Formation of, and succession on, *Atriplex cinerea*-induced dune ridges in the Entrance Point Scientific Reference Area, Wilsons Promontory National Park, Victoria.

Petrus C. Heyligers

CSIRO Sustainable Ecosystems, Queensland Biosciences Precinct, 306 Carmody Road, St. Lucia, Qld 4067, AUSTRALIA.
petrus@harbourSat.com.au

Abstract: The Entrance Point Scientific Reference Area (lat 38º 48' S long 146º 38' E) in the north-eastern corner of Wilsons Promontory, Victoria, is notable for numerous parallel sandy dune ridges covered with dense *Leptospermum laevigatum* scrub. As a result of some demanding field work in a relatively remote area, together with aerial photos, I have been able to observe the development of this dune topography and follow the vegetation succession from 1981 to 2000.

After a period of erosion early in the 20th century, shore progradation and ridge formation resumed in the central section of the beach between Entrance and Hunter Points and later extended southward. The parallel ridges were found to be the result of successive berm and pool formation on the upper beach of the prograding shoreline. Berm overwash during spring and storm tides fills the depression behind the berm and after the tide has gone out leaves behind a long narrow pool. Buoyant *Atriplex cinerea* fruits present in the flotsam strand on either or both of the pool margins, depending on prevailing wind directions. After fruits have germinated, seedlings provide nuclei for sand accumulation. If they are sufficiently numerous, a dune ridge builds up along the outer pool margin while plants on the inner margin contribute to the consolidation of the previous ridge. As long as progradation continues, this process is repeated at intervals and results in the formation of series of parallel dune ridges.

A small number of other species establish in the lee of the new ridge. *Acacia sophorae* with its fast growth and spreading habit, together with *Olearia glutinosa* contribute to stabilising the ridge. They provide protection for *Leptospermum laevigatum, Myoporum insulare* and *Banksia integrifolia* during their early growth. After about 20 years, *Leptospermum laevigatum* becomes the dominant element of the scrub as *Acacia sophorae* diminishes in vigour and eventually dies. Virtually no evidence, even on the oldest ridges, was found of candidate species to continue the succession and hence, *Leptospermum laevigatum* thicket needs to be regarded as the end of the succession on young dune ridges.

Once the pool depressions are cut off from flooding by seawater, the groundwater freshens and a sward of *Isolepis cernua* and *Samolus repens*, often with *Juncus kraussii* and *Isolepis nodosa* on somewhat higher areas, becomes established. Flooding occurs during heavy rain and water may stay above the surface for several days.

At the same time, the older ridges of the central section were attacked by erosion which left large amounts of tree debris on the upper beach. This erosion resulted in the formation of a spit which, in time, carried a series of successively younger ridges built on flotsam lines. *Atriplex cinerea* was again the dominant pioneer species, but in the 1990s the influence of **Thinopyrum junceiforme* had become equally important. Succession on these ridges was similar to that of the ridges on the prograding beach, but scrub height remained somewhat lower. Saltmarsh vegetation, dominated by *Sarcocornia quinqueflora*, gradually established in the lower sections between the ridges. However, the impact of erosion which had provided the sediment for building the spit, gradually shifted northward and began to destroy what had come into existence only decades earlier.

Beach progradation along the western entrance to Corner Inlet is fortuitous and linked to changing channel locations in the tidal delta, while the dominant role of *Atriplex cinerea* in incipient dune formation is a consequence of the relatively sheltered environment at the entrance. It could well be that this combination of environmental factors is rarely if ever duplicated elsewhere in Australia.

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'And it rained and it rained;' it sounds like a Winnie the Pooh story! Yesterday the wind increased to gale force and its sound in the trees surpassed the roar of the surf. Glad to be in a secluded spot, but I was cloistered in the tent for the whole day, which became quite uncomfortable. ... At last, during the night the rain stopped and the wind abated, now only the surf making a tremendous noise.

The rough conditions should have warned me for the sights I beheld this morning: coming over the dune, the swale with the waterholes was largely flooded and the foreshore had dramatically changed as well. The sea had washed right to the outer saltbush mounds and into the low area in front of the higher saltbush dune, where I had found good freshwater. But that was not all! The gales had whipped sand over saltbushes and sea spurges alike and these looked as if bearing a heavy load of snow. I then also understood why I had found so much sand on the outer tent: it was driven in by the rain even into my sheltered spot, where it must have dripped from the Myoporum bushes around the tent.

The beach was all puddles and pools; water everywhere among the saltbush ridges and in the swales behind the older dunes. I shot more than a roll of film to capture the highest water levels, which were already markedly going down as the day progressed. ...

Now, in the evening, the high tide has just been overlapping the berm. I still saw it filling the 'pool' with the overwash, after which the water began to flow out in a northerly direction. ...

Extract from my diary entry for Friday, 12 October 1990.

Introduction

In the 1970s, surveys of the Victorian coastal region were carried out for the Town and Country Planning Board to describe sites of special scientific interest. Barson and Calder (1976) reported on botanical aspects and their description of the area near Entrance Point (lat 38º 48' S long 146º 38' E) (Fig. 1) is as follows:

'The north-eastern corner of Wilson's Promontory is notable for numerous parallel sandy beach ridges held in place by dense *Leptospermum laevigatum* scrub. On prograding sectors of the sandy shoreline, embryonic dunes are forming on washed up weed. *Cakile maritima* and *Atriplex cinerea* are early colonisers of bare sand, the invasion of *Acacia longifolia* is followed by that of *Leptospermum laevigatum, Banksia integrifolia, Myoporum insulare* and *Olearia glutinosa*. Grass species are not a major component of the dune flora; whereas on other prograding sectors of the Victorian coast they are important early colonisers and stabilisers of bare sand.'

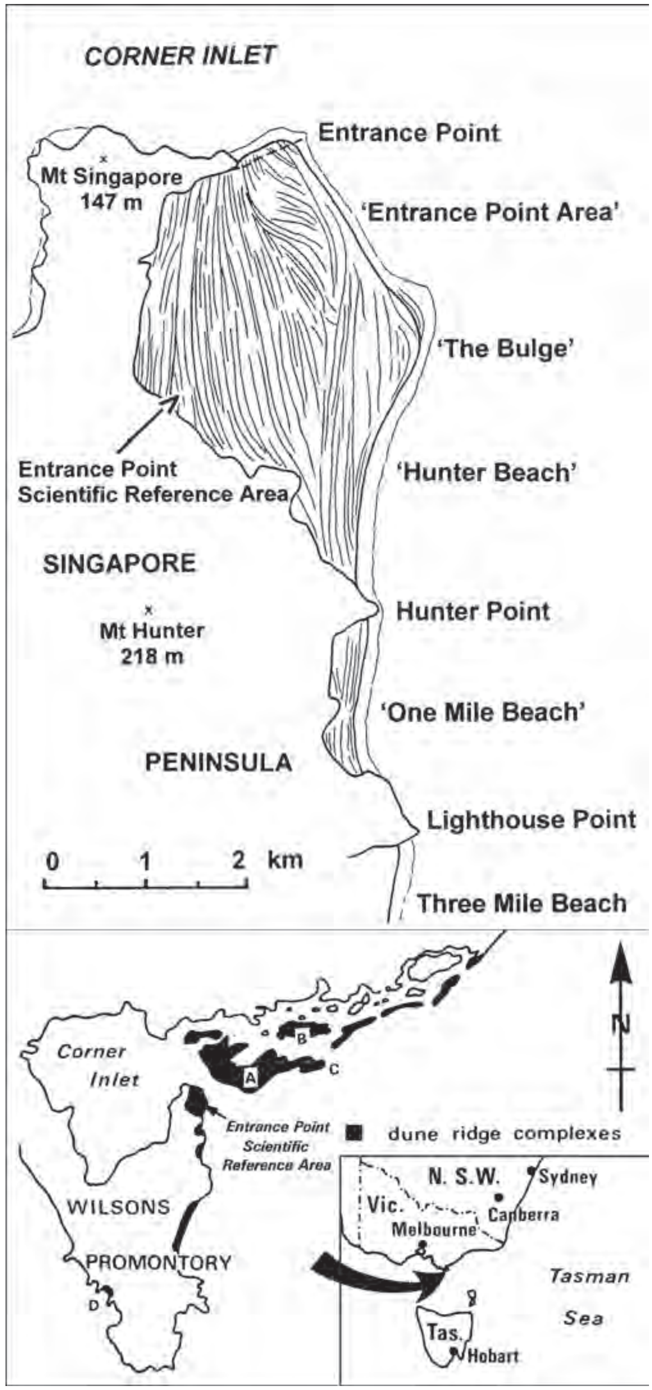

Fig. 1. The Entrance Point Scientific Reference Area (lat 38º 48' S long 146º 38' E) comprises the ridge-and-swale complex north from Hunter Point except for a 120 m wide exclusion zone west of Entrance Point (indicated by the broken line). Dune ridge alignments have been sketched in with air photos of 24 October 1969 as base. The actual recognisable ridges are about double the number shown. My study area is limited to the outer ridges and the beach between Entrance Point and Hunter Point. I used the place names in inverted commas for convenience (they have no official standing). On the lower map, A refers to Snake Island, B to Sunday Island and C to Clonmel Island; along Wilsons Promontory's south-west coast D indicates the location of Norman Beach.

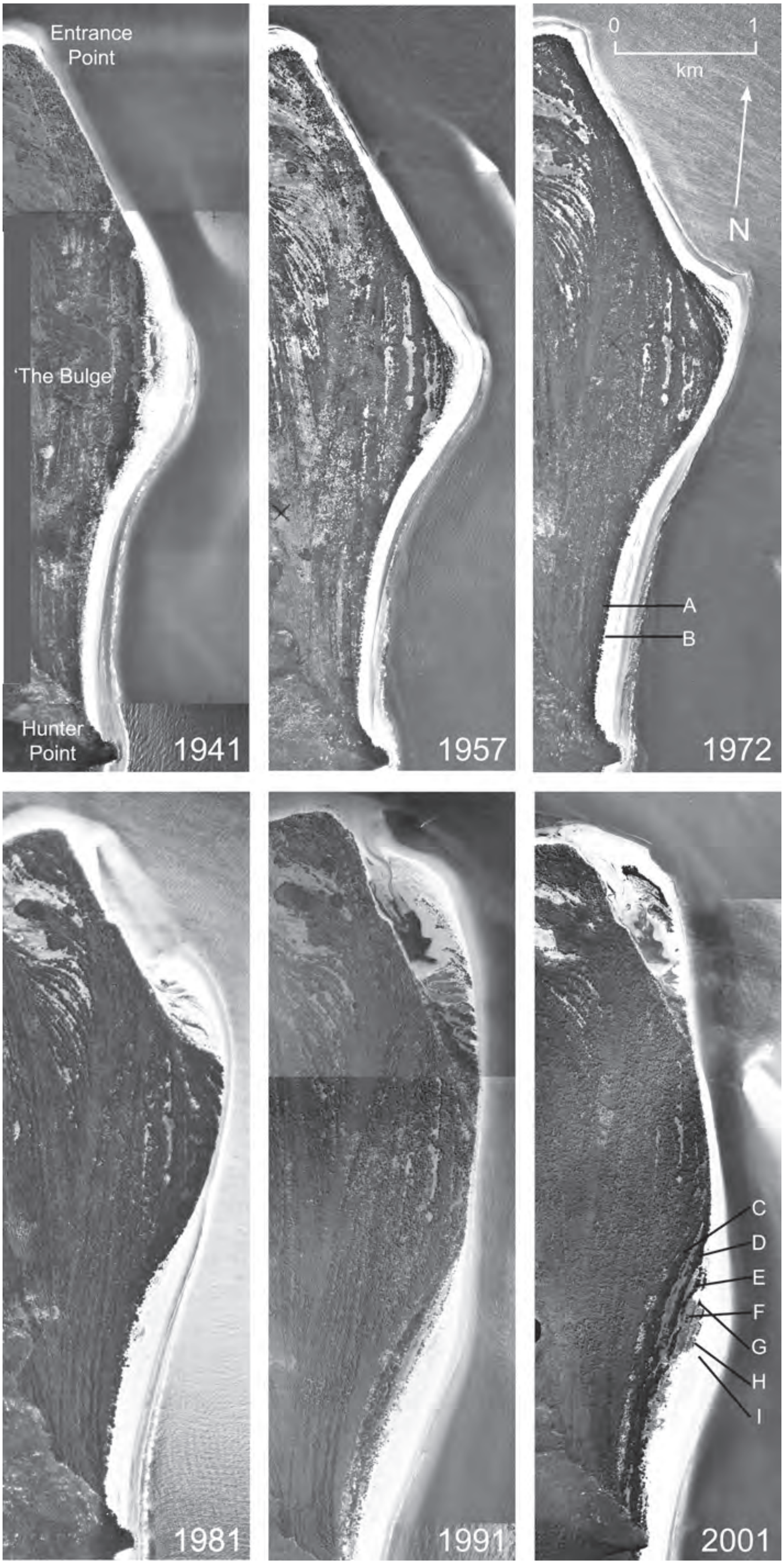

Fig. 2. The coast between Entrance Point and Hunter Point spanning the 60 year period between 1941 and 2001. The series of air photos shows the initial expansion of the central section of the beach (nicknamed The Bulge), the progradation of Hunter Beach to the south and the development of a sand spit from The Bulge towards Entrance Point. It was along Hunter Beach that the processes associated with beach progradation were very much in evidence and thus provided an ideal setting for my study. The capitals refer to the ridges built since progradation resumed, as described in the text and shown in Figs. 4 and 5. (1941 photograph Copyright © Royal Australian Air Force; 1957, 1972 and 1981 photographs Copyright © Crown (State of Victoria); 1991 and 2001 photographs Copyright © Parks Victoria.)

In 1981, looking for sites to investigate the interactions between plants and dune formation, I found that the coast between Entrance Point and Lighthouse Point provided an excellent opportunity for such study (Fig. 2). Here, long stretches of beach were prograding, apparently due to changes in the tidal delta of Corner Inlet. Although prograding coastlines are rare nowadays, this particular area proved to be unique in that the major plant species involved in dune building was *Atriplex cinerea* (Heyligers 1985). Also, it soon became apparent that understanding the circumstances under which these dune ridges were formed would help explain the formation of the extensive ridge-and-swale complex of the Entrance Point Scientific Reference Area.

Bird (1993) gives a short description of the area, illustrated by a 1965 air photo with a 1984 inset. Tuddenham (1970) provides the only detailed geomorphological study of the ridge-and-swale complex. He is the only person who has traversed the eighty or so ridges. As the results have only been presented in a chapter of a MSc thesis on a very different subject, I have summarised his findings below.

Tuddenham distinguishes six consecutive stages in the formation of the ridges. With the possible exception of the oldest stage, the ridges were formed after the sea had reached its present-day level after the last Glacial about 6000 years ago. The necessary sediment was provided by onshore deposition of large quantities of sand suspended in the strong tidal currents at the entrance of Corner Inlet. The oldest series of ridges carried *Eucalyptus viminalis – Banksia serrata* open woodland with an understorey of *Pteridium esculentum*. Coffee rock had begun to form in the siliceous sand. A high dune ridge separated this series from the next oldest, of which the outer edge was also marked by a higher ridge, again the result of a period of erosion. Podzol development was minimal, the woodland was sparser and *Banksia serrata* almost absent, *Melaleuca ericifolia* scrub occurred in wetter areas and *Leptospermum laevigatum* was found on higher parts of the outer ridges.

Ridges formed during the next three stages were lower, about 2.5–3 m above high watermark, and with only a humic top layer present, showed minimal soil development. Radiocarbon dating of a sea grass deposit buried below the water table in a ridge of the middle stage yielded a date of around 1300 years before the present, giving a rough indication of when these ridges were formed. Their vegetation was dominated by dense stands of *Leptospermum laevigatum* with scattered large trees of *Banksia integrifolia*, occasionally associated with *Eucalyptus viminalis*. Dense *Melaleuca ericifolia* scrub occupied the wetter swales, 'open grassland and rush communities' the broader swales with *Myoporum insulare* along the margins.

The youngest of these three stages was again affected by erosion; the position of the coastline as mapped on the 1868–69 Admiralty Chart corresponds closely to the nearly straight outer margin of these ridges. The high bank along the backwater south of Entrance Point is a remnant of that coastline. Further south however, another area of ridges of variable height and spacing was added, with swales at or slightly below present high tide level. It is closed off by a 3 m high massive foredune complex. The vegetation on these new ridges was similar to that on the adjacent older ones, but it is older, *Leptospermum laevigatum* is better developed and only present as a co-dominant. From air photo evidence Tuddenham surmises that this apparent anomaly can be explained by the destruction of the vegetation of the inner ridges by fire, with the subsequent regeneration producing dense stands of *Leptospermum laevigatum*, a process that has been observed elsewhere on Wilsons Promontory (J. Whelan pers. comm.). The names of the other co-dominants are not mentioned, but Tuddenham compares the vegetation with mature stands of 'Scrub Woodland' as described by Turner *et al*. (1962) for Sunday Island in Corner Inlet. This would imply that these other species were *Leucopogon parviflorus*, *Banksia integrifolia* and some *Eucalyptus viminalis*.

In this paper I describe the formation of, and subsequent vegetation succession on the dune ridges that have come into existence after Tuddenham's work. The large number of illustrations aims to give a detailed documentation of my observations semi-independently of the main text.

Physical environment of the study area

Wilsons Promontory lighthouse, the meteorological station closest to the study area is situated on the southern tip of the Promontory and exposed to the full impact of the often strong, predominantly westerly winds on Bass Strait. Annual rainfall is about 1050 mm; average rainfall for January and February is about 50 mm per month and rises to 120 mm per month in the winter season. This compares with an average rainfall of about 850 mm per year at Shallow Inlet on the north-west side of the Promontory. There, monthly totals vary from about 40 mm during the summer months to more than double during late autumn and winter (Heyligers 2006). The dune ridges on the east coast of the Singapore Peninsula lie in the shelter of the high ridge that forms its spine. During my time in the field it was not unusual to see low scudding clouds, moving in from the west, evaporate once they began to descent from the ridge. Hence, it is possible that the rainfall in the study area would be less than at Shallow Inlet. Average monthly maximum and minimum temperatures at the lighthouse range from about 20ºC and 15ºC during summer, to about 13ºC and 8.5ºC in winter. There are no equivalent records for Shallow Inlet.

Tides are semidiurnal with a daily inequality of about 0.3 m between High Waters. The tidal amplitude is about 1.8 m,

Fig. 3. The early phases of ridge-and-swale formation on Hunter Beach; **(a)** northerly view over a long pool behind the berm, with the overwash running out through the drain at the right and **(b)** over the pool after water level had fallen below drain level; **(c)** linear *Atriplex cinerea* establishment on the outer and inner shore of a depression earlier occupied by a pool; **(d)** *Atriplex cinerea* bushes building up a dune ridge by catching sand dislodged from the wide beach.

with only a small difference between neap and spring tides. Strong south-easterlies may increase tidal height by 0.5 m, sufficient to inundate low-lying areas between the ridges closest to the beach.

The sandy sediments of the Corner Inlet tidal delta provide the parent material for the dune ridges of the Peninsula. These sediments are predominantly siliceous and hence, the calcium carbonate content in the shore deposits is low. The figures obtained by Tuddenham (1970) for the youngest dune ridges vary between 0.9 and 3.1% and drop to negligible amounts in the oldest ones. Cecil (1984) recorded values of between 1.5 and 2.9% for the upper beach and 0.9 and 3.6% for the youngest dune ridges. The few samples I took from *Atriplex* hummocks gave carbonate values of 0.3–0.7% (R. Sageman, pers. comm.). These figures are in sharp contrast with those of the calcareous sediments at the west coast of the Promontory, where the carbonate content of the young dunes is generally >30% and may be as high as 52.5% (Cecil 1984). The recent dunes of the study area show very little soil development. At best one could see a humic discolouration under the layer of litter and decaying organic material on the older ridges, but the 'soil' of the new ridges was just recent wind-deposited sediment.

Methods

Between 1981 and 2000 I visited the coast between Lighthouse Point and Entrance Point nine times; until November 1986 at about yearly intervals, but later spaced further apart, as access became more difficult. Time in the field varied from one or two days to a fortnight. For convenience of description and discussion I gave names to the beaches as they lack official ones (Fig. 1).

Air photos have been an indispensable research tool. There are 19 sets of air photos, with scales ranging from 1:10 000 to 1:33 000, and taken with increasing frequency since 1941, for the beaches of interest or parts thereof. Unfortunately, recognition of the early stages of dune development is hampered by overexposure of the sandy substrate, sparse vegetation cover and the grey appearance of the *Atriplex cinerea* shrubs.

I concentrated on sections where the effects of progradation were most marked, and documented the changes with photographs, (as far as feasible) taken from the same vantage points during consecutive visits. When intervals between fieldwork became longer, it usually took me a day or two to re-acquaint myself with the area, because the fast growth of *Acacia sophorae* obscured the topography I remembered from the previous fieldtrip. This also presented a problem for photography if there were no suitable open spots left.

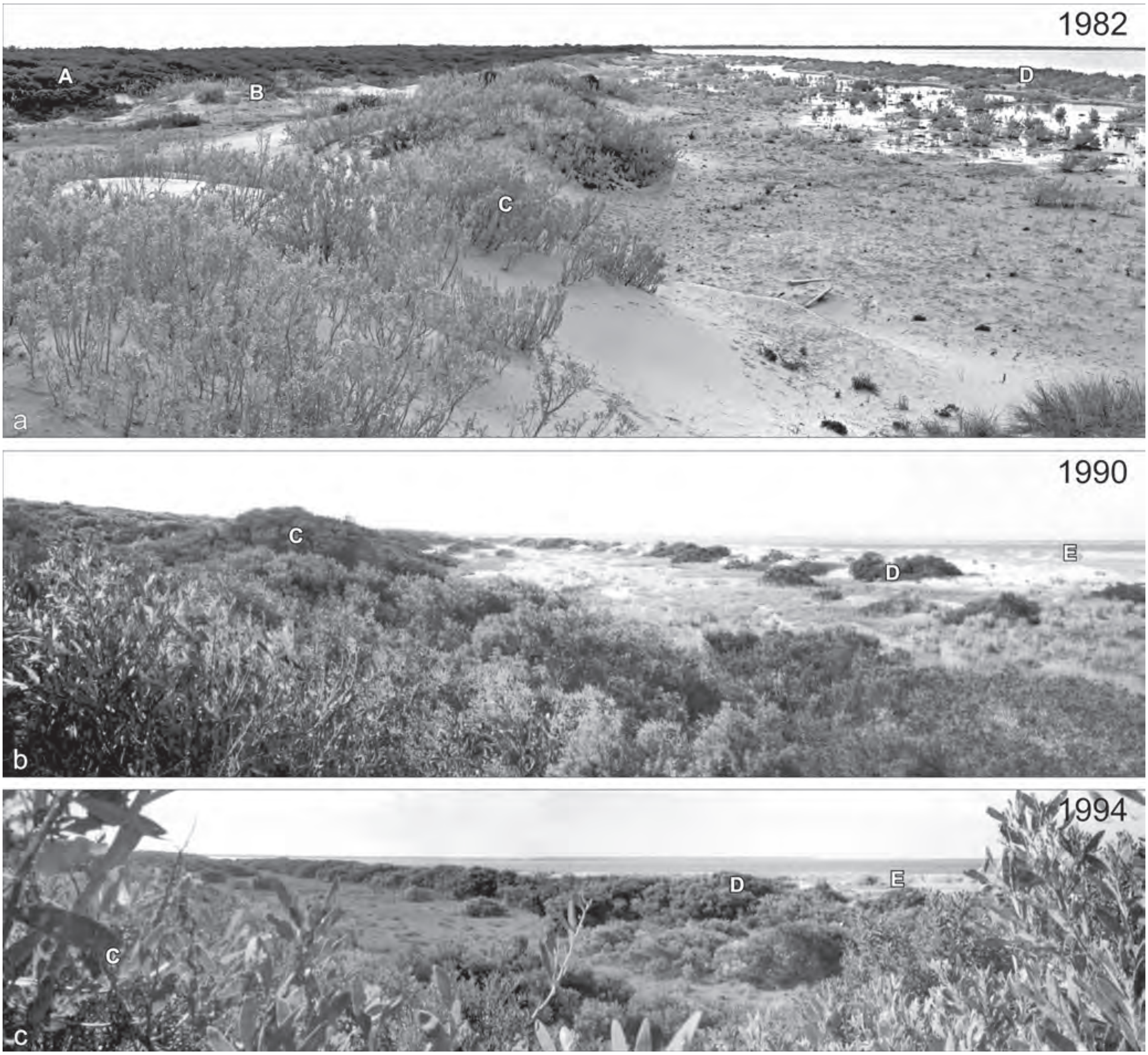

Fig. 4. The earlier stages of ridge-and-swale development of the northern section of Hunter Beach (see Fig. 2); **(a)** the situation in 1982 when a new ridge D was accumulating on the seaward shore of the pool in front of *Atriplex* ridge C which had been developing since the mid-1970s; at the left, A indicates the scree dune which, in the early 1960s, was formed against the old eroded dune ridge, and B the first new dune ridge; **(b)** by 1990 *Acacia sophorae* bushes had replaced the *Atriplex cinerea* shrubs on ridge C, the same process had begun at ridge D and a new ridge E was forming on the upper beach; **(c)** a comparable view in 1994, when the height and density of the *Acacia* scrub made it impossible to take the photographs at exactly the same position. The vegetation in the swale between ridges C and D progressed from scattered *Sarcocornia quinqueflora* and *Atriplex cinerea* bushes in the early stages to a dense sward of *Isolepis cernua* and *Samolus repens* after the pool had been cut off from salt water flooding (see Fig. 12).

Fig. 5. The later stages of ridge-and-swale development at the northern section of Hunter Beach. The photographs taken in 1994 and 2000 show the younger ridges and swales from opposite directions: **(a)** and **(b)** are views northwards from a high mound on ridge F towards the drain of the pools between ridges E and F and F and G while the views on **(c)** and **(d)** look out over these ridges from the northern section of ridge G and show the drain in the foreground. In 1994 *Atriplex cinerea* dominated the vegetation of the ridges but by 2000 scrub with *Acacia sophorae* and *Olearia glutinosa* as major species had replaced the pioneer vegetation. In the meantime the drain had been closed off by the prograding beach and the scattered saltmarsh species had been joined by *Isolepis cernua*, *Samolus repens* and *Apium prostratum* with *Juncus kraussii* and *Isolepis nodosa* in the higher parts. At the extreme right of **(d)** a small section can be seen of the substantial sand-drift which accumulated against ridge E since the drain was blocked. The sequence of ridges and the sand-drift are clearly visible on the 2001 air photo of Fig. 2. At that time erosion was already attacking the outer ridges, which had only accumulated a few years earlier.

Botanical nomenclature follows Walsh and Entwisle (1994–1999) except for *Senecio lautus*, which name has been replaced by *Senecio pinnatifolius* (Belcher 1994). Specific epithets have been used for all species except *Acacia longifolia* var. *sophorae*, for which the varietal name has been substituted. Scientific names for mammals follow Triggs (1996), those for birds Christides and Boles (1994). Asterisks precede the names of introduced species.

Results

Geomorphological processes

Ridge and swale formation: During incoming tides, wave uprush transports sand up the beach; when the tide turns some of the sediment is left behind. This leads to the formation of a berm – 'an accretionary feature common to many beaches, resulting from the accumulation of sediment at the landward extreme of wave influence' (Hughes & Turner 1999). A berm is often ephemeral and destroyed by storm high tides. However, on shallow gradient beaches berms have a better chance of surviving wave attack. A shallow depression separates the berm from the foredunes. During high tides, especially when coinciding with high seas, wave uprush overwashes the berm and fills the depression, thus creating an elongated pool (Eliot 1979). Initially, a pool drains through one or more channels across the lowest sections of the berm, but as the water level drops below channel height, it drains via the ground water table, a process that can take several days. As a result of the low gradient, the berm and pool topography is remarkably well developed on Hunter Beach (Fig 3a, b).

The significance of a pool for dune ridge formation lies in the fact that much of the flotsam on the pool surface eventually strands on the margins. If seeds and fruits are sufficiently numerous, a linearly spread plant population develops on the pool margin. This linear arrangement of seedlings is the catalyst for the formation of a dune ridge. At Hunter Beach, the shrub *Atriplex cinerea* assumes this role. This species has buoyant fruits and the bushy plants are able to cope with salt spray and salty ground water, while their growth appears to be stimulated by wind-blown sand accumulating amongst the branches (Heyligers 1985, 2001). Plants that grow from fruits

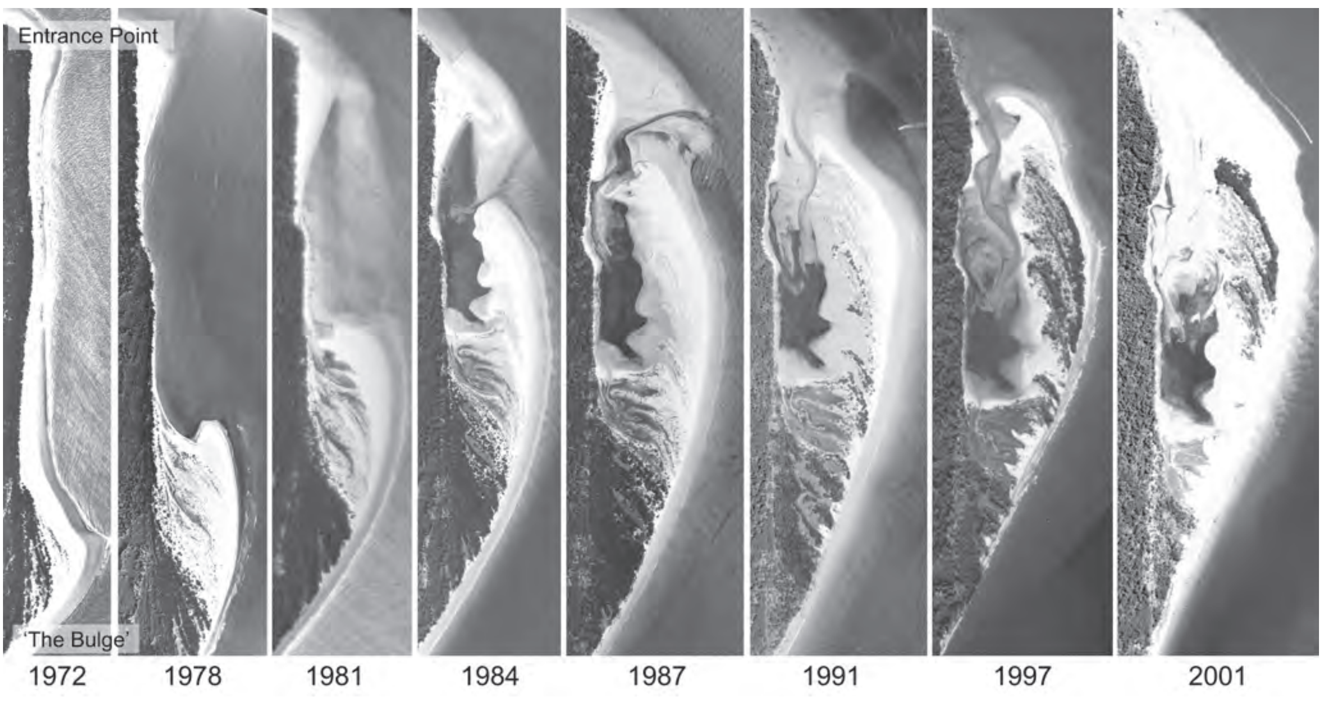

Fig. 6. The coast between Entrance Point and The Bulge. During the 1970s, along the northern side of The Bulge, ridge-and-swale formation degraded into a more subdued topography. This was followed by a phase in which deposition not longer extended to the old frontal dune but left shallow, tidally inundated areas between low ridges. In the 1980s, probably due to an even stronger increase in sand supply, a spit built out towards Entrance Point and turned the channel along the frontal dune into a backwater. By 2000 the outlet of it fell dry at low tide and the spit was connected to the beach at Entrance Point. As the spit grew, flotsam lines formed the foundation for a fan-shaped series of ridges. However, while the spit continued to grow, erosion which had already taken away much of what was built over the last few decades, also began to affect the older stages of spit formation and by 2000 had almost washed out the first of the two high ridges. (1972, 1978, 1981, 1984 and 1981 photographs Copyright © Crown (State of Victoria); 1991, 1997 and 2001 photographs Copyright © Parks Victoria.)

Fig. 7. Scenes of destruction: the effects of erosion between the northern section of The Bulge and Entrance Point; **(a)** a swale between ridges with *Leptospermum-Banksia-Acacia* scrub smothered by sand washing in from the beach; **(b)** high-tide attack on the low saltmarsh shore, **(c)** the seaward side of one of the older ridges of the spit with *Leptospermum-Banksia-Acacia* scrub, **(d)** another ridge formed about 10 years later and dominated by *Acacia sophorae*, and **(e)** one of the youngest ridges, still dominated by *Atriplex cinerea*, as it appeared in November 2000; **(f)** the *Leptospermum laevigatum* and *Banksia integrifolia* dominated old frontal dune south of Entrance Point, showing the debris left on the beach where it tumbled down during the time this section of the coast was still being eroded.

stranded on the inner pool margin increase the population which resulted from a former flooding event, while plants that develop from the fruits stranded along the outer margin are instrumental in building a new ridge (Fig. 3c, d). These ridges may be several metres high and some hundreds of metres long. As ridges increase in size, drains sand up and pools are closed off from flooding by seawater. This leads to a freshening of the groundwater which, in periods of high tides or heavy rainfall, rises above the surface and inundates the former pool, now transformed into a swale.

Ridge formation on Hunter Beach. Initially, in the early 1960s, a scree dune (A) was formed against the old, cliffed dune ridge, followed by a foredune (B) on the upper beach. In the late 1960s, a long pool had developed with a wide drain near the northern end of the beach (Figs. 2, 4). Colonisation by *Atriplex cinerea* at the beach side gave rise to a new dune ridge (C) and was followed by another pool and another ridge (D) later in the 1970s. These ridges were not continuous, but were broken up into shorter ridges and mounds, with longer or shorter sections missing. Along these sections no fruits had been deposited or high tides had washed out the early colonising stages. Where this was the case, wind-driven sand was deposited on the inland shore of the pool and thus contributed to accretion in front of the previously formed ridge.

During the 1980s, progradation changed from being uniform along the entire length of the beach to being less strongly expressed in much of the southern section. In the northern part several more ridges (E–I) were formed, but they became shorter and F and the southern section of G were strings of mounds rather than ridges (Figs. 2, 5). In 2000 progradation had virtually stopped and erosion was gaining ground towards The Bulge. In the corner of the beach against Hunter Point ridge formation still continued and progradation has progressed to the stage that the beach is now continuous with One Mile Beach.

The Bulge story: Aerial photographs taken in 1941 show a bulging out of the shore immediately north of Hunter Beach (Fig. 2). At that time progradation along this section of the beach was more pronounced than to the north or south. A series of four or five ridges and swales protruded from the old, straight coastline and were separated from it by a wide swale. From 1966 onwards, erosion affected the southern side of The Bulge but at the northern side progradation and ridge formation continued for another ten years, although swales tended to become narrower, irregular and soon ceased to be formed. Manifestly, an increased amount of flotsam stranding on the upper beach led to an almost continuous formation of incipient dunes.

The deposition regime changed dramatically in the second half of the 1970s as a spit began to build out towards Entrance Point (Fig. 6). Sand transported by the longshore current was not sufficient to fill in the abandoned channel of the Corner Inlet tidal delta situated hard along the foot of the old frontal dune. Rapid extension of the spit during the 1980s led to the formation of a fan-shaped series of curved ridges separated by depressions, shallow in the narrow section of the fan and gradually widening and deepening towards the old channel backwater. Ridge formation happened in pulses, probably caused by periods of strong south-easterly winds enhancing the erosion of the southern part of The Bulge. Flotsam of seaweed, dead seagrass and the remnants of shrubs from the eroding shore formed the core for ridge building. Rather narrow along the inlet, strandlines were often more spread out towards the backwater shore. Where that was the case, these ridge sections would be lower, wider and rather moundy. Lower sections of the depressions remained under tidal influence and this provided conditions suitable for saltmarsh development.

The growing spit impinged on the shoals south of Entrance Point. This narrowed the backwater outlet and pushed it gradually northward. By 2000 the outlet was situated close to Entrance Point and fell dry at low tide. In the meantime shore erosion had progressed north of The Bulge and attacked the older parts of the spit, to the extent that much of the sand that built the older ridges had been carried away or washed into the saltmarsh areas (Fig. 7).

Vegetation development at Hunter Beach and The Bulge

The colonising stages: After germination along the outer pool margin, *Atriplex cinerea* shrubs begin to catch sand and, in a couple of years, build up a ridge 2.5–3 m high and 10 m or so wide (Fig. 3c, d). Initially, shrubs grow more rapidly than sand is deposited and branches may overtop the crest by up to 1.5 m. If not cut off by a new ridge, sand supply gradually gains on *A. cinerea* and ridges may increase to a height of 3.5–4.5 m. By that stage the shrubs are senescent and only short spindly branches with little foliage remain above the surface.

Once the area behind the newly formed dune ridges becomes more or less isolated from the beach proper and thus somewhat protected from the direct impact of sea and wind, other species establish, especially in the lee of the ridges and on islands in the swales. They include **Thinopyrum junceiforme, Isolepis cernua, Isolepis nodosa,* **Euphorbia paralias, Epilobium billardierianum*, *Carpobrotus rossii, Apium prostratum* ssp. *intermedium,* **Parentucellia viscosa*, several Asteraceae: *Senecio pinnatifolius,* **Senecio elegans, Senecio biserratus, Pseudognaphalium luteo-album* and **Vellereophyton dealbatum*, as well as five species of woody plants: *Acacia sophorae, Olearia glutinosa, Leptospermum laevigatum, Myoporum insulare* and *Banksia integrifolia*.

Depauperate **Thinopyrum junceiforme* and an occasional **Euphorbia paralias* are the only species that also occur on the crests.

Table 1. General trend of the vegetation succession on the young dune ridges at Hunter Beach, Entrance Point Scientific Reference Area.

Stage	**pioneer**	**early successional**	**mid successional**	**late successional**	**mature**
Year	**1 – 2**	**2 – 4**	**4 – 7**	**6 – 20**	**20 – >45**
General appearance	bushy *Atriplex cinerea* plants with grey foliage on low ridges or strings of mounds	ridges increase in size and reach heights of 2–3 m, rarely 4 m, *Atriplex cinerea* dominates aspect	little or no increase in ridge height, aspect determined by *Acacia sophorae* with some *Olearia glutinosa*; locally *Leptospermum laevigatum* common	*Leptospermum laevigatum* becomes more common, but *Acacia sophorae* still prominent, *Olearia glutinosa* drops out	*Leptospermum laevigatum* dominant, some *Acacia sophorae* still present, *Banksia integrifolia* present, locally common, some emergent
Canopy height & cover	0.5 – 1 m; 30–50%	1.2 – 1.8 m; 30–60%	2 – 4 m; 50–80%	4 – 7 m; 70–90%	8 – 10 m; 70–90%
Atriplex cinerea	dominant, ridge building	ridge building; stems 1–1.7 m above surface	senescing, dropping leaves	gone, dead stems may remain for a few years	
Olearia glutinosa	some seedlings on lee side	more seedlings, especially on lower slopes at lee, grow to bushes 0.5 m tall	shrubs reach their maximum height of 2–3 m, rarely 4 m, and stem diameters of 10 cm; flowering profusely	senescence, characterised by shrubs breaking open and blackening stems, before total demise at about Year 10	
Acacia sophorae	some seedlings on lee side	more seedlings; branches spreading mainly horizontally for several metres, stem diameters 2 to 6 cm	shrubs grow to 3 or 4 m in height and 10–15 m in width, diameters increase to 14 cm; flowering profusely	height increases to 4–7 m, further growth in width on slopes only; branches lose lower leaves, attain diameters up to 20 cm; still flowering	some further growth before senescence sets in; by Year 25 most 'shrubs' are dead, but some remain alive much longer and attain stem diameters of 25 cm, the largest one seen 33 cm
Leptospermum laevigatum	occasional seedlings on lee side	new recruitment, mainly at lee side, seedlings may grow to 0.5 m	single- or multi-stemmed saplings, may not yet reach canopy level, stem diameters <10 cm; some flowering	strong growth and expanding crowns; reaches heights of 4 to 6 or 7 m; stem diameters increase to 20 cm; loses lower leaves	some 'tree-shrubs' attain massive size with crowns >10 m wide, but heights remain about 10 m; stem diameters up to 40 cm; shrub bases much larger; liable to wind-throw
Myoporum insulare	occasional seedlings on lee side	more seedlings; some grow into compact bushes up to 1 m tall	scattered bushes, 2–3 m tall, now present in canopy	little or no new recruitment; established shrubs expand in size; is often a minor element in the vegetation	shrubs reach their maximum height and have wide crowns, but usually remain shorter than *Leptospermum laevigatum*
Banksia integrifolia	occasional seedlings on lee side	some seedlings remain stunted, others grow slowly	saplings remain below canopy level, with stem diameters <7 cm; possibly some new recruitment	saplings reach canopy level and attain a diameter of 15 cm; they form a minor element of the vegetation	most trees remain in the canopy and have diameters of 40–50 cm; some are emergent, 12 m tall and with a diameter of 70 cm

Stage	pioneer	early successional	mid successional	late successional	mature
Year	**1 – 2**	**2 – 4**	**4 – 7**	**6 – 20**	**20 – >45**
Monotoca elliptica					occasionally present, but remains small, < 1 m tall
Leucopogon parviflorus					rarely present as small shrubs
Clematis microphylla		seedlings, young plants	some reach the canopy and flower	twining in the canopy, conspicuous flowering	vines persist and become liane-like, with stem diameters of 8 or 9 cm
Rhagodia candolleana		young plants, up to 1.8 m, some flowering	often scrambling in margins	common in undergrowth; dense tangles, to 3 m high	tangles widespread but locally absent
Tetragonia implexicoma			plants become established	present in tangles of *Rhagodia candolleana*, scrambles into branches	common in *Rhagodia candolleana* tangles

Scrub and thicket development (Table 1; Figs. 4, 5, 8 and 9)**:** The numbers of seedlings of each woody plant species that survive the pioneering stage of colonisation determine to a large extent the canopy composition of the developing thicket, a woody vegetation in structure classifiable somewhere between scrub and low forest. The first branches of an *Acacia sophorae* seedling spread over the soil surface before producing upward branches at various angles (Fig. 10a–c). In this way a single shrub may attain a spread of over 15 m, while its height may not be more than 3 or 4 m. Given this architecture, *Acacia sophorae* shrubs are efficient catchers of sand that spills over from the seaward side of ridges and take over from *Atriplex cinerea* on the crest when the ridge gains protection from new ridges to seaward.

The growth of *Olearia glutinosa* is also rapid and shrubs often become common in the developing *Acacia sophorae*

Fig. 8. The youngest section of the sequence of ridges at Hunter Beach; **(a)** shows the latest addition: just a short ridge (I) in which the mounds formed in the *Atriplex cinerea* bushes are still recognisable; **(b)** the wide footslope on the seaward side of ridge H and the pool depression between H and I, which is sanding up while the vegetation of ridge I is still discontinuous. As progradation along this section of Hunter Beach had almost stopped, no further ridges will be added and the aerial photograph of 2001 (Fig. 2) shows already the first signs of erosion of ridges I and H.

Fig. 9a. Ridge-and-swale development at southern end of Hunter Beach viewed from the lower slopes of Hunter Point. **(a)** A 1985 view of the short, 2 m high *Atriplex* ridge backed by a wide swale which was still occasionally flooded but was later cut off by *Atriplex cinerea* growing on the upper beach. It had a sparse cover of *Isolepis cernua* and *Sarcocornia quinqueflora*. **(b)** and **(c)** Five years later several *Acacia sophorae* seedlings which established in the lee of the ridge had grown into 3–4 m high bushes, while the height of the ridge had increased to 3 m. Towards the shore an incipient *Atriplex* ridge bounds the pool depression. **(d)** and **(e)** show the development of the *Acacia*-dominated scrub which in due time straddled the ridge, and the increasing vegetation cover in the swale which, in 2000, was still liable to flooding by rising groundwater. The lowest areas were covered by a mat of green algae, other parts by *Isolepis cernua*, *Hydrocotyle tripartita, Samolus repens* and some *Centella cordifolia*.

scrub. However, this species has a short lifespan and after about ten years shrubs decline in vigour and soon disappear from the vegetation. *Leptospermum laevigatum* seedlings develop more slowly. Sapling growth varies from single-stemmed individuals to bushy, stooling, multi-stemmed shrubs with upright branches (Fig. 11). Plants catch up with *Acacia sophorae* and become canopy members when the scrub reaches a height of about 4 m. For another decade or so they keep pace with each other, but as *Acacia sophorae* gets older its population gradually dies off and *Leptospermum laevigatum* becomes the dominant species. At that stage the canopy is about 7 m high and crowns of bushy *Leptospermum laevigatum* may be 8 m wide. *Myoporum insulare* and *Banksia integrifolia* usually are less common. Both species are long-lived and some *Banksia integrifolia* trees eventually become emergents in the thicket which, dominated by *Leptospermum laevigatum*, has reached its maximum height of 8–10 m.

While on the young ridges at Hunter Beach *Olearia glutinosa* was common among *Acacia sophorae*, at The Bulge *Leptospermum laevigatum* was often prominent. This was even more marked in the area transitional to the sand spit (Fig. 11d). There *Acacia sophorae* shrubs were often outnumbered by *Leptospermum laevigatum*, probably because this area was adjacent to old *Leptospermum laevigatum* dominated ridges, rather than hundreds of metres removed as on Hunter Beach; although wind-dispersed, the effective seed dispersal range for good establishment of *Leptospermum laevigatum* is less than 100 m (Hazard and Parsons 1977).

Fig. 9b. The lowest areas were covered by a mat of green algae, other parts by *Isolepis cernua*, *Hydrocotyle tripartita, Samolus repens* and some *Centella cordifolia*. **(f)** and **(g)** overlook the younger ridges; **(f)** shows the further development of the incipient ridge seen in **(b)** towards the right and the addition of a new ridge seaward, with the pool depression partly filled in by sand deposited at the foot of the headland (note rocks). Before the new ridge was formed, sand also extended the footslope of the previous ridge, a process shown in its initial stages on the new ridge, where a row of *Atriplex cinerea* bushes grows on a former strandline; **(g)** portrays the same scene in 2000, six years later.

The consequence of more *Leptospermum laevigatum* is that it becomes co-dominant in maturing scrub and explains the variations in its density on older ridges. Increased density has a detrimental effect on the establishment and growth of other species and results in a monotonous monoculture with hardly any undergrowth. In contrast, on ridges where *Leptospermum laevigatum* is sparse among the *Acacia sophorae*, it forms open stands and stems may attain tree stature with diameters up to 40 cm. *Banksia integrifolia* and *Myoporum insulare* are more prominent in such vegetation and also attain large stem diameters: 56 cm and 23 cm respectively. Still, canopy height remains at about 10 m. Often the trees are growing on the ridge slopes rather than on the crests, possibly a legacy of their seedling position in the young *Acacia sophorae* scrub (Fig. 11a).

During the expansion of *Acacia sophorae* three other species appear. *Rhagodia candolleana* is first, followed by *Clematis microphylla* and *Tetragonia implexicoma*. In time, when the interior of the thicket becomes more open due to *Acacia sophorae* leaf fall, *Rhagodia candolleana*, usually with *Tetragonia implexicoma*, forms dense tangles in the undergrowth, while *Clematis microphylla* climbs into the canopy. *Polyscias sambucifolia, Senecio biserratus* and *Urtica incisa* are other species occasionally present. The ground cover consists mainly of leaf litter with scattered *Parietaria debilis*, *Daucus glochidiatus* and young *Clematis*

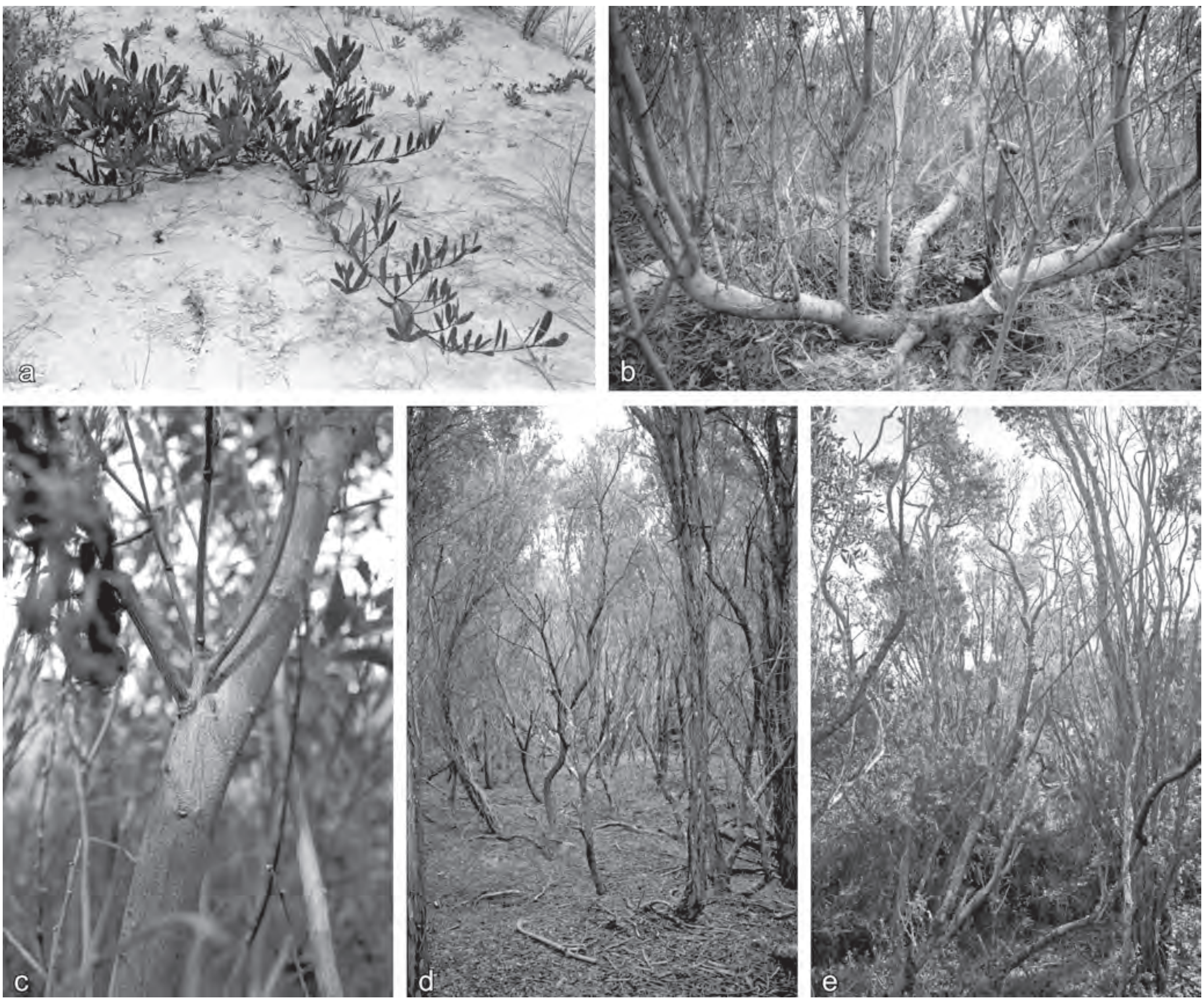

Fig. 10. A life history of *Acacia sophorae*: **(a)** initially, seedlings produce mostly horizontal branches, a trait that continues in later growth as long as there is no competition from neighbouring shrubs; **(b)** upright branches grow as side-branches from horizontal stems and often are quite irregular in structure as there does not appear to be a strong apical dominance, a case of which is shown in **(c)** where a side-branch has taken over from the three-branch main shoot; **(d)** and **(e)** show the demise of shrubs after some decades, either still standing as skeletons in *Leptospermum laevigatum* thicket, or broken down and then overgrown by *Rhagodia candolleana* or *Tetragonia implexicoma*.

Fig. 11. Other aspects of scrub development and demise. **(a)** *Leptospermum laevigatum* and *Banksia integrifolia* seedlings at the foot of an *Atriplex cinerea* shrub in the lee of the outer dune ridge. **(b)** The growth of *Leptospermum laevigatum* varies from single-stemmed individuals to multiple-branched shrubs, an example of which is shown in this photograph. **(c)** Scrub on one of the older ridges of The Bulge, dominated by *Leptospermum laevigatum* and with scattered *Banksia integrifolia* and *Myoporum insulare*. **(d)** About 10 year old scrub on a low ridge in the northern section of The Bulge, dominated by *Leptospermum laevigatum*. **(e)** A ridge in the interior of The Bulge with some old *Leptospermum laevigatum* shrubs; note that the shrubs are mainly growing on the sides of the ridge, a legacy of the period when ridge building in *Atriplex cinerea* was still in progress (see **(a)**). **(f)** About 12 m tall *Banksia integrifolia* trees and lower *Myoporum insulare* after collapse of *Leptospermum-Acacia* thicket, caused by wind-throw; in the shrub layer, up to 3 m high, *Rhagodia candolleana, Tetragonia implexicoma, Clematis microphylla, Olearia glutinosa, Polyscias sambucifolia* and *Senecio minimus*. **(g)** Collapsed *Leptospermum laevigatum* vegetation near the 1965 ridge. Most old *Acacia sophorae* shrubs and several *Banksia integrifolia* are dead, but *Myoporum insulare* shrubs are still alive and joined by some younger *Acacia sophorae*, both up to 4 or 5 m tall; the undergrowth is similar to **(f)**.

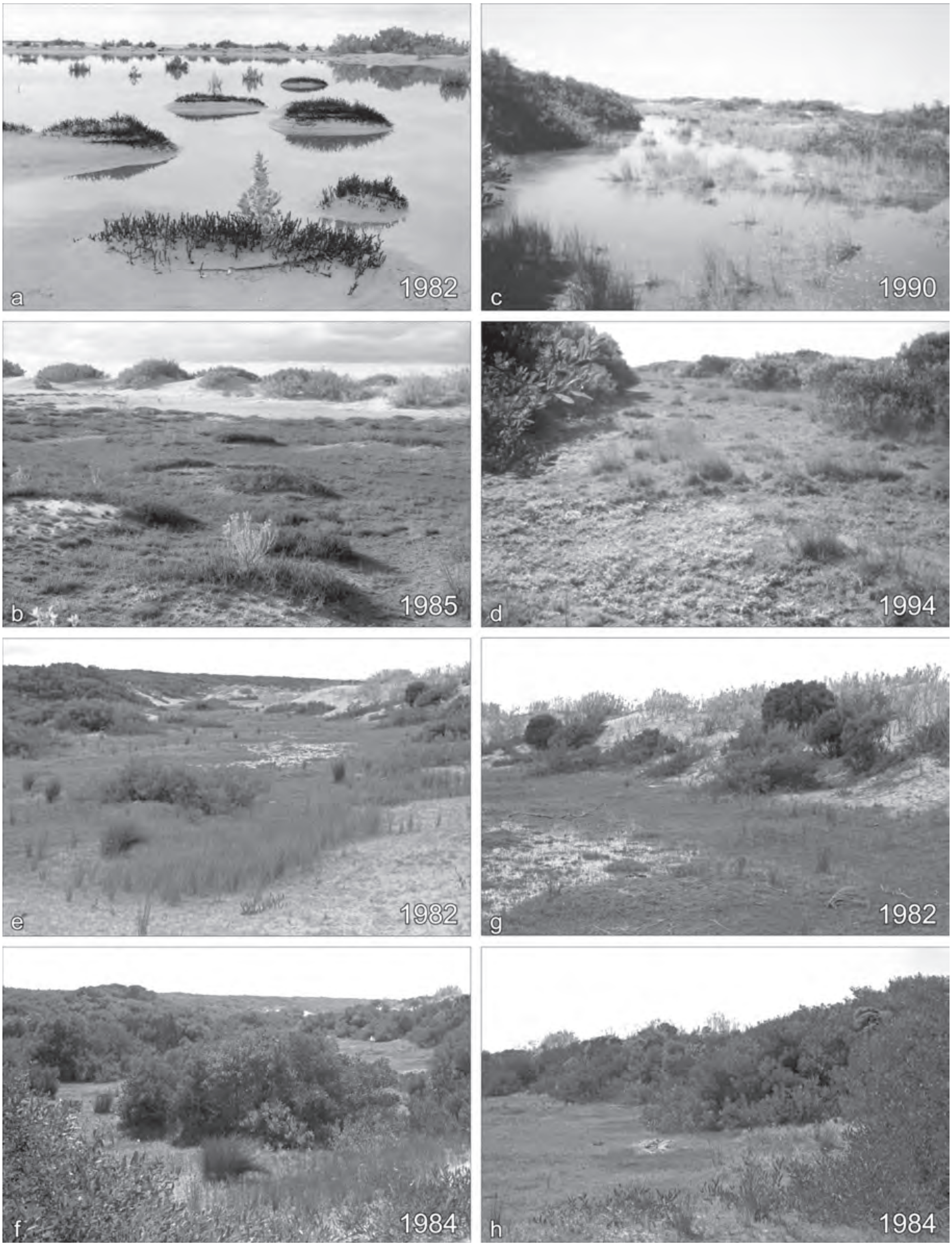

Fig. 12. Swale histories: **(a)** to **(d)** are photographs of the swale between ridges C and D; **(a)** shows the flooded pool in 1982 with low mounds formed in *Sarcocornia quinqueflora*, which also carry an occasional *Atriplex cinerea* plant; ridge D is in the background; **(b)** shows the same mounds three years later and the colonisation of the swale floor by *Isolepis cernua*; **(c)** and **(d)** are views over the swale in the 1990s, cut off from flooding by seawater, but inundated by rising groundwater during high tides or heavy rainfall. The swale now has a dense cover of *Isolepis cernua* and *Samolus repens* with scattered tussocks of *Isolepis nodosa* and an *Acacia sophorae* bush growing on one of the old *Sarcocornia* mounds; also note the development of the *Acacia* scrub on ridge D. **(e)** and **(f)** show the swale between ridges B and C in 1982 and 1984 to highlight the rapid growth of *Acacia sophorae* in higher parts of the swale, while **(g)** and **(h)** show the same on the lee slope of ridge C, together with that of *Olearia glutinosa, Leptospermum laevigatum* and *Myoporum insulare* (the two bushes with dark foliage).

microphylla in openings between the tangles. Depauperate remnants from the early stages of succession, such as *Isolepis nodosa* and **Euphorbia paralias* and even dead *Atriplex cinerea* stems, can occasionally be found in the older *Acacia sophorae* scrub, while in turn *Acacia sophorae* skeletons may still be standing in maturing *Leptospermum laevigatum* thickets (Fig. 10d).

During further exploration of the older ridges I came across pockets, especially on lee slopes, where *Leptospermum laevigatum* and *Banksia integrifolia* had crashed through wind-throw. These showed that both species were rather shallow-rooted. In these pockets a dense undergrowth developed, with much *Polyscias sambucifolia, Senecio minimus, Senecio biserratus, Urtica incisa* and the usual *Rhagodia candolleana* and *Tetragonia implexicoma* tangles (Fig. 11f, g). Also present were some young plants of *Leptospermum laevigatum, Monotoca elliptica* and *Banksia integrifolia* and more of *Myoporum insulare*, but there were no signs of any other woody species coming in.

Hunter Beach swales: The area between the ridges is a heterogeneous habitat. Pools, later swales, are the main elements (Fig. 12). They are flanked by footslopes of variable width, which form the transition from ridge to swale. During inundation of the pools, the tides not only leave behind flotsam on the margins, but also scattered in shallower sections of the pool. Drain outlets shift over time and may break through incipient ridges. As in areas where no ridges were formed on the outer pool margin, such breakthroughs lead to sand accumulation across the pool and contribute to the variability of footslope relief and ridge height.

As long as pools are regularly inundated by spring tides they remain bare except for flotsam patches in which some sand has accumulated and *Atriplex cinerea* seedlings have sprung up and grown into low, straggling bushes. Some *Sarcocornia quinqueflora*, *Isolepis cernua* and **Thinopyrum junceiforme* establish too, the latter spreading over the swale as inundation becomes less frequent. The misery sprouts coming up from the rhizomes are scattered and ineffective in sand catching. *Limonium australe* and *Suaeda australis* sometimes occur on the pool margins.

Growing conditions ameliorate when a pool is cut off from the immediate influence of saltwater flooding and thus becomes a swale in which groundwater begins to freshen. *Isolepis cernua* becomes widespread and common, together with *Samolus repens* and, to a lesser extent, *Selliera radicans* and *Lobelia alata*. For a few years the saltmarsh species remain present, but then gradually disappear. Most of the time the groundwater level lies below the surface, but rises above it during spring tides or periods of heavy rain. Variations in the floristic composition of the vegetation reflect, at least partly, differences in the frequency and duration of inundation.

The main species occurring on the footslopes have already been mentioned. A few tussocks of *Stipa stipoides* together with *Juncus kraussii* characterise the lower areas and the latter becomes common along some swale margins as does *Isolepis nodosa*. *Centella cordifolia* and *Hydrocotyle tripartita* occur in the *Isolepis cernua-Samolus repens* sward of older swales where sprawling *Acacia sophorae* branches encroach on and grow out into a swale. I have only found an occasional *Melaleuca ericifolia* sapling in these older swales and am not sure that this represented the early phase of a succession to denser *Melaleuca ericifolia* scrub.

The vegetation of the spit area (Figs. 13, 14 and 15)

In the flotsam lines on the spit **Cakile maritima* was the first species to appear in any numbers, but was soon joined by *Atriplex cinerea* and **Thinopyrum junceiforme* and, in much smaller numbers, by *Austrofestuca littoralis, Spinifex sericeus, *Ammophila arenaria* and **Euphorbia paralias* (Fig. 13a). This last species became more common during the 1990s but appeared to prefer fill-in scree slopes of eroded ridge sections, rather than incipient ridges. As at Hunter Beach, *Atriplex cinerea* was the major ridge builder. **Thinopyrum junceiforme* usually formed only an open ground cover but was denser on the long ridge formed in the late 1980s as the outer ridge of the fan. Ridges remained lower than at Hunter Beach; usually highest at the inlet side, but even there rarely more than 2 m high. Sections near the backwater shore were often less than 1 m high. Obviously, ridge height is determined by sand supply which would be greatest along the inlet shore where the incipient ridges are most exposed to easterly and south-easterly winds.

In comparison with Hunter Beach, woody plants established somewhat later, probably due to the slower increase in height of the ridges. *Acacia sophorae* was the main coloniser, but *Leptospermum laevigatum* also established in good numbers. *Myoporum insulare* shrubs were often conspicuous and flowered along protected footslopes, but surprisingly, *Olearia glutinosa* was uncommon, while *Banksia integrifolia* saplings were rare. Shrub growth was somewhat slower than at Hunter Beach and *Acacia-Leptospermum* scrub on the older ridges was at best 4 or 5 m high at the less exposed backwater sections, lower at the inlet side. The scrub on Hunter Beach ridges of a similar age (14 to 18 years) was about 2 m higher. *Rhagodia candolleana* and *Clematis microphylla* established soon after the canopy closed up, but *Tetragonia implexicoma* was uncommon.

On the higher ridge sections *Acacia sophorae*, once it gained in height, soon replaced *Atriplex cinerea* and shortly thereafter formed a closed canopy, leaving little room for mostly shade-intolerant herbaceous plants. But on lower areas near the backwater, *Acacia sophorae* shrubs were often fewer, and a wide variety of herbaceous species established

Fig. 13. Processes on the sand spit north of The Bulge. **(a)** The wide flotsam deposit on the upper beach, colonised by **Cakile maritima*, some *Atriplex cinerea* and occasional **Thinopyrum junceiforme*. Note the more recent deposit further out on the beach and the curve in the strandlines. **(b)** Young *Atriplex cinerea* shrubs, about 1 m high, on one of the early ridges formed on the spit. Two years earlier this was a strandline comparable to the one shown in **(a)**. The shrubs grow on low mounds, remnants of the sand accumulations in **Cakile maritima*. Among them are some spreading *Tetragonia implexicoma* as well as *Acacia sophorae* and *Leptospermum laevigatum* seedlings. The dark shrubs are *Myoporum insulare*. **(c)** Taken in 2000, this view shows the latest addition to the spit, which is now approaching Entrance Point. Among the *Atriplex cinerea* bushes **Thinopyrum junceiforme* covers most of the low rises. **(d)** A new ridge developing seaward of the older one, both dominated by **Thinopyrum junceiforme*, which has become increasingly common since the spit began to form in the late 1970s. By 2000 *Atriplex cinerea* played a secondary role on the incipient ridges. **(e)** and **(f)** are views along the backwater side of the spit, seen from the ridge of **(b)**, to show the flooding of the swales at high tide. The tele-photo view on **(e)** also shows the top sections of the ridges that successively developed as the spit lengthened.

Fig. 14. A series of views from the seaward end of the *Atriplex* ridge of Fig. 13b to show the development of the next ridge to the north which in 1984 was only a strandline. In 1990 *Acacia sophorae* had taken over from *Atriplex cinerea*, the scrub was 4 m high and I had to find a foothold on a branch to be able to take the photographs. On the younger ridge *Acacia sophorae* also had gained dominance, but was still lower. In the mean time the *Sarcocornia quinqueflora* patches had begun to close up in the swale. In November 2000 the scene had totally changed as erosion had taken its toll. The seaward section of the older ridge was gone and only the 4 m tall *Leptospermum laevigatum* shrubs with some lower *Myoporum insulare* and *Olearia glutinosa* were still hanging on, while all *Acacia sophorae* shrubs, which were taller than those of *Leptospermum laevigatum*, were dead and collapsing. *Rhagodia candolleana* and *Tetragonia implexicoma* still formed the tangled understorey. The seaward side of the second ridge had also disappeared through erosion (see Fig. 7c) while a thick layer of sand mixed with flotsam covered the saltmarsh area between the ridges. In the remaining vegetation on the younger ridge wind and salt spray had already markedly affected *Acacia sophorae*, while *Leptospermum laevigatum* appeared less sensitive to the adverse conditions. (The use of a different camera in combination with the havoc caused by erosion, may make the 2000 view difficult to reconcile with the older views, but Entrance Point visible in this picture on the horizon at the left lies at the end of the Singapore Peninsula which forms the backdrop in the other pictures.)

in the spindly **Thinopyrum junceiforme* vegetation. Many of these were the same as on the footslopes of the *Atriplex* ridges at Hunter Beach, but several, mostly ruderal species, enriched the variety while others were absent, most notably *Isolepis cernua*. **Senecio elegans, Senecio pinnatifolius, Isolepis nodosa,* **Conyza albida* and **Euphorbia paralias* were widespread and common, with patches of *Crassula sieberiana* on one of the younger ridges. *Actites megalocarpa, Acaena novaehollandiae,* **Cerastium glomeratum, Sonchus hydrophilus* and *Stackhousia spathulata* were species which I had not seen at Hunter Beach. Some moss patches were also present, probably of *Tortula antarctica*, known to be tolerant of salt spray (Moore & Scott 1979).

The depressions between the ridges, especially the lower areas along the backwater, were liable to flooding by higher tides (Fig. 13f). During the early stages of spit growth the wide outlet provided unencumbered access to the tides and large amounts of flotsam, mainly seagrass from Corner Inlet, accumulated at the southern end. This proved to be fertile ground for saltmarsh establishment. Shallow, meandering channels drained the marsh when the tide was out. When the outlet became constricted, the copious supply of flotsam ceased and the vegetation on the lower areas of the depressions developed on a more sandy substrate. However, in both cases *Sarcocornia quinqueflora* became the dominant species but was particularly lush on the old seagrass deposits (Fig. 15b). *Suaeda australis* and *Sclerostegia arbuscula* performed a secondary role. On low rises and along the margins other salt-tolerant species enriched the assortment, namely **Parapholis incurva, Sporobolus virginicus, Stipa stipoides, Juncus kraussii, Limonium australe, Disphyma crassifolium, Frankenia pauciflora* and *Samolus repens*.

Fig. 15. Saltmarshes of the spit area. **(a)** The saltmarsh area with low ridges north of the last dune ridge of The Bulge as seen from the old frontal dune in June 1985. At that time this ridge was still dominated by *Atriplex cinerea*, while *Stipa stipoides* was, and remained, common on the saltmarsh ridges. Other species present there were *Limonium australe, Apium prostratum, Isolepis nodosa, Senecio pinnatifolius* and *Selliera radicans*, with some *Atriplex cinerea* and young *Acacia sophorae* and *Myoporum insulare*. **(b)** The saltmarsh along the tidal channel at the southern end of the backwater in May 1994. The vegetation is dominated by *Sarcocornia quinqueflora* and *Suaeda australis* while *Limonium australe* and *Disphyma crassifolium* are less common. The tall shrub is a 1.4 m bush of *Sclerostegia arbuscula*. **(c)** Saltmarsh swale between ridges near the northern end of the spit, photographed on 13 November 2000. *Sarcocornia quinqueflora* dominated the vegetation and there was only some *Suaeda australis* and *Limonium australe* present; *Stipa stipoides* tussocks and some **Euphorbia paralias* occurred on slightly higher spots.

By 1990 the northward creeping erosion, which had removed a large area of The Bulge, had reached the base of the spit. This led to undermining and removal of older ridges and large quantities of sand began to spill onto the saltmarsh flats (Fig. 14). When in 2000 I sampled the spit for the last time, much of the older ridges had gone and what was left of the saltmarsh area had disappeared under a thick layer of sand. This implied that waves overwashed the beach at very high tides and deposited sand in the depressions. But further north, at the end of the spit, the beach was still accreting and a new ridge was building up in *Atriplex cinerea* bushes, wide and moundy on the north-eastern side, narrower and obviously younger where the shore curved to the backwater outlet. In the older part mounds were 2 m high, still higher away from the shore, topped by about 2 m tall *Atriplex cinerea* and covered by sparse **Thinopyrum junceiforme* interspersed with some **Euphorbia paralias*.

Discussion

Geomorphological aspects

Foredune formation along Australian beaches has been a subject much discussed by geomorphologists since early papers were published in the 1950s. These have been reviewed by Hesp (1984, 1989), who pointed out that seed-bearing flotsam left on the upper beach is necessary to start incipient foredunes, and that the pioneer vegetation fulfils a crucial role in this process. If the young dunes are not washed out by high tides, they develop into dune ridges or dune terraces. The latter, as the word implies, abut existing dunes, while ridges are separated from older dunes by a depression, often called a swale. As sandy coastlines are generally receding or at best stationary, the possibility to observe the formation of dune ridges has become limited, and information about the process is commonly deduced from analysing existing ridge sequences. Since air photos became available, repeated ridge formation could be assessed more accurately. Hesp (1984) gives a good example for the prograding cuspate foreland at Cervantes, Western Australia, where, over a period of 35 years, from four to ten ridges were formed, each one initiated by the growth of **Cakile maritima* germinating at the limit of spring high tide swash. Bird (1985) gave a similar example for the Sandy Point area at the western entrance to Westernport Bay, Victoria. Air photos served me well in my work on dune ridge formation along Waratah Bay and on the sand spit of Shallow Inlet (Heyligers 2006).

The ridges on the spit north of The Bulge are classic examples of the process of dune ridge formation. Flotsam on the upper beach of the growing spit formed the foundation, and the interaction between sand-laden wind and pioneer vegetation was instrumental in building the ridges. However, the process at Hunter Beach was different. Because of the very shallow gradient of the prograding beach and a relatively moderate wind regime a clearly defined berm was formed on the middle beach. This left a depression between berm and foredune which was flooded by wave uprush during higher tides. What flotsam had accumulated on the beach, and in contrast to the spit there usually was not a great deal of it, washed into the pool and stranded somewhere in the pool or against the foredune. However, floating *Atriplex cinerea* fruits shed from plants on the foredune or present in the flotsam remained afloat after the tide had gone out and, depending on wind direction, stranded on either of the shores or between scattered flotsam in the pool. After germination and plant establishment, incipient dunes were formed on the pool margins. While incipient dune formation against the existing foredune is comparable with what happens on upper beaches, the dune formed along the inner berm margin is a feature that, as far as I am aware, has never been mentioned in the literature.

The air photos of the Entrance Point Scientific Reference Area show an arrangement of long, apparently continuous well-bushed ridges. However, following ridges on the ground reveals a different picture. The canopy of the tall scrub hides irregularities in the topography dating back to the time that these ridges were formed and still received wind-blown sand. Also, although they have herbaceous vegetation in their centre, short transverse swales remain hidden under the canopy unless they are quite wide. Hence, what looks like one continuous ridge often is a series of more or less aligned longer and shorter ridges. Once I understood how new ridges formed, I could read the history preserved in their hidden topography.

The Reference Area appears to be unique in that *Atriplex cinerea* was the major ridge initiator. To what degree ridge and swale formation on an open coast is comparable to what happened in the relatively sheltered environment of the Reference Area is a question that will remain unanswered until beach progradation again becomes a common feature along Australia's coast.

Botanical aspects

Pioneer species: *Atriplex cinerea* is widespread but rarely common along sandy coasts of southern Australia. Its fruits are buoyant in seawater and may float for up to five weeks (Heyligers 2001). Some have even reached New Zealand, where there are scattered occurrences near Cook Strait (de Lange *et al*. 1988). Hence one would expect this species to be common along our coasts, but in my experience it appears to avoid very open coasts and for that reason is often found on somewhat sheltered beaches such as those of the Gulfs in South Australia. It is also common along the shores of Corner Inlet, and its occurrence on the adjacent relatively sheltered beaches of the Singapore Peninsula is not surprising. That *Atriplex cinerea* was the major pioneer species for dune formation and crucial in the creation of the dune and swale landscape of the Entrance Point Scientific Reference Area, was rather unexpected.

Other pioneer species were rare on the incipient ridges, but were seen more often in the copious flotsam on the Bulge spit. *Spinifex sericeus*, the most important dune pioneer species along the coast of southeast and eastern Australia, occurred only as a few, widely separated individuals. It dominates the foredune on nearby Clonmel Island which, however, is more exposed than the Singapore Peninsula beaches (Turner *et al*. 1962). If a population was present on the Peninsula beaches at some earlier stage it would have disappeared during a prolonged period of erosion which eliminated all younger dunes, as for instance happened in the 1940s and '50s. Recolonization will be hampered by the fact that *Spinifex sericeus* is dioecious. Also, the plants that were present were browsed by wombats *Vombatus ursinus*, hog deer **Axis porcinus*, and rabbits **Oryctolagus cuniculus*, although the latter are now rare in the area. *Austrofestuca littoralis* is also rather uncommon. Like *Spinifex sericeus* it was best represented on the Bulge spit. The other pioneer species are exotics, namely **Cakile maritima*, **Ammophila arenaria*, **Thinopyrum junceiforme* and **Euphorbia paralias*. **Cakile maritima*, native to Europe and first found in Australia near Perth in the 1890s, is now common along most beaches in southern Australia. However, in the study area it has only been present in good numbers during the early period of sand spit building. It was readily browsed by wombats and emus *Dromaius novaehollandiae*.

**Ammophila arenaria*, a prime dune-building species from the Atlantic coast of Europe, is only sporadically present and has played no significant role in ridge or mound building. This is unexpected as it has been widely used for dune rehabilitation in south-eastern Australia, and spontaneously established populations are now common. Maybe wombats have something to do with it, as the few tussocks present were often heavily grazed and mounds were used for digging burrows. In contrast, **Thinopyrum junceiforme* has had a greater influence. Native to north-western Europe and the Mediterranean, it is a pioneer species that, unlike *Spinifex sericeus* and **Ammophila arenaria*, is tolerant of brackish groundwater and can cope with occasional wave overwash. First found in Australia along the shores of Port Phillip Bay in the 1930s, it has become an important sand-binder along the shores of Waratah Bay and played a significant role in primary dune formation on the sand spit at Shallow Inlet (Heyligers 2006). In the early 1980s **Thinopyrum junceiforme* was already widespread in the study area but only as spindly sprouts scattered throughout most of the vegetation of the younger ridges and swales where its extensive rhizome root system played a role in stabilising the surface. Only on the last ridges formed on the Bulge spit has it contributed substantially to sand catching.

**Euphorbia paralias*, a compatriot of **Ammophila arenaria*, appeared at Norman Bay on the east coast of Wilsons Promontory in the early 1970s which became a staging post in its eastward expansion from Western and South Australia, where it was first observed near several ports about 40 years earlier (Heyligers 1989). In 1986 I spotted some plants at the southern end of Hunter Beach and north of The Bulge, and it is now common throughout the younger dunes. Capable of growing through accumulating sand (Heyligers 1985, 2002), it fulfils its role as pioneer on scree deposits along eroding sections of the foredunes. It has also become common along swale margins and on ridge footslopes, especially at Hunter Beach.

A comparison with Clonmel Island: Clonmel Island is a barrier island adjacent to and in line with the foreshore of Snake Island (Fig. 1). In the 1950s Turner *et al*. (1962) recorded the vegetation sequence on the dune ridges of this long narrow island. They described the first stage of this sequence as follows:

'The dominant plant of the Clonmel embryonic dunes, and the chief sand binder, is *Festuca littoralis*, which takes the place here of *Agropyron junceum* and *Ammophila arenaria* of the English dunes. *Atriplex cinerea* (a shrub up to 4 ft high) and the annual *Senecio lautus* [*S. pinnatifolius*] occur occasionally, but play no important part in sand binding. *Cakile maritima* [apparently regarded as native] and the introduced *Sonchus asper* [*Actites megalocarpa*?] are the only other species recorded for this zone, *Cakile*, as in Europe, being really a plant of the drift-line along the foreshore' [comments in square brackets are mine].

The next ridge inland, the foredune, was dominated by *Spinifex sericeus*. Species of the embryonic dunes were still present and were joined by several others including *Apium prostratum* and *Carpobrotus rossii*, with mosses and lichens becoming established in the older sections. Two large shrubs, *Ozothamnus turbinatus* and *Olearia axillaris*, were invading from the dune scrub on the adjacent older ridges where they and *Acacia sophorae* were dominant. The vegetation on the foredune and the stable ridges is similar to that on the dunes at Waratah Bay (Heyligers 2006), but the description of the pioneer vegetation shows how much has changed during the last half of the 20th century. The European grasses are now widespread and occurred in my study area, and although there is no recent information on Clonmel Island, I have also seen them on the young dunes at Snake Island. Another point of interest is that *Atriplex cinerea* occurred only occasionally on the embryonic dune and foredune, but was common in the drift line along the inland side of Clonmel Island, in other words this species came into its own on the somewhat sheltered shore, comparable to the situation in my study area.

Succession: Over two decades I have witnessed the succession from *Atriplex cinerea* vegetation via *Acacia sophorae* scrub to *Leptospermum laevigatum* thicket. I also found that on older ridges *Leptospermum laevigatum* is liable to wind-throw, which leaves gaps in the canopy. Other gaps occurred where *Leptospermum laevigatum* establishment in the *Acacia sophorae* scrub had been poor. I have searched intact stands and gaps for species which could indicate progress to the next stage in the succession, but to no avail. On the older ridges, probably dating from the 1930s and 1940s, the near monoculture of *Leptospermum laevigatum* prevailed. Apart from *Banksia integrifolia* I only saw a few low shrubs of *Monotoca elliptica* and only once a young, or maybe suppressed, *Leucopogon parviflorus* plant. I had hoped to find signs of a succession towards the vegetation on the adjacent older ridges, where Tuddenham (1970) assessed the vegetation as similar to the 'Scrub Woodland' of Sunday Island where, in the early 1960s, a few scattered *Eucalyptus viminalis* were present in up to 6 m high vegetation of *Leptospermum laevigatum* and *Leucopogon parviflorus* with emergent *Banksia integrifolia* up to 12 m high (Turner *et al.* 1962). However, in view of the extreme rarity of *Leucopogon parviflorus* on the young ridges, I wonder how accurate this comparison is as Tuddenham, not being a botanist, has not mentioned this species in descriptions of vegetation on the other ridges.

In trying to explain the apparent halt to succession in the *Leptospermum laevigatum* thicket stage I checked the literature on dune ridge vegetation at Norman Bay, on the western side of Wilsons Promontory (see Fig. 1; Parsons 1966, Ashton & van Gameren 2002), and at Sandy Point near Westernport Bay, about 140 km west-north-west of Norman Bay (Robin & Parsons 1976, Hazard & Parsons 1977). Like the ridges of my study area, where the calcium carbonate content of the siliceous sand rarely exceeds 3%, those at Sandy Point are also quartzose (Bird 1985), but the dunes at Norman Bay are calcareous, albeit that in the top layers the calcium carbonate fraction has been leached out and reduced to 6–10%. These differences in calcium carbonate content do not appear to have a great influence on species composition, because Ashton & van Gameren (2002) found that the major species at Norman Bay were the same as on the siliceous ridges at nearby Leonard Bay.

The foredune at Norman Bay is backed by six parallel dunes about 3 m high and 65 m apart, covered by *Leptospermum laevigatum* thicket up to 7.5 m high with *Leucopogon parviflorus* present 'as a tall shrub or undershrub' (Parsons 1966). Less frequent were *Banksia integrifolia*, up to 10 m tall, *Myoporum insulare, Bursaria spinosa, Ozothamnus turbinatus, Olearia axillaris* and *Olearia glutinosa* with *Rhagodia candolleana* and *Clematis microphylla* scattered in the understorey. No eucalypts were present and in view of being subject to lime chlorosis, Parsons regarded establishment of eucalypts on calcareous sands unlikely, at least in Victoria. He also points out that *Leptospermum laevigatum* is one of the most salt-tolerant species in the area, irrespective of soil type.

Hazard & Parsons (1967) investigated the influence of fire on *Leptospermum laevigatum* thicket and *Banksia integrifolia* woodland at Sandy Point. They found that after fire or disturbance *Leptospermum laevigatum* re-establishes by shedding copious amounts of seed. This led to its dominance in burnt areas if the seed source was less than about 65 m away, while further out establishment diminished. They also found that significant seedling establishment of *Leptospermum laevigatum* and *Banksia integrifolia* only occurred immediately after fire. Both species do shed seed in the absence of fire, but without it *Leptospermum laevigatum* germination is very rare and only where litter is sparse. *Banksia integrifolia* seed germinates more frequently, but seedlings do not establish. In contrast, *Leucopogon parviflorus* was not dependent on fire and could also establish under a dense *Leptospermum laevigatum* canopy. Hazard and Parsons found that *Leucopogon parviflorus* is the most shade tolerant of the three and is able to survive for long periods in a suppressed state. They concluded that *Leptospermum laevigatum* could be regarded as a seral 'fire-weed' and *Leucopogon parviflorus* as the 'climax dominant' in the areas seaward from *Banksia integrifolia* woodland.

So, where does this leave us with regard to the *Leptospermum laevigatum* thicket at Hunter Beach? I found *Leptospermum laevigatum* and *Banksia integrifolia* seedlings on the inner footslopes of *Atriplex cinerea* ridges and from what I have seen, this is the main establishment event, although some germination may also occur later in young, open *Acacia sophorae* scrub. There have been no fires and *Leptospermum laevigatum* showed a clear age-gradient on the recently formed ridges, with a noticeable difference in stature between these ridges and those dating from before the resumption of progradation. However, there was no difference in vegetation composition between the younger and the older stages and one must assume that for the foreseeable future this remains the end stage of the succession. From Tuddenham's description of the vegetation on older ridges further inland, one may surmise that it could take centuries to reach the *Banksia integrifolia – Eucalyptus viminalis* stage, and then only, in the absence of fire that would set back the succession to a pure *Leptospermum laevigatum* stage.

Monotoca elliptica reaches its western limit at Wilsons Promontory (Albrecht 1996), but *Leucopogon parviflorus* is widespread in Victoria and beyond and I presume the reason for its rarity in my study area is a lack of dispersers. The only resident, partly frugivorous species is the Common Blackbird **Turdus merula* which occurs in low numbers and seems to prefer the ecotone habitat between the ridges and the heathy slopes of Hunter Point. Except for scattered *Myoporum insulare* and rare occurrences of *Monotoca elliptica,* there are no other berry-carrying plants around to attract frugivorous birds. Hence, it possibly is the scarcity of dispersal agents which limit the species diversity in the *Leptospermum laevigatum* thickets.

There remains the question why I found *Olearia axillaris* only once and *Ozothamnus turbinatus* not at all. These species are wind-dispersed and were important in the dune vegetation of nearby Clonmel Island. I suspect the conditions along the coast between Entrance Point and Lighthouse Point are not sufficiently extreme to provide the right environment. Both species, especially *Ozothamnus turbinatus*, thrived on the windswept sand spit at Shallow Inlet (Heyligers 2006). So it may well be that the circumstances favouring the establishment of *Atriplex cinerea* proved unsuitable for *Ozothamnus turbinatus* and *Olearia axillaris*.

Epilogue

One may well ask: why has there been so little scientific research in the Entrance Point Scientific Reference Area if it has so much to offer? It is undoubtedly due to its inaccessibility. Earlier in the 1980s Lighthouse Point could be reached by a sturdy 4WD, because an exceedingly challenging track was still used to replenish the gas supply for the light. From there it was still a good hour of bush bashing and rock jumping to get to Hunter Beach. I used a CSIRO Land Cruiser parked at the light as base and actually camped in the car. However, later in that decade the light was switched over to solar power and is now serviced by helicopter. The track fell into disrepair and became impassable and from 1990 onwards the Parks Victoria people dropped me off on the open beach and picked me up after an agreed period, usually 10 or 12 days, if the weather allowed. If not, then the next day, or the day after! Almost ran out of food once. To get ashore, I stripped, went overboard and ferried my gear to the beach through the surf. Same procedure in reverse on pick-up. Moreover, the boat that was used for my visit in 2000 was inadequate for the job and notwithstanding wrapping my cameras in plastic bags, overwash flooded the bottom of the boat, my rucksack was drenched and the wrapping turned out to be not sufficiently waterproof. Fortunately, damage to exposed film was only minor (Basset Hull (1908), returning from his first trip to Montagu Island, lost all his glass plates when the boat capsized on the notorious Narooma bar!). This as background to the logistic aspects of the research I have reported in this paper. And a reason why I thought it appropriate to start with a diary extract on some of the extreme events experienced during my time in the field.

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