UNIVERSITY OF MELBOURNE

A GEOMORPHOLOGICAL STUDY

OF

SPARTINA TOWNSENDII (SENSU LATO) MARSHLANDS

IN AUSTRALIA

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A thesis for the degree of Doctor of Philosophy, presented in the Department of Geography

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ABSTRACT

The halophytic grass _Spartina townsendii_ (s.l.) was widely introduced from England to Australia in the late 1920s and early 1930s, but has established successfully only in estuaries and lagoons in the south east of the country. It now occupies 620 ha, the major stations being the Tamar River, Tasmania, where the fertile form of the grass was planted in 1947, and Andersons Inlet, Victoria, where the same vigorous species was introduced as recently as 1962.

Because of their comparative youth, Australian _Spartina_ marshes are in a much earlier stage of development than many marshes in Britain, where _S. townsendii_ (s.l.) was first collected in 1870. It has therefore been possible to examine in this country the initial and early stages of _Spartina_ marsh formation. Particular attention has been given to Andersons Inlet, where the growth of _Spartina_ and the accompanying transformation from mudflat to marshland have been observed from the time of marsh inception.

By 1980, _Spartina_ in Andersons Inlet occupied 63.6 ha. In favourable environments, _Spartina_ cover in sample quadrats was approaching 100 per cent after 14 years from initial establishment of seedlings and young plants. Colonisation commenced within a narrow vertical range of 0.61 m to 0.83 m above Inverloch datum, but _Spartina_ quickly expanded both seawards and landwards to its present vertical limits of 0.25 m and 1.13 m. The seaward limit of _Spartina_ is now regularly submerged by both spring and neap tides for more than 6 hrs, while the landward limit is submerged by mean spring tides. _Spartina_ has similar submergence limits at other Australian stations, and is most abundant in sheltered
conditions regularly inundated by water of less than 18°/oo salinity.

At many sites the spread of *Spartina* has been accompanied by rapid accretion of sediment, which is trapped and retained by plant foliage. Sediment deposition in *Spartina* at Andersons Inlet is generally greater than 2 cm per annum, and rates of up to 7 cm per annum have been recorded. The role of *Spartina* in promoting accretion may be apparent even before sward formation is completed, as indicated by the development of microtopographic highs coincident with *Spartina* clones and clumps.

As a result of high rates of accretion, previously unvegetated mudflats are rapidly transformed into depositional terraces, of which six major types may be recognised. Their upward growth is accompanied by a change from non-channelised to partly channelised tidal flow, as creeks develop between *Spartina* tussocks and within continuous sward. Pans may form on the surface of the marsh as a result of deposition of tidal wrack, impeded drainage, or restriction of light beneath mangroves. *Spartina* thus acts as a geomorphological agent, by greatly accelerating the processes of marsh formation.
ACKNOWLEDGEMENTS

In preparing this thesis, I have received a great deal of valuable assistance from many people. Principal among them is Dr. E. C. F. Bird, Reader in Geography at the University of Melbourne, who first drew my attention to the presence of Spartina in Australia, and pointed out that recent attempts by himself and others to establish the features of Spartina colonisation in Britain had been hampered by an absence of detailed information on the early stages of Spartina spread and accompanying modifications to intertidal topography. I am indebted to Dr. Bird for his constant interest in the progress of my work, for his helpful advice and supervision over many years, and for his critical and constructive scrutiny of the drafts of this thesis.

As Spartina has not yet attracted much attention from the scientific community in Australia, I am grateful for having been able to discuss aspects of my research with overseas workers during trips to libraries and field sites in other countries. My approach to the research program was considerably sharpened in discussion with Dr. D. S. Ranwell, now of the University of East Anglia, at Norwich in 1972. I also wish to acknowledge assistance I have received from Mr. V. J. May of Bournemouth College of Education, England; Dr. J. S. Smith of Aberdeen University, Scotland; Dr. Ir. W. G. Beeftink, of the Delta Institute for Hydrobiological Research, Yerseke, The Netherlands; Dr. W. Joenje of Groningen University, The Netherlands; Dr. D. König, formerly of Kiel University, Germany; and Prof. J. T. Møller, of Aarhus University, Denmark. My understanding of marshland morphology was also greatly assisted by a visit to S. alterniflora marshes on the
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Thanks also are due to countless farmers and landowners at sites in south east Australia, for allowing access to Spartina sites and ensuring that datum points and other markers were not disturbed; to officers in various government departments and agencies, for the thoroughness with which they have provided information; to students, colleagues and friends, who have given freely of their time to provide field assistance; and to Melbourne State College for several periods of study leave to undertake full-time research. Particular gratitude is owed to Neville Green, technical officer in the Department of Geography at Melbourne State College, for assistance with fieldwork, reduction of figures and processing of photographs; to my mother, Enid Boston, for typing of drafts and the final thesis; and to my wife, Yvonne, who has assisted with translation of papers in foreign languages, and who continues to maintain her good humour despite having seen every blade of Spartina in Australia.
1. **Numbering of Figures, Plates and Tables**

These are numbered consecutively within the section or subsection of the chapter to which they apply. For example, Figures 4.31 and 4.32 are the first and second figures in Section 4.3. In addition, some pairs of plates and figures have been given a letter suffix. For example, Plates 5.232a and 5.232b, which are photographs of the same site in different years.

2. **Plant names**

Nomenclature is in accordance with Willis (1970, 1972) (Australian species) and Clapham, Tutin and Warburg (1962) (British species), with the exception of Gramineae where Hubbard (1968) is the authority.
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CHAPTER ONE

INTRODUCTION

1.1 The origin of *Spartina townsendii* (s.l.)

*Spartina townsendii* (s.l.) is a salt-tolerant grass which colonizes the intertidal zones of estuaries and lagoons, where it commonly forms the pioneer plant community. It spreads by dispersal of seeds and plant fragments, and by lateral expansion of tussocks due to rhizome growth.

The genus *Spartina* occurs mainly on the Atlantic coasts of North and South America, with minor stations on the Atlantic coasts of Europe and Africa, on the Pacific coasts of the Americas and in the Mediterranean (Goodman 1969). The most common species in North America are *S. alterniflora* and *S. longispica*, in Africa *S. capensis*, and in the Mediterranean Sea *S. patens* and *S. pectinata* (Ranwell 1967a).

In Britain and northern Europe there are four *Spartina* species: the native *S. maritima*, the introduced American species *S. alterniflora* and *S. glabra*, and a relatively new plant, *S. townsendii* (sensu lato), which exists in both sterile and fertile forms (Marchant 1967). The area occupied by the two species from America is small, and they may be ignored. The new plant *S. townsendii* (s.l.) has spread with such vigour that it has now replaced *S. maritima* as the major British species.

*S. maritima* has grown in British estuaries for several hundred years, having been first recorded by Merrett (1666). At the present time
it is found mainly in The Wash, along the coast of Essex and on the shores of the Hampshire Basin. The American *S. alterniflora* was first collected in England in 1829 from the estuary of the River Itchen at Southampton Water, where it may have been established for at least 20 years prior to its discovery (Bromfield 1836). The grass had spread to become locally abundant in Southampton Water, parts of which were also occupied by *S. maritima* at that time. It has since been generally accepted that the American species was accidentally introduced by ship from North America (Hubbard 1965a), although Montagu of Beaulieu (1907) reported to the Royal Commission on Coast Erosion and Afforestation (1907-11) that the accidental introduction had been in a wheat cargo from the River Plate in Argentina, where *S. alterniflora* is abundant (Mobberley 1956).

In 1870, *Spartina* collected at Hythe in Southampton Water included plants which were thought to be a luxuriant form of *S. maritima*. Further specimens were collected in 1877, and in 1881 the grass was identified as a new British plant. It was subsequently named *S. townsendii* in honour of Frederick Townsend, author of *The Flora of Hampshire* (Groves 1927).

For many years the origin of the new plant was not established. It was thought that it could be either an unknown introduction from overseas, or a result of mutation, or a hybrid between two different species (Lambert 1964). Foucaud (1894) noted that the new species was morphologically intermediate between the two other species in Southampton Water at that time, and suggested that *S. townsendii* arose as a result of hybridization between the native *S. maritima* and the introduced *S. alterniflora*. Stapf reported that a similar plant, named *S. neyrautii*, was found in the River Ardour and Bidasoa estuaries in the Bay of Biscay, and that both *S. maritima* and *S. alterniflora* were also present at these
sites (Stapf 1908, 1909). This plant however was less robust than
*S. townsendii*, and sufficiently different to indicate that it had not
spread to this site from the south of England. Subsequent taxonomic
investigation of both plants and their supposed parents further supported
the hybrid theory (Stapf 1914a).

Hybridization was confirmed by Huskins (1930), who gave chromosome
numbers for *S. maritima* and *S. alterniflora* (Table 1.1). However
Hubbard (1957a) showed that early collections, including the 1870 type
specimen, were composed of a plant with sterile stamens comparable to an
F1 hybrid. Huskins was unaware of the existence of this sterile plant
(Lambert 1964), and examined a more common fertile plant which had not
been noticed until the 1890s (Hubbard 1957b).

As two morphologically distinct plants have thus been collected
as *S. townsendii*, the suffix *sensu lato* (s.l.) is conventionally used when
referring to this species. The sterile form is called *Spartina x townsendii*,
and the fertile form until 1968 was called *Spartina X*. However, the name
*Spartina anglica* was then assigned to the fertile variety, which is by far
the more common form (Hubbard 1968).

Marchant (1963, 1968) gave corrected chromosome complements for
both sterile and fertile forms (Table 1.1). The hybrid nature of the
sterile plant was confirmed by irregularities in chromosome pairing at
meiosis, while careful comparison of chromosome morphology verified
derivation from *S. maritima* and *S. alterniflora*.

It is now generally agreed that *S. townsendii* (s.l.) arose as a
result of hybridization between the English and American species, and
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**Note:** Huskin's inaccurate chromosome counts resulted from the inadequacies of cytological techniques in 1930, which did not enable examination of the small chromosomes of *Spartina* with great precision. Further, Huskins believed *S. alterniflora* to be extinct in Southampton Water, and consequently used material from America. Marchant's chromosome counts for *S. alterniflora* were on a small quantity of this species which he found surviving in Southampton Water.
that early collections were of a sterile F1 hybrid. The fertile form is an amphidiploid derived from the primary hybrid by doubling of the chromosomes. Differing cytological behaviour in separate communities implies that hybridization and restoration of fertility by chromosome doubling occurred on more than one occasion (Goodman et al. 1969), and suggests that some of the sterile hybrids may be polyhaploids which have originated from the fertile form by a halving process (Hubbard 1968).

Where no specific reference is made in this thesis to either the sterile or fertile form, or to other Spartina species, the name Spartina refers to S. townsendii (s.l.).

1.2 World distribution

Figure 1.2 gives the world distribution of S. townsendii (s.l.), after Ranwell (1967a). This distribution is partly the result of natural spread, and partly a consequence of deliberate introduction.

While both forms of S. townsendii (s.l.) may spread naturally in newly colonised habitats by vegetative growth from rhizome fragments, only the fertile S. anglica may spread also by dispersal of seeds. The rate of seed production by S. anglica is very high, with seedling densities of up to 13,000/m² having been recorded on bare mud (Goodman 1957). Both seeds and plant fragments are dispersed by tidal currents.

Because of its high seeding capacity, S. anglica spreads more rapidly than the sterile form. Marchant (1967) suggests that the fertile amphidiploid appeared first in Southampton Water in about 1890, which would account for the sudden extension of Spartina at that time. This was noted by several writers, including Stapf (1914a) who observed that
FIGURE 1.2

Ranwell's map of world distribution of *S. townsendii* (s.l.). Solid circles show sites where plants were known to be established in 1965. Open circles show sites where plantings are known to have failed. Further information on Australian introductions is provided in this thesis.
"towards the end of the eighties something occurred that favoured the spread of the grass". The amphidiploid rapidly spread by natural dispersal in Southampton Water and other sheltered areas along the south coast of England, being collected from Lymington in 1892, Isle of Wight in 1893, and Poole Harbour in 1899 (Hubbard 1957b). By 1907 S. townsendii (s.l.) was estimated to cover 6000–8000 ac (2428–3237 ha) within the Hampshire Basin alone (Montagu of Beaulieu 1907), and by 1913 it had invaded or been introduced to every estuary and harbour from Chichester to Poole (Goodman et al. 1959).

It was soon apparent that the new Spartina species not only had remarkable powers of spread, but that accelerated rates of sediment accretion were occurring in colonised areas. Its potential as an agent of coastal engineering was recognized by the Royal Commission on Coast Erosion and Afforestation, the terms of reference of which included reporting on "measures desirable for prevention of encroachment of the sea" and "facilities for the reclamation of tidal lands". The Commission concluded inter alia that the process of natural accretion on alluvial flats could be hastened by the introduction of Spartina (Min. Roy. Comm. Coast Erosion and Afforestation 1911). As a result of both this recommendation and a good deal of popular and scientific interest in the grass, Spartina was planted extensively throughout the British Isles for reclamation and coast protection (Oliver 1920, Bryce 1931). It was introduced by river boards and harbour authorities as an aid in the prevention of shoreline erosion, by navigational interests to stabilise mudflats and reduce source areas for channel silting, and by farmers to reclaim mudflats for grazing and crops (Ranwell 1967a). While much of the transplanted material undoubtedly was obtained from local and unrecorded sites, many introductions of seeds and plant fragments were from a Spartina nursery established by
Cartridge at Poole Harbour, and from experimental plantings of Poole Harbour stock along the Essex shoreline (Hubbard 1965a).

Stock from Essex and Poole Harbour was also planted extensively outside Britain. In the period 1923 - 1936 Cartridge exported over 175000 plant fragments and many samples of seed to at least 130 sites in over 40 countries (Hubbard 1965a). Many requests for plant material were stimulated by the publication of a pamphlet by Oliver et al. (1929), which was widely quoted in the overseas press.

One of the first and largest overseas consignments was to the Netherlands in 1923, when 40000 plant fragments were imported for reclamation projects by the Dutch Government (Oliver 1927-28). Planted initially at a small number of sites in the estuaries of the Rhine, Meuse and Scheldt, 'Engels slijkgras' spread rapidly throughout the south west delta region.

The largest single Dutch reclamation project undertaken using Spartina was in the Zuid Sloe near Vlissingen (Kalkwijk 1954). The intertidal zone south of the dam constructed to join the islands of Walcheren and Zuid-Beveland was reclaimed in two stages, the first reaching completion in 1950. Here Spartina fragments planted in 1923 in a regular grid 3 m apart over 490 ha achieved complete cover in eight years (Verhoeven 1951). By 1950 the area was converted from rough grazing pasture to arable land; it is now under extensive wheat production. The second stage, commenced later than the first, was completed in 1956 (Beefink 1976 pers. comm.); this area is now a pastoral and industrial zone. Similar reclamation projects were commenced in the 1960s along the shorelines joining the former islands Goeree to Overflakkee and Schouwen to Duiveland (Ranwell 1967a), but they have been largely unsuccessful due
to lack of tidal action in areas now affected by the building of dams across the Haringvleit (1970) and Brouwerhavense Gat (1971) (Beeftink 1976 pers. comm.). *Spartina* is also common, but less vigorous, on the colder and sandy Friesland and Groningen coastlines in the north.

*Spartina* was introduced to Germany from Poole Harbour in 1927 (König 1976 pers. comm.). It was planted at numerous sites on the west coast of Schleswig-Holstein, where it established within a zone of 30 cm below to 20 cm above mean water level. Many plantings were unsuccessful and the performance of others highly variable until 1933, when a rapid expansion began (König 1948, 1949). *Spartina* now occurs at sites along the entire west coast. The rapid expansion is possibly explained by the development of *Spartina anglica* from sterile stock; as it was not until 1957 that Hubbard identified the difference between the sterile and fertile forms, many early plantings were of mixed sterile and fertile material. *Spartina* also has been introduced to the coast north of Wilhelmshaven, although no further deliberate plantings of *Spartina* have been made since 1953 (Ranwell 1967a).

*Spartina* has been planted in several parts of the Danish Wadden Sea (Jorgensen 1931, 1934) and in Mariager Fjord and Nissumfjord, the latter being the most northerly *Spartina* site on the main European coastline (56°30'N) (Ranwell 1967a). As in the Netherlands it has been used for reclamation and coast protection. Extensive plantings are still in progress in the Ho Bugt and Ribe estuary areas of the Wadden Sea (Müller 1976 pers. comm.).

*S. townsendii* (s.l.) forms extensive discontinuous marshes along the French coast, its limits being Grande-Forte-Phillipe in the north west
and the Pontieux estuary in the south west (Ranwell 1967a). The principal French stations are the Baie des Veys, the Seine estuary and the Baie du Mont-Saint-Michel. The grass was first reported in the Vire estuary at the beginning of the century (Corbière 1907). It is likely to have been the same grass as that identified as _S. neyrautii_, which Stapf (1914a) described as similar to _S. townsendii_ (s.1.) and growing in association with _S. maritima_ and _S. alterniflora_ in the Bay of Biscay. Ranwell (1967a) notes that although the status of _S. neyrautii_ is still in doubt, it bears a strong morphological resemblance to the sterile form of _S. townsendii_ (s.1.). Groves (1927) has suggested that _S. alterniflora_ may be the female parent in the case of _S. neyrautii_, and _S. maritima_ the female parent in the case of _S. townsendii_ (s.1.).

The other major sites of _S. townsendii_ (s.1.) are in New Zealand and Australia, although many introductions have been attempted elsewhere (Figure 1.2). While _S. alterniflora_ is extensive on the east coast of North America and _S. foliosa_ on the west coast, _S. townsendii_ (s.1.) has been successful only in the Stilligしまう estuary in Washington State (Ranwell 1967a). Plantings in Central and South America, Africa, the Middle East, the Indian Subcontinent, South East Asia and some sites in Australia have failed. This has resulted generally from unsuitable conditions for plant growth, the requirements of which are discussed elsewhere in this thesis.

_S. townsendii_ (s.1.) was first introduced to New Zealand in 1913, when clumps obtained from Southampton Water were planted at Foxton in the Manawatu River estuary (Allan 1924). Subsequently material was distributed from this site to farmers and government authorities for shoreline protection and land reclamation. It is now widespread in both
islands. Generally it has been more successful in the South Island, particularly in the Waihopai River estuary (Harbord 1949) where 12 ha (30 ac) of the 20 ha (50 ac) *Spartina* marsh have been reclaimed by dumping (Ranwell 1967a). At the northerly sites it has suffered from depredation by crabs and livestock, and would appear unsuited to the sub-tropical climate. There is evidence to suggest that poor performance at some sites may also be due to the introduction of sterile plants (Allan 1930). The lack of vigour in *S. townsendii* (s.l.) at sites in the North Island, such as Kaipara Harbour, contrasts with the rapid extension of *S. alterniflora* (Bascand 1968) which was introduced from Florida in 1957.

*S. townsendii* (s.l.) has now become established in nine countries, and is the dominant species over an area of at least 21000 ha (approximately 80 square miles). The most recent estimate of world resources of *Spartina* marshland is summarised in Table 1.2, adapted from Ranwell (1967a). The fertile plant is now the common form: for example, of the 12000 ha in Great Britain, probably not more than 20 ha are of sterile *S. x townsendii* (Hubbard and Stebbings 1967). Australian *Spartina* resources are estimated at 620 ha in 1980 (see Table 2.11).

1.3 Previous work

The origin and spread of *S. townsendii* (s.l.) has generated a great deal of literature. Material published before 1965 has been included in a comprehensive bibliography prepared by Hubbard (1965b). It is useful to review the scope of the literature briefly, in order to define the context of the present study.
### TABLE 1.2

WORLD RESOURCES OF SPARTINA TOWNSENDII (S.L.) in 1967

<table>
<thead>
<tr>
<th>Country</th>
<th>Hectares</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Britain</td>
<td>12000</td>
<td>30000</td>
</tr>
<tr>
<td>Ireland</td>
<td>200-300</td>
<td>500-1000</td>
</tr>
<tr>
<td>Denmark</td>
<td>500</td>
<td>1230</td>
</tr>
<tr>
<td>Germany</td>
<td>400-800</td>
<td>1000-2000</td>
</tr>
<tr>
<td>Netherlands</td>
<td>4000-5800</td>
<td>9800-14300</td>
</tr>
<tr>
<td>France</td>
<td>4000-8000</td>
<td>10000-20000</td>
</tr>
<tr>
<td>Australia</td>
<td>30-60</td>
<td>75-150</td>
</tr>
<tr>
<td>New Zealand</td>
<td>20-40</td>
<td>50-100</td>
</tr>
<tr>
<td>United States</td>
<td>Less than 1</td>
<td>Less than 1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>21000-27700</strong></td>
<td><strong>52400-68500</strong></td>
</tr>
</tbody>
</table>

**Notes:**

1. Area estimates are the ground covered 50 per cent or more by *Spartina*, and must be considered as approximate.

2. *Spartina* in Australia now occupies 620 ha (1532 ac) (see Table 2.11)

**Source:** adapted from Ranwell (1967a)
A common element in the early British literature is simple reporting of the existence and advance of the grass at various sites. Some of this material was published in semi-popular scientific journals, such as *Science Gossip*, the *North West Naturalist*, the *Reports of the Botanical Exchange Club of the British Isles*, the *Papers and Proceedings of the Hampshire Field Club*, the *Gardener's Chronicle* and the magazine of the Southampton Ramblers Club. Linton (1894) reported on *S. townsendii* (s.l.) at Norton's Spit, Yarmouth; J. and A. Bennett (1902) reported its existence at the head of Bosham Creek, Hampshire; and Sherring (1911-1919) presented detailed reports and photographs of its spread in Poole Harbour, Dorset.

At the same time there was much interest in the taxonomy of the grass and its relationship to other *Spartina* species. H. and J. Groves, who collected the type-specimen from Hythe in 1870, published a description of the grass first in the *Journal of Botany* in 1879, with related papers in various journals in 1881, 1882 and 1901. Stapf (1908) discussed the possible origins and early spread of *Spartina*, and in 1914 published in the *Journal of Ecology* a paper on its distribution, artificial propagation, seeding potential and supposed origin (Stapf 1914a). Oliver (1913-1929) presented a series of reports on *Spartina* at Blakeney Point, and among other publications prepared papers for the *Annals of Applied Biology* (Oliver 1920) and the *Journal of Ecology* (Oliver 1925).

It soon became apparent that the spread of the grass was accompanied by rapid accretion of sediment. As a consequence a new theme developed in the literature, with attention being focussed on the possible role of *Spartina* in shoreline protection and land reclamation. Both Stapf (1909) and Oliver (1909) made submissions on the use of *Spartina* to the
Royal Commission on Coast Erosion and Afforestation (1907-11). Following the introduction of *Spartina* to Holland, Oliver (1927-8, 1930) gave progress reports on plantings in the Zuid Sloe. Bryce (1928, 1931, 1932, 1936a, 1936b, 1941a, 1941b) dealt with the economic possibilities of the grass, which Britten (1916) had earlier raised in the context of paper manufacture. Generally *Spartina* was seen to be beneficial as an agent for shoreline protection and land reclamation, with additional possibilities as a fodder crop. Publication of papers on applied aspects of *Spartina* introduction was in journals such as *Agricultural Progress*, the *Journal of the Ministry of Agriculture and Fisheries* and in reports to various government agencies.

Apart from Huskin's 1930 paper on the identification of *S. townsendii* (s.l.) from cytological evidence, no new directions appeared in the British literature until the late 1950s, although many papers were published on the performance of *Spartina* at different sites, on the associated accretion of sediments and on the use of the plant in coastal engineering. Papers after 1957 developed new themes concerned with the autecology of the plant and the physiography and ecology of *Spartina* marshes.

The autecological papers embrace various studies of plant physiology, genetics and floral biology. Goodman (1959, 1960), Goodman *et al.* (1959) and Goodman and Williams (1961) investigated the occurrence and cause of *Spartina* die-back, a phenomenon which had become apparent in many of the older *Spartina* marshes. Marchant (1963, 1968) gave corrected chromosome numbers, Hubbard (1967) reported on cleistogamy in *Spartina* and Caldwell (1957) described the morphology of the developing clone in terms of alternating rings of high and low stem density.
Interest in the physiography and ecology of *Spartina* marshes is exemplified in the series of papers on *Spartina* salt marshes in southern England published in the *Journal of Ecology* from 1961. Ranwell examined the effects of sheep grazing at the upper limits of *Spartina* at Bridgwater Bay, Somerset (Ranwell 1961), reported on the rates and seasonal pattern of sediment accretion in *Spartina* marshes at Bridgwater Bay and Poole Harbour (Ranwell 1964a), and for the former site determined rates of *Spartina* establishment, succession and nutrient supply (Ranwell 1964b). Other papers were concerned solely with Poole Harbour: Bird and Ranwell (1961) described the physiography of the harbour and discussed the role of *Spartina* as a physiographic agent; Ranwell et al. (1964) reported on tidal submergence and chlorinity; Hubbard (1965a) examined the pattern of *Spartina* invasion; and Hubbard and Stebbings (1968) described the stratigraphy of the Keyworth marsh. Papers subsequent to this series have reported on world resources of *S. townsendii* (s.l.) and economic use of *Spartina* marshland (Ranwell 1967a); distribution, dates of origin and acreage of *S. townsendii* (s.l.) marshes in Great Britain (Hubbard and Stebbings 1967); light in relation to tidal immersion and *Spartina* growth (Hubbard 1969); the effects of cutting and seed production (Hubbard 1970); and tidal immersion of *Spartina* marsh at Bridgwater Bay (Morley 1973).

Outside Britain the earliest papers were published in France and New Zealand. The themes of the first French papers were similar to the British: Foucaud (1894, 1897) was concerned with the identification of the new plant, and Corbière (1907, 1909, 1910, 1926), Chemin (1921), Chevalier (1923, 1929, 1933, 1934) and Lémee (1933) reported its spread and status at particular sites. There was however no great interest in the applications of the plant in coastal engineering, nor apart from Verger (1968) has there been much recent work on the physiography and ecology of *Spartina* marshlands.
In New Zealand the ability of *Spartina* to assist in shoreline protection and land reclamation was made known by Allan in several papers in the *New Zealand Journal of Science and Technology* and the *New Zealand Journal of Agriculture* (Allan 1924, 1929, 1930, 1931), and more recently by Blick (1965). Bascand (1968, 1970) has examined aspects of the autecology of *Spartina* species occurring in New Zealand, reflecting in part some of the later British work.

In other countries the literature on *Spartina* has been concerned mainly with the establishment and spread of the grass and evaluation of its role in coastal engineering. In Holland, Jansen and Sloff (1938) and Bakker (1950a, 1950b) have reported on *Spartina* performance at particular sites, and Verhoeven (1938, 1951) and Kamps (1962) have discussed the function of *Spartina* in land reclamation. Several papers by Beeftink (e.g. 1965, 1975) have provided synecological evidence of the role of *Spartina* in salt marsh communities. The German literature is sparse, the most notable papers being König (1948, 1949). In Denmark the series of papers by Møller (1956, 1960, 1961, 1963a, 1963b, 1964) have provided useful information on the role of *Spartina* as a factor in the physiography and ecology of the intertidal zone.

It is evident from this summary review that *Spartina* has been the subject of extensive semi-popular and scientific writing. The former has been directed at the informed public, particularly field naturalists and farmers, and has been concerned primarily with local regional studies of *Spartina* spread (e.g. Bennett 1902), and with the practical applications of the grass especially as an agent of coastal engineering (e.g. Blick 1965). Both aspects have however also been developed in scientific journals (e.g. Hubbard 1965a, Kamps 1962). In addition, the scientific
work has ranged across plant genetics (e.g. Marchant 1968), plant physiology (e.g. Goodman and Williams 1961), ecological factors which affect *Spartina* performance (e.g. Ranwell et. al 1964) and the impact of *Spartina* on the physiography of coastal environments (e.g. Bird and Ranwell 1964). *Spartina* has thus attracted the attention of a fairly wide spectrum of scientific interests, particularly in specialist fields within biology, geomorphology, agricultural science and engineering.

1.4 Objectives of the present research

Little has been published about *Spartina* in Australia, despite many plantings in this country in the late 1920s and early 1930s. While there were several newspaper reports during this period, the first substantial journal reference to *Spartina* in Australia was the entry given in Ranwell's survey of world *Spartina* resources (Ranwell 1967a). The first paper to be published on the subject was on *Spartina* in Victoria (Bird and Boston 1968), which was followed by a preliminary account of the initial stages of *Spartina* establishment in Andersons Inlet, Victoria (Boston 1973). The only other paper is that by Phillips (1975) who traced the spread of *Spartina* in the Tamar estuary, Tasmania, and assessed rates of accretion at two sites on the basis of stratigraphic evidence.

The subject of *Spartina* in Australia is therefore ripe for study in a number of different subject fields, each with its own purpose and direction. The author has approached the subject as a geographer with particular interests in geomorphology and biogeography. The objectives and emphases of this thesis arise very largely from perspectives and interests generated by that background.
The first objective of the present research has been to give an account of the distribution and impact of *Spartina* in Australia. This is intended as a base-line study similar to those prepared for Britain by Goodman *et al.* (1959) and Hubbard and Stebbings (1967), and designed to modify and expand the summary of Australian *Spartina* resources given by Ranwell (1967a). In explaining the distribution, it has been necessary to reconstruct the chain of events which led to importation of *Spartina* and its diffusion from initial points of introduction. Although other alien species such as *Eichhornia crassipes* (Water Hyacinth) and *Opuntia inermis* (Prickly Pear) have also been successful in Australia, the presence of an exotic Anglo-American hybrid grass which originated on the mudflats of Southampton Water little more than a century ago is a remarkable phenomenon which invites explanation.

The second objective has been to examine the initial stages of *Spartina* marsh development from the date of "marsh inception" (Pethick 1980), which is the time when vegetation appears on previously bare intertidal flats. This objective requires elaboration.

Although *S. townsendii* (*s.l.*) was first discovered in 1870 it aroused little interest until rapid spread began in the 1890s. As noted previously this is now believed to have been due to the appearance of the fertile amphidiploid at that time (Marchant 1967). In the early years of expansion scientific attention was focussed primarily on the origin and taxonomy of the grass, its adaptation to a habitat which previously had not been utilised by plants, and its potential value for coastal engineering. Very little scientific work was undertaken on actual rates of increase in *Spartina* abundance, associated changes in intertidal topography and environmental factors which affect its initial establishment and spread.
As a consequence, the early literature does not provide any detailed information on changes in plant density and cover from the time of marsh inception, nor does it monitor microtopographic responses to increased rates of sediment deposition associated with the growth of the grass. It left unanswered many questions which were to become important once the impact of the grass on coastal waters had become fully apparent. At what level does *Spartina* first establish on an intertidal zone? At what rates does species abundance increase? Is the rate of sediment accretion in *Spartina* greater than that which would occur in the absence of the grass? If so, what rates of accretion are common in a youthful marsh? At what stage of growth does accretion in *Spartina* first begin to affect the microtopography of the intertidal zone? What changes occur in the profile of the intertidal zone in the early and intermediate stages of growth? How and at what stage do the narrow tidal channels characteristic of mature *Spartina* marshland first begin to develop? At what stage of marsh development do microtopographic features such as pans first become evident? Are they relict features of unvegetated mudflats, or do they develop within *Spartina* turf? Under what conditions may *Spartina* be invaded or replaced by other plants? What factors are important in initiating erosion along the seaward margin of the marsh?

Questions of this type were not fully considered in the literature until the 1960s, when, as noted previously, Ranwell, Hubbard, Bird and others published a series of papers on *Spartina* in southern England. These papers presented detailed physiographic studies of *Spartina* marshes, precise measurements of rates of spread, data on rates of sediment accretion in colonised areas and information on environmental factors affecting *Spartina* growth and succession. Having primarily physiographic
and ecological emphases, such work was quite different from that undertaken in the early part of this century, and represented a new direction in the literature on Spartina marshlands.

By the time this research was undertaken, Spartina had been established at Poole Harbour for probably 70 years and at Bridgwater Bay for over 30 years. Many of the Spartina marshes in southern England were over 60 years old; some had been established for 90 years. In favourable environments, complete Spartina cover had been achieved and the surface of the formerly unvegetated mudflats had been raised by sediment accretion to about the level of mean high water. The landward margins of some Spartina marshes were being invaded by other plants. Die-back, or patchy degeneration of previously healthy plants, had become common in excessively wet sites, and in places the outer margin of the marsh was cliffed by wave erosion and had begun to recede. At some sites in Poole Harbour, the seaward margin of Spartina had been receding since 1924 (Hubbard 1965a).

Because of the relatively recent introduction of Spartina to Australia, most local marshes are immature in comparison with those in Britain and Europe. This is especially true of the two major stations - the Tamar estuary and Andersons Inlet. Fertile S. anglica was introduced to the former in 1947 and to the latter in 1962. Marshes in early or intermediate stages of growth are common, and the grass is generally still expanding rapidly in newly colonised sites. At only a few sites has accretion in Spartina brought the level of the intertidal zone to that of mean high water. The relative youth of Australian marshes provides an opportunity to study the early phases of Spartina establishment, and to examine the initial impact of the grass on estuarine physiography.

The second objective of this thesis is thus to examine the early
stages of *Spartina* invasion, by applying aspects of the methodology generated by the British workers of the 1960s to Australian *Spartina* marshes similar to those which existed in Britain and Europe in the early part of this century. The intention is to complement recent British research on the physiography and ecology of mature *Spartina* marshes by documenting initial and intermediate stages of growth, and identifying changes in the morphology of the intertidal zone which result from increased rates of sediment accretion associated with *Spartina* spread. In this way it is hoped that some of the questions left unanswered by the earlier literature might be resolved.

In achieving this objective, particular importance has been attached to *Spartina* in Andersons Inlet, where fertile *S. anglica* was introduced in 1962. Detailed work began at this station in 1967, and change in plant abundance and intertidal topography have been recorded over 14 years since the time of marsh inception. Over a similar length of time Corbière and Chevalier (1922) saw a few plants in the Vire estuary in France meadow over an area in excess of 1000 ha (4 sq. mls.); at about the same time after marsh inception, Sherring began to make his reports on the spread of *Spartina* in Poole Harbour (Sherring 1911-19).
CHAPTER TWO

SPARTINA IN AUSTRALIA

2.1 Present resources

Spartina was introduced from England to Australia in the late 1920s and early 1930s. Material was also obtained from New Zealand, where Spartina from Southampton Water had been planted in 1913 (Allan 1924). As the author has published a monograph on the introduction of Spartina to Australia (Boston 1981), a further account is not given here. However, the monograph is included within this thesis as an appendix.

Despite introductions to all Australian states, Spartina has survived only in Tasmania and Victoria, with minor stations in South Australia and New South Wales (Figure 2.1). Reasons for its failure elsewhere has been considered by Boston (1981). Table 2.11 is an estimate of present Australian Spartina resources.

In obtaining data for Table 2.11, it has been necessary to take into account the manner in which Spartina reproduces and spreads. Spartina colonisation commences when young plants first establish from seeds and plant fragments on a previously bare intertidal flat. They subsequently enlarge laterally by rhizome extension and production of new tillers to form tussocks, which are also called clones because they arise from outward growth of a single parent plant. Continued enlargement results in the merging of clones to form clumps, which in time may fuse to form a sward, or large mass of Spartina with a single limiting outline. These types of population unit are defined in Table 2.12.
### Table 2.11

**Australian Spartina Resources**

<table>
<thead>
<tr>
<th>Station</th>
<th>Hectares</th>
<th>Date of estimate</th>
<th>Scale of base map</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tasmania</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamar River</td>
<td>520.4</td>
<td>1978</td>
<td>1:5000</td>
</tr>
<tr>
<td>Duck Bay and Robbins Passage</td>
<td>10.5</td>
<td>1979</td>
<td>1:4000 +</td>
</tr>
<tr>
<td><strong>Victoria</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andersons Inlet</td>
<td>63.6</td>
<td>1980</td>
<td>1:2000</td>
</tr>
<tr>
<td>Corner Inlet</td>
<td>15.6</td>
<td>1980</td>
<td>1:4000</td>
</tr>
<tr>
<td>Bass River</td>
<td>7.2</td>
<td>1979</td>
<td>1:4200</td>
</tr>
<tr>
<td>Albert River</td>
<td>1.8</td>
<td>1980</td>
<td>1:3000</td>
</tr>
<tr>
<td>Agnes River</td>
<td>0.5</td>
<td>1979</td>
<td>1:3000</td>
</tr>
<tr>
<td>Moodys Inlet</td>
<td>0.2</td>
<td>1979</td>
<td>1:4200</td>
</tr>
<tr>
<td>Gippsland Lakes</td>
<td>0.01</td>
<td>1978</td>
<td>*</td>
</tr>
<tr>
<td>Shallow Inlet</td>
<td>0.002</td>
<td>1978</td>
<td>*</td>
</tr>
<tr>
<td><strong>New South Wales</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currambene Creek, near Falls Creek township</td>
<td>0.003</td>
<td>1980</td>
<td>*</td>
</tr>
<tr>
<td><strong>South Australia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gawler River at Buckland Park</td>
<td>0.002</td>
<td>1979</td>
<td>1:500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>619.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

+ Base map for Duck Bay only.

* No base map; *Spartina* area estimated in the field.
TABLE 2.12  TERMINOLOGY OF SPARTINA POPULATION UNITS

**Seedling:** the stage of growth between germination and the development of not more than three leaves.

**Plant fragment:** a unit of material, torn from a parent plant, capable of enlarging itself by vegetative reproduction. It may consist of tillers, roots and/or rhizomes, and may be of any size or age.

**Young plant:** an arbitrary term used to cover the period of growth from the appearance of secondary shoots to the development of flowers, usually in the second year of growth.

**Small tussock or clone:** the product of a mass of shoots and rhizomes radiating from the original stem of a parent plant and forming a circle of growth of less than 1 m diameter as measured by the perpendicular projection of the leaf and floral canopy on to the ground.

**Large tussock or clone:** as for the above, but with a minimum diameter of 1 m.

**Clump:** the product of fusion of clones developed from several parents to form a disconnected mass of irregular outline.

**Sward:** a large mass of continuous Spartina resulting from fusion of clumps, and contained within a single limiting outline.

For the purposes of this thesis, population units less than 0.5 m apart have been regarded as a single population unit.

**Source:** Adapted from Hubbard (1965a).
As a consequence of this habit of growth, there are unvegetated areas of varying dimensions and diminishing size within Spartina communities at each stage prior to complete sward formation. It follows that there is a distinction between the area which Spartina actually covers and the area in which Spartina occurs. The extent to which this distinction can be taken into account in estimating Spartina resources depends on the size of population units, their distribution, and the scale at which Spartina is to be mapped.

The distribution of Spartina at each Australian station was recorded in the field on base maps prepared from enlargements of vertical aerial photographs, the scales of which are given in Table 2.11. Field inspection at some stations was supplemented by low altitude oblique aerial photography. An estimate of Spartina cover was obtained for swards, clumps and clones visible on photographic enlargements, or of sufficient size to be plotted at map scale in the field. For smaller population units an estimate was made of the area of colonisation as defined by lines which enclosed all young plants and tussocks within zones in which Spartina cover exceeded 10 per cent. Area estimates most closely approximate cover estimates for the Tamar River and Andersons Inlet, where swards are the dominant population units.

Estimates of the areas covered or colonised by Spartina were made by planimeter measurements or by weight, when areas occupied by Spartina were drawn to scale on heavy-weight polyester drafting film, then cut out by scalpel and weighed on a precision balance. Total weight was expressed as a percentage of the weight of a piece of film representing 1 km$^2$, to derive an estimate of Spartina area. This method was used principally for fringing swards or zones of clumps parallel to the shore,
as it was found that planimeter measurements of long narrow shapes with irregular outlines was subject to a high degree of operator error.

The area colonised by *Spartina* in Australia is estimated at 620 ha (Table 2.11), the major station being the Tamar River estuary. *Spartina* is also abundant in Andersons Inlet, where it has spread rapidly since the introduction of the fertile amphidiploid in 1962. The area of *Spartina* is greater than the estimate of 30-60 ha given for Australia by Ranwell (1967a) (Table 1.2), partly because of spread since 1967 but also as a result of inadequate information provided by Australian respondents to a questionnaire on local *Spartina* resources. For example, Ranwell was informed by Martin (1964 *in litt.*) that *Spartina* occupied 20-25 ac (8-10 ha) in Tasmania in 1964, whereas Phillips (1975) has since shown that by 1963 the grass had colonised approximately 150 ha in the Tamar estuary alone. In comparison with 1967 estimates given by Ranwell (1967a) for other countries (Table 1.2), Australia ranks behind Britain, The Netherlands and France, but has *Spartina* resources equal to or greater than those of Germany, Denmark, Ireland and New Zealand.

2.2 Tamar River

*Spartina* was introduced to the Tamar River estuary in 1947. Phillips (1975) has given the source of this material as the Waite Agricultural Research Institute, South Australia, but it is now known that the Waite Institute was not involved in the introduction. The source of the material was Buckland Park, South Australia (Neal-Smith 1951 *in litt.*), from where plants were collected by agronomists from the Tasmanian Department of Agriculture acting on information supplied by the CSIRO Division of Plant
Industry, Canberra (Fricke 1951 in litt.). The Waite Institute was aware of the successful establishment of Spartina at Buckland Park (Symon 1978 in litt.), but there is no evidence that the Institute promoted the spread of the grass to other sites.

The plants were introduced to the Tamar estuary at the request of the Marine Board of Launceston, with the intention of reducing siltation in the main navigation channel. It was hoped that Spartina would stabilise the source areas for sediment and increase the rate of channel scour by promoting accretion and progradation which would be accompanied by narrowing and deepening of the channel. At the same time, it was expected that the colonised areas would become useful land above high water level (Martin 1971 in litt.).

The material was planted by the Department of Agriculture at Windermere on the east side of the estuary (Figure 2.21). Of the three "lots" of plants brought from South Australia only two plants survived, but they were sufficient to produce a nursery of a few dozen plants by 1951 (Fricke 1951 in litt.). At some stage during the next four years a line of plants was set out from this nursery for a distance of 30 m (1.5 chns); by 1955 it had developed into a "merged area" 60 m x 10 m (3 chns x 0.5 chns). In 1955 a further area of 0.4 ha (1 ac) was planted out by boat; plants were spaced at intervals of approximately 1.5 m (5-6 ft) and extended from high tide level seawards for approximately 100 m (5 chns). Survival was high and establishment rapid within 60 m (3 chns) from the shore, but seawards from that point the rates of survival and establishment were low. Further plantings also made in 1955 by the Marine Board and extending to low water mark indicated that the plant would not survive more than 100 m (5 chns) from the shore. It was believed that either
FIGURE 2.21

duration or depth of submergence was the limiting factor (Martin 1966 in litt.).

By 1962, the 1955 plantings had merged to form a continuous band of *Spartina* extending for 80 m (4 chns) seaward from high water mark. The original planting extended for 90 m (4.5 chns); by 1966 it extended outwards for 110 m (5.5 chns) and was still advancing as new plants established to seaward of the sward and rapidly expanded in size (Martin 1966 in litt.).

The site of the 1947 and 1955 plantings is now occupied by a large *Spartina* sward (Plate 2.21) averaging about 110 m in width. In appearance the grass is exceptionally vigorous, with a very high stem density, stout tillers and long broad leaves. In summer the flowering heads reach a height of 1.2 - 1.3 m, and even in winter conditions the average stem height is about 0.7 m. The site is sheltered from frequent strong wave action on high tides: many dead flowering heads remain attached to the plants throughout winter and are not carried away as tidal wrack.

*Spartina* is estimated to have colonised 520 ha in the Tamar estuary by 1978. This differs from an earlier estimate by Phillips (1975), who has given the area of colonisation as 555 ha in the summer of 1971/72. The discrepancy between the two estimates does not indicate a reduction in *Spartina* area, for comparison of aerial photographs taken on 16 April 1970 and 14 February 1978 shows that by the latter date the grass had become locally more abundant at sites which were formerly only sparsely colonised and had established a further 2 km downstream. The explanation lies in differences in the techniques used to delimit areas of *Spartina* colonisation at a relatively
PLATE 2.21

small scale, which necessarily involves a good deal of subjective
generalisation. The author believes that the present estimate of 520 ha
is based on a finer degree of discrimination than the previous estimate,
in that a higher proportion of the area of bare mud between groups of
population units has been eliminated from the final calculation. It is
clear that by 1972 Spartina had colonised nearly all suitable sites, and
that subsequent increase in Spartina abundance has been primarily due to
increased cover within zones which Phillips (1975) had already counted as
areas occupied by the grass.

As shown in Figure 2.21, Spartina has spread further downstream
from its point of introduction at Windermere than it has in an upstream
direction. Phillips (1975) attributes this to two factors: a net transport
of water downstream arising from a 7 hour ebb and a 6 hour flood; and
insufficiently saline water at the upstream limit, where Spartina is
replaced by Phragmites communis. Except at Nelson's Shoal, a broad
intertidal expanse of which 106 ha is occupied by Spartina (Plate 2.22),
the grass forms a shoreline fringe which is almost continuous in the upper
part of the estuary. Sward development is most extensive in sheltered sites
and at the heads of small embayments; at more exposed sites the swards
are narrow and often cliffed, or Spartina is distributed as large clumps
and clones (Plate 2.23).

Phillips (1975) has discussed the relationship between Spartina
distribution and rock types along the Tamar shoreline. The estuary
occupies the Tamar Trough, which was formed by faulting in the late
Mesozoic or early Tertiary, subsequently infilled during the Tertiary
by silts, sands, clays and gravel, and then drowned during the Holocene
marine transgression. Marked lithological variations arise from faulting of
PLATE 2.22

Part of Nelsons Shoal, Tamar estuary, July 1978.
PLATE 2.23

_Spartina_ clones and clumps, Swan Bay, July 1978.

PLATE 2.24

_Spartina_ rooted in pockets of mud on weathered basalt, Windermere, July 1978.
the basement rock, which is Jurassic dolerite; from fossil soils, bauxite and ferricrete which developed at various levels within the sediments laid down during the Tertiary; and from periodic volcanism which produced basalt flows.

The dolerite and basalt outcrops produce steep, irregular shores with small promontories and embayments and angular boulders up to 1 m in diameter. *Spartina* has established successfully on the thin veneer of mud accumulated on dolerite and ferricrete, but has remained only sparsely distributed along the basalt shoreline sectors (Plate 2.24). The Tertiary sandstones, sands and clays produce a smoother, more regular shore of lower gradient readily colonised by *Spartina*, which roots on overlying sediments and also penetrates weathered rock. The most rapid colonisation has occurred where the rock outcrops are extensively overlaid by fine sediments as at Nelsons Shoal, where they produce intertidal areas of very low gradient. However *Spartina* can colonise all available intertidal slopes, some of which are as steep as $28^\circ$.

In describing the spread of *Spartina* in the Tamar estuary between 1947 and 1971/72, Phillips (1975) reports that growth was slow in the late 1940s and early 1950s, and that rapid spread began to take place only in the late 1950s. It is suggested that the initial planting was possibly sterile \( S. \times \text{townsendii} \), and that the fertile hybrid was either introduced in the 1955 plantings or developed independently at this site in the late 1950s. These aspects of the paper require discussion.

Correspondence relating to the planting of *Spartina* in the Tamar estuary rules out the likelihood of mixed introductions or of the 1947 introduction being infertile. It is clear that the 1955 plantings were
of material obtained locally from the 1947 plantings, which by that time had expanded into a continuous cover of 600 m² (Martin 1966 in litt.).

Further, the source of the 1947 plantings was Buckland Park, South Australia, where *Spartina* was planted in 1931 (Neal-Smith 1951 in litt.). The plants introduced there had been germinated from seeds of *S. townsendii* (s.l.) supplied from Poole Harbour and from Holland via London (Boston 1981, Table 1). Seed is produced only by the fertile form of *S. townsendii* (s.l.). It is therefore certain that the plants introduced to Buckland Park were fertile *S. anglica*.

It is also virtually certain that the fertile form was introduced to the Tamar estuary in 1947. Allowance must be made for the possible development of a sterile polyhaploid hybrid, which sometimes originates from the fertile form by a chromosome halving process thereby reversing the chromosome doubling by which *S. anglica* is produced (Hubbard 1968). However an herbarium specimen collected from Buckland Park in 1943 (Symon 1978 in litt.) accords well with morphological descriptions for the fertile plant given by Hubbard (1968) and Goodman et al. (1959), and on many occasions up to 1974 when the Buckland Park property was sold the plant was observed to bear seed (Brooks 1979 pers. comm.).

Further, it is believed that Phillips has underestimated the rate of spread of *Spartina* in the late 1940s and early 1950s. The estimates were based on aerial photographs for March 1952 at a scale of 1:23760 and showing almost high water conditions with small areas of saltmarsh exposed, and for January 1956 at a scale of 1:17820 (1:35640 x 2) showing shores and mudbanks clearly exposed.

Phillips notes that at these scales *Spartina* will be recognizable
on black and white photographs only where it is growing in closely spaced clumps or as continuous swards, and that her description of Spartina spread does not exclude the "possible existence in addition of scattered clumps and isolated shoots". The photographs indicate no Spartina in 1952 although it is accepted that some had survived since 1947, and only the 1955 planting at Windermere is evident in photographs for 1956. Subsequent photographs (1961, 1963, 1968, 1969, 1970) indicate a rapid spread throughout the central section of the estuary, on which basis it is concluded that the rate of expansion increased markedly in the late 1950s.

It is believed that there is insufficient evidence to support this conclusion. Young plants and tussocks cannot be recognized at scales as small as those of the 1952 and 1956 photographs of the Tamar River: at scale 1:23760 a clone with a diameter of 5 m would appear on a photograph as a dot of 0.2 mm. Such a population unit, large enough to indicate several years growth, would almost certainly be indistinguishable from mudflat on a black and white print; photographed close to high water, it would in all probability be partly or wholly submerged. At the scale of the 1956 enlargements, a clone of the same size would have a diameter of 0.3 mm, but even if then visible at low water conditions many hundreds of smaller plants and tussocks would not be evident.

This point is confirmed by examination of black and white aerial photographs of Andersons Inlet, where the initial stages of Spartina colonisation were observed and recorded on the ground (see Chapter 3). The first 5-10 years of Spartina invasion were characterised by the rapid establishment of widely scattered young plants, tussocks and small clones, which enlarged and merged to form large clones and clumps. The rate of
expansion, expressed as percentage increase in the colonised area, was far
greater in this early stage than at the later stage of sward and clump
formation. However, photographs for November 1968 at a scale of 1:15880 do
not permit mapping of Spartina distribution, even though by that time the
growth had colonised 8.67 ha since its introduction six years earlier. Tones
registered on the photographs by isolated mangroves, Zostera and standing
water can not be distinguished from tones known on the basis of ground
surveys to indicate Spartina. Reasonably accurate delimitation of Spartina
zones from black and white aerial photographs of Andersons Inlet first
became possible with the photographic survey of May 1974, by which time
Spartina had colonised more than 40 ha and consisted mainly of swards,
clumps and large clones. Enlarged three times to a scale of 1:5300,
and printed in colour, these photographs still presented difficulties in
mapping small population units, for a 1 m clone at this scale registers
as a dot of 0.17 mm diameter.

It is therefore suggested that lack of photographic evidence
does not indicate that the rate of spread of Spartina in the Tamar estuary
in the late 1940s and early 1950s was low. Indeed available evidence
suggests otherwise. The two plants which survived at Windermere in 1947
covered 600 m² by 1955, by when isolated plants had established for 200 m
(10 chns) on either side of the planting site, and subsequently were
observed to have spread across the river to Rosevears (Martin 1966. in litt.).

Figure 2.22 shows change in the area of Spartina in the Tamar
estuary, after Phillips (1975). The conclusion that the rate of spread
increased after 1955 is based on the assumption that the area occupied
by Spartina in 1947 was between 2000 m² and 3000 m². It is now known
that only two plants survived at that time (Fricke 1951 in litt.), which
might be estimated to occupy 2 m². Further, while overestimating the area
FIGURE 2.22

Rate of spread of Spartina in the Tamar estuary, after Phillips (1975), and revised estimate suggested by the author.
for 1947, Phillips has probably underestimated the area for 1955. In that year the initial introduction covered 600 m², a further 4000 m² (1 ac) had been planted, and an allowance of at least 1000 m² should be made for isolated plants scattered for 200 m on either side of the 1947 planting and across the river at Rosevears. Thus the 1955 area of colonisation is estimated at 5600 m² rather than 4000 m². A plot of adjusted estimates for 1947 and 1955, extended to include the 1978 estimate, indicates that the rate of increase in the area of *Spartina* colonisation actually decreased after 1955 (Figure 2.22).

2.3 Andersons Inlet

Andersons Inlet is the estuary of the Tarwin River. The inlet has been formed by growth of a sand spit across the mouth of a former broad embayment, the relict shoreline of which may be identified as bluffs along the margin of the present coastal plateau (Figure 2.31). The world-wide glacio-eustatic oscillations in Pleistocene times caused a rise in sea level in the embayment during interglacial periods, and a retreat during glacial phases to reveal an emerged sea floor. The presence of consolidated dune calcarenite at exposed sites on the spit suggests that it has a Pleistocene core, and that it evidently grew sufficiently to persist during phases of cliffing resulting from rises in sea level during interglacials and in Holocene times. Recurs at the distal end indicate that longshore drift has been a factor in the growth of the spit.

In the shelter provided by the spit, the Tarwin River and smaller streams have laid down clays, silt and sand to a depth of approximate 0.5 m on the former sea floor, thus reducing the inlet to its present size. Much
FIGURE 2.31  Andersons Inlet: morphology and vegetation, 1980.
of the saltmarsh and *Melaleuca* swampland which occupied this low plain of estuarine deposition has now been reclaimed for agriculture by means of embankments which have reduced the saltmarsh to a narrow littoral fringe of about one-tenth its previous area.

The occurrence of outcrops of fine organic alluvial soils in eroded shoreline sectors near the mouth of the estuary indicates that at times the inlet may have experienced lagoonal conditions. During recorded history however the mouth has remained open, and although cyclic progradation and recession of Point Smythe has undoubtedly affected the degree of tidal ventilation, the inlet has remained truly estuarine. The mean spring tide range decreases from 2.13 m at the mouth to 1.35 m at the head of the estuary. The total area of the inlet is 20.98 km$^2$, of which 15.80 km$^2$ is exposed at low tide.

There have been two deliberate plantings of *Spartina* in Andersons Inlet, the first at Cherry Tree Creek and the second at Nolans Bluff (Figure 2.31). It has previously been reported that the first introduction was circa 1932 and that the source of material was unknown (Boston 1971). It has since been found that the initial planting date was actually in the early 1940s (Sparks 1974 pers. comm.), and that the source of material was Tidal Creek, Foster (Jones 1978 pers. comm.). *Spartina* may also have been planted elsewhere in the inlet at about that time (Jones 1978 pers. comm.), although there is no evidence of it having survived at any other site. Aerial photographs for 1950 give no indication of *Spartina* apart from clones and clumps at Cherry Tree Creek. C. W. Wyeth, a local field naturalist familiar with the inlet, has reported that the grass did not occur elsewhere until the second introduction at Nolans Bluff in 1962 (Wyeth 1969 pers. comm.); local land-owners and fishermen confirm that the spread of the grass began in the mid 1960s.
Spartina established successfully in sheltered conditions at the mouth of Cherry Tree Creek along the seaward margin of Avicennia marina. It spread steadily but not rapidly from the half dozen or so plants which had been introduced. When first observed by the author in 1960 the dominant population units were clones and clumps, which were then merging to form the present single main sward.

The failure of Spartina to spread from Cherry Tree Creek to other parts of Andersons Inlet can be explained only tentatively. One strong possibility is that the plantings were of sterile Spartina x townsendii, which does not seed and therefore spreads only slowly by growth from plant fragments. The Cherry Tree Creek material was obtained from Tidal Creek, Corner Inlet, where Spartina did not begin to seed until about 1966, when it also increased in vigour and height and began to spread rapidly (Jones 1978 pers. comm.). Spartina introduced to Tidal Creek in 1930 was obtained from stock which could then only be propagated from runners (Philip 1970 in litt., see also Boston 1981). It therefore seems likely that the Cherry Tree Creek planting was entirely or largely of sterile material, and that the sudden vigour of the grass at Tidal Creek after 1966 was due to the fertile amphidiploid S. anglica being derived from the sterile F1 hybrid by chromosome doubling.

S. anglica may be distinguished from S. x townsendii on morphological grounds. S. anglica has mostly broader and more widely spreading upper leaf-blades, mostly longer, wider and more hairy spikelets, longer ligular hairs, and longer, more perfect antlers (Hubbard 1968). Spartina specimens collected from Cherry Tree Creek in 1970 were submitted for morphological examination to the National Herbarium, Melbourne, where they were compared with material filed in the plant collection and with type
descriptions given by Hubbard (1968) and Goodman et al. (1969). It was found that the morphological features did not agree well with those assigned to S. anglica, and that the specimens were almost certainly S. x townsendii (Court 1970 in litt.).

Although the Cherry Tree Creek plantings were probably of sterile material, it is curious that Spartina did not spread slowly to other areas by establishment from root and rhizome fragments. The explanation might be the locally sheltered conditions which do not promote erosion of the marsh and dispersal of Spartina fragments. The sward occupies a littoral zone within the mouth of the creek, and is not subject to strong wave action. Upstream from the sward the creek is crossed by an embankment fitted with a sluice-gate, which prevents tidal flooding of the land and the consequent generation of a strong ebb current which might erode the seaward margin of the sward. There is insufficient surface runoff entering the creek via the sluice-gate to scour the edge of the marsh. In the absence of wave or current action, it is unlikely that any great quantity of viable root and rhizome fragments would be separated by Spartina population units and carried away by the tide.

Float tests have been conducted at Andersons Inlet in a variety of tidal conditions, to determine the pattern of water circulation and the likely direction of movement of tidal-borne Spartina material (Section 4.3). Floats released in Spartina at Cherry Tree Creek do not travel far: at low tide they are trapped behind an offshore bar, and with the incoming flood they move up Cherry Tree Creek to lodge in the main Spartina sward. Although floats from Cherry Tree Creek have been found up to one month later along the shoreline within 1 km south of their point of release, they have never been carried as far as the now extensive areas of
Spartina at the head of the inlet and along the inner margin of the spit.

The invasion of Andersons Inlet by Spartina began with the second introduction in 1962, when six clumps of whole plants selected from the most vigorous growth at Bass River were introduced to Nolans Bluff, and planted at intervals of about 1 m in front of a low cliff in alluvium. The plants were in flower, and some bore seed (Arbuthnot 1966 pers. comm.). The presence of the fertile amphidiploid at both Bass River and Nolans Bluff was confirmed in 1970 (Court 1970 in litt.). In spite of the introduction of Spartina to Cherry Tree Creek in the early 1940s, colonisation of large areas in the upper part of Andersons Inlet did not begin until after the second plantings about twenty years later. It has therefore been possible to trace the development of these Spartina marshlands from the time of inception.

Figure 2.32 shows the spread of Spartina in Andersons Inlet between 1967 and 1980. Within five years of the introduction of the fertile amphidiploid, thousands of seedlings, young plants, tussocks and small clumps were scattered throughout the upper part of the estuary, with sites of greatest Spartina abundance at Nolans Bluff, along the inner margin of the spit, and on the central intertidal mudflats to the south of Split Islands. The tussocks and larger population units were growing to a height of 80 cm, and rhizoming vigorously. The sudden appearance of the grass across large expanses of previously barren mudflats has a parallel in the rapid invasion of Poole Harbour in the early part of this century.

It is estimated that Spartina had colonised 8.67 ha by May 1967, as defined by the method described in Section 2.1. By January 1970 the distribution was still one of widely-scattered seedlings, young plants and
FIGURE 2.32  Spartina in Andersons Inlet, May 1967 to January 1980.
tussocks, with certain highly localised areas being occupied by population units of greater maturity. However the area colonised by *Spartina* had increased more than three-fold, from 8.67 ha to 27.74 ha in a period of 32 months.

This rapid advance was achieved by invasion of large expanses of bare mud within the broad outline of areas in which *Spartina* was already sparsely distributed three years earlier. The only new site outside the perimeter defined by outlying population units in May 1967 was at Andersons Beach (Figure 2.31), where a single young plant was first observed in February 1968. *Spartina* had spread to new sites along the inner margin of the spit, to previously bare areas on the central intertidal flats, and to new sites along the shoreline between Cherry Tree Creek and Nolans Bluff. At the same time, many hundreds of seedlings and young plants had established within areas which were already sparsely colonised in May 1967. These new plants occupied vacant areas between clumps and clones; in combination with vigorous rhizome extension from existing population units, they led to the formation of large clumps and incipient swards along the mudflats to the south of Central Split Island, and narrow but continuous shoreline swards along the inner margin of the spit and at Nolans Bluff.

*Spartina* continued to spread rapidly in the early 1970s. By 1975 it occupied 48.77 ha, nearly double the estimate for five years before. It increased by one third in the second part of the decade, to 63.57 ha in 1980. Expansion resulted from continued establishment on bare mud within and between occupied areas (Plates 2.31, 2.32), and from advance of the seaward and landward margins (Plates 2.33, 2.34, 2.35). At the same time the seaward margin became more clearly defined.
PLATE 2.31 Young plants and tussocks, central intertidal flats, January 1968. Stake D marks a corner of quadrat II 3 (see Section 5.23). The photograph was taken using a 50 mm lens.

PLATE 2.32 Photograph taken from the same location as the above, using a 55 mm lens, July 1978. Note the continuous Spartina sward, which had formed by 1975.
Spartina near Fishermans Jetty, April 1969 (Plate 2.33), May 1971 (Plate 2.34), and December 1977 (Plate 2.35). Note the spread of Spartina to both lower and higher levels on the intertidal flats.
One of the striking features of the invasion of Andersons Inlet by *Spartina* is the fact that plant mortality has been low. Along the northern and eastern shorelines many small tussocks and clones have not survived on mobile substrates exposed to strong wave action. At Andersons Beach clones have been buried by sand, although some have partially regenerated. On the central intertidal flats patchy degeneration (die-back) has occurred in waterlogged sites within the sward, and many small plants observed near Foot Island in summer have not survived the following winter, probably because of wave action and prolonged inundation when the Tarwin River is in flood. Further, some plants have been removed by farmers from the mouths of creeks, where they had begun to impede land drainage. However such casualties are exceptional: once young plants had established on the intertidal zone, their chance of survival at most sites was high.

*Spartina* in Andersons Inlet is still spreading steadily. While the phase of most rapid advance is over, the grass has not yet reached its maximum limits. Although tussocks have established within 2 km from the mouth of the estuary, it is expected that future expansion will be largely confined to the head of the inlet and the inner margin of the spit, where *Spartina* is already abundant. Factors which contribute to these areas being most suited to *Spartina* growth are considered in Chapter 4.

2.4 Minor stations

In addition to the Tamar River, *Spartina* is believed to occur in Tasmania only at scattered sites in Duck Bay and Robbins Passage, in the north west of the state (Figure 2.41). The grass was also introduced successfully to the Forth River, to the Brid River at Bridport, and to the
FIGURE 2.41  Spartina in Duck Bay and Robbins Passage, 1979.
Derwent River at Bridgewater, but was eradicated at all three sites (Boston 1981). It is possible that a few small tussocks persist at the head of Little Swanport Lagoon, where they were observed in 1976 (Kirkpatrick 1980 in litt.). However as these could not be found in 1980 at the site at which they were reported, they are believed not to have survived.

The spread of *Spartina* in north west Tasmania has been most vigorous on the west bank at the mouth of Duck River, where there are now extensive areas of swards and large clumps. Clones and clumps are sparsely scattered along the east bank, and extend upstream along both sides of the river for about 1 km above Smithton. Small swards have also developed in Morgans Bay, in the mouth of Deep Creek, and in Deep Creek Bay. Plantings appear to have failed in East and West Inlets, at Kemps Bay, and at Stony Point and Montagu River; it has not been possible to ascertain whether the planting on Montagu Island was successful.

Small clones and tussocks have been found at several sites along the southern shoreline of Robbins Passage, between Montagu River and Perkins Island. Although the author has not been able to traverse the entire area, it seems likely that *Spartina* is sparsely scattered along much of this coastal sector. Depauperate clones are found on sandy substrates near the mouths of small creeks, with taller growth in isolated clones established in drainage channels and low-lying areas of saltmarsh. As *Spartina* at most sites in Duck Bay and Robbins Passage has been observed to seed profusely, and as no confirmation of further local plantings can be obtained, it would appear that the spread of *Spartina* in this area is largely the result of natural dispersal.

Although the area occupied by *Spartina* in Victoria is less than
in Tasmania, the grass is more widely distributed. The major Victorian station apart from Andersons Inlet is the north west of Corner Inlet (Figure 2.42). Here *Spartina* has spread by deliberate planting and natural dispersal from Tidal Creek, where the grass was introduced in 1930 (Boston 1981).

*Spartina* in Tidal Creek has established at both lower and higher levels than the discontinuous shoreline fringe of *Avicennia marina*, and is advancing rapidly (Plates 2.41, 2.42). Although little spread has occurred near the mouth of the creek, which is exposed to strong wave action, new plants are establishing beyond the upstream limit of mangroves. Since 1974 the limit of *Spartina* has advanced upstream by 250 m, solely as a result of natural dispersal. As noted in Section 2.3, previously low-growing *Spartina* in Tidal Creek suddenly grew taller in the mid 1960s, and for the first time began to flower and produce seed (Jones 1978 *pers. comm.*).

*Spartina* also grows as single clones and small clumps on both sides of earthen sea-walls constructed to prevent tidal inundation of pasture land. Most clones and clumps arise from deliberate plantings, intended to protect the walls from wave erosion and to reduce the incidence of burrowing by crabs (Boston 1981). Many transplants along the seaward margins of sea-walls have failed, particularly where there is no mangrove fringe to provide shelter from wave action. Where mangroves are present, *Spartina* grows between the wall and their upper limit as stunted clumps and clones which have never been observed to flower and are spreading only slowly by rhizome extension. Landward of sea-walls, small clumps of *Spartina* have established in shallow waterlogged pans and along the margins of borrow-pits from which material for construction of sea-walls was removed.
FIGURE 2.42  
Spartina in the north west of Corner Inlet, 1980.
PLATE 2.41

Spartina in Tidal Creek, Corner Inlet, February 1964.
(Photograph E.C.F. Bird)

PLATE 2.42

Spartina at Tidal Creek, Corner Inlet, November 1978.
Note the growth of the two mangroves shown in Plate 2.421 and the advance of the Spartina frontier.
The most vigorous recent growth of *Spartina* in Corner Inlet has occurred at the Van Dyke property (Figure 2.42), where the grass has spread by natural dispersal to extensive intertidal flats landward of a derelict timber sea-wall, which permits tidal flow but provides shelter from wave action. Here the surface is composed of fine soft silt and clay, in contrast to the firmer fine and medium sands along more exposed shoreline sectors of Corner Inlet. *Spartina* established at this site in the late 1960s, and now grows as a series of large widely-spaced clones of up to 8 m diameter, interspersed with many smaller clones and tussocks.

The remaining Victorian stations may be divided into estuarine environments (Bass River, Moodys Inlet, Albert River, Agnes River) and lagoonal environments (Gippsland Lakes, Shallow Inlet). The major concentration of *Spartina* in Bass River, in the south east corner of Westernport Bay, is in an ox-bow or cut-off river meander (Figure 2.43). This feature was formed before the introduction of the grass, and is now occupied by continuous *Spartina* meadow. Elsewhere *Spartina* grows as marginal swards and scattered clones and clumps. *Spartina* has now occupied most available sites in the central section of the estuary, but is continuing to spread steadily towards the upstream limit of marine influence. The growth form of the plant is notably dwarfed at the mouth of the river, where depauperate clumps and small clones persist on sandy substrates exposed to strong and frequent wave action.

Moodys Inlet, a natural tidal channel on the northern shoreline of Westernport Bay, forms an outlet for the Toomuc Drain, one of the smallest of a series of artificial channels constructed for flood control in the former Kooweerup Swamp. Unlike other channels in this district, the lower reaches of Moodys Inlet have not been dredged, and the stream follows a meandering course below its junction with the drainage outfall.
FIGURE 2.44
Spartina in Moody's Inlet, 1979.
Spartina was planted in 1964 on narrow mudflats near the South Gippsland Highway bridge (Figure 2.44) (Boston 1981). Despite a later attempt at eradication, the grass has spread more than 1.5 km upstream, and has been transplanted to downstream sites in order to stabilise channel banks and facilitate access to boat moorings. The dominant population units are clones and tussocks, with small clumps at sites where the intertidal zone is broadest. The grass has established on much steeper slopes than those commonly observed at other Australian stations, and erosion of plant margins is general following episodes of peak stream discharge. Spartina has not spread to the nearby shore of Westernport Bay, nor has it established in adjacent large channels which have artificially-steepened banks and are scoured by strong tidal currents.

In both Albert River (Figure 2.45) and Agnes River (Figure 2.46) Spartina grows as marginal clones, clumps and swards, and is most abundant in the middle reaches of the estuary. Extensive swards have formed along the inner banks of meanders, beyond the outer edge of the mangrove fringe. At both sites the present distribution is the result of natural dispersal following an initial introduction of small quantities of plant material (Boston 1981). As at Bass River, Spartina growth is sparse and stunted near the mouths of these rivers, but the grass is continuing to spread upstream. At both places the upstream limit of Spartina is now well beyond the downstream limit of Phragmites communis.

Despite several attempts to introduce Spartina to Gippsland Lakes and to the Sale and Bairnsdale districts (Boston 1981), the only surviving plants are those at Purran Corner, Waddy Island and Balfour Swamp on Sperm Whale Head (Figure 2.47). This lack of success is believed to be due to lagoonal tidal conditions, an account of which has been given for the Gippsland Lakes by Bird (1978). At Purran Corner and Sperm Whale
FIGURE 2.45  *Spartina* at Albert River, 1980.
Head *Spartina* was planted in unvegetated saline clay pans which contain standing water after heavy rain or exceptionally high tides, while at Waddy Island the grass was introduced to a shallow creek in the expectation that it might assist in reclamation and hence facilitate the movement of livestock (Bird 1977 *pers. comm.*). *Spartina* has now persisted at each site for approximately 50 years, but has spread only slowly by rhizome extension.

*Spartina* also grows in a lagoonal environment in Victoria at Shallow Inlet (Figure 2.1), where a single small clump was introduced to the western shore in 1962. Since that time there has been very little growth, and the present depauperate condition of the plant suggests that it is unlikely to survive.

Outside Victoria and Tasmania, *Spartina* is found only at Currambene Creek, near Falls Creek township, New South Wales, and at the Gawler River, Buckland Park, South Australia. Currambene Creek (Figure 2.48) is a narrow tidal estuary in which the river mangrove *Aegiceras corniculatum* occurs in small clumps and as isolated individuals almost to the upstream limit of marine influence, about 1 km east from the Princes Highway. Two clumps of *Spartina* have spread steadily at the planting site (Figure 2.48) since the early 1930s, and accretion accompanying the growth of the grass has produced small terraces which are steeply cliffed during periods of high stream discharge. At levels below the limit of grazing the stems of *Spartina* are up to 40 cm long but also notably limp, giving the plant a semi-prostrate growth form which contrasts with the normally erect appearance of more vigorous clones at other sites. *Spartina* at this site has never been observed to flower or seed (Frost 1980 *pers. comm.*), and while local transplants within a few metres of the planting site have
FIGURE 2.48

Spartina site in Currambene Creek, near Falls Creek township, New South Wales. July 1980.
been successful, the grass has not spread to other apparently suitable locations despite the availability of plant fragments following erosion during periods of flood.

The present distribution of *Spartina* in the Gawler River is shown in Figure 2.49. There are four clones with adjacent scattered tussocks, but it is doubtful that these correspond to the sites to which the original four plants were introduced (Boston 1981), as the area has since been considerably disturbed by construction of a salt-works. Lateral expansion is not vigorous and *Spartina* has not spread downstream from the planting site, although it is reported that the grass has flowered and set seed annually since its introduction in 1931 (Brooks 1979 pers. comm.). It seems likely that either the seed is not viable, or that germination is greatly inhibited by the high water salinity at this station, for fresh water is discharged over the spill-way (Figure 2.49) only infrequently in flood conditions. Despite growing at the northern limit of *Spartina* in Australia (latitude 35°S), plants at both Currambene Creek and the Gawler River show no signs of die-back, recession or dwarfing, and although the rate of growth is minimal it seems certain that the grass will persist.

The physiographic and ecological impact of *Spartina* at several of the above minor stations has been negligible. Its continued survival at sites such as the Gippsland Lakes, Shallow Inlet, Currambene Creek and the Gawler River is of considerable biogeographical interest, but of little geomorphological significance. Although it is important that details of the present distribution of *Spartina* at these sites be placed on record, greater attention is given in the remainder of this thesis to stations where *Spartina* is relatively more abundant.
FIGURE 2.49  *Spartina* at Buckland Park, South Australia, 1979.
CHAPTER THREE

SPARTINA MARSH INCEPTION : INITIAL STAGES OF ESTABLISHMENT AND GROWTH

The rapid spread of Spartina in British estuaries around the turn of the century was noted by many observers, including Sherring (1911) who described the invasion in Poole Harbour in terms of

"numerous dots in the mud, noticed last year, now becoming bunches of grass, bunches into patches, patches into belts and then to acres."

However, despite widespread reports of the sudden appearance and rapid growth of the grass, rates of change in Spartina abundance have rarely been measured from the time when the first young plants establish on an intertidal mudflat. The introduction of fertile S. anglica to Andersons Inlet in 1962 provided an opportunity for such documentation of the initial phases of Spartina colonisation and spread. As a preliminary to discussion of the stages of Spartina colonisation at this station, it is necessary to further consider briefly the manner of plant reproduction and growth.

3.1 The growth cycle of Spartina

The young Spartina plant has a primary root and a basal rosette of leaves attached to a developing young stem. Each axil contains one central bud which may produce a stem, and two outer initials which may produce roots (Goodman 1960). The stems may be either tillers, which are green and leafy and extend obliquely upwards, or rhizomes, which are white and scaly and extend obliquely beneath the surface. When the plant has three leaves, root initials grow out and take over the function of the primary root, which withers at the six-leaf stage.
Flowering occurs in the second year of growth of the plant (Goodman et al. 1969). Subsequent tillers usually flower in their first year of growth. While tiller production leads to intensive flowering and creates ideal conditions for a high rate of seed production, it contributes little to the enlargement of the plant as it is limited to the region near the parent stock and depends on the development of the few suitable tiller buds near ground level.

The annual growth cycle of the plant begins with bud production in leaf axils in late autumn. The buds quickly develop into tillers in spring, and flower in summer and early autumn. The first seeds ripen towards the end of the flowering period, and are shed during winter often as entire spikelets which float due to air trapped in the glumes. The flowering stems die and are carried away by the tide, to be deposited as tidal wrack above the level of mean high water. The plant overwinters as low-growing rosettes of clustered leaves with axillary buds, but in summer the tillers may be as tall as 1.3 m (Hubbard 1968).

Goodman (1960) and Goodman et al. (1969) have described the conditions required for seed germination. Although some seeds may set in late autumn, the highest germination rates occur in the following spring, after frosts. Germination is inhibited by salt water, so seeds must be desalinised by rain, seepage, or immersion in brackish water before growth can occur. Seedling development is favoured by an initial period of cold, and optimum growth requires a subsequent period of relatively high humidity and temperature (e.g. 25°C). In twelve collections from Britain and Holland in nine different years, seed set averaged 58 per cent, ranging from 18 per cent in 1955 to 92 per cent in 1954, both from the Lymington estuary, Hampshire (Goodman et al. 1969). It has been found that seed set is unrelated
to locality or time of year, and is presumably climatically determined.

Lateral enlargement of the plant results from rhizome extension. Caldwell (1957) and Goodman (1960) refer to the first rhizomes produced by the plant as first-generation rhizomes. The nodes each have a bud, and the buds lie alternately on the upper and lower faces of the rhizome. After the production of 3-6 internodes, the first-generation rhizomes turn upwards close to the parent stock, and growth is continued by second-generation rhizomes which arise from buds on the lower and outwardly-directed side of the first-generation rhizomes (Figure 3.1). Tillers meanwhile develop from the apices of the first-generation rhizomes, resulting in the formation of a shoot-clump or small tussock, consisting of the parent stock and its tillers, and the first-generation rhizomes and their tillers.

Second-generation rhizomes develop from, and at right angles to, the first generation rhizomes, and their buds are positioned horizontally (Goodman 1960). If these buds grow out, they form rhizomes. Forward and linear growth is thus checked in the second generation, as the new rhizomes are laterally directed and do not give rise to new stems. Third-generation rhizomes develop at right-angles to the second-generation rhizomes, with their buds now again in the vertical plane: shoots form on the upper side, and rhizomes on the under side, and linear forward growth is continued. New shoots appear around the shoot clump, forming a roughly circular tussock. As this process continues, the population unit forms a solid expanding circle of growth, with rhizomes giving rise to new main stems capable of producing many new tillers and rhizomes at a distance from the parent plant.

Caldwell (1957) has shown that enlargement is accompanied by changes in the distribution of shoot density within a *Spartina* clone, which
FIGURE 3.1

Diagrammatic representation of rhizome extension and tiller production (after Caldwell 1957 and Goodman 1960).
develops a concentric pattern of alternating rings of high and low shoot density with the number of rings being proportional to the clone diameter. The zones of high and low stem density degenerate and regenerate periodically, as a result of tiller growth from inwardly-directed rhizomes. However, while two clones of the same diameter will usually be of the same complexity they will not necessarily be of the same age, for they may be growing at different rates under different habitat conditions.

3.2 **Spartina** abundance in Series I quadrats

In order to monitor rates of change in **Spartina** abundance arising from initial colonisation and subsequent growth, permanent quadrats were established on the developing marsh. Seventeen quadrats each 30.5 m (100 ft) × 30.5 m were marked out with stakes, at sites chosen to include areas having differences in surface sediments, length of tidal inundation and exposure to wave action. These quadrats are referred to as Series I quadrats, as a second set of quadrats of varying sizes (Series II) was established for examination of the relationship between plant growth and change in microtopography (see Chapter 5). Figure 3.2 shows the locations of Series I quadrats; site characteristics are summarised in Table 3.2.

Series I quadrats were surveyed in May 1967, January 1970, January 1975 and January 1980. On each survey date the quadrats were subdivided using measuring tapes and twine into a grid of 100 squares. **Spartina** abundance was assessed by ground survey using measures of plant cover and density adapted from Kershaw (1964). **Spartina** cover, which is the area occupied by each population unit as measured by its vertically-projected shadow on the ground, was estimated in each grid square; the cover
<table>
<thead>
<tr>
<th>Number</th>
<th>Location</th>
<th>Site</th>
<th>Level</th>
<th>Exposure to wave action</th>
<th>Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>I 1</td>
<td>Cherry Tree Creek</td>
<td>Creek mouth</td>
<td>Mid-tide</td>
<td>Very protected</td>
<td>Soft, fine sand and silt</td>
</tr>
<tr>
<td>I 2</td>
<td>Cherry Tree Creek</td>
<td>Creek mouth</td>
<td>Mid-tide</td>
<td>Very protected</td>
<td>Soft, fine sand and silt</td>
</tr>
<tr>
<td>I 3</td>
<td>Cherry Tree Creek</td>
<td>Entrance to Creek mouth</td>
<td>Mid-tide</td>
<td>Exposed to wave action from south west quarter</td>
<td>Firm sandy mud</td>
</tr>
<tr>
<td>I 4</td>
<td>Cherry Tree Creek</td>
<td>Shoreline south from entrance to creek</td>
<td>Between mid-tide and high tide</td>
<td>Exposed to strong and frequent wave action</td>
<td>Firm sandy mud</td>
</tr>
<tr>
<td>I 5</td>
<td>Masons Beach</td>
<td>Shoreline</td>
<td>Between mid-tide and high tide</td>
<td>Exposed to strong and frequent wave action</td>
<td>Firm sandy mud</td>
</tr>
<tr>
<td>I 6</td>
<td>Bluff Island</td>
<td>Broad inter-tidal flat</td>
<td>Mid-tide</td>
<td>Very protected: in lee of island</td>
<td>Soft wet mud</td>
</tr>
<tr>
<td>I 7</td>
<td>Nolans Bluff</td>
<td>Narrow shoreline sector</td>
<td>Mid-tide</td>
<td>Fairly protected</td>
<td>Fine sandy mud</td>
</tr>
<tr>
<td>I 8</td>
<td>Nolans Bluff</td>
<td>Narrow shoreline sector</td>
<td>Mid-tide</td>
<td>Fairly protected</td>
<td>Fine sandy mud</td>
</tr>
<tr>
<td>I 9</td>
<td>Arbuthnots Inlet</td>
<td>Creek mouth</td>
<td>Mid-tide</td>
<td>Very protected</td>
<td>Soft wet mud</td>
</tr>
<tr>
<td>I 10</td>
<td>Tarwin mouth</td>
<td>Shoreline</td>
<td>Between mid-tide and low tide</td>
<td>Very protected</td>
<td>Very soft, wet silts and clay</td>
</tr>
<tr>
<td>Number</td>
<td>Location</td>
<td>Site</td>
<td>Level</td>
<td>Exposure to wave action</td>
<td>Substrate</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------</td>
<td>---------------------</td>
<td>-------------------</td>
<td>-------------------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>I 11</td>
<td>Foot Island</td>
<td>Shoreline</td>
<td>Mid-tide</td>
<td>Very protected</td>
<td>Very soft, wet silts and clay</td>
</tr>
<tr>
<td>I 12</td>
<td>Brown Bay</td>
<td>Shoreline</td>
<td>Mid-tide</td>
<td>Very protected</td>
<td>Fine sandy mud</td>
</tr>
<tr>
<td>I 13</td>
<td>Central intertidal flats</td>
<td>Broad intertidal flats</td>
<td>Mid-tide</td>
<td>Fairly protected</td>
<td>Sandy mud</td>
</tr>
<tr>
<td>I 14</td>
<td>Central Split Island</td>
<td>Shoreline</td>
<td>Between mid-tide and high tide</td>
<td>Very protected</td>
<td>Soft wet mud</td>
</tr>
<tr>
<td>I 15</td>
<td>Western Split Island</td>
<td>Shoreline</td>
<td>Mid-tide</td>
<td>Very protected</td>
<td>Soft wet mud</td>
</tr>
<tr>
<td>I 16</td>
<td>Western Split Island</td>
<td>Shoreline</td>
<td>Between mid-tide and low tide</td>
<td>Very protected</td>
<td>Soft wet mud</td>
</tr>
<tr>
<td>I 17</td>
<td>Andersons Beach</td>
<td>Shoreline</td>
<td>Between mid-tide and high tide</td>
<td>Fairly exposed</td>
<td>Firm sandy mud</td>
</tr>
</tbody>
</table>
value for each quadrat was expressed as the sum of the values for the grid squares, and also calculated as a percentage of the total area of the quadrat.

Spartina density was recorded as the total number of individual population units. For the purpose of density assessment, it was necessary to adopt a standard procedure for distinguishing one population unit from another. Without excavation, it is not possible to determine whether young Spartina stems adjacent to an older population unit have tillered from rhizomes growing from that unit, or whether they are separate young plants. It was found in twenty sample excavations that new stems resulting from tillering were not found at a distance greater than 0.5 m from the periphery of the parent plant. Accordingly, for the purpose of density estimates in Series I quadrats, it was assumed that all new stems within 0.5 m of a population unit had been established by lateral expansion, and that all new stems greater than 0.5 m from another population unit were new plants. Such an assumption was necessary in order to facilitate later comparisons of density at different sites. Its arbitrary nature is indicated by the fact that the excavations also showed that many new plants established within 0.5 m from other plants; they undoubtedly also established on small patches of bare mud within the perimeter of larger plants.

3.21 Cover

Between 1962 and 1980 there was a quite remarkable increase in Spartina cover. Within eighteen years Spartina attained at least 10 per cent cover over an area of 63.57 ha, of which 54.9 ha were colonised during the survey period 1967 to 1980. Extensive areas of formerly unvegetated mudflats rapidly became the sites of large and continuous swards. Seventy years before, a similar phenomenon in British estuaries had been described by an apparently delighted Oliver (1909):

"The change in scenic effect on bare mud is profound. To what had been a boundless mire there has succeeded a
covering of tender green, taking wonderful tints from
sun and sky. The meanest place is thus ennobled."

Evidence of the "ennobling" of Andersons Inlet is provided in
Table 3.21, which gives cover data for Series I quadrats during the period
May 1967 to January 1980. **Spartina** cover is given in square metres and as
a percentage of the area of each quadrat (930.25 m²). Change in cover is
shown in square metres. Rate of change has been expressed two ways: as
a cover change factor, which is the multiplier by which **Spartina** cover (m²)
increased or decreased between survey dates; and as mean annual change in
cover expressed as a percentage of quadrat area. In calculating the latter,
allowance has been made for the 32 month interval between May 1967 and
January 1970, the 60 month intervals between the following surveys, and
the 152 month period between May 1967 and January 1980.

Data for 1980 have not been given for quadrat I 9 (Arbuthnoots
Inlet), nor have data for earlier years been included in calculations of
totals and means. This quadrat was sited in vigorous **Spartina** at the mouth
of a creek. During the 1970s rapid accretion in **Spartina** promoted
waterlogging of surrounding farmland, which formerly had been adequately
drained. In 1979 the creek was artificially deepened and much of the
**Spartina** in the quadrat was removed. Fortunately, this is the only quadrat
site at which there was human interference with the natural growth of
**Spartina** during the survey period.

In May 1967 only two quadrats had cover values in excess of
20 per cent. Quadrat I 1, which included part of the small sward which
had developed from the planting in the early 1940s at Cherry Tree Creek,
had 54.8 per cent cover. Quadrat I 14, which was established in a small
colony of young plants, clones and incipient clumps which had developed
<table>
<thead>
<tr>
<th>QUADRAT</th>
<th>COVER (M²)</th>
<th>CHANGE IN COVER (M²)</th>
<th>COVER CHANGE FACTOR</th>
<th>MEAN ANNUAL CHANGE IN COVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>I 1 Cherry Tree Creek</td>
<td>509.6</td>
<td>597.2</td>
<td>648.7</td>
<td>734.4</td>
</tr>
<tr>
<td>I 2 Cherry Tree Creek</td>
<td>73.5</td>
<td>195.8</td>
<td>295.5</td>
<td>446.5</td>
</tr>
<tr>
<td>I 3 Cherry Tree Creek</td>
<td>64.5</td>
<td>84.5</td>
<td>273.6</td>
<td>474.2</td>
</tr>
<tr>
<td>I 4 Cherry Tree Creek</td>
<td>46.5</td>
<td>81.8</td>
<td>167.5</td>
<td>258.6</td>
</tr>
<tr>
<td>I 5 Masons Beach Bluff</td>
<td>8.0</td>
<td>17.5</td>
<td>120.5</td>
<td>245.2</td>
</tr>
<tr>
<td>I 6 Island Bluff Nolans Bluff</td>
<td>39.5</td>
<td>101.5</td>
<td>481.8</td>
<td>714.9</td>
</tr>
<tr>
<td>I 7 Nolans Bluff</td>
<td>137.5</td>
<td>165.5</td>
<td>250.0</td>
<td>312.8</td>
</tr>
<tr>
<td>I 8 Nolans Bluff</td>
<td>180.5</td>
<td>239.6</td>
<td>281.2</td>
<td>304.9</td>
</tr>
<tr>
<td>I 9 Arbuthnots Inlet</td>
<td>120.9</td>
<td>203.7</td>
<td>585.5</td>
<td>-</td>
</tr>
<tr>
<td>I 10 Tarwin Mouth</td>
<td>26.4</td>
<td>64.2</td>
<td>243.2</td>
<td>325.5</td>
</tr>
<tr>
<td>I 11 Foot Island Bay</td>
<td>140.6</td>
<td>241.2</td>
<td>540.8</td>
<td>742.2</td>
</tr>
<tr>
<td>I 12 Central Flats</td>
<td>36.0</td>
<td>74.5</td>
<td>614.5</td>
<td>882.6</td>
</tr>
<tr>
<td>I 13 Central Split Is. Western</td>
<td>409.5</td>
<td>425.9</td>
<td>597.6</td>
<td>809.3</td>
</tr>
<tr>
<td>I 14 Split Is. Western</td>
<td>10.5</td>
<td>26.5</td>
<td>745.2</td>
<td>884.5</td>
</tr>
<tr>
<td>I 15 Split Is. Western</td>
<td>27.5</td>
<td>55.6</td>
<td>448.2</td>
<td>504.5</td>
</tr>
<tr>
<td>I 16 Andersons Beach</td>
<td>0</td>
<td>11.6</td>
<td>167.5</td>
<td>119.6</td>
</tr>
<tr>
<td>TOTALS*</td>
<td>1710.1</td>
<td>2436.7</td>
<td>6424.5</td>
<td>8549.6</td>
</tr>
<tr>
<td>MEANS*</td>
<td>106.9</td>
<td>152.3</td>
<td>401.5</td>
<td>534.4</td>
</tr>
</tbody>
</table>

* Excluding I 9, Arbuthnots Inlet (for explanation see text).  
since 1962 on broad intertidal flats to the south of Central Split Island, had a cover value of 44.0 per cent. These two areas of relatively high cover were isolated and localised.

In four other quadrats, all near the site of the 1962 planting of fertile S. anglica, cover was between 10 per cent and 20 per cent. At Nolans Bluff quadrats I 7 and I 8 had cover values of 14.8 per cent and 19.4 per cent respectively. These values are low in comparison with quadrat I 14, where Spartina could not have established until two or three years later. They are explained by the fact that the intertidal zone at Nolans Bluff is relatively narrow, the width of mudflat available for Spartina colonisation being only about 15 m. Given the dimensions of Series I quadrats (30.5 m x 30.5 m), a maximum of 50 per cent of any quadrat at Nolans Bluff would be available for Spartina growth. Despite its greater abundance, Spartina on the virtually flat surface of quadrat I 14 occupied a more limited vertical range than that at Nolans Bluff, which by 1967 had spread both seawards and landwards from the level at which it had been planted. To the east of Nolans Bluff, cover in quadrat I 9 at Arbuthnots Inlet was 13.0 per cent, and near Foot Island, along the inner margin of the spit, cover in quadrat I 11 was 15.1 per cent.

The remaining eleven quadrats had less than 10 per cent cover and an average cover value of 3.0 per cent. Spartina did not occur at Brown Bay or Andersons Beach, where young plants were first observed in February 1968.

By 1980, Spartina in Series I quadrats covered almost five times the area occupied in 1967. Average cover had risen from 12.3 per cent to 57.5 per cent. However, rates of increase varied considerably between quadrats, as shown in Figure 3.21.
Low rates of cover increase were recorded in quadrats which had the greatest cover values at the start of the survey period. Cover in quadrat I 1 (Cherry Tree Creek) increased by a factor of 1.44 to 78.9 per cent in 1980. As the quadrat lies astride the outer margin of the Cherry Tree Creek sward, which is now advancing only slowly, substantial further expansion is unlikely. Cover in quadrat I 14 (Central Split Island) doubled to reach 87.0 per cent.

Low rates of cover increase were also recorded in the two Nolans Bluff quadrats (I 7 and I 8). *Spartina* at these sites now occupies 33-34 per cent of the possible maximum cover of 50 per cent, which is limited, as noted previously, by the narrowness of the relatively steep intertidal zone. Higher rates were recorded at the other two sites which also had 10 per cent to 20 per cent cover in 1967. *Spartina* coverage in quadrat I 9 (Arbuthnoots Inlet) increased from 13.0 per cent in 1967 to 62.9 per cent in 1975, and in quadrat I 11 near Foot Island *Spartina* spread vigorously to occupy 79.8 per cent of the quadrat area by 1980.

The most rapid increases in *Spartina* cover occurred in quadrats which had less than 10 per cent cover in 1967. These may be divided into quadrats along the north west shore, and quadrats along the inner margin of the spit and on the central intertidal flats (Figure 3.21).

Along the north west shore, the highest rates of increase occurred at Masons Beach (quadrat I 5) and Bluff Island (quadrat I 6). At the former site cover increased between 1967 and 1980 by a factor of 30.65. However at the end of the survey period *Spartina* occupied only 26.4 per cent of the quadrat area, which was fairly representative of cover values at similarly very exposed sites. In more sheltered conditions in the lee of Bluff Island, *Spartina* in quadrat I 6 attained a cover of
76.9 per cent by 1980, although the cover change factor of 18.09 was less than that at Masons Beach.

The remaining three quadrats along the north west shoreline were quadrats I 2, I 3 and I 4 at Cherry Tree Creek. Cover in quadrat I 2 increased by a factor of 6.08 to 48 per cent. As at Nolans Bluff, the intertidal zone at this quadrat site is narrow, and it is likely that cover could not exceed 50 per cent. The other two quadrat sites are more exposed to wave action. In quadrat I 3, cover increased during the survey period by a factor of 7.35 to reach 51 per cent in 1980. In quadrat I 4, which is as exposed to strong and frequent wave action as the site at Masons Beach, *Spartina* cover increased from 5.0 per cent to 27.8 per cent.

Greater rates of cover increase and higher cover values at the end of the survey period were recorded at sheltered sites along the inner margin of the spit and on the central intertidal mudflats. The maximum rate occurred in quadrat I 15 at Western Split Island, where *Spartina* cover increased 84 times from 10.5 m$^2$ in 1967 to 884.5 m$^2$ in 1980, the latter being 95.1 per cent of the quadrat area. Similarly high coverages were recorded in 1980 in quadrats I 12 (Brown Bay) and I 13 (intertidal flats south from Central Split Island), although the rate of increase at the latter site was less due to a greater local abundance of *Spartina* at the start of the survey period. At Brown Bay, cover increased from nil in 1967 to 84.9 per cent in 1980.

There were however three sites along the inner margin of the spit where *Spartina* spread was less vigorous. Two were quadrats near the mouth of the Tarwin River (quadrat I 10) and to the west of Western Split Island (quadrat I 16). These were the lowest of the Series I quadrats,
being situated between mid-tide and low tide levels. *Spartina* in quadrat I 10 attained only 35.0 per cent cover by 1980, which was an increase of about 12 times the coverage in 1967. However, at higher levels to landward of the quadrat, an extensive sward developed parallel to the shore. Cover in quadrat I 16 in 1980 was 54.2 per cent; cover values in adjacent but higher sites were similarly much greater. The third site was the quadrat at Andersons Beach (quadrat I 17), which was the only site at which a decrease in *Spartina* cover was recorded in the period 1967 to 1980. *Spartina* grew vigorously between February 1968, when it was first observed at Andersons Beach, and January 1975 when it occupied 18.0 per cent of the quadrat. However between 1975 and 1980 an area of 47.9 m² of low-growing clones and tussocks failed to persist after burial beneath surficial lobes of sand deposited on the marsh during periods of strong wave action. Such partial failure of *Spartina* was common at Andersons Beach during this period.

It is evident from the estimates of mean annual change in cover and the cover change factors between survey periods (Table 3.21) that the rate of *Spartina* invasion varied temporally as well as spatially. In the majority of quadrats the period of most rapid expansion of *Spartina* cover was from 1970 to 1975, when the estimated mean annual change in cover was 5.9 per cent. At that rate *Spartina* in a newly-colonised quadrat would achieve 100 per cent cover in approximately 17 years.

Change in mean cover (m²) for all quadrats is shown in Figure 3.21. *Spartina* cover increased rapidly between 1967 and 1970, increased even more rapidly in the next five years, and continued at a reducing rate between 1975 and 1980. Although rates of increase varied between quadrats, a similar sequence of development was characteristic of most sites, regardless
of the cover value achieved by 1980. Thus quadrats 15 (Masons Beach) and 17 (Western Split Island) underwent similar sequences of change in Spartina cover, despite their differing rates of change and the much greater abundance of Spartina in quadrat 15 at the end of the survey period.

There were however a number of quadrats which did not conform with this general pattern. Some had a greater rate of increase between 1967 and 1970 than between 1970 and 1975 (Figure 3.21). These include quadrats 12 (Brown Bay) and 17 (Andersons Beach), the two quadrats in which Spartina was absent at the start of the survey period. Spartina was not observed at these sites until February 1968. Had there been even 1 per cent cover in May 1967, the rates of increase between 1967 and 1970 would have been less than those in the following five years.

The other quadrats with highest rates of Spartina spread in the first three years of the survey included two quadrats where cover in 1967 was relatively high and two others where the area available for Spartina colonisation was considerably less than the total area of the quadrat. In quadrat I 1 at Cherry Tree Creek, which had a cover value of 54.8 per cent in May 1967, the rate of cover increase declined after 1970 and subsequently remained low and virtually constant. As Spartina at this site now occupies almost the whole area suitable for its growth, a further reduction in the rate of spread can be anticipated. The same applies to quadrat I 11 (Foot Island), which had a Spartina cover of 15.1 per cent in 1967. In quadrats I 2 (Cherry Tree Creek) and I 8 (Nolans Bluff), both of which have only about 50 per cent of their areas potentially available to Spartina, the rate of increase also declined after 1970. In each case this reflects the greater difficulty of
establishing at less favourable lower or higher mudflat levels than the zones of initial occupancy.

At the beginning of the survey period, *Spartina* cover was closely related to length of colonisation. By 1980 variations in cover between quadrats reflected only the suitability of each site for *Spartina* growth. Under ideal conditions and where the whole quadrat area was available for colonisation, *Spartina* cover was approaching 100 per cent after 14 years from the time of marsh inception. While it is expected that *Spartina* cover will continue to increase gradually in most quadrats for perhaps the next ten years, the period of most rapid expansion is over.

3.22 Density

The rapid increase in *Spartina* cover during the survey period was due to the establishment of new plants from seeds and plant fragments, and the lateral expansion of existing plants by production of new tillers from outward-growing rhizomes. Where new plants established more than 0.5 m from other population units there was an increase in density; where fusion resulted from enlargement of existing plants, *Spartina* density was reduced. *Spartina* density at any time was determined by the relative importance of each process in contributing to *Spartina* abundance.

Given the habit of growth of *Spartina*, it is to be expected that density will increase during the initial stages of colonisation due to addition of new plants, and then decline as individual population units expand and merge. Evidence for this is provided in Table 3.22, which gives *Spartina* density and estimated mean annual changes in density during the survey period. Figure 3.22 shows change in density in quadrats grouped according to cover classes used in Figure 3.21.
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### TABLE 3.22 (Contd.)

**SPARTINA DENSITY IN SERIES I QUADRATS  1967 - 1980**

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</tbody>
</table>

**MEANS** *  

|       | 54.8          | 62.4                 | 38.7                 | 14.9                 |                 |   |   |   |   |   |   |   |   |

**MEAN ANNUAL CHANGE IN DENSITY**

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* Excluding I 9, Arbuthnots Inlet
FIGURE 3.22 Change in Spartina density in Series I quadrats, 1967 to 1980.
Quadrats I 12 (Brown Bay) and I 17 (Andersons Beach) were both first colonised by Spartina between May 1967 and February 1968. By the latter date each contained no more than four young plants. Each plant consisted of a single stem less than 10 cm high, together with one or two leaves. They were almost certainly seedlings, as similar plants dug up from nearby sites either still had seeds attached or had no evidence of a parent rhizome. By January 1970 there were 146 plants in quadrat I 12 and 59 plants in quadrat I 17. Most were young plants with a single stem and a basal rosette of leaves, others consisted of small tussocks of up to 25 cm diameter, and a few adjacent plants had merged to form small clumps.

A similarly rapid increase in density must have occurred in other quadrats where Spartina establishment followed the 1962 introduction to Nolans Bluff. For example, in 1967 there were 105 plants in quadrat I 6 at Bluff Island, 155 plants in quadrat I 9 at Arbuthnots Inlet, and 135 plants in quadrat I 13 on the central intertidal flats. Each of these quadrat sites was bare in 1962, as were all other sites except those of quadrats I 1, I 2, I 3 and possibly I 4 at Cherry Tree Creek, where Spartina was planted in the early 1940s. While plant density in many quadrats probably peaked in 1965 or 1966, it is possible that maximum density at some sites was reached between 1967 and 1970 and was therefore not recorded.

By 1970 a general reduction in Spartina density had begun in most quadrats, and all but one site (quadrat I 10) had fewer population units in 1980 than in 1967. This trend is reflected in the plot of mean density for all quadrats (Figure 3.22). However, the rates of density reduction varied between sites.
Quadrat I 1, in Spartina planted in the early 1940s at Cherry Tree Creek, was the only site at which density declined throughout the survey period at a constantly diminishing rate. By 1980, the 11 population units in the quadrat consisted of one large sward occupying about 70 per cent of the quadrat, together with small clumps and clones seaward of the sward and accounting for the balance of the total cover of 78.9 per cent. It is expected that the rate of density decline will continue to be low, for the outer margin of the sward is advancing only slowly. Further, accretion in the sward has been accompanied by a steepening of the slope along its seaward limit, and the few small clumps and clones have not been vigorous on the resulting mobile surface. A similarly prolonged expansion of tussocks prior to fusion has been reported along the margins of Spartina swaths in Poole Harbour (Hubbard 1965a).

In 1967, quadrat I 1 had the highest cover of any site. The site with the second greatest Spartina cover, quadrat I 14 at Central Split Island, exhibited a different pattern of density reduction. Density declined sharply after 1970, and then continued at a slightly reduced rate after 1975 giving a gentle concavity to the lower end of the curve (Figure 3.22). A similar trend is more apparent in the graphs for quadrat I 7 (Nolans Bluff) and quadrat I 2 (Cherry Tree Creek). Although these two quadrats had lower cover values than quadrat I 14 in 1967, the former site had been established in 1962 and the latter had been colonised by Spartina some time after the 1940s plantings. They were therefore sites of relatively older stands of Spartina than sites along the inner margin of the spit and on the central intertidal mudflats, which had been colonised in the mid 1960s.

Another group of quadrats showed a constant or increasing rate of decline in Spartina density after 1970. These include quadrat I 8 at
Nolans Bluff, which unlike quadrat I 7 had no peripheral clones or tussocks seaward of its section of the continuous littoral sward which had developed along the shoreline by 1980. The group also includes sites where density reductions were at a maximum: quadrat I 6 at Bluff Island, quadrat I 12 at Brown Bay, quadrat I 13 at Central Split Island and quadrat I 15 at Western Split Island.

The remaining five quadrats are those where the addition of new plants occurred at a faster rate than the enlargement and fusion of existing plants, and consequently brought about an increase in density. Density in each peaked in 1975, but the form of the graphs indicates that at least three sites had a previous density maximum in the period 1962 to 1967. The group includes the two quadrats most exposed to strong and frequent wave action - quadrat I 4 at Cherry Tree Creek and quadrat I 5 at Nolans Bluff. It also includes the two quadrats sited between mid tide and low tide levels - quadrat I 10 near the mouth of the Tarwin River, and quadrat I 16 at Western Split Island. It is possible that wave action and prolonged tidal inundation respectively reduced the rate of lateral expansion of tussocks at these pairs of sites to the extent that establishment and survival of new plants became the greater factor in Spartina cover increase. However there is no apparent impediment to rapid outward growth which would account for the 1970 density maximum in quadrat I 11 near Foot Island. It would appear that the graph for quadrat I 11 does not illustrate a local aberration for which some explanation is necessary, but simply demonstrates that density decline may be interrupted temporarily in an area of relatively low Spartina cover which receives a plentiful supply of seeds.
3.3 Rates of spread of Spartina

Even given that the plants introduced to Nolans Bluff in 1962 were selected from the most vigorous stands of fertile S. anglica at Bass River, the rate of spread from the six introduced clumps was extremely rapid. In Section 2.3 it was noted that zones drawn to enclose all Spartina within areas of more than 10 per cent cover were estimated to have a total area of 8.67 ha in 1967. A rough calculation gives an approximation of an actual Spartina cover of 8670 m$^2$, of which about 4000 m$^2$ was at Cherry Tree Creek. The remaining 4670 m$^2$ had developed since the 1962 planting. If 0.1 m$^2$ is allowed as the average size of each young plant, the total number of new plants is estimated at 46700. As sufficient plant material was not available for growth of this order of magnitude to arise from rhizome fragments, establishment must have been almost entirely from seed.

Although the exact date of the 1962 planting cannot be recalled, it is known that the plants obtained from Bass River were in flower, and that some bore seed (Arbuthnot 1966 pers. comm.). It therefore seems certain that the introduction was made between January and May, as most flowering in Victorian Spartina occurs during those months. In the light of the previous discussion of seedling establishment and plant growth, it is likely that seed shed from the Nolans Bluff plantings in the winter of 1962 would have germinated in the spring of the same year. The seedling plants would first have flowered and produced seed two years later in 1964. These seeds in turn are likely to have produced flowering plants in 1966, with further flowering plants in 1968. At the same time other seedling plants would have established from Nolans Bluff seed in 1965, 1966 and 1967. The rapid spread of Spartina during these years indicates very high rates of seed
production and germination. High rates of both production and germination have previously been reported for *S. anglica*, with seedling densities of up to 13000/m² having been recorded on bare mud and 9750/m² in continuous sward (Goodman et al. 1969).

The rate of *Spartina* invasion in Andersons Inlet is similar to its rate of spread at British sites in the early part of this century. Oliver et al. (1929) reported that meadowing generally took place after 15-20 years of natural spread. In Andersons Inlet meadowing was well-advanced on the intertidal flats south of Central Split Island by 1973, and swards were the dominant population units in the inlet by 1980. Although rapid, the colonisation of 63.57 ha of Andersons Inlet in only 18 years is not exceptional. While the figures are not strictly comparable because of differences in the method of assessment of *Spartina* cover, the invasion of Andersons Inlet is reminiscent of that of Poole Harbour, where 866.9 ha were colonised between the mid 1890s and 1924 (Hubbard 1965a).

Although no detailed study of rates of spread in sample quadrats was undertaken at overseas sites during initial stages of *Spartina* colonisation, there are several reports of rates of enlargement of individual population units. In New Zealand, Allan (1924, 1930) recorded the extent and rate of spread of material introduced from Southampton Water by K. W. Dalrymple, which was planted out in small clumps on the Foxton mudflats in the Manawatu River estuary. The dimensions of the main patch increased from 1.4 m x 1.3 m in 1915, to 18.4 m x 10.1 m in 1930. The average annual increase in diameter was 0.6 - 0.9 m (2-3 ft), and after 17 years the clump covered about 169 m² ('one twenty-fourth of an acre') (Allan 1930). Enlargement was achieved solely by rhizome extension, the rate of growth being similar to that recorded by Stapf (1914b) in Holes
Bay, Poole Harbour, where clumps of 3 m diameter had developed from young plants within 5 years.

Bascand (1968) has noted that similar results have not always been attained at New Zealand sites. Material obtained from Foxton and planted in 1926-27 in the Waitemata Harbour on sand underlaid by peat made very slow growth. Only five of the 200 clumps survived until 1967, and the average rate of spread was only 1.2 m$^2$ per annum. More rapid growth was achieved in the south in the New River estuary at Invercargill, where offsets from Foxton planted in 1931 at intervals of 0.9 m achieved complete cover in about 3 years.

Oliver et al. (1929) reported that plantings at 3 m intervals in the Sloe area of south west Holland, between the islands of Walcheren and Zuid-Beveland, had meadowed in only 5 years. This rate of spread is similar to that at Foxton, and in Holes Bay. Kamps (1962) has shown that spread was much slower in the colder north of Holland, where the average diameter of tussocks three years after planting was only 0.82 m$^2$.

While lateral expansion of individual population units at Andersons Inlet has been rapid, the most significant factor contributing to increased Spartina abundance during the initial stages of colonisation has been the establishment of new seedling plants. One of the few reports of Spartina growth following natural establishment of seedlings is given by Chater and Jones (1957), who found that Spartina cover in a 70 m$^2$ quadrat in the Dovey estuary increased as a result from 3.5 per cent to 90 per cent of the quadrat area in two years. It was noted that an important factor in the rate of cover increase was seedling density, for young plants quickly coalesce when closely spaced together. Rates of growth were found
to vary with substrate: on mud the radius of tussocks increased by an average of 33.8 cm per annum, but on sand the annual increase was only 13.4 cm.

The rates of spread in Series I quadrats at Andersons Inlet are believed to be typical of the initial phases of marsh colonisation in an area suited to establishment and growth of the fertile amphidiploid. It is of interest to compare them with rates of growth in quadrats at a much older Spartina station. Spartina was introduced to Bridgwater Bay, Somerset, in 1929, and by 1963 had colonised approximately 106 ha (Hubbard and Stebbings 1967). Beyond the limit of continuous Spartina there is a zone of 90 m width containing isolated clumps, which form the seaward limit of the marsh. In 1958, Ranwell (1964b) established eight 61 m x 30.5 m (200 ft x 100 ft) quadrats in this zone, with their short axes parallel to the shoreline. Changes in Spartina distribution were measured by air survey up to 1961, and results were checked against plane table ground survey of selected plots.

The quadrats used by Ranwell were exactly twice the area of Series I quadrats at Andersons Inlet. In order to compare the spread of Spartina at the two sites, the cover estimates for the Bridgwater Bay quadrats have been halved. It is acknowledged that this necessarily introduces error, as Spartina distribution within the quadrats is unlikely to have been uniform. However, it is believed that the degree of error is insufficient to invalidate broad comparisons between the two sets of quadrats.

Table 3.3 has been prepared from estimates of Spartina cover for 30.5 m x 30.5 m quadrats at Bridgwater Bay, derived from data given for 61 m x 30.5 m quadrats by Ranwell (1964b). The table is presented in the same way as Table 3.21, which gives Spartina cover in Series I quadrats.
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<th>COVER CHANGE (m²)</th>
<th>INCREASE IN COVER (m²)</th>
<th>MEAN ANNUAL CHANGE IN COVER (per cent quadrat area)</th>
<th>MEAN ANNUAL CHANGE IN COVER AREA (per cent quadrat area)</th>
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**SOURCE:** Adapted from Ranwell (1964b)
between 1967 and 1980. Cover is expressed in square metres and as a percentage of the quadrat area (930.25 m$^2$). Increase in cover between surveys is given in square metres, and mean annual change in cover has been calculated as a percentage of quadrat area. In addition a cover change factor has been derived for each quadrat, being the multiplier by which the area (m$^2$) occupied by *Spartina* in 1968 increased by 1961.

*Spartina* in Andersons Inlet and the clumps along the seaward margin of the sward at Bridgwater Bay are representative of two distinctive patterns of spread which have been recognized in Poole Harbour by Hubbard (1965a). The first, characteristic of Andersons Inlet, results from initial seedling establishment and subsequent rapid expansion of tussocks by vegetative growth in optimum conditions on level mud. The second, characteristic of Bridgwater Bay, results from much more limited establishment on sloping mud surfaces joining accreting swards. On such surfaces, *Spartina* establishment is slow due to the accompanying mobility of substrate, and there is prolonged expansion of tussocks prior to fusion. Seedling establishment along this zone at Bridgwater Bay is rare, and most new growth is from rhizome fragments (Ranwell 1964b). The mean spring tide range is 11.5 m (Morley 1973), which generates strong tidal currents.

The difference between the sites is indicated in the mean cover data for the two sets of quadrats. In 1967, *Spartina* at Andersons Inlet had been established for no more than 5 years, except at Cherry Tree Creek. Mean cover for all Series I quadrats was 106.9 m$^2$ (Table 3.21). Sites of initial establishment were also those where conditions of growth were most favourable. In contrast, mean cover at Bridgwater Bay in 1958 was only 62.4 m$^2$ (Table 3.3), in less suitable conditions along the seaward margin of a sward at a site where *Spartina* had been present for 29 years.
Increases in mean cover for the three-year periods 1967-70 at Andersons Inlet and 1958-61 at Bridgwater Bay were not greatly dissimilar. Mean cover increased by 45.4 m$^2$ or 2.1 per cent per annum at Andersons Inlet, and by 31.7 m$^2$ or 1.14 per cent per annum at Bridgwater Bay. However, similar rates of cover increase were due to different processes. At Andersons Inlet, increasing Spartina abundance was due primarily to establishment of young plants, and only secondarily to enlargement by rhizome extension. Rates of expansion were to become greater once lateral enlargement became general. At Bridgwater Bay, cover increase was a function of rhizome extension and the gradual establishment of new plants by vegetative growth from clods eroded from the body of the marsh. The rate of cover increase was less than that which had occurred during formation of the sward, for if the rate of advance had been steady since initial colonisation only half the width of marsh could have been formed (Ranwell 1964b). Despite their similar rates of cover increase, the two sites in 1967-70 and 1958-61 were at opposite extremes of a sequence of marsh development.

Between 1970 and 1975 Spartina cover increased in Series I quadrats as a result of vigorous rhizome extension combined with continued establishment of new plants. Mean cover increased by 249.2 m$^2$, which is a rate equivalent to 149.5 m$^2$ over three years. The mean cover change factor, also adjusted for three years, was 3.80, indicating that each quadrat on average contained almost four times the amount of Spartina of three years previously. Over a similar period mean cover at Bridgwater Bay increased by only 31.67 m$^2$, although the mean cover change factor was 2.45. If the cover change factor for quadrat 3 (8.69) is ignored, the mean cover change factor is 1.55. During a three-year period, the area of Spartina in most quadrats increased by half.
Mean annual increase in *Spartina* cover in Bridgewater Bay quadrats is given by Ranwell (1964b) at 1.15 per cent. He noted that if the three quadrats (1, 2 and 6) with maximum *Spartina* cover, which might be expected to give the most accurate results under aerial survey, are considered alone, then the mean annual increase in cover is 2.65 per cent. With respect to the clump zone as a whole, Ranwell concluded that the rate of increase is about 2 per cent per annum.

The figure of 2 per cent has sometimes been quoted misleadingly (e.g. Bascand 1968). Ranwell did not conclude that the area of *Spartina* along the margin of the sward at Bridgewater Bay was increasing in size by 2 per cent per annum, but that it was expanding at a rate which would occupy an additional 2 per cent of a 61 m x 30.5 m quadrat each year. Actual increase in area covered by *Spartina*, expressed as a percentage, was much greater than 2 per cent. Between 1958 and 1961, total *Spartina* cover in the eight 61 m x 30.5 m quadrats at Bridgewater Bay increased from 998.68 m² to 1504.82 m² (Ranwell 1964b). This is an increase of 50.68 per cent, or 16.89 per cent per annum.

Between 1967 and 1970, the mean annual increase in *Spartina* cover at Andersons Inlet was 14.16 per cent. It subsequently rose during the period of most rapid lateral expansion to 32.73 per cent per annum in 1970-75, and fell to 6.6 per cent per annum in 1975-80. By the latter period, most suitable sites within the quadrats had been colonised. Over the period 1967-80, *Spartina* cover increased by an average of 30.77 per cent per annum and occupied an additional 3.5 per cent of a 30.5 m x 30.5 m quadrat each year.

Changes in plant cover and plant density in Series I quadrats between 1967 and 1980 suggest that *Spartina* colonisation may be described
in terms of four stages defined by measures of species abundance. The very earliest phase of *Spartina* marsh inception was characterised by low cover and low density, as small seedlings developed along drift-lines and across broad expanses of intertidal mudflats. This stage is likely to have been brief, for sites which received an ample supply of seed and provided suitable conditions for the survival and growth of seedlings rapidly became highly populated. In less than two years, sites such as those at Brown Bay and Western Split Island were transformed into the second stage of low cover and high density. This was the stage of "numerous dots in the mud" described in Poole Harbour by Sherring (1911).

During these two initial stages in *Spartina* colonisation the important factor contributing to greater *Spartina* abundance was the rapid establishment of young plants rather than enlargement due to lateral growth of rhizomes. However, once rhizome extension and associated tiller growth became widespread, *Spartina* cover increased sharply and density began to decline. The dominant population units changed from young plants and small tussocks to larger clones and clumps, but sward formation had not begun. This third stage may be defined as one of high cover and high density.

The final stage in the colonisation of many sites was that of high cover and low density, characterised by large clumps or swards with a single limiting outline. Sward formation occurred only in favourable environments, particularly those sheltered from strong and frequent wave action. At exposed sites such as quadrat I 4 (Cherry Tree Creek) and quadrat I 5 (Masons Beach) cover in 1980 was less than 30 per cent, and the dominant population units were clones and clumps. These quadrats were in marked contrast to sites such as quadrat I 15 at Western Split Island, which had a plant density of one and a cover value of 95.1 per cent.
CHAPTER FOUR

ENVIRONMENTAL FACTORS IN SPARTINA GROWTH

Between 1967 and 1980 there was a marked diminution in the rate of increase in the area occupied by Spartina in Andersons Inlet. The area of colonisation increased three times between 1967 and 1970, almost doubled by 1975, but increased by only one third in the remaining five years of the survey period (Section 2.3). Within colonised areas, there was also a decline in the rate of increase in Spartina cover (Table 3.1). By 1980 the sites most suited to Spartina growth had been occupied, and in much of the inlet the advance of the seaward and landward margins had ceased.

Largely as a result of ecological work in Britain in the late 1950s and 1960s, a good deal is known about the factors which affect Spartina establishment and growth. The plant shows an adaptable morphological response to varying environmental parameters, enabling it to colonise a wide range of sites which might otherwise remain vacant. However, there are certain environmental factors which prevent Spartina from occupying the entire intertidal zone, and sometimes a change in habitat conditions will be accompanied by Spartina recession.

Ranwell (1967a) has described the broad geographical factors affecting the world distribution of Spartina, which have been further considered by Boston (1981) in relation to the success or failure of Australian introductions. The purpose of this chapter is to examine the ecological amplitude of Spartina at the principal Australian stations, in terms of factors which are known to impose limits on colonisation and spread elsewhere.
4.1 Tidal inundation

Duration and frequency of tidal immersion have been shown by Chapman (1960) to be major controls over saltmarsh habitats. On the basis of extensive studies of saltmarshes in Britain and North America, Chapman distinguished between two main habitat types roughly separated by the level of mean high water: the lower marsh, which undergoes more than 360 submergences per annum, is never continuously exposed for more than nine days, and experiences more than 1.2 hrs submergence in daylight each 24 hrs; and the upper marsh, which has fewer than 360 submergences annually, has a minimum period of continuous exposure of more than 10 days, and has less than 1 hr submergence daily during daylight. Ranwell (1972) has labelled these types 'submergence marshes' and 'emergence marshes' respectively. Spartina marsh develops under regular tidal influence and is almost entirely submergence marsh, except along its landward margins where it merges with a higher zone of comparatively infrequent inundation and prolonged exposure.

It is known that the duration of Spartina submergence at high tide is an important factor limiting its growth. Stapf (1914a) found that the grass did not grow beyond a point about 0.9 m (3 ft) below high water mark, which Oliver (1925) related to a duration of tidal submergence of 6 hours. Goodman et al. (1959) found that recession occurred at levels subject to submergence for longer than 6 hours, and Hardy (1960) noted that in areas with 5 hours tidal submergence, Spartina seldom grows more than 0.6 m (2 ft) high, and rarely flowers.

Goodman (1960) has distinguished spring, summer, autumn and winter phases of growth in British Spartina marshes. The period of most active growth is from about the middle of the spring phase (March, April,
May) to the early part of the autumn phase (September, October, November). In studies at Poole Harbour, Ranwell et al. (1964) observed that Spartina was occasionally submerged for up to 9 hours during maximum spring tides associated with the vernal and autumnal equinoxes (March 21, 22; September 22, 23), which occur at the beginning and end of the period of most active growth. However, during normal spring tides the grass was submerged for about 6 hours. It was concluded that Spartina grows down to levels which are subject to inundation for not more than 6 hours during high tides in the monthly cycle of normal spring tides in the growth period, but when plants are dormant they can survive up to 9 hours submergence during high tides in the equinoctial period of maximum spring tides.

Implicit in the work of Ranwell et al. (1964) is the assumption that Spartina spreads both seawards and landwards from the level of initial colonisation, until its growth is inhibited by either prolonged or infrequent tidal immersion or by other unsuitable habitat conditions. Evidence to test this assumption is available from Andersons Inlet, where it has been possible to observe seaward and landward expansion since the introduction of fertile S. anglica in 1962.

In order to monitor the spread of Spartina to lower (seaward) and higher (landward) levels, permanent local datum points were established at sites in Andersons Inlet. Each consisted of a 50 cm wooden stump driven firmly into the ground, except at Masons Beach where the datum was taken as the top of a fence-post, and at Fishermans Jetty where the reference was the top of the main beam at the end of the boat-ramp. The levels of the permanent local datum points were determined in relation to the Inverloch datum, which is a point 3.05 m (10 ft) below
the top of the main beam of the Inverloch jetty. These were found by levelling across the mudflats at low tide. The datum level at each site was subsequently checked by observers in radio contact with a tide reader at Inverloch jetty, at slack water during neap tides on calm days when the water surface throughout the inlet varies by less than 0.3 m. It is believed that the levels of the permanent local datum points are accurate to within \( \pm 0.05 \) m. Fishermans Jetty datum is 0.76 m above Inverloch datum; the elevation of other datum points is given below in Table 5.2.

The extreme seaward and landward limits of *Spartina* within 1 km of permanent datum points were surveyed by dumpy level at intervals between 1967 and 1980. *Spartina* limits were identified by the first and last population units to be covered by flood tide at each vicinity.

The first survey of the seaward and landward limits of *Spartina* in Andersons Inlet was made in 1967. By 1970 the grass was sparsely established in most areas where it would later become abundant. A notable feature of the spread of *Spartina* to new sites between 1967 and 1970 was the narrow vertical range within which initial colonisation occurred. With very few exceptions, young plants first appeared on the intertidal mudflats at levels between 0.61 m and 0.83 m above Inverloch datum. For example, in 1970 the seaward and landward limits of newly-established small plants were 0.70 m and 0.79 m at Andersons Beach, 0.67 m and 0.79 m on the central intertidal flats, and 0.64 m and 0.83 m near Foot Island. The lowest level of 0.61 m was common for new growth at the head of the inlet along the inner margin of the spit.

An important factor accounting for this narrow vertical range was the high proportion of the intertidal zone which occurred at these
levels before accretion in *Spartina* became pronounced. In 1967 the highest parts of the central intertidal flats were about 0.80 m above Inverloch datum, and as the mudflats were broad and of low relative relief the zone between 0.60 m and 0.80 m was extensive. It is likely that seeds were deposited on the higher levels during and shortly after slack water high tide, and that few seeds were deposited or retained at lower levels once the ebb stream had commenced.

Initial colonisation along shorelines occurred between mid-tide and mean high water neap tide levels, either on mudflats at the base of low cliffs formed in saltmarsh, or at similar levels in the zone of pneumatophores along the seaward margin of the mangrove fringe. It would appear that seeds were deposited at or slightly below high tide level, but that those which were deposited above the level of mean high water neap tide did not survive subsequent periods of exposure during neap tide cycles. At exposed sites where small sandy beaches were emplaced against the cliff, as at Masons Beach, the first plants established further seaward at levels not much above 0.60 m, where the substrate was finer and less mobile.

The narrow vertical range of newly-colonised sites was in contrast to the range at places where *Spartina* had established before 1967. By 1969, *Spartina* at these sites lay between 0.30 m and 0.91 m above Inverloch datum. The most seaward *Spartina* was at Nolans Bluff, where the grass occurred between 0.30 m and 0.82 m; the upper level was at Cherry Tree Creek, where *Spartina* occupied a zone between 0.42 m and 0.91 m. It is believed that initial colonisation before 1967 was also largely restricted to levels approximately 0.61 m to 0.83 m above Inverloch datum, and that the greater vertical range at older sites was the result of landward and seaward expansion achieved partly by rhizome
extension but also by seedling growth at lower and higher levels than the first pioneers.

Figure 4.11 shows the approximate limits of initial colonisation and the levels of seaward and landward *Spartina* at six stations at intervals between 1969 and 1980. The *Spartina* frontier advanced to successively lower levels near Fishermans Jetty, on the central intertidal mudflats and at Cherry Tree Creek, but at Nolans Bluff, Andersons Beach and Masons Beach the seaward limit was at a higher level in 1980 than at the start of the survey period. At the two latter sites this is explained by sediment accretion along the seaward margins of the marsh which raised the level of the intertidal zone, but at Nolans Bluff the outer edge of the sward had retreated by 1980 to a level 9 cm higher than in 1975 as a result of marginal die-back. *Spartina* at Nolans Bluff is subject to prolonged inundation during strong westerly winds, particularly when the Tarwin River is in flood.

In terms of vertical distribution, the landward margin of *Spartina* advanced further than the seaward margin at all sites (Figure 4.11). A few plants failed to survive at higher levels near Andersons Beach, Masons Beach and Cherry Tree Creek, but generally *Spartina* expanded steadily towards the higher saltmarsh zone, in which it established on patches of bare mud. The greatest potential for landward advance was along shorelines exposed to strong and frequent wave action, where initial colonisation had been up to 20 cm lower than at more sheltered sites. In such places the upper limit of *Spartina* tended to advance to higher and usually sandier levels, primarily by rhizome extension, while seaward advance was slight. However, despite the change in vertical distribution being greater along the landward margin of colonised zones, *Spartina* cover at higher levels remains much less than
FIGURE 4.11  Levels of seaward and landward Spartina limits at six stations at intervals during the survey period, in relation to Inverloch datum. Levels are plotted against a line representing mean spring tide range at each station. Approximate limits of initial colonisation, and extreme limits at Andersons Inlet, are shown at right.
at sites further seaward. The greatest increase in *Spartina* abundance has occurred across broad sections of intertidal flat between 0.3 m and 1.0 m above Inverloch datum, which are now the approximate levels of the seaward and landward limits of continuous swards.

Figure 4.11 has been prepared from data given in Table 4.11, which also gives spring tide ranges at each station. Tide readings were taken at 15 or 30 minute intervals from surveying staves attached to pylons at Fishermans Jetty and Inverloch Jetty, and at other sites from ranging poles graduated to 2 cm and driven 0.5 m into the mud. Water level was taken as the mid-point between crests and hollows, and readings were standardised to the heights of permanent datum points. All readings were taken within a few days of the new or full moon.

A factor which must be taken into account in determining the submergence limits of *Spartina* in Andersons Inlet is tidal variability arising from non-astronomic causes. The form and dimensions of tide curves within the inlet are affected irregularly by abnormally high or low discharge from the Tarwin River, and more frequently by wind. West, south west and south winds cause a rise in sea level in Venus Bay, outside the entrance to the inlet. This results in an increase in both the rate and duration of the ingoing tidal stream, and a corresponding decrease in the outgoing stream. As the winds continue, the flood stream runs until water levels outside and inside the inlet have reached equality. On the winds ceasing, sea level in Venus Bay falls to normal, causing the ebb stream to increase in duration and rate until water level in Andersons Inlet has fallen to the level outside.

Tidal variability arising from wind action is evident in the readings for 18 August 1969 (Table 4.11), when water was banked up in
**TABLE 4.11**

**SPRING TIDE RANGES AND SPARTINA LIMITS ON SELECTED DATES**

Data are in metres above Inverloch datum

|-----------------------|-------------|------------|------------|--------------|--------------|----------------------|---------------------------------|--------------------------------------------------------------------------------
| **Fishermans Jetty**  |             |            |            |              |              |                     |                                 |                                                                                |
| Tide range            | 1.07        | 1.26       | 1.59       | 1.53         | 1.62         | -                   | 1.41                            | 1.50 (17 observations)                                                      |
| Level of seaward limit| 0.39        | 0.35       | 0.32       | 0.30         | 0.27         | 0.27                |                                |                                                                                |
| Level of landward limit| 0.76       | 0.85       | 0.88       | 0.95         | 1.05         | 1.11                |                                |                                                                                |
| **Central Intertidal Flats** |         |            |            |              |              |                     |                                 |                                                                                |
| Tide range            | 1.07        | 1.26       | 1.59       | 1.52         | 1.61         | -                   | 1.41                            | 1.50 (17 observations, as above)                                          |
| Level of seaward limit| 0.40        | 0.35       | 0.28       | 0.30         | 0.27         | 0.25                |                                |                                                                                |
| Level of landward limit| 0.89       | 0.95       | 0.95       | 1.07         | 1.10         | 1.13                |                                |                                                                                |
| **Andersons Beach**   |             |            |            |              |              |                     |                                 |                                                                                |
| Tide range            | 1.25        | 1.52       | 1.75       | 1.78         | 1.95         | -                   | 1.65                            | 1.81 (13 observations)                                                      |
| Level of seaward limit| *           | 0.61       | 0.65       | 0.63         | 0.70         | 0.76                |                                |                                                                                |
| Level of landward limit| *           | 0.86       | 0.97       | 1.10         | 1.20         | 1.09                |                                |                                                                                |
| **Masons Beach**      |             |            |            |              |              |                     |                                 |                                                                                |
| Tide range            | 1.08        | 1.47       | 1.65       | 1.71         | 1.79         | -                   | 1.54                            | 1.66 (12 observations)                                                      |
| Level of Seaward limit| *           | 0.40       | 0.28       | 0.28         | 0.31         | 0.35                |                                |                                                                                |
| Level of landward limit| *           | 0.64       | 0.82       | 0.90         | 1.10         | 1.06                |                                |                                                                                |
### Table 4.11 (continued)

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<td>-</td>
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* Not recorded
the inlet by a strong breeze estimated at about 35 km/hr. The ebb stream fell not much below mean water level, and the tide range was unusually small. Tide levels on 1 May 1971, 7 April 1973 and 17 September 1977 were recorded in light or gently breezes, but is is believed that variations between them primarily reflect astronomical rather than meteorological factors. The tide levels for 26 July 1975 were taken in calm conditions; tide ranges for this date best approximate both the predicted mean spring tide range at Inverloch Jetty (2.13 m) (Tide Tables, Victoria) and the means of total observations of spring tide ranges within the inlet (Table 4.11).

In order to estimate the duration of submergence of seaward and landward Spartina limits, it is necessary to establish mean tide ranges for spring and neap tides. As there is no permanent tide gauge at Andersons Inlet, the only available tidal data are those from field observations. As indicated above, the tide for 26 July 1975 represents the mean of observed spring tides, ranging from 17 observations at Fishermans Jetty to 12 observations at Masons Beach. Fewer observations were made of neap tide ranges, as tide records usually were prepared in conjunction with other field activities deliberately planned for spring tide phases when the intertidal zone is accessible for longer periods. Of two sets of simultaneous neap tide readings around the inlet, and 24 additional readings at various sites on different days, the mean neap tide range at each site is best represented by simultaneous readings on 19 March 1977.

Tide curves for 26 July 1975 and 19 March 1977 are plotted in Figure 4.12. The level of initial Spartina colonisation, between 0.61 m and 0.83 m above Inverloch datum, is shown on the curves for Fishermans Jetty. The seaward and landward limits of this zone are submerged for
Mean spring and mean neap tide curves for Andersons Inlet, showing seaward and landward Spartina limits at the beginning and end of the survey period. The levels of initial Spartina colonisation are denoted by X (landward) and Y (seaward) on the curves for Fishermans Jettie.

FIGURE 4.12
4.5 hrs and 3.6 hrs during ordinary spring tides, and 4.1 hrs and 2.4 hrs during ordinary neap tides. The depth of submergence ranges from 0.60 m to 0.38 m at the seaward edge, and from 0.35 m to 0.13 m along the landward margin. The duration and depth of *Spartina* submergence at the time of marsh inception were considerably less along the lower limit, and greater along the upper limit, than in mature *Spartina* marshland which had formed by 1980.

The seaward and landward limits of *Spartina* near the beginning and at the end of the survey period are shown on the tide curves for each of the six stations (Figure 4.12). Assuming that initial colonisation was within a zone between 0.61 m and 0.83 m above Inverloch datum at most sites, the seaward frontier had advanced very rapidly by the first survey date. Within seven years (1969) or nine years (1971) of the 1962 planting at Nolans Bluff, young plants and tussocks had colonised sites to within 15 cm above or below the lowest levels in 1980. Landward spread was slower and more prolonged, but by 1980 small areas of *Spartina* at all sites except Masons Beach were above the level of mean high water neap tide. A similarly rapid seaward expansion has been reported in the Dee estuary by Taylor and Burrows (1968), who found shoot production and establishment of new seedlings to be at a maximum in the lowest parts of the marsh.

Table 4.12 shows the duration of tidal submergence at the seaward and landward margins of the *Spartina* zone at intervals during the period 1969 to 1980. The data have been obtained by applying the levels of upper and lower *Spartina* limits on six survey dates (Table 4.11) to the mean spring and mean neap tide curves (Figure 4.12).

The seaward limits of *Spartina* at Andersons Inlet are
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Data are in hours.
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### MEAN DURATION OF SUBMERGENCE

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* Not recorded
submerged for more than 6 hrs by both mean spring and mean neap tides. Immersion for periods longer than 6 hrs first occurred as early as 1969, when the seaward limit at Nolans Bluff was submerged by mean spring tides for 6.7 hrs, and by mean neap tides for 7.2 hrs. The present abundance of *Spartina* at levels down to 0.25 m above Inverloch datum has resulted in such periods of immersion now being general throughout the inlet. The duration of submergence by mean spring tides was as high as 8.0 hrs at Nolans Bluff in 1973, but the seaward margin has since receded to a level submerged for 6.4 hrs. At Fishermans Jetty, Cherry Tree Creek and on the central intertidal flats, expansion of the *Spartina* frontier to increasingly lower levels was accompanied by a steady increase in the period of immersion.

A notable feature of tidal immersion at the seaward margin of the marsh is that there is little difference between the periods of immersion by mean spring and mean neap tides. Further, as the marsh extends down to lower levels there is a tendency for submergence by mean neap tides to be longer than that during springs. At Nolans Bluff and Cherry Tree Creek, the oldest *Spartina* sites in the inlet, inundation by neap tides is commonly more prolonged. At sites of more recent establishment near Fishermans Jetty and on the central intertidal flats, *Spartina* was initially inundated for longer periods during spring tides, but as the outer margin advanced to lower levels the period of inundation by neap tides became the greater component of total immersion. This is evident in Figure 4.12, and can be expected to occur at any site at which *Spartina* grows below the level of intersection of the mean spring and mean neap tide curves.

Although data given in Table 4.12 are based on tide curves for 26 July 1975 and 19 March 1977, which are believed to represent mean
spring and mean neap tide conditions, field observations on other occasions have confirmed that the seaward limit of *Spartina* is rarely submerged for less than 6 hrs at any site. When the seaward limits are plotted against tide curves for other dates, the duration of submergence is greater than 6 hrs except for clearly atypical tides. Immersion of less than 6 hrs occurs only when the tide has a pronounced meteorological component, particularly during offshore winds which reduce the duration and rate of the ingoing stream from Venus Bay. However, as winds from the north west and north east are weak and infrequent in comparison with winds from the west and south west, it is more common for the length of tidal immersion to be prolonged rather than reduced by wind action. Reduced periods of immersion also occur at times of high atmospheric pressure, which depresses the elevation of the water surface.

The total annual submergence of *Spartina* in Andersons Inlet can be estimated only approximately, due to lack of a continuous-recording tide gauge. The longest period of submergence in 1980 is at Cherry Tree Creek, where the seaward limit is immersed by mean spring tides for 6.6 hrs and by mean neap tides for 6.9 hrs (Table 4.12). The elevation of the seaward margin on one section of the central intertidal mudflats (0.25 m) is actually lower than at this site (0.29 m) (Table 4.11), but inundation is slightly less prolonged due to the different forms and dimensions of the tidal curves (Figure 4.12). During a 366 day year (1980), the seaward margin at Cherry Tree Creek is submerged by 707 tides. Assuming half the tides have curves similar to those of mean spring tides, and the remainder have curves similar to mean neap tides, the annual hydroperiod may be roughly estimated at 4740 hrs/yr, which is an average of 13.04 hrs/day. The degree of error present in this estimate is unlikely to be excessive, as the
mean spring and mean neap tide curves on which it is based were selected as the average of a total of 128 tide records prepared over 100 different days, which is about 14 per cent of the number of high tides occurring in a year.

The standard work with which the data for Andeरons Inlet can be compared is that by Ranwell et al. (1964), who recorded tide levels at three sites in Poole Harbour during an ordinary spring tide and a maximum equinoctial tide, in calm and dry conditions. The lower limit of Spartina at each site was submerged for between 5 hrs and 6 hrs during the ordinary spring tide, and for up to 9.42 hrs during the maximum tide. As noted previously, it was concluded that Spartina grows down to a level submerged for no more than 6 hrs during ordinary spring tides, and that it can withstand occasional submergence for up to 9 hrs at this level when dormant.

In addition, Ranwell et al. (1964) determined total annual submergence of the seaward and landward Spartina limits. Observations of tides at various points in the harbour had shown that, with the exception of maximum spring tides, the tide curves have much the same form and dimensions as the tide curve at Poole Bridge. It follows that, under normal conditions, the depth and duration of submergence at any known level on the Spartina marshlands are comparable with the depth and duration recorded at the same level on the tide gauge at Poole Bridge. From the Poole Bridge tide records for July 1962 to July 1973, a total annual submergence curve was constructed, relating levels above and below Ordnance Datum (Newlyn) to total submergence in hours per annum. Thus the total submergence of known points on the marsh could be read from the graph. Having determined the levels of landward and seaward
Spartina, it was found that the landward limit of Spartina was submerged for approximately 100 hrs/yr, and the seaward limit for 5800 hrs/yr (15.9 hrs/day).

A further analysis of tide records from the gauge at Poole Bridge has since qualified the conclusion that the seaward limit of Spartina is the level of 6 hrs submergence by mean spring tides. Hubbard (1969) has shown that although Spartina marshes in Poole Harbour may be immersed to their greatest depth during spring tides, their lowest level may be covered for a longer period during the neap tide cycle. Further, it was found that the lowest level was immersed by approximately 60 per cent of all tides from July 1962 to July 1973 for between 8 hrs and 9 hrs, and by 20 per cent of the tides for between 6 hrs and 7 hrs. Approximately 9 per cent of neap tides, but only 3 per cent of spring tides, exceeded an immersion duration of 9 hrs. On one occasion the lowest level of Spartina was covered by a neap tide for 23.5 hrs; the longest period of immersion by a spring tide was 11 hrs.

The duration of submergence of the lower limit of Spartina at Andersons Inlet is greater than that reported by Ranwell et al. (1964), but consistent with subsequent information provided by Hubbard (1969). It would appear that Spartina at Poole Harbour is regularly submerged for periods longer than 6 hrs, by more than 80 per cent of all tides. The two sites are alike in that the seaward limit of Spartina is inundated about as frequently by neap tides as by spring tides. Judged by its position in relation to mean tidal curves, and by its annual hydroperiod, the lowest level of Spartina in Andersons Inlet is believed to be similar to, or slightly above, but certainly
not below, the lowest level occupied by the grass in Poole Harbour. As Hubbard (1969) confirms rather than questions the conclusion that the seaward limit at Poole Harbour is submerged for 5800 hrs/year, the estimate of 4740 hrs/year at Andersons Inlet suggests further potential for seaward colonisation.

The seaward and landward limits of *Spartina* in Andersons Inlet are 0.25 m to 1.13 m above Inverloch datum, a vertical range of 0.88 m. While the mean level of the seaward limit at six sites is 0.38 m (Table 4.11), most *Spartina* grows down to about 0.30 m. In Poole Harbour the seaward and landward limits are from 0.04 m to approximately 0.9 m above Ordnance Datum (Newlyn) (Ranwell et al. 1964), which is a range of 0.86 m. Most *Spartina* however grows at levels between 0.1 m and 0.6 m (Bird and Ranwell 1964).

High tides in Poole Harbour are characterised by a double high water phenomenon which is typical of that part of the southern England coast, and is transmitted into the harbour from Poole Bay (Bird and Ranwell 1964). Approximately each 12.4 hrs there is one high water, one low water, a second high water and a second low water. The first high water is greater during spring tides, but the second high water is greater during neaps. The first low water is much higher than the second low water during spring tides, and lower during neap tides, and as the higher of the two low waters commonly falls to levels no lower than Ordnance Datum (Newlyn) (*Tide Tables for Poole*) the seaward edge of *Spartina* is often not exposed between the twin peaks of the high tide.

Figure 4.13 shows tide ranges and the seaward and landward limits of *Spartina* at Poole Harbour and Andersons Inlet. The tide ranges for Poole Harbour are the means given for Poole Bridge in the 1972
FIGURE 4.13

Tide ranges and limits of seaward and landward *Spartina* at Poole Harbour and Andersons Inlet.
Tide Tables for Poole, in which levels are referred to a datum 1.097 m (3.6 ft) below Ordnance Datum (Newlyn). As the form and dimensions of the tide curve at Poole Bridge are similar to tides recorded elsewhere around the harbour (Ranwell et al. 1964), the tide ranges may be taken as representative of the major Spartina sites. The tide ranges for Andersons Inlet are the means for Fishermans Jetty, near which Spartina is most abundant. As the total annual submergence curve prepared for Poole Harbour by Ranwell et al. (1964) indicates that the level of 0.12 m above Ordnance Datum (Newlyn) is submerged for approximately 4740 hrs/yr, the seaward limit of Spartina in Andersons Inlet has been drawn to correspond with that point.

Except for the double high water at Poole Harbour, the tidal characteristics of both sites are similar. The ranges of mean spring and mean neap tides at Poole Bridge are 1.77 m and 0.79 m, which is a mean tide range of 1.28 m. The mean spring tide range at Andersons Inlet is less (1.50 m), and the mean neap tide range is greater (1.39 m), but the mean tide range of 1.45 m is not much different from the British station. The vertical ranges of Spartina at both sites are virtually identical, accounting for 67 per cent of the mean tide range at Poole Harbour and 61 per cent of the mean tide range at Andersons Inlet.

While the upper limit of Spartina at Andersons Inlet is regularly submerged (at ground level) by mean spring tides, the upper limit at Poole Harbour is about 0.11 m above mean spring tide level. At this elevation Spartina is submerged (at ground level) for only about 100 hrs/yr by maximum spring tides (Ranwell et al. 1964). If Spartina at Andersons Inlet is eventually to approximate the total annual submergence limits of mature marsh at Poole Harbour, there is potential for further landward expansion.
The relationship between the levels occupied by Spartina and the shape and size of tidal curves affects not only the duration of tidal submergence, but also the depth. The maximum depth of water at the lower limit of Spartina was found by Ranwell et al. (1964) to be 0.85 m on the day when an ordinary spring tide was recorded, and 1.02 m during the extreme spring tide. The mean spring tide range at Poole Bridge (Figure 4.12) indicates an average depth of 0.75 m, but it is expected that this is exceeded at many sites due to the steepening of tide curves as they pass up the harbour (Ranwell et al. 1964), and to the impact of wind on tidal flow (Bird and Ranwell 1964). In the Lymington estuary, Goodman et al. (1959) found that channel die-back occurred in Spartina at or below the level of 0.90 m depth of submergence, which was equated with an immersion time of about 6 hrs.

Table 4.13 shows the depth of submergence at the seaward and landward limits of Spartina in Andersons Inlet. At Fishermans Jetty, on the central intertidal flats, and at Cherry Tree Creek, the depth of water at the seaward margin of Spartina at high tide has increased steadily throughout the survey period as a consequence of continued occupation of successively lower levels. The maximum depth of water at mean high water spring tide is 0.99 m. At Andersons Beach, Masons Beach and Nolans Bluff the depth of water has decreased since maxima in the mid 1970s. As noted previously, sediment accretion at the first two sites subsequently raised the level of the intertidal zone, and at Nolans Bluff the seaward margin of Spartina receded between 1975 and 1980.

It seems likely that depth rather than duration of submergence is the more significant factor affecting Spartina growth. The grass is able to withstand continued inundation through low tide, which is a total immersion time of about 23.5 hours. In 1964, Spartina was
## TABLE 4.13

DEPTH OF SUBMERGENCE OF SEAWARD AND LANDWARD SPARTINA LIMITS DURING MEAN SPRING AND NEAP TIDES

Data are in metres

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* Not recorded
reported as surviving prolonged submergence on the Mitchell River silt jetties in the Gippsland Lakes, Victoria, in clear water with little tidal action (Mitchell 1964 in litt.). The grass is known to have persisted at this site until at least 1976 (Boston 1981). In laboratory conditions, *Spartina* has continued to grow when completely immersed in sea water for up to 4.5 months, although production of new shoots has been less vigorous than in the field (Hubbard 1969).

Ranwell *et al.* 1964) have suggested that since *Spartina* normally grows in silt-laden water, it is likely that the amount of light it receives at its seaward edge is a critical factor in its growth, and one which will vary with the depth to which *Spartina* is submerged. Hubbard (1969) has shown that the amount of light available to *Spartina* is affected by turbidity in relation to depth of submergence, and by the length of daylight during which the marsh is exposed. Field observations at Bridgewater Bay indicate that the incoming tide may contain sufficient suspended sediment to prevent penetration of visible light below a depth of 2 cm, which would exclude light from reaching the lowest levels of the marsh during periods of immersion, and hence govern the duration and number of photoperiods during a day. Where sediment load is less, the intensity of light may be reduced without alteration to photoperiod.

However, in a subsequent paper, Hubbard (1970) reported highest germination rates in laboratory conditions of total darkness, which suggests that tidal immersion would favour germination by a reduction in the intensity and duration of light. This may partly account for the fact that the seaward frontier of *Spartina* in Andersons Inlet expanded largely by seedling establishment,
while landward spread was mainly achieved by rhizome extension. Forward establishment in the Dee estuary is also reported to be primarily by growth from seedlings (Taylor and Burrows 1968). Hubbard has observed that the inhibitory effect of light on germination would ensure that the *Spartina* seed has first been buried by sediment which provides a stable habitat for seedlings.

Andersons Inlet is the site at which study of the tidal submergence limits of *Spartina* has been most intensive. Table 4.14 gives the depth and duration of tidal submergence at several other Victorian stations. While the records are inadequate for estimation of total annual submergence, they confirm that the seaward edge of *Spartina* will grow down to levels frequently submerged for more than 6 hrs.

Two high neap tides and four spring tides have been recorded at Agnes River, the mean of observed tides being 1.64 m. *Spartina* occupies 67 per cent of the mean tide range, and was submerged on the six survey days for between 6.2 hrs and 6.9 hrs. As at Andersons Inlet and Poole Harbour, there is no apparent relationship between tide range and duration of immersion along the seaward margin of *Spartina*, for even during the smallest tide the lower limit of the grass was submerged for 6.6 hrs. This tide occurred at a time when land drainage maintained low tide levels within the river to within a few centimetres of the most seaward tussocks. Despite immersion to a depth of over 1 m during spring tides there has been no frontal recession in *Spartina* at Agnes River, although seaward advance has now virtually ceased.

The longest periods of submergence of the seaward limit of *Spartina* have been recorded at Albert River, where the grass is submerged
<table>
<thead>
<tr>
<th>SITE</th>
<th>DATE</th>
<th>TIDE RANGE (m)</th>
<th>SPARTINA RANGE (m)</th>
<th>DURATION OF SUBMERGENCE (hrs)</th>
<th>DEPTH OF SUBMERGENCE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Seaward limit</td>
<td>Landward limit</td>
</tr>
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<td>1.75 Neap</td>
<td>0.86</td>
<td>6.2</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>23.3.75</td>
<td>1.48 Neap</td>
<td>&quot;</td>
<td>6.4</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>11.4.75</td>
<td>1.05 Spring</td>
<td>&quot;</td>
<td>6.6</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>24.7.75</td>
<td>1.80 Spring</td>
<td>&quot;</td>
<td>6.9</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>16.7.77</td>
<td>1.78 Spring</td>
<td>1.10</td>
<td>6.3</td>
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</tr>
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<td>1.97 Spring</td>
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<td>6.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Means</td>
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<tr>
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<td>0.83</td>
<td>23.0</td>
<td>3.1</td>
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<td>SPARTINA RANGE (m)</td>
<td>DURATION OF SUBMERGENCE (hrs)</td>
<td>DEPTH OF SUBMERGENCE (m)</td>
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<td>1.30 (Spring)</td>
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<td>2.19 (Neap)</td>
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<td>7.5</td>
<td>0</td>
</tr>
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<td>2.38 (Spring)</td>
<td>&quot;</td>
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<td>1.7</td>
</tr>
<tr>
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<td>0.9</td>
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<tr>
<td>Bass River</td>
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<td>1.40</td>
<td>6.9</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>29.4.75</td>
<td>2.55 (Spring)</td>
<td>1.50</td>
<td>6.2</td>
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<tr>
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<td></td>
<td>2.59</td>
<td>1.45</td>
<td>6.6</td>
<td>3.7</td>
</tr>
</tbody>
</table>
for between 8 hrs and 9 hrs by normal spring tides. On one occasion the lower limit was not uncovered at low water, giving a total immersion period of 23.0 hrs (Table 4.14). As low tide has often been observed to fall not much below the most seaward Spartina, it is believed that the lower limit is probably submerged on some occasions for several consecutive low tides. However the depth of tidal inundation is no greater than at other stations, with depths of less than 1 m being recorded during the periods of most prolonged immersion.

The largest tide ranges in Victorian Spartineta occur at the two sites in Westernport Bay. At Tooradin, 5 km from the Spartina station at Moodys Inlet, the mean spring and mean neap tide ranges are 2.74 m and 1.83 m (Tide Tables, Victoria). The ranges of ordinary spring and neap tides recorded at 15 minute intervals on two occasions at Moodys Inlet were 2.38 m and 2.19 m (Table 4.14), but it is believed from observations at other times that mean tide ranges and levels are similar to those at Tooradin. Spartina had a vertical range of 1.68 m in 1974, but has since spread further landward to occupy 1.90 m. The upper limit of Spartina is a few centimetres above the level of mean spring tides; the lower limit is at a level submerged for between 7 hrs and 8 hrs by most tides.

Spartina in Moodys Inlet is most abundant above mean water level, along the higher parts of a steep and narrow intertidal zone. At lower levels the grass grows as depauperate clumps and clones around which sediment is deposited to form low mounds or tussocks, which are shaped in response to strong ebb and flood currents. At these levels Spartina growth is not vigorous. The seaward limit of Spartina is regularly submerged in more than 1.5 m of water, during both spring and neap tides.
Similar depths of inundation occur in the ox-bow occupied by *Spartina* at Bass River, where the seaward limit was submerged in more than 1.90 m of water on both occasions when tide levels were related to *Spartina* distribution (Table 4.14). Here however the lower limit of *Spartina* is the edge of a continuous and healthy sward, which suggests that water depth alone does not account for the poor performance of the grass at the lowest levels at Moodys Inlet. Nor does the period of immersion, for it is known from Albert River that *Spartina* is not impeded by regular inundation for more than 8 hrs. It therefore seems likely that the lower limit of *Spartina* at Moodys Inlet is determined not by prolonged duration or depth of submergence, but by strong tidal currents which promote substrate instability.

The tidal submergence limits of *Spartina* in the Tamar River estuary have been described by Phillips (1975). At Georgetown, near the entrance to the estuary, the mean spring and mean neap tide ranges are 2.45 m and 1.83 m. Tide ranges increase steadily to 4.28 m and 2.75 m at Launceston, 22 km south at the head of the estuary. The tide range in the *Spartina* zone is greater than at Victorian sites, but has similar semi-diurnal components. The vertical limits of *Spartina* are 1.20 m and 3.05 m above Georgetown Chart Datum. The uppermost part of the marsh is submerged by all spring tides, but exposed by even the higher of the two daily high tides during minimum neap tides. The lower limit of *Spartina* is exposed by all tides, except once daily at high low water during minimum neap tides.

In July 1978 the vertical range of *Spartina* at the original planting site at Windermere was 1.85 m. As this is consistent with the vertical range given by Phillips (1975), it is evident that no further seaward or landward expansion had occurred. At Swan Bay, which is
representative of sites to which *Spartina* spread after its introduction in 1947, the vertical limit was 1.45 m. The uppermost 1.15 m consists of continuous marsh, while the lower part is occupied by large clones and tussocks.

*Spartina* occurs mainly in the middle and upper reaches of the estuary. The mean spring and mean neap tide ranges in this area are estimated at 3.4 m and 2.3 m, being half-way between those for Georgetown and Launceston. The mean tide range is 2.9 m. *Spartina* has colonised approximately 64 per cent of the mean tide range at this station, which is comparable to 67 per cent in mature *Spartina* marshland at Poole Harbour, and 61 per cent in younger marsh at Andersons Inlet.

Tidal predictions for Georgetown (*Australian National Tide Tables*) indicate that the level of high low water did not fall below 1.20 m above Georgetown Chart Datum on 24 days in 1978, during neap tide periods in January, May, June, July and August. Although this cannot readily be translated into tidal levels in the *Spartina* zone, it suggests that periods of immersion for 23-24 hrs may be expected to occur fairly frequently. The landward limit of *Spartina* remained exposed during 197 high neap tides, on seven occasions for periods of 7-8 days.

The above discussion has considered the submergence limits of *S. townsendii* (s.l.), without distinguishing between its sterile and fertile forms. Where *Spartina* has extended down to levels inundated for 6 hrs or much longer it is almost certainly fertile *S. anglica*, for Hubbard (1965a) has found that the seaward limit of sterile *S. x townsendii* approximates to 4.5 hrs submergence during the period of active growth. This has been confirmed by Bascand (1968) at Kaipara
Harbour, New Zealand. \textit{S. x townsendii} at Poole Harbour is limited to the landward margin of \textit{Spartina} marsh, where it is encouraged or maintained by grazing. Of 12044 ha of \textit{S. townsendii} (s.l.) in Great Britain, not more than 20 ha are of the sterile plant (Hubbard and Stebbings 1967).

It is known that \textit{S. x townsendii} occurs at Cherry Tree Creek (Court 1970 \textit{in litt.}), and it is likely that it is also found elsewhere in the upper levels of \textit{Spartina} marsh in which the fertile form is dominant. Identification requires cytological examination and comparison of plant morphology with type descriptions; the two plants cannot readily be distinguished in the field. Although Bascand (1968) found that \textit{S. x townsendii} was stunted in comparison with \textit{S. anglica} in New Zealand, this is not a characteristic on which the two plants can be separated, for Goodman \textit{et al.} (1969) have noted that the sterile form may reach a height of 1.3 m.

At exposed sites such as the outer faces of sea-walls at Corner Inlet and the mouth of Bass River, and at sites where \textit{Spartina} in inundated by only maximum spring tides, stem height is often less than 20 cm and leaves are small and sometimes brown. It is possible that such plants are \textit{S. x townsendii}, but they could also be a variant of the fertile amphidiploid such as the dwarf brown mutant reported in the Dovey estuary by Chater and Jones (1957). However, given the extreme conditions in which such plants are found, the most likely explanation is that they are simply 'environmentally dwarfed' (Goodman \textit{et al.} 1969). The tall and vigorous plants now found at Agnes River are derived from dwarfed specimens obtained from saltmarsh at Tidal Creek in the 1940s (Jones 1978 \textit{pers. comm.}).
4.2 Salinity

*Spartina townsendii* (s.l.) is known to be tolerant of a broad range of salinity conditions. Only rarely has it grown naturally in fresh water, although it has been successfully cultured in fresh water with an occasional addition of Knop's solution containing a trace of manganese (Goodman 1960). Ballinger (1968 *in litt.*) has reported *Spartina* persisting in small pools of fresh water on piles of dredge material in the Waihopai estuary, New Zealand, although it is probable that the grass was rooted in soil with a high salt content. In their survey of British Spartineta, Goodman *et al.* (1959) found only one site where *Spartina* grew in a completely fresh water environment, above a weir in the River Clyst in Devon. At the other extreme, Hubbard (1969) has shown that *Spartina* may grow in a condition of total immersion in sea water for up to 4.5 months.

Like all true estuaries, Andersons Inlet is characterised by daily and seasonal variation in water salinity. The salinity of surface water has been recorded simultaneously with tide readings, with total soluble salts being determined by conductivity methods corrected for temperature. Direct measurements by boat have revealed a distinct salt wedge (Bowden 1967) during the early stages of the flood stream, indicated by a marked increase in salinity with depth. As the wedge moves up the estuary the interface between the relatively fresh surface layer and the underlying dense layer of salt water is broken down due to intermixing, and at high tide salinity variation in the water column is small.

*Figure 4.21* is a generalised representation of the salinity of surface water during a normal spring tide, with salinity categories defined according to the Venice system (*Symposium on the Classification* ....)
FIGURE 4.21 Surface water salinity at Andersons Inlet during a normal spring tide.
of Brackish Waters, 1959). Salinity varies from that of sea water in the lower reaches of the estuary, to oligohaline at the head. In addition to a longitudinal salinity gradient, there is a lateral gradient across the inlet, as shown by deflection of the isohalines. In calm and dry conditions, water salinity along the north and west shoreline is slightly greater than at sites equidistant from the mouth along the inner margin of the spit, and the time of high water is up to 15 minutes earlier. This effect is even more pronounced during strong south west winds.

Spartina is most abundant in Andersons Inlet where surface water salinity is generally less than 18°/oo during normal spring tides. However the grass is not restricted to such areas, for the Andersons Beach site is immersed in water of 18°/oo to 30°/oo salinity, and scattered clones closer to the mouth of the inlet rarely experience salinities lower than sea water. Further, there is marked seasonal variation, with high salinities in summer and autumn when evaporation is high and both precipitation and stream discharge are low, and low salinities in winter and spring when there is little evaporation and the inlet is freshened by rainfall and river flow. While most Spartina has colonised areas where surface water is usually diluted to about half the salt concentration of sea water, excessive salinity evidently imposes no limit on growth.

Figure 4.22 shows fluctuation in water salinity at sites around the shores of the inlet during the passage of four tides, two of which are those representative of mean spring tides (26 July 1975) and mean neap tides (19 March 1977). High tide on 18 August 1969 occurred during a strong south west wind, which had caused the level of the previous low tide to be maintained at about mean water level. As the Tarwin River was at bankfull stage, salinity in the inlet was lower than normal, and
FIGURE 4.22 Surface water salinity at selected stations on four survey dates. H and L denote high and low water.
fell to 16°/oo at the mouth. Water salinity in **Spartina** at Fishermans Jetty, Cherry Tree Creek and Nolans Bluff was much lower than at the other two recording stations, and their salinity ranges were less. With the exception of Fishermans Jetty, salinity at these sites did not vary in relation to the level of the tide, due to the banking of fresh water in the upper part of the inlet behind the more saline flood.

The other three high tides were unaffected by exceptional wind or stream discharge, and show normal conditions similar to those of Figure 4.21. The curves for Fishermans Jetty and Nolans Bluff are typical of sites where **Spartina** is most abundant, which are characterised by both low salinities and a narrow salinity range between low and high water. Water salinity at Cherry Tree Creek is affected by land drainage at low water, but increases sharply with the passage of the flood.

Salinity ranges in Andersons Inlet are similar to those at other Victorian **Spartina** sites. Table 4.2 gives spot readings taken simultaneously with tide readings (Table 4.14) at selected stations. Although the extreme downstream limits of **Spartina** at these sites are frequently inundated by sea water at high tide, **Spartina** is most vigorous close to the upstream limits, where immersion in water greater than 18°/oo salinity is rare. Salinity data supplied by the Port of Launceston Authority (Phillips 1975) confirm that this is also the case in the Tamar estuary.

As **Spartina** is known to withstand salinities in excess of sea water, its common occurrence in areas most frequently immersed by mesohaline or oligohaline water cannot be explained by intolerance of higher salinity conditions. One of the factors which has contributed to **Spartina**
### TABLE 4.2
SURFACE WATER SALINITY AT SELECTED VICTORIAN STATIONS

<table>
<thead>
<tr>
<th>SITE</th>
<th>DATE</th>
<th>WATER SALINITY (‰) IN SPARTINA ZONE</th>
</tr>
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<td></td>
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</tr>
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<td>23.9.78</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>28</td>
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</table>
abundance in these areas is the need for seeds to be desalinated prior to germination. Goodman et al. (1969) have reported that germination of seeds is inhibited by salt water, and that desalinisation by rain, seepage, or immersion by water of low salinity must occur before seedling growth can commence. Taylor and Burrows (1968) have reported 100 per cent germination rates in fresh water, compared with only 29 per cent in sea water. The slow spread of Spartina at sites such as the mouth of Bass River, and near the mouth of Andersons Inlet, is thus believed to be largely by growth from plant fragments.

Spartina must be regarded as an obligate rather than a facultative halophyte (Strogonov 1964), for its physiological adaptation to salt concentrations is such that it has only rarely persisted in fresh water. However, effective reproduction from seedling establishment requires lower salinities than those which can be tolerated by the mature plant, and hence is largely restricted to sites where salt water is diluted by land drainage. It is of interest that Chapman (1940) noted that surface chloride content in S. alterniflora and S. patens at Lynn, Massachusetts, attained its lowest values (less than 0.5 per cent sodium chloride) at the time of the year when seeds were germinating, and later verified experimentally that germination rates of these and other salt-marsh plants was best in tap water or in solutions of up to 1 per cent sodium chloride.

Bascand (1968) has provided evidence that salinity affects Spartina growth as well as germination. In laboratory culture it was found that S. anglica grew well in both tap water and a solution of 1 per cent sodium chloride, but deteriorated in height, colour and production of new shoots in higher salt concentrations. The sterile S. x townsendii, in contrast, showed little reaction to up to 5 per cent
sodium chloride. It was concluded that although the salinity of marsh soils is unlikely to reach levels which will limit the vegetative spread of either form, optimum growth will occur in areas of moderately saline or brackish water.

Submergence marsh and emergence marsh have characteristically different salinities, as described by Ranwell (1972). The chlorinity of the soil solution in submergence marsh rarely rises above that of the tidal water in which it is regularly immersed, while emergence marsh develops much higher chlorinities as a result of evaporation during dry periods between tides. While relatively low chlorinity, increasing gradually landwards, has been recorded in submergence marsh at Andersons Inlet, *Spartina* does not occur in emergence marsh as defined by Chapman (1960) at this or any other Australian site.

Salinity higher than sea water has been reported in the upper levels of *Spartina* marsh at several overseas sites. In New Zealand, Bascand (1968) found *S. x townsendii* occurring at salinities up to 4.7 per cent in the Firth of Thames, and also growing elsewhere in zones of high salinity at levels infrequently covered by high tide. Holmes (1960) recorded values just in excess of sea water in a Lincolnshire marsh at the end of the 1959 summer. In Poole Harbour, Ranwell et al. (1964) found mean annual chlorinity in ten plots at mid-ward level to be between 1.41 per cent and 1.49 per cent, but with an extreme high of 2.44 per cent during a period of low rainfall. Regular measurements of soil chlorinity showed a distinctive seasonal pattern in which chlorinity was closely correlated with rainfall, but not with tidal submergence. It was concluded that chlorinity in Poole Harbour is unlikely to attain a limiting concentration for *Spartina*, although it may well limit the spread of
**Scirpus maritimus** and **Phragmites communis** which are invading **Spartina** marshland towards the head of the harbour.

4.3 Other factors

As far as is known, **Spartina** does not occur at any site exposed to ocean swell and frequent strong winds. It is found in sheltered estuaries, as in the Hampshire Basin and south west Holland, in large but relatively protected embayments such as The Wash and the Bristol Channel, and in the lee of barrier islands, as in the Wadden Sea. Occasionally it extends along open shoreline, as near Hoylake in Cheshire (Taylor and Burrows 1968); it also occurs in patches along the outer margins of sea-dikes in Holland and Germany. However its occurrence in such stronger wave energy environments is restricted to locally sheltered sectors where protection is provided from frequent wave action.

It has been shown that **Spartina** will grow in sea water, and persists in salt concentrations greater than sea water in emergence marsh. Its absence from ocean shorelines therefore cannot be attributed to salinity, which reduces plant vigour but imposes no limit on vegetative spread. Salinity alone would not prevent plant fragments from Andersons Inlet from establishing outside the estuary along the sandy Venus Bay coastline, for in the lower part of the inlet **Spartina** tussocks are immersed in sea water which is only rarely diluted at high tide.

The preference shown by **Spartina** for sheltered environments must therefore be explained in terms of other characteristics by which they are distinguished from more exposed coasts. One such characteristic is the finer substrates which are typical of estuaries and embayments colonised by the grass.
There is little agreement in the literature on \textit{Spartina} about the
relations between the character of surface sediment and rates of \textit{Spartina}
growth. Carey and Oliver (1918) and Oliver (1925) stated that \textit{Spartina}
favours a finely-particled substrate and accretes fine wet muds, and König
(1949) and Deloffre (1953) observed failure of \textit{Spartina} in sand or at least
much slower growth than in mud. Chater and Jones (1957) reported the rate
of spread on muddy substrates in the Dovey estuary to be twice that on
sand, while Caldwell (1957) found \textit{Spartina} clones on muddy sand at Blakeney
Point, Norfolk, to be increasing in diameter faster than those on pure mud.
Chapman and Ronaldson (1958) noted that seeds of \textit{Avicennia} are more likely
to stick and remain in a mud area than a sand area, because the former
offers more resistance to mechanical tide action than the latter. A
similar argument could be applied to seeds of \textit{Spartina}.

Following their review of \textit{Spartina} sites throughout the British
Isles, Goodman \textit{et al.} (1959) found no apparent substrate preference.
Their survey showed that \textit{Spartina} grows on a wide range of soils, from
the very fine clays of the Hampshire Basin to the silts and sands of the
east and west coasts, and even occurs in a dwarfed condition on shingle
at sites such as the Yankee Lateral at Blakeney Point. Their conclusion
was that occasional stunting of \textit{Spartina} in sandy localities is possibly
due as much to exposure as to the actual texture of the soil, for coarser
substrates in general are often associated with less sheltered positions,
where other adverse factors may be operating.

\textit{Spartina} in Australia also grows on a range of substrate types. At
no site is it found on shingle, although the mud along the banks of Duck
River contains a high proportion of pebbles, and in parts of the Tamar estuary
the grass is rooted in a thin veneer of mud between angular boulders derived
from dolerite and basalt outcrops. It grows on firm compact sand of largely marine origin along the outer edges of sea walls at Corner Inlet, and at the mouths of the Bass and Albert Rivers. The most common substrate is a fine sandy mud, but there are areas of very soft, wet silts and clay near the upper limits of *Spartina* at Agnes River and in Tidal Creek.

Andersons Inlet contains the greatest range of sediment types of any Victorian *Spartina* station. The surface sediments are almost entirely medium and fine sands as defined by Folk (1954), with grains larger than 4.0 Ø diameter comprising more than 90 per cent of the weight of any sample. The coarsest material is of 1.5 Ø to 2.0 Ø mean grain diameter, and occurs in the lower reaches of the estuary near the mouth of the inlet. Sediment calibre diminishes towards the head of the estuary, where fine sandy mud has a mean grain diameter of 2.5 Ø to 3.0 Ø. Along shorelines exposed to strong wave action in the upper part of the inlet, as at Masons Beach, the substrate of the intertidal zone grades seawards from medium sand to fine sand, which forms a soft wet mud. Very soft fine silts occur at the mouths of Cherry Tree Creek and smaller streams, to the immediate south of Central Split Island (Section 5.23), and along the inner margin of the spit between Foot Island and the mouth of the Tarwin River.

*Spartina* is most abundant on fine sands of 2.0 Ø to 2.6 Ø mean grain diameter, which might suggest that such sediments have been colonised preferentially. However sediments of this calibre extend across the whole middle part of the estuary and account for about 60 per cent of its total area, of which only shoreline littorals and the intertidal flats to the south and west of Split Islands have been colonised by *Spartina*. At some places along the north shore *Spartina* growth is slow on sands similar to those on which it is thriving along the inner margin of the spit. Further,
the grass has spread rapidly on fine silts and clays except where the substrate is waterlogged or exposed by the tide for only short periods, and has colonised coarser material of 1.5 ø to 2.0 ø mean grain diameter within 1.5 km from the entrance to the inlet. While *Spartina* tends to favour fine sands at Andersons Inlet and other Australian stations, it also grows on coarser and finer material. It is therefore expected that other environmental factors are of greater significance in accounting for its differential performance at various sites.

A second characteristic distinguishing sheltered environments from open coasts is the degree of exposure to mechanical action by waves. It is thought that wave action is not only a significant factor affecting the suitability of sites for *Spartina* colonisation, but is also important in determining the seaward limit of growth.

While the foreshore zone of an open sandy shoreline is so unstable that it cannot be colonised by flowering plants or even micro-algae (Ranwell 1972), certain plants are able to colonise the high tide strandline where tidal litter assists in overcoming nutrient deficiencies and lack of soil moisture, and reduces daily temperature fluctuations to a point at which plant growth can be sustained. *Spartina* root and rhizome fragments have occasionally been observed at high water mark on the Venus Bay beach outside the entrance to Andersons Inlet, and the frequent recovery at this site of floats released within the estuary indicates that there is certain to be delivery of a substantial quantity of such fragments following periods of erosion of the marsh. The beach is comprised of medium sands of 1.0 ø to 1.5 ø mean grain diameter, only slightly coarser than the pure sand colonised by the grass in the lower part of the inlet. However no plant fragments have established successfully. *Spartina* cannot
take root in the intertidal zone due to substrate instability, and hence cannot locate at a level which suits its particular requirement for regular tidal immersion. Nor is it able to withstand periods of prolonged exposure along the strandline. While pioneer plants, notably Cakile maritima, spring up above high water mark, formerly viable Spartina fragments are left as tidal litter.

Wave action also exercises an important control over the distribution of Spartina within sheltered embayments. According to Johnson (1950), the effectiveness of locally generated wave action on an estuary or lagoon is a function of fetch and wind strength. The longest fetch in Andersons Inlet is for winds from the north west and south east quarters, which are infrequent (Figure 4.31) and also weak. Winds from the west are strongest and most frequent, and blow over a fetch of 6 km. South west winds have a fetch of only 5 km, but a high frequency. At the entrance to the inlet, south west winds have an uninterrupted fetch across Bass Strait and through the inlet entrance, sometimes exposing the inlet shoreline as far east as Screw Creek to waves up to 1 m in height.

Figure 4.32 is a wind resultant vector diagram for Wilsons Promontory, which is 70 km from Andersons Inlet and the nearest permanent wind recording station. The diagram has been prepared according to the method devised by Schou (1945), in which vectors of wind forces are obtained by multiplying the frequency of winds in each velocity class by the cube of its mean velocity, and summing the results for each wind direction. The vectors are expressed graphically by lines proportional to the calculated vectors of wind frequency and strength from each of 16 compass directions.

Figure 4.33 gives onshore wind resultants (Jennings 1957) for
FIGURE 4.31

Wind rose for Wilsons Promontory. (Based on data for January 1974 to November 1978).

FIGURE 4.32

Wind resultant vector diagram for Wilsons Promontory. (Based on data for January 1974 to November 1978).
FIGURE 4.33  Onshore wind resultants for selected sites at Andersons Inlet.
sites in Andersons Inlet, obtained from the wind resultant vector diagram for Wilsons Promontory. As an onshore wind resultant prepared for Venus Bay coincides with the orientation of the axes of blow-out dunes, it is apparent that the records for Wilsons Promontory can be applied to the Andersons Inlet area. The west shoreline between Cherry Tree Creek and the Tarwin mouth is exposed to the strongest and most frequent winds, although the fetch diminishes towards the head of the estuary. The north shore between the mouth of the inlet and Pound Creek is not so exposed to west winds, but wave action generated by winds from the south west quarter is augmented by ocean swell at high tide.

The sites most protected from onshore wave action produced by strong and frequent west and south west winds are those along the inner margin of the spit and on the central intertidal flats between Split Islands and the mouth of the Tarwin River. It is in this area that Spartina is most abundant. Onshore winds from the north and east are weak and infrequent, providing a calm water environment and a stable substrate which facilitates seedling establishment. Although onshore wave action along the inner margin of the spit is rare, the water is very turbulent near the mouth of the inlet during the passage of the flood, at the interface between ebb and flood currents.

Along sheltered shoreline sectors, Spartina in Andersons Inlet grows to lower levels than at more exposed sites. In 1980 the seaward limit is at 0.27 m above Inverloch datum at Fishermans Jetty, 0.25 m on the central intertidal flats and 0.29 m at Cherry Tree Creek (Table 4.11). In each case the lower limit is marked by the edge of continuous sward. At Masons Beach, which is subject to strong wave action, the seaward limit is at 0.35 m above Inverloch datum, and consists of isolated and depauperate clumps and clones. The seaward limit at Nolans Bluff is at
0.34 m, although as noted previously it is believed that irregular periods of prolonged submergence are probably the major factor affecting the outer margin of the sward at that site. This evidence supports the suggestion made by Hubbard (1969) that the lowest level of *Spartina* may be affected by the mechanical action of waves, which prevents the plant from taking root in the resulting mobile substrate.

Additional evidence of the importance of wave action has been provided by Morley (1973) from Bridgwater Bay, where *Spartina* grows down to levels inundated for only 4.4 hrs during normal spring tides. Morley considered that this may be explained by either restriction of light due to turbidity, or by mechanical disturbance by waves. It was noted that Hubbard (1969) had concluded that as buds developing in November (Northern Hemisphere) produce shoots for the following year, the amount of light reaching *Spartina* in Poole Harbour at that time may be critical for its survival. Morley found that the length of exposure to daylight at Bridgwater Bay during November was three times that at Poole Harbour, which indicated that light is not a limiting factor. It was concluded that the lower limit of *Spartina* at Bridgwater Bay, where the Bristol Channel is 21 km wide and subject at times to rough seas, is determined primarily by wave action.

Waves may limit the seaward spread of *Spartina* not only by creating a mobile substrate, but also by creating conditions which impede the growth of established plants. Hubbard (1969) has reported that *Spartina* at Bridgwater Bay shows a distinct change in morphology associated with a decrease in the level of the marsh, including a general diminution in height from 150 cm to only 30 cm, a decrease in the number of spikes per inflorescence from over fourteen to only two or three, and a decrease
in the diameter of flowering stems and the size of leaves. Similar
dwarfing combined with discoloring of leaves has been reported on the
east bank of the Lymington estuary by Goodman et al. (1959), and
attributed to the effect of south westerly gales. It is therefore likely
that depauperate clones at the seaward limit of Spartina at Masons Beach,
at the mouth of Bass River and along the seaward margins of sea walls at
Corner Inlet are due at least partly to the relatively strong wave action
to which they are frequently exposed.

One important environmental factor which has not been investigated
in Australian Spartina is the chemical composition of substrates, and
very little work on the relationship between nutrient supply and Spartina
growth has been reported in the literature. Ranwell (1964b) found high
values for nitrogen, phosphorus and potassium at Bridgewater Bay, reflected
in exceptionally vigorous growth. Preliminary nutrient studies by Bascand
(1968) indicated that low phosphorus levels may limit Spartina vigour in
some New Zealand localities, and that balanced ratios of nitrogen,
phosphorus and potassium are likely to be of more importance than abundance
of these elements. There is clearly a need for comparative studies of
nutrient levels in areas of differential Spartina performance.

While the above discussion has considered some of the factors
which favour or impede Spartina growth, it must be noted in conclusion
that not all sites within an estuary necessarily receive similar quantities
of seeds and plant fragments from which new plants may establish. Although
some seeds may be dispersed by birds, the direction of Spartina spread is
primarily determined by the direction of tidal currents. The alignment of
such currents in relation to sources of plant material and suitable sites
for further colonisation is important in determining rates of increase in
Spartina abundance.
The pattern of surface water circulation in Andersons Inlet has been observed in a variety of tidal conditions with the aid of floats released at hourly intervals from points on the shore. Each float was marked to show the source, time and date of release, and was of a type which had been found to offer minimum resistance to the wind. Figure 4.34 is a generalised representation of the paths followed by floats released between two successive low tides, based on boat and shoreline observations and recoveries one month after introduction.

Float paths indicate that Andersons Inlet has a roughly clockwise pattern of water circulation. Floats released from Inverloch Jetty are carried more than 6 km up the estuary on the flood tide, to be deposited along the north shore at high water, or along the inner margin of the spit during the ebb. Distances travelled by these floats are much greater than those for floats released from Point Smythe. Floats from Nolans Bluff are carried across to the opposite shoreline, while floats released along the inner margin of the spit may drift for short distances towards the head of the inlet during the flood stream, but are carried for greater distances towards the mouth of the inlet on the ebb. Floats from Cherry Tree Creek have never been retrieved more than 1 km south from their point of release, and most are trapped behind an offshore bar (Section 2.3). The features of this clockwise circulation pattern are also suggested by the pattern of surface water salinity at high tide (Figure 4.21). It would appear that the ebb stream moves from the main channel at low tide to the inner margin of the spit at high tide, as the flood stream becomes dominant along the north shore. At high tide, the inlet has ebb and flood channel systems similar to those described by Robinson (1960), Bowden (1967) and Pritchard (1967).

It therefore follows that different sites within the estuary
receive different quantities of seeds and plant fragments, regardless of the suitability of such sites for Spartina growth. Floats from Nolans Bluff are widely dispersed along the inner margin of the spit, which is consistent with the rapid spread of Spartina in this area following the introduction of S. anglica to Nolans Bluff in 1962. However, despite the frequency and strength of winds from the west and south west, which might be expected to promote the drift of water-borne Spartina material across the inlet, floats released along the inner margin of the spit have never been recovered from the opposite shoreline. For that reason, it seems likely that a factor in the relatively low abundance of Spartina along the north shore is a comparatively smaller supply of plant material.
CHAPTER FIVE

MORPHOLOGICAL RESPONSES TO SPARTINA COLONISATION

At sites in Britain and Europe where Spartina grew vigorously in the early part of this century, the spread of the grass was generally accompanied by accretion of sediment. The impact in Poole Harbour was described by Stapf (1914b):

"The result is an increased and accelerated deposition of mud over the area tenanted by the grass. The level of the mudflat becomes raised . . . the mud itself firmer . . . . On the landside of the Spartina belt, where there is only a foot of water at high tide, a growth of Aster tripolium and Obione portulacoides springs up among the grass, the first heralds of the reclamation of land that has set in."

The physiographic consequences of Spartina colonisation are now fully apparent at many overseas sites. Formerly bare intertidal flats over which the tide moved as a single sheet of water have been transformed into marshes across which the tide rises and falls along a series of intricate marsh creeks. In the terminology of Barnes and King (1961), the intertidal zones have changed from 'slob-land' to 'salting'. As rates of accretion are commonly greatest near the seaward edge of the marsh, saltings are not only higher but usually flatter than the previously unvegetated mudflats. Their surfaces are at about the level of mean high water; the outer margins frequently are clipped by wave and current action which causes recession. Saltings represent a final stage in the development of Spartina marshlands, which begun with the colonisation of slob-land by seedlings and young plants.

It has been noted previously that rates of change in Spartina
abundance have rarely been measured from the time of marsh inception. Initial morphological responses to *Spartina* establishment and spread have also been largely ignored. This chapter seeks to identify some of the changes which occur in the plan and profile of the intertidal zone during and after the earliest stages of *Spartina* colonisation.

5.1 *Spartina* growth and sedimentation

The frequent association between the spread of *Spartina* and accretion of sediment has led to the assumption that the rate of accretion in *Spartina* is normally greater than that which would have occurred at the same site in its absence. While few writers have stated explicitly that *Spartina* causes accretion, it has been generally accepted that increased marsh levels are a direct consequence of *Spartina* colonisation.

An alternative explanation for the relationship between *Spartina* growth and accretion is that *Spartina* might establish most successfully in areas of rapid sedimentation. Without an ample supply of sediment *Spartina* growth might not be vigorous; in areas where such a supply is available, *Spartina* might grow successfully but not contribute by its presence to the rate of sedimentation.

A problem in resolving the nature of the relationship between *Spartina* and sediment deposition is that there are few comparisons between rates of accretion in *Spartina* zones and rates of accretion on bare mudflats in otherwise identical environments. Although the spread of *Spartina* was reported widely in the early part of this century, few accurate records of change in marsh levels were prepared. Writers such as
Harbord (1949) and Ranwell (1964a) have since reported systematic measurements of rates of accretion in *Spartina* marshes, but not in comparison with similar measurements of rates of accretion in otherwise identical but unvegetated sites. Møller (1963a) has noted that it is easy to make incorrect assumptions about high rates of accretion as a result of an illusory appearance given by the height of the grass.

Although many early British assessments of rates of accretion were possibly exaggerated, it is reasonable to conclude that the extensive plantings of *Spartina* in Britain and Europe between 1910 and 1936 would not have been made had the grass not been at least moderately successful in promoting accretion and hence assisting with various types of coastal engineering. The scores of saltings formed in Britain since the establishment of *Spartina* provide at least circumstantial evidence that its growth has been the cause of accelerated rates of sediment deposition. However the possibility that the presence of *Spartina* is simply a consequence of accretion cannot be eliminated until evidence is provided of accretion rates at *Spartina* stations and accretion rates at unvegetated sites in otherwise similar environments.

Partial evidence of this type is available from the Danish Wadden Sea, where sections of intertidal flats have been surveyed from fixed control points since 1953 as part of a program on behalf of the Danish Wadden and Salt-Marsh Investigations (Møller 1956, 1958, 1960, 1961, 1963a, 1963b, 1964). *Spartina* is widespread in the area, growing down to 0.3 - 0.5 DNN (Dansk Normal Nul : Danish Ordnance Datum) along sheltered shorelines, and 0.6 - 0.7 DNN on intertidal flats exposed to wind and wave action (Møller 1963b).

Regular surveys have shown that *Spartina* has there been of only
minor importance as a factor affecting the elevation of the mudflats. Although at some sites accretion in *Spartina* tussocks has been at the rate of 6 cm per annum while the level of the surrounding mudflats has not changed, many surveys have shown no significant differences between rates of accretion in bare and colonised zones. Øiil (1963b) has shown that the distribution, elevation and topography of the intertidal flats are dynamic, and that the movement and deposition of sediment is primarily in response to ebb and flood currents and wave action.

The Danish research indicates that the relationship between *Spartina* growth and high rates of accretion must be investigated on a small scale. The Wadden Sea is a large estuarine system containing a range of sedimentary environments associated with a complex pattern of tidal currents and varying tidal and wave regimes. It is to be expected that rates of accretion at different sites will be determined primarily by these factors in combination and only secondarily and locally by the growth of *Spartina*. For the purpose of determining whether accretion in *Spartina* is usually greater than that which would have occurred had a particular section of mudflat remained bare, it is necessary to make comparisons on a small scale between adjacent sites where the only variable is the presence or absence of the grass. Further, such comparisons of accretion rates must be made at intervals of only two or three years, for similar and adjacent sites are likely to be similarly invaded by the grass.

The following discussion of morphological responses to the spread of *Spartina* seeks to make this type of comparison. As a preliminary to that discussion, it is worth reporting a simple experiment which suggested that sediment accretion is promoted by the physical baffle
represented by *Spartina* stems and leaves. Four artificial clones were established near Fishermans Jetty in May 1971. Each clone consisted of 1 m wooden rods of 0.6 cm diameter driven 50 cm into the mud at 1 cm intervals, and arranged to form a circle of 1 m diameter. The four clones were spaced 4 m apart on the bare mud at about mid-tide level. Accretion marker layers of 1 cm depth of crushed brick dust were laid down in each clone and in the spaces between the clones. The depth of accretion on each marker layer was measured at yearly intervals until October 1976, by which time the clones and intervening spaces were being colonised by *Spartina*. By 1976 an average of 5.2 cm depth of sediment had been deposited in the artificial clones; the average depth on the intervening spaces was 3.1 cm (Table 5.1). While rates of accretion in the artificial clones were lower than the maximum rates recorded in *Spartina* elsewhere in Andersons Inlet, they were consistently higher than rates of accretion on adjacent bare mud.

5.2 Series II quadrats: plant distribution and microtopography

Series II quadrats were established at Andersons Inlet as permanent sites for recording the growth of individual population units and accompanying changes in the morphology of the intertidal zone. Their dimensions were determined by the characteristics and extent of sections of marshland which appeared likely to change under the impact of *Spartina* spread. Such sites included broad intertidal flats, narrow shoreline littorals and the mouths of creeks, not all of which can be conveniently accommodated within quadrats of a common size. Unlike Series I quadrats, Series II quadrats were thus of varying size and shape, and although *Spartina* cover and density can be assessed from each quadrat plan they cannot be compared with those for quadrats of different dimensions.
<table>
<thead>
<tr>
<th>DATE</th>
<th>DEPTH OF SEDIMENT ON ACCRETION MARKER LAYER (CM)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CLONES 1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1.2</td>
<td>2.3</td>
</tr>
<tr>
<td>May 1971</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>October 1972</td>
<td>1.2</td>
<td>1.0</td>
<td>1.1</td>
<td>1.4</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>January 1974</td>
<td>3.0</td>
<td>2.2</td>
<td>2.5</td>
<td>3.1</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>July 1975</td>
<td>3.8</td>
<td>3.5</td>
<td>3.5</td>
<td>4.0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>October 1976</td>
<td>5.2</td>
<td>5.0</td>
<td>5.0</td>
<td>5.5</td>
<td>2.4</td>
<td>3.5</td>
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<tr>
<td>Average Depth</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>3.13 cm</td>
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<td>Rate per annum</td>
<td>0.96 cm</td>
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<td></td>
<td></td>
<td></td>
<td>0.58 cm</td>
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</table>
The location of Series II quadrats is shown in Figure 5.2. Each was marked by corner stakes identified as A, B, C and D, with A and D being the corners of the seaward margin. Vegetation was mapped primarily by ground survey. Quadrats were sub-divided into a grid of 2 m x 2 m squares, and the location, size and shape of individual population units were recorded on scaled sectional paper. Some maps also were prepared from oblique air photographs using a method given by Ranwell (1964b) for estimation of *Spartina* cover, with the distorted plans derived from the photographs being redrawn. However, while subsequent ground surveys of the same sites confirmed Ranwell's belief that cover estimates were generally accurate to within ± 5 per cent where the majority of population units were greater than 1 m (Ranwell 1964b), reconstruction of the location and shape of individual population units from the distorted plans introduced an unacceptable degree of error except where most population units were large clumps or swards. Table 5.2 gives the dimensions, survey dates and methods used for mapping plant distribution in each quadrat.

Surface microtopography was recorded using a dumpy level, with the tripod mounted on a flat wooden frame when used on very soft mud. Each survey was tied to a permanent local datum, the heights of which are also given in Table 5.2. Profiles were taken from the landward to seaward boundaries, and contour maps were prepared for all but the largest quadrat (II 7).

Within each quadrat, and at other sites, accretion marker layers of about 1 m² of crushed brick dust 1 cm thick were laid down at high, intermediate and low marsh levels. Similar marker layers, of coal dust, have been used by Ranwell (1964a) at Bridgwater Bay. The depth of
<table>
<thead>
<tr>
<th>Number</th>
<th>Location</th>
<th>Dimensions (M)</th>
<th>Survey Dates</th>
<th>Method for Mapping Plant Distribution</th>
<th>Location of Permanent Local Datum (PLD)</th>
<th>Height of PLD above Inverloch Datum (M)</th>
</tr>
</thead>
<tbody>
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<td>II 1</td>
<td>Western Split Island</td>
<td>25 x 16</td>
<td>January 1968</td>
<td>Oblique aerial photographs; ground survey</td>
<td>7.3 m from corner pole C, bearing 240°</td>
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<td></td>
<td></td>
<td></td>
<td>May 1971</td>
<td>Ground survey</td>
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<td></td>
<td></td>
<td></td>
<td>April 1973</td>
<td>Ground survey</td>
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<td></td>
<td></td>
<td></td>
<td>January 1976</td>
<td>Ground survey</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>June 1979</td>
<td>Vertical aerial photographs; ground survey</td>
<td></td>
<td></td>
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<td>II 2</td>
<td>Central Split Island</td>
<td>30 x 30</td>
<td>May 1971</td>
<td>Ground survey</td>
<td>79.2 m from corner pole A, bearing 163°</td>
<td>0.93</td>
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<td></td>
<td></td>
<td></td>
<td>April 1973</td>
<td>Ground survey</td>
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<td></td>
<td>January 1977</td>
<td>Ground survey</td>
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<td></td>
<td></td>
<td></td>
<td>August 1980</td>
<td>Ground survey</td>
<td></td>
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<tr>
<td>II 3</td>
<td>Central intertidal flats</td>
<td>183 x 183</td>
<td>January 1968</td>
<td>Oblique aerial photographs</td>
<td>83 m from corner pole B, bearing 346°</td>
<td>0.93</td>
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<td></td>
<td></td>
<td>30 x 30</td>
<td>May 1971</td>
<td>Ground survey</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>April 1973</td>
<td>Ground survey</td>
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<td>September 1977</td>
<td>Ground survey</td>
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<td></td>
<td></td>
<td></td>
<td>September 1980</td>
<td>Ground survey</td>
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<tr>
<td>II 4</td>
<td>Andersons Beach</td>
<td>21 x 18</td>
<td>August 1969</td>
<td>Ground survey</td>
<td>35 m from corner pole b, bearing 165°</td>
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<td></td>
<td></td>
<td>30 x 30</td>
<td>May 1971</td>
<td>Ground survey</td>
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<td></td>
<td></td>
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<td>April 1973</td>
<td>Ground survey</td>
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<td></td>
<td>November 1976</td>
<td>Ground survey</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>July 1979</td>
<td>Ground survey</td>
<td></td>
<td></td>
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<tr>
<td>II 5</td>
<td>Masons Beach</td>
<td>100 x 30</td>
<td>May 1971</td>
<td>Ground survey</td>
<td>Top of fence post at corner pole B</td>
<td></td>
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<td></td>
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<td>August 1980</td>
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<tr>
<td>II 6</td>
<td>Nolans Bluff</td>
<td>61 x 15</td>
<td>January 1968</td>
<td>Oblique aerial</td>
<td>9.75 m from corner pole B (1980),</td>
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<td>photographs</td>
<td>bearing 48°</td>
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<td></td>
<td></td>
<td>January 1970</td>
<td>Ground survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>April 1973</td>
<td>Ground survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>May 1977</td>
<td>Ground survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>August 1980</td>
<td>Ground survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II 7</td>
<td>Cherry Tree</td>
<td>61 x 46</td>
<td>January 1968</td>
<td>Oblique aerial</td>
<td>29.1 m from corner pole B, bearing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>photographs;</td>
<td>258°</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ground survey</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>August 1969</td>
<td>Ground survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>May 1971</td>
<td>Ground survey</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>April 1973</td>
<td>Ground survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>November 1976</td>
<td>Ground survey</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>August 1979</td>
<td>Ground survey</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
sediment was recorded at intervals by excavation of small trenches, each in an untouched section of the layer. Results correlated closely with accretion indicated by regular topographic surveys, but some marker layers were removed during phases of erosion. Letzsch and Frey (1980) have shown that a thin layer of polyester plastic embedded with fine sand is probably superior to brick dust as a marker layer as it is not subject to bioturbation by plant roots, but this technique similarly is not suited to measurement of erosion below the initial level of the surface. Accretion layers at Andersons Inlet were each marked by stakes placed at sites where they could not promote scour of the brick dust surface, but as several stakes were tampered with or removed during the survey period their exposure could not be used as a reliable measure of erosion.

As the largest quadrat is only 75 m x 65 m, identical levels within each quadrat may be regarded as receiving sediment of similar volume and calibre at similar rates and frequencies, and as having the same tide range and exposure to wave and current action. The significant variable affecting differential rates of accretion both temporally and spatially is the presence or absence of Spartina.

5.21 Quadrat II 1, Western Split Island

The quadrat was established in January 1968 on the south west shore of Western Split Island, extending from the mangrove fringe to approximately mean low water level (Plate 5.211). The tidal regime at this site is virtually identical to that at Fishermans Jetty 0.5 km to the east, where the mean spring tide range is 1.50 m. The mean neap tide range is approximately 0.97 m. The site is sheltered from strong
PLATE 5.211

Aerial oblique photograph showing site of quadrat II 1, south west shore of Western Split Island, January 1968. Young Spartina plants are barely visible.

PLATE 5.212

Low altitude vertical aerial photograph of part of quadrat II 1, July 1978. Note lower Spartina tiller density associated with shallow tributary channels. White rectangle is ground scale marker.
winds and is rarely subject to wave action: even in storm conditions at high water the waves are no greater than 0.2 m in height. However, being situated at the mouth of the strait between Western and Central Split Islands the site is affected by ebb and flood currents which maintain a channel immediately seaward of the quadrat. This channel restricts progradation of the *Spartina* marsh which has developed since 1968. The site lies in the normally mesohaline or oligohaline sections of the inlet, and experiences only rarely a water salinity greater than 24⁰/oo at high tide.

The surface of the intertidal zone consists of fine sand of 2.0 - 2.5 ø diameter. While much of this sediment is derived from the Tarwin River, the site additionally is nourished by reworked material of marine origin and aeolian sand which is eroded episodically by wave and current action at Point Smythe.

*Spartina* spread naturally to the area occupied by the quadrat in 1967. Vegetation distribution and topography were recorded by ground survey in January 1968, May 1971, April 1973, January 1976 and June 1979, as shown in Figure 5.211. *Spartina* cover and density on each survey date are given in Table 5.211.

By January 1968 the quadrat supported 42 separate *Spartina* population units, being young plants either growing singly or grouped as small tussocks. *Spartina* cover was 1.16 m², which was less than 1 per cent of the area of the quadrat. All plants lay between 0.41 m and 0.76 m above Inverloch datum. The intertidal zone formed a typical slob-land (Barnes and King 1961) characterised by tidal ebb and flow as a continuous sheet of water, although in its final stages the ebb drained to the south west along a shallow channel (Plate 5.211). Relative relief within the quadrat was 0.44 m.
FIGURE 5.211
Vegetation and topography, quadrat II 1,
Western Split Island
<table>
<thead>
<tr>
<th>Year</th>
<th>Cover (M²)</th>
<th>Cover (% Total Area)</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>1.16</td>
<td>0.29</td>
<td>42</td>
</tr>
<tr>
<td>1971</td>
<td>89.37</td>
<td>22.34</td>
<td>106</td>
</tr>
<tr>
<td>1973</td>
<td>174.59</td>
<td>43.65</td>
<td>65</td>
</tr>
<tr>
<td>1976</td>
<td>276.30</td>
<td>69.08</td>
<td>39</td>
</tr>
<tr>
<td>1979</td>
<td>349.78</td>
<td>87.45</td>
<td>1</td>
</tr>
</tbody>
</table>
By May 1971 *Spartina* density had increased to 106 population units and cover had increased to 89.37 m² (22.34 per cent). The expansion was due to enlargement of existing population units by rhizome extension and to the establishment of new plants. However, 14 population units, or 33 per cent of the 1968 population, failed to survive. These included all but one of the plants at the seaward edge of the marsh, which by 1971 had become more clearly defined.

The increase in *Spartina* cover and density was accompanied by changes in the topography of the marsh (Figure 5.211). Establishment of tussocks and clumps across the former shallow ebb channel in the southwest corner of the quadrat and astride C-D led to a redirection of ebb and flood tidal flow towards and from the lower centre part of the quadrat. The early stages of the flood and the later stages of the ebb were by 1971 confined to a broad shallow channel fed by three incipient tributaries. At the same time the general level of the marsh had been raised.

By April 1973 cover had increased to 174.59 m² (43.65 per cent). While the pattern of *Spartina* distribution was similar in broad outline to that for 1971, density had fallen to 65 population units. This was due primarily to the lateral expansion and fusion of plants mapped in 1971, to form larger population units with a single limiting outline. However, comparison of maps for 1971 and 1973 shows that 16 young plants and three small tussocks present in 1971 were not present in 1973. The close proximity of these plants to others which increased greatly in cover suggests that their apparent failure to survive might be explained by annual alternations of high and low tiller density in vigorously expanding *Spartina* clones, as reported by Caldwell (1957).
The channel first noted in 1971 had by April 1973 extended by headward erosion into a zone formerly 0.5 - 0.7 m above Inverloch datum. Approximately the first 50 per cent of the flood and the last 50 per cent of the ebb now moved as channelised flow into and from the quadrat. At the same time, sediment accretion in *Spartina* had raised the level of the surface in three places to 0.8 m above Inverloch datum, and the outer margin of the marsh had steepened.

By January 1976 *Spartina* cover was 276.3 m$^2$ (69.08 per cent). There were 18 population units, the reduction being due to enlargement and fusion. The channel had extended further into the quadrat and had become deeper and narrower, and incipient tributaries had formed in areas of locally lower elevation between large *Spartina* clumps.

By June 1979 the *Spartina* clumps and tussocks had fused to form part of a sward which extended on either side of the quadrat. *Spartina* cover was 349.78 m$^2$ (87.45 per cent). Only the channel and a narrow zone along the seaward margin of the quadrat had not been colonised; they remain unvegetated in October 1980. *Spartina* of locally lower tiller density occupied the broad shallow tributaries to the main channel, but being spaced closer than 0.5 m they were not mapped as discrete population units. Variation in tiller density coincident with tributary channels is however apparent from air photographs (Plate 5.212).

As a consequence of continued sediment accretion in *Spartina*, relative relief within the quadrat had increased to 0.62 m by June 1979. The main channel had become narrow and deeply incised due to accretion in *Spartina* on its banks (Plate 5.213). As approximately 60 per cent of tidal ebb and flood was confined to the creek and its tributaries
PLATE 5.213

Tidal channel, quadrat II 1, June 1979.

PLATE 5.214

Tidal channel, quadrat II 1, June 1979. Photograph taken from the mouth of the channel at 60 per cent flood tide; water level 0.65 m above Inverloch datum.
(Plate 5.214), the marsh was well advanced towards the 'salting' stage defined by Barnes and King (1961) as that in which the tide rises and falls along a series of channels.

Table 5.212 gives the number of Spartina population units in each survey year according to the classification set out in Table 2.12. The majority of population units in all years until 1979 were either young plants or small tussocks, although their significance as a component of Spartina cover declined after density began to fall in May 1971. The number of large tussocks began to decline from 1971 and that of clumps from 1973, each indicative of the rapid development of the sward.

The increase in Spartina cover between 1968 and 1979 is shown in Plates 5.215 and 5.216. These indicate also a substantial increase in the number and size of Avicennia marina plants. The extension of Spartina in the quadrat has been accompanied by advance of mangrove fringe.

Change in Avicennia density during the study period is shown in Figure 5.212, along with change in Spartina density and cover. Until April 1973, Avicennia numbers were fairly constant; they then increased slightly to January 1976 and thereafter very rapidly to June 1979. Table 5.213 shows total number for each year and dates of establishment. Of 131 plants mapped within the quadrat between 1968 and 1976 only 32 (24 per cent) survived until 1979, and of these 24 had established after 1973. Only 3 per cent of the 1979 population was more than 6 years old.

Avicennia in Andersons Inlet grows as a shoreline fringe 0.2 m - 0.8 m below the level of mean high water spring tide. Where Avicennia is present, Spartina has established to seaward on the lower level of the
<table>
<thead>
<tr>
<th>Year</th>
<th>Young plants</th>
<th>Small tussocks</th>
<th>Large tussocks</th>
<th>Clumps</th>
<th>Swards</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>34 (Note 1)</td>
<td>8 (Note 2)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>42</td>
</tr>
<tr>
<td>1971</td>
<td>55 (Note 3)</td>
<td>28 (Note 4)</td>
<td>19</td>
<td>4</td>
<td>-</td>
<td>106</td>
</tr>
<tr>
<td>1973</td>
<td>24 (Note 5)</td>
<td>26 (Note 6)</td>
<td>8</td>
<td>7</td>
<td>-</td>
<td>65</td>
</tr>
<tr>
<td>1976</td>
<td>8</td>
<td>23</td>
<td>5</td>
<td>3</td>
<td>-</td>
<td>39</td>
</tr>
<tr>
<td>1979</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes:
1. 11 young plants failed to survive until May 1971
2. 3 small tussocks failed to survive until May 1971
3. 16 young plants failed to survive until April 1973
4. 3 small tussocks failed to survive until April 1973
5. 3 young plants failed to survive until January 1976
6. 1 small tussock failed to survive until January 1976
PLATE S.215

Quadrat II 1, January 1968.

PLATE S.216

Quadrat II 1, June 1979.
FIGURE 5.212
Change in Spartina cover and density, and density of Avicennia, quadrat II 1, Western Split Island, January 1968 to June 1979.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 1968</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>May 1971</td>
<td>3</td>
<td>18</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>21</td>
</tr>
<tr>
<td>April 1973</td>
<td>3</td>
<td>1</td>
<td>32</td>
<td>-</td>
<td>-</td>
<td>36</td>
</tr>
<tr>
<td>January 1976</td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>61</td>
<td>-</td>
<td>69</td>
</tr>
<tr>
<td>June 1979</td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>24</td>
<td>223</td>
<td>255</td>
</tr>
</tbody>
</table>
tidal flats. *Avicennia* seeds are viviparous; to establish successfully the seedlings require a stable substrate and suitable periods and depth of tidal inundation. Both conditions are improved by the growth of *Spartina*; the grass provides a stable substrate and shelter from wave action, and its spread is accompanied by accretion which raises the level of the mudflats to that at which the length and depth of submergence are suited to *Spartina* growth.

*Avicennia* in the quadrat in January 1968 was restricted to levels higher than 0.7 m above Inverloch datum. The three plants which survived from the 20 present at that time were the largest plants, estimated to be 3-4 years old. The remainder consisted of seedlings and small plants no more than 20 cm in height.

As the surface of the marsh increased in elevation as a consequence of accretion in *Spartina*, the survival rate for young mangroves improved. No young mangroves survived the period 1968-1971; one in 18 survived 1971-1973; 5 in 32 survived 1973-1976; 24 in 61 survived 1976-1979. Given that the potential supply of seedlings from the extensive mangrove communities on Split Islands probably remained fairly constant during the period, it is evident that the protection afforded by *Spartina* allowed an increasingly higher proportion of seedlings to establish on the marsh, and that the increase in elevation of the surface provided submergence conditions under which a greater proportion of the young plants could survive. By 1979 all *Avicennia* within the quadrat lay between 0.7 m and 0.3 m below MHWST (0.5 m - 0.9 m above Inverloch datum), which is within the vertical range of mature *Avicennia* communities elsewhere in the inlet.

The rates of sediment accretion in the quadrat were among the
highest recorded in Spartina in Andersons Inlet. Small trenches were dug at sites of accretion marker layers laid down in May 1971 (Figure 5.211) on each of the subsequent survey dates. Depths of sediment and estimated annual rates of accretion are given in Table 5.214. The maximum recorded rate was 5.27 cm per annum between 1973 and 1976, on the marker layer placed in the seaward margin of Spartina. By 1979 a layer of 34.0 cm of sediment had been deposited at this site.

Sedimentation in Spartina marshes has been discussed by Ranwell (1964a) in connection with actively developing marshes as Bridgwater Bay, Somerset. Ranwell found that maximum rates of accretion occurred close to the upper or landward limit of the marsh, and showed a positive or almost linear correlation between marsh elevation and accretion. He suggested that as the marsh continues to develop the point of maximum accretion would migrate seawards. At Western Split Island however accretion has been lowest at the originally higher levels of the marsh. Accelerated rates of accretion first occurred at sites occupied by Spartina, as shown by comparison of the 1971 profile and the distribution of Spartina along side C-D (Figure 5.213). Since 1968 the point of maximum accretion has been in the lower zone of the marsh, moving gradually further seaward as the Spartina frontier has advanced and Spartina cover has increased. In this respect the marsh resembles the Dovey marshes where Richards (1934) found maximum accretion rates towards the seaward limits, a fact he attributed to increasing density of vegetation. At Cherry Tree Creek (Section 5.27), higher rates of accretion in the middle and lower reaches of the marsh have been sufficient to cause the higher levels to develop slopes to landward, thereby reversing the normal pattern of drainage which existed before Spartina establishment.

As a consequence of high rates of accretion near the seaward
<table>
<thead>
<tr>
<th></th>
<th>1. HIGH LEVEL</th>
<th>2. INTERMEDIATE LEVEL</th>
<th>3. LOW LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth</td>
<td>Rate P.A.</td>
<td>Depth</td>
</tr>
<tr>
<td>May 1971</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>April 1973</td>
<td>2.0 cm</td>
<td>1.0 cm</td>
<td>4.5 cm</td>
</tr>
<tr>
<td>January 1976</td>
<td>5.5 cm</td>
<td>1.27 cm</td>
<td>8.5 cm</td>
</tr>
<tr>
<td>June 1979</td>
<td>8.0 cm</td>
<td>0.73 cm</td>
<td>18.5 cm</td>
</tr>
</tbody>
</table>
PLATE 5.217

Outer margin of *Spartina* in quadrat II 1, June 1979.
Note undercutting of *Spartina* leading to cliff formation.
margin of the marsh, the angle of slope along its outer edge has been steepened. In 1968 the slope was about 6°; in 1979 the average slope from MLWST to the seaward crest of the developing terrace was 13.5°. The steepening has been accompanied by undercutting and minor slumping (Plate 5.217), which were first evident in 1978. However although marsh progradation has ceased there has been no general frontal recession.

5.22 Quadrat II 2, Central Split Island

In several respects the site of this quadrat is similar to that of quadrat II 1. Being only 400 m apart, the two quadrats have virtually the same tide and salinity ranges. They also have similar south easterly aspects, and are sheltered from frequent strong wave action. Further, both quadrats were established in a zone of juvenile mangroves along the outer edge of the main Avicennia fringe.

The site of quadrat II 2 was selected because it combined these similarities with two principal but related differences. First, the site was at the landward limit of a broad intertidal zone above mean water level. In contrast, the Western Split Island site traversed a much narrower littoral zone down to approximately the level of mean low water. Quadrat II 2 therefore permitted examination of the morphological response to Spartina spread in an area unaffected by the presence of a near-shore channel. Second, the site was almost uniformly flat, and lacked any gradient similar to that along the seaward margin of quadrat II 1. Relative relief when the 900 m² quadrat was pegged out in 1971 was 0.21 m (0.84 m - 0.63 m above Inverloch datum); in the same year relative relief in quadrat II 1 (400 m²) was 0.57 m (0.78 - 0.21 m). Quadrat II 2 was therefore subject to only small variations in length
and depth of tidal submergence of *Spartina*, although there was sufficient
micro-relief for standing water to be retained in small pools at low tide.
At Western Split Island however, relative relief was almost 40 per cent
of the mean spring tide range, and the slope was sufficient to ensure
that the mudflat was completely drained.

Individual *Spartina* plants and small tussocks were first
observed at the site later occupied by quadrat II 2 in 1966. At the
time of the initial survey in May 1971, the *Spartina* colony along the
south shore of Central Split Island was well established. *Spartina*
covered almost 30 per cent of the quadrat area, the dominant population
units being tussocks and small clumps. Figure 5.22 shows change in
vegetation and topography during the study period, and Table 5.221
gives *Spartina* abundance on each survey date.

Throughout the period of survey, but particularly up to 1975,
there was a pronounced variation in *Spartina* abundance in areas mapped
as single population units. This could not be recorded at the scale of
Figure 5.22, which shows all plants closer than 0.5 m as part of the
same population unit. However, the variation is apparent in Plate 5.221,
which shows closely spaced but discrete tussocks and clumps surrounded
by standing water or separated by soft wet mud. Areas shaded as large
population units in May 1971 and April 1973 (Figure 5.22) were zones in
which such tussocks were closer than 0.5 m; they do not represent
continuous and uniform stands of *Spartina*.

The area covered by *Spartina*, so defined, increased to 54.14
per cent between 1971 and 1973, and density decreased from 62 to 41
population units. The greater abundance of *Spartina* is apparent in
Opposite

FIGURE 5.22

Vegetation and topography, quadrat II 2,
Central Split Island
TABLE 5.221
SPAR TINA ABUNDANCE, QUADRAT II 2 CENTRAL SPLIT ISLAND

<table>
<thead>
<tr>
<th></th>
<th>Cover</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M^2$</td>
<td>% Total Area</td>
</tr>
<tr>
<td>May 1971</td>
<td>264.85</td>
<td>29.43</td>
</tr>
<tr>
<td>April 1973</td>
<td>487.29</td>
<td>54.14</td>
</tr>
<tr>
<td>January 1977</td>
<td>757.29</td>
<td>84.14</td>
</tr>
<tr>
<td>August 1980</td>
<td>672.43</td>
<td>74.71</td>
</tr>
</tbody>
</table>
PLATE 5.221

Clumps and tussocks in quadrat II 2, April 1973.

PLATE 5.222

Accretion mounds formed around Spartina tussocks, quadrat II 2, May 1975.
Figure 5.22. However, close examination of the outlines of the major population units reveals local failure of some tussocks, leading to redefinition of the outlines of zones in which such population units were less than 0.5 m apart. For example, *Spartina* at the intersection of perpendiculars to 10 m on side A-B and 27 m on side A-D did not persist between the two survey years. In every case, failure was coincident with pools of standing water which had developed since 1971.

The growth form of tussocks in quadrat II 2 differed noticeably in the early 1970s from that at similar sites which lacked only its excessive wetness of substrate. Outward growth as a result of rhizome extension was restricted to the immediate periphery of each plant, with new tillers arising only 1-2 cm from the parent. At other sites, new tillers up to 10 cm from the parent plant were common. Outward growth was steady but slow, leading to prolonged expansion of tussocks prior to fusion. On the other hand, stem density in each tussock was much higher than elsewhere. The stems were stout, closely-spaced and not separated by patches of bare ground; they formed dense, erect and brush-like masses of *Spartina* quite different from its commonly reed-like appearance at other sites. Growth was vigorous, but evidently directed into tiller production rather than rhizome extension.

It is believed that microtopographic change in the quadrat during the survey period was determined primarily by this habit of growth. Each tussock acted as a locus for sediment deposition, and formed about its base a low platform of fine sand and silt trapped by the baffle of leaves and stems (Plate 5.222). These features were evident as microtopographic highs as early as 1973 (Figure 5.22), each being coincident with tussocks which had been established before 1971. Their
upward growth continued to 1980, and further similar features developed. Many mounds were too low to be recorded at a 0.1 m contour interval, but others by 1980 were 20-30 cm above the elevation of the marsh in 1971.

Accretion mounds in **Spartina** not only grew upwards, but also enlarged laterally. Field observations have shown such growth to be episodic. Bare mud around the perimeter of tussocks has been periodically cliffed, suggesting that local ebb currents after exceptionally high tides have been sufficient to promote scour. When stabilised by tillers as a result of outward rhizome growth, cliffing of the margins has not occurred. Occasional cliffing indicates that in addition to acting as a locus for deposition at the time of sediment supply, **Spartina** also acts to retain sediment during phases of removal.

Despite the formation of accretion mounds and the consequent increase in relative relief, rates of deposition in quadrat II 2 were not high in relation to quadrat II 1 or several other sites discussed below. Accretion as measured by marker layers is given in Table 5.222. The greatest depth of sediment deposited was on layer 3, which subsequently became the site of a microtopographic high. Although the mean annual rate of deposition from 1971 to 1973 was 4.4 cm, the average annual rate over the total period was only 2.6 cm. This is much less than at the low level marker layer in quadrat II 1, where the mean annual rate over the same period was 4.3 cm. It is evident that the supply of sediment near the landward margin of the broad intertidal flat is less than that along the seaward margin of the marsh in an otherwise identical environment.

By 1977 **Spartina** across most of the quadrat had encroached upon the larger bare areas between tussocks, and had formed an almost continuous
TABLE 5.222

ACCRETION AS MEASURED BY MARKER LAYERS, QUADRAT II 2 CENTRAL SPLIT ISLAND

<table>
<thead>
<tr>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>Rate p.a.</td>
<td>Depth</td>
</tr>
<tr>
<td>May 1971</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>April 1973</td>
<td>4.0 cm</td>
<td>2.0 cm</td>
</tr>
<tr>
<td>January 1977</td>
<td>7.5 cm</td>
<td>4.5 cm</td>
</tr>
<tr>
<td>August 1980</td>
<td>11.0 cm</td>
<td>8.5 cm</td>
</tr>
<tr>
<td></td>
<td>1.0 cm</td>
<td>1.1 cm</td>
</tr>
</tbody>
</table>

All marker layers were sited in *Spartina* from May 1971
sward (Figure 5.22). Although few remaining unvegetated areas were large enough to be mapped, there were many zones of low tiller density associated with small pools which had developed between accretion mounds. The major depression was adjacent to side AD; being waterlogged for long periods it supported only a few depauperate clones and clumps.

Between January 1977 and August 1980, Spartina cover decreased from 84.1 per cent to 74.7 per cent, and density increased from 12 to 13 population units. The latter resulted from the break-down of the sward into smaller components. Recession was due to pan die-back (Goodman et al. 1959), which is associated with excessive wetness of substrate and characterised by failure of the rhizomes and production of fewer and weaker tillers. Die-back was widespread below the level of 0.75 m above Inverloch datum. The seaward part of the quadrat was by 1980 almost permanently waterlogged, but broken into pools by accretion mounds higher than 0.8 m on which Spartina growth was profuse. Excessive wetness had been promoted not only by differential rates of accretion within the quadrat, but by accretion further seaward beyond side A-D.

As in quadrat II 1, the spread of Spartina at Central Split Island was accompanied by the growth of mangroves. It is believed that their spread at Western Split Island was due to conditions created by Spartina, which stabilised the intertidal mudflat, raised the level of the surface to a point at which Avicennia could withstand regular tidal inundation, and provided shelter from wave action for seedlings. It is however unlikely that this is also the case at Central Split Island.

Of the 31 mangrove plants present in quadrat II 2 in 1971 (Table 5.223), about half were at least 3-4 years old. They were growing
<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>May 1971</td>
<td>31</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>31</td>
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<td>April 1973</td>
<td>21</td>
<td>64</td>
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<td>-</td>
<td>85</td>
</tr>
<tr>
<td>January 1977</td>
<td>21</td>
<td>44</td>
<td>22</td>
<td>-</td>
<td>87</td>
</tr>
<tr>
<td>August 1980</td>
<td>21</td>
<td>40</td>
<td>19</td>
<td>14</td>
<td>94</td>
</tr>
</tbody>
</table>
at levels on which Avicennia is the pioneer plant elsewhere in Andersons Inlet. Although many were growing in or near Spartina, none were on sites which had been measurably affected by accelerated accretion. The population increased to 85 in 1973, but the rate of establishment then slowed. By 1980 only 94 plants were present in an area of 900 m², which contrasts with the 255 plants in quadrat II 1 (400 m²) in 1979, most of which had established since 1976 (Table 5.213).

As both quadrats are bounded by extensive mangrove fringes along their landward margins, it is expected that each receives an adequate supply of seeds to ensure continued mangrove establishment. However, very few mangroves have established in quadrat II 2 since 1973, and each is on a microtopographic high beyond the level of prolonged submersion. While many older mangroves survive in such conditions at this site, it is evident that excessively wet substrates and standing water are not conducive to seedling growth.

5.23 Quadrat II 3, Central Split Island mudflat

Plate 5.231 shows the site of quadrat II 3 in 1968, before Spartina growth on the mudflat south of Central Split Island had become extensive. In order to report the nature of changes in Spartina distribution and surface morphology which occurred in the quadrat up to 1980, it is necessary first to describe the sedimentological and drainage characteristics of the surrounding intertidal zone.

The central intertidal flats to the immediate south, east and west of Split Islands are among those areas nourished by a supply of fine sand delivered by flood currents from the lower part of the inlet.
Central intertidal flats, Andersons Inlet, 1968. Numbers show sites of quadrats II 1, II 2, II 3. The distance from Fishermans Jetty to quadrat II 3 is 900 m.
This material is partly of marine origin, and partly aeolian material derived from erosion at Point Smythe. This erosion is episodic: for example, the beach, foredune and part of the second dune ridge at Point Smythe were eroded between 1970 and 1975, but since that time progradation at the mouth of the inlet has narrowed the entrance by about 500 m at low tide. Successive periods of cut and fill have occurred at Point Smythe at least since the turn of the century (Wyeth 1969 pers. comm.). Much of the eroded material is carried into Andersons Inlet, where it is reworked by wave and current action.

The intertidal flats to the south of Split Islands form a small tidal delta built at the southern end of the strait between Western and Central Split Islands. The strait has a depth of over 5 m, and currents of up to 2 m/sec have been recorded on the flood during maximum spring tides. Sediment borne by the tide is deposited on intertidal flats where the strait broadens to the south and divides into two shallower channels (Plate 5.231). The flats south of Central Split Island and the area between the two channels are the principal sites nourished by this supply, although some material is also deposited to the south and west of Western Split Island. Fine sand of marine and aeolian origin mixes with terrigenous sand, silts and clays derived primarily from the Tarwin River, to form a soft, wet mud.

To a lesser degree a small tidal delta has also developed at the northern end of the strait, where the channel is only a few centimetres deep at low tide. This is formed from sediment carried by ebb currents, which have generally lower velocities than those recorded on the flood. Similar minor features have developed at both ends of the narrow channel between Central and Eastern Split Island.
Sediment from the lower part of the inlet is also deposited to the east and west of Split Islands. To the east of Eastern Split Island, material deposited by flood currents forms a large lobe of fine sand extending towards the head of the inlet. In the west, sediment carried along the Fishermans Jetty channel is deposited to the west and south of Western Split Island, where it mixes with material supplied through the strait.

The lighter-coloured marine and aeolian sands are readily distinguishable from material of largely terrigenous origin, as shown in Plate 5.231. It is noticeable that lobes of sand to the west of Western Split Island and to the south of Central Split Island extend towards the head of the inlet but do not meet in the lee of the two islands. Between them is a zone of very soft fine silt about 0.2 m - 0.3 m below the general level of the sandier mudflats, which has been colonised by *Spartina* only along its western and northern margins.

Quadrat II 3 is located on the mudflat to the south of Central Split Island, in the zone nourished by fine sand. At the start of the survey period, the level of the intertidal flats at the southern tip of the island had been raised by sediment accretion to a level at which it could be colonised by *Salicornia quinqueflora* and *Juncus maritimus* (Plate 5.232a). The configuration of the southern end of Central Split Island (Plate 5.231) suggests that gradual progradation under native pioneer species was a long-term characteristic of this site. The high level zone was however limited to the periphery of the island; the remainder of the mudflat was colonised only by sparsely-scattered *Spartina* tussocks and young plants, growing at levels at which native species could not be supported (Plate 5.233a).
PLATE 5.232a

Salicornia quinqueflora and Juncus maritimus at the southern tip of Central Split Island, August 1967. Spartina was by then sparsely distributed over the entire mudflat, at this level and lower levels.

PLATE 5.232b

Photograph taken from same position as the above, September 1977. Note extensive Spartina sward and young mangroves in the distance. Juncus maritimus has become locally more abundant.
PLATE 5.233a  Spartina at southern end of Central Split Island mudflat, January 1968.

PLATE 5.233b  Photograph taken from same position as the above, July 1978. Note young mangroves (arrowed), and steepening of channel banks.
The spread of Spartina on the intertidal flat had a significant impact on the nature of tidal flow in the area, which affected topography and vegetation in quadrat II 3. Before Spartina became extensive, there were no tidal channels (Plates 5.231, 5.234a). In east-west profile the mudflat was gently convex, with a local tidal divide running approximately north-south from the southern end of the island. Flood water entered the site from the eastern distributary channel at the south of the strait separating the two major islands, and also from the west from the low-lying area of fine silts which filled from channels in the south. The ebb drained as a single sheet of water on either side of the divide. The area of fine silts was drained by a dendritic channel network which entered the Fishermans Jetty channel to the south of the Central Split Island mudflat (Plate 5.231), and by other channels to the east. However it remained saturated throughout low tide.

Although tidal channels were absent, the surface of the mudflat had sufficient micro-relief for standing water to be retained in pools during low tide. These are shown in Plate 5.235 and are also evident in Plate 5.236. Many of them were linear depressions about 2-3 cm deep aligned approximately east-west. Their origin is uncertain: they may have been scoured by exceptionally strong ebb currents, or perhaps represented phases of growth of the mudflat arising from episodic supply of sediment and shaping by waves. The latter mechanism is suggested by their rough concentricity with the southern end of Central Split Island. While initial Spartina colonisation was generally on higher land between the depressions, most low-lying sites were quickly occupied during the stage of sward development.
PLATE 5.234a

Aerial oblique photograph of Central Split Island mudflat, January 1968.

PLATE 5.234b

Aerial oblique photograph of Central Split Island mudflat, February 1977. Note extensive Spartina sward and linear development of tidal creeks. Numbers indicate sites of quadrats II 2 and II 3.
PLATE 5.235

Linear pattern of depressions and low ridges, Central Split Island mudflat, April 1973.
Plate 5.236

Quadrat II 3, January 1968. The quadrat was then 183 m x 183 m (600 ft x 600 ft). Note the widely scattered Spartina plants and low Spartina cover. Dark areas are surface pools. The channel drains the area of fine silts to the east (top of photograph), and marks the boundary of the Central Split Island mudflat. Pole B is the point of origin of the 30 m x 30 m quadrat established in May 1971.
The spread of *Spartina* across the mudflat was accompanied by high rates of accretion. Although no natural marker layers exist to compare deposition before and after *Spartina* colonisation, it is believed that rates of accretion were far greater following the spread of *Spartina* than rates which might have occurred in its absence. By 1977 the extreme southern edge of the mudflat, about 300 m from the island, had reached a level at which it could be colonised by *Avicennia marina* (Plate 5.233b). A depth of 28 cm of sediment was deposited on a marker layer at this site between 1968 and 1979, which is an average accretion rate of about 2.5 cm per year. Had such rates been common before the introduction of *Spartina*, it is evident that marsh progradation along the southern margin of the island would have been rapid. While there is no reason to expect that the supply of sediment to the site was greater in the period 1967 - 1980 than at any previous time, the presence of *Spartina* allowed an increased proportion of available material to be fixed in situ, instead of being dispersed and deposited elsewhere in the estuary or out to sea.

Although an extensive sward developed over most of the mudflat by 1973, there were several linear depressions which were not colonised by *Spartina*. These were the larger depressions which contained standing water for long periods. *Spartina* established on intervening ridges, but failed to spread by either rhizome extension or growth of new plants to almost permanently waterlogged sites. As accretion in *Spartina* was rapid, these linear depressions became more pronounced, and were quickly transformed into broad and shallow tidal creeks (Plate 5.234b). By 1975 the creeks were carrying the lower 50 per cent of the tide into and from the marsh.
Spartina distribution and topography in quadrat II 3 have been affected by such a channel. The quadrat initially was pegged out as a square 183 m (600 ft) on a side (Plate 5.236), and it was intended that vegetation would be mapped from the air. However subsequent ground survey of part of the quadrat indicated that cover estimates of small population units from oblique air photographs were grossly in error. For that reason, the size was reduced to a 30 m x 30 m quadrat with its point of origin at pole B (1968), to be mapped from the ground. Subsequent surveys were made in May 1971, April 1973, September 1977 and September 1980. It was not until 1975 that it was evident that the quadrat would be affected by a tidal channel.

Quadrat II 3 is 900 m from Fishermans Jetty, where the mean spring tide range is 1.50 m and water salinity is rarely greater than 14°/oo. It may therefore be regarded as having the same tide and salinity regimes as quadrats II 1 and II 2. The substrate is slightly coarser, although there is sufficient fine material of terrigenous origin to form soft wet mud. Unlike quadrats II 1 and II 2 however, the quadrat is not in the lee of a shoreline mangrove fringe, and is exposed to wave action at high tide. Although protected by the spit from the extreme wave conditions which occur along the north east shore of the inlet under the influence of west and south west winds, waves of up to 30 cm height have commonly been observed at this site.

Figure 5.23 shows Spartina distribution and topography in quadrat II 3 on each survey date. Because of the initially low relative relief of the site, contours for 1971, 1973 and 1977 are given at a 0.05 m interval. Spartina abundance data are given in Table 5.231.

In 1971 the surface of the quadrat was virtually flat. Over
Opposite

FIGURE 5.23

Vegetation and topography, quadrat II 3, Central Split Island mudflat
**TABLE 5.231**

**SPARTINA ABUNDANCE, QUADRAT II 3, CENTRAL SPLIT ISLAND MUDFLAT**

<table>
<thead>
<tr>
<th></th>
<th>Cover</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M^2$</td>
<td>% Total Area</td>
</tr>
<tr>
<td>May 1971</td>
<td>341.31</td>
<td>37.92</td>
</tr>
<tr>
<td>April 1973</td>
<td>526.27</td>
<td>58.47</td>
</tr>
<tr>
<td>September 1977</td>
<td>539.62</td>
<td>59.96</td>
</tr>
<tr>
<td>September 1980</td>
<td>663.56</td>
<td>73.73</td>
</tr>
</tbody>
</table>
an area of 900 m², relative relief was little more than 20 cm. A gentle rise near pole C and a depression near the centre of the quadrat conformed to the tendency for micro-relief to be arranged in a roughly east-west linear pattern, as described previously. *Spartina* was distributed in small tussocks and clumps across the entire quadrat, but with several areas where plants were spaced closer than 0.5 m apart and were therefore grouped as single population units. These also tended to be in a linear arrangement.

By 1973 *Spartina* cover had increased from 37.9 per cent to 58.5 per cent, although many small tussocks and clumps had failed to persist. Failure was coincident with minor surface depressions, but recession did not occur in all waterlogged sites. Plant density had increased within the outlines of population units as a result of rhizome extension. The linear arrangement of population units was still apparent, although their distribution had changed. Microtopography also had altered: two areas above 0.85 m were coincident with *Spartina*, but a third, centred on side A-B, was a zone in which *Spartina* growth was sparse.

Between 1973 and 1980 *Spartina* cover rose to 73.7 per cent and density declined from 58 to 9 population units. However, as in quadrat II 2, tiller density within population units was highly variable with many unvegetated areas too small to be mapped (Plate 5.237). Prolonged waterlogging was accompanied by further recession, although this did not offset the continued increase in cover through rhizome extension elsewhere. By 1980 the site resembled a "panne marsh" (Redfield 1972), characterized by vigorous growth on microtopographic highs and *Spartina* die-back in localized areas of standing water resulting from unequal deposition of sediment over the surface.
PLATE 5.237 Quadrat II 3, September 1980, showing poles D (left) and A (right). The photograph was taken at low tide. Note areas of low tiller density associated with waterlogged conditions. The tidal creek drains the quadrat to the left of pole A.
A feature which distinguishes this site from the two previous quadrats is that by 1977 parts of the surface had begun to erode. A broad tidal creek which had formed in minor depressions beyond pole A (Plate 5.238) had extended back into the quadrat, and had reduced the level of a zone in its north east corner (near pole A) by about 5 cm. Scouring in low-lying areas extended through to 1980, while sediments continued to accrete in *Spartina* on low ridges and accretion mounds. Of the four accretion marker layers put down in 1971, two have been washed out as a result of this process (Table 5.232). The other two became sites of an accretion ridge, and have been covered by deposits of 14.5 cm and 12.0 cm of sediment. At the time of the most recent survey, the general level of the surface at the base of microtopographic highs had been reduced to a few centimetres below 0.5 m above Inverloch datum, and was continually waterlogged throughout low tide.

The accretion mounds and ridges are now bounded by low but steep cliffs (Plate 5.239) which result from erosion at the base combined with steady accretion on the surface. It is expected that these microtopographic features will be further reduced in area as a result of pan die-back around the margins, continued erosion, and the inability of rhizomes to produce new tillers in permanently saturated sites. It should be noted that panne marsh is not characteristic of the entire intertidal mudflat to the south of Central Split Island, which can be verified by comparison of Plate 5.238 with Plates 5.232b and 5.233b. However, while rapid accretion is expected to continue in most of this area, it is estimated that about 25 per cent of the sward is affected by excessive wetness as a consequence of the development of tidal creeks.
PLATE 5.238


PLATE 5.239

Cliffing at the edge of accretion ridge, quadrat II 3, September 1980.
TABLE 5.232
ACCRETION AS MEASURED BY MARKER LAYERS, QUADRAT II 3 CENTRAL SPLIT ISLAND MUDFLAT

<table>
<thead>
<tr>
<th></th>
<th>LAYER 1</th>
<th></th>
<th>LAYER 2</th>
<th></th>
<th>LAYER 3</th>
<th></th>
<th>LAYER 4</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Depth</td>
<td>Rate</td>
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<td>Rate</td>
<td>Depth</td>
<td>Rate</td>
<td>Depth</td>
<td>Rate</td>
</tr>
<tr>
<td>May 1971</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0*</td>
<td>-</td>
</tr>
<tr>
<td>April 1973</td>
<td>8.0 cm*</td>
<td>4.2 cm</td>
<td>1.0 cm*</td>
<td>0.5 cm</td>
<td>4.0 cm</td>
<td>2.1 cm</td>
<td>1.0 cm</td>
<td>0.5 cm</td>
</tr>
<tr>
<td>September 1977</td>
<td>9.0 cm*</td>
<td>0.2 cm</td>
<td>5.0 cm*</td>
<td>1.1 cm</td>
<td>5.0 cm</td>
<td>1.1 cm</td>
<td>Washed out*</td>
<td>-</td>
</tr>
<tr>
<td>September 1980</td>
<td>14.5 cm*</td>
<td>2.2 cm</td>
<td>12.0 cm*</td>
<td>2.8 cm</td>
<td>Washed out*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Marker layer site in *Spartina*
5.24 Quadrat II 4, Andersons Beach

Andersons Beach is a broad intertidal zone averaging 50 m in width (Plate 5.241). Its landward margin is flanked by a low cliff in alluvium, which has receded by 5 - 10 m during the study period. The cliff bounds a narrow saltmarsh in which the dominants are Stipa teretifolia and Juncus maritimus; this grades through a discontinuous zone of Melaleuca ericifolia into sandy terrain formed by stabilised blow-out dunes on which the dominant species are Banksia integrifolia and Eucalyptus viminalis. At several places near the eastern end of the site these dunes have advanced across the saltmarsh to the shore of the inlet where they are now undercut as a consequence of shoreline recession. The eastern and western extremities of the site are marked by advancing shorelines developing under Avicennia marina, which is absent from Andersons Beach.

Andersons Beach is more exposed to wave action than the sites of quadrats II 1, II 2 and II 3. Although protected by the spit from strong and frequent west and south west winds, it is exposed to winds from the north west and north east quarters which generate waves across fetches of 2-3 km. The substrate is much coarser than at more sheltered sites, and consists of firm medium sands of 1.5 ø - 2.0 ø diameter. Mean spring and mean neap tide ranges are 1.80 m and 1.35 m. Water salinity at high tide is in the euhaline or high polyhaline ranges, depending on fresh water discharge into the inlet. At low water, salinity is rarely less than 10⁰/oo.

A single young Spartina plant was first observed at Andersons Beach in February 1968. By August 1969 young plants and tussocks were
PLATE 5.241

Andersons Beach, July 1978, showing eroding shoreline.

PLATE 5.242

Quadrat II 4, Andersons Beach, August 1969. 
Young *Spartina* plants and tussocks are less than two years old.
scattered sparsely along a section approximately 2 km in length. Of ten small plants removed for inspection in July 1970, four retained fragments of a parent rhizome and the remainder were apparently seedlings. It is possible, but unlikely given the youth of the plants, that some of the remainder were plants from which signs of a parent rhizome had disappeared.

Vegetation and topography were first recorded in quadrat II 4 in August 1969 (Plate 5.242). At that time the dimensions of the quadrat were 21.3 m x 18.28 m (70 ft x 60 ft). The quadrat subsequently was increased in size to 30 m x 30 m. The enlarged quadrat was surveyed in May 1971 (Plate 5.243), April 1973, November 1976 and July 1979 (Plate 5.244). The vegetation and contour surveys are shown in Figure 5.241. *Spartina* abundance in each year is given in Table 5.241.

Like quadrat II 1 at Western Split Island, the quadrat at Andersons Beach was populated by only a few small plants and tussocks at the time of initial survey. However, the sites differ in the subsequent pattern of *Spartina* development. While density increased greatly in both quadrats in the early years of the study period, and subsequently declined, a sward has not developed at Andersons Beach. As late as 1976 tussocks and young plants were the dominant population units, although by 1979 four clumps accounted for the greater part of *Spartina* cover.

Compared with the three quadrats discussed so far, *Spartina* cover in quadrat II 4 has been low throughout the study period. Cover in the enlarged 30 m x 30 m quadrat changed little between 1971 and 1976, although there was a pronounced increase in cover by 1979. Even
PLATE 5.243  Quadrat II 4, May 1971. Tillers from previous year's growth have not yet been shed as *Spartina* wrack.

PLATE 5.244  Quadrat II 4, July 1979. Note surficial lobes of sand, and pools. *Spartina* is in over-wintering condition; tillers have been shed.
TABLE 5.241

SPARTINA ABUNDANCE, QUADRAT II 4 ANDERSONS BEACH

<table>
<thead>
<tr>
<th>Years</th>
<th>Plants</th>
<th>Small tussocks</th>
<th>Large tussocks</th>
<th>Clumps</th>
<th>Swards</th>
<th>TOTAL</th>
<th>$m^2$</th>
<th>% TOTAL AREA</th>
<th>Cover failing to persist until next survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>2</td>
<td>17</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>24</td>
<td>4.12</td>
<td>1.07</td>
<td>4.04</td>
</tr>
<tr>
<td>1971</td>
<td>30</td>
<td>62</td>
<td>19</td>
<td>-</td>
<td>-</td>
<td>111</td>
<td>36.38</td>
<td>4.04</td>
<td>25.0</td>
</tr>
<tr>
<td>1973</td>
<td>15</td>
<td>22</td>
<td>14</td>
<td>3</td>
<td>54</td>
<td>49.56</td>
<td>5.51</td>
<td>32.32</td>
<td>65.2</td>
</tr>
<tr>
<td>1976</td>
<td>5</td>
<td>17</td>
<td>14</td>
<td>6</td>
<td>42</td>
<td>62.72</td>
<td>6.97</td>
<td>34.48</td>
<td>54.9</td>
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<tr>
<td>1979</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>13</td>
<td>152.24</td>
<td>16.92</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Quadrat 21.3 m x 18.28 m (70 ft x 60 ft).
in that year however *Spartina* occupied only about 17 per cent of the quadrant area.

A further difference between quadrant II 4 and the previous three quadrats is that the distribution of *Spartina* at Andersons Beach changed significantly between 1969 and 1979, as indicated in Figure 5.241. This contrasts, for example, with the development of *Spartina* in quadrant II 1, which as early as 1973 assumed in plan the rough outline of the eventual sward.

Figure 5.242 shows for each pair of survey years those areas of *Spartina* which were present in the first year but not in the second, derived from comparisons of vegetation maps for the five survey dates. The area of *Spartina* which failed to persist between survey dates is given in Table 5.241. Almost all *Spartina* present in the small 1969 quadrat had gone by 1971, the only survivors being two small tussocks which contracted in size. By 1973, 68.7 per cent of *Spartina* present in 1971 had failed. The rate of failure subsequently declined but remained high; 54.9 per cent of *Spartina* present in November 1976 had failed by July 1979.

Temporary minor contractions in the size of *Spartina* population units are to be expected given the phasic pattern of growth described by Caldwell (1957), which is characterised by episodic degeneration of zones of high stem density. As this process affects the outer concentric zone of each expanding tussock as well as zones closer to the centre, population units may periodically appear to be receding along their outer margins. However this is not only temporary but also relatively insignificant as a factor in reduction of *Spartina*
FIGURE 5.242

Spartina loss between pairs of survey years, quadrat II 4, Andersons Beach.
cover, for the width of zones of high and low stem density in Victorian *Spartina* is rarely more than 10 - 15 cm. Rhizomes obtained from exhumed clones at Andersons Inlet have a maximum length of 15 cm and are rarely more than 10 cm. Further, while phasic growth may reduce the size of clones it does not affect their shape, and is therefore unlikely to account for the non-concentric areas of *Spartina* loss shown in Figure 5.242.

It is believed that changes in the shape and size of *Spartina* population units at Andersons Beach are not explained by phasic growth within clones, but by local factors which have prevented the growth of clones in a concentric pattern. Asymmetrical growth and contraction in size have occurred as a response to changes in the morphology of the intertidal zone.

The sandy substrate at Andersons Beach is highly mobile, and throughout the study period has been characterised by alternating periods of erosion and deposition. Unlike the site of quadrat II 1, there has been no sequential development from slob-land to salting arising from continued deposition of sediments across the marsh. Accretion has been episodic, localised and generally temporary. In plan (Figure 5.241) and in profile (Figure 5.243) surface microtopography has fluctuated about a mean condition. Although the 1979 survey shows substantial deposition since 1976 and a steepening of the outer edge of the intertidal zone, field observations between survey dates have confirmed this to be a temporary and recurring feature which is not indicative of any long-term morphological response to *Spartina* growth.

A principal factor in microtopographic variation over the
FIGURE 5.243 Cross-sectional profiles along side B-A, quadrat II 4, Andersons Beach
past ten years has been the deposition of lobes of sand on the intertidal zone and their gradual movement from west to east (Plate 5.244). This is believed to be related to erosion at Point Smythe between 1970 and 1975, as described in Section 5.23. The eroded sand was carried into the inlet, and was presumably supplemented by an increased volume of marine sand accompanying enlargement of the inlet entrance. Reworked by waves, this material has been deposited during periods of constructive wave action as beaches and cheniers along the inner margin of the spit in the lower part of the estuary, and on the north shore. As Point Smythe has been prograding since 1976, the supply of sediment from this source is now limited.

The deposition of sand on Andersons Beach has been the most important factor affecting change in _Spartina_ distribution. The apparent disappearance of _Spartina_ clones, as indicated by the absence of formerly-existing tillers, is a consequence of sediment being deposited at a rate faster than that at which growth can occur. _Spartina_ has been suppressed by advancing lobes of sand, particularly during low-growth conditions in winter and early spring when only the stumps of previous tillers protrude through the surface. The former presence of _Spartina_ is confirmed by _Spartina_ remains in trenches dug in bare sand.

Increasing micro-relief accompanying unequal distribution of sand has led to the formation of pools which contain standing water throughout low tide (Plate 5.244). These have inhibited _Spartina_ advance and locally promoted die-back. Rhizomes growing outwards from healthy clones have produced new tillers in raised sites subject to regular immersion and exposure, but not in adjacent semi-permanent pools. As a consequence, the growth of population units has been asymmetrical.
### TABLE 5.242

ACCRETION AS MEASURED BY MARKER LAYERS, QUADRAT II 4 ANDERSONS BEACH

<table>
<thead>
<tr>
<th></th>
<th>HIGH LEVEL (Outside quadrat)</th>
<th>INTERMEDIATE LEVEL</th>
<th>LOW LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 1971</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>April 1973</td>
<td>10.0 cm</td>
<td>5.2 cm</td>
<td>4.0 cm</td>
</tr>
<tr>
<td>November 1976</td>
<td>15.0 cm</td>
<td>* 1.4 cm</td>
<td>10.5 cm</td>
</tr>
<tr>
<td>July 1979</td>
<td>24.5 cm</td>
<td>3.6 cm</td>
<td>Washed out</td>
</tr>
</tbody>
</table>

* Marker layer site in *Spartina*
Deposition of sediments on the intertidal zone has alternated with phases of erosion and scour, particularly along the seaward margins (Figure 5.243). Sand has not been fixed at the site by *Spartina*, and has been returned to the sub-tidal zone during periods of destructive wave action. Erosion in the lower part of the quadrat is believed to account for the failure of many small plants and tussocks between 1971 and 1973 (Figure 5.242).

Rates of sediment accretion at Andersons Beach bear no apparent relationship to *Spartina* distribution. Table 5.242 gives accretion measurements on four marker layers laid down in May 1971. The high level layer was placed in the most landward *Spartina* at Andersons Beach, and the other three within quadrat II 4 (Figure 5.241). Layer 1 and 3 were placed in *Spartina* which subsequently failed to survive, and layer 2 was placed on bare sand. Two of the four layers were washed out during phases of erosion; the maximum depth of sediment deposited by 1979 was 31.0 cm on layer 2. Deposition across the marsh was highly variable temporally and spatially, and was actually greatest in a zone which was not colonised by *Spartina*. The sole physiographic effect of *Spartina* at Andersons Beach is occasional and temporary fixing of the positions of advancing sand lobes by individual clones, and in cases where this has been observed the clones eventually have been wholly or partly suppressed.

5.25 Quadrat II 5, Masons Beach

It has been noted previously that the inner margin of the spit is far more protected from wind and wave action than the opposite shoreline. With the exception of sheltered sectors at Cherry Tree Creek and Pound Creek, both colonised by mangroves, the saltmarsh along the
northern shore is steeply cliffed (Plate 5.251) and has receded in places by up to 20 m since first observed in 1966. Embankments have been constructed to prevent inundation of agricultural land by maximum spring tides, and attempts have been made to halt erosion by dumping rubble and other material at the base of the cliff.

The cliff is formed in alluvium laid down in Recent times in the shelter provided by the spit. Estuarine deposition evidently occurred in a calmer sedimentary environment than is presently available along the north shore. As noted in Section 2.3, exposed alluvium near the mouth suggests that the inlet may at times have experienced lagoonal conditions, which presumably were characterised by low wave energy and low water salinity accompanied by reed-swamp encroachment. Alternating periods of progradation and recession of saltmarsh along the north shore are believed to be related to phases of growth and recession at the distal end of the spit.

Masons Beach is part of the shoreline sector between Cherry Tree Creek and Nolans Bluff. This shoreline has a roughly north west-south east alignment and is exposed to waves generated by westerly winds which blow over a maximum fetch of 6 km. Such winds are the strongest and most frequent at Andersons Inlet. South west winds are also frequent, and the fetch of 3 km is sufficient to generate strong wave action. In comparison with other parts of the inlet, Masons Beach is a high wave energy environment; in strong winds at high tide, waves of up to 40 cm in height are common, and tidal litter thrown up against the seaward faces of embankments suggests that wave height may be considerably greater in storm conditions with maximum spring tides.

The greater exposure of Masons Beach is reflected in a coarser
PLATE 5.251

Cliff in alluvium near Masons Beach. Dominant species on the saltmarsh are Juncus maritimus and Stipa teretifolia (the latter mainly on cheniers). Note embankment. September 1979.

PLATE 5.252

Narrow beach of sand and shell, quadrat II 5, July 1977. The stake is pole C. Cliff in alluvium is locally lower at this point than at most other sites along the shore. Dominants on the saltmarsh are Agropyron junceum and Hemichroa pentandra.
substrate than other sites towards the head of the inlet. The intertidal zone is composed of a firm compact sand which has a mean grain diameter of 1.5 \( \Phi \) to 2.0 \( \Phi \) near high water mark, and becomes finer towards low tide level. Small beaches of sand and shell are built against the cliffed saltmarsh edge during periods of constructive wave action (Plate 5.252); sand also is deposited on the surface of the marsh in the form of cheniers. The sand is primarily of marine origin, but some of the shell material appears to be derived from beach deposits which underlie the alluvial plain and outcrop intermittently at the base of the cliff.

The mean of observed spring tides at Masons Beach is 1.66 m. As at other sites towards the head of the inlet, tide level varies considerably with wind strength. At times when strong winds from the south west quarter are combined with a high discharge from the Tarwin River, the ebb tide frequently falls not much lower than mean water level. Water salinity also fluctuates with wind conditions and the volume of fresh water entering the inlet; the extreme recorded values at high tide are 30°/oo in summer drought and 10°/oo when the Tarwin River was in flood.

*Spartina* along the north shore has not been as vigorous as at sheltered sites along the inner margin of the spit, and sward development has occurred only at Cherry Tree Creek. Elsewhere enlargement and fusion have been slow, and most population units still retain a basically cellular shape (Plate 5.253). *Spartina* has been of little assistance in reducing the rate of recession of the saltmarsh edge, except where small cuspatte forelands of sand and shell have developed in the lee of clones and clumps, causing the cliff to be wholly or partly covered
PLATE 5.253

High angle, low altitude aerial oblique photograph of Spartina tussocks, clones and clumps along the north west shore at Masons Beach, February 1977. The rate of Spartina expansion here has been much less than at sites along the inner margin of the spit.
(Plate 5.254). In other places, tombolo-like features (Plate 5.255) indicate an early stage in the development of such forelands, and suggest the possibility of eventual shoreline progradation should Spartina become more widespread.

Quadrat II 5 was established in May 1971 as a 100 m x 30 m traverse, its longer axis running seawards from the saltmarsh. The quadrat was resurveyed in April 1973, July 1977 and August 1980. Figure 5.25 shows vegetation and topography on each survey date; species abundance data is given in Table 5.25.

The area covered by Spartina increased steadily from 2.3 per cent to 30.9 per cent of the quadrat area over nine years. Expansion was achieved by enlargement and fusion of population units, combined with continued establishment of young plants from seeds or rhizome fragments. Despite the exposed conditions, plant mortality was low and few new plants failed to survive. Although the rate of spread was much less than at sheltered sites along the inner margin of the spit, it was higher than anticipated at the start of the survey period when the quadrat was occupied by only a few depauperate clones and clumps.

As in quadrat II 4 at Andersons Beach, the site has been characterized by a mobile substrate since the date of first survey. Changes in microtopography have been evident in the development, growth and contraction of minor depressions and ridges, the former generally retaining standing water at low tide (Plate 5.256). During phases of deposition, clones and clumps have been partially buried beneath a veneer of sand (Plate 5.257). During phases of scour, unconsolidated sand around the perimeters of population units has been eroded away,
PLATE 5.254

Cuspate foreland developed in lee of Spartina clumps,
Masons Beach, August 1980.

PLATE 5.255

Tombolo development in lee of Spartina clump,
Masons Beach, August 1980.
TABLE 5.25
SPECIES ABUNDANCE, QUADRAT II 5 NASONS BEACH

<table>
<thead>
<tr>
<th>Cover</th>
<th>Spartina</th>
<th>Spartina and other plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m^2$</td>
<td>12'</td>
<td>18'</td>
</tr>
<tr>
<td>Total</td>
<td>12'</td>
<td>18'</td>
</tr>
<tr>
<td></td>
<td>COVER</td>
<td>SPARTINA DENSITY</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td></td>
<td>Spartina (\text{M}^2)</td>
<td>Spartina and other plants (\text{M}^2)</td>
</tr>
<tr>
<td></td>
<td>% Total area</td>
<td>% Total area</td>
</tr>
<tr>
<td>May 1971</td>
<td>67.76</td>
<td>0</td>
</tr>
<tr>
<td>April 1973</td>
<td>298.14</td>
<td>0</td>
</tr>
<tr>
<td>July 1977</td>
<td>487.86</td>
<td>0</td>
</tr>
<tr>
<td>August 1980</td>
<td>853.76</td>
<td>57.59</td>
</tr>
</tbody>
</table>
PLATE 5.256

Quadrat II 5, Masons Beach, August 1980.
Side B-A is 1 m to left of fence-line.

PLATE 5.257

Partly-buried Spartina clones, quadrat II 5, July 1977.
Note ripple-marks.
leaving the matted roots of clones and tussocks embedded in a more resistant layer of sediment (Plate 5.258).

There are however differences between the two exposed sites. First, microtopographic changes at Masons Beach have occurred far more gradually. On no occasion have large, surficial lobes of sand been suddenly emplaced on the marsh, suggesting that the volume of available sediment is considerably less than at Andersons Beach. Second, *Spartina* at Masons Beach has acted as a locus for sediment retention. The slow spread of *Spartina* has been accompanied by greater rates of accretion than on adjacent bare areas, with accretion mounds forming in several population units which persisted throughout the survey period. Third, despite periods when *Spartina* has been temporarily covered, the grass has not been suppressed by prolonged burial under deep layers of sand as at Andersons Beach.

As a result of strong wave action, none of the accretion marker layers put down in 1971 (Figure 5.25) survived until 1980. Layer 1 was washed out within a few months of establishment, and the other two layers had been scattered across the marsh surface by 1973. Further layers were then put down, together with stakes driven deeply into the sand and protruding 50 cm above the surface. It was anticipated that accretion could be measured by burial of each stake even if the marker layers did not persist. However the layers were not only again eroded, but the stakes were removed, apparently by local fishermen, for use as channel markers between Masons Beach and Nolans Bluff.

Between 1977 and 1980 several *Spartina* sites higher than 0.6 m above Inverloch datum were colonised by other plants. The initial invader
Spartina clone at Masons Beach, July 1978. Except around the landward perimeter, the previous year’s growth has been shed as tidal wrack, leaving only root crowns. Accretion has been greater in the clone than on surrounding bare areas. Cliffting of the margins results from scour.

Vegetation on accretion mound at 0.72 m above Inverloch datum, quadrat II 5, August 1980. Species present are Spartina townsendii (s.l.), Samolus repens, Triglochin striata, Selliera radicans and Puccinellia stricta.
was *Samolus repens*, followed by *Triglochin striata*, *Selliera radicans* and *Puccinellia stricta* (Plate 5.259). Such plants now commonly grow in association with *Spartina* on accretion mounds and ridges elsewhere along the shoreline between Cherry Tree Creek and Nolans Bluff. On even higher sites above 0.8 m above Inverloch datum, *Suaeda australis* has also established. However, although *Avicennia* seedlings have often been observed at Masons Beach, they have never persisted for more than a season.

5.26 Quadrat II 6, Nolans Bluff

Quadrat II 6 was established along the section of shoreline to which six small clumps of fertile *S. anglica* from Bass River were introduced in 1962, thus initiating the spread of the grass in Andersons Inlet. The clumps rapidly expanded by rhizome extension to form clones, and new plants quickly developed (Plate 5.261).

*Spartina* was planted on a narrow intertidal zone along the margin of saltmarsh comprised mainly of *Juncus maritimus*, with *Stipa teretifolia* on locally higher levels formed by low cheniers. The saltmarsh has developed on a former shore platform cut in Jurassic mudstone at the base of Nolans Bluff, which was cliffed before emplacement of the spit behind which Andersons Inlet has formed. The saltmarsh now forms a veneer about 70 cm deep over the platform, parts of which are exposed near low water mark (Plate 5.262). In the past few years, much of the saltmarsh between the bluff and the intertidal zone has been converted to rough pasture.

Before the introduction of *Spartina* to this site, *Juncus maritimus* was the pioneer along the upper margins of the intertidal flats,
Site of quadrat II 6, Nolans Bluff, April 1967. *Spartina* clones include those developed from the 1962 planting.

*Spartina* and *Juncus* north from quadrat II 6, showing Nolans Bluff in background, August 1980. Note exposed sections of shore platform.
at about the level of mean high water spring tide. Although *Avicennia* grows extensively at other sites near the head of the inlet under evidently suitable tide and salinity conditions, mangroves have never survived for more than two or three years at Nolans Bluff. This is probably due to exposure to waves generated by west and south west winds, from which other mangrove sites in this vicinity are sheltered. However an additional factor might be an insufficient depth of sediment for the development of root systems in mangroves more than a few years old, for the shore platform lies only a few centimetres beneath the surface of the intertidal zone. If this is the case, mangroves could be expected to establish in the future at sites where accretion in *Spartina* has been most pronounced.

Tide range at Nolans Bluff is greatly affected by wind strength and duration, and by discharge from the Tarwin River. The mean of observed spring tides in calm conditions, and excluding readings taken in drought or flood, is 1.40 m. Although tide ranges diminish from the mouth to the head of Andersons Inlet in calm conditions, sustained strong winds from the south west quarter cause the level of high tide to be greater at the head of the inlet than in the wider middle reaches, with the maximum levels being reached when the Tarwin River is also in flood. When such conditions persist throughout the ebb, the tide does not fall much below mean water level. Water salinity similarly varies with fresh water discharge and the degree of penetration of salt water, and although the maximum recorded reading at the site is 24°/oo, salinity is rarely higher than 10°/oo.

Quadrat II 6 was first mapped in January 1968, as a 61 m x 15 m section of the intertidal zone (Figure 5.261; Plate 5.263). Between
Opposite

FIGURE 5.261

Vegetation and topography, quadrat II 6,
Nolans Bluff
VEGETATION

JANUARY 1968

JANUARY 1970

APRIL 1973

MAY 1977

AUGUST 1980

TOPOGRAPHY

Height in metres above Inverloch Datum

Permanent local datum 9.75m from B (1900), bearing 48°

The diagram shows a map of vegetation changes from January 1968 to August 1980, with different months labeled. The legend includes symbols for different types of vegetation and locations marked with dots. The topographic changes are indicated with contour lines.
1968 and 1970, cover increased from 11.8 per cent to 14.0 per cent of the quadrat due to enlargement of clones, and density remained constant as a result of the establishment of new plants (Table 5.261).

By 1973, Spartina had advanced landwards beyond side B-C, which was therefore moved back 5 m to the saltmarsh fringe (Figure 5.261). The grass had formed a continuous sward with an irregular outline reflecting the previous pattern of clones and clumps. Along its landward margin, the sward was separated from Juncus marsh by a discontinuous zone of bare mud; along its outer edge, there were several new tussocks and small plants. Cover was 59.4 per cent of the enlarged quadrat area.

By 1977, the outer edge of the sward had become more regular, resulting from increased tiller density combined with the failure of Spartina along the seaward margin. Much of the formerly bare zone along the landward margin of the sward had however been colonised. In this zone Spartina was growing in association with Salicornia quinqueflora, Selliera radicans and Triglochin striata, which had also invaded those areas occupied by the landward margins of the sward in 1973. Spartina covered 830.6 m$^2$, of which 64.9 m$^2$ were also colonised by other plants.

In 1980 the landward boundary of the quadrat was again moved a further 5 m inland, as Spartina and newly-colonised herbaceous plants had begun to encroach on bare patches in the Juncus marsh. These new plants were also continuing to invade the higher parts of the sward. While the area colonised by Spartina had increased only slightly, from 830.6 m$^2$ to 842.2 m$^2$, other saltmarsh plants had become much more abundant. Of the total area occupied by Spartina, 153.2 m$^2$ had also been colonised by other species.
<table>
<thead>
<tr>
<th></th>
<th>Spartina</th>
<th>Spartina and other plants</th>
<th>SPARTINA DENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$m^2$</td>
<td>% Total area</td>
<td>$m^2$</td>
</tr>
<tr>
<td><strong>January 1968</strong></td>
<td>108.34</td>
<td>11.84</td>
<td>0</td>
</tr>
<tr>
<td><strong>January 1970</strong></td>
<td>128.47</td>
<td>14.04</td>
<td>0</td>
</tr>
<tr>
<td><strong>April 1973</strong></td>
<td>724.96</td>
<td>59.42</td>
<td>0</td>
</tr>
<tr>
<td><strong>May 1977</strong></td>
<td>765.69</td>
<td>62.76</td>
<td>64.90</td>
</tr>
<tr>
<td><strong>August 1980</strong></td>
<td>688.99</td>
<td>45.18</td>
<td>153.19</td>
</tr>
</tbody>
</table>

* Quadrat size 61 m x 15 m
+ Quadrat size 61 m x 20 m
** Quadrat size 61 m x 25 m
It was evident by 1980 that the primary coloniser of the sward was Triglochin striata (Plate 5.264) which established on patches of bare mud between Spartina tillers at about 0.9 m above Inverloch datum. At slightly higher levels between mean high water neap tide and mean high water spring tide (0.93 m - 1.14 m above Inverloch datum), the flora had become more diverse than in 1977. In addition to the three species present at that time, Spartina was also growing in association with Samolus repens, Distichlis distichophylla and Apium prostratum, the latter elsewhere being characteristic of drier saltmarsh sites. A few patches of Juncus maritimus had also established within the higher parts of the sward, although the ecotone between the former pioneer and the newly-developed saltmarsh fringe was quite distinct (Plate 5.265). At no site however had Spartina been suppressed by the establishment and growth of other plants.

Before Spartina became widespread, the intertidal zone at Nolans Bluff was subject to alternating phases of deposition and scour. While the principal source of sediment for the site is the Tarwin River, coarser sand of largely marine origin was periodically deposited at about mean spring tide level by waves generated by westerly winds, and occasionally driven into the outer margin of the Juncus marsh (Plate 5.266). Such phases were followed by periods of erosion, resulting in cliffing of the seaward margin of the marsh and the removal of much of the sediment from the mudflat, thus revealing part of the underlying shore platform (Plate 5.267). Erosion was most rapid in flood conditions, when it was promoted by the near-shore presence of the Tarwin River channel. Prevention of such erosion was the motive behind the introduction of Spartina in 1962 (Arbuthnot 1966 pers. comm.).

While deposition of coarse material still occurs episodically,
PLATE 5.264

Triglochin striata (arrowed) in Spartina in quadrat II 6, August 1980. The plants are approximately 6 cm tall. Spartina is in winter condition of low growth.

PLATE 5.265

Ecotone between Juncus marsh and zone of Spartina and saltmarsh plants, quadrat II 6, August 1980.
PLATE 5.266

Sand deposition along seaward margin of Juncus marsh, Nolans Bluff, April 1967. Spartina clone and several small plants in foreground.

PLATE 5.267

Nolans Bluff mudflat following erosion of the intertidal zone, September 1967. Note coarse gravel, beneath which lies the shore platform.
phases of erosion are now rare. The edge of the Juncus marsh is subject to only minor cliffing, and the shore platform is revealed only occasionally beyond the seaward limit of the sward. Sediment delivered to the site, either by the Tarwin River or by wave action from the lower part of the inlet, has been bound up within the sward.

Accretion in Spartina has brought about changes in the microtopography of the intertidal zone, which in comparison with other sites in Andersons Inlet is relatively steep and narrow. First, the general level of the surface has been raised, to the point where the upper limit of Spartina lies at about the level of mean high water neap tides (Figure 5.262). Second, the formerly fairly straight slope has become slightly convex, due to maximum amounts of accretion in the centre of the sward between about 0.45 m and 0.65 m above Inverloch datum. Third, the surface of the intertidal zone now has greater microrelief than previously. The contours reflect differential rates of accretion within the sward, and no longer run closely parallel to low water mark (Figure 5.261).

Differential rates of accretion across the marsh are reflected in comparison of deposition on the three marker layers (Table 5.262) with changes in the profile of side B-A (Figure 5.262). The greatest depth of sediment on the former was 5.0 cm deposited on the landward marker layer, which was 0.46 m above Inverloch datum in 1973. At the same level on side B-A, 21 cm of sediment was laid down over the same period. Differences in rates of accretion at initially similar levels are believed to arise from local variations in tiller density, from the pattern of clones and clumps which existed before complete sward formation, and from episodic delivery of coarse material which is rarely deposited
FIGURE 5.262 Profiles along side B-A, quadrat II 6, Nolans Bluff
(Note that the hollow at 7 m from the landward end of the traverse resulted from diminished accretion upslope from an isolated clump of Juncus which had developed in Spartina by 1973. It is an isolated feature and not typical of the quadrat.)
### Table 5.262

**Accretion as Measured by Marker Layers, Quadrat II 6 Nolans Bluff**

<table>
<thead>
<tr>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>Rate p.a.</td>
<td>Depth</td>
</tr>
<tr>
<td>April 1973</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>May 1977</td>
<td>2.0 cm</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>August 1980</td>
<td>5.0 cm</td>
<td>0.9 cm</td>
</tr>
</tbody>
</table>

Layers 1 and 2 were in *Spartina*; layer 3 was on bare mud.
as a veneer of uniform depth. Field observations suggest that an increasingly higher proportion of fine material is now being fixed in situ by the marsh, for the fine sandy mud of 2.5 ø - 3.0 ø mean grain diameter contains less coarse sand than at the start of the survey period.

5.27 Quadrat II 7, Cherry Tree Creek

Cherry Tree Creek is the site of the first planting of *Spartina* in Andersons Inlet, in the early 1940s. An account of its introduction has been given in Section 2.3, where it was noted that the grass became locally abundant at the planting site, but did not spread to other parts of Andersons Inlet.

The narrow mouth of Cherry Tree Creek is sheltered from strong wind and wave action, and is fringed by *Avicennia marina* (Plates 5.271, 5.272). Until 1970 the creek and the adjacent shoreline were flanked by an extensive saltmarsh 0.5 km wide, which was regularly grazed by cattle. An embankment designed to prevent inundation of land by exceptionally high tides was then constructed (Plate 5.272). A sluice-gate in the embankment permitted continued land drainage into Andersons Inlet through Cherry Tree Creek but prevented the movement of tidal inflow upstream. The saltmarsh was reduced to a narrow littoral zone which is now rarely grazed.

The mean spring tide range in the mouth of Cherry Tree Creek is 1.61 m, which is about 10 cm less than the tide range along adjacent sections of shoreline unaffected by outflow from the creek. The smaller range is explained by locally higher water levels at low tide due to
Aerial oblique photograph of mouth of Cherry Tree Creek, January 1968. White stakes mark the corners of quadrat II 7. Original planting site is marked by a cross. Photograph taken facing east.

High-angle aerial oblique photograph of mouth of Cherry Tree Creek, facing west, February 1977. Note the embankment (E) and borrow pit (B).
discharge of land drainage and by embankment of this water behind intertidal flats offshore from the mouth of the creek. At high water, the fresh water discharge generally maintains oligohaline and mesohaline salinity ranges in the mouth of Cherry Tree Creek despite the higher salinity ranges characteristic of the central part of Andersons Inlet at that stage of the tide.

Differences in the degrees of exposure experienced between the sheltered mouth of Cherry Tree Creek and the adjacent shorelines are accompanied by differences in the sediment composition of their intertidal zones. Within the mouth of the creek the substrate is soft, wet dark mud comprised of silt and fine sands of mainly terrigenous origin. Along the adjacent shoreline sediments are light-coloured medium sands of 1.5 Ø - 2.0 Ø mean grain diameter, which derive partly from a band of sand and shell material revealed intermittently at the base of the low cliff in alluvium at a depth of about 0.6 m, and partly from marine or reworked aeolian material eroded from the dunes at Point Smythe. This material forms incipient and discontinuous beaches at the base of the low cliff; where not fixed by *Spartina* the sand may be removed during periods of destructive wave action to reveal an abrasion ramp formed in sand and soft clay.

The material introduced to Cherry Tree Creek in the early 1940s was planted outside the mouth of the creek, on sand (Plate 5.272). Sparks (1974 *pers. comm.*) has given information on its performance. About six plants were placed out in an area of not more than 10 m², but they spread only slowly in the first five years. However in the early 1950s it was noted that the plants had formed clones, and that several new plants had established. Some of the material was transplanted to more exposed local sites to the south east, but did not survive.
In 1959 or 1960 there was a further unsuccessful attempt at transplantation. It was observed that the clones had merged to form a large clump of approximately 10 m length parallel to the shore, and that many tussocks and small clones had established on mud within the mouth of the creek at sites which were hidden from view from the land by the extensive mangrove fringe. It was evident that the grass was spreading naturally, although not to the exposed sandy sites which it had been hoped would be colonised.

Quadrat II 7 was established in January 1968 at the entrance to the mouth of the creek (Plate 5.271). It was mapped at that time and again in August 1969 as a rectangle 60.96 m x 45.72 m (200 ft x 150 ft). The quadrat was then enlarged to 75 m x 65m to include part of an extensive sward which had developed along its northern margin. Further surveys were made in May 1971, April 1973, November 1976 and August 1979. The distribution of Spartina and Avicennia on each survey date is shown in Figure 5.271, and Table 5.271 gives Spartina abundance data.

At the time of the first survey in January 1968, quadrat II 7 was already a well-established Spartina site (Plate 5.273). It therefore represents a different situation from the other Series II quadrats, which were established virtually at the time of marsh inception. However, by 1979 it also had undergone a number of major changes in both vegetation distribution (Plate 5.274) and surface morphology. Spartina cover had increased, density had decreased, sward formation was completed, the marsh had a single limiting outline and the rate of advance of the seaward frontier had almost halted. At the same time the Spartina marsh had been invaded by Avicennia marina, its surface had developed
TABLE 5.271

SPARTINA ABUNDANCE, QUADRAT II 7, CHERRY TREE CREEK

<table>
<thead>
<tr>
<th>M²</th>
<th>% 7 cm</th>
<th>Large</th>
<th>Clumps</th>
<th>Swards</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>$M^2$</td>
<td>% Total Area</td>
<td>Young plants</td>
<td>Small tussocks</td>
<td>Large tussocks</td>
</tr>
<tr>
<td>--------------</td>
<td>--------</td>
<td>--------------</td>
<td>--------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>January 1968*</td>
<td>468.23</td>
<td>16.8</td>
<td>7</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>August 1969*</td>
<td>574.14</td>
<td>20.6</td>
<td>9</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>May 1971</td>
<td>1856.97</td>
<td>38.1</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>April 1973</td>
<td>2457.98</td>
<td>50.4</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>November 1976</td>
<td>2824.97</td>
<td>57.9</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>August 1979</td>
<td>3011.03</td>
<td>61.8</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Quadrat size 60.96 m x 45.72 m (200 ft x 50 ft)
microtopographic features not present on the previously unvegetated mudflats, and there had been substantial modification of cross-sectional profiles.

The colonisation of the quadrat by *Avicennia* is summarised in Table 5.272, which gives mangrove densities and dates of establishment. The data for 1968 and 1969 include mangrove seedlings, but when the quadrat was enlarged in 1971 it was decided to record only plants with woody stems, several leaves and a height greater than 25 cm, which field evidence suggested was indicative of a plant at least two years old. Mangroves were well-established in *Spartina* at the time of the 1968 survey, with some plants approaching 1 m in height (Plate 5.273) and being reported as 4-6 years old (Sparks 1969 pers. comm.). Between 1971 and 1979 there was a more than three-fold increase in plant density, reflecting a sustained high survival rate for plants after their second or third year of growth (Table 5.272). By 1979 approximately 38 per cent of the mangroves mapped in the quadrat were more than 6 years old and many were more than 1 m in height (Plate 5.274). Along the landward margin of the quadrat, mangroves estimated to be over 15 years old had attained a height in excess of 2 m (Plate 5.275).

As in Quadrat II 1 at Western Split Island, *Spartina* at Cherry Tree Creek initially established at and below the level already sparsely colonised by *Avicennia*. The further spread of mangroves has been aided by the shelter provided by *Spartina* for establishment of mangrove seedlings, and by the decrease in the length and depth of tidal inundation which has resulted from sediment accretion within the *Spartina* sward. As a consequence the mangrove frontier has advanced seawards.
### TABLE 5.272

**AVICENNIA DENSITY AND DATES OF ESTABLISHMENT, QUADRAT II 7, CHERRY TREE CREEK**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>January 1968*</td>
<td>46</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>46</td>
</tr>
<tr>
<td>August 1969*</td>
<td>44</td>
<td>19</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>63</td>
</tr>
<tr>
<td>May 1971+</td>
<td>9</td>
<td>5</td>
<td>26</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>April 1973+</td>
<td>5</td>
<td>5</td>
<td>16</td>
<td>51</td>
<td>-</td>
<td>-</td>
<td>77</td>
</tr>
<tr>
<td>November 1976+</td>
<td>5</td>
<td>5</td>
<td>16</td>
<td>31</td>
<td>33</td>
<td>-</td>
<td>90</td>
</tr>
<tr>
<td>August 1979+</td>
<td>5</td>
<td>5</td>
<td>16</td>
<td>29</td>
<td>8</td>
<td>80</td>
<td>143</td>
</tr>
</tbody>
</table>

* Quadrat size 60.96 m x 45.72 m (200 ft x 50 ft). Data include seedlings.

+ Quadrat size 75 m x 65 m. Data do not include seedlings.
Mangroves along side B-C of quadrat II 7, August 1979.

Unvegetated depression between Spartina sward (foreground) and former shoreline fringe of mangroves, Cherry Tree Creek, July 1978. Note mangrove pneumatophores. The stake is the site of an accretion marker layer landward of quadrat II 7.
Between 1971 and 1979 a characteristic of the development of the *Spartina* marsh at Cherry Tree Creek was the formation of unvegetated patches within otherwise continuous sward (Figure 5.271). These are minor topographic depressions of two types. Some are pans (Yapp et al. 1917), being unvegetated hollows with gently sloping sides; others resemble pond holes (Redfield 1972), having vertical or undercut walls and flat bottoms. All such depressions at Cherry Tree Creek contain standing water. The causes of such microtopographic features at this and other sites are considered below in Section 6.4.

As at the sites of other Series II quadrats, accretion of sediments accompanying the spread of *Spartina* at Cherry Tree Creek brought about changes in the elevation and slope of the intertidal zone. As quadrat II 7 was large, change in microtopography was recorded by means of surveyed profiles across the marsh rather than by detailed contour surveys of the quadrat as a whole. The profiles are shown in Figure 5.272; their location is given in Figure 5.271. Depths of sediment deposited on accretion marker layers set down in May 1971 are given in Table 5.273.

During the survey period there was a general increase in the level of the vegetated marshland, but accretion was variable over the surface. As in quadrat II 1 at Western Split Island, rates of accretion were lowest at the originally higher levels of the marsh, and greatest in *Spartina* near the seaward margins. Accretion in marker layer 5, near the outer edge of the sward, increased from 1.6 cm per annum in 1971-73 to 6.2 cm per annum in 1976-79, the depth of the deposit being 33.0 cm over eight years (Table 5.273). The average annual rate of accretion at intermediate levels was 2.4 cm, but the maximum annual rate
FIGURE 5.272 Profiles, quadrat II 7, Cherry Tree Creek.
<table>
<thead>
<tr>
<th></th>
<th>HIGH LEVEL</th>
<th>INTERMEDIATE LEVEL</th>
<th>LOW LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.</td>
<td>2.</td>
<td>3.</td>
</tr>
<tr>
<td>May 1971</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>April 1973</td>
<td>2.0 cm 1.0 cm</td>
<td>4.0 cm</td>
<td>2.1 cm</td>
</tr>
<tr>
<td>November 1976</td>
<td>4.5 cm 0.7 cm</td>
<td>9.5 cm</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>August 1979</td>
<td>8.5 cm 1.5 cm</td>
<td>19.5 cm</td>
<td>3.6 cm</td>
</tr>
</tbody>
</table>
recorded at the high level marker layer was 1.5 cm. Accretion on the only marker layer not colonised by **Spartina** during the survey period (layer 6) was less than 1 cm per annum between 1971 and 1976, but increased to 2.7 cm per annum between 1976 and 1979. The increase was due to deposition of sediments against the seaward margin of the sward, which by 1979 had encroached to within 2 m of the marker site (Figure 5.271).

The effect of differential rates of accretion is evident in the four profiles (Figure 5.272). The landward limits of Profiles 1 and 3 were raised by 8 cm and 17 cm respectively between 1971 and 1979, and those of Profiles 2 and 4 by 15 cm and 10 cm between 1968 and 1979. The average of the annual rates of accretion at these four sites is 1.3 cm per annum. Accretion was much greater in the middle and seaward zones of continuous **Spartina** cover. Table 5.274 gives the location of the point of maximum accretion on each profile in each survey year, and the depth of sediment laid down at that point since the previous survey. Where sediment has been deposited as layers of even depth in a broad zone along the profile, the point of maximum accretion has been taken as the mid-point of the zone.

Ranwell (1964a) has suggested that the point of maximum accretion will migrate seawards as a **Spartina** marsh develops, and that as the marsh approaches its upper level of growth, which is defined by the level of mean high water spring tide, the rates of accretion will decline. Table 5.274 provides evidence of such seaward migration, the best example being Profile 4. Along Profile 3 the point of maximum accretion migrated seawards then became stationary; two points of maximum accretion developed on Profile 2 but seaward migration also
<table>
<thead>
<tr>
<th>POINTS OF MAXIMUM ACCRETION</th>
<th>PROFILE 1</th>
<th>PROFILE 2</th>
<th>PROFILE 3</th>
<th>PROFILE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>JANUARY 1968 - MAY 1971</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from side B-C</td>
<td>-</td>
<td>11.5 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Depth of sediment</td>
<td>-</td>
<td>6.0 cm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mean annual accretion</td>
<td>-</td>
<td>1.8 cm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>MAY 1971 - APRIL 1973</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from side B-C</td>
<td>46 m</td>
<td>13 m / 41 m</td>
<td>18 m</td>
<td>16 m *</td>
</tr>
<tr>
<td>Depth of sediment</td>
<td>8.5 cm</td>
<td>7.5 cm / 10.0 cm</td>
<td>6.0 cm</td>
<td>9.0 cm *</td>
</tr>
<tr>
<td>Mean annual accretion</td>
<td>4.4 cm</td>
<td>3.9 cm / 5.2 cm</td>
<td>3.1 cm</td>
<td>4.7 cm</td>
</tr>
<tr>
<td><strong>APRIL 1973 - NOVEMBER 1976</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from side B-C</td>
<td>37.5 m</td>
<td>19 m</td>
<td>29 m</td>
<td>25.5 m</td>
</tr>
<tr>
<td>Depth of sediment</td>
<td>12.0 cm</td>
<td>12.0 cm</td>
<td>7.5 cm</td>
<td>11.0 cm</td>
</tr>
<tr>
<td>Mean annual accretion</td>
<td>3.4 cm</td>
<td>3.4 cm</td>
<td>2.1 cm</td>
<td>3.1 cm</td>
</tr>
<tr>
<td><strong>NOVEMBER 1976 - AUGUST 1979</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from side B-C</td>
<td>53 m</td>
<td>21 m / 44 m</td>
<td>29 m</td>
<td>28 m</td>
</tr>
<tr>
<td>Depth of sediment</td>
<td>21.0 cm</td>
<td>14.0 cm / 9.0 cm</td>
<td>9.0 cm</td>
<td>15.5 cm</td>
</tr>
<tr>
<td>Mean annual accretion</td>
<td>7.6 cm</td>
<td>5.1 cm / 3.3 cm</td>
<td>3.3 cm</td>
<td>5.6 cm</td>
</tr>
<tr>
<td><strong>TOTAL SURVEY PERIOD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth to first surveyed level</td>
<td>37.0 cm</td>
<td>28.0 cm / 29.5 cm</td>
<td>19.0 cm</td>
<td>24.5 cm</td>
</tr>
<tr>
<td>Mean annual accretion</td>
<td>4.5 cm</td>
<td>2.4 cm / 2.6 cm</td>
<td>2.3 cm</td>
<td>2.1 cm</td>
</tr>
<tr>
<td>(99 months)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(139 months)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Since first survey in January 1968
occurred; and the point of maximum accretion temporarily migrated landwards along Profile 1 between 1973 and 1975. These variations do not negate the general application of the Ranwell model to this site.

Rates of maximum accretion in general increased during the survey period, the highest rate being 7.6 cm per annum near the seaward Spartina margin on Profile 1. Increasing rates of accretion accompanied increasing Spartina cover, and became greatest once sward formation was complete. It is to be expected that they will decline when the marsh approaches its upper limit of growth and tidal inundation becomes less frequent, but in August 1979 the highest point in the quadrat was still 0.2 m below the level of mean high water neap tides.

Variability in sediment deposition across the marsh led to changes in surface slope. Seaward of the points of maximum accretion the slope of the intertidal zone was steepened, including a zone of unvegetated intertidal flats along the periphery of continuous sward. This increased slope is believed to be a factor in reducing the rate of Spartina advance seawards; Hubbard (1965a) has reported increasing difficulty of Spartina in establishing on the resulting mobile surface in Poole Harbour, recognizable by prolonged expansion of tussocks prior to fusion. However, unlike Poole Harbour, the rise in the height of the sward has not yet caused a breakdown of the seaward slope and formation of a cliff edge.

To landward of the points of maximum accretion, the slope of the intertidal zone was reduced by accretion in Spartina. Further, along Profiles 1 and 2 the former gentle seaward slope from the back of the marsh was changed into a gradual landward slope, as a consequence of low
accretion at the rear of the quadrat and higher rates of accretion in the centre. This has reversed the pattern of drainage which existed before Spartina establishment. The Spartina sward now occupies a low broad levee in front of the former shoreline fringe of Avicennia, from which it is separated by a permanently saturated depression of very fine, soft silt (Plate 5.276) which has not been colonised by plants. Although the depression is filled at high tide by water flowing through the Spartina sward, it retains standing water on the ebb and is drained only partly by a small channel which extends around the northern edge of the sward.

Accretion rates in the depression and the Avicennia zone to landward are less than 1.0 cm per annum, as water-borne sediment is largely deposited in Spartina. As accretion in Spartina is rapid, the depression is becoming accentuated. It is expected that mangroves along its landward margin may become waterlogged for long periods. It is unlikely that mangrove seedlings could establish in such conditions, and possible that die-back could occur in adult mangroves as a result of hypersalinity.

5.3 Spartina as a morphological agent

In the introductory section to this chapter, consideration was given to the nature of the relationship between Spartina growth and sediment deposition. Evidence from Andersons Inlet suggests that the spread of Spartina is both a consequence and a cause of high rates of accretion.

The sediment budget of an estuary is determined by the balance between its supply of material of marine, terrigenous and aeolian origin,
and the volume of sediment carried out to sea at times of peak river discharge. Within the estuary, available sediment is moved about in response to wave and current action, and may be bound up for short or long periods in semi-permanent loose-boundary features such as beaches and intertidal mudflats. These features are formed as a result of a net gain of sediment, at sites where the volume of material supplied during depositional phases exceeds that removed during periods of erosion.

*Spartina* will establish in such an estuary only at levels which provide suitable conditions of tidal immersion in relation to local factors such as water turbidity and wave action. As seedlings and young plants are unlikely to persist at these levels at sites undergoing erosion, growth is largely restricted to depositional environments where accretion of sediment has raised the surface of the intertidal zone to levels at which plant growth can be supported. At Andersons Inlet, *Spartina* spread most rapidly across the extensive intertidal flats to the south of Central Split Island, which are nourished by a steady supply of sediment delivered from the lower part of the estuary (Section 5.23). Rates of accretion at this site are believed to have been greater than elsewhere in the inlet even before the appearance of *Spartina* in the mid 1960s, when the general elevation of the surface was already above that of other intertidal mudflats and the higher parts were being colonised by *Salicornia* and *Juncus* spp. Similarly, most rapid spread at Bass River has occurred at the ox-bow site, where large volumes of sediment deposited when the river exceeds bankfull discharge cannot be depleted during subsequent periods of erosion, which is confined to the main channel. At such sites the spread of *Spartina* is a consequence of high rates of accretion, which rapidly convert large sections of the intertidal zone to a suitable habitat for plant growth.
It is also apparent that *Spartina* in Andersons Inlet has been the cause of accelerated rates of sedimentation at many colonised sites. While marker layers and cross-sectional profiles have indicated a relationship between *Spartina* growth and sediment accretion, the most compelling evidence for this conclusion is the formation of microtopographic highs at sites occupied by *Spartina* population units, as shown in the quadrat plans. There is no mechanism to explain the formation of such features, which are not characteristic of unvegetated mudflats, apart from accretion in *Spartina* being greater than on adjacent areas of bare mud, which presumably receive a similar supply of sediment but retain less in situ. While microtopographic highs are most evident as accretion mounds in quadrats II 2 (Figure 5.22) and II 3 (Figure 5.23), a close association between areas of maximum accretion and *Spartina* growth is seen in all quadrats except that at Andersons Beach, where sedimentation was largely unrelated to *Spartina* distribution (Section 5.24).

Three factors are believed to contribute to differential rates of accretion between colonised areas and adjacent bare mud. First, *Spartina* appears to trap and retain a greater proportion of available material during and after the time of sediment delivery. This process is thought to be the principal factor accounting for differential rates of accretion in calm sedimentary environments, such as quadrats II 1 and II 2. Second, sediment bound up within the perimeters of population units is more resistant to erosion than material not stabilised by vegetation, and thus less will be removed during periods of erosion. This is likely to be the more important factor in the formation of microtopographic highs at sites exposed to strong wave action (for example, quadrat II 5 at Masons Beach), or subject to erosion by tidal
creeks, (for example, quadrat II 3 on the Central Split Island mudflat). Similar depths of sand are deposited on colonised and unvegetated sites during periods of constructive wave action at Masons Beach (Section 5.25), but during periods of wave erosion unconsolidated sand is removed to leave steeply cliffed accretion mounds formed in *Spartina* (Plate 5.258). Third, it is evident that *Spartina* itself contributes organic matter which assists the upward growth of the marsh, although the present study has not attempted to assess the significance of decayed plant material as a component of total accretion.

The role of *Spartina* in promoting sediment accretion is similar to that of mangroves. Bird (1971) and Chapman (1976) have noted that siltation must precede the growth of mangroves, as the surface of the intertidal zone must first be raised to a point at which colonisation by seedlings can occur. Once established however, the roots and pneumatophores of mature plants accelerate the process of accretion, by trapping and fixing material that would otherwise have remained mobile. The result is the gradual formation of a depositional terrace, which is slowly raised to a level at which the mangrove community is succeeded by saltmarsh.

Quantitative data on rates of accretion in mangroves is almost non-existent (Chapman 1976). One of the few contributions is that by Bird (1971), who recorded depths of sediment ranging from 0.4 cm to 4.6 cm deposited over three years in *Avicennia marina* at Yaringa, Westernport Bay, Victoria. However, as rates of accretion vary from site to site according to the available supply of sediment, the relative effectiveness of *Spartina* and mangroves as morphological agents can be compared only at sites where the two plants grow together.
There are very few sites where *S. townsendii* (s.l.) grows in association with mangroves, which do not occur in Britain, Europe, or Tasmania. *S. townsendii* (s.l.) and *Avicennia marina* occur at sites in the North Island of New Zealand, such as Kaipara Harbour, but the growth of the grass has not been vigorous and its morphological impact is negligible. Both plants also are found in the Gawler River in South Australia, but *Spartina* is not abundant. In Currambene Creek in New South Wales, the mangrove *Aegiceras corniculatum* grows as isolated mature plants in the vicinity of the three *Spartina* clumps which have persisted at that site since the 1930s, but neither species has spread vigorously or caused pronounced accretion. It is only in Victoria that *Spartina* and mangrove (*Avicennia marina*) commonly occur together, at all *Spartina* sites except those in the Gippsland Lakes.

While accretion has not been rapid in either species at exposed sites such as the mouth of Bass River or the shores of Corner Inlet, deposition in *Spartina* has been greater than in *Avicennia* in calm sediimentary environments. As indicated above in records of deposition on accretion marker layers in Series II quadrats in Andersons Inlet, annual rates of accretion in *Spartina* marsh have commonly been greater than 2 cm, with rates in excess of 5 cm being recorded at Western Split Island and Cherry Tree Creek. Although no systematic study has been undertaken of rates of accretion in *Avicennia*, which has now largely been replaced by *Spartina* at the pioneer species on the intertidal flats, there is sufficient evidence to indicate that deposition within the mangrove fringe has been much less. Only 8.5 cm of sediment was deposited on an accretion marker layer within the main belt of mangroves at Cherry Tree Creek between May 1971 and August 1979, which is an annual accretion rate of about 0.9 cm. On Central Split Island, stumps placed within
the mangrove zone and used as intermediate stations for linking permanent datum points were buried by only 4-7 cm of sediment between 1971 and 1980, leaving the top few centimetres still exposed. Further, although levee formation in *Spartina* is most pronounced at Cherry Tree Creek, there are several other sites along the inner margin of the spit and on Central Split Island where high rates of accretion in *Spartina* have promoted waterlogging of the landward *Avicennia* fringe, in which rates of accretion have clearly been lower.

By promoting accretion of sediment, *Spartina* reduces the volume of material which would otherwise be flushed out to sea, and hence brings about a net increase in total sediment reserves. Although the volume of sediment delivered to an estuary is independent of the presence of *Spartina*, a higher proportion of that material is fixed within the intertidal zone once the grass becomes widespread. The following chapter examines the morphological features characteristic of the consequent transition from slob-land to salting, and the physiographic impact of *Spartina* in Australia.
CHAPTER SIX

THE MORPHOLOGY OF THE DEVELOPING MARSH

6.1 The formation of *Spartina* terraces

In discussing marsh development at different latitudes, Guilcher (1979) has provided a schema for description of the morphological features of marshes in temperate climates (Figure 6.1). Such climates are defined as those which have a marked temperature differential between summer and winter, which distinguishes them from intertropical areas, but where the lowest temperatures are normally not sufficiently cold for the sea to freeze each winter. As *Spartina* is largely confined to temperate climates, this schema provides a useful framework for examination of its morphological impact.

With reference to temperate marshes in the Northern Hemisphere, Guilcher distinguishes three principal morphological components: the high marsh, which is submerged only by spring tides and colonised by mainly perennial herbaceous plants and shrubs; the low marsh, which is submerged by all high tides and colonised by annual species of *Salicornia*; and the mudflat, which is exposed only at low tide and is usually devoid of vegetation except for algae and seagrasses such as *Zostera* spp.. The three components are also referred to respectively as schorre, high slikke and slikke, which are Flemish terms now in international use. The seaward edge of the schorre or high marsh is frequently cliffed and at such sites the low marsh may be missing.

Although isolated plants may establish in the wettest areas of
FIGURE 6.1

Morphological features of tidal marsh and mudflat in temperate climates, after Guilcher (1979).
high marsh, Spartina colonisation is largely confined to the low marsh, or to similar mudflat levels seaward of the micro-cliff (Figure 6.1). Sites at which the grass has established in Australia and New Zealand have a generally warmer climate than Spartina sites in Britain and Europe, for the limits of Spartina in the Southern Hemisphere are 35°S and 46°S while in the Northern Hemisphere the grass occurs between 48°N and 57.5°N (Ranwell 1967a). Guilcher's schema may be applied to sites where Spartina has established in Australia, but there are certain differences in the vegetation of the high marsh and low marsh which are primarily a response to higher temperatures.

Compared with Spartina sites in Britain and Europe, the high marsh at Australian stations is characterised by a greater abundance of shrubs, which are also generally taller than at sites in the Northern Hemisphere. This is especially the case in high marsh at Victorian Spartina sites, where the shrub Arthrocnemum arbusculum is commonly more than 1 m in height. Further, while trees are absent from high marsh in Britain and Europe, the landward margins of high marsh at Australian Spartina sites are occupied by Melaleuca spp., at levels occasionally inundated by maximum spring tides.

In contrast to the low marsh at sites described by Guilcher (1979), the low marsh at Australian sites is not extensively colonised by Salicornia spp.. Patches of S. quinqueflora occur on the higher levels of low marsh where the substrate is sandy, but generally the species is confined to the lowest levels of high marsh. Nowhere has its spread been as extensive as that of S. europaea and S. dollychostachya at sites in the Wadden Sea (Plate 6.1) or as rapid as that described by Joenje (1978) for the same two species in the Lauwerszeepolder, Northern Holland.
PLATE 6.1

In addition, *S. quinqueflora* is a perennial plant, while most European species die out in winter and thereby increase the susceptibility of the low marsh to erosion. Kamps (1962) has shown that annual *Salicornia* species promote accretion only indirectly, by trapping viable fragments of *Puccinellia maritima* which would otherwise be deposited as tidal litter at high water mark. König (1976 *pers. comm.*) has suggested that the spread of *Spartina* has suppressed the growth of annual species of *Salicornia* along the west coast of Schleswig-Holstein, as the tall perennial grass restricts the amount of light available for seed germination and seedling growth.

A final difference between Guilcher's schema and marshes at Australian *Spartina* sites is that the low marsh in Australia is colonised by mangroves, except in Tasmania and in the Gippsland Lakes. As noted in Section 5.3, *Aegiceras corniculatum* occurs at Currambene Creek, New South Wales, but elsewhere *Avicennia marina* is the only mangrove species to grow in association with *Spartina*. Chapman (1976) has given the southern limit of this species in Australia and New Zealand as 37°S, but isolated plants are found at 38°55'S in Corner Inlet, Victoria, which is evidently the southern world limit of mangroves. As the roots and pneumatophores of mangroves persist throughout the year, the potential for sediment accretion is greater than at European sites where the low marsh is colonised by annual species of *Salicornia*.

There are many sites in Australia where the spread of *Spartina* has had no measurable impact on the level of the intertidal zone. In these places, its occurrence is of little geomorphological significance. However, at sites where the spread of *Spartina* is accompanied by accretion of sediment, depositional features are formed on the low marsh and upper
levels of mudflat. Such features are hereafter referred to as terraces, a term used to describe any minor or major depositional landform which has developed in response to Spartina growth. The development of Spartina terraces may substantially modify the elevation, slope, drainage and microtopography of the intertidal zone, to the extent that Guilcher's schema is not characteristic of sites at which accretion has been pronounced. The early stages of this transformation may be described in terms of changes to the profile of the intertidal zone, the initiation of tidal channels, and the development of surface features not characteristic of unvegetated mudflats.

6.2 Terrace profiles

The development of Spartina terraces in Australia is most clearly seen at sites where the intertidal flats are most extensive - the Tamar estuary, Andersons Inlet, and along the inner banks of meanders at Albert River and Bass River. The potential for development of broad terraces is less along the banks of smaller streams such as Tidal Creek and Agnes River, and also along the steeply-cliffed outer banks of meanders at the sites of larger rivers, but in many places small terraces only a few metres wide have been formed. Figure 6.2 gives examples of the types of terrace profile now found on low marsh in Australia, each reflecting differences in morphological responses to Spartina growth.

6.21 Type A

Type A profiles are those where accretion in Spartina has been at a maximum within the middle of the sward, with negligible
FIGURE 6.2 Types of terrace profile in Australian Spartineta, 1981. P indicates point of maximum accretion.
sedimentation at the seaward (lower) and landward (upper) margins. They are characterised by a break of slope at the point or zone of maximum accretion, to landward of which the slope of the intertidal zone is less than that of the previously bare mudflat, while the gradient to seaward has been steeplened. The example given in Figure 6.2 is representative of profiles developed under continuous sward on the outer banks of meanders at Albert River, and similar to those at Bass River, where the tide range is greater and the intertidal zone consequently steeper. Profiles of the same type also occur on the broadest sections of intertidal mudflat in Tidal Creek and Agnes River. While terraces in the Duck River and at some sites in the Tamar estuary bear a strong morphological resemblance to Type A profiles, they have not been surveyed over sufficiently long intervals for this to be confirmed.

Field evidence suggests that the Type A terrace profile is a common early stage in the development of terraces, but one which is unlikely to persist as a permanent feature. Such terraces occurred along the inner margin of the spit in Andersons Inlet in the late 1960s, during the initial stages of *Spartina* colonisation. As noted in Section 4.1, seedlings first established at this site at levels between 0.61 m and 0.83 m above Inverloch datum, and in areas where seedling density was high the young plants quickly merged to form clumps and incipient swards. As a consequence of accretion in the centre of colonised zones, where stem density was generally greatest, low Type A terraces soon developed on the formerly bare intertidal mudflat.

However, at the same time that *Spartina* cover was increasing within the colonised zone due to lateral expansion of clones and tussocks, new plants had established along the seaward margin. Seedlings quickly
developed at levels down to 0.31 m above Inverloch datum, where they soon fused to extend the seaward margin of the sward. Because of high stem density resulting from coalescence of numerous young plants and tussocks, the point of maximum accretion rapidly advanced towards the outer edge of the marsh. The result was a break of slope near the seaward margin of the sward rather than in its centre, which is the chief characteristic by which the Type A profile has been defined.

Even at sites where the *Spartina* frontier is advancing solely by rhizome extension, Type A profiles generally do not persist once *Spartina* has reached its lower limit of growth. Where the seaward margin becomes stable, stem density increases in the lowest zone of the sward and soon approximates that in zones further landward. This is normally accompanied by seaward migration of the point of maximum accretion, which changes the terrace profile.

The Type A profile is the nearest Australian equivalent to profiles described by Ranwell (1964a) at Bridgewater Bay, Somerset. Ranwell found that maximum accretion in continuous marsh about 200 m wide occurred at a point about 50 m from the landward margin, and that seaward of this point the rate of accretion fell almost linearly in relation to decreasing height of the marsh. The mean spring tide range of 11.5 m at this site (Morley 1973) is far greater than spring tide ranges at Australian stations, and accounts for the marsh being much wider than marshes of similar gradient in this country. The morphological transformation of Type A profiles described above is consistent with Ranwell's conclusion that the point of maximum accretion at Bridgewater Bay is advancing steadily seawards, and that the marsh will eventually approximate those described by Richards (1934) in the Dovey estuary,
where maximum accretion was recorded near the seaward limit.

Type A terrace profiles have persisted in Australia only at sites sheltered from wave action but exposed to strong tidal currents moving laterally along the intertidal zone. They are characteristic of river channels, but do not occur on broad intertidal flats in very calm sedimentary environments. In the absence of vegetation, sites exposed to strong tidal currents commonly have a convex upper surface above mid-tide level, and a concave lower surface extending to low water mark. Sediment deposition is greatest at the highest mudflat levels, which are submerged only at slack water high tide and during the last part of the flood stream and the beginning of the ebb. The progressive steepening of the intertidal zone from high tide to mid-tide level reflects an increase in current velocity, which causes less sediment to be deposited or retained at mid-tide level than higher up on the mudflat. Similarly, the concavity below mid-tide level reflects diminishing water velocity towards slack water low tide.

*Spartina* has colonised the convex upper surface between high tide and mid-tide levels, where its growth has locally reduced the velocity of ebb and flood currents. Not only has sediment deposition often been accelerated, but maximum accretion has occurred at lower mudflat levels than previously. As a consequence, that part of the formerly convex upper surface which lies landward of the point of maximum accretion has been converted to a virtually flat surface of very low gradient (Figure 6.2). To seaward of the point of maximum accretion, the gradient of the intertidal zone is steeper than that of the previously unvegetated mudflat. However, as the point of maximum accretion lies well behind the *Spartina* frontier, this slope is much less than at sites
occupied by Type D terraces (Figure 6.2), where maximum accretion is within the seaward zone of the sward.

Three factors are thought to be important in the maintenance of Type A terraces. The first is the habit of growth of _Spartina_. In Albert River, Bass River and at other sites where this type of terrace occurs, seedlings no longer establish on bare mud at lower levels than the seaward frontier of the sward, which is advancing solely by production of new tillers from outwardly-directed rhizomes. The absence of seedlings is believed to be due to strong ebb and flood currents, which create a mobile substrate unsuited to seedling establishment and survival. At sites where Type A profiles still persist, tiller density in a zone along the margin of the sward is less than that in its centre, where the fusion of individual clones has obscured the phasic pattern of growth described by Caldwell (1957) and a thick mat of rhizomes produces an abundance of stems. A greater volume of sediment is trapped and retained in areas of high stem density than in areas of low stem density, which in addition occur at lower levels of the marsh where the higher velocity of tidal currents causes less sediment to be deposited.

The second factor contributing to stability of Type A terraces is the method of delivery of sediment, which is entirely by tidal currents. The margins of terraces with steeper seaward slopes sometimes also receive sediment during periods of constructive wave action, which deposits along the outer edge of the marsh generally coarser material than that precipitated by the tide. This causes more rapid seaward migration of the point of maximum accretion than would otherwise occur, and a consequent increase in gradient of the seaward margin of the marsh.
Where fine sediment is deposited in dense *Spartina* towards the rear of the marsh, the gentle seaward gradient of Type A terraces is retained.

Finally, those Type A terraces which still persist in Australia all occur at sites where sediment deposition has not been rapid. At no site has the rate of accretion been greater than 2 cm per annum, even at the point of maximum accretion. Deposition at the present seaward and landward limits of *Spartina* has been insufficient to bring about a change in elevation which could be detected by repeated surveys from permanent datum points, and only a thin veneer of sediment has been deposited on brick dust layers originally put down on bare mud. While Type A terraces are a transitional stage in the development of other types of terrace, their existence is prolonged at sites which lack an abundant supply of sediment.

6.22 Type B

Type B terraces are those where sediment is deposited within the outer margin of the sward and beyond its seaward limit, but which are otherwise similar to Type A terraces. The example given in Figure 6.2 is side B-A of quadrat II 6 at Nolans Bluff (see Section 5.26), where the zone of maximum accretion is broad and the terrace surface consequently convex. This convexity is common in Type B profiles, but as many have quite marked breaks of slope it has not been taken as a defining characteristic.

Terraces of this type occur in Victoria only along the north and west shores of Andersons Inlet, and at the mouths of Tidal Creek, Agnes River and Bass River. They are found in front of formerly eroding shorelines along the margins of high marsh, where small beaches were
periodically emplaced on the intertidal zone during phases of constructive wave action and removed during phases of scour. Two factors are important in their formation.

First, Type B terraces form where sediment is delivered episodically by constructive wave action. Usually this material is sand of largely marine origin, which is deposited on the sward and against its seaward margin. The amount of sediment deposited is largely independent of the presence of Spartina, for a similar depth of sediment is also laid down on adjacent unvegetated mudflats at the same level.

Unconsolidated sediment in front of the seaward margin of Spartina may raise the level of the intertidal zone to the point at which it can be colonised by the grass. Where this occurs, invasion by rhizomes and growth of tillers will stabilise this material, which then becomes a permanent part of the terrace. However, it is more common for much of the unconsolidated material to be removed during subsequent periods of erosion, leaving a low cliff in Spartina exposed at the edge of the sward (Figure 6.2).

The second factor affecting the development of Type B terraces is the growth form of Spartina in the lower part of the sward. Such terraces have formed only at sites where Spartina near the seaward margin is low-growing or depauperate, either as a result of irregular periods of prolonged immersion, as at Nolans Bluff, or as a result of the mechanical action of waves. Because of low stem density and generally small tillers, much of the sediment deposited on the sward can be removed by destructive wave action or strong tidal currents, leaving only a shallow layer of sand. Where Spartina growth is more vigorous this material is largely
retained, which brings about seaward migration of the point of maximum accretion and transformation of the terrace to Types C or D (Figure 6.2).

*Spartina* terraces of any type are formed as a result of the ability of *Spartina* to promote localised deposition of sediments which might otherwise be carried elsewhere, and its ability to retain that sediment during periods of marsh degradation. In the case of Type B terraces, the latter is by far the more important process. It seems likely that the consequent gradual accretion of sediments will eventually raise the level of the terrace to a point at which factors causing loss of plant vigour in the lower part of the marsh are reduced or eliminated, in which case other types of terrace might develop. However, there is no evidence to suggest that this has so far occurred at any Australian site.

6.23 Type C

Type C terraces are those where the profile beneath the seaward margin of the sward is gently concave, in contrast to the constant seaward slope of Type A terraces and the constant or convex seaward slope of Type B terraces. They are common in the Tamar estuary, at sites where sward formation is completed and the main channel is sufficiently far offshore to impose no limit on marsh progradation. The example given in Figure 6.2 is of the terrace at Windermere (see Plate 2.21), where *Spartina* was introduced in 1947 and 1955. In other places in the Tamar estuary such features are more extensive, ranging from 200 m to 900 m in width. Type C terraces have also developed on the broad intertidal flats in Andersons Inlet, but at most sites they have been temporary features which were soon transformed into terraces of other types.

Except in the Nelsons Shoal area, where young plants continue
to establish beyond the limit of continuous sward, the seaward spread of *Spartina* along the margins of swards occupying Type C terraces in the Tamar estuary is now very slow. Small clones along the outer margin of the sward at Windermere have increased in size only slightly in the past four years. The lower levels of the marsh show signs of channel die-back (Plate 6.231) associated with excessive wetness of substrate (Goodman et al. 1959), and suggesting that *Spartina* is approaching its limit of tolerance to submersion. The concave outer margins of the terrace are separated by a gently convex break of slope from the upper part of the marsh, which has a low seawards gradient.

A notable contrast between the Tamar estuary and other Australian *Spartina* stations is the virtual absence of high marsh (Guilcher 1979) along the landward margin of areas colonised by *Spartina*. As described by Phillips (1975), the estuary occupies the Tamar Trough, which was formed by faulting in the late Mesozoic or early Tertiary, subsequently infilled during the Tertiary by silts, sands, clays and gravel, and then drowned during the Holocene marine transgression. The upper level of the intertidal zone is flanked by an abrupt break of slope (Plate 6.232), and areas available for saltmarsh development are few. Before the introduction of *Spartina* the intertidal zone was almost completely bare of vegetation, with areas of high marsh restricted to a narrow fringe at the base of the valley-side slopes and the most sheltered sections of small embayments.

Type C terraces in the Tamar estuary have been identified solely in terms of surface morphology, for their present rate of growth is slow, and it has not been possible to record surface profiles over an interval of time sufficient to reveal the manner in which they develop. However,
PLATE 6.231

Outer margin of Windermere sward, July 1978, showing broken stems and rotting root-crowns. Although typical of over-wintering growth forms this condition was observed to persist in the summer of 1980/81, suggesting the beginning of channel die-back.

PLATE 6.232

Rear of Spartina marsh at Rosevears, January 1980. Note abrupt break of slope where marsh abuts the shoreline.
Phillips (1975) has reported results of a series of bores put down along a transect at Windermere, within a few metres of the Type C terrace example given in Figure 6.2. From a photographic enlargement of a cross-section diagram in which the results are presented, Figure 6.231 has been prepared at the same vertical exaggeration as profiles in Figure 6.2.

Phillips found that brown sandy silt beneath the Windermere sward extended down to a layer of blue and brown clay (Figure 6.231), which was taken to be the surface of the intertidal zone before the introduction of Spartina. Remains of Spartina roots were recovered from the base of the surface layer down to a maximum depth of 2.35 m, at a distance of 75 m from the landward edge of the sward. Seawards from that point a greater depth of sedimentation was recorded above the clay surface, but root remains of Spartina were found at increasingly shallow depths until at the outer margin of the sward their maximum depth was 1.83 m.

There is reason to believe that the depth at which Spartina remains were recovered may have been misjudged. Both Phillips (1975) and the author have confirmed that the uppermost part of the marsh is submerged by all spring tides, but exposed during minimum neap tides. When the estimated mean tide ranges for the Windermere site, extrapolated from known tide ranges at Georgetown and Launceston (Section 4.1), are plotted on the profile at levels consistent with the submergence characteristics of the highest parts of the sward, it is found that the lowest level of Spartina remains is not much above the level of mean low water spring tide, and below that of mean low water neap tide (Figure 6.231). This is also the case using known tidal data for Launceston, which has the highest
Section through Spartina Sward at Windermere redrawn from Phillips (1975), with additions by the author (as described in text).
tide ranges in the Tamar estuary. It is unlikely that *Spartina* could have established at a level subject to such prolonged submersion, and although tide ranges may alter as a result of estuarine infilling and consequent changes in tidal ventilation, there is no evidence to suggest a substantial variation in tidal regimes in the Tamar estuary over the past thirty years.

Phillips (1975) does not give details of the corer used to extract *Spartina* remains or of the number of cores taken. The use of coring instruments in *Spartina* marshland has been discussed by Hubbard and Stebbings (1968), who note the difficulties of recording accurately the sequence of biological remains in relation to level. Major problems are that of minimizing displacement of soft sediments during sampling, blockage by a plug from the dense layer of roots and rhizomes near the surface, and an inability to retain soft or waterlogged sediments within the sampling head. While the author has been able to recover *Spartina* remains down to 45 cm depth in the centre of the Windermere sward using a piston corer built according to specifications given by Redfield (1975), and down to 20 cm near the seaward limit of the sward, deeper sampling at both sites was prevented by excessively wet substrates which could not be held as a core.

It is known that by 1955 the Windermere plantings extended out to a point 100 m from high water mark, although rates of survival and establishment were low at a distance greater than 60 m (Martin 1966 in litt.). Subsequent further growth has brought the seaward margin within this general vicinity to a point about 110 m from the shore, although along the transects surveyed both by Phillips (Figure 6.231) and the author (Figure 6.2) the sward is approximately 92 m wide. If the
estimate of 2.35 m of sediment at a distance of 75 m from the shore is accurate, it indicates one of the highest rates of accretion so far recorded in Spartina marsh, for as deposition occurred between 1955, when growth was sparse (Martin 1966 in litt.), and 1972, when the cores were taken (Phillips 1975), the average rate of accretion was 13.8 cm per annum over 17 years. Allowing for negligible accretion before sward formation was completed, and taking into account the various processes of settlement described by Ranwell (1964a), which include oxidation of organic matter and direct compression from the weight of overlying sediment, it would appear that accretion rates in some years were as high as 15-20 cm.

Such rates are not impossible, for extreme rates of accretion over short periods have previously been reported: 17 cm per annum over three years in the Vire estuary, France (Corbiere and Chevalier 1922); 17 cm per annum for one year at Bridgwater Bay, Somerset (Ranwell 1967a); and 20 cm per annum for five years in the Sloedam, Holland (Verhoeven 1951). However they are believed to be highly unlikely, particularly given doubt about the level from which the lowest Spartina remains were taken. A sustained rate of accretion as high as 13.8 cm per annum over a period as long as 17 years, and a total depth of accretion of the order of 2.35 m, are greatly in excess of sedimentation in Spartina swards previously reported in the literature. Even under exceptionally favourable conditions of a large tide range and an abundant supply of sediment, the foreshore level at Bridgwater Bay was raised by only 1.8 m over 37 years, which is an average accretion rate of 5 cm per annum (Ranwell 1967a).

The mudflats seaward of the Windermere sward are over 500 m wide, and slope gradually out to the edge of the main channel. The position of the channel has remained unchanged at least since 1956, as
seen from aerial photographs taken at that time. As the seaward edge of the sward shows no signs of cliffing (Plate 6.231), Phillips' diagram (Figure 6.231) implies that up to 1.83 m of sediment has been deposited over a large expanse of bare mudflat since 1955. While the Windermere mudflats are clearly a depositional environment, charts held by the Port of Launceston Authority suggest that shoals have risen at most by 0.6 m to 0.9 m (2-3 ft) during the past 20 years. It is therefore believed that the layer of blue and brown clay (Figure 6.231) was probably not the level of the surface of the intertidal zone at the time of Spartina introduction, at least beyond the point where it dips sharply beneath the surface layer at about 20 m from the shore. Instead, it is suggested that this initial surface is best approximated by the dashed line shown in Figure 6.231, which places the lowest surviving plant in 1955 at about mid tide level, as described by Martin (1966 in litt.).

The development of the Type C terrace at Windermere is a response to the colonisation of this assumed initial surface by Spartina, and the subsequent pattern of sediment deposition within and beyond the Spartina sward. Martin (1966 in litt.) has reported that sward formation was rapidly achieved from the 1955 plantings within 60 m from the shore, but that growth was sparse among plants placed further seaward, many of which failed to survive. By 1962 the seaward limit of the sward had advanced by 30 m, and by 1966 the outer margin was 110 m from the shore. This was achieved primarily by establishment of new plants, yet in 1955 none of the plants introduced by the Tasmanian Department of Agriculture or the Marine Board of Launceston had been able to survive at a distance beyond 100 m. Martin (1966 in litt.) observed that "the process of expansion is by appearance of new colonies beyond the consolidated area and the gradual mergence with the main area . . . as a result of progressive
raising of the level of the mud." Sediment deposition against the margin of the sward thus created a favourable habitat for *Spartina* growth, and thereby promoted its seaward extension.

Although the growth and development of Type C terraces has not been recorded in the Tamar estuary, terraces with similar morphological properties have occurred on a much smaller scale in Andersons Inlet, where they also were formed at sites where emplacement of sediment against the seaward margins of swards had raised the level of the mudflat to a point at which forward *Spartina* growth could continue. However such terraces were largely transitory features, for at most sites the advancing seaward frontier of *Spartina* soon encountered permanent channels marking the edges of segments of the intertidal zone. At this stage marsh progradation ceased, but continued rapid accretion of sediment in *Spartina* on the concave seaward slope caused the point of maximum accretion to migrate almost to the outer margin of *Spartina*, thus changing the terrace profile.

Observations of profile changes in Andersons Inlet have suggested a possible sequence of development for the Windermere terrace. This is given in Figure 6.232, which seeks to demonstrate the relationship between sediment deposition on bare mud and the formation of a concave seaward slope. The vertical exaggeration in the figure is twice that used in Figures 6.2 and 6.231.

It is likely that the initial depositional feature in the 60 m wide sward was a Type A terrace, with highest rates of accretion near the centre of the sward and lower rates in the seaward and landward margins (Stage 1). As stem density increased and accretion continued, the general level of the terrace was raised, the point of maximum accretion moved
Evolution of a Type C Spartina terrace, as applied to the Windermere site.
seawards, and the outer slope was steepened (Stage 2). The terrace increased in size but maintained its Type A characteristics, which are common in the early stages of formation of several different types of terrace.

In Stage 3, sediment was emplaced on the intertidal mudflat seaward of the sward, where *Spartina* growth was sparse and deposition largely independent of its presence. This may have been either episodic or continual, and could have occurred at any time during growth of the Type A terrace. The result was formation of a concave outer slope, most clearly defined where the seaward gradient of the Type A terrace was already steep, or where a large volume of sediment was emplaced over a short period of time.

By raising the level of the mudflat, sedimentation encouraged the forward spread of *Spartina* seedlings. Growth was most rapid at the higher levels of the newly-colonised zone, where high seedling density combined with rhizome extension from the sward to quickly extend the outer margin of continuous *Spartina* cover. As the higher parts of the marsh were by then approaching their upper limits of growth, and *Spartina* cover was low at the outer limit of colonisation, highest rates of accretion occurred within the seaward half of the sward. As a result, the concavity of the seaward slope of the terrace was reduced (Stage 4).

Where no subsequent sedimentation occurs along the seaward margin of the sward, or where marsh progradation is prevented by some other factor, the Type C terrace may revert to a Type A terrace (Stage 5). This occurred at Andersons Inlet, where further outward growth was prevented by channels at the outer limit of colonisation. Eventually the point of
maximum accretion advanced even further seaward and the gradient of the seaward slope was increased sharply, thus forming terraces of Types D and E (Figure 6.2). In the Tamar estuary however, the characteristic terrace profile is that shown in Stage 6, where the seaward slope of the terrace is gently convex beneath continuous *Spartina* sward.

As the width of the Windermere mudflats is over 500 m, there is no reason why marsh progradation could not continue as rapidly as sediment is deposited along the outer margin of the sward. However, as noted previously, seaward expansion at most sites is presently slow. This suggests that the supply of sediment is at least partly episodic, or, if continual, then at very low rates.

6.24 Type D

Type D terrace profiles are defined by a steep outer margin and a marked break of slope at the point or zone of maximum accretion, which lies almost at the seaward limit of *Spartina* growth (Figure 6.2). They occur at sites where the spread of *Spartina* has been accompanied by pronounced deposition of sediment, and where the edge of continuous sward is exposed to wave or current action. While examples of Type D terraces are found at all Australian sites except Buckland Park, South Australia and Duck Bay and Robbins Passage, Tasmania, they are common only in Albert River and Bass River, at sites in the Tamar estuary where the main channel is close to the shore, and on the central intertidal flats in Andersons Inlet.

Three different sequences of profile development have been observed in Type D terraces in Australia, as shown in Profiles 1, 2 and 3 in Figure 6.24. The first is characteristic of sites where the inter-
FIGURE 6.24

Type D terraces: evolution (Profiles 1, 2 and 3) and outer margins (Profiles 4, 5 and 6).
tidal zone was initially steep, while the second and third have occurred on broad intertidal flats of much gentler gradient.

At Albert River and Bass River, and to a lesser extent at Moodys Inlet and Agnes River, Type D terraces have developed from Type A terraces (Profile 1, Figure 6.24). In addition to steep intertidal gradients before the introduction of Spartina, sites at which this has occurred have two other elements in common. First, Spartina reached its lower limit of growth at least by 1974, and since that time there has been no further seaward colonisation by either seedling establishment or rhizome extension. At most sites the seaward limit is thought to have been determined by strong tidal currents rather than intolerance to greater periods or depths of immersion, for Spartina has grown to lower levels on nearby mudflats further from the main channel. Tidal currents have not only prevented seedling establishment but in places have eroded the edge of continuous sward, and in Moodys Inlet broken tillers in new growth along the lower margins of clumps suggest that alternating ebb and flood currents may reach sufficient velocities to weaken stems produced from outwardly-directed rhizomes.

Second, at all sites where Type D terraces have formed from Type A terraces, stem density and stem height have been at a maximum for Australian conditions. Densities of up to 90 stems per 25 cm x 15 cm quadrat have been recorded at Bass River, and stem heights greater than 60 cm are common. The resulting thick network of stems and leaves has provided a very effective sediment filter; accretion rates of up to 7 cm per annum have occurred within the margins of swards occupying Type D terraces at Andersons Inlet. At sites where frontal advance has ceased and Spartina growth is profuse, high rates of sedimentation on Type A terraces have been accompanied by rapid seaward migration of the point
of maximum accretion, which has created a Type D profile.

Profile 2 (Figure 6.24) and Figure 6.2 show the second sequence of development found in Type D terraces. This is characterised by maximum accretion near the seaward limit of Spartina from the time of marsh inception, with diminishing rates of accretion to landward. The result is a general increase in level but reduction in gradient of the intertidal zone, and development of a steep terrace margin beyond the point of maximum accretion near the outer edge of the sward. The example given in Figure 6.24 is of terrace formation in quadrat II 1 at Andersons Inlet (see also Figure 5.213); the tidal creek shown in the cross-section for 1979 is not necessarily characteristic of either Type D terraces or this sequence of development, as such creeks are also formed in terraces of other types.

Type D terraces have developed in this manner only at sites where the initially unvegetated mudflats were already of very low gradient, and at such a level that the depth and duration of tidal submergence over most of the intertidal zone were well within the limits of Spartina tolerance. Further, they occur only in places where mudflats of this type were rapidly and almost uniformly colonised by Spartina seedlings, and where spread was sufficiently vigorous for the grass to attain up to 100 per cent cover within a few years of seedling establishment. In such conditions, accretion rates have been greatest near the seaward limit of Spartina, where plant cover, stem density and stem height are similar to those at slightly higher levels of the marsh. As noted in Section 5.21, 34 cm of sediment was deposited in the seaward margin of the Type D terrace at Western Split Island between 1971 and 1979, while only 8 cm was deposited at the rear of the marsh during the same period.
Profile 3 (Figure 6.24) shows the development of Type D terraces from Type C terraces. This third method of Type D terrace formation has been observed only at Andersons Inlet where, as noted in the previous section, Type C terraces have been mainly transitory features. Type C terraces have formed on the intertidal zone south of the strait between Western and Central Split Islands (see Plate 5.231), where forward growth of Spartina on low-level mudflats has been promoted by emplacement of sediment against the edge of the sward. Where marsh progradation has been halted by the presence of major channels, the concave seaward slope has gradually been transformed into a steep Type D seaward slope, as the point of maximum accretion has moved nearer to the outer edge of the marsh.

In Australian Spartineta, the steep outer margins of Type D terraces are generally stable, although recession has occurred at some sites. Stable margins are found at sites sheltered from wave action, and where the velocity of tidal currents is low. Profile 4 (Figure 6.24) shows paired Type D terraces with stable margins in the ox-bow colonised by Spartina at Bass River, where the former river channel has been narrowed to a tidal creek which transmits the ebb and flood streams to and from the marsh (Plates 6.241, 6.242, 6.243). In the total absence of waves, and with current velocities much lower than those in the main river channel, the position and slope of the steep seaward margin has not changed since channel markers were pegged out in 1972. Stable margins are also common in Type D terraces in the low wave energy environment of the central intertidal mudflats at Andersons Inlet (Plate 6.244).

At Poole Harbour, Hubbard (1965a) has shown that seaward slopes along the outer margins of Spartina swards have eventually over-steepened as the elevation of the marsh has continued to increase. This is evident
Type D terraces with stable outer margins at the ox-bow site in Bass River, April 1975. Photographs show the passage of a high spring tide. (Photographs R.A. Gell)
PLATE 6.244

Type D terrace with stable outer margin,
Andersons Inlet, April 1979.

PLATE 6.245

Frontal erosion of Type D terrace near
Rosevears, Tamar estuary, January 1981.
in the formation of cliff edges at sites such as Keysworth Marsh, followed by frontal erosion and *Spartina* recession. While examples of minor cliffing can be found at all Australian stations where Type D terraces have developed, frontal erosion and *Spartina* recession are not common at any site.

Incipient frontal erosion of Type D terraces is most clearly seen in this country along the west bank of the Tamar estuary to the south of Rosevears (see Figure 2.21), where a low cliff generally not more than 20 cm in height has exposed the near-surface layer of living *Spartina* roots and rhizomes (Plate 6.245; Profile 5, Figure 6.24). However, *Spartina* recession has so far been negligible. It is unlikely that cliffing has been initiated by over-steepening accompanying upward growth of the marsh, for terraces of similar elevation at nearby sites retain stable margins. Rather it is believed that erosion has been caused primarily by the wash created by power boats and shipping, for cliffing occurs only at sites where the main navigable channel is closest to the shore.

At Albert River, frontal erosion of Type D terraces has been followed by *Spartina* recolonisation. This has occurred along the outer banks of meanders, where accretion in *Spartina* has formed a protective sediment terrace against formerly-eroding saltmarsh (Plate 6.246). Current action has undercut the steeply cliffed outer margins, where up to 0.7 m of sediment has been deposited, by eroding soft sediments beneath the more resistant upper layer of living roots and rhizomes. Clods of *Spartina* which has slumped from the top of the undercut cliff have re-established seaward of the terrace margin, where continued accretion leads to the formation of complex terraces consisting of near-horizontal
PLATE 6.246

Development of complex terrace, Albert River, February 1979. The clone in the foreground has established from Spartina clods eroded from the cliff marked by the lower pole. The higher pole indicates the now largely inactive cliff in formerly eroding saltmarsh.

PLATE 6.247

Repaired slump in S. alterniflora marsh, Scorton Creek, Barnstable Marsh, May 1976. Scar left by former slump is being indicated. Further slumped blocks are evident along the channel margin.
steps at different levels. This process of healing and repair has not
been observed elsewhere in Australian *Spartineta*, although the author has
seen a similar process occurring in *S. alterniflora* marshes at Sapelo
Island, Georgia and Barnstable Marsh, Massachusetts, U.S.A. (Plate 6.247).

6.25 Type E

Type E terrace profiles are defined by a landwards slope
towards the rear of the marsh (Figure 6.2). The only Australian examples
are at Cherry Tree Creek, as described in Section 5.27, and at one site
on Nelsons Shoal in the Tamar estuary. However, it is evident that
similar slopes are developing in Type D terraces abutting the islands in
Andersons Inlet, for mangroves along the landward margins of the swards
are now waterlogged for long periods.

In France, Verger (1968) has distinguished between "contrary
marshes", which have a landward slope, and "conformable marshes", which
slope towards the sea. He notes that marshes with landward slopes are
characteristic of sites exposed to frequent wave action, while seaward
slopes are more common in sheltered environments. Jakobsen (1954, 1964)
has given examples of contrary marshes developed in the Danish Wadden
Sea, at sites where tidal currents are weak and wave action is the more
important factor in saltmarsh development. Sediment removed by wave
action along cliffted high marsh (Guilcher 1979) may be deposited as an
offshore bar, which can withstand tidal currents and is subsequently
colonised by pioneer species such as *Salicornia europaea* and *Puccinellia
maritima*. Accretion of sediments raises the bar above mean high water
level, and the lagoon by which it is separated from high marsh is gradually
infilled and invaded by plants. Thus the previously eroding marsh will
prograde, but between its new outer margin and the former cliff edge
the surface of the marsh has a marked landward slope.

Verger and Jakobsen were both primarily concerned with sites where Spartina had not been a factor in saltmarsh development. While depositional features similar to Type E Spartina terraces have been shown to evolve through wave action, the process described by Jakobsen cannot account for the formation of landward slopes in Spartina at Andersons Inlet. The Type E terrace profile which has developed at Cherry Tree Creek, and those in an incipient stage of development elsewhere in the estuary, occupy low wave energy sites where saltmarsh was slowly prograding under Avicennia marina at the time of Spartina colonisation. Such areas are nourished by sediment supplied from other parts of the inlet by tidal currents and constructive wave action, rather than derived from wave erosion of the adjacent saltmarsh fringe.

Two different processes are thought to account for the formation of Type E terraces. The first is emplacement of cheniers on the seaward edge of the marsh. Although storm surge deposits are common on terraces of various types, the only Australian site at which they have caused a pronounced landward slope is on the western edge of Nelsons Shoal (Plate 6.251). Here successive ridges of coarse sand have been deposited along the seaward margin of the sward, providing a source of sediment for gradual transfer towards the rear of the marsh. A similar feature is seen at Patchins Point, Poole Harbour (Plate 6.252), where a shingle chenier forms a rim around the margin of the sward. While storm surge deposits undoubtedly occurred before the development of Spartina marshlands, such material was spread fairly evenly over the entire intertidal zone or deposited at high tide along the margin of high marsh. By reducing the gradient of the intertidal zone and providing a locus for
PLATE 6.251

Sand chenier emplaced against outer margin of Spartina sward, Nelsons Shoal, Tamar estuary, January 1981. Photograph is taken from offshore.

PLATE 6.252

Shingle chenier at Patchins Point, Poole Harbour, June 1976. Note pan die-back arising from prolonged saturation.
sediment deposition, *Spartina* has encouraged chenier formation and reduced the rate at which sediment may be dispersed.

The second process involves higher rates of accretion in the seaward half of the sward than in the zone to landward, which results in development of a gradual landward slope. At Andersons Inlet this has occurred in the absence of storm surge deposits, although it is likely that both processes have elsewhere combined to form Type E terraces.

Landward slopes in *Spartina* terraces at Andersons Inlet are developing only at sites where the grass grows along the seaward margin of an extensive *Avicennia* fringe. Before the introduction of *Spartina*, the intertidal zone formed gently-shelving shoals of lower gradient and slightly higher elevation than at more exposed sites. Although mangroves occur only in calm sedimentary environments, their presence contributes to the creation of such shallow water conditions, as they shelter the nearshore zone from the effects of offshore winds at high tide, and thereby promote deposition of sediment (Bird 1971).

Figure 6.25 is a diagrammatic representation of the formation of Type E terraces seaward of mangroves, and of terrace development at sites where mangroves are absent. At the time *Spartina* was introduced to the estuary, sites colonised by mangroves were slowly prograding (Stage A1), while recession was common along shorelines with unvegetated intertidal zones (Stage B1).

*Spartina* is tolerant of longer periods of tidal submersion than mangroves, and was therefore able to establish at lower levels to seaward (Stage A2). As mudflats along prograding shorelines had very gentle gradients, seawards colonisation was more extensive at these
A. Mangroves present

B. Mangroves absent

Diagrammatic representation of Type B terrace development seaward of mangroves (left), and terrace development at sites where mangroves are absent (right).

FIGURE 6.25
sites than in places where the intertidal zone was steeper. However, the grass was unable to colonise bare mud in the zone of pneumatophores beneath the *Avicennia* canopy, presumably because of insufficient light. Along unvegetated mudflats, *Spartina* established seaward as far as its limit of tolerance to submersion, and also colonised the higher intertidal levels elsewhere occupied by mangroves (Stage B2).

As rates of accretion in *Spartina* are greater than in *Avicennia* (see Section 5.3), terraces have developed along the seaward margin of the mangrove fringe, which now occupies a shallow waterlogged depression. Type A terraces (Stage A3) have been transformed into Type C or Type D terraces (Stage A4), at sites where emplacement of sediment against the edge of the marsh has permitted further seawards expansion. At Split Islands, Foot Island and Bluff Island (see Figure 2.31), waterlogging of the mangrove fringe is most prolonged at sites where the surface of the Type D terrace is almost horizontal. At Cherry Tree Creek, accretion in the seaward half of the sward has been sufficient to produce a reverse slope to landwards, thus creating a Type E terrace (Stage A5).

Terraces have also formed on previously eroding shorelines, which are now prograding as a result of *Spartina* growth. Some are Type A terraces (Stage B3), which have gradually developed steep outer margins as the point of maximum accretion has moved seawards (Stage B4). Type C or Type D terraces (Stage B5) have formed where deposition of sediment against the edge of the sward has been accompanied by continued *Spartina* spread.

The conditions under which Type E terraces may develop can be summarised briefly. First, their formation is favoured by near-shore
shoaling, which reduces the gradient of the intertidal zone and thus facilitates formation of landward slopes towards the rear of the marsh. Second, *Spartina* growth and hence high rates of sediment accretion must be suppressed along the landward margin of the intertidal zone, by the presence of a dense stand of mangroves in which *Spartina* fails to colonise. Where mangroves are absent at this level, accretion within *Spartina* maintains the seaward gradient of conformable marsh. Third, accretion must be at a maximum in the middle or seaward parts of the sward, in order that rates of deposition steadily diminish towards the landward margin of the terrace.

Landward-sloping terraces have so far not developed in the absence of mangroves at any Australian site. It is however expected that this might eventually occur in places where Type D terraces have approached their upper limit of growth, and where the point of maximum accretion is near the seaward edge of the sward. Hubbard (1965a) has noted that tidal flow over *Spartina* marshes in Poole Harbour was reduced as the surface of the marshland approached high tide level, thus restricting the shift of sediment to the landward parts of the sward. As a result, accretion was centred on the lower regions of the marsh, forming a bank or levee which impeded drainage and created conditions in which *Spartina* die-back could occur.

6.26 Type F

Type F terrace profiles are those which have developed on intertidal slopes composed mainly of pebbles, cobbles and boulders. The gradient of the intertidal zone is determined primarily by the angle of repose of this material, and only secondarily by accretion promoted by *Spartina* growth. Such terraces are common in the Tamar estuary, and also
PLATE 6.261

Type F terrace formed on weathered basalt, Windermere, Tamar estuary, July 1978.

PLATE 6.262

Spartina rooted in fine sediments between boulders of Tertiary sandstone, Tamar estuary.
occur at Duck River, but *Spartina* terraces at Victorian
developed only on sand and silt.

The example given in Figure 6.2 is of a terrace formed on
weathered basalt at Windermere, where *Spartina* has taken root in pockets
of sediment between large boulders up to 50 cm in diameter (Plate 6.261).
Here accretion accompanying the spread of *Spartina* has embedded the
boulders within a layer of silt, but as these continue to protrude through
the surface it is clear that *Spartina* has done little to alter the
intertidal profile.

*Spartina* has similarly colonised dolerite, ferricre
sandstone outcrops (Plate 6.262). Dolerite has weathered to gen
smaller fragments than basalt, and in places dolerite boulders h
completely covered with a thin veneer of sediment. However, sur
probing has revealed that terraces at such sites retain the conto
the previously unvegetated surface. Ferricrete 'pavements' have a
been covered, but former intertidal slopes have only been significantly
modified at sites where Tertiary sandstone, sands and clay have produced
shorelines of low gradient, on which other types of terrace profile have
developed.

6.27 Minor depositional features

In Section 6.1, *Spartina* terraces were defined as any major or
minor depositional landforms which have developed in response to *Spartina*
growth. The above discussion has considered major changes to the elevation
and slope of the intertidal zone, although in Type F terraces the
morphological response to the spread of *Spartina* has been minimal.
Several minor depositional features have been described in discussion of Series II quadrats (Chapter 5), including accretion ridges (Section 5.23), small cuspatate forelands in the lee of Spartina clones and clumps (Section 5.25), and hummocks formed on sandy shorelines exposed to strong wave action, where sediment is retained by Spartina during phases of erosion (also Section 5.25). While examples of these features occur at other sites, they are most fully developed in Andersons Inlet and need not be considered further. However, an additional comment is necessary on hummock formation in calm sedimentary environments, as described in quadrats II 2 (Section 5.22) and II 3 (Section 5.23).

The most extensive development of Spartina hummocks in Australia is at Swan Bay in the Tamar estuary (see Figure 2.21), where the grass has spread seawards for approximately 180 m from the shore. The landward margin of this zone is occupied by continuous sward, seaward from which Spartina tussocks and clones extend for over 100 m. These are arranged in a cellular pattern, with each plant separated from its neighbours by several metres of bare mud (Plate 6.27). Sedimentation has raised the level of the surface within each population unit by up to 20 cm above that of the adjacent unvegetated mudflat.

Hubbard (1965a) has reported very slow rates of lateral expansion in similar areas of discrete tussocks and clones in Poole Harbour, although sedimentation within such population units has not been pronounced. This has occurred at sites where Spartina has colonised bare mud along the seaward margins of extensive swards. As a result of high rates of accretion within continuous Spartina, these margins have been steepened and the substrate has become mobile. Spartina establishment has proved difficult on such unstable slopes, and the period of
PLATE 6.27

*Spartina* hummocks at Swan Bay, Tamar estuary, July 1978.
expansion prior to fusion has been prolonged. However, while the same phenomenon has been observed during the development of Type D terraces both in the Tamar estuary and at other Australian stations, the slow rate of clump formation at Swan Bay is not explained by steep intertidal slopes. As shown in Figure 6.27, the zone of tussocks and clones has only a very gentle seaward gradient, which is less than in the zone of continuous sward.

The prolonged expansion of tussocks and clones at Swan Bay is believed to be explained by an excessively wet substrate, which has restricted the rate of rhizome extension and promoted marginal die-back. The plants lie landward of a sandy offshore bar, which is aligned roughly parallel to the shore. Behind the bar, the surface consists of very fine sandy silt, which is saturated even at low tide. In these conditions, plant vigour has been directed mainly into tiller production rather than rhizome extension, for each tussock and clone consists of a very dense mass of tall, erect and stout stems, but without the peripheral zone of shorter or fresher tillers which is usually characteristic of vigorous lateral expansion. Rotting root-crowns around the margins of plants in the lowest-lying areas confirm that die-back and consequent recession are also factors in the low rate of cover increase.

As in quadrats II 2 and II 3 at Andersons Inlet, hummock formation has resulted from high stem density, with each population unit acting as a locus for deposition of sediment during the flood stream, and retention of sediment during the ebb. However, there are differences between these sites and that at Swan Bay. At Andersons Inlet, hummocks were formed in much smaller and closely-spaced population units, which rhizomed at the rate of 1-2 cm per annum and eventually merged. This was
FIGURE 6.27 Profile across intertidal zone at Swan Bay, Tamar estuary, from emergence marsh to seaward limit of Spartina, July 1978.
hastened by continued seedling establishment, while at Swan Bay no seedlings and few small plants are found within the hummock zone. Their absence suggests that the tussocks and clones either established before tidal drainage was affected by growth of the offshore bar, or represent the few chance survivors at a site where germination rates have been low. Eventual sward formation at Andersons Inlet has transformed the hummocks into microtopographic highs on generally accreting *Spartina* terraces, but at Swan Bay they have persisted as isolated depositional features on bare mudflat otherwise unaffected by *Spartina* growth. While hummock formation is sometimes a transitional phase in terrace development, it is also a long-term morphological response to *Spartina* growth at sites where complete sward formation may never be able to occur.

6.3 Tidal creeks and channels

The development of major types of *Spartina* terrace, as distinct from minor depositional features, creates conditions under which the intertidal zone may change from slob-land to salting, as defined by Barnes and King (1961). Where sediment deposition in *Spartina* has raised the terrace surface to approximately mean high water level, the tide no longer ebbs and flows as a continuous sheet of water, but enters and leaves the marsh by a series of tidal channels. This change may also be described as one from submergence marsh to emergence marsh (Ranwell 1972), or from low marsh to high marsh (Guilcher 1979).

Many *Spartina* marshes in Britain and Europe now exhibit drainage patterns similar to those commonly found in much older high marsh developed under different plant cover. For example, the complex dendritic drainage network at Arne Bay, Poole Harbour (Figure 6.31), where *Spartina* established in 1898 (Hubbard 1965a), bears a strong morphological
FIGURE 6.31
Tidal creeks in mature Spartina marshland at Arne Bay, Poole Harbour.
resemblance to creek systems in Australian high marsh, and to channel patterns at sites such as Plover Marsh, Scolt Head Island, Norfolk, which is known to have originated in the early sixteenth century (Pethick 1980). The similarities include features reported to be characteristic of drainage systems in mature marshes (Pestrong 1965, Pethick 1976): intricate drainage networks which are commonly of the fourth to eighth order, as defined by Strahler's adaptation (Strahler 1952) of the scheme given by Horton (1945) for classifying channel segments; meandering low-order tributaries which have a greater sinuosity than that of the higher order channels; and a 'flare' in width of the relatively straight main channels, as described by Myrick and Leopold (1963).

The immaturity of Australian Spartina marshes in comparison with those at many British sites is reflected in relatively limited development of tidal channel networks. Although the period of time necessary for channel development can be expected to vary with local environmental controls such as tide range, slope and sediment size, Pethick (1976) has shown that channel systems in Norfolk marshes have become stable between 50 to 100 years after colonisation by vegetation. While Spartina has been growing at the major British sites for well over 50 years, its spread in Australia is more recent.

The relationship between Spartina colonisation and the development of drainage networks is best seen on the central intertidal flats at Andersons Inlet (Figures 6.32A, B), and on Nelson Shoal in the Tamar estuary (Figures 6.33A, B, C). The two sites had quite different drainage patterns before Spartina became extensive, features of which have since been maintained.

At the Andersons Inlet site there were few tidal creeks (Figure
FIGURE 6.32A

FIGURE 6.32B

Development of tidal creeks on the central intertidal flats at Andersons Inlet.
Development of tidal channels on Nelsons Shoal, Tamar River estuary.
6.32A). The mudflats drained directly to shallow and generally broad channels, most of which contained standing water at low tide and hence divided the intertidal zone into several compartments. The only major tidal creek was that which separated the mudflat to the south of Central Split Island from the low-lying area of fine silts to the west (Section 5.23). In addition, tidal channels too small to be mapped at the scale of Figure 6.32A occurred along the mudflat margins (see Plate 5.211), where they strayed, braided or disappeared in response to tidal currents.

In contrast, a well-developed drainage system had formed on Nelsons Shoal before Spartina became widespread (Figures 6.33A, B). Two major channels with beds below low water level were partly maintained by land drainage, but all other channels were strictly tidal creeks, which contained no water at low tide.

Between 1956 (Figure 6.33A) and 1968 (Figure 6.33B) the density of tidal creeks on Nelsons Shoal increased markedly. Peetrong (1965) has shown that such channels are formed during the ebb stream, by a similar process to that described for terrestrial streams by Horton (1945). The erosion of tidal creeks is determined by the same factors as those controlling rill formation: surface slope, runoff intensity, the infiltration capacity of the soil, and the resistance of the soil to erosion. While the three latter characters are unlikely to have changed significantly at Nelsons Shoal between 1956 and 1968, hydrographic charts prepared by the Port of Launceston Authority indicate a high rate of sediment deposition on the higher levels of the intertidal zone in the past 20 years, which has presumably been accompanied by a steepening of the seaward gradient. As Spartina swards were not extensive by 1968, the grass is not believed to have been a factor in creek development at that
stage, for it is unlikely that accretion promoted by clones and clumps
would alone have been sufficient to increase seaward slopes to a point
at which channel erosion could be initiated.

At both Andersons Inlet and Nelsons Shoal, Spartina colonisation commenced on the highest mudflat levels, well above the smallest creeks and finger-tip tributaries. In order to describe the impact of Spartina on drainage systems at these sites, it is first necessary to examine the manner in which the growth of the grass may affect each of the four factors which Pestrong (1965) and Horton (1945) have shown to determine the extent of creek formation.

First, where the growth of Spartina is accompanied by accelerated rates of sediment deposition, the surface slope seaward of the point of maximum accretion is steepened. The consequent increase in hydraulic gradient creates conditions under which channel erosion may occur (Horton 1945). Slopes previously drained by sheet flow, in which the tide falls as a single body of water, may then be drained solely by tidal creeks during the last part of the ebb. Similarly, the increased hydraulic gradient will facilitate headwards erosion in pre-existing channels. Due to the combined effects of stream incision and continued accretion in Spartina, slopes also are steepened along channel banks, which promotes development of tributary creeks.

Second, while runoff intensity is determined primarily by the elevation of the marsh surface in relation to the tidal column, it varies at any particular level on the marsh according to the placement of Spartina clones and clumps. As shown in quadrat II 1 at Andersons Inlet (Section 5.21), Spartina had begun to exercise a control over tidal flow within
three years of marsh inception (Figure 5.211), when plant cover was only 22 per cent. As accretion in *Spartina* is greater than on bare mud, the ebb stream is directed around population units, the enlargement and upward growth of which increases local runoff intensity and creates incipient channels.

The third factor is the infiltration capacity of the soil, which has been discussed in relation to the Norfolk marshes by Pethick (1976). At sites where *Spartina* begins to colonise estuarine sands, the permeable nature of the substrate favours sub-surface drainage and thus restricts the development of surface creeks. However, as the intertidal zone becomes vegetated, the velocity of the incoming tide is reduced, and suspended silt and clay are precipitated. The resulting relatively impermeable layer of fine sediment reduces sub-surface drainage and provides an increasing discharge into surface channels, which adjust to higher runoff intensity by increasing their length and decreasing their slopes. The first is achieved by headwards erosion, and the second by meandering, which is characteristic of tributary creeks in mature drainage systems.

While the growth of *Spartina* promotes creek development in each of these ways, its spread also is accompanied by increasing resistance to erosion, which is the fourth factor governing channel formation. The thick mat of roots and rhizomes prevents the formation of new channels or the landward extension of existing creeks, except where surface slope and runoff intensity are sufficient for this resistance to be overcome. Thus the spread of *Spartina* may restrict the development of marsh drainage systems, especially on gentle slopes where accretion has not been pronounced. As the density of sub-surface living plant material reaches a maximum in continuous sward, greatest resistance to erosion occurs at
that stage, which reduces or halts the growth of creek systems earlier developed around clones and clumps.

The spread of *Spartina* across previously bare intertidal flats therefore affects all four factors which determine the extent of creek development. The drainage networks which evolve in *Spartina* marsh are an expression of the balance between the forces of erosion, which are increased by accretion accompanying *Spartina* growth, and the resistance of the surface, which also becomes greater following *Spartina* colonisation. On marshland, as distinct from mudflat, the vegetation itself is the greatest single control over channel development.

At both Andersons Inlet and Nelsons Shoal, *Spartina* colonisation has been accompanied by the development of new creek systems, and by changes in the form and dimensions of pre-existing channels. It is not always easy to distinguish between changes which result from *Spartina* growth, and those which might be expected to occur over a period as long as 1968-1979 purely in response to hydraulic flow phenomena. At some sites, (for example Site 1, Figure 6.32B), channel networks have altered in areas presently unoccupied by the grass, and presumably unaffected by its presence elsewhere. In the following discussion, attention is given only to sites at which the spread of *Spartina* has been accompanied by morphological changes of a type unlikely to occur in its absence.

The most extensive development of new tidal channels at Andersons Inlet is on the large mudflat to the south of Central Split Island (Site 2, Figure 6.32B). As described in Section 5.23, this site had sufficient micro-relief before the introduction of *Spartina* for water to be retained in shallow pools at low tide. While *Spartina* colonised intervening ridges and areas of locally higher relief, it did not
establish in almost permanently waterlogged sites. Accretion in *Spartina* caused those depressions not colonised by the grass to become more pronounced, and by 1975 they had been linked to form broad, shallow tidal creeks (see Plate 5.238).

The initial creek system at this site consisted of first-order channels along roughly parallel paths determined by the alignment of the major surface depressions. Several changes are now in progress: the main channels are becoming deeper and narrower as a result of channel erosion combined with continued accretion on adjacent channel banks; channel mouths are becoming steeply incised (Plate 6.31); tributary creeks have begun to form at sites where channel erosion has increased channel-side gradients (Plate 6.32); and both tributaries and main channels are extending by headwards erosion, particularly where *Spartina* cover is low. The drainage system is evidently in its early stages of evolution, and is certain to undergo further change within the next few years.

In terms of the chronological sequence of marsh drainage development described by Pethick (1976), it is likely that the present linear drainage network will eventually be transformed into a dendritic network similar to drainage systems shown in Figure 6.31. Pethick has recognized three stages in the continuum of creek formation: a stage in which the central drainage system possesses straight low order creeks, most clearly defined where channels are bounded by vegetation, and which are beginning to erode headwards; a second stage, in which headwards erosion continues, but channels are more sinuous and tributaries more extensive; and a final stage in which headwards erosion has ceased, low order tributaries are far more sinuous than higher order channels, and channel depth has increased.
PLATE 6.31

Mouth of small tidal creek on mudflat south of Central Split Island, July 1980.

PLATE 6.32

Incipient tributary (arrowed) to creek shown in Plate 6.31.
A major control over this sequence of development is the contrast between tidal flow in large channels and that in small channels, as noted by Myrick and Leopold (1963) and Pestrong (1965). In large channels, ebb tides and flood tides reach similar velocities, but in small channels the flow velocity is significantly higher during the ebb stream. The plan, cross-section and long profile of small tidal creeks are therefore determined by ebb flow, while those of larger channels are a response to alternating currents from opposing directions. As noted previously, the increased ebb stream discharge which results from decreased soil permeability is accompanied by headwards erosion and meandering of small tidal channels. Larger creeks however are comparatively unaffected by this increased discharge, which is small in relation to the volume of water carried into and from the marsh. As adjustments to slope are limited by the two-way flow regime, large channels become deeper and wider (or 'flare') as they approach the seaward perimeter of the marsh. Pethick (1976) suggests that as the marsh approaches its upper limit of growth and ebb discharge diminishes due to a decreased volume of water covering the surface, the flood current will extend further into the drainage system so that eventually all but first-order tributaries will exhibit two-way flow.

While drainage systems similar to the second or third stages described by Pethick (1976) have not yet developed at any Australian site, the linear network south of Central Split Island is representative of the first stage. About 60 per cent of the tide now enters and leaves the marsh by the main channels, although the seaward-sloping long profiles indicate that the ebb stream is still the dominant factor in creek formation. The base level of erosion, which is mean low water spring tide, lies beyond the seaward margin of Spartina, and the creeks are dry at low tide except at sites where channels traverse panne marsh.
With continued channel deepening, it is expected that much of this marsh may be drained, and that the lower part of the main channels will be eroded downwards to a level at which they retain standing water during low tide.

A noteworthy feature of several creeks in this area is the presence of small knick-points near the mouths (Plate 6.33). These are formed at sites where creek development has breached continuous Spartina growth, or where channels have been formed between closely-spaced tussocks (Plate 6.34). Spartina roots and rhizomes have offered greater resistance to erosion than unconsolidated sand beyond the seaward margin of the sward, resulting in a marked break of slope. It is thought that such features are likely to be temporary, and that the knick-points will advance upstream as ebb discharge increases and creek systems are deepened.

Creek systems have also formed at other sites on the central intertidal mudflats (for example Sites 3 and 4, Figure 6.32B), in places which lacked the initial minor surface depressions which affected channel development south from Central Split Island. At these sites creek development has been determined by the initial placement of Spartina clones and tussocks, as in quadrat II 1 (Section 5.21). Until the mid 1970s, incipient channels were most clearly defined on the highest mudflat levels, where the density of Spartina population units was greatest and the developing network of roots and rhizomes permitted the steepening of channel sides (Plate 6.35). Seawards of the vegetated zone, the ebb tide drained across unconsolidated sediment in shallow braided channels or as sheet flow. However, as Spartina has extended further seawards and the general elevation of the marsh has been raised, channel formation on the lower mudflat levels has become much more pronounced. A similar method of creek formation, in which channels first develop on the vegetated zone
PLATE 6.33

Knick-point (arrowed) at mouth of tidal creek on mudflat south of Central Split Island, July 1980.

PLATE 6.34

Initial stage in creek development, April 1973. Channel mouth has formed between Spartina tussocks.
PLATE 6.35

Channel developed between Spartina clones on mudflat north from Western Split Island. The channel is well-defined within the Spartina zone, but braids to seaward (top of photograph). July 1980.

PLATE 6.36

Slumping (arrowed) along outer bank of meander in tidal channel, November 1978.
and subsequently extend further seawards, has been observed by Pethick (1976) in the youngest marshes at Scolt Head Island, Norfolk.

New channels have formed in Spartina only where the intertidal zone is broad, or at sites which receive ebb flow from Split Islands, most of which is covered by mean high spring tides. Creeks have not developed in narrow peripheral swards, such as those along the inner margin of the spit, presumably because runoff intensity is insufficient to initiate erosion. The only channels which occur at such sites are artificial drains and creeks which pre-date the spread of Spartina. As with terrestrial streams, it is evident that a certain critical length of overland flow (Horton 1945) must be exceeded before channel erosion can commence.

The discussion so far has dealt with tidal creeks. As indicated by comparison of Figures 6.32A and 6.32B, there are several sites where changes also occurred between 1968 and 1979 in the size and shape of larger channels with bed levels below low water mark. These were accompanied by alteration to the dimensions of the intertidal flats. While such morphological instability is a characteristic of the intertidal and subtidal zones within estuaries, and will occur independently of Spartina growth, there is evidence to suggest that the grass has now become an important factor in the development of the major channel systems.

Although no systematic hydrographic survey has been undertaken in the vicinity of the central intertidal flats, there is no doubt that the major channels have become deeper since Spartina became extensive. Until the mid 1970s, Split Islands were inaccessible by boat from Fishermans Jetty at mean low water spring tide; the channels are now navigable by small craft throughout the tidal cycle. Fresh water discharge
into the estuary has not recently been greater than in previous years, so increased channel depths cannot be explained by unusually high rates of flushing. It is possible that the volume of sediment supplied to the inlet has been reduced, but there is no evidence to suggest that this is the case. While erosion at Point Smythe contributed a good deal of sediment to the central intertidal flats between 1970 and 1975 (Section 5.23), channel depths are now greater than in the mid 1960s when Point Smythe was similarly prograding. It is therefore believed that increased channel depths reflect the fixing of sediment within *Spartina* swards i.e. a part of the sediment which formerly moved freely about the estuary in response to tidal currents, and was exchanged between the intertidal and subtidal zones with the passage of the flood and ebb streams, has now been bound up in *Spartina* marsh. This effect has evidently been noted previously, for Ranwell (1967a) has reported that one of the reasons for *Spartina* plantings in Britain was the stabilisation of mudflats, which reduces the source areas for channel silting.

In addition to its impact on channel depth, the spread of *Spartina* has also affected other components of hydraulic geometry. Figure 6.34 shows cross-sections of the channel at Site 5 (Figure 6.32B) in 1968 and 1979. At this site, *Spartina* had grown down to mean water level by 1971, and subsequent accretion has brought about the formation of Type D terraces with stable outer margins. The growth of *Spartina* has increased the threshold of erosion along channel banks, which have steepened as a consequence of this factor in combination with increased depth and a rise in elevation of the marsh. Previously the channel had no clearly-defined banks, but now it is bounded by breaks of slope near the outer limits of *Spartina*, which are over-topped by the flood stream only just before the tide reaches its peak.
FIGURE 6.34 Cross-sections of tidal channel at Site 5 (Figure 6.32B).
As a consequence of the growth of *Spartina*, the hydraulic radius (i.e. ratio of cross-section area to wetted perimeter) has been increased. While workers such as Leopold and Maddock (1955), Schumm (1963) and Leopold, Wolman and Miller (1964) have considered the impact of changes in channel form on the velocity of terrestrial streams experiencing one-way flow, and on their capacity to transport sediment, very little is known about the significance of hydraulic radius in tidal channels. The author does not have sufficient data on related parameters, particularly changes in channel slope which may have accompanied narrowing and deepening of the cross-section, to contribute usefully on this point. However, there is an obvious similarity between wide, shallow tidal channels and terrestrial 'bed-load' channels, which are subject to shoaling, and between deeper, narrow tidal channels and terrestrial 'suspended-load' channels, in which sediment deposition is minimal. It therefore seems likely that channel deepening is not simply a function of an increasing volume of sediment being trapped in the marsh, but also a result of hydraulic factors which reduce the amount of bed-load sediment as the channel becomes narrower and deeper.

A further effect of the increased threshold to channel bank erosion is stabilisation of channel plan. As noted above, the size and shape of several major channels and mudflats changed between 1968 and 1979 (Figures 6.32A, B), and changes of greater magnitude are apparent when comparisons are made with aerial photographs for 1950. It is evident that the spread of *Spartina* will restrict lateral migration and widening of channels, and thus reduce mudflat instability. Eventually however, the continued upward growth of the marsh might be accompanied by cliffing and frontal recession, particularly where the surface layer of living turf is undercut by strong tidal currents. In Andersons Inlet this is presently
seen in an incipient form at Site 6 (Figure 6.32B), where a pre-existing meander in a channel which has now been narrowed has promoted slumping along the margin of a Type D terrace (Plate 6.36).

While the impact of **Spartina** on drainage networks at Nelsons Shoal is broadly similar to that at Andersons Inlet, there are two notable differences. The first is observed at Windermere (Site 1, Figure 6.33C), where development of a system of parallel linear creeks has accompanied continued increase in the elevation of the Type C terrace described in Section 5.23. These creeks are commonly only 20 cm wide but up to 40 cm deep (Plate 6.37), which contrasts with the broader, shallower creeks at Andersons Inlet. As at the latter site, many creeks become less clearly defined beyond the seaward margin of **Spartina**, and break down into a series of wide, braided channels.

The morphological difference between the two creek systems is thought to be explained by the fact that the Windermere creeks have formed in continuous sward, while those at Andersons Inlet have generally developed on bare mud between **Spartina** clones. Once the surface layer of roots and rhizomes in continuous growth has been breached, the underlying sediments offer less resistance to erosion than the vegetated channel banks, and hence downcutting becomes the major process by which adjustments are made to tidal flow. On the other hand, channels which develop on bare mud tend to widen as well as deepen, until restricted by adjacent **Spartina** clones.

While accretion within **Spartina** has caused channel banks to steepen, and rhizome extension has reduced channel width, it is unlikely that channels initially formed on bare mud at Andersons Inlet will ever approximate the width/depth ratio of those at Windermere. To do so, it
PLATE 6.37

Tidal creek in Windermere sward, January 1980.
would be necessary for *Spartina* to spread to within a few centimetres of the centre of the channel beds, which is unlikely given the excessively wet conditions at this level, and then to cause rapid accretion of sediment, which is also unlikely given the relatively high flow velocities of tidal creeks. However, it is expected that creeks similar to those at Windermere may eventually develop at Andersons Inlet, at sites where accretion in *Spartina* has increased the hydraulic gradient to a point at which resistance to erosion is overcome.

The second difference between the two stations is that *Spartina* on Nelsons Shoal has colonised an area which was already extensively dissected by tidal creeks (Sites 2, 3 and 4, Figure 6.33C), whereas none were present on the central intertidal mudflats at Andersons Inlet before the grass was introduced.

Comparison of Figures 6.33B (1968) and 6.33C (1979) indicates substantial changes to drainage networks since *Spartina* became widespread. However, it is believed that these were caused primarily by hydraulic factors unrelated to *Spartina* growth, for drainage patterns also changed between 1968 and 1979 well beyond the seaward limit of colonisation. Emplacement of cheniers on the outer edge of the mudflat has also affected channel patterns, especially at Site 5 (Figure 6.33C).

Figures 6.33A, B and C have been prepared from aerial photograph enlargements at a scale of approximately 1:5000. While it is difficult to trace all finger-tip tributaries at such a scale, particularly where channels are narrow and *Spartina* growth dense, field inspection of present-day tributaries indicates little, if any, headward erosion of creeks in colonised sites since 1968. It is not known whether the drainage systems were still developing landwards at that time, or whether they had attained
a steady state, but if the former was the case then headwards extension
has been halted by the increased resistance to erosion which is caused by
Spartina growth. Comparison of stream networks at Sites 2, 3 and 4 in
1968 and 1978 in fact suggests that the number and length of tributary
channels have diminished, but air photographs are insufficient evidence
for this to be confirmed.

Although the spread of Spartina has not greatly affected
channel plan, it has had a considerable impact on channel shape.
Accretion in Spartina on channel banks has raised the level of the marsh,
and at the same time the creeks have been deepened. In most channels the
depth is now roughly the same as the width (Plate 6.38), these dimensions,
even in tributary creeks, being sometimes more than 1 m. While the author
had not visited this site as early as 1968, it is unlikely that such
steep-sided channel cross-sections could have occurred at that time on
unvegetated mudflats. The channels probably then resembled the much
broader and shallower channels which still occur beyond the seaward
margin of Spartina.

Figure 6.35 represents in diagrammatic form the three ways in
which Spartina has been observed to affect the development of tidal creek
cross-sections at the two major Australian stations. Sequence 1 occurs
amongst discontinuous Spartina growth, in minor surface depressions or
where accretion in Spartina clones creates sufficient micro-relief to
concentrate tidal runoff on intervening bare mud, where it overcomes the
low resistance to erosion of unconsolidated sediment and begins to form
a channel. Most common in Andersons Inlet, this method of creek
development has also been observed in the Tamar estuary, and amongst
clones and clumps at the mouth of Duck River.
PLATE 6.38

Tidal creek at Nelsons Shoal, January 1980. At this point the creek is 80 cm deep and 1 m wide. Evidence from aerial photographs confirms the presence of a channel at this site in 1968.
Diagrammatic representation of formation of tidal creeks in Spartina marshland.
Sequence 2 is characteristic of creek development in continuous Spartina sward, where a local concentration of surface runoff promoted by factors such as low stem density or surface depressions is able to erode the surface layer of living turf, forming a narrow but deep channel in which downcutting exceeds bank erosion. This occurs at many sites in the Tamar estuary, is expected to occur in Andersons Inlet, and has also been observed at the ox-bow site in Bass River. It seems likely that this type of creek could in future be subject to undercutting beneath the layer of living turf, followed by slumping, but so far this has not been observed.

In Sequence 3, Spartina colonises the banks of a pre-existing channel, which increase in elevation and cause the creek to deepen. In terms of the number of sites at which this sequence of development has occurred, it is the most common way in which Spartina has affected channel cross-sections. Spartina at most Australian stations grows as narrow bands of clumps and swards along river margins, where tidal runoff is generally over an insufficient distance to initiate erosion by means of Sequences 1 and 2. In such places, tidal creeks usually occur only where the rivers are entered by drains or channels nourished by freshwater discharge, which in most cases pre-date Spartina growth. The Tamar estuary is the only site at which extensive development of creeks of this type has occurred in the absence of terrestrial streams.

It is likely that the deepening of tidal creeks at Nelsons Shoal and other sites in the Tamar estuary is partly a function of bed erosion, caused by increased discharge and increased flow velocity which arise from upward growth of the relatively impermeable marsh surface. However, where this sequence of development has occurred in linear swards along river margins, for example Albert River, there is little evidence
of channel downcutting, and channel deepening is solely a result of accretion on channel banks. The creeks affected by *Spartina* at Nelsons Shoal are headwater tributaries on the higher levels of the marsh, while the river-bank sites are the mouths of terrestrial streams which have attained their base levels of erosion. The increased intensity of tidal runoff which accompanies upward growth of narrow marginal swards has been insufficient to promote further scouring.

While tidal creek systems at both Andersons Inlet and the Tamar estuary are still in an early stage of development, it is anticipated that the mature channel networks eventually formed at each site will be somewhat dissimilar, because of their contrasts in tide range. This is suggested by a comparison between older *Spartina* marshes at Poole Harbour, where a dendritic channel network has developed in a microtidal environment (Figure 6.31), and Bridgwater Bay, where a linear channel network is now steeply incised on a shelving shoreline in a macrotidal environment. A tendency towards incision and hence preservation of parallel channels is also observed at other sites where the tide range is large. Although the tide range in the Tamar estuary is less than half that at Bridgwater Bay, it is expected that the future pattern of major creeks and tributaries will retain some of the features of existing linear channel systems, while the marshes in Andersons Inlet will be drained by dendritic networks similar to those at *Spartina* stations on the south coast of England.

6.4 Salt pans and pond holes

In discussion of marsh development at Cherry Tree Creek (Section 5.27), attention was drawn to the presence of pans and pond holes within otherwise continuous sward. Such features, especially pans, are
now common on developing Spartina terraces in Andersons Inlet and the Tamar estuary, and examples may also be found at all other Australian stations where sward formation is complete. In the following discussion, the term 'pans' shall be taken to include pond holes, except where the latter are considered separately.

A great deal has been published on the subject of salt pans since their occurrence in the Dovey estuary was described by Yapp et al. (1917). Although several types of pans were distinguished, the essential difference proposed in this study was one between primary pans, which are roughly circular pools with flat bottoms and gently sloping sides, and channel pans, which are elongated and sinuous. Primary pans originate contemporaneously with the marsh, where uneven colonisation by vegetation leaves bare patches of mud in which subsequent plant invasion is prevented or restricted by standing water and high salinity. Channel pans are formed where the courses of shallow creeks are blocked at various points by collapsed channel banks, which are soon colonised by vegetation. It was noted that both types of pan are formed on bare mud, and that no evidence was forthcoming from the Dovey estuary to indicate that such features ever arise in continuous marshland as a result of destruction of surface turf. Both Warming (1904) and Harshberger (1916) had previously suggested that pans are initiated where marsh vegetation is suppressed by putrefying masses of algae.

Most later authorities have accepted in broad outline the account given by Yapp et al. (1917) of the processes involved in pan formation, and the conclusion that pans do not develop on existing marsh. The most recent restatements are those by Steers (1960, 1969), Pestreong (1965), Verger (1968) and Packham and Liddle (1970). However, other writers have proposed that pans may also develop where decay of surface
vegetation is promoted by tidal litter (Ranwell 1964b), seasonal waterlogging of minor depressions (Redfield 1972), prolonged survival of snow patches (Chapman 1938), or the entrainment of surface layers of the marsh in ice floes raised by high tide (Dionne 1968). In addition, it has been shown that sub-surface drainage may promote pan formation, by causing parts of the surface to subside (Turmel 1958, Kesel and Smith 1978, Smith 1979).

In a paper of much significance to discussion of pans at Cherry Tree Creek, Pethick (1974) observed that if Yapp et al. (1917) were correct in believing that such features do not arise on existing marsh surfaces, then pan density should either decrease or remain constant as the marshes mature. A reduction in density is suggested by factors which Yapp et al. (1917) had already described as likely to affect the later development of both primary and channel pans: the enlargement and eventual coalescence of adjacent pans as a result of peripheral undercutting caused by tidal eddies; the filling of pans by sediment, followed by colonisation by plants; and the headwards extension of tidal creeks which may cause other pans to be captured and drained. These three factors together could be expected to more than outweigh the addition of new channel pans.

In order to identify the nature of any relationship between pan density and marsh age, Pethick (1974) mapped all pans visible on aerial photographs of 75 randomly sited quadrats on part of the Norfolk coast. The numbers of primary pans, distinguished by shape from channel pans, were taken as a measure of pan density. Marsh elevation, determined by levelling in the field, was taken as an indirect measure of marsh age. Sequential multiple regression analysis revealed a positive correlation between pan density and marsh height, a quite opposite relationship to
that which might have been anticipated. Accordingly, it was concluded that in addition to primary pans which date back to the time of marsh inception, new pans may develop on mature marsh surfaces at vegetation has for some reason been suppressed.

As Pethick (1974), Steers (1977) an have noted, there is at present little empirical evidence for this conclusion, as few studies have been made of such pans. A sufficient period of time for pan formation to occur study goes part-way towards providing such evidence, for a few pans at Cherry Tree Creek has been recorded since 1968.

The distribution of pans in quadrat II 7 at Cherry has previously been shown in Figure 5.27, where pans are denoted by unshaded areas of varying size and shape within otherwise continuous sward. These were recorded by the same method as that used for mapping Spartina, i.e. subdivision of the quadrat into a grid of 2 m x 2 m squares (Section 5.2), with bare patches of less than 0.5 m maximum dimension being ignored (Section 3.2). The most recent survey, that of August 1979, has been redrawn as Figure 6.4.

Pans were first recorded at Cherry Tree Creek in May 1971, when two patches together occupied 17 m². Although some pans failed to persist, the number and total area of these features subsequently increased: seven pans in April 1978, totalling 22 m²; 16 in November 1976, accounting for 22 m²; and 24 pans in August 1979, occupying 35 m². In Table 6.4, these have been numbered according to their order of appearance, i.e. pans 1 and 2 had formed by 1971, pans 3-7 by 1973, pans 8-19 by 1976, and pans 20-27 by 1979. By using large scale tracing overlays of maps for each
FIGURE 6.4

Distribution of pans in quadrat II 7, Cherry Tree Creek, August 1979. Pans are unshaded areas within continuous Spartina (shaded). Mangroves are shaded black. Numbers assigned to pans are as listed in Table 6.4.
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1. Developed in <strong>Spartina</strong></td>
<td>1. Larger</td>
<td>1. Larger</td>
<td>1. Larger</td>
</tr>
<tr>
<td>2. Primary pan</td>
<td>2. Smaller</td>
<td>2. Larger</td>
<td>2. Larger</td>
</tr>
<tr>
<td>3. Primary pan</td>
<td>3. <strong>Covered by Spartina</strong></td>
<td>3. --</td>
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<tr>
<td>5. Primary pan</td>
<td>5. <strong>Covered by Spartina</strong></td>
<td>5. --</td>
<td>5. Smaller</td>
</tr>
<tr>
<td>7. Primary pan</td>
<td>7. <strong>Covered by Spartina</strong></td>
<td>7. --</td>
<td>7. --</td>
</tr>
<tr>
<td>8. Developed in <strong>Spartina</strong></td>
<td>8. Larger</td>
<td>8. Larger</td>
<td>8. Larger</td>
</tr>
<tr>
<td>10. Developed in <strong>Spartina</strong></td>
<td>10. Larger</td>
<td>10. Larger</td>
<td>10. Larger</td>
</tr>
<tr>
<td>11. Developed in <strong>Spartina</strong></td>
<td>11. Larger</td>
<td>11. Larger</td>
<td>11. Larger</td>
</tr>
<tr>
<td>12. Developed in <strong>Spartina</strong></td>
<td>12. Larger, rounder</td>
<td>12. Larger, rounder</td>
<td>12. Larger, rounder</td>
</tr>
<tr>
<td>14. Developed in <strong>Spartina</strong></td>
<td>14. <strong>Same size, rounder</strong></td>
<td>14. <strong>Same size, rounder</strong></td>
<td>14. <strong>Same size, rounder</strong></td>
</tr>
<tr>
<td>16. Developed in <strong>Spartina</strong></td>
<td>16. Larger</td>
<td>16. Larger</td>
<td>16. Larger</td>
</tr>
<tr>
<td>17. Developed in <strong>Spartina</strong></td>
<td>17. <strong>Same size, narrower</strong></td>
<td>17. <strong>Same size, narrower</strong></td>
<td>17. <strong>Same size, narrower</strong></td>
</tr>
<tr>
<td>18. Primary pan</td>
<td>18. Primary pan</td>
<td>18. Primary pan</td>
<td>18. Primary pan</td>
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<td>22. Developing</td>
<td>22. Developing</td>
<td>22. Developing</td>
<td>22. Developing</td>
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<tr>
<td>27. Developing</td>
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</tr>
</tbody>
</table>
successive survey year, it has been possible to distinguish between pans which developed on bare mud and those which formed in continuous sward, and also to estimate change in size (Table 6.4). Numbers in Figure 6.4 are provided as a key to pans in 1979.

None of the pans in quadrat II 7 are channel pans formed by the blockage of tidal creeks, which do not occur at this site. Of the 27 pans which formed between 1968 and 1979, 24 survived to the latter date.

Twelve of the 27 pans were primary pans as defined by Yapp et al. (1917), formed by uneven colonisation of Spartina along the advancing seaward margin of the sward. Of these, three pans (3,5,7) were colonised by Spartina between 1973 and 1976, having not persisted for sufficiently long to inhibit plant growth. The remaining 15 pans are those for which Steers (1977) has coined the term 'Pethick-type' pans, having originated de novo on existing marsh.

In order that such pans can develop, it is necessary for surface vegetation to be weakened and finally destroyed. Two different factors have been observed to initiate pan formation at Cherry Tree Creek - prolonged waterlogging of low-lying sections of the marsh, and the shade provided by mangroves, which inhibits Spartina growth.

As described in Sections 5.27 and 6.25, accretion in the sward at Cherry Tree Creek has formed an almost flat Spartina terrace characterised by a gentle landward slope along the rear of the marsh. A combination of low gradients and the absence of tidal creeks has promoted prolonged waterlogging of minor depressions on the marsh surface. In some waterlogged sites, 'rotten spots' (Chapman 1960, Redfield 1972) have developed, being patches of ground on which previously vigorous Spartina has become depauperate (Plate 6.41).
PLATE 6.41

'Rotten spot' formed in Spartina sward,
Cherry Tree Creek, July 1977.

PLATE 6.42

'Pan die-back' (Goodman et al. 1959) at Cherry Tree Creek,
August 1979. The plate shows an intermediate stage between
the appearance of a rotten spot and formation of a pan.
The minor surface depressions in which rotten spots are initiated are no more pronounced than at other sites in Andersons Inlet, but their effect on drainage is compounded by the low marsh gradient. They are unlikely to result from subsidence promoted by sub-surface drainage, for no evidence can be found of sub-surface 'pipes' (Kesel and Smith 1978), which have previously been reported only in much sandier substrates than occur at this site. Instead these minor depressions are thought to be caused by unequal deposition of sediment over the surface, although the process by which this occurs is not fully understood. While variation in depth of deposition might be related elsewhere to episodic delivery of large volumes of sediment, especially during storm surges, this is an unlikely explanation in the calm sedimentary environment at Cherry Tree Creek. Local variations in rates of deposition are more probably determined by variations in stem density within the sward, which in a youthful marsh will reflect plant density before complete Spartina cover was achieved.

Prolonged waterlogging in minor depressions has been accompanied by pan die-back (Goodman et al. 1959), the symptoms of which include failure of the rhizomes, the production of fewer and weaker tillers, and a general yellowing of the plant (Goodman 1960). The death of underground buds and rotting of rhizome apices are also characteristic (Lambert 1964). Spartina failure of this type has previously been reported extensively in the literature at sites where soft, wet finely particled substrata are similarly associated with impeded drainage, although the effect of such conditions on plant physiology is not certain (Williams 1964). As die-back at Cherry Tree Creek has spread outwards from the initial points of marsh decay, rotten spots have been gradually transformed into larger pans (Plate 6.42).
The second factor contributing to break-down of the marsh surface is shade provided by the canopies of mangroves. As described in Section 5.27, mangroves were well-established in quadrat II 7 at the time the present study began, and had increased substantially in both number (Table 5.272) and size by 1979.

The establishment and growth of young mangroves within continuous Spartina sward has commonly been followed by Spartina recession. Until reaching a height of about 50 cm, small mangroves have few branches and are tall in relation to their width, but beyond that stage the canopy broadens to a diameter about equal to plant height (Plate 6.43). As the lowest branches and leaves are not much above the tallest Spartina, the ground at the base of the mangroves is perpetually shaded. Fewer and weaker tillers are produced in these conditions of reduced light intensity, which causes locally lower rates of sediment accretion than in surrounding areas of dense sward. As a consequence, small waterlogged pans develop beneath the mangrove canopy, in which already depauperate Spartina begins to die back. Many of these pans are at present smaller than 0.5 m diameter, and have therefore not been recorded. Spartina recession in shaded sites appears to confirm the positive relationship between light intensity and shoot production previously demonstrated in laboratory conditions by Hubbard (1969).

Mangroves which pre-date the spread of Spartina have also contributed to pan formation. As noted in Section 5.27, Spartina did not establish beneath the fringe of continuous mangroves which formerly comprised the pioneer plant community at this site. Similarly, the grass failed to colonise the shaded areas beneath isolated mangroves further out on the mudflat, which in time were encircled by Spartina growth
PLATE 6.43

Juvenile mangroves in Spartina sward at Cherry Tree Creek, July 1978. Note shade beneath broad canopies.

PLATE 6.44

Pond hole formed beneath mangrove canopy, Cherry Tree Creek, July 1978. The pond hole was first observed in 1966, when the mangrove was large and healthy. Although no longer shaded, the pond hole has increased in size since that time by about 20 per cent.
(Plate 6.44). These features are primary pans, although formed by a process which had not been envisaged by Yapp et al. (1917).

During the time in which pan development has been observed at Cherry Tree Creek, there have been substantial changes in the size of both primary pans and pans formed by decay of surface turf (Table 6.4). Primary pans have become generally smaller, while those formed on existing marsh have tended to enlarge. As the entire marsh is covered by all high tides, alteration to pan size cannot be explained by factors affecting the dimensions of pans on emergence marsh, such as varying concentrations of salts in pan soils (Redfield 1972), or drying and dessication (Smith 1979). Rather, pan size appears to be determined solely by substrate wetness at low tide. New growth from inwardly-directed rhizomes has reduced the size of most primary pans, but encroachment has ceased at the margins of small pools which persist between successive high tides. Conversely, pans formed on existing marsh have enlarged as a result of the outwards expansion of die-back zones, which extend as far as the local limit of saturation.

Changes in pan size have been accompanied by an increase in pan depth and a steepening of pan sides. Where most pronounced, this has transformed pans into pond holes, which are characterised by near vertical or undercut sides and a depth greater than the surface layer of living turf. They also have flat bottoms, and at Cherry Tree Creek invariably contain standing water at low tide.

The term 'pond hole' has been used with reference to the New England marshes, U.S.A. (Redfield 1972), but has not yet been widely accepted in the literature. The term 'pan' generally is taken to refer to both unvegetated hollows with gently sloping sides (Plate 6.45), and to
PLATE 6.45

Primary pan in Spartina at Cherry Tree Creek, August 1979.

PLATE 6.46

Pond hole at Cherry Tree Creek, August 1979. The pond hole has much steeper sides and a greater depth than the pan shown in Plate 6.45.
morphologically different features which resemble pond holes (Plate 6.46). Many of the pans at Nigg Bay, Scotland (Plate 6.47), which have been described by Kesel and Smith (1978), and those on the Isle of Lewis (Smith 1979), are identical features to the pond holes of Barnstable Harbour, Massachusetts, which have been reported by Redfield (1972). Although both pans and pond holes have similar origins, and there are intermediate forms, they are sufficiently different from each other to warrant the use of the two separate terms.

Pond holes have developed at Cherry Tree Creek from both primary pans and pans formed by decay of surface vegetation. Regardless of mode of formation, the longest-established depressions generally have steep walls, although only those developed on vegetated areas have a firm bottom associated with underlying turf. Several factors are important in creating conditions under which pans may be transformed into pond holes. First, the outline of the pan must become relatively stable. In primary pans this occurs at a point where inward encroachment of new tillers is halted by standing water; in pans developed on existing marsh, enlargement ceases at the outer limit of Spartina die-back. Second, the volume of sediment supplied to the site must be sufficient to promote high rates of accretion in Spartina around the periphery of the pan, thus increasing the height of the vegetated surface. It is however evident that some deposition also occurs in pans and pond holes, for at Cherry Tree Creek the maximum depth of pond holes developed from primary pans is about 20 cm, at sites where up to 37 cm of sediment has been deposited since 1968 (see Table 5.274).

A third factor required for pond hole formation is a process by which the sides of the pan are steepened to form near vertical walls, which are often undercut beneath the surface layer of living turf. Several
PLATE 6.47

Pond holes at Ankerville marsh, Nigg Bay, Scotland, June 1976.

PLATE 6.48

Spartina wrack and pan formation, Swan Bay, Tamar estuary, July 1978.
processes have been suggested to explain this characteristic of pond holes, as reviewed by Kesel and Smith (1978), but few have relevance to Cherry Tree Creek. For example, processes such as wetting and drying and freeze-thaw activity can operate only on emergence marsh or in much colder climates than that of southern Victoria. Pan-generated wave action is also an unlikely explanation given the sheltered conditions of pond holes surrounded by a dense growth of tall Spartina, and the eddying effects reported by Yapp et al. (1917) at the time flood tide enters a pan have not been observed at this site. As at Nigg Bay (Kesel and Smith 1978), the water level in pond holes is raised by seepage accompanying a tide-generated rise in the water table, rather than as a consequence of spillage from the adjacent higher surface.

Two different processes are believed to account for the formation of vertical or undercut sides in pond holes at Cherry Tree Creek. The first is gradual slumping of the lower parts of the sides, which occurs once accretion in Spartina has been sufficient both to steepen pan margins and to cause pools of water to be retained at low tide. Although containing root remains of Spartina, sediments at this level are less well consolidated than those closer to the surface which are bound together by living plant material, and being permanently saturated, their angle of repose is less. Material removed by this process contributes to the slow rate of accretion characteristic of pond hole floors.

The second process is marginal overgrowth of vegetation, which has also been reported by Yapp et al. (1917). Some of the tillers produced by dense Spartina on pan edges extend inwards over the outer margin of the pool, and promote accretion of sediment which either steepens the pond hole wall, or produces a small overhanging margin of a few centimetres in width.
In appearance, pond hole walls with marginal overgrowth resemble those which have been undercut by slumping, and usually the two processes operate together. While marginal overgrowth causes a gradual reduction in the size of pond holes, slumping at the base of the walls has in some cases been followed by collapse of sections of the surface layer of living turf. As plants rooted in eroded blocks of sediment deposited in pond holes cannot survive in conditions of permanent immersion, this causes the size of pond holes to increase.

Pond holes on emergence marsh are commonly round or oval in shape, a characteristic explained by Yapp et al. (1917) in terms of a circular movement of water when pans are filled at flood tide, which erodes projecting or angular portions of the sides. However, while some of the pans and pond holes at Cherry Tree Creek have become rounder since initial formation (Table 6.4), there has been no general tendency for this to occur. Changes in shape are simply a response to inward encroachment of Spartina, combined with either collapse of pan sides or Spartina die-back at sites which become excessively wet due to uneven deposition of sediment over the surface. While the processes causing rounding of pond holes on emergence marsh are not yet fully understood, there is no evidence at Cherry Tree Creek to suggest that they are also operative on submergence marsh.

Although pan and pond hole formation at Cherry Tree Creek has been initiated by either the development of rotten spots or the shade cast by mangroves, the most common method of pan formation in Australian Spartineta is the deposition of tidal litter on the marsh surface. This material consists almost entirely of Spartina wrack. Its absence from
Cherry Tree Creek is explained by weak and infrequent onshore wave action; at more exposed sites along the north shore of Andersons Inlet, tidal litter is common.

Tidal litter has been reported as having quite different effects on marsh vegetation at various sites. Macdonald (1977) has described vigorous growth of *Puccinellia phryganodes* in Alaskan marshes following deposition of algal mats, and Bird (1980 pers. comm.) has observed similarly vigorous growth promoted by nutrient-rich tidal litter along strandlines in the marshes of the Fraser River delta, British Columbia. Other writers, including Ranwell (1964b) and Hubbard and Stebbings (1968) have shown that tidal litter in British marshes suppresses the growth of *Spartina*, creating pans which may be colonised by other plants. However, Yapp et al. (1917) found no evidence in the Dovey estuary to suggest that pan formation is initiated by putrefying masses of algae or *Zostera* deposited on the marsh, and Miller and Egler (1950) reported the regeneration of marsh vegetation in Connecticut following the disintegration of tidal litter and its subsequent removal.

At Australian stations, and in particular the Tamar estuary and Andersons Inlet where *Spartina* is most abundant, large masses of *Spartina* wrack are deposited along the landward margins of continuous sward in winter and early spring. At the former site, which has the highest tide ranges of any station, such material is often deposited in the middle of the marsh during high neap tides, but subsequently moved further landwards during springs. Where the landward margin of the marsh is flanked by embankments, as in Corner Inlet and along the north shore of Andersons Inlet, tidal litter is deposited in long narrow bands along the break of slope; otherwise, as in Swan Bay in the Tamar estuary (Plate 6.48),
Spartina wrack forms a broad zone between mean spring and maximum spring high water levels. Although the volume of tidal litter is reduced as decayed remnants of tillers are removed by the tide, much of it persists throughout the year. Litter zones are thus a relatively permanent feature of Spartina marshlands in Australia, reaching their maximum extent on replenishment each winter but never entirely disappearing from the rear of the marsh.

The impact of tidal litter on Australian Spartina marshes is similar to that reported in British marshes. Deposition of Spartina wrack has suppressed the growth of live Spartina plants, presumably by temporarily reducing or cutting off the light supply (Ranwell 1972). It has also restricted the landward migration of Spartina along the rear of the marsh, for Spartina has failed to invade zones occupied permanently or seasonally by tidal litter at levels elsewhere occupied by continuous sward. However, unlike the situation at some British stations, the accumulation of tidal wrack has not opened the upper levels of the marsh to invasion by other plants. At Bridgwater Bay, Somerset, Spartina litter has been temporarily colonised by Atriplex hastata (Ranwell 1961), and bare patches which remain once Spartina wrack has decayed have been invaded by Phragmites communis, Puccinellia maritima and Scirpus maritimus (Ranwell 1961, 1964b). In contrast, the litter zones at Australian sites persist as bare patches of ground partly or wholly covered by Spartina wrack. Where sediment accretion within continuous sward along the seaward margin of litter zones has been pronounced, the consequent restriction of drainage has caused the formation of extensive waterlogged pans.

It is worth noting that although tidal litter has suppressed Spartina growth, it has had little impact on vegetation at sites where it
has been deposited on high marsh. Tidal litter has not been observed on low-growing herbaceous plants such as *Salicornia quinqueflora*, which even in the absence of litter are not abundant along exposed shorelines where the accumulation of *Spartina* wrack is greatest, but it is common in the zone of grasses and rushes which occurs along these shorelines at about the level of maximum spring tides. The vigour of plants such as *Juncus maritimus*, *Scirpus nodosus* and *Stipa teretifolia* has not been impeded by *Spartina* wrack, which given the tall growth form of these species is unable to smother whole plants. Suppression of *Spartina* is believed to be assisted by the fact that wrack accumulates in winter and early spring, when tillers from the previous year have been shed and the plant is in a condition of low growth.

6.5 Summary and discussion

In Section 6.1, Guilcher's schema for description of the morphological features of marshes in temperate climates (Guilcher 1979) was presented as a framework for examination of the morphological impact of *Spartina* in Australia. The following sections have reported changes in the morphology of the intertidal zone at sites where *Spartina* growth has been accompanied by accretion of sediments. The levels of low marsh and mudflat are being raised to form often broad depositional terraces, which eventually may reach the level of mean high water spring tide. Where such terraces have developed in front of formerly-eroding high marsh, the partially buried micro-cliffs have become largely relict features, which may finally disappear as a consequence of continued accretion in *Spartina* swards. Creek systems have begun to develop on terrace surfaces, causing a change from non-channelised to partly channelised tidal flow. Pans and pond holes have formed within otherwise continuous sward, and together with tidal creeks have increased the micro-relief of the marsh.
surface. At many sites the outer margins of terraces have been steepened, and in a few cases this has been followed by cliffing and minor frontal recession.

As a result of the growth of *Spartina*, many colonised sites now have morphological characteristics similar to high or emergence marsh, at least in an incipient form. The processes of marsh formation, involving build-up of the marsh surface, its dissection by creeks, the development of surface microtopography and the possible eventual formation of a cliffsed outer margin, have been greatly accelerated as a result of high rates of accretion promoted by the spread of the grass. In their mature form, not yet apparent in Australia but evident at many British sites (Plate 6.51), *Spartina* terraces bear a strong morphological resemblance to high marsh, which their formation may cause to prograde.

Despite the rapid development of morphological features similar to those of emergence marsh, *Spartina* marshlands in Australia retain the floristic characteristics of submergence marsh. Virtually the entire area of *Spartina* in Australia is inundated by all spring tides, and only a small proportion is left uncovered by neap tides. Those plants which have established on patches of bare mud within the highest levels of *Spartina* swards are species adapted to regular tidal immersion. Principal among these is *Avicennia marina*, which has extensively colonised Victorian *Spartineta*. Other species include *Samolus repens*, *Triglochin striata*, *Sellieria radicans*, *Puccinellia stricta* and *Suaeda australis*, as in quadrat II 5 at Andersons Inlet (Section 5.25); the only additional plants presently found within *Spartina* swards are *Agropyron junceum*, *Hemichroa pentandra*, *Apium prostratum*, *Salicornia quinqueflora*, *Distichlis distichophylla* and *Juncus maritimus*. None of these species
Mature *Spartina* terrace, Patchins Point, Poole Harbour, showing cliffed outer margin of a type not found in Australian *Spartina* marshes. *Spartina* established at this site in 1898, and achieved complete colonisation in 1915 (Hubbard 1965a).

Degenerate *Spartina* terrace following die-back, Lymington estuary. Note erosion of terrace margins and surface. *Spartina* established at this site in 1892 (Hubbard 1965a).
is dominant at any site at which it grows in association with *Spartina*, and in some places the occurrence of *Spartina* in mixed saltmarsh is the result of its landward encroachment rather than its invasion by other plants. Although restriction of light by *Avicennia marina* has promoted localised areas of *Spartina* die-back, the growth of *Spartina* has not been otherwise suppressed by plant invasion at any site.

Even in older *Spartina* marshlands in Britain, *Spartina* has not been widely succeeded or replaced by other species. Ranwell (1964c) has noted that "just as lower and middle marsh species are unable to compete successfully with *Spartina*, so higher marsh species find difficulty in invading the upper limits of *Spartina* marsh direct". At Bridgwater Bay, Ranwell (1961, 1964b) found that sheep grazing and compaction of the surface by treading promoted succession to *Puccinellia maritima* along the landward margins of continuous sward, and that *Phragmites communis* and *Scirpus maritimus* tend to replace ungrazed *Spartina* marsh at sites where its upper limits are in soft mud and salinity has been reduced by seepage from land drainage. It was also found that the ability of species to invade *Spartina* marsh is to a large extent due to the opening up of the sward by *Spartina* wrack. In noting that marsh levels suitable for colonisation by *Scirpus* and *Phragmites* are being built up at about four times the rate they can be colonised by advance of the continuous *Scirpus/Phragmites* front, Ranwell (1964b) concluded that such advance is retarded only by the inherent powers of spread of these species in the face of competition with *Spartina*.

At many British stations, accretion in *Spartina* has raised terrace surfaces to about the level of mean high water spring tide, which is the upper limit of *Spartina* growth. While *Spartina* in a mesohaline
environment at the rear of the Bridgwater Bay marsh has been succeeded by other species, this has not necessarily occurred elsewhere. In euhaline and polyhaline high water conditions at stations such as Southampton Water (Goodman et al. 1959) and Poole Harbour (Hubbard 1965a), _Spartina_ which dies back at high tide level is not succeeded by other plants. As the binding effects of the rhizome network are reduced with failure of the grass, the terraces are no longer protected from wave and current action, and large quantities of sediment are thus released by cliffing along the edge of the marsh (Bird and Ranwell 1964).

Widespread die-back leading to erosion at sites such as Southampton Water, Poole Harbour and the Lymington estuary (Plate 6.52) is thought to be linked to excessive wetness of substrate and the cessation of accretion once high tide level is reached (Goodman 1960). However, Ranwell (1972 pers. comm.) has noted that die-back is also promoted by the smothering of _Spartina_ by algal mats, the growth of which is encouraged by the present unusually high nitrogen levels in many British estuaries, caused by the discharge of agricultural fertilizers, industrial waste and sewage. An additional important factor is land subsidence and 'drowning' of the marshes, which is characteristic of southern England where die-back and _Spartina_ recession are most apparent (Ranwell 1980 in litt.); the tide gauge at Newlyn indicates a rise of approximately 15 cm in mean sea level since the 1916-21 mean was established for Ordnance Datum (Bird 1980 pers. comm.), which is primarily attributable to tectonic rather than eustatic movement. Very little is known about changes in the relative levels of land and sea in south east Australia since the time of _Spartina_ introduction, but it is believed that they have not been sufficient to affect marsh development.

While the causes of die-back have not yet been fully explained,
it is evident that *Spartina* creates a disfunction in the saltmarsh ecosystem (Beefink 1975, 1977), in that it is largely incapable of fitting into the succession series of saltmarsh vegetation in euhaline and polyhaline environments. Habitats available in die-back sites in such areas are not colonised by saltmarsh species which might have been expected to succeed *Spartina* given the level to which terrace surfaces have been raised. However, at the present stage of marsh development in Australia, the likelihood of extensive *Spartina* die-back cannot be predicted.
CHAPTER SEVEN

CONCLUSION

Despite its introduction to all Australian states, *Spartina* has been successful only in the south east of the country. All but a few square metres of the 620 ha now occupied by the grass are found in the embayments, estuaries and lagoons of Bass Strait, which separates Tasmania from Victoria. Moreover, the Tamar estuary alone accounts for 85 per cent of the total *Spartina* area, and a further 10 per cent occurs in Andersons Inlet. While *Spartina* is of local significance as an agent of change on marshy shorelines, its impact is not widespread.

At Andersons Inlet it has been possible to record rates of spread of *Spartina* from the earliest stages of colonisation. New growth from six clumps introduced in 1962 occupied 8.67 ha by 1967, 27.74 ha by 1970, 48.77 ha by 1975 and 63.57 ha by 1980, as defined by the total area of zones drawn to enclose all *Spartina* within areas of at least 10 per cent cover. The broad outline of the present distribution of *Spartina* was apparent as early as 1967-70, for the grass quickly but sparsely colonised most suitable habitats. Since that time *Spartina* density has declined due to fusion of population units, and *Spartina* cover has increased. In sample 30.5 m x 30.5 m quadrats, the rate of increase in *Spartina* cover peaked between 1970 and 1975, when the mean annual rate of expansion was 5.9 per cent of quadrat area. The average rate of cover increase over the period 1967-80 was 3.5 per cent of quadrat area per annum, and in some quadrats *Spartina* cover was approaching 100 per cent within 14 years of marsh inception.

Initial colonisation at Andersons Inlet occurred within a narrow
vertical range of 0.61 m - 0.83 m above Inverloch datum. **Spartina** rapidly expanded to lower and higher levels, and soon approached the present vertical limits of 0.25 m and 1.13 m above Inverloch datum. The seaward limit of **Spartina** is now submerged for an average of 6.3 hrs during mean spring tides and 6.2 hrs during neaps, and tidal submergence for periods longer than 6 hrs is common at other Australian stations. However, the landward limits of **Spartina** in Australia are submerged by spring tides and the area of **Spartina** which remains uncovered by neap tides is small.

**Spartina** has become most abundant at Andersons Inlet at sites which have four characteristics in common: water salinity of less than 18⁰/oo during normal spring tides; shelter from strong and frequent wave action; a substrate of fine sands of 2.0 Ø to 2.6 Ø mean grain diameter; and a steady supply of seeds and plant fragments from which new growth could commence. Similar conditions are found in areas of greatest **Spartina** abundance at other stations. The plant is usually stunted at exposed sites where the substrate consists of coarser material, and in areas of higher salinity the rate of expansion is low.

There are many sites in Australia where the growth of **Spartina** has not been accompanied by accelerated accretion of sediment. There are also sites, such as Andersons Beach, where the deposition of large quantities of sand is unrelated to the presence of the grass and has resulted in its local suppression. However, at many sites in the major Australian stations, **Spartina** has promoted greater rates of sediment accretion than would have occurred in its absence. Further, this accelerated deposition of sediment may sometimes be recognised before sward formation is completed, as indicated by the development of microtopographic highs coincident with **Spartina** clones and clumps. While rates of accretion vary
temporally and spatially, the depth of sediment deposited on marker layers in *Spartina* at Andersons Inlet has commonly been greater than 2 cm per annum, and rates as high as 7 cm per annum have been recorded.

Where *Spartina* growth is accompanied by increased rates of sediment accretion, depositional terraces are formed on low marsh and the upper levels of mudflat. Six major types of terrace may be recognised:

(i) Type A terraces, defined by maximum accretion in the middle levels of the marsh. These are a common early stage in the formation of other types of terrace, but persist only where the seaward margins of linear swards are characterised by low stem density, and where small quantities of sediment are supplied by tidal currents rather than wave action.

(ii) Type B terraces, also characterised by maximum accretion in the middle levels of the marsh, but formed on more exposed shorelines where coarser sediment is deposited by constructive wave action and retained within *Spartina* zones during subsequent phases of erosion.

(iii) Type C terraces, which have a concave profile seaward of the point of maximum accretion. Emplacement of sediment against the seaward margin of *Spartina* swards allows forward growth to continue, until marsh progradation is halted by either prolonged tidal inundation or the presence of a major channel.

(iv) Type D terraces, characterised by a steep outer margin and a marked break of slope at the point of maximum accretion, which lies near the seaward limit of *Spartina* growth. Such terraces are most common at sites receiving an abundant supply of sediment, and where the outer margin of the marsh is exposed to wave or current action. They may form from any of the previous three types of terrace as a result of seaward migration of the point of maximum accretion; they also develop at sites where very flat intertidal mudflats are rapidly and
uniformly colonised by seedlings, which causes the point of maximum accretion to be near the seaward limit of *Spartina* almost from the time of marsh inception. The outer margins of most Type D terraces are stable, but there are isolated examples of cliffing and frontal erosion.

(v) Type E terraces, which have a landward slope towards the rear of the marsh. These terraces may form where sediment accretion in continuous *Spartina* is greater than that in *Avicennia* along its landward margin; they also occur where cheniers are emplaced along the seaward edge of a sward.

(vi) Type F terraces, the gradients of which are determined primarily by the slope of rocky shorelines on which *Spartina* has established in patches of bare mud, and only secondarily by accelerated accretion promoted by its presence.

The upward growth of *Spartina* terraces is accompanied by the development of tidal creeks. Accretion in discontinuous clones and clumps is greater than on interspersed unvegetated areas, in which tidal runoff becomes concentrated. Creeks thus may be initiated as a result of micro-relief created by differential rates of accretion, before sward formation is completed. In continuous sward, tidal creeks may develop by erosion of the surface layer of living turf. Further, where *Spartina* has colonised mudflats already traversed by creeks, the channels have been narrowed by lateral encroachment and deepened by accretion of sediment on the banks. Although creek systems at present consist of fairly straight low order channels, it is anticipated that dendritic drainage networks will develop with continued rise in the elevation of marsh surfaces, and that tidal flow will eventually be confined to tidal channels except near the peak of the flood.

Pan formation is common along the landward margins of *Spartina* swards, where growth of the grass is suppressed by large masses of *Spartina*
wrack. Pans also may be initiated elsewhere in the marsh by the
development of rotten spots caused by impeded drainage, by Spartina
die-back in shaded sites beneath juvenile mangroves which have established
within continuous sward, and by the failure of Spartina to colonise sites
beneath the canopies of large mangroves. The sides of pans in areas of
high rates of accretion may be steepened by slumping at the base combined
with marginal overgrowth at the surface, thus producing features resembling
pond holes.

At Victorian stations, Spartina has created habitat conditions
suitable for the forward growth of Avicennia marina, which has promoted
local die-back at some sites. While plants characteristic of submergence
marsh have established on patches of bare mud in the highest levels of
Spartina at Andersons Inlet, the grass has not been widely invaded by other
species. There are few sites at which Spartina has established in
pre-existing saltmarsh, where isolated tussocks and clumps are restricted
to drains and the margins of waterlogged pans. Except where colonised
by mangroves, Spartina grows as essentially monospecific communities,
which have established at levels which were formerly virtually unvegetated.

The geomorphological significance of Spartina in Australia lies
in its ability to hasten the processes of marsh formation. In areas of
abundant sediment supply, the rapid upward growth of depositional terraces
and the transformation from non-channelised to partly channelised flow have
created intertidal landforms which bear a strong morphological resemblance
to high or emergence marsh, at least in an incipient form. While not within
the scope of the present study, it is important that attention be given to
the impact of this physiographic change on the ecology of Australian
estuaries and their utilisation by man, and to the possible need for
management and control of Spartina growth in this country.
REFERENCES


Arbuthnot, A. (1966 pers. comm.). Conversation with the author. (Mr. Arbuthnot was responsible for transplanting Spartina from Bass River to Nolans Bluff).


Ballinger, K. A. (1968 in litt.). Letter to Dr. E.C.F. Bird, 20 March. (Mr. Ballinger was then City Engineer at Invercargill, New Zealand.)


Brooks, H. G. (1979 pers. comm.). Conversation with the author. (Mr. Brooks was formerly the owner of Buckland Park property, Two Wells, South Australia.)


Court, A. B. (1970 in litt.). Notes on the identification of *Spartina* specimens. 27 July. (Mr. Court is Senior Botanist at the National Herbarium, Melbourne.)


Fricke, E. F. (1951 in litt.). Letter to C. A. Neal-Smith, Plant Introduction Officer, Division of Plant Industry, CSIRO Canberra, 22 August. (Mr. Fricke was then Chief Agronomist, Department of Agriculture, Hobart.)

Frost, J. N. (1980 pers. comm.). Conversation with the author. (Mr. Frost is the son of Mr. F. A. Frost, who planted *Spartina* at Currambene Creek.)


Spartina x townsendii H. and J. Groves sensu lato. 
J. Ecol. 57 : 298-313.

in Spartina townsendii agg. III. Physiological correlates 

17 : 277.

Cl. Manchr. 1 : 37.


archaeol. Soc. 1 : 509-513.


Harbord, W. L. (1949). Spartina townsendii: a valuable grass on tidal 

Hardy, E. (1960). Control of Spartina grass in tidal estuaries. Dock and 


7 : 31-37.

Horton, R. E. (1945). Erosional development of streams and their drainage 

Hubbard, C. E. (1957a). In report of British Ecological Society Symposium 
on Spartina. J. Ecol. 45 : 613.

Hubbard, C. E. (1957b). Observations on species and hybrids of Spartina 
in the British Isles. Advisory Committee on Sea Defence 
Research, CSD 46. Unpublished.


VI. Pattern of invasion in Poole Harbour. J. Ecol. 53 : 
799-813.

Hubbard, J. C. E. (1965b). A bibliography of S. townsendii (s.l.) 
H. and J. Groves, European S. alterniflora Lois and British 
S. maritima (Curt.) Fernald. Unpublished typescript, Nature 
Conservancy, Furzebrook, Dorset.


Jones, B. (1978 pers. comm.). Conversation with the author. (Mr. Jones is the present occupier of Kooratang Estate, Foster, and the son of Mr. J. G. Jones who planted Spartina in Tidal Creek.)


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Martin, G. J. (1964 in litt.). Reply to Dr. D. S. Ranwell's questionnaire on Spartina resources in Tasmania. (Mr. Martin was then an agronomist with the Department of Agriculture, Launceston.)

Martin, G. J. (1966 in litt.). Letter to D. Steane, Conservation Officer, Lands and Surveys Department, Bridport, Tasmania, 14 March.

Martin, G. J. (1971 in litt.). Background information on the rice grass areas of Tasmania. Unpublished typescript, Department of Agriculture, Launceston.


Mitchell, A. (1964 in litt.). Reply to Dr. D. S. Ranwell's questionnaire on Spartina resources in Victoria. (Mr. Mitchell is Chairman of the Soil Conservation Authority, Victoria.)


Neal-Smith, C. A. (1951 in litt.). Letter to E. F. Fricke, Chief Agronomist, Department of Agriculture, Hobart, 30 July. (Mr. Neal-Smith was then Plant Introduction Officer in the Division of Plant Industry, CSIRO, Canberra.)


Philip, J. R. (1970 in litt.). Letter to the author, 29 July. (Mr. Philip was Acting Chief of the Division of Plant Industry, CSIRO, Canberra.)


Ranwell, D. S. (1972 pers. comm.). Discussion with the author.


Sparks, T. (1969 pers. Comm.). Conversation with the author. (Mr. Sparks is the grandson of the farmer who introduced Spartina to Cherry Tree Creek.)

Sparks, H. (1974 pers. comm.). Conversation with the author. (Mr. Sparks is the son of the farmer who introduced Spartina to Cherry Tree Creek.)


Stapf, O. (1914a). Townsend's grass or ricegrass. Proc. Bournemouth nat. Sci. Soc. 5 : 76-82. (This paper was also published in the same year in J. Ecol. 2 : 192.)


Symon, D. E. (1978 in litt.). Letter to the author, 21 December. (Mr. Symon is an agronomist at the Waite Agricultural Research Institute.)


(Mr. Wyeth is an engineer, surveyor and field naturalist who has resided at Inverloch for over 70 years.)

APPENDIX

The Appendix consists of an unbound copy of a monograph by the author, which has been published as Melbourne State College Occasional Paper No. 6, May 1981.
THE INTRODUCTION OF *SPARTINA TOWNSENDII* (S.L.) TO AUSTRALIA

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My interest in tracing the introduction of Spartina to Australia was initially aroused by the occurrence of this exotic species in Victorian estuaries, and by a summary of known Spartina exports from Britain prepared by Dr. D. S. Ranwell, now of the University of East Anglia (Ranwell 1964 in litt.). The project was subsequently discussed with Dr. Ranwell at Norwich in 1972.

In reconstructing the sequence of events which led to widespread but often unsuccessful plantings in all the Australian states, I have received assistance from a large number of people. Some are in state and local government authorities, and others are farmers or the relatives of persons known to have played a role in the introduction of Spartina in the late 1920s and early 1930s. While the list is too long for all names to be included, special thanks are due to the following:

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<td>FIGURE</td>
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<tr>
<td>1</td>
<td>Small <em>Spartina</em> tussock, Duck Bay, Tasmania.</td>
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<td>2</td>
<td><em>Spartina</em> clones and clumps, Tamar River, Tasmania.</td>
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<td>3</td>
<td><em>Spartina</em> swards at Andersons Inlet, Victoria.</td>
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</tbody>
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INTRODUCTION

*Spartina townsendii* (s.l.) is an erect, halophytic grass which colonises the intertidal zones of estuaries and lagoons. Known commonly as 'rice-grass' or 'cord-grass', *Spartina* grows to a maximum height of 1 m in summer. Like mangroves, the grass requires regular tidal immersion in salt water, and forms a pioneer plant community between low tide and high tide levels.

*S. townsendii* (s.l.) originated in Southampton Water, England, a little more than 100 years ago, as a result of hybridisation between native *S. maritima* and American *S. alterniflora*. The latter had apparently been introduced accidentally by ship, possibly from the River Plate in Argentina (Montagu of Beaulieu 1907). The first collections in 1870 were of a plant which has since been identified as a sterile F1 hybrid (Hubbard 1957a). The new grass began to spread rapidly in the 1890s, and plants collected at that time are now known to have been fertile (Hubbard 1957b). Marchant (1963, 1968) has shown that the fertile form is an amphidiploid derived from the primary hybrid by chromosome doubling.

As two morphologically distinct plants have thus been collected as *S. townsendii*, the suffix *sensu lato* (s.l.) is conventionally used when referring to this species. Individually, the sterile form is called *S. x townsendii*, and the fertile form is known as *S. anglica* (Hubbard 1968). Where no specific reference is made below to either the sterile or fertile form, or to other *Spartina* species, the name *Spartina* refers to *S. townsendii* (s.l.).

Fertile *S. anglica* is by far the more common of the two forms of *S. townsendii* (s.l.). It spreads primarily by dispersal of seeds, while the sterile form reproduces only by growth from fragments of roots and rhizomes eroded from mature plants. New plants of both forms expand laterally by rhizome extension to form small tussocks (Plate 1), which further enlarge to form clones (Plate 2), so named because they are the product of a mass of shoots and rhizomes radiating from a parent plant. Clones merge to form clumps and eventually swards (Plate 3), which are large masses of *Spartina* with a single limiting outline. Very extensive
swards are known as *Spartina* meadows, which may occupy an area of several hundred hectares.

Because it seeds profusely, the amphidiploid quickly spread by natural dispersal in Southampton Water and in other sheltered areas along the south coast of England, within a few years of its discovery. *Spartina* was collected from Lymington in 1892, Isle of Wight in 1893 and Poole Harbour in 1899. By 1907 the grass was estimated to cover 6000–8000 ac (2428-3237 ha) within the Hampshire Basin alone (Montagu of Beaulieu 1907), and by 1913 it had invaded or been introduced to every estuary and harbour from Chichester to Poole (Goodman et al. 1959).

It was soon apparent that the new grass not only had remarkable powers of spread, but that accelerated rates of sediment accretion were occurring in colonised areas. Its potential as an agent of coastal engineering was recognized by the Royal Commission on Coast Erosion and Afforestation (1907-11), the terms of reference of which included reporting on "measures desirable for prevention of encroachment of the sea" and "facilities for the reclamation of tidal lands". The Commission concluded *inter alia* that the process of natural accretion on alluvial flats could be hastened by the introduction of *Spartina* (Min. Roy. Comm. Coast Erosion and Afforestation 1911). As a result of both this recommendation and a good deal of popular and scientific interest in the grass, *Spartina* was planted extensively throughout the British Isles for reclamation and coast protection (Oliver 1920, Bryce 1931). It was introduced by river boards and harbour authorities as an aid in the prevention of shoreline erosion, by navigational interests to stabilise mudflats and reduce source areas for channel silting, and by farmers to reclaim mudflats for grazing and crops (Ranwell 1967). While much of the transplanted material undoubtedly was obtained from local and unrecorded sites, many introductions of seeds and plant fragments were from a *Spartina* nursery established by Mr. B. Cartridge at Poole Harbour, and from experimental plantings of Poole Harbour stock along the Essex shoreline (Hubbard 1965).

*Spartina* from Essex and Poole Harbour was also planted extensively outside Britain. In the period 1923-36, Cartridge alone exported over 175000 plant fragments and many samples of seed to at least 130 sites in over 40 countries (Hubbard 1965). Many requests for plant material
followed a publication by Oliver et al. (1929) on the use of *Spartina* in reclamation, shoreline protection and as a fodder crop, which was widely quoted in the world press.

One of the first and largest overseas consignments was to the Netherlands in 1923, when 40000 plant fragments were imported for reclamation projects by the Dutch Government (Oliver 1927–28). Introduced initially to a small number of sites in the estuaries of the Rhine, Meuse and Scheldt, 'Engels slijkgras' spread rapidly throughout the south west delta region and proved particularly useful as an agent of coastal engineering in the Zuid Sloe near Vlissingen (Kalkwijk 1954). *Spartina* was also introduced successfully to cool or temperate climates in countries in Central and South America, Africa, the Middle East, India and South East Asia. In 1967, *Spartina* was estimated to be the dominant species over an area of at least 21000 ha (approximately 80 square miles), at sites in nine countries (Ranwell 1967).

Like other alien species such as *Eichornia crassipes* (Water Hyacinth) and *Opuntia inermis* (Prickly Pear), *Spartina* has been successful in Australia. This monograph seeks to reconstruct the chain of events which brought *Spartina* to this country, and gives a brief account of its present distribution.

PLATE 1

Small *Spartina* tussock, Duck Bay, Tasmania.
PLATE 2

Spartina clones and clumps, Tamar River, Tasmania.
Sward formation is almost complete.

PLATE 3

Aerial oblique photograph of Spartina swards at Andersons Inlet, Victoria. The swards have developed since the mid 1960s, when young Spartina plants first colonised this site.
THE IMPORTATION OF Spartina TO AUSTRALIA.

Spartina was introduced to Australia in the late 1920s and early 1930s, in response to reports from Europe on the value of the grass for land reclamation and shoreline protection, and on its possible use as a pasture crop. Seeds, seedlings, root-stock, cuttings and whole plants were obtained by landowners, commercial companies and various government authorities.

There is no central register of Spartina introductions to Australia. Records have been maintained by Plant Introduction Officers in the various Departments of Agriculture in each state and by other government agencies such as soil conservation authorities. Records also have been kept by Commonwealth Government agencies such as the Division of Plant Industry of the Commonwealth Scientific and Industrial Research Organization (CSIRO), although it is only recently that material introduced by the states has been recorded centrally by this body.

Both the Commonwealth and state records are incomplete. It would appear that many introductions, which can be confirmed from other sources, were made without a quarantine clearance and escaped the notice of the appropriate government authority (Grant Lipp 1978 in litt., Kloot 1979 in litt.). Further, the eventual destination of many confirmed introductions is not known. Given that it is fifty years since the majority of Spartina consignments were received in Australia, it is inevitable that some records have been lost or are otherwise unavailable.

Information on Spartina introductions has been assembled from a variety of sources. The starting-point was information on known Spartina exports from England to Australia, culled by Ranwell from records kept by B. Cartridge of Poole and the East Anglian Institute of Agriculture, Chelmsford, England (Ranwell 1964 in litt.). This was checked against records of plant introductions held by the CSIRO Division of Plant Industry, Canberra, and by the Department of Agriculture in each state. The comparison provided information on consignments additional to those listed by Ranwell, and revealed that many introductions by private persons had apparently not been registered by government agencies.
On the basis of the two sets of records, a preliminary list of Australian *Spartina* recipients was prepared. These people or their descendants, or the present occupiers of their properties, were contacted by letter. Letters also were sent to government authorities with a possible interest in *Spartina*. Additional information was obtained from the private papers of the late Sir Samuel Wadham, formerly Professor of Agriculture at the University of Melbourne (Wadham *in litt.*, various dates). As a result, it was possible for information on most consignments to be cross-checked and corrected or confirmed.

Details of *Spartina* introductions to Australia are given in Table 1, at the end of this section. The sites of confirmed plantings are shown in Figure 1, which also indicates the success or failure of each introduction.

The first known introduction of *Spartina* to Australia was in Victoria. Professor A. J. Ewart of the University of Melbourne planted *Spartina* at Corner Inlet, without success (Wadham 1929b *in litt.*, Philip 1970 *in litt.*). The date of planting is uncertain although it may have been many years before the numerous *Spartina* introductions beginning in the late 1920s, for Ewart was appointed from England to the Chair of Botany and Plant Physiology at The University of Melbourne as early as 1906. Wadham (1929b *in litt.*) refers to the planting being made "some years ago", and the Division of Plant Industry of the former Council for Scientific and Industrial Research (CSIR) recorded that the planting was "some time prior to 1930" (Philip 1970 *in litt.*). Unfortunately no record made by Ewart at the time of planting now survives. He was apparently aware of the failure of the introduction for his own *Flora of Victoria*, which lists alien plants, includes no reference to *Spartina* (Ewart 1930). Wadham provides no information on the exact location or date of the planting, although he and Ewart were colleagues from Wadham's arrival in Melbourne in 1926 until Ewart's death in 1937. Wadham's single reference to the planting (Wadham 1929b *in litt.*) implies only a casual conversation with Ewart on the subject: in Wadham's words it was "merely a case of putting the seeds or runners in and wishing them luck".

From 1927 to 1929 there were at least fourteen separate introductions of *Spartina* to Australia. With the exception of the 1927 consignment
Figure 1  Initial Spartina plantings in Australia.
of plants to Tasmania, all consignments were of seed. It is evident that there were difficulties in achieving successful germination.

The problems of seed germination were noted in relation to the 1929 consignments to the Department of Agriculture, South Australia. On arrival the seed in both consignments was mouldy, a condition attributed by Wadham (1930b in litt.) to salt in the seed collecting moisture as it passed through the tropics. Germination proved difficult even in a germinating chamber using fresh and salt water. Success was achieved only where the seed was placed in mud, lightly covered with sand, watered with fresh water until germination and then watered with a mixture of fresh and sea water in the early stages of seedling development (Spafford 1930a in litt.). Only 20 plants were raised from the two consignments; there is evidence to indicate that germination rates were higher for the seed obtained from Poole Harbour than for seed obtained by Oliver from plants introduced to Holland (Kloot 1979 in litt.).

Germination and planting of the South Australian seedlings was supervised closely by W. J. Spafford, then Deputy Director of Agriculture. The material was imported with the intention of assessing its performance on 'sapphire flats, seepage patches and beaches' (Spafford 1930a in litt.). The sites to which it was introduced fall into several categories: inland, wet saline environments along the Murray River at Waikerie, Barmera, Morgan and Murray Bridge; similar but not riverine environments at Kybybolite and Beachport (presumably in the vicinity of coastal but non-tidal Lake George); a lagoonal environment at Milang and Narrung; a tidal high-salinity environment at North Arm; and a tidal estuarine environment in the Gawler River at Buckland Park. Spartina has persisted only at the latter site, where four clones and a few small tussocks occur 3 km upstream from the mouth. Of the fourteen consignments received in Australia between 1927 and 1929, only part of one has survived.

The first effective establishment of Spartina in Australia occurred in 1930. In that year thirteen consignments were received, two of which provided material for planting in Tidal Creek, in the north west of Corner Inlet, Victoria, in September and October 1930. This material has survived. As the Buckland Park seedlings were not planted until January 1931, Tidal Creek is the oldest Australian Spartina station.
The 1930 consignments were predominantly seedlings and cuttings, not seeds. These plantings were more successful, persisting at many sites for several years. The most ambitious planting project was that attempted by the Geelong Harbour Trust, Victoria, which introduced more than 3000 plants to Lake Connewarre and the lower Barwon River estuary, with the intention of reclaiming "much of the shallow lake bed, which it is thought will eventually become good grazing land" (Geelong Advertiser 26 May 1930).

The Geelong Harbour Trust obtained its first plants from a box of cuttings sent to D. F. Griffiths of Geelong in May 1930 (Grey 1931 in litt.). The Trust subsequently imported five more consignments between September and December 1930, comprising 26 cases at an average landed cost of 25 pounds (Australian) per case (Grey 1932 in litt.). These later consignments were of seedling plants, not cuttings (Ranwell 1964 in litt., Wadham 1970 in litt.). They were planted out on the northern and southern shores of Lake Connewarre, and at Ocean Grove and Barwon Heads in the lower Barwon estuary (Phillips 1959 in litt.).

Although Spartina imported by the Trust was intended for use near Geelong, a box of cuttings was made available to the Victorian Department of Agriculture in September 1930. This was offered by the Department to the Great Southern Agricultural Society, at Foster, which nominated Mr. J. G. Jones of the Kooratsang Estate to conduct trial plantings. The stock was planted on 20 September (Wadham 1930f in litt.) along the outer and inner edges of an embankment fringing Tidal Creek. Wadham was notified of the plantings by the Department of Agriculture, and invited to take an interest in the progress of the experiment (Mullett 1930 in litt.).

By this time Wadham had already obtained a supply of Spartina material. His interest in planting the grass in Victoria had been expressed in May 1930 in a letter to Dr. Dickson, then Chief of the CSIR Division of Plant Industry, Canberra (Wadham 1930a in litt.). Wadham asked whether the Division would arrange for the importation of seeds and plant fragments through its Introductions Branch, or alternatively facilitate quarantine clearance if he were personally to bring material back from England in the early part of 1931. Dickson subsequently arranged the
importation of 100 plants from New Zealand (Dickson 1930a, b in litt.). The stock was obtained from R. O. Dalrymple of Bulls, New Zealand (Philip 1970 in litt.), whose family in 1913 had transplanted small clumps of Spartina from Southampton Water to the Foxton mudflats in the estuary of the Manawatu River (Allen 1924).

The consignment arrived in Canberra in late July; a batch of 30 plants was then railed to Melbourne where they were received by Wadham on August 5. On arrival the plants appeared dead (Wadham 1930d in litt.). They were placed in a green-house and watered regularly with both fresh and salt water, and although each plant showed some growth by late September only one had produced a shoot over 7.5 cm (3 inches) (Wadham 1930f in litt.). From the description given by Wadham it appears likely that this material consisted of root-stock rather than seedling plants.

On receipt of the invitation from the Department of Agriculture, Wadham arranged to plant some of his own material at Foster (Wadham 1930e in litt., Jones 1930 in litt.). Eighteen plants were taken to Foster on October 3. They were placed out with the clay in which they had been shipped from New Zealand still attached to the roots, in six different types of site along the shores of Tidal Creek.

Wadham (1930f in litt.) provided a sketch map of the plantings (Figure 2). Three plants were placed at sites on either side of an earthen sea-wall. The sites were described by Wadham as follows:

"A. Mud/sandy mud outside bank.
B. Brackish water on sandy mud inside bank.
C. Sandy mud at medium level outside bank.
D. Very thick sandy mud at low level outside bank.
E. Very thick sandy mud between two mangrove belts.
F. Mud among mangroves".

Wadham also observed that the two-week-old plantings of Geelong Harbour Trust material were not healthy, a fact he attributed to them being placed at too high a level.

By June 1931, Spartina that had been planted adjacent to mangroves (sites E and F) was dead. A few plants outside the bank (sites A, C
Koorakang Estate Grazing Paddocks.

A 3 plants in mud and sandy mud outside bank.
B 3 " brackish water on sandy mud inside bank.
C 3 " sandy mud at medium level outside bank.
D 3 " very thick sandy mud at low level outside bank.
E 3 " " " " between two mangrove belts.
F 3 " mud among mangroves.

Figure 2 Wadham's sketch of the 1930 Spartina plantings at Tidal Creek, Corner Inlet. (Published with permission of The University of Melbourne Archives)
Spartina and mangroves (Avicennia marina) at Tidal Creek, Corner Inlet, November 1978. The photograph includes Wadham's sites A and C, where Spartina introduced in October 1930 had failed by February 1932 (Wadham 1932 in litt.). Spartina growth has resulted from survival of Geelong material planted in September 1930, and also from local transplants of vigorous material from inside the bank (left of photograph) (Jones 1978 pers. comm.).
and D) were described as "still alive"; the only plants which showed signs of growth were two survivors in brackish water inside the bank (site B) (Wadham 1931a in litt.). By February 1932 the only plants surviving were those at site B where *Spartina* was growing vigorously in association with *Salicornia* spp., and two of the Geelong Harbour Trust plants, one of which was described as making "fair progress" (Wadham 1932 in litt.). These plants persisted, and have since spread extensively within Tidal Creek (Plate 4).

In December 1930, Wadham inspected the Geelong Harbour Trust plantings in Lake Connewarre and the lower Barwon. The Trust had made no further plantings since receipt of the last consignment despatched from England on 20 September 1930; the success of the grass was regarded as doubtful and no further importations were to be made until it had been proved (Grey 1931 in litt.). Wadham found that plantings made in the spring of 1930 had been generally more successful than those of the previous autumn. *Spartina* planted at higher marsh levels, in zones of "rhizomatous and tussock forming grasses" and "shrubby perennial *Salicornias* and *Suædas*", had disappeared or made slow progress (Wadham 1931b in litt.).

There was however excellent progress in the zone of "herbaceous *Salicornias*, probably largely annuals, *Spermularia* spp. etc.", where plants of 4 cm diameter had enlarged to 30 cm diameter in 16 months. No plantings had been attempted amongst mangroves; plantings on bare mud were inaccessible on the day of inspection and hence could not be assessed.

As at Foster, Wadham (1930b in litt.) concluded that *Spartina* could flourish in the *Salicornia* zone, which he recommended be used for the establishment of *Spartina* nurseries. He saw the prospect for development on bare mudflats as uncertain, but the eventual key to rapid colonisation. He recommended that future plantings at Geelong and elsewhere should be made in the spring, and suggested that fencing would be required to avoid depredation of plantations by rabbits. His observation that "the project if successful would involve reclamation of about 8500 acres of Lake Connewarre and confluent basins" encouraged the Commissioners of the Geelong Harbour Trust to consider ordering a further consignment (Grey 1932 in litt.).

Unfortunately neither Wadham nor the Harbour Trust provided a map of
Figure 3  Lake Connewarre and the lower Barwon estuary, showing sites at which *Spartina* was planted in 1930-31.
Spartina plantings in the Geelong district. Wadham's papers include several photographs of Spartina tussocks, but they give no indication of their precise location. It is certain that Spartina was planted at the southern end of Lake Connewarre (Phillips 1959 in litt.); at Lake View in Lake Connewarre, where it could not be found in May 1933 (Wadham 1933 in litt.); at Ocean Grove, where it was reported and photographed growing in association with Salicornia (Wadham 1931b in litt.); and at Barwon Heads, where it was recorded as spreading steadily and flowering in May 1933 (Wadham 1933 in litt.) (Figure 3.). It is not likely to have been planted in the central reach of the lower Barwon, as it is reported that Spartina had not been introduced in the mangrove zone (Wadham 1931b in litt.). The Trust also planted Spartina at two sites at Corio Quay on the shore of Corio Bay, where by 1933 one plot 107 cm x 46 cm (42 ins x 18 ins) had expanded to 152 cm x 102 cm (60 ins x 40 ins) (Grey 1933 in litt.). Both sites have since been artificially reclaimed (Phillips 1959 in litt.).

It is also unfortunate that the failure of Spartina in the Geelong district was not monitored, and the date of its final disappearance is unknown. In 1934 Lake Connewarre and the Barwon estuary passed from the control of the Geelong Harbour Trust, and no further heed was paid to the progress of Spartina (Phillips 1959 in litt.). Wadham did not continue his interest in the grass after the mid 1930s (Wadham 1970 in litt.).

Of the 30 plants sent by CSIR to Wadham in August 1930, only eighteen were planted at Foster. He retained in the green-house twelve plants "which I propose to try in one or two other locations as opportunity offers" (Wadham 1930f in litt.). The Wadham papers held in The University of Melbourne Archives contain no reference to the eventual destination of these plants, nor do they indicate whether Wadham ever collected seed or cuttings from which to produce more stock.

In a letter to the author, Wadham (1970 in litt.) provided information on plantings which appear to account for the balance of the consignment. Root-stock was given to Mr. J. Grieve for planting "in the mouths of streamlets" flowing into Bass River, Westernport Bay, Victoria. In addition, Wadham himself planted Spartina "on the flats of Westernport Bay in various places". No date is given for these introductions, although the letter implies that they occurred some months later than
those at Tidal Creek. Local residents in the Bass River vicinity, including Mr. Grieve's descendants, recall the grass being planted in the early 1930s. Unfortunately Wadham was unable to revisit any of the sites, and the subsequent performance of the grass was ignored. *Spartina* established successfully in Bass River (Plate 5), but evidently failed elsewhere.

Plants from the CSIR consignment of July 1930 were also sent to Western Australia and Queensland, but the attempt to establish them was eventually without success. Root-stock was widely planted on the coast of Western Australia from Wyndham in the north to Albany in the south (Figure 1). The most successful planting was in Oyster Harbour at Albany, where the grass persisted for about five years (Fitzpatrick 1978 in litt.). In Queensland three plants from the consignment survived for several years in the Fitzroy River estuary at Rockhampton (Philip 1970 in litt.).

The remaining introductions in 1930, and those in subsequent years up until the last introduction in 1952, were all unsuccessful. Failure occurred even with large consignments such as those received by the Tasmanian Department of Agriculture in August 1930 and R. Macansh of Anna Plains, Western Australia, in September 1930, despite the fact that both consignments were of seedlings or mature plants which were introduced to a wide range of environments in each state. *Spartina* planted in 1932 at Falls Creek township near Nowra, New South Wales, still persists, but as this cannot be traced back to a consignment from overseas it is treated as a transplant from local Australian material. Records are not sufficiently accurate to allow all plants in every consignment to be accounted for; some may have died before planting, others are likely to have been planted at unrecorded sites. However, with the possible exceptions of the Fall Creek planting, it appears certain that the only *Spartina* stations in Australia which arise from the initial planting of material from overseas consignments are those at Buckland Park, South Australia, and Tidal Creek and Bass River, Victoria.
<table>
<thead>
<tr>
<th>DATE</th>
<th>IMPORTER</th>
<th>SOURCE OF MATERIAL</th>
<th>NATURE OF MATERIAL</th>
<th>PLANTING LOCATION</th>
<th>PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1927</td>
<td>Not known. Consignment sent to Tasmania (21)</td>
<td>Poole Harbour, England (21)</td>
<td>Plants (21)</td>
<td>No reports.</td>
<td>Believed not to have survived.</td>
</tr>
<tr>
<td>1928 or earlier</td>
<td>Not known. Address 11 Wentworth Street, Manly, Sydney, NSW (21).</td>
<td>England (21)</td>
<td>Seed (21)</td>
<td>No reports.</td>
<td>Seed failed to germinate (21).</td>
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<td></td>
<td>A. Francis, Keira Street, Wollongong, NSW (21)</td>
<td>England (21)</td>
<td>Seed (21)</td>
<td>No reports.</td>
<td>Seed failed to germinate (21).</td>
</tr>
<tr>
<td>1928,29</td>
<td>Both the above (21).</td>
<td>England (21)</td>
<td>Seed (21)</td>
<td>No reports.</td>
<td>No reports. Believed not to have survived.</td>
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<td>1928</td>
<td>G. Beedham, Chemlows, Claremont, Hobart, Tas. (21)</td>
<td>England (21)</td>
<td>Sample of seed (21)</td>
<td>No reports.</td>
<td>No reports. Believed not to have survived.</td>
</tr>
<tr>
<td>1928,29</td>
<td>E. Ollett, Habana, Mackay, Qld. (21)</td>
<td>England (21)</td>
<td>Seed. One sample sent 8 February 1928; second sample sent 11 December 1928 (21)</td>
<td>No reports.</td>
<td>First sample failed to germinate (21); no report of second. Believed not to have survived.</td>
</tr>
<tr>
<td>1929</td>
<td>Department of Agriculture and Stock, Brisbane, Qld. (14, 16)</td>
<td>Prof. F.H. Oliver, University College, London (14).</td>
<td>Two parcels of seed (14)</td>
<td>Brisbane, Qld. 1 parcel to Brisbane City Council (14).</td>
<td>No reports. Believed not to have survived.</td>
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<tr>
<td></td>
<td></td>
<td>Originally from Holland (16)</td>
<td></td>
<td>1/3 parcel to Nudgee Creek; planted 24 June 1929 (14)</td>
<td>No reports. Believed not to have survived.</td>
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<tr>
<td></td>
<td></td>
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<td>1/3 parcel to Mr. Gibson, for planting in Tingalpa Creek (14)</td>
<td>No reports. Believed not to have survived.</td>
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<td>Rockhampton, Qld. 1/3 parcel to G.B. Brooks (14)</td>
<td>No reports. Believed not to have survived.</td>
</tr>
<tr>
<td>Year</td>
<td>Location</td>
<td>Details</td>
<td>Notes</td>
<td></td>
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</tr>
<tr>
<td>1929</td>
<td>Poole Harbour, England</td>
<td>4 lb. seed (21)</td>
<td>No reports.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td>Poole Harbour, England</td>
<td>Sample of seed (21)</td>
<td>Intended for &quot;Inland salt patches&quot; (21), probably near Bussendan (6).</td>
<td></td>
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<tr>
<td>1929</td>
<td>Poole Harbour, England</td>
<td>3 lbs. seed (21)</td>
<td>No reports. No record of successful germination. Possibly intended for trial on salt patches at Anama Station, Brinkworth, or for tidal flats at Hawker's property at Port Broughton (12).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td>1. F.W. Oliver, University College, London</td>
<td>Small parcel of seed (16)</td>
<td>In January 1932 seed was sent by Hawker to Morgan Hills Light Lands Farm, Western Australia. It is believed that this was part of the 1929 consignment; it is unlikely to have been seed obtained from Spartina growing at Brinkworth or Port Broughton. Believed not to have survived.</td>
<td></td>
<td></td>
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<tr>
<td>1929</td>
<td>2. R. Cartridge, Poole Harbour, England</td>
<td>2 lb seed (16, 21)</td>
<td>Rates of seed germination were low. 20 plants were successfully raised by May 1930 (22). These had gained secondary shoots by September.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td>Barmera, SA</td>
<td>Three plants introduced to R.A. Wansley property 18 Dec. 1930 (16). Located in an area of &quot;salt lagoons and seepage patches&quot; (1).</td>
<td>Persisted for three years in an almost permanently water-logged saline environment (34). Known not to have survived.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
North Arm, SA
Six plots established on intertidal flats, 19 Jan. 1931 (16). January 1932: surviving in five plots; did not survive among other vegetation in most landward plot (16). Known not to have survived.

Morgan, SA
Plants introduced to T. Richards property, 26 Jan. 1931 (16). No reports. Believed not to have survived.

Narrun, SA

Further planting Apr. 1932 (16).

Murray Bridge, SA
Seed sent to Murray Bridge Agricultural High School, 13 June 1931 (16). No reports. Known not to have survived (3).

Beachport, SA
Two plants introduced 1 July 1931 (16). No reports. Believed not to have survived.

Kybybolite, SA
One plant introduced 2 July 1931 (16). Presumably planted at Kybybolite Experimental Farm. No reports. Believed not to have survived.

Lake Connemara, Vic.
Part of consignment given to Geelong Harbour Trust; planted 20-26 May 1930. It was hoped that Spartina would "reclaim much of the Shallow lake bed, which it is thought will eventually become good grazing land" (7). Doing well in December 1930(21)
Alive December 1931, but making less progress than material imported directly by the Geelong Harbour Trust in September-December 1930 (see below), and planted at the same site (30). Not evident in May 1933 (32). Known not to have survived.

May 1930
D.F. Griffiths, of Harwood and Pin
cott (Solicitors), Geelong, Vic. (7, 9)

1. B. Cartridge, Poole Harbour, England (7, 21) 1 lb. seed (21)

2. East Anglia Institute of Agriculture, Chelmsford, England (9) Box of cuttings (7, 21)
Lovely Banks (near Geelong), Vic.

Unconfirmed planting. Reported to have been planted in brackish water on Griffiths' property near Geelong (26). Griffiths' property was at Lovely Banks; it is said to have had no brackish water sites (11).

Believed not to have survived.

Kiowa Valley and Swan Hill, Vic.

Unconfirmed plantings. D.F. Griffiths is known to have given advice on pasture improvement in saline irrigation areas to Kiowa Valley Orchards and to citrus growers in the Swan Hill district in the early 1930s. It is possible that Spartina was introduced to these areas (11).

Believed not to have survived.

July 1930

Council for Scientific and Industrial Research (CSIRO), Canberra.

R.O. Dalrymple,
Bulls, Rangitikei,
New Zealand (19).

In 1913 the Dalrymple family had transplanted
Spartina from Southampton Water to the Manawatu
River estuary at Foxton, NZ (2).

100 plants (5), "each with a block of native clay attached" (28).

1. Thirty plants received by S.M. Madham, Professor of
Agriculture, University of Melbourne, 5 Aug. 1930 (28)
Planted as follows:

Corner Inlet, Vic.

Planted 5 Oct. 1930 in Tidal Creek, near Foster, 18 plants. Introduced to six different types of site (see Fig. 2.) (28).

Initially appeared dead (28).
Successful growth in greenhouse; watered with fresh, then salt, water (28).

Bass River, Vic.

Planted at J. Griewe property, early 1930s (33).

No early reports; planting site not revisited by Madham (33).
Successful establishment.

Westernport Bay, Vic.

Planted "on the flats of Westernport Bay in various places" in the early 1930s (33).

Known not to have survived.
8. Forty plants sent 1 Aug. 1930
From Canberra to Director of
Agriculture, Perth WA (19).
Planted as follows:

Albany, WA
Planted in Oyster Harbour by Mr. Vaughan. 10 plants. (6)
Initially successful growth, but had failed by 1942 (6).

Anna Plains, WA
Planted by R. Macensh. 10 plants. (19, 6).
Known to have failed by 1942 (6).

Bunbury, WA
Planted in Leschenault Inlet by H.D. Johnson. 3 plants. (19, 6)
Known to have failed by 1933 (19).

Broome, WA
Planted by the Tropical Adviser, F.G.S. Wise. 2 plants (19, 6).
Known to have failed by 1942 (6).

Derby, WA
Planted by A.B. Scott; obtained from F.G.S. Wise. 5 plants (16)
Known to have failed by 1942 (6).

Onslow, WA
Planted by S.P. Heddick; obtained from F.G.S. Wise. 4 plants (6)
Known to have failed by 1933 (19).

Wyndham, WA
Planted by C. McCombe, obtained from F.G.S. Wise. 5 plants (6).
Known to have failed by 1942 (6).

3. Tenterden, WA
Twelve plants from Canberra delivered 12 Aug. 1930, for planting "along side a salt creek where there was plenty of moisture" (19).
Roots had struck and plants were making good progress by March 1931. No further progress by June 1932, attributed to the previous dry summer. Only two plants survived by August 1933 (19). Believed not to have survived.

4. Rockhampton, Qld.
Three plants despatched from Canberra 10 Dec. 1930, at request of Hon. W. Angliss and Dr. Gilruth, for planting by Central Queensland Meat Company in the Fitzroy River (19).
Survived for a few years, failure attributed to crabs (19).
Known not to have survived (8).
<table>
<thead>
<tr>
<th>Date</th>
<th>Origin</th>
<th>Plants/Seedlings Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 1930</td>
<td>Department of Agriculture, Hobart, Tas.</td>
<td>K.W. Dalrymple, Bulls, Rangitiki, New Zealand (23) 100 seedlings in pieces of turf (23)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Little Swanport Lagoon, Tas. 24 plants introduced by T. Mitchell to tidal mudflats, 21 August 1930 (13) 6 plants alive 16 April 1931 (13). Did not survive for long. Known not to have survived (17).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lisdillon Lagoon, Tas. 24 plants introduced by C. Mitchell to tidal mudflats, 22 August 1930 (13). 4 plants alive 10 August 1931 (13). Known not to have survived.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Austin's Ferry, Derwent River, Tas. 4 plants introduced by R.B. Stoeic to tidal mudflats, August 1930 (23). Plants healthy in August 1931, but little growth (23). Known not to have survived (17).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unknown sites, Tas. Cannot account for 48 plants. Known to have been given to Mr. Malcolm, District Agricultural Organiser, Hobart (23). Some plants possibly given to T. Terry, Bushy Park, who is known to have had New Zealand material in 1933 (21). Known not to have survived any site.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anna Plains, WA. 25 plants - R. Macansh (6) Known to have failed by 1942 (6).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Albany, WA. 12 plants - Mr. Vaughan Initially successful growth, but had failed by 1942 (6).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Australind, Bunbury, WA. 5 plants - L. Clifton Known to have failed by 1933 (6).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leschenault, Bunbury, WA. 5 plants - H.D. Johnson Known to have failed by 1933 (6).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bassendean, Perth, WA. 4 plants - C.B. Palmer Known to have failed by 1933 (19).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brunswick Junction, near Bunbury, WA. 10 plants - A.J. Talbot Known to have failed by 1933 (6).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clontarf, Perth, WA. 10 plants - Clontarf Orphanage Known to have failed by 1933 (6).</td>
</tr>
</tbody>
</table>
Sept.- Dec. 1930

Geelong Harbour Trust, Vic. (9)

East Anglia Institute of Agriculture, Chelmsford, England.

Seedling plants (21).

Five different consignments totalling 26 cases, and containing 3000 plants (10).

Lake Connewarre and lower Barwon River, Vic.

Planted on N and S shores of Lake Connewarre, and at Ocean Grove and Barwon Heads in the lower Barwon River (20). Hoped to reclaim about 3400 ha (8500 ac) of Lake Connewarre (30).

Growing but "still uncertain" in June 1931 (9). By December 1931 flourishing in the Sallacotta zone; suppressed by other plants at higher levels and being uprooted by swans at lower levels on bare mud (30).

Not evident on N shore of Lake Connewarre in May 1933, but flowering and spreading steadily at Barwon Heads (32).

No further reports.

Known not to have survived.

Corio Bay, Geelong, Vic.

Planted in the Log Pond (a tidally-affected excavation), and in Corio Quay inlet (20).

Little spread, largely due to grazing by rabbits. Both areas since artificially reclaimed.

Known not to have survived.

Corner Inlet, Vic.

No reports.

Box of cuttings supplied by Geelong Harbour Trust to Victorian Department of Agriculture, September 1930.

Trial plantings at Tidal Creek, Foster, on September 20. Prof. Wadham was invited by Department of Agriculture to supervise the trial (18).

On 3 October 1930, Wadham planted material obtained from CSIR Canberra at the same site (see above).

No reports.

Plants not healthy on 3 October 1930; believed to have been planted at too high a level (28).

By February 1932 only two plants survived; plantings of CSIR material were more successful (31).

Spartina has established successfully at this site. It is not possible to distinguish growth from Geelong Harbour Trust material from growth from CSIR material.

No reports.

Field inspection of estuaries and lagoons on the east Gippsland coast indicates that there is no Spartina in potentially suitable locations in the Orbost district. Believed not to have survived.

1930

G. Harris, Orbost, Vic.

England (21)

Cuttings and seedling plants (21)

No reports.

1930

Not known

Not known

Seed. Known to have been acquired by F.H. Bruning, Seed Merchants, Melbourne, Vic. and supplied to the Geelong Harbour Trust (9).

No reports.

Presumably for use at Lake Connewarre.

No reports.

Company has no record of Spartina introductions.

Believed not to have survived.
1930  J. Campbell, 
Wynella, Corobimilla, near 
Narranderra, 
NSW (21).

England (21)  Box of cuttings (21)  Corobimilla

Saline desert area (21), irrigated by water of approximately 10% salinity. After 15 months flowered but produced no seed. Height 40 cm. By winter 1931 had increased in area by 50 times. Further growth in spring 1931; 24 plants covering an area of 10 m x 0.5 m. Survived summer temperatures of 42°C. Best growth achieved when planted under water. Last report 1933 (21). Known not to have survived.

1930  W.G. Johnston, 
Allworth via 
Stroud, NSW (21)

England (21)  4 boxes of plants (21)  No reports.

No reports. Believed not to have survived.

1930  Department of 
Agriculture and 
Stock, Brisbane, 
Qld. (14)

B. Cartridge, Poole 
Harbour, England (14).

England (21)  7 oz. seed (14)  No reports.

No reports. Nil germination in 59 days (14). Known not to have survived.

1930  Not known. Consignment sent to Queensland via Agent-General in London (21)

Poole Harbour, England (21)  1 lb. seed and 500 cuttings (21)  No reports.

No reports. Believed not to have survived.

1930  Not known

Not known  Small sample of seed acquired by Barrett Bros., Hobart, Tas. (13)  No reports.

No reports. Believed not to have survived.

1930  W.H. Lange, 
Cronton Farm, 
Port Pirie, SA (21)

England (21)  Box of plants (21)  Port Pirie, SA

Planting site described as "the head of Port Pirie" (21). No reports. Believed not to have survived.

1931  Department of 
Agriculture and 
Stock, Brisbane, 
Qld. (14)

R.O. Dallympie, Bulls, 
Rangitikei, New 
Zealand (14)

England (21)  500 rootlets (10 cases) (14)  Brisbane, Qld.

3 cases, planted rear of Department of Agriculture and Stock, William Street (14). No reports. Known not to have survived.

2 cases, sent 22 September, for planting at Church of England Grammar School in Kingfisher Creek (East Brisbane) (14). No reports. Known not to have survived.

2 cases sent to Mr. Curney, Redland Bay, 21 September (14) No reports. Believed not to have survived.

Rockhampton, Qld.

1 case sent to Mr. Straughan, Department of Agriculture and Stock, 18 September (14) No reports. Believed not to have survived.
1931
W.R. Carpenter and Coy. Ltd.,
19 O'Connel St.,
Sydney, NSW (21)

England (21)

Sample of seed (21)

I case sent to J.M. Macdonald,
Reglan Bay, 18 September (14)

Gladstone, Qld.

1 case sent to Gladstone Meat-
works, 23 September (14)

No reports.
Believed not to have survived.

1934
T. Terry, Bushy
Park, Tas. (21)

England (21)

Parcel of seed, sent
in cool storage (21)

No reports.
Believed not to have survived.

1934, 5
J. Adams, Karkoo,
SA (21)

England (21)

Seeds 1934
Plants 1935 (21)

Karkoo, SA

Planted in an inland saline
swamp (3).

No reports.
Believed not to have survived.

1936
F.F. Thompson,
Kardoo Station,
Port Hedland, WA
(21)

England (21)

Sample of seed, and
two boxes of plants
(21)

No reports.
Believed not to have survived.

1937
W.C. Bedlington,
Forth, Tas (21)

England (21)

Plants (21)

No reports.
Believed not to have survived.

Early
1940s
Department of
Agriculture,
Sydney, NSW (35)

Thames River,
New Zealand (35)

Roots (35)

NSW Coast

Trails conducted at twenty sites
(35). Locations not known.

In 1965 it was reported that nine-
teen of the plantings had failed
within a few years due to high
summer temperatures, and that
Spartina had survived only in a
small tidal creek near Nowra,
where the grass was shaded by tall
trees (35).

The only Spartina which persists
near Nowra, and indeed in NSW,
is that at Falls Creek. This was
planted in 1932 (see Table 2.)
It is believed that the 1965
report is in error, and that none
of the early 1940s plantings have
survived.
1942 
Wheat Pool of Western Australia, Perth, WA (6) 
England (6). Obtained through Overseas Farmers Co-operative Federation Ltd. (21) 
Seed (6, 21) 
No reports. 
Part of consignment sent via Department of Agriculture to H.C. Poole, Kalgoorlie, via Albany (6). Not known if germinated or planted. 
Also tried in other unknown localities (21). 
Pelican Point, Swan River, Perth, WA 
Cape River near Bunbury, WA (6) 
Carnarvon, WA (6) 

1952 
G.H. Miller, Toolinilla via Narrogin, WA (6, 21) 
Essex Institute of Agriculture, Chelmsford, England (6) 
Box of Spartina roots (21) 
Weak viability of seeds made efforts unsuccessful (21). 
No reports. 
Believed not to have survived (6). 
No reports. 
Believed not to have survived (6). 

1. Adelaide Chronicle, 16 April 1931 
3. Boerth, B. (1979 in litt.) 
5. Dickson, B.T. (1950b in litt.) 
7. Geelong Advertiser (26 May 1930) 
13. Holland, C.G. (1931 in litt.) 
17. Martin, G.J. (1966b in litt.) 
18. Malott, H. (1930 in litt.) 
22. Spafford, W.J. (1930a in litt.) 
23. Steele, R.B. (1931 in litt.) 
25. Wadham, S.M. (1929b in litt.) 
26. Wadham, S.M. (1930b in litt.) 
27. Wadham, S.M. (1930d in litt.) 
28. Wadham, S.M. (1930f in litt.) 
29. Wadham, S.M. (1931a in litt.) 
30. Wadham, S.M. (1931b in litt.) 
31. Wadham, S.M. (1932 in litt.) 
32. Wadham, S.M. (1933 in litt.) 
34. Womasley, D.B. (1979 in litt.) 
35. Whittet, J.M. (1965)
LOCAL SOURCES OF INTRODUCED SPARTINA

Spartina introduced to Australia was subsequently distributed widely. Seedlings and cuttings which established successfully provided a source of material for transplants to other sites, and consignments of seeds were divided for distribution. Much of this diffusion of Spartina stock was on the basis of individual arrangements between landowners, and was not recorded by appropriate government agencies.

All known further plantings were in the southeast of Australia, as shown in Figure 4. Details of confirmed inter-state and intra-state consignments are given in Table 2. The table has been prepared from the limited information provided in government records, and from correspondence and interviews with landowners and other persons known to have been involved in the further spread of the grass.

Although many of these plantings were successful, it cannot be concluded that the rate of success of local stock was higher than that of material introduced from overseas. In reconstructing sequences of deliberate Spartina dispersal in the absence of detailed records, it has been necessary to start with surviving plantings and work backwards to find the original Australian source. There were undoubtedly many unsuccessful introductions about which information cannot now be obtained.

The dispersal of material from Tidal Creek, Corner Inlet, illustrates the largely unsupervised and unrecorded practice of transplanting Spartina from sites of first introduction, including those where the grass was ultimately unsuccessful. Over 30 years, farmers visited this site to obtain Spartina for planting elsewhere, having learned from bodies such as local agricultural societies of the presence of the grass and its ability to establish on intertidal mudflats. As the dates of these transplants, the amount of Spartina taken, the person responsible and the eventual destination of the material were not recorded, details of distribution from this site have been assembled largely from the recollections of the present landowner (Jones 1978 pers. comm.). It is known that material was transplanted successfully to sites in the Gippsland Lakes, to Bairnsdale, Andersons Inlet, Albert River, Agnes River, Shallow Inlet and other sites in Corner Inlet in addition to Tidal Creek; it is certain that it was also transplanted unsuccessfully to many other sites.
The most significant of the transplants of local Australian stock was the supply of *Spartina* plants from Buckland Park, South Australia, to the Tasmanian Department of Agriculture at Launceston in 1947 (Fricke 1951 in litt.). This material established successfully in the Tamar River estuary (Plate 6), which is now the largest single *Spartina* station in Australia. Although *Spartina* had been introduced from overseas to Tasmania in the late 1920s and early 1930s, none of it had survived at the time of the Tamar River plantings.

The Tamar River was the source of many further introductions to sites in Tasmania and other states. Transplanted material has established successfully in Tasmania at Duck Bay and in Robbins Passage near the Montague River, and at several other sites where it has since been eradicated. Tasmanian material was introduced unsuccessfully to Port Lincoln and Port Pirie, South Australia, and to the Mitchell River silt jetties in Victoria; from the latter site it was successfully transplanted to Moodys Inlet on the north shore of Westernport Bay, Victoria, in 1964.
FIGURE 4  
Spartina plantings in south east Australia. 
(Tasmania excluding Bass Strait islands).
<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DATE</th>
<th>PLANTING LOCATION</th>
<th>PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>W. Hawker, Anama Station, Brinkworth, S.A. (4)</td>
<td>1934 (4)</td>
<td>Wongan Hills Light Lands Farm, near Moora SA (4).</td>
<td>Consignment of seed sent to A. R. Venton, Manager. Believed to have been part of the 1929 consignment from Poole Harbour to Brinkworth. No record of germination or planting. Believed not to have survived.</td>
</tr>
<tr>
<td>Not known</td>
<td>1932 (6, 23)</td>
<td>Falls Creek township, near Nowra, N.S.W.</td>
<td>Two small plants sent by post from N.S.W. Department of Agriculture to F.A. Frost (6). Planted at Currambene Creek. Likely to have been one of several experimental plots established in the early 1930s as a result of the efforts of J.M. Whittet, Government Agrostologist (24), and certainly the only one which survived (28). As there is no record of the N.S.W. Department of Agriculture having imported Spartina from overseas at this time, the introductions are regarded as transplants from an Australian site.</td>
</tr>
<tr>
<td></td>
<td>Early 1930s</td>
<td>Bairnsdale, Vic.</td>
<td>Planted in small saline swamp on A.B. Macarthur property (17). Slow vegetative spread. By 1964 formed a patch of low-growing Spartina about 10 m² (17). Now cannot be located. Believed not to have survived.</td>
</tr>
</tbody>
</table>
1932

Alberton, Vic.

Ten plants introduced to "pig-face country" only occasionally inundated by the tide, on J. R. Stockwell property (27). Tidal Creek source likely but not confirmed.

By 1936 only four plants survived. Began to tiller 1936-37 (27). Believed not to have survived.

1940

Black Swamp, Yanakie, Vic.

Planted outside sea-wall by J.G. Jones, Foster (10)

No reports. No evidence of plantings 1979. Believed not to have survived.

1940s

Early

Andersons Inlet, Vic.

Taken to Andersons Inlet district by Black family (10). Planted on Sparks property in tidal zone of Cherry Tree Creek.


1940s

Late

Albert River, Vic.

Planted along banks of river by F. Dawson (10).

No early reports. Successful establishment.

1940s

Late

Agnes River, Vic.

Planted near mouth of river. Taken from Tidal Creek (10), but person responsible not known.

No early reports. Successful establishment.

1949

South Australia

1949

Sydney, NSW

Sent to J. Richmond (10). Address now unknown. Believed not to have survived.

1950s

Early

Clydebank, near Sale, Vic.

Planted in saline swamp on Ross property (10).

Sent to now unknown address (10). Believed not to have survived.

No evidence of planting 1979. Believed not to have survived.
Early 1950s

Hedley, Vic.
Planted outside sea-wall on Todd and McPhail properties (10).

Slow vegetative spread.
Successful establishment.

Toora, Vic.
Planted outside sea-wall on Doran and Miller properties (10).

Slow vegetative spread.
Successful establishment.

Broadlands, near Bairnsdale, Vic.
Planted in inland saline swamp. Supervised by Soil Conservation Authority (12).

Could not be found 1962.
Believed not to have survived.

1961

Mitchell River, Gippsland Lakes, Vic.
Planted by Soil Conservation Authority on silt jetties of the Mitchell River (17).

Not vigorous (17). Successful establishment of Spartina from Tamar estuary, Tas., at same site (see below); success of Corner Inlet material not known, although persisted until at least 1964 (17).

1962

Shallow Inlet, Vic.
Planted by J. Baron (10).

Slow vegetative growth
Successful establishment.

1947

Buckland Park, S.A. (5, 19)

Tamar River, Tas.
Three "lots" of plants (5) obtained by Department of Agriculture, Tas., for planting at the request of the Marine Board of Launceston (16).

Initially only a few plants survived, but by August 1951 there was a nursery of a few dozen plants (5). Additional plantings up to 1964 using local material (13, 15). Rapid natural spread in late 1950s; by 1975 occupied 555 ha. Successful establishment.

1949-51

Duck Bay and Montagu River, Tas.
Planted by Tas. Department of Agriculture in tidal zone of Duck River (14, 25)

Relatively slow growth (15).
Successful establishment.
1953-63
Local material transplanted by Smithton Harbour Trust to sites between Stanley and the Montague River (25)

"About 1950" (15)
Little Swanport Lagoon, Tas.
Possibly refers to consignment sent to Swansea in 1952 (see below).

1951
Port Lincoln, S.A.
Planted on intertidal mudflats in August 1951 by S.A. Department of Agriculture (9)

1952
Swansea, Tas.
Consignment to Dr. Brettingham-Moore, 12 August 1952 (14, 20). Planting location unknown.

1953
Port Pirie, S.A.
Trial plots planted by Chemical Engineering Division, S.A. Department of Mines (1).

1957
Not known
Consignment sent to Snowy Mountains Authority, presumably for planting in Victoria or N.S.W. (14).

Successful establishment and spread in most locations by 1963 (25). 1963-72 failed at five sites, survived at six sites. Surviving areas mainly tussocks and clumps, some small swards (21)


No reports. Believed not to have survived.

No reports. Possibly planted in Little Swanport Lagoon (see above). No evidence of successful establishment at any other site.

No reports. Believed not to have survived.

No reports. Believed not to have survived.
<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1958</td>
<td>Not known, Vic.</td>
<td>Consignment sent to Public Works Department, Melbourne, Vic. (14). No reports Believed not to have survived.</td>
</tr>
<tr>
<td>1959</td>
<td>Egg Island, Huonville, Tas. (14)</td>
<td>Not evident 1980 (11) Believed not to have survived.</td>
</tr>
<tr>
<td>1961</td>
<td>Pyramid Hill, Tas.</td>
<td>Intended for trial in an inland irrigation area of high salinity (14). No reports Believed not to have survived.</td>
</tr>
<tr>
<td>1960s</td>
<td>Bridport, Tas (25)</td>
<td>Plantings by persons unknown, in Brid River. Formed three clones each 4 m diameter. Removed by Department of Lands and Surveys 1969-70 (26).</td>
</tr>
<tr>
<td>1965-68</td>
<td>Mersey River, Quoiba, Tas</td>
<td>Planted at Quoiba by C. Loone of Speyton (7). Growth unsuccessful (7). Believed not to have survived.</td>
</tr>
<tr>
<td>1974-7</td>
<td>Bridgewater, Tas.</td>
<td>Small patch, presumably derived from Tamar material, found in Derwent River estuary (3). Removed by Tas. Department of Agriculture.</td>
</tr>
<tr>
<td>1947-7</td>
<td>Forth River, Tas.</td>
<td>Small patch, presumably derived from Tamar material, found in Forth River estuary (3). Attempted eradication (3). Believed not to have survived.</td>
</tr>
</tbody>
</table>
Bass River, Vic. 1962
Andersons Inlet, Vic.
Six clumps planted in estuary, near Nolans Bluff (2).

Mitchell River, Gippsland, Vic. 1964
Moodys Inlet, near Tooradin, Vic.
Two small patches planted by Soil Conservation Authority (18).

Rapid natural spread.
Successful establishment.

Grew vigorously, then removed by hand. Re-established from seeds and plant fragments which remained (18).
Continued rapid spread.
Successful establishment.

(1) Almond, J. (1953 in litt.)
(2) Arbuthnot, A. (1966 pers. comm.)
(3) Carpenter, J.A. (1979 in litt.)
(4) Fitzpatrick, E.N. (1978 in litt.)
(5) Fricke, E.F. (1951 in litt.)
(6) Frost, J.N. (1979 in litt.)
(7) Halpern, E. (1968 in litt.)
(8) Hancock, I.S. (1962 in litt.)
(9) Johnston, W.C. (1951 in litt.)
(10) Jones, B. (1978 pers. comm.)
(11) Kirkpatrick, J. (1980 in litt.)
(12) Lee, M.J. (1978 in litt.)
(13) Martin, G.J. (1964 in litt.)
(14) Martin, G.J. (1966a in litt.)
(15) Martin, G.J. (1966b in litt.)
(16) Martin, G.J. (1971 in litt.)
(17) Mitchell, A. (1964 in litt.)
(18) Mitchell, A. (1975 in litt.)
(19) Neal-Smith, C.A. (1951 in litt.)
(20) Paton, D.F. (1952 in litt.)
(21) Phillips, A.W. (1972 in litt.)
(22) Phillips, A.W. (1975)
(23) Poggendorff, W. (1962 in litt.)
(24) Ranwell, D.S. (1964 in litt.)
(25) Sampson, M. (1963 in litt.)
(27) Stockwell, J.R. (1937 in litt.)
(28) Whittet, J.M. (1965)
REASONS FOR SPARTINA INTRODUCTION.

Although Spartina was imported from England as recently as 1952 and local transplants are known to have occurred as late as 1974-7, the period of most intense interest in the grass was in the late 1920s and early 1930s. By 1933 it was generally thought that Spartina would not be successful. In August 1932 Spafford made the last entry in the docket on Spartina still held by the South Australian Department of Agriculture; with reference to the plantings at North Arm, the Murray River and Buckland Park, he noted that "they had not done very well" (Kloot 1979 in litt.). In Victoria, Wadham "became interested in other things" (Wadham 1970 in litt.)

This brief period of interest reflected overseas successes with the plant in the 1920s. Both Wadham and Spafford are known to have read Oliver's paper on the establishment, economic uses and taxonomic status of Spartina (Oliver 1925), and to have been aware of the monograph on the economic possibilities of Spartina published by the British Ministry of Agriculture and Fisheries (Oliver, Bryce and Knowles 1929) (Wadham 1929a in litt.). It is to be expected that they were also familiar with work being undertaken on Spartina in New Zealand by Allan of the Plant Research Station at Palmerston North (Allan 1924, 1929, 1930, 1931.)

In addition to scientific interest in Spartina, a good deal of popular interest was aroused by magazine and newspaper articles. Oliver's paper "A Plant that Builds New Territory" (Oliver 1930) appeared in The Illustrated London News, which was widely seen in Australia; the article is known to have been read by at least one farmer who subsequently introduced Spartina to his property (Wamsley 1979 in litt.). It described Spartina as "the most promising agent of mud-reclamation yet discovered", and reported on the recent use of Spartina for reclamation in Essex and on the intertidal areas of the Scheldt in Holland. It noted that Spartina provided good feed for stock, and was of particular value for grazing because it continued to grow in the later part of the year when ordinary meadow grasses are not available. Further, it suggested that Spartina might usefully be planted along the outer edges of seawalls to protect them from wave impact and scour, and noted that the
grass had even been tried for paper-making. Similar articles appeared in Australian newspapers (e.g. Geelong Advertiser 20 and 26 May 1930, Adelaide Chronicle 16 April 1931).

There was however no single or principal application for which Spartina was introduced to Australia. Unlike Holland, where Spartina was planted for land reclamation and shoreline protection, there was no major agricultural or engineering problem which it was hoped the grass would solve. Most of the government agencies which imported Spartina were interested principally in determining whether or not the plant could grow in Australia; they were aware of its potential for reclamation and grazing, but were primarily concerned with trial plantings rather than using Spartina for any specific purpose. Departments of Agriculture in South Australia, Tasmania, Queensland and New South Wales each imported Spartina for trial plantings, and the Victorian and Western Australian departments obtained material for similar experiments from other importers. By 1933 Spartina had been tried in a wide range of climatic regimes and sites, the latter including inland swamps and clay pans, coastal lagoons and tidal estuarine environments. To Wadham and Spafford, the then widespread failure of Spartina and the poor condition of surviving plantations were evidence of the unlikelihood of successful Spartina establishment in this country.

Many of the Spartina introductions by private persons also were made purely out of interest in whether the exotic hybrid grass could survive at particular sites. This seems an inadequate explanation for such widespread plantings, but it is one which is recurrent in interviews with and correspondence from such people or their descendants. It echoes the general interest in the acclimatisation of overseas flora and fauna which was current around the turn of the century. E. A. Brooks, who obtained Spartina from the South Australian Department of Agriculture in 1931, "was a very keen amateur agronomist and was always trying new grasses at Buckland Park" (Brooks 1979 in litt.). D. F. Griffiths, a solicitor who imported Spartina from England to Geelong, Victoria in 1931, was "intensely interested in pasture improvement" (Griffiths 1978 in litt.). F. A. Frost, who introduced Spartina to Currambene Creek, New South Wales in 1932, simply wanted "to find out if it would grow" (Frost 1979 pers. comm.). R. A. Wamsley, who obtained Spartina from
Spafford for planting on his property at Barmera, South Australia in 1930, was sufficiently interested in the grass despite its failure at Barmera to visit the Poole Harbour marshes on his retirement many years later (Wamsley 1979 in litt.).

This interest in Spartina trials must be seen within the context of the publicity given to the grass in the late 1920s and early 1930s, and its representation as a botanical oddity. "Just as new stars appear in the firmament of heaven" wrote Oliver in The Illustrated London News (1930), "so, on rare occasions, is a new plant added to the terrestrial flora". Such statements and sometimes extravagant claims about the success of Spartina attracted the attention of farming communities and stimulated experimentation. It is also apparent that agricultural societies (Mullett 1930 in litt.) and field officers of the various state Departments of Agriculture acted as advocates for Spartina introduction.

There were however some introductions and plantings which were made with specific applications in view. The plantings by the Geelong Harbour Trust were intended to promote reclamation of much of Lake Connewarre for grazing (Dickson 1930a in litt., Wadham 1931b in litt.). Similarly, and many years later, the 1947 planting in the Tamar River was an attempt to "stabilise the mudflats so that they would eventually be above high water level and become relatively useful land"; in addition, it was hoped that this would "force the stream flow into the central part of the river, creating a scouring effect and keeping the main channel relatively free of mud" (Martin 1971 in litt.).

Many of the early introductions were to inland saline environments, including swamps and clay pans. It would appear that most of these were made with a view to converting otherwise useless land into pasture, for it was known that Spartina could thrive in salt water and also provide palatable food for stock. This is thought to have been the reason for the introduction of Spartina to sites such as Anna Plains (Western Australia), Corobimilla (New South Wales) and Brinkworth and Karkoo (South Australia); at the two latter sites, there was a need for a pasture grass which could be established on low-lying "magnesia country" (Crittenden 1978 in litt., Hawker 1979 in litt.). Spartina persisted at some inland sites for several years, but eventually failed.
At sites adjacent to the Murray River, *Spartina* was introduced in an attempt to overcome seepage problems in irrigated areas. By the late 1920s the irrigation of fruit districts had led to the widespread formation of large seepage patches in low-lying sites. Such patches were saline, and with continued irrigation they were almost permanently waterlogged and encroached steadily on agricultural land. By 1930, encroachment of a large seepage patch on the R. A. Wamsley property at Barmera had caused the loss of several acres of vines (Wamsley 1979 in litt.). *Spartina* was known to grow in salt water, and was introduced to provide a grass cover and to promote reclamation. Although *Spartina* survived at this site for three years, it did not assist in reclamation, for the grass did not spread and accretion was negligible given the low sediment yield of groundwater seepage. *Spartina* was introduced for the same purpose to Waikerie and Morgan, and was similarly unsuccessful.

While most of the early plantings were made without any specific application of *Spartina* in view, its possible uses gradually became apparent at sites where establishment was successful. As noted previously, *Spartina* introduced to Tidal Creek in 1930 was planted on either side of an earth sea-wall about a metre high. Similar walls had been built elsewhere around Corner Inlet to prevent inundation of rough pasture by all but the highest tides. A major problem in their maintenance at that time was damage by crabs, which burrowed into the base at about high water level. As it was observed that crabs avoided *Spartina* sites, the grass was planted along the outer margins of the walls. Crabs ceased to be a problem where plantings were successful (Jones 1978 pers. comm.), although it is uncertain whether this was because the grass was unpalatable or because the network of *Spartina* roots and rhizomes provided a firm substrate which was resistant to burrowing.

The success of *Spartina* in reducing the problem of maintenance of sea-walls was an important motive for transplanting material from Tidal Creek to other sites in Victoria (Jones 1978 pers. comm.). The low structures of the 1930s have now been replaced by larger walls about 2.4 m high and 4 m wide at the base, flanked on the landward side by a drain or 'borrow-pit' from which the earth for the walls has been removed. The incidence of seepage arising from crab attack has declined with the increase in the width of the walls, and their bases are now constructed from sand and shell which apparently provides a less suitable habitat for crabs.
than silt or clay. However, *Spartina* is still widely planted along the outer edges of the walls, where it provides protection from wave erosion and scour.

The initial trials with *Spartina* also confirmed its palatability as food for stock. Soon after successful establishment it was grazed by horses at Currambene Creek (Frost 1979 *in litt.*) and by beef cattle at Tidal Creek (Jones 1978 *pers. comm.*). The ability of *Spartina* to increase the grazing capacity and utilisation of the lower levels of saltmarsh zones has been an important if secondary factor in many of the transplantings in Victoria. It is now widely grazed at sites where *Spartina* marshes abut farming properties.

*Spartina* plantings in Australia also demonstrated the role the grass could play in shoreline protection. Its ability to promote accretion and thereby cause progradation of formerly eroding shorelines was an important factor in many further transplants. This was the motive behind the transplantation of *Spartina* from a prograding channel-bank at Bass River to an eroding shoreline at Andersons Inlet in 1962 (Arbuthnot 1966 *pers. comm.*), where it established successfully and has since spread vigorously. For the same purpose, *Spartina* from Tidal Creek and the Tamar River was planted along the Mitchell River silt jetties, Victoria, in 1961 and 1962 (Hancock 1962 *in litt.*, Mitchell 1964 *in litt.*), in an attempt to reduce wave erosion which had accompanied *Phragmites* die-back (Bird 1970). Although *Spartina* made a promising start at this site, it eventually failed to persist.

**FACTORS AFFECTING SPARTINA FAILURE**

Despite widespread plantings in all the Australian states, *Spartina* now survives only in the south east of the country. The northern limit is approximately 35°S, at Buckland Park, South Australia (34° 40'S) and Falls Creek, New South Wales (35° 00'S). The most southerly station is believed to be the Tamar River estuary, Tasmania (41° 20'S). It is possible, but unlikely, that the grass persists at the head of Little Swanport Lagoon, Tasmania (42° 20'S) where a few small patches of *Spartina* were observed in 1976 (Kirkpatrick 1980 *in litt.*) but could not be found in October 1980.
The consistent failure of *Spartina* in New South Wales, Queensland, Western Australia and South Australia is believed to indicate a broad climatic control over the northern limit of successful establishment. The failure of *Spartina* at most sites in New South Wales is thought to be due to high summer temperatures; its survival at Falls Creek has been attributed to the shade provided by large trees (Whittet 1965). The surviving *Spartina* at Buckland Park in South Australia is also partially shaded, by mangroves and by a pipe-line across the Gawler River. At neither site is *Spartina* abundant. The only Western Australian site at which there was any promise of growth was near the southern extremity of the state at Oyster Harbour, Albany (34° 58'S), but even there the grass persisted for only a few years (Fitzpatrick 1978 in litt.).

Despite repeated attempts to establish *S. townsendii* (s.l.) in subtropical and tropical areas, it has not survived closer to the Equator than latitudes 35°S or 48°N (Ranwell 1967), although plantings are reported to have persisted for up to two years at latitude 5°N in Guyana (Case 1938) and for a similar period at latitude 21°N at Honolulu (Bryce 1936). At latitude 35°S in New Zealand winters are too warm for normal development: Saxby (1964 in litt.) has reported that establishment is slow and growth is sparse, and Chapman (1964 in litt.) has noted that very little seed is set. In Kaipara Harbour, New Zealand (35°S), *S. townsendii* (s.l.) is much less successful than *S. alterniflora*, which is evidently tolerant of a greater climatic range (Bascand 1968).

Given the absence of high latitude land masses in the Southern Hemisphere, there is no broad climatic control over the southern limit of *Spartina* in Australia, or New Zealand. *Spartina* established successfully at Bridgewater in the Derwent River (42° 43'S), near the southern extremity of Tasmania, before being eradicated in the mid 1970s (Carpenter 1979 in litt.), and in New Zealand the grass grows vigorously in the New River estuary near the southern tip of the South Island (46°S). In high latitudes in the Northern Hemisphere *Spartina* vigour can be impeded by cool summers in which little seed is set, and the grass is subject to damage by frost, which Kamps (1962) has reported as destroying all but one per cent of plantings at latitude 53° 30'N in the Dutch Wadden Sea. The highest latitude at which *Spartina* persists is 57° 30'N at Udale Bay in Scotland (Ranwell 1967).
In addition to the climatic unsuitability of much of the Australian continent, there are other factors which contributed to the failure of many Spartina introductions. One of these factors is the nature of the material introduced to Australia.

As noted previously, many of the early introductions were of seed obtained from England. Spartina seed does not ripen in the Northern Hemisphere until October or November; germination rates are highest when the seed is sown as soon as possible when ripe (Ranwell 1963 in litt.). Seed remains viable for less than seven weeks in dry conditions at room temperature, but if stored at 5°C over water it will keep at least 12 months and remain clean and easy to transport (Goodman et al. 1969).

Available records indicate a considerable delay between despatch of seeds from England and their receipt in Australia, due to transportation by sea. Seed sent from London by Oliver late in 1928 was not received by the Queensland Department of Agriculture and Stock until March 1929 (Johnson 1978 in litt.); seed sent from Poole on 13 November 1929 (Kloot 1979 in litt.) was not received by the South Australian Department of Agriculture before February 1930 (Spafford 1930a in litt.); seed despatched from England late in 1941 (Ranwell 1964 in litt.) was received by the Wheat Pool of Western Australia in April 1942 (Fitzpatrick 1978 in litt.). Thus a delay of several months between despatch and receipt was common. Further, there is evidence to suggest that some consignments may have consisted of seed harvested several months before despatch; seed sent by Oliver on 9 May 1929 to the South Australian Department of Agriculture was obtained from Holland (Kloot 1979 in litt.), and had presumably ripened late in 1928.

There is no evidence of special care having been taken in the handling of Spartina seed during transit, although Hubbard (1970) has noted that after the 1930s seed was successfully despatched from England via the tropics in vacuum flasks. Consequently, it is likely that much of the seed received in Australia was not viable. Germination is known to have been achieved from only one of the 27 consignments received between 1927 and 1942; definite failure is recorded for seven introductions, and the others are believed not to have survived (Table 1). The success was achieved in 1930 by Spafford, who managed to raise only 20 plants from approximately 1 kg (2.2 lb) of seed which arrived covered with mould (Spafford 1930a in litt.).
The conditions required for successful *Spartina* germination have been described by Goodman et al. (1969). As salt water inhibits germination the seeds must be de-salinised by fresh water. Germination occurs rapidly under conditions of relatively high humidity and temperature; after germinating, the seedlings require regular immersion in sea water and respond favourably to a period of cold. Spafford’s success with seed which was probably largely inviable is believed to be due to his use of a germinating chamber in which seeds were watered with fresh water until germination, and then with a mixture of fresh and sea water in the early stages of seedling development (Spafford 1930a in litt.).

No information is available on whether other importers of seed carried out similar germination trials under laboratory or green-house conditions. It is likely that most farmers and other importers sowed seed directly; for example, at least part of the consignment received in 1929 by the Queensland Department of Agriculture and Stock was sown at two sites in Brisbane, apparently without success. The requirements for sowing of seed have been described by Ranwell (1963 in litt.): the site should be a sheltered position of bare mud at about MHWST level, and the seed should be broadcast over a moist surface just after the spring tide period and gently pressed down. As nothing is known about the conditions under which *Spartina* seed was sown at any Australian site, its significance as a factor in the failure of *Spartina* cannot be assessed.

The more successful importations of *Spartina* to Australia were those comprising seedling plants, root-stock, cuttings, and whole plants. Available records indicate that these generally arrived in good condition, but Wadham’s plants appeared dead after an inexplicably-long five day train journey from Canberra to Melbourne (Wadham 1930d in litt.). However, unlike most other *Spartina* importers, he had the green-house facilities and expertise necessary to ensure their survival.

One of the major factors accounting for the failure of plant material was an inadequate understanding of its habitat requirements. In particular, it was not fully appreciated that the saline environments required by the plant also had to be tidal. *Spartina* was introduced to saline swamps and clay pans at several inland sites (Figures 1, 4) and in some of these places persisted for several years. Plants introduced to Tenterden, Western Australia (Philip 1970 in litt.), Corobimilla, New South Wales
(Ranwell 1964 in litt.) and Barmera, South Australia (Wamsley 1979 in litt.) survived for three years, the first two making substantial growth despite high summer temperatures.

Although *Spartina* may persist in microtidal conditions, its survival in non-tidal environments is rare. It continues to grow in a non-tidal salt water environment at Wolphaartsdijk in Holland, and has been reported in similar conditions near Salwarpe, England (Goodman et al. 1959). It has survived also in non-tidal fresh water conditions at Invercargill, New Zealand (Ballinger 1968 in litt.) and in the River Clyst in Devon, England (Goodman et al. 1959). However, such occurrences are exceptional. The failure of *Spartina* in inland sites in Australia is due primarily to lack of tidal inundation; important contributing factors at some sites were extreme summer temperatures, drought, and excessively high water salinity.

Tidal conditions on the Australian coast are generally suited to *Spartina* growth, except in the south and west of Western Australia. *Spartina* growth is most successful in a semi-diurnal tidal regime, its seaward limit having been reported by Ranwell et al. (1964) as the level subject to inundation for not more than six hours during high spring tides in the growth period of the plant. A semi-diurnal regime occurs around the entire coast of Australia except the south west. Tide ranges vary from microtidal in the south east, south and south west to macrotidal in the north.

In the south west of Western Australia, tides are mixed-diurnal and microtidal. It would be unlikely for *Spartina* to persist in a diurnal tidal regime, where it was not subject to regular inundation at intervals of approximately twelve hours. Further, in most of the estuaries and lagoons along this coastal sector, the pattern of small astronomical tides is significantly and irregularly modified by wind and barometric pressure, and water salinity is generally high. Leschenault Inlet, where three batches of *Spartina* were introduced in 1930, has a seasonal rather than daily pattern of salinity variation (Hodgkin and Smith 1971). Between December and May the inlet receives little fresh water discharge and usually has a salinity greater than sea water. Even in the June-November period of greatest fresh water discharge from the Collie River, water in the inlet is rarely sufficiently diluted to permit desalinisation
of Spartina seeds, which is a prerequisite for germination (Goodman et al. 1969). Although the failure of Spartina in the south west of Western Australia is believed to be due primarily to high summer temperatures, irregular tidal flow and high water salinity are likely to have been important contributing factors.

Irregular tides and high water salinities are thought to have contributed also to the failure of Spartina in Lake Connewarre and the lower Barwon River, Victoria (Figure 3). Like many of the Western Australian sites, Lake Connewarre is a lagoon rather than an estuary, and the effect of the marine tide is often less significant in determining water levels than the inflow from the Barwon River and the effect of wind. Spring tide range decreases from about 2 m at the mouth of the Barwon to about 0.3 m at its outlet from Lake Connewarre. Average salinity within most of Lake Connewarre is about 23⁰/oo (Rosengren 1973), although actual salinity at any place varies with the state of the tide, the preceding weather conditions and the volume of fresh water entering from the upper Barwon River. In drought years when flow from the upper Barwon is much reduced, Lake Connewarre becomes hypersaline due to evaporation, while during floods the whole Connewarre basin is extensively inundated by fresh water.

In several early reports of Spartina performance its failure is attributed to an unsuitable substrate, particularly in Western Australia where most of the plantings were on sand (Fitzpatrick 1978 in litt.). However it is believed that this is not a satisfactory explanation, for Spartina has established elsewhere in Australia on sands which range from medium to coarse in texture. In their review of Spartina sites throughout the British Isles, Goodman et al. (1959) found no apparent substrate preference, and concluded that Spartina can colonise a wide range of soils from clays and silts to sand. While occasional stunting of Spartina may occur in sandy localities, it is possibly due as much to exposure to wave action as to the actual texture of the soil, for coarser substrates are often in less sheltered positions.

A significant factor contributing to the failure of many early plantings was grazing or disturbance by animals. In the early 1930s there was a large rabbit population, which has since been deliberately reduced by the introduced myxomatosis virus. Severe grazing by rabbits occurred at Geelong (Phillips 1959 in litt.) and Foster (Jones 1978 pers. comm.), and
given the extent of the rabbit infestation in the 1930s is certain to have occurred elsewhere. Grazing by kangaroos destroyed the 1935 plantings at Karkoo, South Australia in less than a year (Ranwell 1964 in litt.), and a fence was necessary to prevent them from destroying the 1930 planting at Barmera (Wamsley 1979 in litt.). Seedlings and young plants on bare mud at Lake Connewarre were up-rooted by swans (Wadham 1931b in litt.), although it is not known whether this was a major factor in Spartina failure at that site or elsewhere in Australia.

Grazing of surviving Spartina is still common. The Gippsland Lakes sites are grazed by wallabies, sheep and goats; most other Victorian sites are grazed by cattle. Grazing by rabbits is universal, but only locally intensive. Horses and cattle regularly graze the plantings at Falls Creek, New South Wales (Frost 1979 in litt.). While continued grazing of established Spartina colonies may reduce their vigour and rate of expansion, it does not now appear to seriously threaten their survival.

Finally, there is evidence to indicate that many early consignments of plant material to Australia were either a mixture of fertile S. anglica and sterile S. x townsendii, or were entirely sterile. The existence of sterile and fertile forms was not known until demonstrated by Hubbard (1957a, b) and subsequently clarified by Marchant (1963, 1968). Dr. Dickson of the CSIR Division of Plant Industry noted that Spartina obtained from New Zealand in 1930 "does not set seed and must be vegetatively propagated from runners" (Philip 1970 in litt.), which suggests that material was sterile. Wadham subsequently made no reference to plants obtained from this consignment ever producing seed. The slow growth at many Australian sites might well have been due to the plant material being entirely sterile, in which case it could spread only by rhizome extension and from plant fragments.

Part of the consignment described by Dickson was planted by Wadham at Bass River and Tidal Creek, Corner Inlet. Both sites now have vigorous swards of fertile S. anglica, which seeds profusely. In the mid 1960s, the previously low-growing Spartina at Tidal Creek grew suddenly taller, spread rapidly, and for the first time began to flow and produce seed (Jones 1978 pers. comm.). At this and several other sites in Victoria
there is circumstantial evidence to suggest that the fertile amphidiploid has been derived independently in Australia from sterile F1 hybrids, as in Southampton Water circa 1890.

PRESENT DISTRIBUTION

The area colonised by Spartina in Australia is estimated at 620 ha (Table 3), the major station being the Tamar River estuary. Spartina is also abundant in Andersons Inlet, where it has spread rapidly since the introduction of the fertile amphidiploid in 1961. In comparison with estimates given for other countries by Ranwell (1967), Australian Spartina resources rank behind those of Britain, the Netherlands and France, but are equal to or greater than those of Germany, Denmark, Ireland and New Zealand.

The surviving Spartina colonies at Currambene Creek, New South Wales and Buckland Park, South Australia are of biogeographical interest, but otherwise have little significance. The grass has persisted at each site for almost fifty years, but growth has not been vigorous and rates of sediment accretion have been low. As the area of Spartina at these stations is small, the grass may be regarded as virtually confined to estuaries and lagoons in northern Tasmania and in Gippsland, Victoria.

At these Bass Strait stations, the exotic Anglo-American hybrid grass has now become an important new element affecting the physiography and ecology of marshy shorelines. This results from three factors. First, because the fertile amphidiploid seeds profusely, the grass quickly and uniformly colonises favorable environments. At Andersons Inlet, swards and clumps covering 63.5 ha have developed from six plants introduced in 1962. Second, being tolerant of prolonged tidal inundation, the grass has occupied previously unvegetated mudflats and has formed a new frontal zone along the seaward margin of saltmarsh. Spartina grows to lower levels than the native white mangrove (Avicennia marina var. resinifera), which reaches its southern world limits in Victoria, and which has consequently been replaced as the pioneer species on the intertidal flats. Third, Spartina promotes rapid accretion of sediments, which was the reason for its introduction as an agent of coastal engineering to sites in Britain and Europe. While the usual accretion rate on vegetated temperate marshlands is 0.2 - 1 cm per annum (Ranwell 1964a), rates of 3 - 5 cm per annum
### TABLE 3

**AUSTRALIAN SPARTINA RESOURCES**

<table>
<thead>
<tr>
<th>Station</th>
<th>Hectares</th>
<th>Date of estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tasmania</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamar River</td>
<td>520.4</td>
<td>1978</td>
</tr>
<tr>
<td>Duck Bay and Robbins Passage</td>
<td>10.5</td>
<td>1979</td>
</tr>
<tr>
<td><strong>Victoria</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andersons Inlet</td>
<td>63.6</td>
<td>1980</td>
</tr>
<tr>
<td>Corner Inlet</td>
<td>15.6</td>
<td>1980</td>
</tr>
<tr>
<td>Bass River</td>
<td>7.2</td>
<td>1979</td>
</tr>
<tr>
<td>Albert River</td>
<td>1.8</td>
<td>1980</td>
</tr>
<tr>
<td>Agnes River</td>
<td>0.5</td>
<td>1979</td>
</tr>
<tr>
<td>Moodys Inlet</td>
<td>0.2</td>
<td>1979</td>
</tr>
<tr>
<td>Gippsland Lakes</td>
<td>0.01</td>
<td>1978</td>
</tr>
<tr>
<td>Shallow Inlet</td>
<td>0.002</td>
<td>1978</td>
</tr>
<tr>
<td><strong>New South Wales</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currambene Creek, near Falls Creek township</td>
<td>0.003</td>
<td>1980</td>
</tr>
<tr>
<td><strong>South Australia</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gawler River at Buckland Park</td>
<td>0.002</td>
<td>1979</td>
</tr>
</tbody>
</table>

**TOTAL** 619.8
have been recorded in developing marsh at Andersons Inlet, and rates of
10-12 cm per annum have been reported in older Spartina marshes in
Britain. At Bridgwater Bay, Somerset, accretion in Spartina has raised
the foreshore level by 1.87 m in 37 years (Ranwell 1964a).

The spread of Spartina at the principal Australian stations and its
impact on estuarine geomorphology have been considered elsewhere by the
author (Boston 1981), and are therefore not further developed here.
However, it should be noted that there are still many suitable areas in
south east Australia to which the grass could be successfully introduced.
Although Spartina may be usefully employed in shoreline protection and
reclamation projects, and is suitable for grazing, its uncontrolled
spread has potentially adverse effects. Spartina appears to be incapable
of fitting into the natural succession series of saltmarsh vegetation
(Beetink 1975), and may reduce the variety and interest of local flora
by landwards invasion of the lower parts of pre-existing saltmarsh.
The British Spartina marshes are not significantly utilised by
invertebrates, evidently because the appearance of the grass is too
recent for an associated fauna to develop, and wildfowl productivity
has declined in estuarine habitats once Spartina has become abundant
(Ranwell 1964b). Further, accretion in Spartina reduces the depth and
area of water available for boating at high tide, and its invasion of
sandy beaches on the Somerset coast has been accompanied by accretion
of finer sediments which have converted the surface to mud (Ranwell and
Downing 1960). As eradication is difficult and costly, it is important
that further Spartina plantings in Australian coastal waters be supervised
by appropriate government authorities, and approved only within the
context of a management plan for conservation of our estuarine resources.
REFERENCES

Adelaide Chronicle, 16 April 1931.


Almond, J. (1953 in litt.). Letter to E. F. Fricke, Department of Agriculture, Hobart, 29 October. (Mr. Almond was the Chief Chemical Engineer, Chemical Engineering Division, South Australia, Department of Mines.)

Arbuthnot, A. (1966 *pers. comm.*). Discussion with the author. (Mr. Arbuthnot was responsible for transplanting *Spartina* from Bass River to Nolans Bluff).


Boerth, B. (1979 in litt.). Letter to the author, 10 September. (Mr. Boerth is Senior Agriculture Master, Murray Bridge High School, South Australia).


Brooks, H. G. (1979 in litt.). Letter to the author, 23 January. (Mr. Brooks was formerly the owner of Buckland Park property, Two Wells, South Australia).


Carpenter, J. A. (1979 in litt.). Letter to the author, 17 May. (Mr. Carpenter is Senior Plants Research Officer, Department of Agriculture, Launceston).


Chapman, V. J. (1964 in litt.). Reply to Dr. D. S. Ranwell's questionnaire on *Spartina* resources in New Zealand. (Cited in Ranwell 1967).

Crittenden, B. R. (1978 in litt.). Letter to the author. (Mr. Crittenden is the present owner of the former Adams property at Karkoo, South Australia).

Dickson, B. T. (1930a in litt.). Letter to Prof. S. M. Wadham, 10 June. *Wadham Collection: University of Melbourne Archives.*


Fitzpatrick, E. N. (1978 in litt.). Letter to the author, 29 November. (Mr. Fitzpatrick is Director, Department of Agriculture, Perth).

Fricke, E. F. (1951 in litt.). Letter to C. A. Neal-Smith, Plant Introduction Officer, Division of Plant Industry, CSIRO Canberra, 22 August. (Mr. Fricke was Chief Agronomist, Department of Agriculture, Hobart).

Frost, J. N. (1979 in litt.). Letter to the author, 29 September. (Mr. Frost is the son of Mr. F. A. Frost, who planted *Spartina* at Falls Creek, NSW).

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Grant Lipp, A. E. (1978 in litt.). Letter to the author, 28 November. (Mr. Grant Lipp is Plant Introduction Officer, CSIRO Canberra).

Grey, J. H. (1931 in litt.). Letter to Prof. S. M. Wadham, 12 June. (Mr. Grey was Secretary to the Geelong Harbour Trust Commissioners). Wadham Collection: University of Melbourne Archives.


Griffiths, A. D. F. (1978 in litt.). Letter to the author, 12 December. (Mr. Griffiths is the son Griffiths, who imported Spartina to Geelong in 1930).

Halpern, E. (1968 in litt.). Letter to Chief Extension Officer, Department of Agriculture, Hobart, 9 April. (Mr. Halpern was District Agricultural Officer, Devonport).

Hancock, I. S. (1962 in litt.). Letter to G. J. Martin, Department of Agriculture, Launceston, Tas. (Mr. Hancock was Acting Secretary, Soil Conservation Authority, Victoria).

Hawker, R. (1979 in litt.). Letter to the author. (Mr. Hawker is the present owner of Anama Station, Brinkworth, South Australia).


Holland, C. G. (1931 in litt.). Letter to C. L. Gillies, Chief Agronomist, Department of Agriculture, Launceston, 10 August. (Mr. Holland was District Agricultural Organiser, Agricultural Extension Service, Department of Agriculture, Hobart).


Johnson, R. W. (1978 in litt.). Letter to the author, 8 December. (Mr. Johnson is Director, Botany Branch, Department of Primary Industries, Brisbane).
Johnston, W. C. (1951 in litt.). Letter to D. F. Paton, Agronomist, Department of Agriculture Launceston, 26 August. (Mr. Johnston was Agricultural Adviser, Department of Agriculture, Port Lincoln S.A.).

Jones, B. (1978 pers. comm.). Discussions with the author. (Mr. Jones is the present occupier of Kooratang Estate, Foster, and the son of Mr. J. G. Jones who planted Spartina in Tidal Creek in September 1930).


Kirkpatrick, J. (1980 in litt.). Letter to the author, 7 July. (Dr. Kirkpatrick is Senior Lecturer in Geography at The University of Tasmania).

Kloot, P. M. (1979 in litt.). Letter to the author, 20 February. (Mr. Kloot is Senior Weeds Research Officer, Department of Agriculture and Fisheries, South Australia).

Lee, M. J. (1978 in litt.). Letter to the author, 19 December. (Mr. Lee is Senior District Officer, Department of Agriculture, Bairnsdale, Victoria).


Martin, G. J. (1964 in litt.). Reply to Dr. D. S. Ranwell's questionnaire on Spartina resources in Tasmania, 6 May. (Mr. Martin was an agronomist with the Department of Agriculture, Launceston).

Martin, G. J. (1966a in litt.). Notes on Spartina introductions in Tasmania. Department of Agriculture, Launceston. (Unpub.).

Martin, G. J. (1966b in litt.). Letter to D. Steane, Conservation Officer, Lands and Surveys Department, Bridport Tasmania, 14 March.

Martin, G. J. (1971 in litt.). Background information on the rice grass areas in Tasmania, 5 November. (Unpub.).

Mitchell, A. (1964 in litt.). Reply to Dr. D. S. Ranwell's questionnaire on Spartina resources in Victoria. (Mr. Mitchell is Chairman of the Soil Conservation Authority, Victoria).


Mullett, H. (1930 in litt.). Letter to Prof. S. M. Wadham, 24 September. (Mr. Mullett was Agricultural Superintendent, Department of Agriculture, Victoria). Wadham Collection: University of Melbourne Archives.

Neal-Smith, C. A. (1951 in litt.). Letter to E. F. Fricke, Chief Agronomist, Department of Agriculture, Hobart, 30 July. (Mr. Neal-Smith was Plant Introduction Officer in the Division of Plant Industry, CSIRO, Canberra).


Paton, D. F. (1952 in litt.). Letter to Dr. Brettingham-Moore, Swansea, 4 August. (Mr. Paton was an agronomist at the Department of Agriculture, Launceston).

Philip, J. R. (1970 in litt.). Letter to the author, 29 July. (Mr. Philip was Acting Chief of the Division of Plant Industry, CSIRO, Canberra).


Phillips, R. R. (1959 in litt.). Letter to Dr. E. C. F. Bird, 9 June. (Mr. Phillips was Secretary to the Geelong Harbour Trust Commissioners).

Poggendorff, W. (1962 in litt.). Letter to G. J. Martin, Agronomist, Department of Agriculture, Launceston. (Mr. Poggendorff was Chief of the Division of Plant Industry, Department of Agriculture, New South Wales).


Ranwell, D. S. (1964 in litt.). Letter to Dr. E. C. F. Bird, 30 January, and typescript of list of *Spartina* material known to have been sent from England to Australia.


Sampson, M. (1963 in litt.). *Spartina townsendii* (Rice Grass): Its History in Circular Head Municipality. (Mr. Sampson was formerly Chairman of the Smithton Harbour Trust). (Unpub.).

Saxby, S. H. (1964 in litt.). Reply to Dr. D. S. Ranwell's questionnaire on Spartina resources in New Zealand. (Cited in Ranwell 1967). (Mr. Saxby was an officer in the Department of Agriculture, Wellington).
Smith, R. A. (1970 in litt.). Letter to D. F. Paton, Chief Agronomist, Department of Agriculture, Hobart, 6 May. (Mr. Smith was District Agricultural Officer, Scottsdale).

Spafford, W. J. (1930a in litt.). Letter to Prof. S. M. Wadham, 28 May. (Mr. Spafford was Deputy Director of Agriculture, South Australia). Wadham Collection: University of Melbourne Archives.

Spafford, W. J. (1930b in litt.). Letter to Prof. S. M. Wadham, 1 September. Wadham Collection: University of Melbourne Archives.

Steele, R. B. (1931 in litt.). Letter to C. L. Gillies, Chief Agronomist, Department of Agriculture, Launceston, 12 August. (Mr. Steele was District Agricultural Organiser, Agricultural Extension Service, Department of Agriculture, Hobart).

Stockwell, J. R. (1937 in litt.). Letter to Prof. S. M. Wadham, 8 April. (Mr. Stockwell was a landowner at Alberton, Victoria). Wadham Collection: University of Melbourne Archives.


Wadham, S. M. (1929a in litt.). Letter to W. J. Spafford, Deputy Director of Agriculture, South Australia, 9 April. (Prof. Wadham was Professor of Agriculture in the University of Melbourne). Wadham Collection: University of Melbourne Archives.


Wadham, S. M. (1930a in litt.). Letter to Dr. B. T. Dickson, Chief of the Division of Plant Industry, CSIR, Canberra, 19 May. Wadham Collection: University of Melbourne Archives.


Wadham, S. M. (1930c in litt.). Letter to Mr. Miller (initials unknown), Department of Agriculture, Victoria, 31 July. Wadham Collection: University of Melbourne Archives.

Wadham, S. M. (1930d in litt.). Letter to Dr. B. T. Dickson, 12 September. Wadham Collection: University of Melbourne Archives.


Wadham, S. M. (1930f in litt.). Letter to Dr. B. T. Dickson, including notes of Spartina performance in the greenhouse at the University of Melbourne and notes on the plantings at Foster. 7 October. Wadham Collection: University of Melbourne Archives.

Wadham, S. M. (1931b in litt.). Memorandum: observations on plantations made by the Commissioners of the Geelong Harbour Trust at the mouth of the Barwon, 18 December. *Wadham Collection: University of Melbourne Archives.*


Wamsley, D. E. (1979 in litt.). Letter to the author, 26 August. (Mrs Wamsley is the wife of Mr. R. A. Wamsley, formerly property owner at Barmera, South Australia).

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