1974 (Continued)

Station	Time	Depth (m)	Org.N (μg/l)	NO_3 (μg/l)	Inorg.P (μg/l)	Total (μg/l)	Si (μg/l)
01	1530	S	231	110	2.0	6.5	1120
00	1700	S	214	230	6.5	37.5	2520
20	1400	S	226	238	8.0	25.0	2730
		3	219	251	8.0	32.0	2680
80-	1330	S	260	263	11.0	26.0	2680
		3	304	263	11.0	47.0	2800
90	1030	S	273	221	14.0	26.0	2580
		3	262	284	14.0	23.0	3220
180	1000	S	445	312	9.5	43.0	3610
		3	458	285	9.5	72.0	3610
210		S	-	-	11.0	-	-

August 1974 (26.8.1974 - 29.8.1974)

Station	Time	Depth	Sal. (‰)	Temp. (°C)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (g/l)
Swan Lakes									
04	1200	S	-	13.7	925	31	53	87	1.8
05.5	1230	S	1.2	16.3	405	11	28	49	0.7
Seine Bay									
12	1700	S	1.1	-	360	8	20	44	0.7
North of Thomas Is.	1000	S	-	-	330	4	18	42	0.5
North Arm									
78	0900	S	-	-	175	7	10	23	0.3
93'	1445	S	0.8	-	285	4	16	38	0.4
93''	"	S	-	-	75	2	5	14	0.1
Blackwood									
95	1400	S	0.7	13.0	280	4	16	36	0.5
Scott									
105	1100	S	0.0	-	45	2	3	8	0.1
Blackwood									
135	1300	S	0.8	13.0	290	4	17	40	0.5
Scott									
118	1000	S	0.0	13.0	40	1	3	7	0.1

August 1974 (Continued)

Station	Time	Depth (m)	Org.N (µg/l)	NO_3 (µg/l)	Inorg.P (µg/l)	Total P (µg/l)	Si (mg/l)
Swan Lakes							
04	1200	S	-	27	5.0	-	1.25
05.5	1230	S	310	34	3.0	27.0	1.60
Seine Bay							
12	1700	S	290	50	11.0	34.0	2.00
North of Thomas Is.	1000	S	-	56	5.0	-	6.00
North Arm							
78	0900	S	-	4	5.0	-	1.32
93'	1445	S	312	73	4.0	-	2.25
93''	"	S	-	22	3.0	-	1.40
Blackwood							
95	1400	S	307	48	5.0	25.0	2.15
Scott							
105	1100	S	362	0	3.0	21.0	1.45
Blackwood							
135	1300	S	223	80	8.0	28.0	2.30
Scott							
118	1000	S	221	3	8.0	13.0	1.30

REFERENCES

Allan, H.E. and Kramer, J.R. 1972. Nutrients in Natural Waters. John Wiley & Sons, Inc., N.Y.

Allender, B.M. 1967. Preservation techniques for algae. W.A. Nat., 10:99.

Allender, B.M. 1974. Hardy Inlet, South Western Australia: A preliminary survey of the benthic flora in August 1966 and February 1967. Unpublished report.

Anon. 1955. Standard Methods for the Examination of Water, Sewage and Industrial Wastes. American Public Health Association, 10th edition, New York.

Anon. 1974. Newsletter of the American Ecological Society.

Aston, H.I. 1973. Aquatic Plants of Australia. University Press, Melbourne.

Bass Becking, L.G.M. 1959. Some aspects of the ecology of Lake Macquarie, N.S.W., with regard to an alleged depletion of fish. 111 Characteristics of water and mud. Aust. J. mar. Freshwat. Res., 10:197-303.

Biggs, R.E. 1967. The sediments of Chesapeake Bay. In: Lauff, G.H. (ed), Estuaries, Publ. No. 83, Am. Assoc. Adv. Sci., Washington, D.C. pp. 239-260.

Brezonik, P.L. 1972. Nitrogen: Sources and transformations in natural waters. In: Allen, H.E. and Kramer J.R. (eds.) Nutrients in Natural Waters. John Wiley and Sons, Inc., N.Y.

Bristow, J.M. 1974. Nitrogen fixation in the rhizosphere of freshwater angiosperms. Can. J. Bot., 52:217-221.

Bristow, J.M. and Whitcombe, M. 1971. The role of roots in the nutrition of aquatic vascular plants. Amer. J. Bot. 58:8-13.

Brooks, Jr., R.H. 1969. Unpublished Ph.D. Thesis. University of Florida. Gainesville. cited in Brezonik, P.L. 1972.

Brooks, Jr., R.H., Brezonik, P.L., Putman, H.D. and Keirn, M.A. 1971. Nitrogen fixation in an estuarine environment: Waccasassa on the Florida Gulf Coast. Limnol. Oceanogr., 16:701-710.

Callome, B. and Debyser, J. 1954. Observations sur les mouvements des diatomees a la surface des sediments marins de la zone intercotidale. Vie et Millieu, 5:242-249.

Chapman, H.D. and Pratt, R.F. 1961. Methods of Analysis for Soils, Plants and Waters. University of California, Division of Agricultural Sciences.

Chu, S.P. 1946. The utilization of organic phosphorus by phytoplankton. J. Mar. Biol. Ass. U.K., 26:285-295.

Clarke, L.D. and Hannon, N.J. 1969. The mangrove and salt marsh communities of the Sydney District. II. The holocoenotic complex with particular reference to physiography. J. Ecol., 57:213-234.

Clarke, L.D. and Hannon, N.J. 1970. Ibid. III. Plant growth in relation to salinity and waterlogging. J. Ecol., 58:351-369.

Clarke, L.D. and Hannon, N.J. 1971. Ibid. IV. The significance of species interaction. J.Ecol., 59: 525-553.

Faure-Fremiet, E. 1951. The tidal rhythm of the diatom, *Hantzschia amphioxys*. Biol. Bull. Woods Hole, 100:173-177.

Fenchel, T. 1969. The ecology of marine microbenthos Part IV. Ophelia, 6:1-182.

Goering, J.J. and Parker, P.L. 1972. Nitrogen fixation by epiphytes on seagrasses. Limnol. Oceanogr. 17:320-323.

Hanna, W.J. 1964. Methods for Chemical Analysis of Soils. In: Bear, F. (ed.) Chemistry of Soil, 2nd edition, Am. Chem. Soc. Monograph Series. Reinhold, New York.

Harlin, M.M. 1973. Transfer of products between epiphytic marine algae and host plants. J. Phycol. 9:243-248.

Harvey, H.W. 1940. Nitrogen and phosphorus required for the growth of phytoplankton. J. Mar. Biol. Ass.U.K. 24:115-123.

Hopkins, J.T. 1966. Some light induced changes in behaviour and cytology of an estuarine mud flat diatom. In: Bainbridge, R., Clifford Evans, G., and Rackham, O. (eds.) Light as an Ecological Factor. Brit. Ecol. Soc. Sym. No. 6. Blackwell Scientific Publications, Oxford.

Jenkin, P.M. 1937. Oxygen production by the diatom Coscinodiscus excentricus Ehr. In relation to submarine illumination in the English Channel. J. Mar. Biol. Ass. U.K. 22:301-343.

Jitts, H.R. 1959. The absorption of phosphate by estuarine bottom deposits. Aust. J. Mar. Freshwat. Res. 10:7-21.

Lean, D.R.S. 1973. Phosphorus dynamics in lake water. Science 179:678-680.

Likens, G.E. (ed.) 1972. Nutrients and Eutrophication: The Limiting Nutrient Controversy. Am. Soc. Limnol. Oceanogr., Allen Press, Kansas.

Major, G.A., Dal Pont, G., Klye, J. and Newell, B. 1972. Techniques in Marine Chemistry - A Manual. Report No. 51, C.S.I.R.O., Cronulla, N.S.W.

McRoy, C.P. and Barsdate, R.J. 1970. Phosphate absorption in eelgrass. Limnol. Oceanogr. 15:6-13.

McRoy, C.P., Barsdate, R.J. and Nebert, M. 1972. Phosphorus cycling in an eelgrass (*Zostera marina* L.) ecosystem. Limnol. Oceanogr. 17:58-67.

McRoy, C.P. and Goering, J.J. 1974. Nutrient transfer between the seagrass *Zostera marina* and its epiphytes. Nature. 248:173-174.

Mortimer, C.H. 1941-2. The exchange of dissolved substances between mud and water in lakes. Parts I-IV. J. Ecol. 29:280-329. 30:147-201.

Mortimer, C.H. 1971. Chemical exchanges between sediments and water in the Great Lakes - Speculations on probable regulatory mechanisms. Limnol. Oceanogr., 16:387-404.

Moul, E.T. and Mason, D. 1957. Study of the diatom populations on sand and mud flats in the Woods Hole area. Biol. Bull. Woods Hole. 113:351.

Nixon, S.W. and Oviatt, C.A. 1974. The Ecology of a New England salt marsh. Ecol. Monographs. 43:463-498.

Nixon, S.W. and Oviatt, C.A. 1972. Preliminary measurements of mid-summer metabolism in beds of eelgrass. *Zostera marina*. Ecology, 53:150-153.

Odum, E.P. 1971. Fundamentals of Ecology. 3rd edition. W.B. Saunders Co., Philadelphia.

Odum, H.T. 1963. Productivity measurements in Texas Turtle Grass and the effects of dredging an intracoastal channel. Pub. Inst. Marine Sc., Texas, 9:48-58.

Paerl, H.W. 1975. Detritus in Lake Tahoe: Structural modification by attached microflors. Science 180:496-498.

Parker, C.R. 1972. Water Analysis by Atomic Absorption Spectroscopy. Varian Techtron Pty.Ltd., Springvale, Victoria.

Patriquin, D. and Knowles, R. 1972. Nitrogen fixation in the rhizosphere of marine angiosperms. Mar. Biol. 16:49-58.

Peck, A.J., Williamson, D.R., Bettenay, E. and Dimmock, G.M. 1973. Salt and water balances of some catchments in the South-West coast drainage division. Inst. Eng. Hydrol. Symp. Perth 1973. 1-4.

Pomeroy, L.R. 1959. Algal productivity in salt marshes of Georgia. Limnol. Oceanogr. 1:386-397.

Pomeroy, L.R., Smith, E.E. and Grant, C.M. 1965. The exchange of phosphate between estuarine water and sediments. Limnol. Oceanogr. 10:167-172.

Pomeroy, L.R., Johannes, R.E., Odum, E.P. and Roffman, B. 1969. The phosphorus and zinc cycles and productivity of a salt marsh. In: Nelson, D.J. and Evans, F.C. (eds.), Proc. 2nd Sym. on Radioecology. Clearinghouse Fed. Sci. Tech. Info., Springfield.

Rochford, D.J. 1951. Studies in Australian estuarine hydrology. I. Introductory and comparative features. Aust. J. Mar. Freshwat. Res. 2:1-116.

Rochford, D.J. 1953. Estuarine hydrological investigations in eastern and south-western Australia, 1951. Oceanographical Station List of Investigations made by the Division of Fisheries, C.S.I.R.O. 12.

Rochford, D.J. 1953. Analysis of bottom deposits in eastern and south-western Australia, 1951, and records of twenty four hourly hydrological observations at selected stations in eastern Australian estuarine systems, 1941. Oceanographical Station List of Investigations made by the Division of Fisheries, C.S.I.R.O., 13.

Rochford D.J. and Spencer, R. 1953. Estuarine hydrological investigations in eastern and south-western Australia, 1952. Oceanographical Station List of Investigations made by the Division of Fisheries, C.S.I.R.O. 15.

Ryther, J.H. 1956. Photosynthesis in the ocean as a function of light intensity. Limnol. Oceanogr. 1:61-70.

Suda, J.R. 1974. Midsummer metabolism of an eelgrass community. Marine Pollution Bull. 5:156-159.

Taylor, W.R. 1964. Light and photosynthesis in intertidal benthic diatoms. Helgd. Wiss. Meeresunters. 10:29-37.

Taylor, R. and Palmer, J.D. 1963. The relationship between light and photosynthesis in intertidal benthic diatoms. Biol. Bull. Woods Hole. 125:395.

Teal, J.M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology, 43:614-624.

Thomas, Thompson and Utterback. 1934. The electrical conductivity of seawater. J. Cons. Explor. Mer. 9:28-35.

Udell, H.F., Zarudsky, J. and Doheny, T.E. 1969. Productivity and nutrient values of plants growing in the salt marshes of the Town of Hempstead, Long Island. Bull. Torrey Bot. Club. 96:42-51.

Waisel, Y. and Shapira, Z. 1971. Functions performed by roots of some submerged hydrophytes. Israel J. Botany, 20:69-77.

Westlake, D.R. 1966. The light climate for plants in rivers. In: Bainbridge, R., Clifford Evans, G., and Rackham, O. (eds.), Light as an Ecological Factor. Brit. Ecol. Soc. Sym. No. 6. Blackwell Scientific Publications, Oxford.

Wood, E.J.F. 1959. Some aspects of the ecology of Lake Macquarie, N.S.W., with regard to an alleged depletion of fish. VI. Plant communities and their significance. J. Mar. Freshwat.Res. 10:322-340.

Wood, R.D. and Imahori, K. 1965. A revision of the Characeae. Weinham, Cramer. 904p.

APPENDIX 1

SPECIES COLLECTED FROM THE BLACKWOOD RIVER ESTUARY

aq = aquatic; fr = fringing; for = forest; sw = other wetlands spp.

APIACEAE
Centella asiatica (aq-fr)
Conium maculatum (fr)
Eryngium pinnatifidum (fr)

ASTERACEAE
Cotula coronopifolia (aq-fr)
Composite sp 1

CHENOPODIACEAE
Atriplex paluodosum (fr)
Salicornia (fr)
Suadea australis (fr)

CYPERACEAE
Cyperus (fr)
Gahnia trifida (fr)
Lepidosperma effusum (fr)
L. tetraquetrum (fr)
Machaerina juncea (fr)
Mesomelaena tetragona (fr)
Tetraria (?) (fr)
Baumea articulata (fr)

APPENDIX I CONTINUED:-

GENTIANACEAE

Centaurium spicatus (fr)

Villarsia (aq-fr) V. parnassifolia, V. Lasiosperma.

HALORAGACEAE

Haloragis brownii (aq)

JUNCACEAE

Juncus maritimus (fr)

J. pallidus (fr)

J. pauciflorus (fr)

MYRTACEAE

Agonis flexuosa (for)

A. spathulata (for)

Beaufortia sparsa (for)

Melaleuca acerosa (sw)

M. cuticularis (fr)

M. raphiophylla (fr-sw)

PAPILIONACEAE

Oxylobium Linearifolium (fr)

POTAMOGETONACEAE

Potamogeton ochreatus (aq)

Potamogeton pectinatus (aq)

APPENDIX 1 CONTINUED:-

PRIMULACEAE

Anagallis arvensis (fr)

Samolus repens (fr) Forst & Forst f) Pers.

PROTEACEAE

Hakea varia (for)

RANUNCULACEAE

Ranunculus muricatus (aq)

RESTIONACEAE

Restio applanatus (sw)

RUPPIACEAE

Ruppia maritima (aq)

SCHEUZERIACEAE

Triglochin procera (sw)

ZOSTERACEAE

Zostera mucronata (aq)

Appendix 3 : Preliminary studies of the light requirements of *Ruppia maritima*

INTRODUCTION

It has been noted that benthic plants require some 5% of the light at the water's surface to survive (e.g. Odum 1971). A specific experiment was designed to establish this figure for *Ruppia maritima* in the Blackwood River Estuary since this is the dominant seagrass in the estuary; of importance in the diet of some fish and birdlife; and since dredging can be expected to increase water turbidity.

In the past light dependence experiments have been based on the short-term measurement of changes in photosynthesis. These have used either dissolved oxygen or ^{14}C techniques, and usually not *in situ*. It is possible that the specific light intensities required by a benthic plant may vary with its age as related to the plant's vigour and mutual shading. For this reason a long-term *in situ* method was adopted.

MATERIALS AND METHODS

Sarlon mesh bags of varying grades were tied over light aluminium frames 75cm high and 50x50cm broad. Control enclosures were covered with chicken wire to obviate grazing pressures. Eight of these enclosures were located in Swan Lakes in April 1975, and nine more in May 1975 over homogeneous beds of *Ruppia*. After a sufficient time to allow differences to develop between the cages samples were collected, as described in Chapter 1, and standing crops determined.

RESULTS

The results are presented in Figures 1-4.

Figures 1 to 4: Productivities of *Ruppia maritima* under different light intensities.

Fig. 1 : 1st April to 24th June 1975

Fig. 2 : 1st April to 21st July 1975

Fig. 3 : 20th May to 11th September 1975

Fig. 4 : 1st April to 11th September 1975

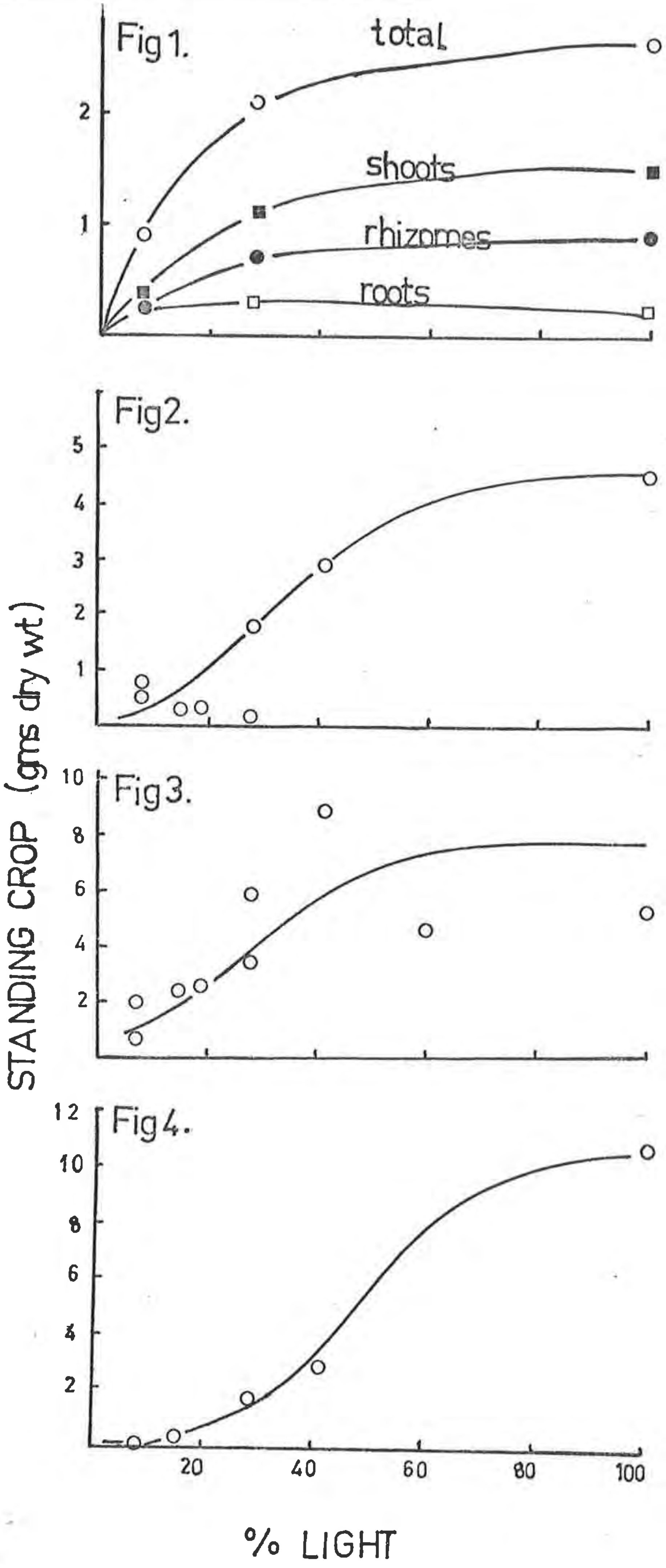


Fig 1.
total
shoots
rhizomes
roots
Fig 2.
Fig 3.
Fig 4.
STANDING CROP (gms dry wt)
% LIGHT

DISCUSSION

The preliminary results suggest that *Ruppia* is not greatly affected by a reduction to 50% of the surface light, but is markedly affected by a reduction to some 20%. Consequently *Ruppia* may become precluded if the light intensity is reduced to 20% or less of its present value by a phytoplankton bloom or other suspended material. Allowing for the reduction in light with depth and turbidity this 20% of surface light is probably very close to the 5% level found by others.

Figures 1 to 4 suggest that productivity differences become greater with increased time at reduced light intensities.

Each of the curves in Figures 1 to 4 were derived from 5 to 9 samples. Continuing experiments include more replication and should thus be more definitive value.

Ruppia's most active growth occurs between July and September in Swan Lakes, and this period is covered by the experiment. As the plant senesces the response to reduced light may differ.

Appendix 4 : Preliminary determinations of nutrients in sediments at depth

INTRODUCTION

Early sediment analyses were made on surface sediments in the zone penetrated by the roots of *Ruppia maritima*. As dredging might be expected to release nutrients from sediments at depth the nutrient content of these deeper sediments is also of interest.

MATERIALS AND METHODS

Sediment cores were collected to 1 metre depth from the sand flat immediately south of Molloy Island. The cores were collected using a PVC pipe 5.5cm in diameter and a pair of sliding handle grips. Cores were divided into 10 to 15cm-long pieces, placed in soil tins and frozen. In the laboratory they were analyzed for interstitial, adsorbed and total phosphorus, organic nitrogen and loss of ignition, using the methods described in Chapter 3.

RESULTS

The results are presented in Table 1.

DISCUSSION

The results suggest an increase in the phosphorus fractions and a decrease in organic nitrogen with increasing depth. The levels are within the ranges found for surface sediments except for high adsorbed phosphorus at 60 to 90cm, and the low organic nitrogen levels.

As there is high interstitial and adsorbed phosphorus at depth it is apparent that disturbing these sediments will liberate some nutrient. The nutrients may be rapidly consumed by a local phytoplankton bloom, carried out to sea or adsorbed onto sediments; depending, of course, on seasonal factors such as riverflow, availability of light, etc. No accurate prediction can be made of the effects of liberating this nutrient, especially in the absence of data concerning dredging rates.

CHEMICAL ANALYSIS OF SEDIMENTS WITH INCREASING DEPTH
(South of Molloy Island - May 1975)

All data are in μg/g D.wt.

	Depth (cm)		
	0-30	30-60	60-90
Interstitial P	65	83	111
Adsorbed P	41	91	191
Total P	565	356	697
Organic N	262	268	122
Loss on ignition	2.2%	2.2%	2.4%

Study of the Blackwood River Estuary: Comments in Relation to Dredging

A. Digest of relevant botanical information

1. It is convenient to distinguish between a 'summer phase' in which the water has high salinity, high light penetration and low nutrients, and a 'winter phase' of low salinity, low light penetration, and high nutrients.

2. The superficial sediments are relatively nutrient rich compared with the water.

3. There is no evidence for an increase in phosphorus levels in the Blackwood between the 1940's and the present.

4. Oxygen levels are relatively high in the water, and this is attributed to the large surface area of the estuary in relation to its volume, rather than to photosynthetic activity.

5. There is relatively little phytoplankton in the estuary. The populations would increase if nutrients (especially phosphorus) were increased during the summer phase.

6. Benthic seagrasses, particularly Ruppia, make up the bulk of the biomass of the open water. These grasses are sparse in the estuary, but dense in the adjoining Swan Lakes and Deadwater.

7. Benthic plants trap nutrients. Growth is seasonal. Plants growing in the winter phase and senescing in late summer allow 'transfer' of nutrients from winter to summer.

8. Occurrence of benthic plants is precluded if light intensities are too low. The lower limit approximates to about 5% of light at the surface in winter.

9. The benthic plants (with their epiphytes) are grazed by swans and fish, and so are important in animal food chains, being a major source of carbon compounds, nutrients and energy.

10. Benthic algae (especially diatoms) are probably also important in trapping light energy and (either directly or via detritus) transferring it to other components of the ecosystem.

11. Most of the plant biomass of the estuary is in the fringing vegetation, which is on stabilised sediments. There is a succession from open water, via Juncus marsh, to Melaleuca woodland. The vegetation traps and recycles nutrients, constituting the largest pool of nutrients in the ecosystem, and builds up organic material in the substratum.

12. Detritus from the fringing vegetation and from the river water in winter contributes organic material, and therefore energy and nutrients, to the open water.

13. Juncus invades sediments in shallow water, both by rhizome growth and (less commonly) by seedling establishment.

B. Botanical aspects of dredging

(1) During the dredging operation.
This is visualised as a continuing process over a period of some years.

1. Sediment will accumulate on benthic plants near to the dredge at a rate which will exceed the ability of the plants to grow through it, and they will be eliminated.

2. Increased turbidity further from the dredging will reduce light intensity at the surface of the sediment, and preclude growth of seagrasses and algae at depth.

3. As the seagrasses are extensively used by fish as a source of energy and nutrients, fish populations will be reduced. (Total energy input to the estuary may not be greatly reduced, as the fringing vegetation will not be affected in any obvious way.)

4. Nutrients from disturbed sediments will increase the nutrient status of the water, and could lead to increased phytoplankton in summer.

5. A sudden release of anaerobic sediments will reduce oxygen levels in the water. This effect should be localised, and reduced if pumped sediment is aerated.

6. Sediment levels will be increased, and the rate at which *Juncus* marsh invades the open water will therefore rise.

7. Severe erosion could occur if fringing vegetation, especially in the river channel, is removed.

(2) After dredging is completed.
It is assumed that dredging ceases completely, and any disturbed banks are re-vegetated.

1. Water quality should return quickly to that seen at present, probably during the first winter, when river water would flush out nutrients and sediment in suspension.

2. Phytoplankton populations should resemble those encountered at present.

3. It is reasonable to suppose that the sediments, which will be reworked river sediments, will not be greatly different to those encountered at present, though the spatial distribution of particle size may be altered. There seems no reason why, in the long term, benthic plants should not become re-established in areas from which they had been eliminated during dredging.

4. Diatoms, being readily distributed by water currents, will recolonize the sediments fairly quickly.

5. Seagrasses will recolonize in time. All species recorded in the lagoonal area occur upstream and/or in the Swan Lakes and Deadwater, and these regions would act as species reservoirs from which reinvasion of a de-populated lagoonal area might occur. It would seem important to conserve these other

areas in the event of dredging in the region proposed. Where establishment by seed occurs, revegetation presents few problems. Seasonal regeneration of Ruppia observed so far is from rhizomes, and so it remains uncertain whether Ruppia would recolonize by seed or, more slowly, by distribution of plant fragments and vegetative growth.

6. Where Ruppia has been covered with sediment but not eliminated, there may be an increase in productivity.

7. As increased sediment will be deposited in the lagoonal areas, the rate of encroachment of the fringing vegetation will be enhanced. In the long term some form of dredging may have to be used, in any event, to prevent the elimination of much of the present shallow water, and increased deposition of sediment will hasten the time when such management dredging will be needed.

C. General

There are undoubtedly rare plant species in the region - for example, an unnamed species of Apium (wild celery) found in the fringing communities has only been collected on two previous occasions. However, the case for conserving vegetation increasingly rests not on the occurrence of a few rare species, but on the need to conserve examples of our major vegetation types. The Blackwood River Estuary is a very useful example of relatively undisturbed benthic and fringing estuarine vegetation. Long-term conservation of such communities depends upon maintaining the light, and the nutrient (or 'trophic') status of the water; in the Hardy Inlet this will involve avoiding pollution of the Blackwood and Scott Rivers by nutrients and turbidity (e.g. from soil erosion), and also avoiding nutrient build up in summer in the lagoonal area near to the town.

The conservation of the communities making up the fringing vegetation involves restraining the sequence of events leading to establishment of woodland. For example, the judicious use of fire may be needed to eliminate tree and shrub seedlings. The encroachment of Juncus marsh onto what is now open water will almost certainly involve, sooner or later, the physical removal of sediment adjacent to the fringing vegetation.