12-1992

Coastal rehabilitation manual

Veronica P M Oma

D M. Clayton

J. B. Broun

C D M. Keating

Bulletin 4248

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Coastal Rehabilitation Manual

V.P.M. Oma
D.M. Clayton
J.B. Broun
C.D.M. Keating

Bulletin 4248
Agdex 340/13
Sand dunes/regeneration
ISSN 0729-0012
December 1992

Coastal Rehabilitation Manual

V.P.M. Oma

D.M. Clayton

J.B. Broun

C.D.M. Keating

This manual has been sponsored by the Coastal Management Coordinating Committee

Editor:

Brian Hillman
23 May Street
GOSNELLS WA 6110

Design and graphics:

Femmeke Roberts
Information and Media Services
Department of Agriculture
Baron-Hay Court
South Perth W A 6151

Acknowledgements

The authors are grateful for the comments and constructive criticism contributed by many people during the preparation of this manual. These include:

Bob Brindley and Ian Hutton	Department of Marine and Harbours
Dr Lindsay Collins	Curtin University
Dr Ian Eliot	University of Western Australia
Ian Lovegrove	formerly of Parry Esplanade Developments
John Grasby	formerly of the Department of Agriculture
Bill Gerard	Australian Sandstill
Fred Zarb	Grass Growers
Greg Hill	Kimberley Seeds
Dr Peter Woods	P.J. Woods and Associates
Graeme Russell	formerly of Department of Sport and Recreation
Dr Neville Marchant and Ray Cranfield	Western Australian Herbarium
Len Hoare	formerly of Fremantle Port Authority
John Riches	Department of Agriculture
Charlie Nicholson	Environmental Protection Authority
Ron Sewell	Dandaragan Shire Council
Norm Wallace	Gingin Shire Council
Jim Elliot	Nedlands City Council
Russell Candy	formerly of Cockburn City Council
Mike Jervis	formerly of Rockingham City Council

The authors are particularly grateful to the Department of Agriculture's Photographic Unit; the wonderfully patient and expert word processing staff of the Department of Agriculture; and Jim Tyler of Dampier Salt Operations and David Bauer of Arid Landscapes Western Australia for their help with the northern coastal species.

The Coastal Management Coordinating Committee

The Coastal Management Coordinating Committee was established in 1988 following a comprehensive review of coastal planning and management in Western Australia. Executive support for the Committee is provided by the Department of Planning and Urban Development, which has functional responsibility for coastal management planning in Western Australia.

The committee comprises representatives from:

Department of Planning and Urban Development
Department of Marine and Harbours
Department of Agriculture
Environmental Protection Authority
Department of Conservation and Land Management
Department of Local Government
Western Australian Tourism Commission
Western Australian Municipal Association
Department of Minerals and Energy
Department of Land Administration

The committee aims to:

- Advise the Government, through the Department of Planning and Urban Development, on coastal planning issues.
- Act as a steering committee for the preparation of coastal plans and studies.
- Coordinate departmental activities on the coast through exchange of information and views.
- Promote the role of local government in coastal management.

Contents

Community planting organised by the Yallingup Land Conservation District Committee

Preface

Western Australia has the longest coastline of all the Australian States. Much of the 12,000 km of the Western Australian coastline consists of sandy landforms which are susceptible to natural erosion by wind and wave. Human activity has caused or accelerated erosion in many areas.

The Department of Agriculture has had a long involvement in coastal management in Western Australia, beginning in the 1950s, and has developed many successful techniques for dune stabilisation and rehabilitation. However, in 1988 the department ended its 'hands on' dune rehabilitation work, favouring instead a role to facilitate the participation of the local community in coastal management. This manual summarises the Department of Agriculture's experience and is presented to enable local communities, land developers and local authorities to protect their coastal areas.

The manual offers practical information on revegetation and rehabilitation techniques, some of which has not been published previously. By following the steps presented, individuals, local authorities and organisations will be able to develop and implement a coastal rehabilitation strategy.

The manual is in three parts. Section 1 provides an overview of the coastal environment to ensure that the natural environment and coastal processes are considered properly. Sections 2 to 6 describe how to develop a successful coastal rehabilitation strategy and detail rehabilitation techniques applicable to Western Australia. Section 7 lists sources of further advice and information.

Section 1. The coastal environment

Contents

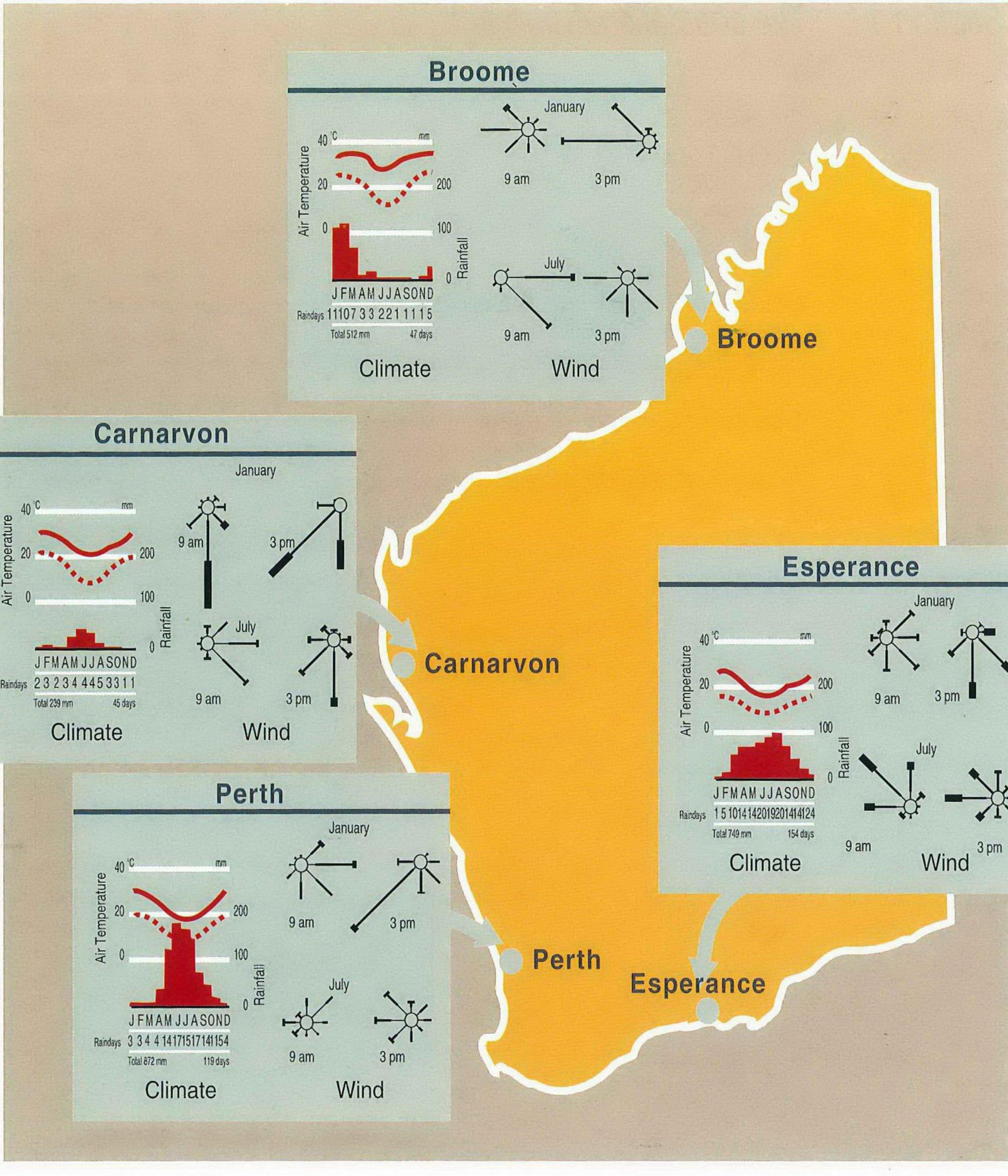


Figure 1. Climate of the Western Australian coastal environment

The coastal environment is naturally dynamic and susceptible to short and long term changes in vegetation, shoreline position and landforms induced by climatic and coastal processes. It is important to understand these natural processes to ensure that relevant aspects are considered in the development of the rehabilitation strategy.

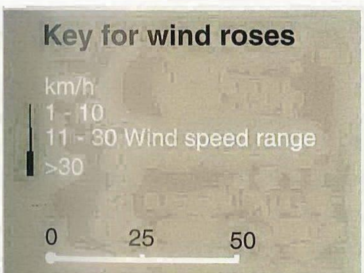
Climate of the Western Australian coast

The climate of the coastal environment influences plant growth and dune stability and has a major bearing on plans for dune rehabilitation and replanting. The important factors are rainfall, temperature, winds, waves and tides.

Rainfall and temperature

The climate along the coast ranges from cool to cold, moist conditions in the extreme south-west; through arid, warm conditions on the central coast; to a sub-humid, hot climate in the extreme north of the State. The north experiences high rainfall from summer monsoons and a dry, hot winter. The central coast receives a low annual rainfall which may fall in winter (remnants of frontal activity from the south) and/or summer (remnants of cyclonic activity from the north). The south-west and south coastal areas receive moderate to high rainfall, predominantly in winter, and a summer drought. Figure 1 illustrates the range of climatic conditions around the coast of Western Australia.

The rainy or growing season is much longer in the south-west and south coastal areas than in the central and northern areas. In the central and northern areas, rain falls in short, intense events which causes flooding, soil loss by water erosion (including erosion of dune sands), and loss of vegetation. In the south-west and southern areas, rainfall is generally not erosive.



Percentage frequency of wind in the direction towards the centre of the wind rose.

From about Kalbarri southwards, high summer temperatures combined with the low moisture status of coastal sands, severely stress the vegetation. It is necessary for coastal plants to be established early in the growing season to ensure they receive the benefit of the full growing season before the onset of the dry season.

Winds

Winds vary in strength and direction around the coast. They also vary between seasons (Figure 1).

In the central to south coastal areas, the stronger and more persistent winds occur in summer. The winds are generally moderate offshore, land breezes in the afternoon. Winds during winter tend to be less strong and more variable in direction. Along northern coasts, winds are slight to moderate onshore in summer and offshore in winter.

Winds play several important roles in influencing the stability of the coastal environment. Strong, onshore winds during storms tend to 'pile up' waves on the coast. A storm surge is created and high energy, erosive storm or wind waves can attack the beach and foredunes. At other times, onshore winds transport sand off the beach and deposit it on vegetated foredunes. If the foredunes are sparsely vegetated or have bare areas, onshore winds will erode them and transport the sand further inland. Eventually the frontal landforms are destroyed and a management problem may result.

The wind regime influences the wave pattern reaching the coast and the type of dunes which form. The strength of onshore winds and their salt spray content affect the distribution of coastal plant species on the dunes, as different plants are adapted to different wind intensities and atmospheric salt content. There are very few species able to tolerate the strong onshore winds, with their high salt and sand loads, which typically occur at the back of the beach.

Waves

Waves are generated by wind blowing over water. Waves may have sufficient power to transport sand in the nearshore zone and to erode dunes and therefore can affect the stability of the coastline.

The coastline experiences two types of waves: swell waves and wind waves.

Swell waves

Successive wave 'trains' or 'fronts' which reach the coast every 11 to 16 seconds, are called swell waves. These long period waves, which are generated in the 'roaring forties', arrive at the coast from the south-west. They are recognised by the regular form of the parallel wave trains and their 'rolling' crests and troughs.

Swells can move loose sediment on the sea floor down to about 20 m below the wave surface. The bottom 'drag' experienced by swell wave trains as they travel from the open ocean, across the Continental Shelf and to the coastline, aligns them with the sea bed contours. This typically causes the swell wave trains to become bent or refracted close to the coast. The swell waves also bend around protrusions along the coastline, such as islands and headlands. The interaction between incoming swells and the nearshore coastal features often produces a complex wave interference pattern which causes significant regional and local differences in wave energy and coastal dynamics.

Wind waves

Wind waves are short period waves which are generated close to the coast by local winds and therefore may arrive from the south-west, south-east, west or north-west. Wind waves tend to be irregular and create 'choppy' seas, depending on the speed and direction of the generating winds. Wind waves generated by onshore winds or the sea breeze tend to reinforce the swells, increasing their height and erosive power; while easterly land breezes tend to dampen the incoming swells, reducing their erosive power.

Tides

Tides are movements in a water body caused by the gravitational effects of the sun and moon acting on the rotating earth.

The tidal range in the open ocean and along the south-west coast, is about one metre, but increases markedly in the north of the State. Tides along the Kimberley coast, for example, can range up to ten metres. The tidal range is also greater in shallow and narrow coastal inlets. Wide tidal flats are developed adjacent to the coastline where large tides are experienced. As the tides ebb and flow, significant currents can develop.

Storm surges are more pronounced in narrow, north facing inlets and along the north coast because the storms, usually generated by north-westerly winds, are able to 'pile up' waves more effectively where the tidal flats are shallow and wide and where the orientation of the coastline traps the waves.

Formation and fluctuations of the coastline

How the coastline has formed

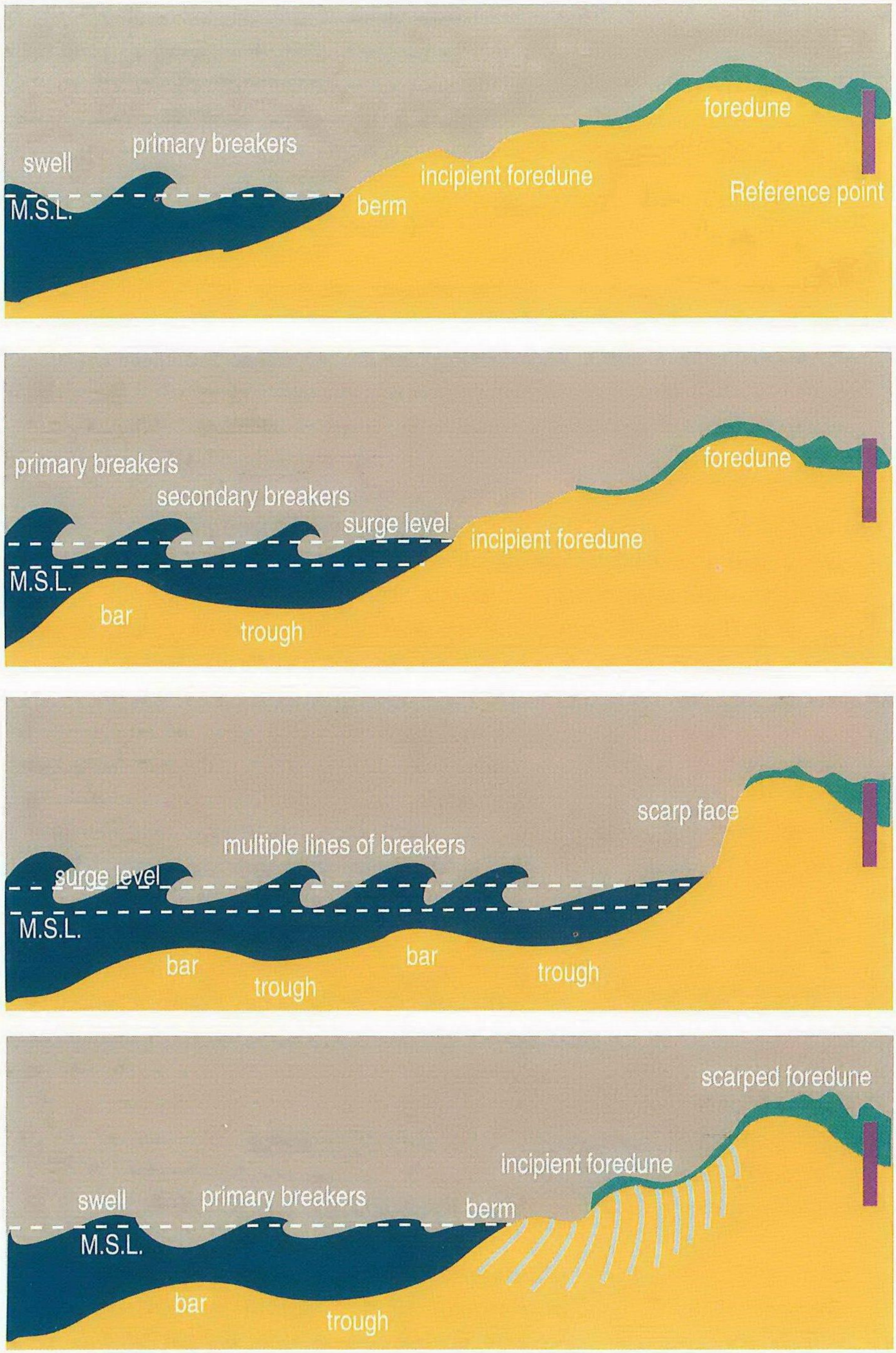
Sea level has fluctuated significantly over geological time in response to global changes in climate (such as the Ice Ages) and vertical movements of the earth's crust. For instance, during the last 300,000 years, sea level reached extremes of 10 m above and 100 m below present sea level. Periods of low sea level corre-

Low energy swell wave regime. Sand is moved onshore and a wide beach berm forms.

Storm event. The beach is eroded and sand is transported seaward to form a sandbar parallel to the shoreline.

Severe storm event. Erosion of the beach continues. More sand is transported seaward and a series of sandbars is formed. The foredune is scarped by wave erosion.

Return to low energy swell wave regime. Sand is moved onshore to re-create the incipient foredune and the beach berm. The shoreline accretes as sand is swept onshore.



* M.S.L. = Mean sea level

Figure 2. The beach sand cycle (after Woods, 1980)

sponded with glacial phases (when the polar ice caps were much larger than at present). Periods of high sea level corresponded with interglacial, warmer periods (when the polar ice caps were much smaller). The last Ice Age ended 20,000 years ago, after which the sea level rose about 100 m, reaching its present position about 6000 years ago. Since then, sea level has remained fairly steady.

As the sea level rose after the last Ice Age, drowning the land which is now the Continental Shelf, large volumes of loose sediment were moved onshore by waves and ocean currents. This produced a major phase of dune building and coastal land formation from about 7000 to 3000 years ago. However since then, the supply of sediment to the coast has reduced considerably, generally slowing down dune building and coastal accretion. In many areas, there is evidence of dune erosion and shoreline retreat.

In historical times (as distinct from geological time), the major process operating on our coastline has been sediment re-working, that is, the erosion of sandy coastal landforms in some areas is contributing to deposition elsewhere along the coast. However, much sand has been deposited into nearshore basins, which, if deeper than 20 m, can act as 'sinks', in which the sediment is lost from the beach system.

Sediment is also contributed to the coastline by erosion of the offshore reef system and production by marine plants and animals.

Fluctuations in the position of the coastline

The position of sandy coastlines is not fixed, but varies seasonally (due to fluctuations caused by the beach sand cycle) and over the years (due to long term accretion or erosion of the shoreline).

The direction of shoreline change depends on a number of factors, including the sediment supply, the configuration of the coastline, the wave climate and the prevailing winds.

The beach sand cycle

The beach sand cycle refers to the natural changes in the coastline and the beach caused by seasonal climatic effects. Sandy beaches around Western Australia generally build seaward during summer in response to low-energy swell waves. The swell waves push sand onto the shore as they break, forming the typically wide, summer beach profile. Onshore winds transport sand off the

A stable coastline is one where there is a balance between sand movement onshore and offshore.

Erosion occurs when sand is lost to the coastline by deposition into deep, nearshore basins . . .

. . . or it is transported inland by winds.

Accretion occurs when sand is transported to the shoreline The sand is stabilised into relict foredunes . . .

. . . or inundates the coastline, often forming sandsheets or blowouts.

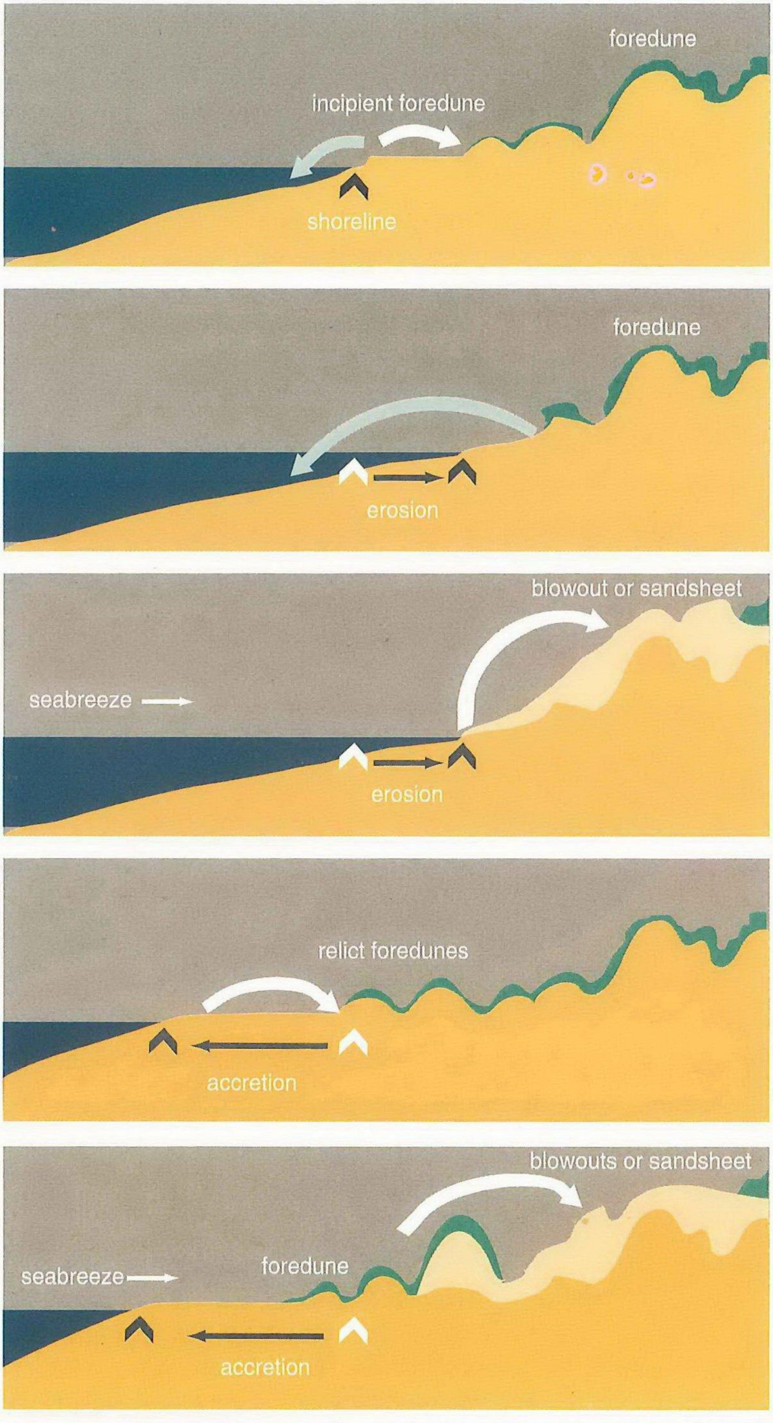


Figure 3. Sediment supply, coastal erosion and accretion (after Woods, 1980)

beach into the foredunes where it is trapped by the dune vegetation. This process is interrupted when high-energy swell and wind waves generated by winter storms and summer cyclones erode the beach and sometimes the foredunes, causing the coastline to retreat (Figure 2). Winter beaches are often narrow and steep, and may have cusps (scallop-shaped depressions) along the beach face. Sand is usually deposited by the waves in a longshore bar (or bars) during a storm and is returned to the beach by swells during calmer periods.

If the beach sand cycle is balanced, that is, all the sand which is removed during storms is returned to the beach and foredunes from year to year, the coastline is said to be stable. A stable coastline may still erode in winter but will recover in summer. The beach sand cycle is unbalanced when there is a nett loss or gain of sediment in the nearshore system (Figure 3). A nett gain of sediment over time causes the coastline to build out (accrete) whereas a nett loss causes the coastline to recede (retreat or erode).

A nett loss of sediment from the nearshore system occurs when the sand supply to the beach and foredunes is reduced. Sand may be deposited by storm waves into deep nearshore basins (deeper than 20 m) instead of in a longshore bar; or sand may be eroded from the foredunes by winds and transported inland.

If the risk of severe erosion during storms is to be minimised, it is essential to maintain as much sand as possible close to the beach. It is vital to protect the foredunes and their covering vegetation, as coastal plants trap and bind sand into dunes, preventing sand from being blown inland by onshore winds.

Identifying eroding and accreting coastlines

It is usually necessary to determine if the coastline is stable, accreting or receding, before the appropriate rehabilitation plan can be developed. The stability of the coastline can be determined from:

- historical records such as newspapers and local government records;
- coastline surveys by the Department of Marine and Harbours;
- examination of maps and aerial photographs; and
- knowing the characteristic features of accreting and receding coastlines (described under 'Sandy landforms of the coast').

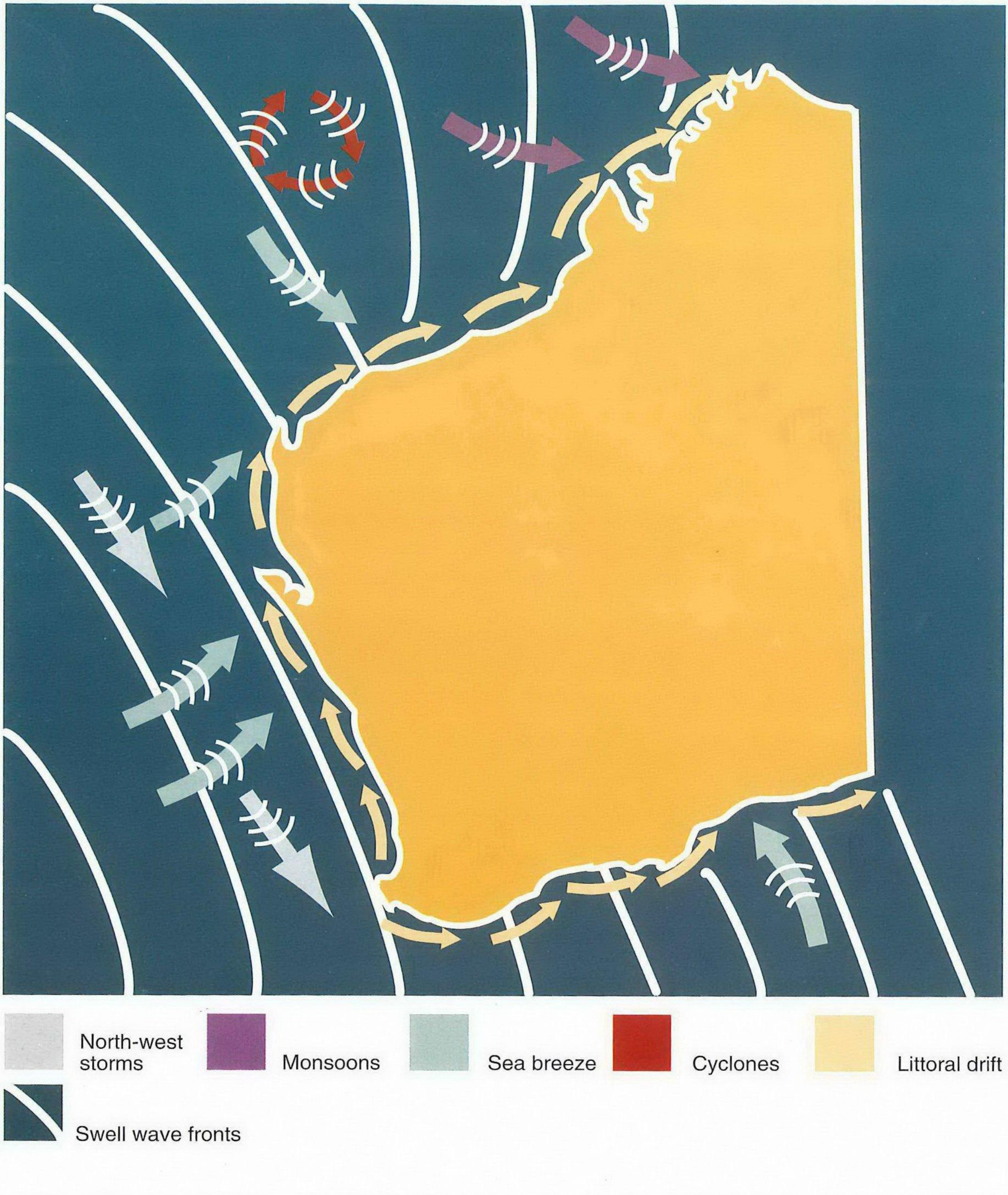


Figure 4. Waves and winds in Western Australia. The local wind wave patterns have been superimposed on the swell wave pattern. The nett direction of littoral drift is also shown (Woods, 1980)

Littoral drift

Sand is transported within the nearshore zone by swell and wind waves. Where these wave fronts are parallel to the coast, sand is recycled purely in the onshore-offshore movement of the beach sand cycle. However, where the wave fronts strike at an angle to the shore – which is the usual case in Western Australia – currents are created which may have enough energy to transport loose sand along the coast in the nearshore zone. This movement of sand is termed longshore or littoral drift. Along the west coast, the dominant south-westerly swell creates a nett littoral drift to the north. North-westerly swell and wind waves generated during storms may temporarily reverse the drift southwards. Along the south coast, the nett littoral drift is to the east, but may temporarily reverse westwards under easterly to south-easterly swell and wind waves generated during storms (Figure 4).

Figure 5 shows how natural and engineered coastal features indicate the presence and nett direction of littoral drift. Obstacles in the nearshore zone which interrupt littoral drift, build up sediment on the updrift side (the southern side of obstacles along the west coast and the western side of obstacles along the south coast) and lose sediment, or erode, on the downdrift side. The downdrift side continues to lose sand to the littoral currents because the obstacle prevents the sand being replenished from the updrift side.

Sandy landforms of the coast

Coastal dunes occur in many forms, sizes and patterns. The common ones include foredunes, relict foredunes, parabolic dunes, blowouts and sand-sheets.

Foredunes and relict foredunes

Foredunes are linear sand ridges which form at the back of the beach and are generally parallel to the coastline. Foredunes are sometimes called frontal or primary dunes, and are vegetated with primary dune colonising plants. Foredunes are generally steep-sided ridges which may be higher than 10 m, although they are generally much lower, averaging 1 to 3 m high (Figure 6).

A foredune is initiated when sand blown off the beach by onshore winds is trapped by plants, debris and other obstacles at the back of the beach. This is called an incipient foredune (Figure 7). The sand supply to the beach determines how this incipient foredune develops. When the sand supply is abundant, the coastline builds rapidly and the incipient foredune does not have sufficient

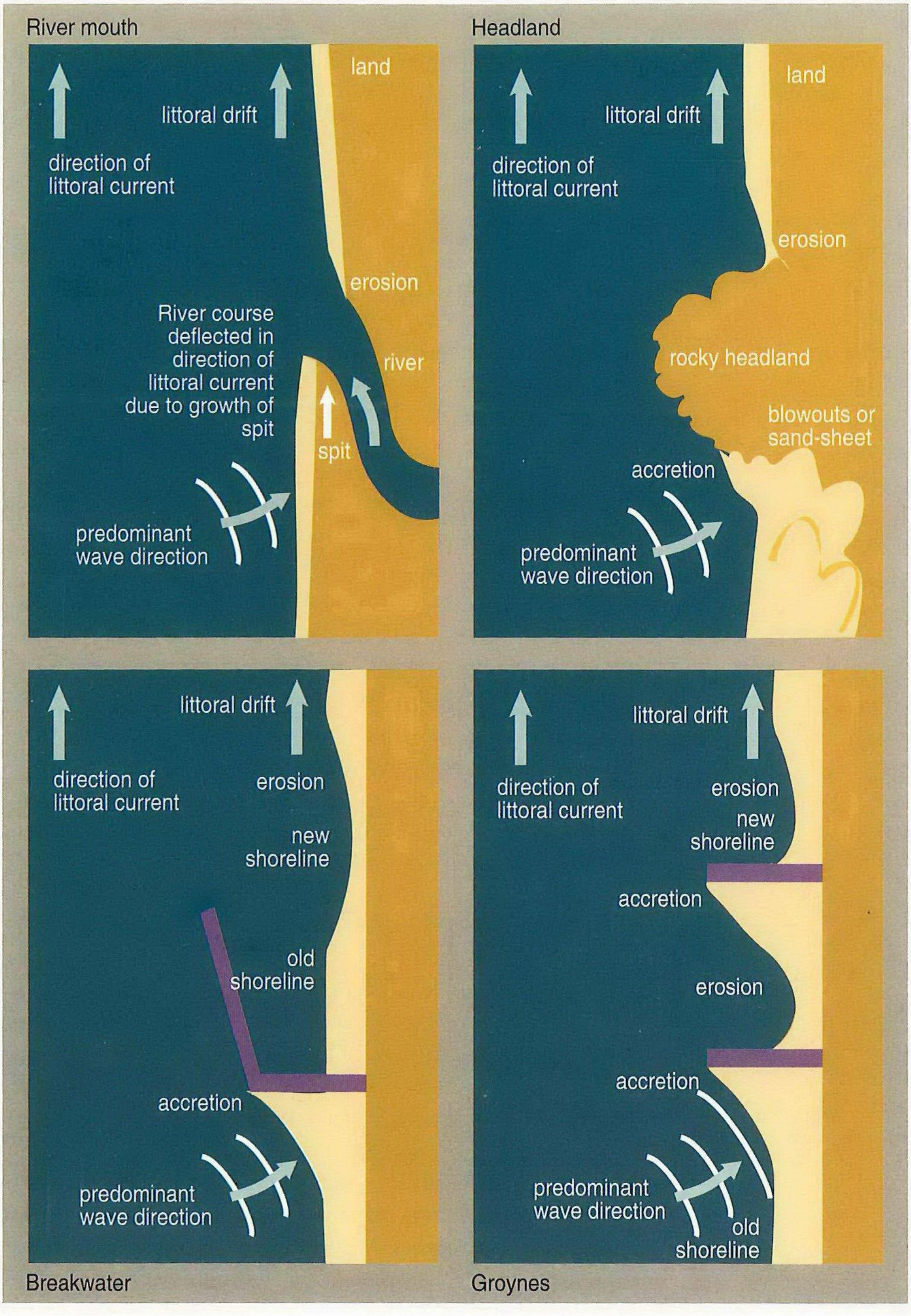


Figure 5. Recognising littoral drift

Figure 6. A large symmetric foredune, vegetated with Atriplex isatidea *Geraldton (photo: J. Broun)*

Figure 7. An incipient foredune forming in front of the scarped and slumped foredune (photo: P. Hesp)

time to trap much sand and develop into a foredune, as vegetation rapidly colonises the area at the back of the beach. This building out of the shoreline, combined with seaward migration of the zone colonised by primary dune plants, leads to a new incipient foredune forming in front of the now abandoned, or relict foredune. Sand supply to the relict foredune is effectively cut off, allowing it to be colonised by secondary, and eventually, tertiary dune species. Relict foredunes (sometimes called beach ridges) do not develop into large dune ridges, and are often only 1 to 2 m high between crest and trough.

Figure 8. The relict foredune plain at Port Kennedy, Rockingham (photo: S. Chape)

Figure 9. A blowout engulfing stable, vegetated dunes (photo: S. Chape)

Wide sequences of relict foredunes (relict foredune plains) formed in Western Australia when much sand was swept onshore after the last Ice Age. For example, the relict foredune plain formed over the last 6000 years at Rockingham and Port Kennedy is about 12 km wide (Figure 8). Substantial relict foredune plains also occur at Busselton, Cervantes and Jurien Bay.

Where the sand supply is limited and the shoreline is stable, a large symmetric foredune, rather than several smaller foredunes, often develops at the back of the beach. This occurs because the foredune may be eroded in winter and the sand which is swept onshore in summer accumulates as a wedge against the wave-scarped foredune and on the foredune's crest. The foredune tends to grow slowly in height and width, but the wedge-shaped incipient foredune does not develop into a separate foredune to seawards.

Blowouts and parabolic dunes

Blowouts are bare, sandy hollows, usually parallel to the dominant wind direction. They are formed by erosive, onshore winds funnelling through a weak point or slight depression in the vegetated foredunes or other dunes where the vegetation has been removed or disturbed. A blowout (Figure 9) consists of:

- an erosional throat – through which the wind flow is compressed and accelerated, removing sand;
- high, steep, eroding lateral walls; and
- a parabolic depositional lobe – where the wind flow expands and decelerates, dropping its sand.

Blowouts may develop and advance downwind quite rapidly – rates of 1 to 10 m per year have been recorded in Western Australia.

Extensive blowout fields are common on eroding coastlines where the foredune (if it exists) and the frontal dunes are continually eroded by wave action. A bare, wave-scarped frontal slope forms, which, if high enough and exposed to onshore winds, may erode and form extensive blowouts.

Blowouts are also common on coasts which are susceptible to periodic, catastrophic storm wave action. The blowouts typically originate either at the back of the beach (indicating an eroding coast) or along a common line inland of a foredune (indicating a return of some sand to the beach following recent, significant wave erosion).

Blowout fields may also develop on accreting coastlines where the sand is supplied to the coast at a faster rate than it can be trapped by dune vegetation and held at the back of the beach.

Figure 10. Parabolic dunes south of Dongara (photo: S. Chape)

Figure 11. Deflation plain with a perched winter water table and extensive blowouts to landwards. Note the cusped beach, Lake Preston (photo: S. Chape)

It is not common to find a blowout occurring singly along the coast, as the natural processes of destabilisation occur over broad sections of the coast. However, single blowouts may form where destabilisation (generally human induced) has occurred, such as along a road cutting.

Parabolic dunes are blowouts which have advanced downwind from the coast before becoming stabilised by vegetation (Figure 10). Parabolic dunes are characterised by a deflation plain or basin – which was originally the erosional

Figure 12. The Southgates Sand-sheet, south of Geraldton (photo: S. Chape)

throat – enclosed by a U-shaped ridge which is generally steep and high. A variety of parabolic dunes are found along the south-western coast of Western Australia, but these all have the characteristic 'U' shape.

Deflation plains or basins are the eroded surface from which much loose material has been removed by wind. Deflation plains or basins may have a very shallow, coarse sandy to stony surface soil, often overlying calcrete or limestone, or the winter water table (Figure 11). They are usually located upwind of parabolic dunes, and have contributed their sand to sand-sheets. Because of the relative stability of their surface to winds, and their proximity to the water table, deflation plains or basins are often rapidly re-colonised by coastal or wetland vegetation.

Sand-sheets

Sand-sheets are large piles of bare sand which blow across the landscape (Figure 12). They generally form where a long length of the foredune is eroded by waves, initiating multiple blowouts which coalesce as they migrate downwind (Figure 13). Sand-sheets are often found along headlands, near the mouths of rivers and at the inlets to coastal lagoons or estuaries because these locations are naturally unstable and susceptible to repeated erosion. Sand-sheets will continue to move across the land, engulfing existing, stable landforms until they become less susceptible to wind erosion and are able to be stabilised by vegetation. This occurs generally through the combined effect of dune migration downwind (that is, away from the influence of the most eroding winds) and by reduction of the height of the sand mass (and therefore the exposure to

1. Incipient foredune forms along the debris line left by storm waves.

2. The incipient foredune grows by trapping sand to form a foredune.

3. A small breach develops within the foredune.

4. Blowout initiated.

5. Re-establishment of incipient foredune.

6. Parabolic dune free from foredune.

7. Blowout depositional lobes coalesce into a sand-sheet.

8. Sand-sheet free from foredune.

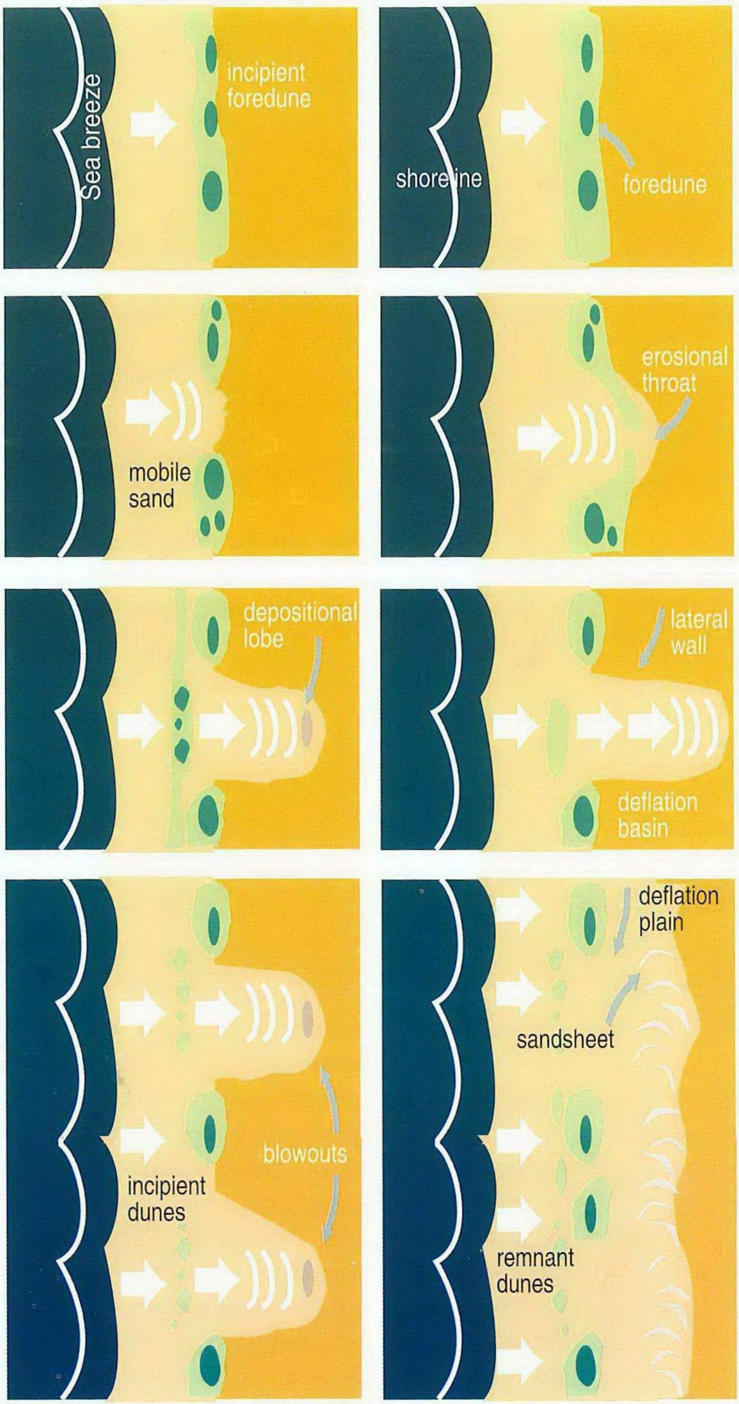


Figure 13. How blowouts and sandsheets are formed (after Evans et al. *1984)*

Figure 14. The wide beach and extensive dune systems characteristic of an accreting coast (photo: P. Hesp)

erosive winds), as sand volume is lost either by deposition into the sea or through colonisation and stabilisation of sand into the deflation plains or dune ridges left behind as the sand mass migrates downwind.

Beaches of eroding and accreting coasts

Accreting coasts typically have:

- wide and flat beaches;
- very fine, 'squeaky' sand;
- a wide and shallow nearshore zone with one or more longshore bars and troughs; and often
- several rows of breakers (Figure 14).

Wave energy is dissipated within accreting coasts as waves break over the longshore bars and sand is moved onshore. The landforms behind the beach often consist of well developed incipient foredunes and several stable, well vegetated foredunes or a relict foredune plain. Vegetation zonation is generally marked. Where the rate of colonisation cannot keep pace with the rate of sand accretion, large sand drifts (sand-sheets and blowouts) are common.

Figure 15. The narrow beach and wave scarped dunes characteristic of eroding coasts (photo: J. Broun)

Eroding coasts are characterised by:

- narrow, steeply sloping beaches which fall away sharply into deep water in the nearshore zone;
- relatively coarse sand; and
- waves which break at, and rush up, the steep beach face.

Wave energy is reflected offshore from eroding coasts, which tends to transport sand offshore. The landforms behind the beach may vary considerably, depending on the nature of the landforms at the coast before the current situation developed. While eroding coasts usually do not have active foredunes, an incipient foredune may develop between major erosional events. As wave action is frequent, foredunes which do occur are generally narrow, steep, wave-scarped and asymmetric in shape (Figure 15).

Coastal vegetation

Coastal plants play an important role in the formation and continued stability of coastal sand dunes. While dunes remain fully vegetated (especially their windward slope and crest) they will not become degraded or eroded by wind or water. However if the vegetation cover is damaged in parts or entirely removed by natural processes or human activity, significant erosion, especially by wind, can develop rapidly.

Role and adaptation

The coast is a particularly harsh environment for plant growth. Plants need to contend with:

- a short growing season;
- long periods of drought;
- periods of extreme heat and water stress;
- wind scouring;
- burial by sand;
- strong onshore winds;
- salt spray;
- sand blasting;
- wave erosion; and
- infertile soil.

Coastal plants have special adaptations to enable them to grow successfully in the coastal environment. There is generally a pronounced succession of coastal plant communities from the foredunes to the most landward dune, which reflects the progressive change in the nature and the intensity of climatic and coastal processes away from the beach (Figure 16).

Plants growing at the back of the beach are crucial to maintaining the stability of the coast by trapping and binding sand to form incipient foredunes and foredunes. These plants, often grass-like, are primary foredune colonisers. They are highly adapted to growing at the dynamic interface between the land and the sea.

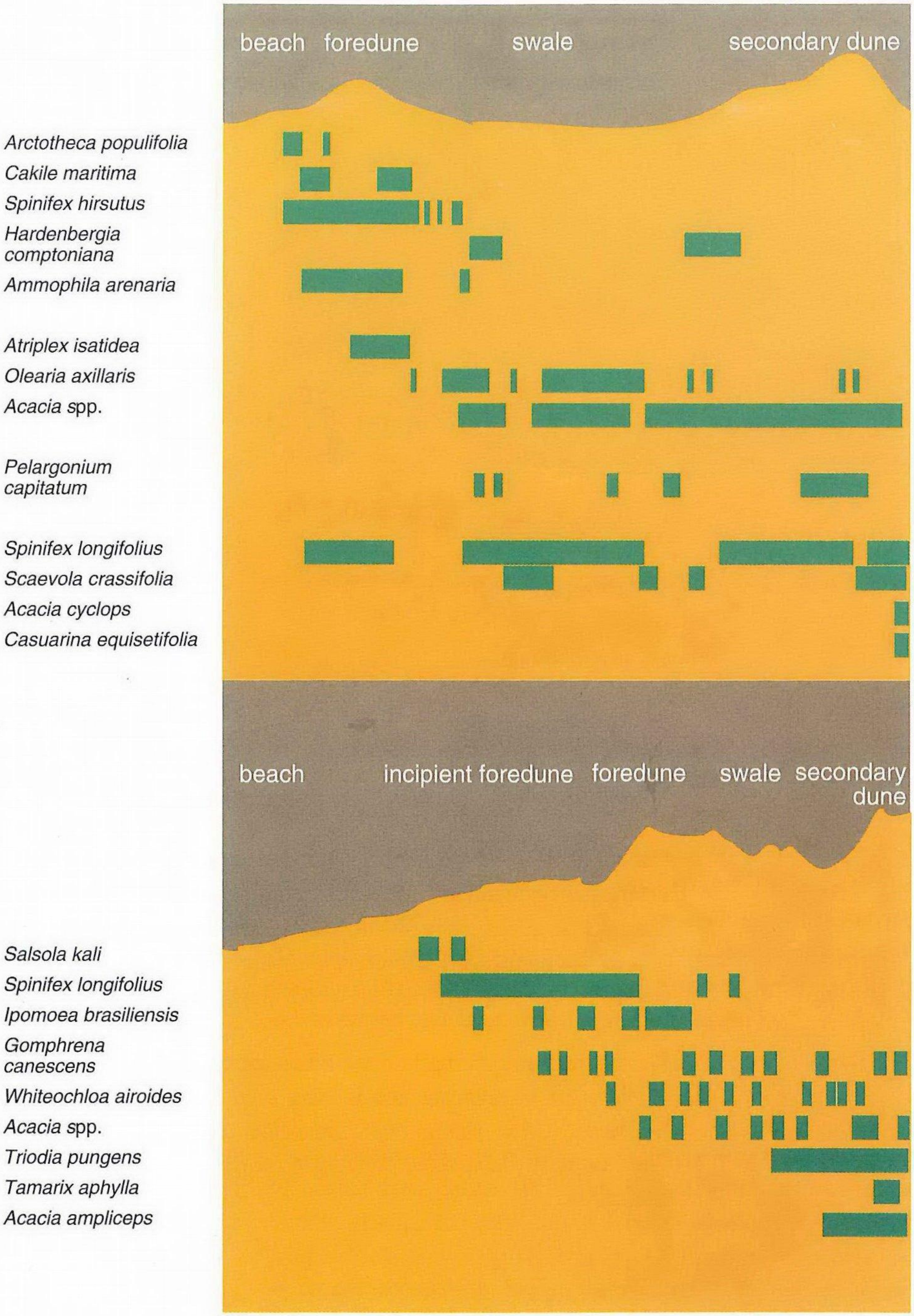


Figure 16. The succession of plant species on dune systems near Perth (top) and Karratha (bottom), Western Australia. The lines show where the species occur on the dunes.

Figure 17. Foredunes are eroded downdrift of the groyne, and the peppermint woodland occurs directly behind the beach (mid to background). Sand accumulation updrift of the groyne is resulting in foredune species becoming established. Siesta Park, Geographe Bay. (photo: S. Chape)

However, because of the harsh nature of this micro-environment, there are only a few species which can be grown successfully. These are described in detail in Section 4. The most important adaptations of these plants include their ability to rapidly produce upright stems and new root growth in response to sand inundation.

Vegetated foredunes absorb much onshore wind and wave energy, thus provide some protection for the landforms behind them, although the degree of protection depends on the height and proximity of the dunes behind the foredunes.

A wider variety of woody perennial or secondary colonising species are able to grow in the less extreme micro-environment behind the foredunes. These are also described in Section 4. The plants generally form dense heath or shrubland communities (1 to 2 m high) having a low, closed canopy which protects the sandy surface from erosive winds.

Areas within the coastal environment furthest away from the beach have a more moderate micro-climate. The heath or shrubland vegetation is generally replaced by woodlands.

If the coast is eroding, then foredunes may not be present and the normal sequence of plants will not be found. In some situations woodlands may occur directly behind the beach (Figure 17). In very sheltered coastal embayments, protected from strong onshore winds and wave action, the vegetation succession sequence may also not be fully developed. Often, a very small, narrow foredune occurs to separate the beach from the woodlands of the hinterland as, for example, at Meelup Reserve, Cape Naturaliste.

Regional variation

As the climate, geology and soils change around the coast, so plant species vary considerably. Coastal vegetation is markedly different in the north and south of the State with the coastal area between Geraldton and Kalbarri being a transitional zone of overlapping species. Sources of detailed information on the ecology and distribution of coastal plants are listed in Section 4.

How coasts are destabilised

'Destabilisation' is the term used to describe the loss of vegetation from coastal dunes and the resulting wind erosion to form sand drifts, blowouts and sand-sheets.

Coastal destabilisation occurs in two stages. In the first stage, the protective vegetative canopy or cover is damaged, enabling winds to attack the sand surface and move sand. With continued wind erosion, surrounding areas of vegetation may be killed or damaged by sand blasting, burial or undermining, and the area which is destabilised increases.

An area that has been destabilised reverts to an earlier stage in the ecological succession. Winds will readily strip any loose organic matter on the sand surface and significant amounts of sand may be moved from the dune surface. This means that primary dune species need to be introduced to restabilise the dune, even though it may have originally been vegetated with secondary or tertiary species.

It is important to understand how destabilisation has occurred, since its cause will suggest an appropriate solution. Destabilisation is caused by both natural processes and human activities.

Natural causes

Natural destabilisation has been important in shaping many of the landforms of our coast. Natural causes include:

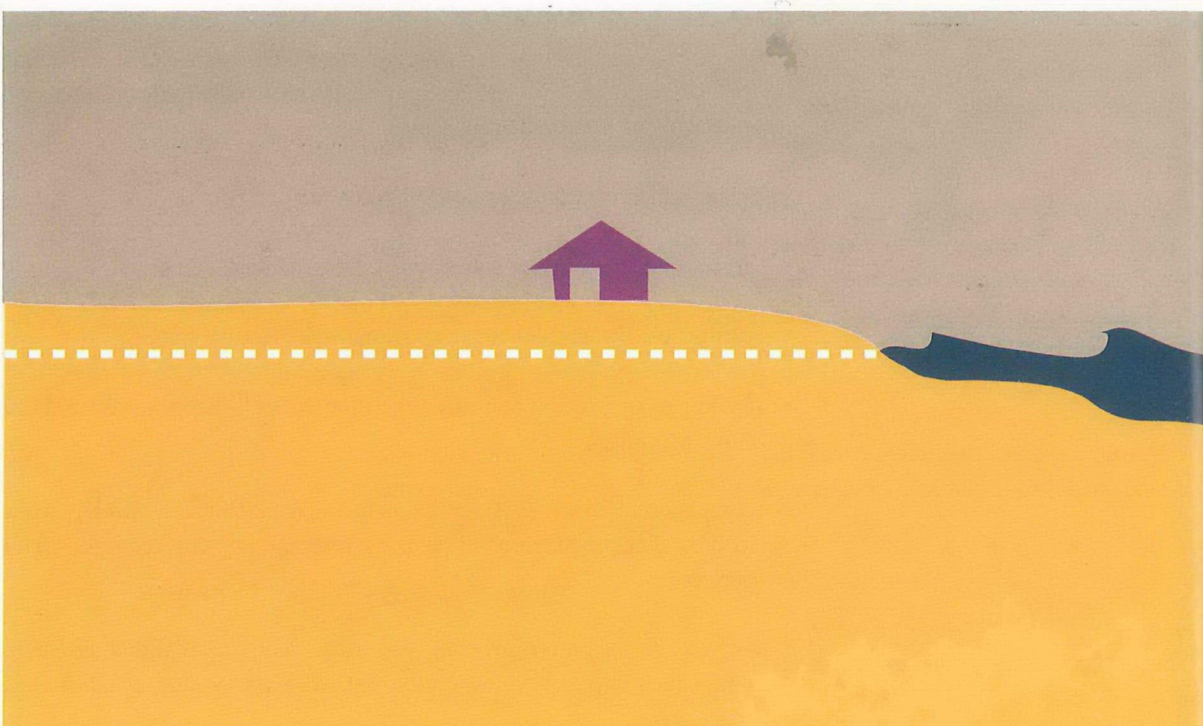
- wave erosion of the foredune or frontal dunes leaving a scarp which is vulnerable to erosion by onshore winds;
- over-wash and breaching of the frontal dunes by storm-surge waves;
- inundation of dune vegetation by sand blown off the beach;
- loss of vigour or death of vegetation due to strong winds and salt spray;
- wind erosion during unusually windy periods;
- loss of vegetation as a result of fire, disease or drought; and
- wind funnelling through low points or troughs in the dunes.

Human causes

The impact of people on the coastal environment has been dramatic. Use of the coastal environment increases stress on the vegetation which often initiates or worsens coastal destabilisation. Virtually all areas of the coast which have been subjected to recreational use, grazing and other land uses have, at some time, become degraded. As land use pressures intensify, coastal destabilisation will increase without improved management.

Activities which contribute to destabilisation are:

- grazing and trampling of dunes by livestock and feral animals;
- destruction of vegetation along pedestrian and vehicular tracks;
- the impact of frequent burns on vegetation density (canopy cover) and species composition;
- destruction of dune vegetation through deliberate human activities such as road building, construction of facilities, firebreaks, mining and urban development;
- the placement of structures such as buildings and groynes within the coastal zone which interrupt the natural coastal processes to cause wind or wave erosion; and
- the spreading of disease, for example, dieback (*Phytophthora cinnamomi*).



Section 2. Developing a coastal rehabilitation strategy

Contents

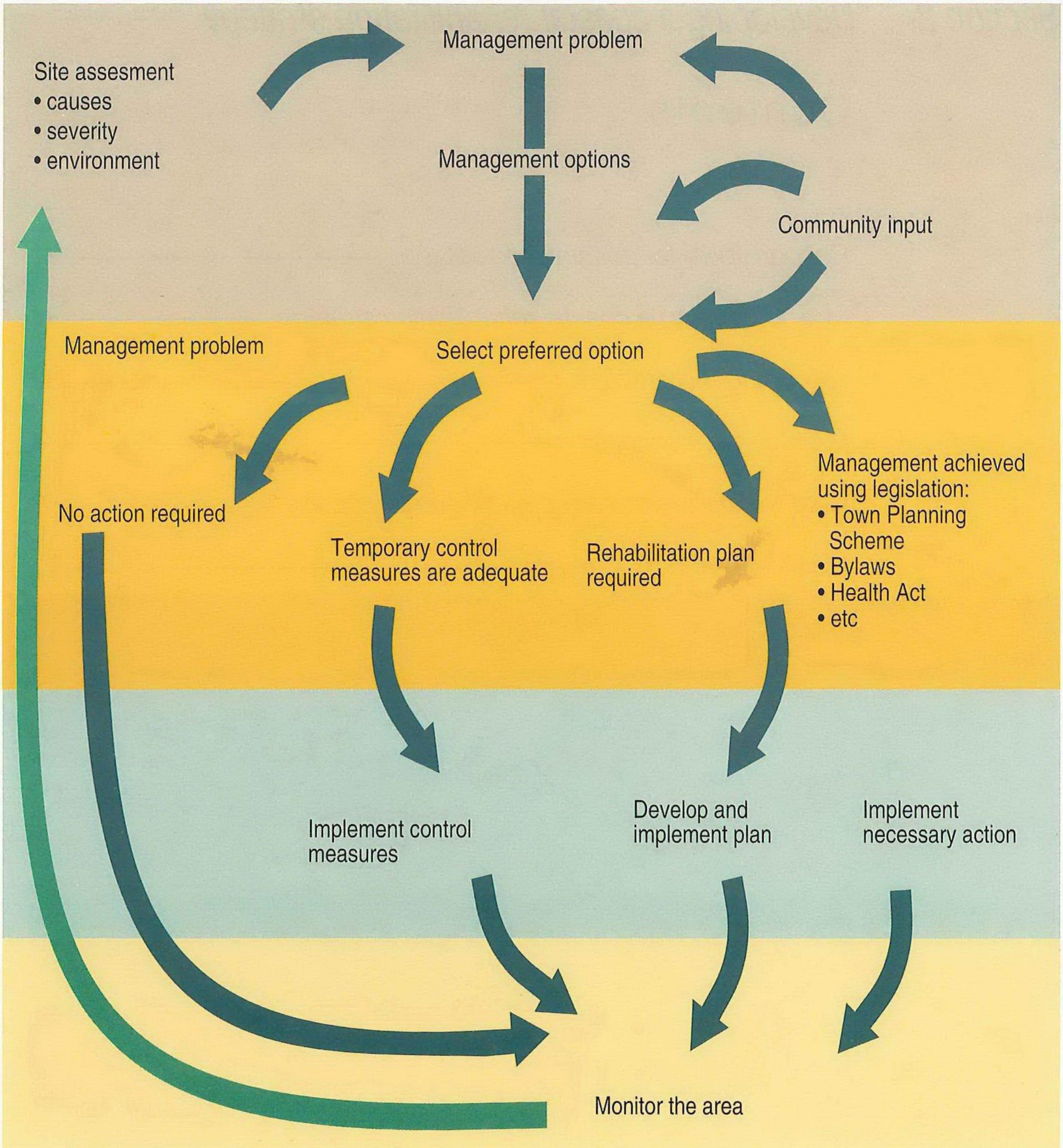


Figure 18. Developing a coastal rehabilitation strategy

Responsibility for coastal rehabilitation

Much of our coast is in public ownership. In the north, the coastline is generally vacant crown land, with much of the coastal landforms being included in pastoral leases, while small isolated areas occur as local authority reserves. In the south, much of the coastline and the coastal landforms are in national parks or local authority reserves, although there are areas that are either owned privately or vested in the federal government.

Thus coastal rehabilitation and management is generally the responsibility of local authorities, the Department of Conservation and Land Management and pastoral lessees. Private companies, landowners and developers in Western Australia may also have responsibility for coastal rehabilitation and management by virtue of conditions attached to approvals for mining and development under the Mining Act 1978, the Environmental Protection Act 1986, and other relevant Acts; and approvals under the Town Planning and Development Act 1928 (for re-zoning, subdivision and development proposals adjacent to the coast).

How to develop a coastal rehabilitation strategy

A coastal rehabilitation strategy should aim to resolve existing or potential problems (and their causes) and be most appropriate for the needs of the local community and the coastal environment.

There are six steps in developing a successful coastal rehabilitation strategy (Figure 18). These are:

1. Identify the problem and the causes of destabilisation;

2. Identify the management options available to address the problem;

3. Determine the preferred management option;

4. Develop the rehabilitation plan, or the appropriate action;

5. Implement the rehabilitation plan or the appropriate action; and

6. Monitor the site to evaluate the effectiveness of the rehabilitation plan or the action undertaken.

Identifying the problem

Identifying the problem and its causes requires an assessment of the natural environment and the current land uses and management practices. The assessment should include a site inspection to determine:

- the features of the environment and the coastal processes operating in the area;
- if the problem needs management;
- the causes of the problem, and
- the severity of the problem.

Environmental features and coastal processes

The landforms and vegetation of the site help to determine the potential for destabilisation to worsen and the specific requirements to be included in the rehabilitation plan. The coastal processes operating in the area (including the nature of the prevailing winds; whether the coast is eroding, stable or accreting; whether there is significant littoral drift, etc.) may be contributing to the problem, and need to be considered.

The site inspection should assess:

- area bared of vegetation;
- stability of the foredune – stable, absent, breached or scarped;
- coast type – accreting, eroding or stable;
- vegetation type – existing primary, secondary and tertiary coastal species;
- health and density of the existing vegetation;
- characteristics of the foredunes and other dunal landforms – their type, height, slope, width, and density of vegetation;
- local climatic conditions – susceptibility to storm waves, exposure to strong winds, seasonal wind and rainfall distribution pattern; and

- coastal processes operating in the area – tidal range and characteristics, swell wave characteristics, presence of nearshore reefs protecting the coastline, and presence of littoral currents.

Does the problem need managing?

The coastal environment is naturally dynamic. Evidence of erosion or the presence of unstable landforms in themselves do not constitute a problem. Generally, a problem is created when the coastal environment is used beyond its capacity to accommodate the use pressures, or the natural environment and processes are seen to be limiting or interfering with existing or potential uses of the area.

An assessment should be made of:

- the values under threat – ecological, aesthetic, economic, recreational or historical values, or threats to infrastructure and existing developments;

- the benefits of rehabilitation – in the short term, the long term, to the community, the local authority, the region; and

- any other considerations (legal requirements, fostering community awareness, etc.).

The causes of the problem

Problems within the coastal environment result from removal or disturbance of vegetation and/or the impacts of coastal processes. The problems are therefore due to natural and/or human activities.

The causes of the problem can be determined by assessing the natural environment and by paying particular attention to any evidence of:

- damage from vehicles;

- damage from pedestrian traffic;

- damage from grazing or trampling of the vegetation;

- damage from fire;

- disease or drought-induced stress in the vegetation;
- wind eddying around structures;
- wind erosion initiated by wave attack and scarping of the foredune;
- sand inundation;
- coastal erosion; and
- inappropriate location of structures (groynes, breakwaters, roads, buildings).

Severity of the problem

Determining whether the problem is severe (causing significant, detrimental impacts to the natural environment, the land use or other values) or minor, will indicate if action is required immediately and whether temporary control measures will be sufficient.

Management options

There are likely to be several management options which could be considered, including taking no action, using temporary control measures, using and enforcing regulatory powers, and implementing a rehabilitation plan.

No action required

No action may be required where a management problem is not yet evident, or if natural coastal processes are destabilising areas where a management problem is not likely to occur.

Temporary control measures

If the problem is not severe or not yet evident it may be appropriate to use temporary control measures. These are useful:

- while a more detailed site assessment is undertaken;
- where the short term climatic or economic situation prevents the desired rehabilitation; and

- while a planned and approved coastal development (such as a marina, tourism or residential development) which incorporates a requirement for coastal management, is constructed.

Regulatory powers

Regulation may be advisable where the management problem is caused by inappropriate or inappropriately located land uses. For example: in Western Australia, Town or District Planning Schemes can provide powers to control grazing activities in specified areas or under specified conditions, or to control the form and scale of development in specified areas; the Soil and Land Conservation Act 1945 can be used to prohibit or control grazing where a land degradation hazard exists; local authority by-laws can be gazetted to discourage vehicular access along beaches; and use of the Control of Vehicles (Off-Road Areas) Act 1978 can restrict use of off-road vehicles in fragile areas and direct such activity to suitable areas.

Regulatory powers can also be used to ensure that proposals for capital-intensive land uses, such as urban and tourism development and hobby farming subdivisions, are not located in fragile areas or other areas susceptible to flooding, wave and wind erosion, storm surges and sand drift.

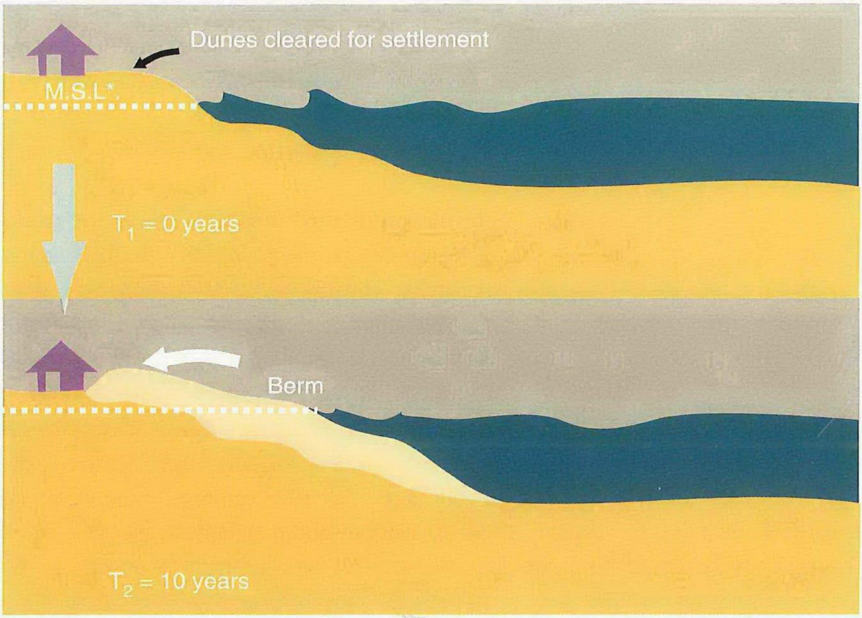
The most appropriate form of control is via the local authority's zoning provisions in the Town Planning Scheme, although the Soil and Land Conservation Act 1945 and the Department of Planning and Urban Development's Country Coastal Subdivision and Development Policy could also be used to achieve adequate development setbacks. Incorporating a Coastal or Landscape Protection Zone, with supporting policy statements, within the Town Planning Scheme or the Local Rural Strategy, is a useful means of highlighting land use and management opportunities and constraints in the coastal environment.

The use of regulatory powers alone may resolve the management problem, although it is probable that a better outcome will be achieved if combined with the development and implementation of a rehabilitation plan.

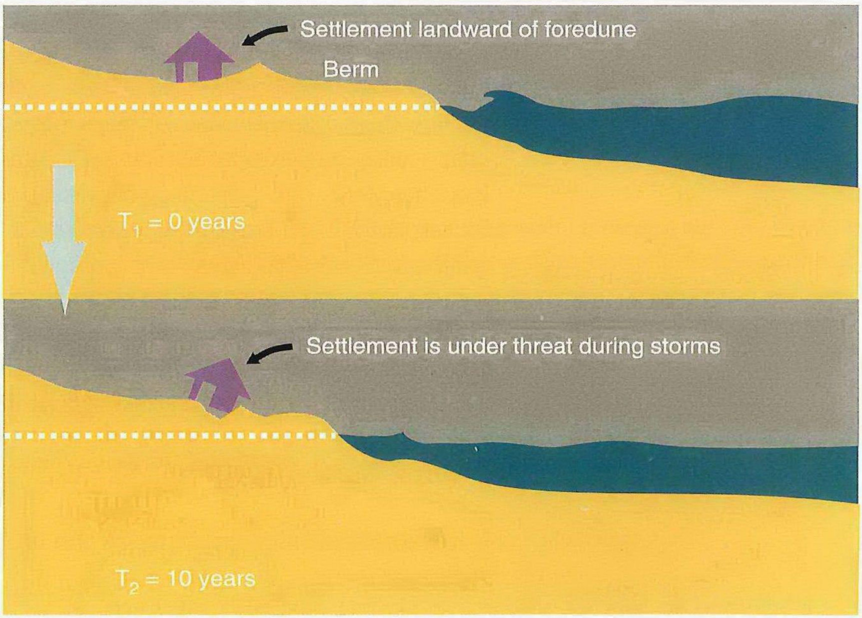
A rehabilitation plan

If full rehabilitation is required, then a plan of action is needed.

A. Nett accretion: beach berm widens, sand drift inland threatens the settlement.



B. Nett erosion: beach berm narrows, settlement threatened by storm surge waves.



M.S.L. = Mean sea level

Figure 19. Shoreline movement and associated management problems (after Evans et al.*, 1984)*

Problems arising directly from human activities on the coast are generally easier and cheaper to manage than those arising from natural processes. It is often possible to manage and rehabilitate the area while maintaining existing land uses (especially recreation), although the natural environment may need to be significantly modified to cope with the pressures of use.

This manual focuses on using vegetation to achieve stability along the coast. However, engineering solutions such as constructing seawalls and groynes, may be appropriate where it is essential to counter natural coastal process – particularly along eroding coastlines – to protect expensive developments.

There are typical problems associated with coastlines which are accreting or eroding (Figure 19). Coastlines which are accreting often have rapid and excessive build-up of sand at the back of the beach, inundating vegetated dunes and facilities such as roads and beachside rockwalled promenades, and causing a nuisance with sand blasting. Accreting coasts are best managed by revegetating the bare areas of accumulating sand and concentrating the rehabilitation efforts in the area immediately behind the beach to prevent sand drift inland.

Shorelines which are eroding in the long term are difficult and costly to manage. Wind erosion needs to be reduced by revegetating bare, wave-scarped areas, but stopping the erosion of the coastline requires engineering measures. The three methods used in Western Australia are beach renourishment, rock walls and groynes.

- Beach renourishment – sand is dumped periodically in the nearshore zone by trucks or dredges. This artificially increases the sand supply to the beach and, depending on how much sand is replaced, maintains the shoreline approximately in its existing position. It allows the sand to come ashore naturally by wave action and temporarily maintains the beach sand cycle. It is the most 'natural' of the engineering solutions and creates the least (or no) detrimental impact, but is expensive and needs to be maintained regularly and indefinitely. It is the best solution for eroding coastlines where it is important to maintain the natural amenity of the beach and the foreshore area.

- Rock walls provide a barrier to wave action and coastal recession in the long term This method is expensive, but apart from minor maintenance, should be a 'one off ' cost. The major problem with rock walls is that the amenity of the beach is often permanently and detrimentally affected, as the width of the beach in front of the rock wall is often significantly reduced and the sand may become less attractive over time, that is, it becomes coarser and contains more stones and drift material. Beach renourishment in front of the rock wall can overcome this problem, but often only with considerably increased expenditure.

- Groynes are often constructed where long term coastal recession is likely to threaten valuable developments (such as residential areas) and are generally preferred to rock walls. Groynes are expensive to construct, but similarly to rock walls, should be a 'one off ' cost. The orientation of the beach changes when groynes are constructed, but the beach and coastal amenity is changed rather than reduced. The major problem with groynes is that they interfere with the littoral drift. The erosion problem is transferred downdrift of the groyne (Figure 17). It is often necessary to construct several groynes as the erosion problem progressively develops downdrift (Figure 5).

Engineering works are generally costly and may have significant, unforeseen impacts on the natural environment. This approach must be fully investigated to ensure that the total costs of engineering solutions and the long term implications for the environment and future management are perfectly clear. This manual will not discuss this approach further. The Department of Marine and Harbours should be consulted for further information.

Determining the preferred management option

Factors which will influence the choice of the preferred option include cost, objectives and community wishes.

Cost

The total cost of managing the problem should be considered for each option. This includes the initial cost of the required action, the cost of on-going management and the cost of correcting unforeseen problems which may occur, such as for beach renourishment associated with rock walls.

Appendix I provides estimates of costs likely in dune rehabilitation.

Objectives

The value of the natural environment and the land use need to be considered. Clear objectives are needed to resolve how much should be spent to fix the problem. The local community should be encouraged to help determine the value of the natural environment and to set appropriate objectives for management.

The objectives of many rehabilitation strategies will probably include:

- providing a permanent solution to the management problem;
- restoring the natural environment; and
- maintaining appropriate access to, and use of, the coastal environment without destabilising the area further.

The views of the local community

It is important to gain the support of the local community to manage the coastal environment effectively. Where the problem is caused by locals, for example, using off-road vehicles in fragile areas or through overgrazing of coastal dunes, it is especially important for them to be involved in all stages of developing the rehabilitation strategy. This will inform everyone about the causes of the problem and the need for remedial action. It will ensure their support and 'ownership' of the preferred management option. Where options involve relocation of existing infrastructure, significant alteration to the natural environment and/or changing or restricting access to the coast, local involvement is vital.

Developing and implementing the rehabilitation plan

The rehabilitation plan is the 'action' or the 'working' plan to implement the preferred management option. The rehabilitation plan should be developed in close consultation with the local community, using the information gained from the site assessment, to achieve the objectives.

Unless the preferred option incorporates an engineering solution to the problem, the rehabilitation plan will generally have up to six components.

The components are briefly discussed here in sequential order, but are discussed in detail in following sections of the manual. The components are:

- rebuilding foredunes which have been breached;
- planting bare dune surfaces;
- brushing or mulching the planted surfaces;
- designing recreational areas and access points to the beach;
- fencing; and
- public information and education.

Rebuilding breached foredunes

Rebuilding foredunes prevents further wind funnelling, sand scour and sand transportation inland. Depending on the size of the breach and whether earthworks are required behind the foredune, rebuilding may be done by earthworking machinery, brush layering or sand-trapping fences. Earthworks are often undertaken in the area behind the foredunes to smooth out steep and severely eroded dune walls, to create pedestrian accessways and carparks, and to create a more favourable grade for planting. Earthworks should be done just before planting, that is, in April-June in southern areas and in December-January in northern areas. See Section 3.

Planting bare dune surfaces

It is best to use a variety of indigenous, locally growing primary and secondary colonising species for foredunes, secondary dunes behind the foredune and mobile dunes. Tertiary species can be planted in protected dune swales or deflation basins and behind the more exposed dunes. Cuttings or seed should be collected locally and planted or scattered when the dune sands are moist, preferably early in the growing season, that is June-July in southern areas, January-February in northern areas. Other coastal species with useful characteristics can be planted in firebreaks and to deter pedestrian access. See Section 4.

Mulching the planted surfaces

Brushing or mulching protects the young plants and bare surfaces from erosive winds and helps to conserve soil moisture. Brushing has the added advantage of acting as a reservoir for wind blown sand and is a deterrent to pedestrians. See Section 5.

Designing recreational areas and access points

The location and capacity of recreational facilities and accessways must be planned so as to control and guide recreational use of the coastal environment into areas which are able to cope, and which can be easily maintained. See Section 6.

Fencing

The whole area should be fenced to keep people and vehicles off the rehabilitating area and to guide access through it. See Section 6.

Public information and education

Signs and information plaques in appropriate locations help inform people of the work which has been undertaken, the reasons why, and to encourage them to protect the area and use the facilities provided with care. See Section 6.

Monitoring and maintenance

It is important to monitor the area and periodically review the rehabilitation plan to ensure:

- Rehabilitation has begun

  Any planting is subject to the vagaries of the weather. In most cases, follow-up work is essential to ensure the rehabilitation strategy is not jeopardised by poor seed germination or plant establishment. Additional brushing or mulching may be necessary to provide temporary cover during the following dry season where plants have not established. Some areas may need replanting, brushing and fencing during the following wet season or two.

As a general rule, *at least 30% of the original budget* should be allocated to maintain the rehabilitated area in the wet season following the implementation of the rehabilitation plan.

- People are using the facilities and accessways

  Facilities and accessways may need to be redesigned or relocated if they are being vandalised or by-passed.

- Signs and information plaques are not vandalised

  If the area begins to look neglected, people are less motivated to help protect the area.

- The rehabilitated area will remain stable

  This requires a commitment to regular review and maintenance of the area once the area appears rehabilitated; and a re-assessment of the rehabilitation strategy to ensure the original problems have been resolved.

  Up to 10% of the original budget may be required for future annual maintenance, depending on the nature of the landforms and coastal processes operating in the area, and the use pressures in the area.

The rehabilitated area must be maintained constantly because even minor damage to dunes can rapidly develop into a major problem, with the area perhaps regressing to its degraded condition within a few years.

Management recommendations

The coastal environment is fragile and easily degraded, but can be successfully and permanently rehabilitated if the responsible management agency has an appropriate rehabilitation strategy and is committed to the management of their coastal environment.

The following are recommendations to local authorities and others responsible for the protection of their coastal environment:

- Inspect the coast periodically to determine if it is stable or degrading, and to anticipate where problems may develop.

- Be aware of the likely impacts of development proposals within the coastal environment.

- Consider the potential impacts of proposed recreational facilities on the coastal environment.

- Act as quickly as possible to rehabilitate areas *before* they develop into major problems.

- Use appropriate rehabilitation techniques.

- Plan ahead to allow plenty of time to develop the rehabilitation strategy; to maximise community involvement in the process; to enable proper assessment of the causes of the problem; to ensure sufficient plant stock and seed is available when it is needed; and to ensure that revegetation can be completed early in the growing season so that seedlings maximise their growth.

- Encourage community involvement in the planning and implementation of the rehabilitation strategy to foster local 'ownership' of the problem and the future management of the area. 'Busy bees' are ideal, and can be arranged to collect cuttings and pick local seed; to establish a local nursery of coastal plants; for planting and brushing; and to transport garden clippings to the area.

- Be committed to the future management of the area and of the coastal environment generally.

Examples of coastal rehabilitation strategies

The major features of appropriate rehabilitation strategies for a range of problems are described on the following pages.

Management problem 1

Vegetation has been lost or disturbed over a broad area, resulting in wind erosion of the bared sandy surface (Figures 20 and 21).

Cause

Fire or grazing and trampling by animals.

Required action

If the damage is caused by grazing animals, fence to exclude them.

If the damage is the result of fire, the area will regenerate naturally in the following season. Monitor the progress of regeneration. It may be necessary to erect information signs and/or fencing if the area is also subject to other uses.

Brushing may be required to protect the sandy surface and to help plants regenerate and germinate. Areas which have failed to regenerate after the first wet season may require replanting, reseeding and rebrushing.

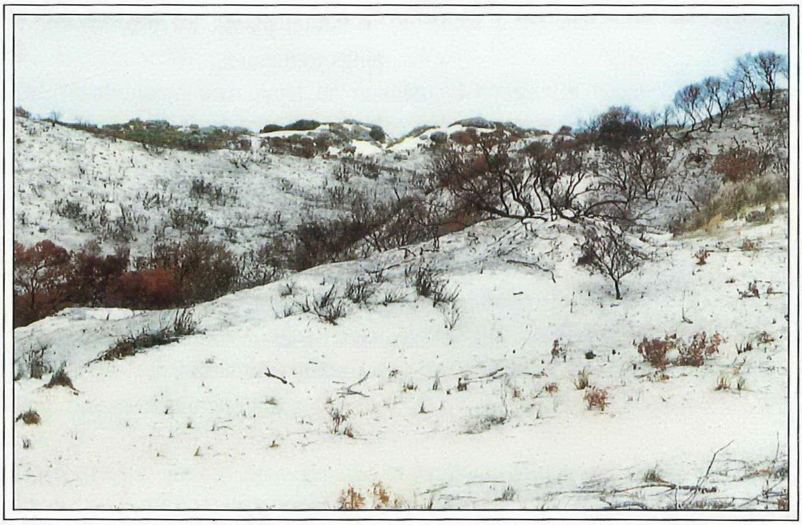


Figure 20. Fire has destroyed the vegetation on the parabolic dunes at Warnbro (photo: J. Broun)

Figure 21. Overgrazing has damaged the coastal vegetation on this parabolic dune at Greenough (photo: J. Broun)

Management problem 2

Vegetation cover has been lost or disturbed in linear strips. The bared sandy surfaces are eroding in the wind (Figure 22).

Cause

Uncontrolled access by vehicles, including trail bikes and beach buggies.

Required action

Review use of, and access by, vehicles in the area. If access is desirable, determine whether the existing track should be maintained or realigned. When old tracks become impassable, new tracks are often forced alongside. Hence, if an existing track is to be maintained, stabilise it using bitumen, crushed limestone, gravel or other locally available material. The road batters and other eroded areas need to be stabilised by brushing, seeding and planting as required.

If a new alignment is preferred or multiple access tracks are to be rationalised, choose a route which avoids steep slopes, coastal wetlands and mobile landforms; areas prone to flooding or storm surge; and alignments facing into the prevailing winds. Choose an alignment which minimises site disturbance, cutting and filling.

If vehicle access is not desirable, the existing tracks should be closed by erecting fencing or barriers and installing signs. The tracks should be rehabilitated. Well-used tracks may be compacted and need deep ripping to encourage plant growth. Replant with local species and brush. A cover crop of cereal rye or triticale may be sufficient protection in sheltered areas.

Figure 22. Multiple access tracks through parabolic dunes and the relict foredune plain at Warnbro is resulting in wind erosion and damage to the vegetation (photo: S. Chape)

Management problem 3

Eroded foredune with a scarped, bare dune face (Figure 23).

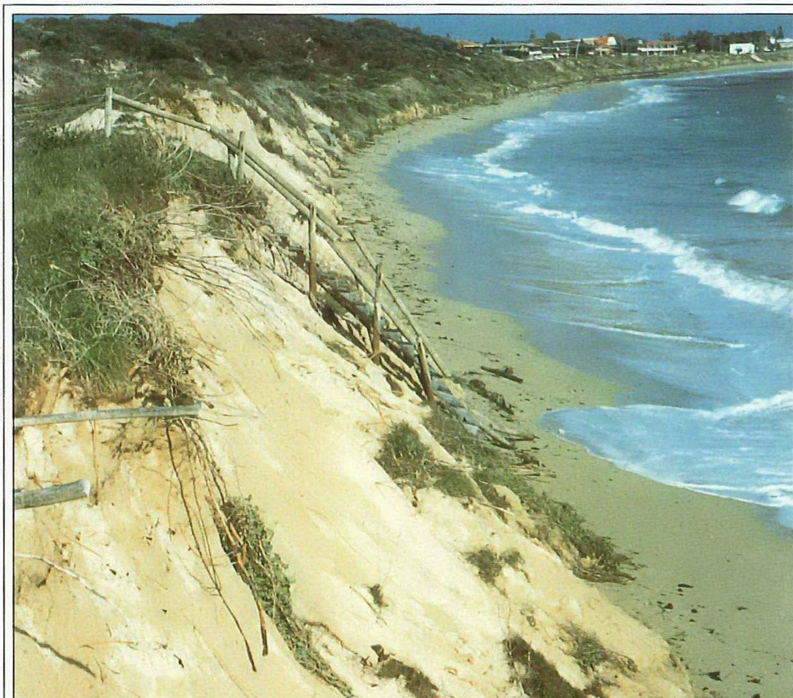
Cause

Wave erosion (during a severe storm) exacerbated by wind erosion of the exposed face.

Required action

Temporary stabilisation is required immediately following the storm. The exposed face should be brushed to stabilise the surface and to reduce further sand loss by wind erosion. Major rehabilitation may be required at the beginning of the following wet season, including re-creation of the foredune in front of the scarp, or reshaping the existing scarped frontal area. The area should then be planted, seeded and brushed. Fencing will protect the planting, and if the area is heavily used, will control access to the beach.

Figure 23. Scarped foredune at Shoalwater Bay (photo: J. Broun)



Management problem 4

Developments or important landscape features are threatened by blowouts (Figure 24).

Cause

The vegetation was probably disturbed initially by continual wave erosion, perhaps exacerbated by excessive vehicular or pedestrian traffic. Winds funnelling through gaps in the dunes and eroded areas often increase the area of destabilisation and blowouts.

Required action

Rebuild a foredune to eliminate any breaches, either using earthworks (using sand blown into the blowouts), sand-trapping fences, or layers of brush. Foredunes should be re-established on the same alignment as the existing foredunes on either side of the breach.

The slopes of the blowout walls may need to be recontoured to more gentle grades to encourage plant growth. The need for access through the area should be reviewed. Fencing may be required to exclude, or to control, access. The foredune area and the blowouts should then be planted, seeded and brushed.

Figure 24. Blowouts threatening the coastal settlement at Preston Beach (photo: S. Chape)

Management problem 5

Loss of vegetation on headlands, and exposure of the underlying rock, usually limestone or crystalline rocks (Figure 25).

Cause

Uncontrolled pedestrian or vehicular access. Headlands are particularly exposed to onshore winds and wind erosion.

Required action

Review access to, and use of, the headland. Locate an access track along the more protected side of the headland. If the headland is a local vantage point, install a viewing platform. Make walking paths and brush adjoining areas – fencing may be visually intrusive – or plant prickly coastal species to ensure the paths will be used. Stabilise paths by surfacing with crushed limestone, gravel, seaweed, woodchips or other locally available, appropriate material. Brush and plant disturbed areas with local species.

Figure 25. Multiple and poorly located tracks are damaging the vegetation and resulting in wind erosion of the headland at Greenhead (photo: S. Chape)

Management problem 6

Frequent but unpredictable undermining of recreational facilities, foreshore protection works and other developments (Figure 26).

Cause

Facilities are located within the area subject to seasonal shoreline movements associated with the beach sand cycle.

Required action

Periodic damage to works such as access ways to the beach and sand-trapping fences, which need to be located at the back of the beach, is unavoidable. If these works are still required, reinstate them or use other techniques (for example, use brush-on-brush layering instead of sand-trapping fences).

Figure 26. Seasonal undermining of recreational facilities and dune protection works can be severe (photo: J. Broun)

Management problem 7

Developments are threatened by wave action (Figures 27 and 28).

Cause

Developments are often located too close to the beach, so are vulnerable to catastrophic wave erosion during severe storms or cyclones. In some cases, the developments are in areas subject to long term wave erosion.

Required action

Determine if the development should be relocated, or maintained and protected. If relocation is required, choose an area which is safe from wave erosion and other problems including storm surge, sand inundation and flooding. Restore the original area by recreating a foredune, to minimise the rate of wave erosion. Remove rubbish and building rubble. Replant, seed and brush the foredune and areas behind it.

To maintain and protect the development on the existing site, groynes or a rock wall may be needed, but renourishing the beach in the area, or importing sand to build a larger foredune in front of the development may be enough (Figure 29). The foredune should be planted, seeded and brushed.

Figure 27 Long-term wave erosion has eroded Ormsby Terrace, Mandurah, threatening houses. This problem was resolved by relocating the road and constructing a series of groynes along the beach (photo: J. Broun)

Figure 28. Cyclone Alby caused severe wave erosion which threatened the North Cottesloe Surf Lifesaving Club (photo: J. Broun)

Figure 29. The wave erosion problem at North Cottesloe was resolved by renourishing and rehabilitating the foredune (photo: J. Broun)

Management problem 8

Undermined access paths, roads and carparks (Figure 30).

Cause

Erosion from uncontrolled rainfall runoff.

Required action

Review the adequacy of stormwater management, including the camber and the length of the sealed surface running downslope; location and adequacy of stormwater drains; and the construction material.

Determine if the facilities should be relocated or redesigned, or whether the existing erosion problems can be resolved by improved drainage.

Figure 30. Erosion of the foredune at Geraldton was caused by runoff from the adjacent caravan park (photo: J. Broun)

Management problem 9

Accessways being eroded by wind, leading to erosion of the adjacent dunes and amenities (Figure 34).

Cause

The location of accessways (particularly relative to the prevailing winds) may be inappropriate. Erosion may also be occurring because pedestrians or vehicles are bypassing the accessways.

Required action

Review the alignment and construction of the accessways. Footpaths may need to be forked at the beach end, to disperse pedestrians onto the beach. Roads and tracks may need to be rationalised, relocated or redesigned (e.g. by 'kinking' them) to minimise exposure to the prevailing winds. Surfaces should be stabilised to the required standards (for pedestrians, bicycles, two or four-wheel drive vehicles) and batters stabilised by brushing, seeding and planting. Signs and fencing may encourage care and maintenance of the area.

Figure 34. Poorly located accessway is resulting in wind erosion of the adjacent dunes (photo: J. Broun)

Management problem 10

Drift sand requires frequent removal to prevent facilities from being buried (Figures 31 and 32).

Cause

Lack of vegetation on dunes and/or absence of dunes behind the beach. Sand is transported inland by winds.

Required action

Determine whether to rehabilitate the area or relocate the facilities. Rehabilitation will require an appropriate plan based on creating foredunes to trap sand. Plant, seed, brush and fence the area (Figure 33).

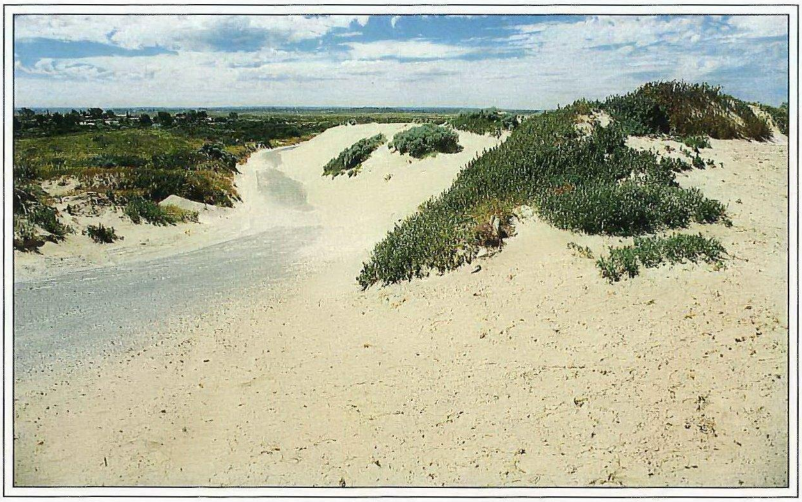


Figure 31. The access road to the carpark at Warnbro is continually inundated by sand from a blowout (photo: J. Broun)

Figure 32. Sand burying the carpark at Scarborough (photo taken in the early 1970s: J. Broun)

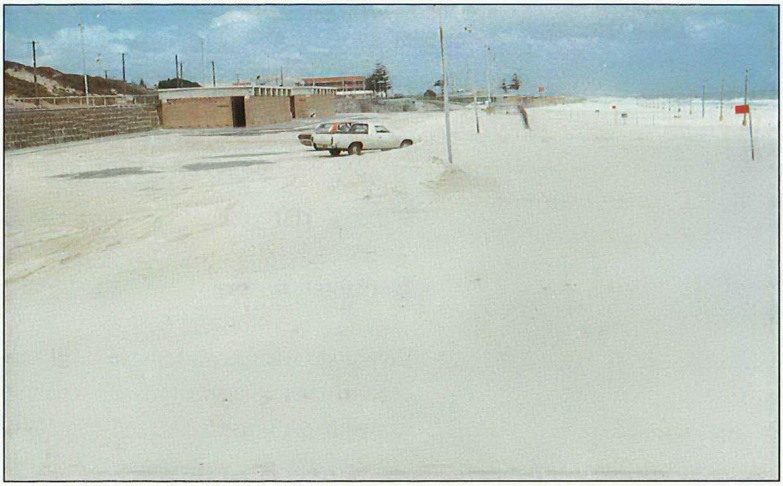


Figure 33. The same area in 1988 after the sand drift was arrested by re-creating vegetated foredunes in front of the carpark (photo: J. Broun)

Management problem 11

Erosion around buildings and amenities (Figure 35).

Cause

Wind eddying around structures in an exposed area.

Required action

Determine whether to remove or relocate the structure to a less exposed area, or to maintain the structure and rehabilitate the eroded area. If the area is to be rehabilitated, brush or a sand-trapping fence may be required as a temporary measure. Planting a shelter belt in front of the structure may reduce eddying. The shelter belt should be planted across the direction of the prevailing winds and comprise shrubs and trees (if these can be grown in the site) – low shrubs upwind, taller shrubs and trees planted downwind to 'lift' the wind over the structure.

Figure 35. Wind erosion can occur due to wind eddying around buildings and structures. This problem area is being temporarily stabilised with brush (photo: J. Broun)

Section 3. Rebuilding dunes

Contents

Figure 36. Bulldozing sand dunes to re-form the foredune at Halls Head, Mandurah (photo: J. Broun)

There are several situations where it is often useful or necessary to recreate or to reshape coastal dunes. Foredunes are often breached or absent on destabilised coastlines. Re-creation of breached or absent foredunes is often an essential first step in rehabilitation. Rehabilitated foredunes will trap and bind sand, increasing the sand supply to the back of the beach to maintain the beach sand cycle. A stable foredune is also a barrier to wave action, storm surge and onshore winds which would otherwise affect the landforms inland.

Eroded and unstable dunes behind the foredune may be reshaped to provide a more stable surface for replanting or to accommodate recreational facilities (pedestrian accessways, carparks, picnic areas, etc.); while dunes within a development area (residential zone, marina or tourism area) may be extensively reshaped to accommodate the design and construction plan.

Dunes may be re-created or reshaped in several ways. Earthworks, fencing and brushing can be involved, depending on the requirements of the rehabilitation plan and local characteristics.

Earthworks

Earthworks are particularly useful where large dunes need to be rapidly re-created or where extensive areas need to be reshaped. Dunes can be re-created by bulldozing sand from dunes, especially eroded dunes or blowouts, further inland

(Figure 36). However, sand should not be bulldozed from the beach to re-create foredunes, as one objective of re-creating foredunes is to increase the sand supply to the foreshore area for the beach sand cycle to be maintained.

The re-created dunes should be built to similar dimensions and shapes and along similar alignments as existing dunes in the area, to ensure that they interact with the climatic and coastal processes in similar ways.

The seaward face of rebuilt dunes should not be too steep, no more than 25° is recommended, otherwise the dune face will be more prone to wind erosion and slumping, and maintaining vegetation will be more difficult.

Before the dunes are reshaped, existing shrubby vegetation should be removed and stockpiled, then the topsoil should be stripped and stockpiled separately. These materials should be respread after the dunes have been reshaped as they are valuable sources of seed, plant stock, brush and organic matter. These materials should be stockpiled for the shortest time possible in order to maintain seed viability and the fertility of the soil. With careful planning, stockpiled material could be respread within three weeks.

Sand-trapping fences

Sand-trapping fences are another way to re-form dunes, especially breached or eroded foredunes (that is, linear dune ridges), where it is not crucial that the dune be re-formed quickly. These fences may take several years to re-form the dune and are best used where a long section of the foredunes is eroded – where costs of earthmoving may be excessive – and public use pressures are not great. Sand-trapping fences have been used extensively in Victoria.

The fences work on the principle that the wind stream flow lines are compressed as they pass over the fence (Figure 37), forming a sheltered zone of lower wind energy immediately behind and downwind of the fence. Sand-laden winds are slowed by the barrier and deposit their sand in the sheltered zone. The width of the sheltered zone created by the fence is five to ten times the height of the fence. The dune created by a single sand-trapping fence may be quite wide but will only be as high as the fence.

The effectiveness of sand-trapping fences depends on the wind speed, the amount of sand transported by winds, and various characteristics of fence construction.

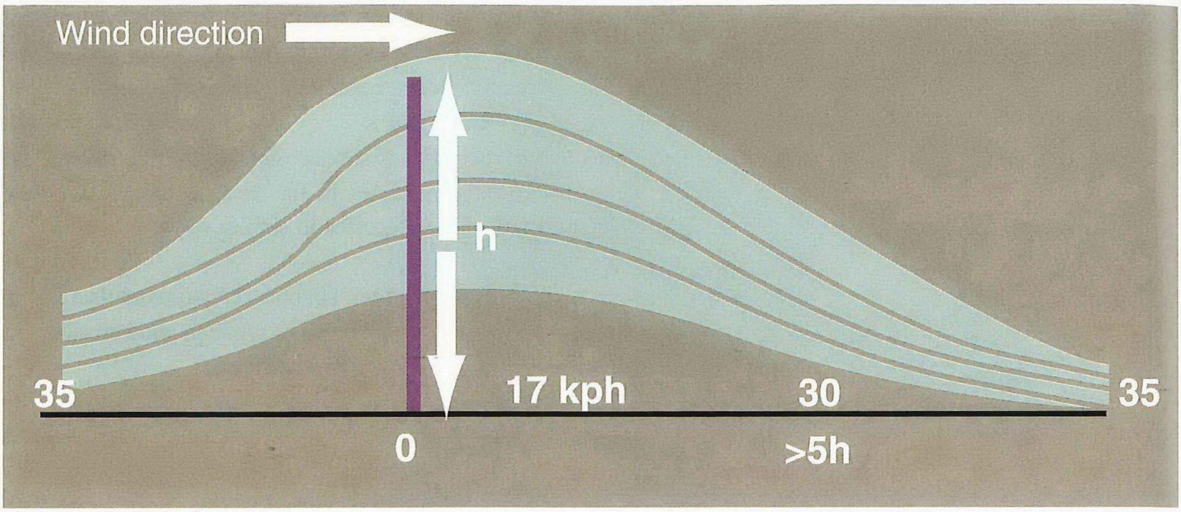


Figure 37. Effect of a windbreak on the flow of air across it. The width of the area protected behind the fence is generally 5 to 10 times the height of the fence (after the Department of Conservation, Forests and Lands, 1985)

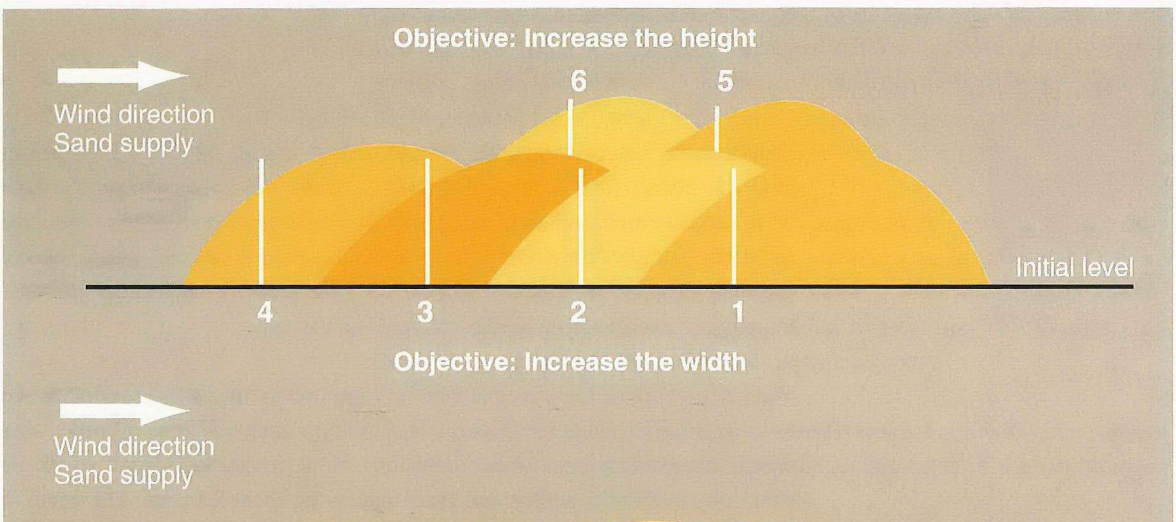


Figure 38: The principle of placing sand-trapping fences to create compound dunes (after the Department of Conservation, Forests and Lands, 1985)

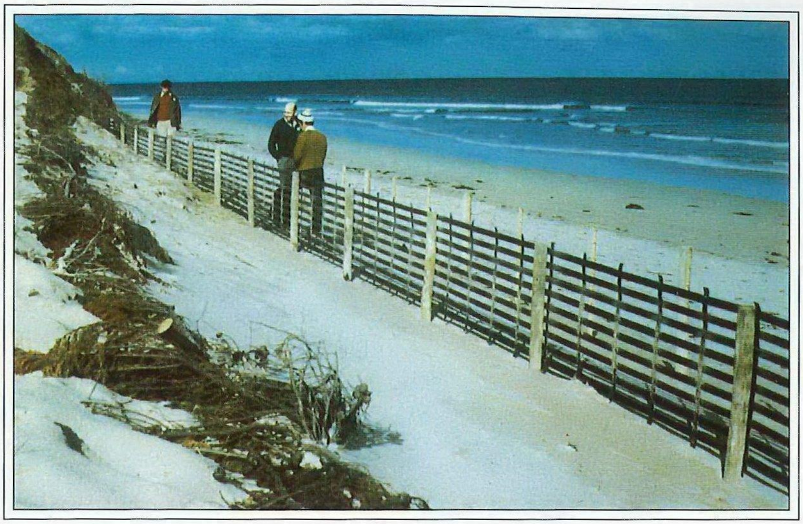


Figure 39. A Paraweb® sand trapping fence (photo: J. Broun)

Sand-trapping fences cannot generally be used to re-form a foredune along an eroding coastline, because there is generally little sand available to be blown off the narrow beach, and incipient foredunes are usually destroyed by waves. However, fences can be used to re-form foredunes along stable or accreting coastlines. A single sand-trapping fence, located along the seaward 'toe' of the original foredune or where the incipient foredune is forming, will usually re-form the foredune over one to several years.

Fences can also be erected on mobile dunes to control wind erosion from the bare sandy surfaces.

The fences are most effective when located at right angles to the prevailing onshore wind and constructed with porosities of 20 to 50%, especially around 50%. Where winds arrive from several directions, such as along the south coast around Albany, sand-trapping fences may need to be located along several alignments.

Several sets of fences (Figure 38) can be used to enlarge dunes. If parallel fences are erected progressively seawards as the original fence is filled, the dune is widened. Height is increased by constructing fences on top of dunes created by an earlier sand-trapping fence. Each fence should be allowed to fill before another is erected. It takes several years to create these compound dunes.

Figure 40. A sand trapping fence constructed with brush woven through wire (photo: J. Broun)

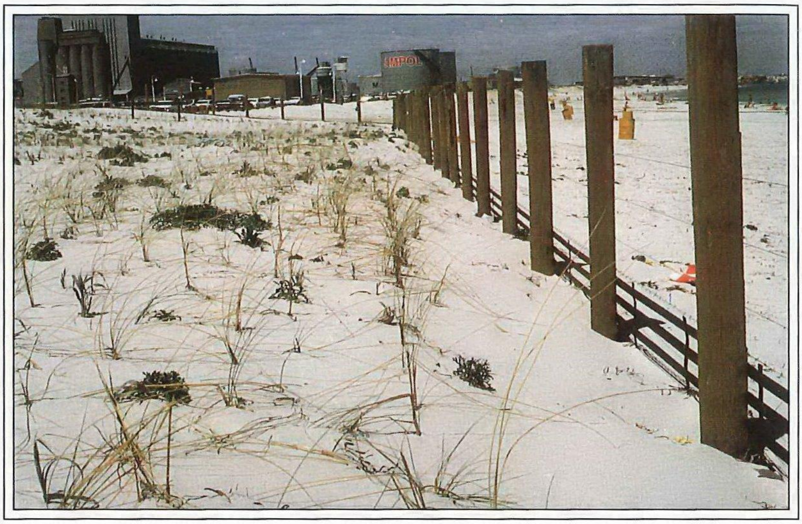


Figure 41. 2 m posts with the first layer (1 m) of Paraweb® attached. The second layer can be attached as the sand has nearly reached the top of the Paraweb®. (photo: J. Broun)

Sand-trapping fences are constructed of synthetic Paraweb® (Figure 39) or of brush woven through wire (Figure 40) attached to wooden posts driven into the sand. Long wooden posts (about 2.4 m), although more difficult to drive into the sand, can have Paraweb® or brush fencing progressively attached to them over time, and are useful where high dunes are to be created (Figure 41). Paraweb® fences have been extensively used in Western Australia but they are easy to vandalise so may only be practical in areas not frequented by the public. Brush fences are generally fairly sturdy.

Figure 42. A sand trapping fence created across a blowout by driving wooden slats into the sand (photo: J. Grasby)

Slat fences are also useful as sand traps (Figure 42). They are easily constructed by driving slats individually into the sand, although they can last longer but are more costly if they are erected by attaching the slats onto a post and rail fence.

Specifications for constructing sand-trapping fences are shown in Appendix I.

Brush-on-brush

Lines of piled brush are a cheap alternative to sand-trapping fences and have several advantages. They are generally not vandalised; the sand surface is protected from wind erosion; and shelter is provided for plant establishment.

To create a foredune, brush has to be laid at the back of the beach and along the alignment where vegetation is establishing an incipient foredune. If a foredune is to be created against an eroded dune, brush must be laid along the wave-scarped face of the foredune. As the layer of brush fills with sand, another layer of brush is laid on top. Layers are continued until the required height and width of the dune is attained.

Section 4. Replanting dunes

Contents

Dunes are replanted with coastal vegetation to ensure stabilisation, minimal maintenance requirements, and preservation or enhancement of environmental quality.

These objectives are most readily achieved by establishing a variety of local native plants in the most appropriate locations within the dunes, taking account of the coastal and climatic processes which operate in that location. It is therefore important to inspect the area and determine which species occur naturally within the different landforms, the abundance of each species and their specific location. This information can then be incorporated into the rehabilitation plan. The types of plants which need to be planted will include primary and secondary dune colonising species. Tertiary species are only appropriate for sheltered areas which are not particularly subject to coastal processes and are often used for landscaping such areas.

There has been a tendency in the past to use some introduced species because they were easy to propagate and knowledge of the locally occurring native species was poor. However, there is a growing understanding of the importance of restoring natural ecosystems and of the detrimental effects of some introduced species. This manual focuses on rehabilitating coastal dunes using locally occurring, native species.

The coast has been divided into two zones for species recommendations. One zone is south of Kalbarri, the other is north of Geraldton. In the transitional area between Geraldton and Kalbarri, native plants from either zone may occur locally and can be planted.

Species to plant on foredunes and mobile dunes

Primary dune colonising plant species are listed in Appendix II and III, and photographs of some of them are arranged alphabetically in Appendix IV. Species most frequently used in Western Australia are the grass-like plants; *Spinifex hirsutus* (sand or hairy spinifex), *Spinifex longifolius* and the naturalised species, *Ammophila arenaria* (marram grass). These plants are adapted to sand blasting and inundation, excessive salt spray and strong onshore winds. They thrive only on foredunes and mobile dunes (sand-sheets and depositional lobes of blowouts) where the area receives a steady supply of sand from the beach.

Figure 43. A stem cutting of Spinifex hirsutus *ready for planting (photo: Department of Agriculture)*

Spinifex

Spinifex hirsutus occurs on foredunes from approximately Jurien to Albany. The seed is not viable in Western Australia. This species is established by taking stem cuttings 40 to 60 cm long, containing several nodes (Figure 43), from established stands and hand planting these 30 to 50 cm deep on a 50 to 75 cm grid. Where sand is accumulating rapidly or where the foredunes are steeply sloping, closer plantings – on a 20 cm grid – are required.

Spinifex longifolius occurs along the whole of the Western Australian coastline, but is the dominant foredune species north of Busselton. It is usually propagated from seed which ripens between August and December north of Perth and November to January south of Perth.

The seed is either threshed and scattered across the sand surface before brushing, or the whole seed head is sown on a 50 to 75 cm grid (or closer as for *S. hirsutus*) with 1 to 2 cm of the spines left protruding. Alternatively, the ripened seed heads can be germinated in pots during the dry season, and the sprouted heads planted out early in the wet season. *Spinifex longifolius* can be propagated from cuttings (as described for *S. hirsutus*), however, this method is not as reliable as germination from seed.

Figure 44. Planting marram grass culms (photo: Department of Agriculture)

Marram grass

Marram grass (*Ammophila arenaria*), a naturalised, European, primary dune species, has been used as a foredune colonising plant south of Perth. If marram grass is used, it should be interplanted with local native species to restore the foredune ecosystem more quickly.

Culms of marram grass are harvested from established stands by pulling out clumps by hand and separating them into single rooted shoots (Figure 44). Harvested culms must be kept wet until they are required for planting. The culms are planted in holes 25 to 35 cm deep, on a 50 to 75 cm grid, made by working a spade, or wedge-shaped marram planter, backwards and forwards several times in the sand. The hole is then filled with sand which must be firmed down by foot around the base of the plant.

Where sand is rapidly accumulating, or where foredunes are steeply sloping, closer plantings of marram grass – on a 20 cm grid – are required.

Exotics

Appendix V contains photographs of a number of exotic plants growing in the coastal environment but which are no longer recommended. These species are pictured to help identify them so that they are not inadvertently used for rehabilitation purposes.

Two South African grasses have been used in southern coastal areas of Western Australia, but both have significant environmental drawbacks and are no longer recommended. They are pyp grass (*Ehrharta villosa*) and sea wheat (*Thinopyrum distichum*, formerly *Agropyron distichum*). Pyp grass is a close relative of, and biologically similar to, Veldt grass (*Ehrharta calycina*) and has recently come under scrutiny in South Africa and Western Australia because of its apparent indiscriminate colonising habit which is potentially detrimental to the native coastal vegetation.

Sea wheat has not been widely used until recently because it can host rye and wheat stem rusts over the summer. However, it propagates easily by vegetative means (culms) and seed, and may be able to out-compete local coastal species for water and nutrients.

Two other exotic species have been used in the north of the State, but are no longer recommended. These are buffel grass (*Cenchrus ciliaris*) and kapok bush (*Aerva javanica*). Both plants are undesirable due to palatability to stock which encourages trampling and destabilisation of the dunes. They are aggressive colonisers and are likely to prevent natural vegetation from providing a permanent cover.

Planting the foredune and mobile dunes

Planting should commence only after the opening rains of the wet season have dampened the sand to a depth of 20 to 30 cm – usually June/July in the southern part of the State and January in the north – and should be completed by the end of the wet season – usually September in the south, April in the Gascoyne and Pilbara, and February in the north of the State. However, the earlier that planting is completed, the greater the likelihood of establishment, as the plants will gain the maximum benefit from the rainy season.

Foredunes and mobile dunes should be:

- planted with *Spinifex hirsutus* and *S. longifolius*, and marram grass, if preferred where found in the local area;
- seeded and planted with some or all of the other primary dune colonising species listed in Appendix II or Appendix III, where found in the local area. Mobile dunes should also be planted with secondary dune colonising species (see Appendix II or Appendix III for details of these species, and Appendix IV for photographs of some of them); and
- brushed.

Species to plant on secondary dunes

Secondary dune colonising species are re-established in *all* dunal landforms behind the foredune, as these areas are slightly more protected from the elements. Secondary species may also be established on the lee, or landward slope of large foredunes. Appendix II and Appendix III list some of the secondary species which can be replanted on dunes, and Appendix VI contains photographs of some of these species.

Planting secondary dunes

Degraded or reshaped dunes behind the foredune should be replanted when the sands are moist – as when planting the foredune. Foredunes and secondary dunes are usually planted together but the planting program is slightly different:

- seed and plant cuttings or seedlings of the secondary species listed in Appendix II or Appendix III;
- seed and plant cuttings of the primary species also listed with the secondary species in Appendix II or Appendix III (i.e. the non-grasslike species);
- seed with a cover crop if preferred (only in the south-west of the State) and fertilise; and
- brush.

Species for sheltered areas behind the foredune

There are a few tree species (listed in Appendix II and Appendix III and pictured in Appendix VII) which may be planted in protected areas behind the foredune, such as in dune swales, sheltered deflation basins and behind very large parabolic dunes. These areas may be suitable locations for recreational facilities such as parking areas, picnic areas and children's play grounds. Couch and *Paspalum* grass species may also be established in these areas with irrigation. The tree species will provide useful shade.

Special dune plants

Some plants have special characteristics which make them useful for planting in certain locations, or to serve particular purposes. *Tribulus occidentalis* (Perennial caltrop, a northern foredune species – Appendix IV) and

Acanthocarpus preissii (a southern, secondary species – Appendix VI) are particularly prickly plants which can be planted along fences and pedestrian accessways to deter pedestrians from entering rehabilitating areas and other highly fragile areas.

Carpobrotus species (pigface – Appendix VI) are low growing, ground-covering plants which can be planted along firebreaks to protect the surface from wind erosion while minimising the fuel load.

Other species

There are other primary, and particularly secondary, colonising plant species native to coastal dunes throughout Western Australia which can also be used. Appendix IV and Appendix VI contains photographs of some of these species. Seeds and cuttings should be collected from plants growing locally, as many have developed site-specific characteristics. Seed from most of these plants can be harvested over the dry season and is generally easy to collect, in many cases accumulating on the ground near the base of the plant.

More information on the distribution of coastal dune species can be obtained for:

South-west coast: Publications by Powell and Emberson (1981), Smith (1985) and APACE (1992)

Pilbara coast: Publications by Craig *et al.* (1983) and Tyler (1990)

These publications are listed fully in Section 8 – References and further reading.

Section 5. Stabilising the sand and protecting the vegetation

Contents

Figure 45. Tea-tree brush laid across a foredune at Rottnest (photo: J.Broun)

Once the dune has been reshaped or re-created and revegetated, it is important to stabilise and protect the surface of the dune as quickly as possible from sand blasting, sand creep, strong winds and excessive drying, so as to create a suitable environment for seed germination and establishment of cuttings or seedlings.

Techniques to stabilise the sandy surface are usually part of the planting program, although they can also be employed to encourage natural colonisation of bare areas. The most commonly used techniques include brushing, mulching and cover crops. Surface (chemical) stabilisers have specialised applications.

Brushing

Brushing is the most effective, and usually the cheapest, method of stabilising the bare sandy surface.

Brushing involves covering the bare dune surface with a single layer of shrub or tree branches (Figure 45). Brushing is particularly suited to sites which are exposed to wind. The brush controls sand movement by impeding the surface wind flow, trapping sand and sheltering plants.

Tea-tree (*Melaleuca* spp.) and pine prunings are ideal brush materials because they retain their leaves for long periods which increases their ability to trap sand and protect the surface. Also, the prickly nature of pine prunings deters pedestrians from crossing the rehabilitating dune.

Figure 46. Hay being used as a mulch to protect the area behind the foredune (photo: J. Broun)

Eucalypt prunings lose leaves quickly so need to be applied more thickly than tea-tree and pine. However, a thick layer of eucalypt brush also deters pedestrians. Prunings of local woody coastal vegetation, such as acacias, have the advantage of introducing local sources of seeds in the dune.

Local authorities are often a good source of prunings during or after their street tree pruning program.

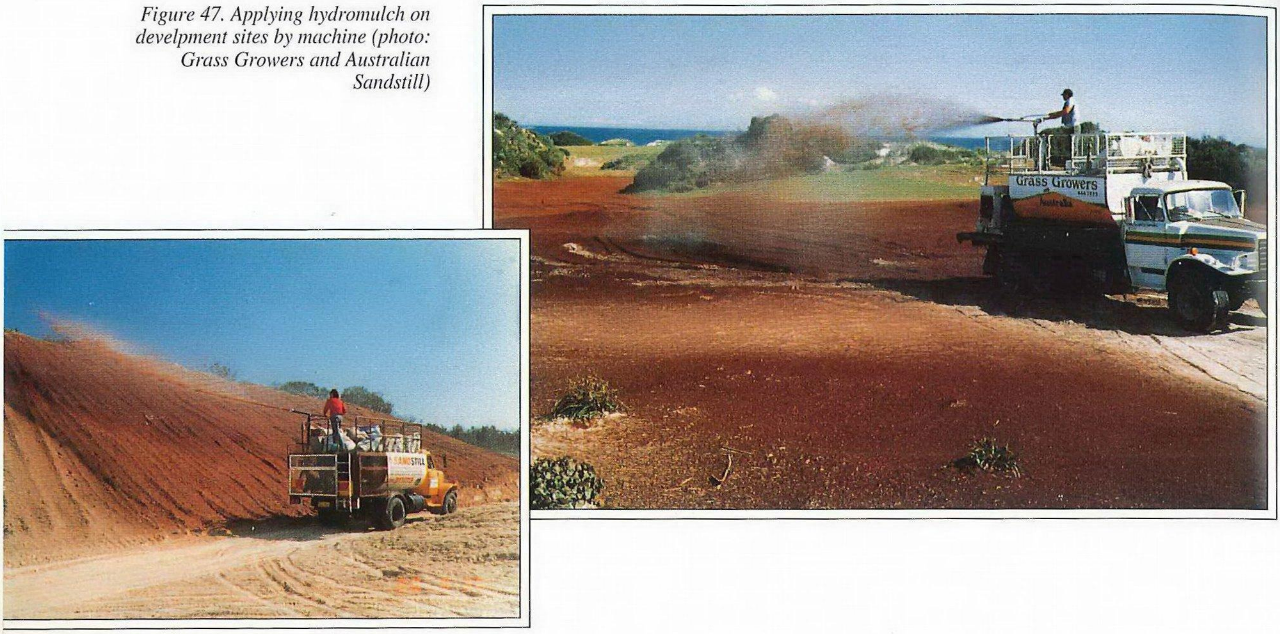
Brush should be laid with the stems facing into the prevailing wind, starting at the top of the dune or area to be protected. Successive layers of brush overlap the stems of the previous rows.

Mulching

Mulching with locally available materials such as hay or seaweed collected from the beach will also stabilise the sandy surface, However, mulches generally have little or no capacity to trap sand, and once the pore spaces are filled, will not protect seedlings from sand blasting or wind. Mulching is best used where sand drift or blasting is not a problem, such as dune swales, deflation basins and other sheltered areas behind dunes.

Hay mulch has been used on the south coast of Western Australia. Spread by hand to a depth of 5 to 10 cm (Figure 46), one bale will cover about six square metres. At more exposed sites, the hay should be anchored by shovelling mounds of sand onto it at 1 to 2 m intervals.

Figure 47. Applying hydromulch on develpment sites by machine (photo: Grass Growers and Australian Sandstill)



Spray-on stabilisers

A variety of spray materials, including hydromulch and chemical emulsions, have temporarily stabilised some coastal problems. Hydromulch is an emulsion of paper or wood pulp, fertiliser and frequently seed (to establish cover crops and/or native species). Chemical emulsions have not been widely used for dune rehabilitation in Western Australia.

Mulch sprays do not trap wind-blown sand, and provide little protection for the vegetation from sand and wind blast. They are therefore not suitable for stabilising exposed coastal areas such as foredunes, blowouts or sand-sheets, without incorporating other forms of treatment such as brushing. Also, most cannot withstand any foot or wheeled traffic and treated areas must be securely fenced, or re-treated as damage occurs. Some specialised materials set firm and are suitable for sealing pedestrian accessways and carpark. The major attribute of sprayed stabilisers is the ease and speed of application compared to laying brush (Figure 47). Also, seed and fertiliser can be applied in the one spraying operation.

Figure 48. A development site temporarily stabilised with a cover crop (photo: J. Broun)

Most mulch sprays are suited to temporary stabilisation of large, disturbed or recontoured areas, which can be protected from all traffic, such as in dune swales, behind stabilised foredunes and on development sites. These materials are used extensively to contain sand movement on large urban subdivisions, industrial construction sites and to stabilise road batters and cuttings.

Further advice can be obtained from a number of commercial outlets which produce, market or use mulch sprays.

Cover crops

Cover crops are used mainly to temporarily and 'instantly' stabilise bare sandy areas. Also, cover crops can be used as an alternative to brushing to protect road verges, open space and future housing developments; in areas which are not particularly exposed to strong onshore winds, such as dune swales and deflation basins; and in the rehabilitation of extensively reshaped dunes behind foredunes (Figure 48). The use of cover crops in these dunal areas is only appropriate in the south-west, winter-dominant rainfall area of the State. Cereal rye (*Secale cereale*) and triticale (*Secale cereale* x *triticum* sp.) are the best cover crops to use.

Cereal rye and triticale are annuals, and so afford protection for one year following planting. However, the stubble from a successful crop of cereal rye or triticale will stabilise the surface until the following wet season. Self-seeding during the following wet season is not usually significant.

The particular benefits of using cover crops rather than brushing are that they can be used in environmentally sensitive areas such as conservation reserves (as they die out after two years); they usually grow very rapidly and hence rapidly stop sand movement; and they are often cheaper to use than brushing, particularly when extensive areas require treatment.

Seeding

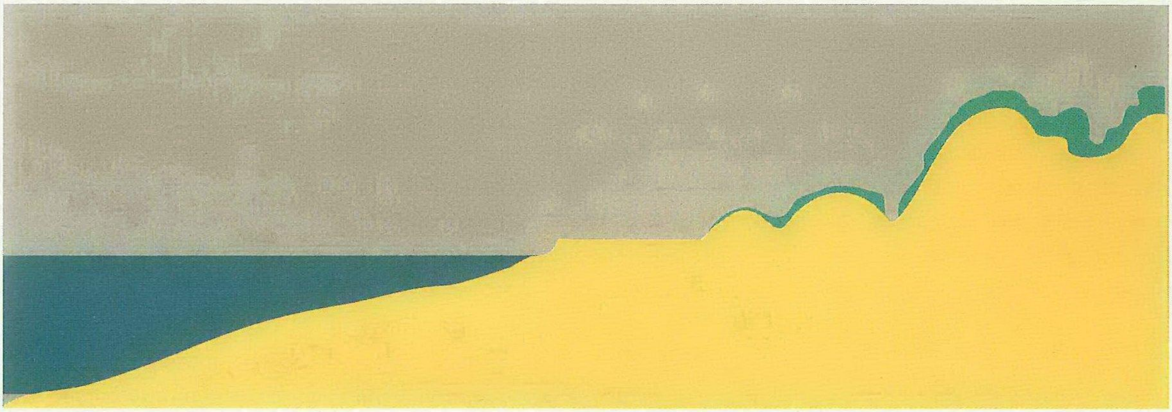
Seeding should begin in May and be completed by mid-August in the southern, winter-dominant rainfall area of the State. Seeding late in the season generally results in poor germination and sparse growth which may not protect the sandy surface.

Seed is planted either mechanically or broadcast by hand at 70 to 100 kg/ha. Mechanical methods by drill or spinner are best when large, relatively flat areas are to be planted.

Fertilising is essential for vigorous growth. A compound fertiliser containing nitrogen and phosphorus (such as Agras No.1) should be applied at about 75 kg/ha shortly after germination and repeated six weeks later. Native seeds of secondary dune species can be sown with the cover crops at about 1 kg/ha mixed seed, although they will take several years to become well established.

Section 6. Recreational use and protection of areas under rehabilitation

Contents



This section discusses the provision of recreational facilities and measures to protect areas under rehabilitation.

Recreational facilities

Providing recreational facilities within the area being rehabilitated may conflict with the long term protection and management of the area. However, these conflicts can be minimised if the recreational requirements of the community are considered and included in the rehabilitation plan.

Consideration of the existing and potential recreational uses and demands of the area (such as visitor numbers), and whether these are causing conflicts or damage, should determine what levels of recreational use can be catered for without causing environmental damage or costly maintenance. This will ensure that the required facilities are located appropriately and will cater for the recreational demands of the community.

The recreational requirements should be identified early in the development of the rehabilitation plan. This will allow:

- Recreational facilities to be located and designed to minimise damage of rehabilitating areas and long term management costs.

  Active recreation areas and other facilities which attract crowds should not be placed next to highly fragile areas. Carparks should be as close as possible to popular beaches and other attractions (within the constraints imposed by the environment);

- Earthworks for recreational facilities (such as access roads, carparks and active recreation areas) to coincide with dune re-creation or reshaping to minimise site preparation costs;

- Costly recreational facilities such as carparks, picnic areas and ablution facilities to be located away from hazardous areas susceptible to wave or wind erosion or sand inundation;

- Public use areas, such as picnic areas and active recreation areas, to be located in sheltered or more protected areas (such as dune swales or deflation areas) where trees and lawn may be successfully established; and

- Water conservation principles to be incorporated into the design and location of public use areas and landscaping.

  Landscaping of public recreational facilities will be more successful – and likely to require less irrigation – if they are located in low areas (dune swales and deflation areas) rather than on dune crests; and if rainfall shed from roads, carparks and roofs can water the area (Figure 49). The publication 'Water conservation through good design' (a Western Australian Water Resources publication) describes a number of methods to use rainfall better in the design and landscaping of public facilities. These measures also eliminate the need to pipe storm water onto the beach or into dunes.

Protecting the rehabilitating area

Fencing and firebreaks are used to protect areas under rehabilitation.

Fencing

Fencing provides protection by excluding people from fragile and rehabilitating areas (barrier fences); and guiding them to their destination through environmentally suitable areas (accessways).

Fence design depends on availability of materials, site characteristics, cost and personal preference. Low post and rail fences (see Appendix I), typically constructed of treated pine, are largely psychological barriers; whilst farm-type fencing, either post and wire or post and ringlock (see Appendix I) is more of a physical barrier. Appendix I also shows approximate costs of the various types of fencing.

Pedestrian accessways should link carparks, ablution and recreation facilities, and the beach. They should avoid fragile areas as much as possible and require minimum maintenance. Pedestrian accessways with farm-type fencing on both sides, must be constructed to control access through foredunes and other dunes to the beach. They should be 1 to 1.5 m wide to encourage pedestrian use and to deter vehicles, but may be wider to suit the needs of users. Bollards or mazes placed at the ends of pedestrian accessways reinforce this message.

Pedestrian accessways should be aesthetically pleasing, readily accessible and easy to negotiate. They should not be aligned parallel to the prevailing winds, so as to avoid forming wind tunnels which will worsen erosion. Where accessways cannot be orientated in any direction other that into the prevailing wind, they

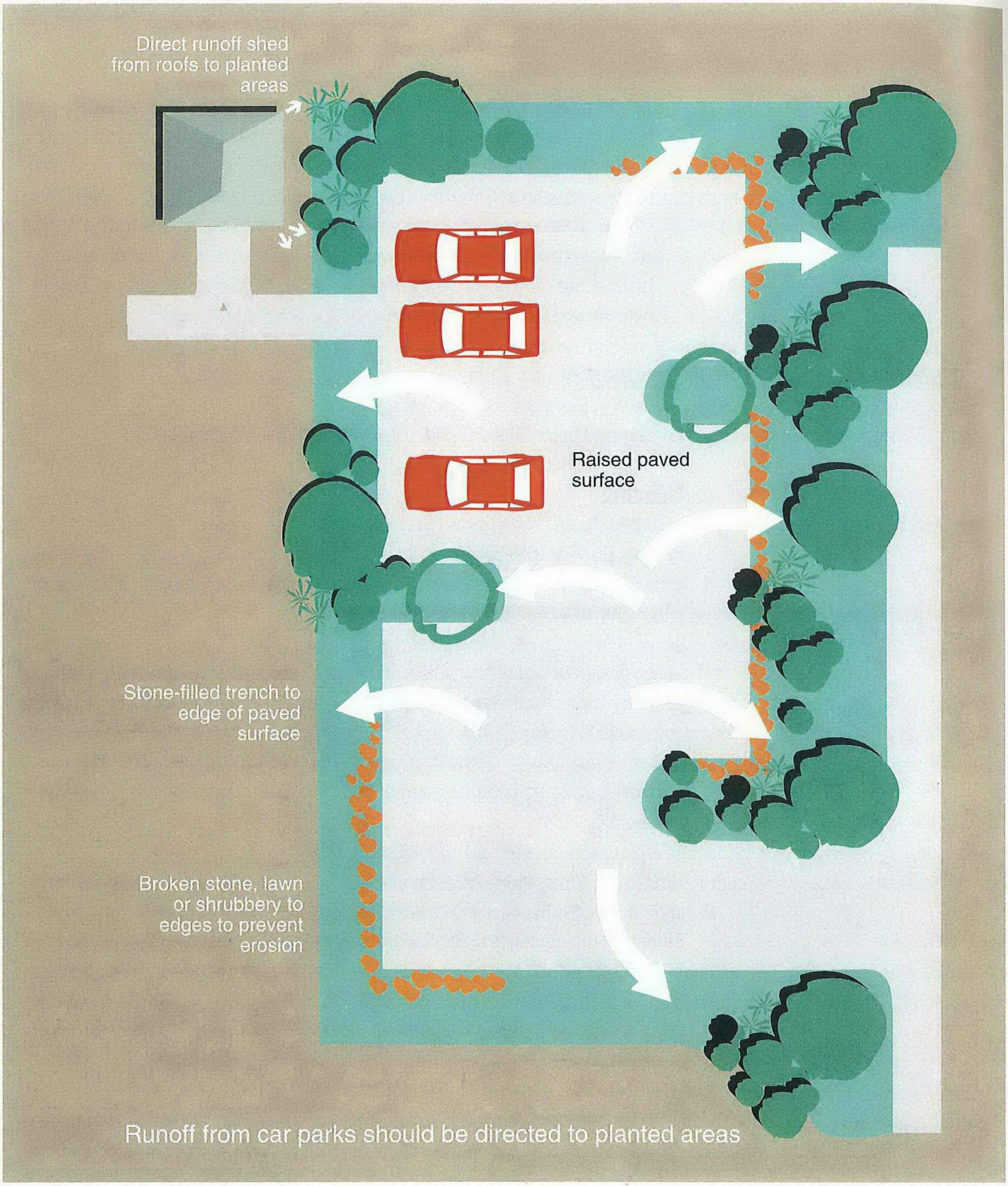


Figure 49. Water harvesting from carparks: runoff from carparks and roofs should be directed to planted areas (adapted from Western Australian Water Resources Council, 1986)

need to be surfaced with crushed limestone, seaweed or other locally available material to minimise the potential for wind erosion. The margins of the accessways should also be brushed thickly to deter access and prevent erosion.

Where paths are not too steep, natural sand is preferable to walk on, while also being cheaper. Where steeper paths need to be developed, they should be covered with seaweed, crushed limestone, tree bark or sawdust to minimise erosion.

Where dunes are too steep for pedestrian accessways, steps should be provided or access should be prohibited. Wooden steps have been widely used, though they can be easily undermined by wind turbulence. Platform steps (see Appendix I) are effective, do not erode and are generally preferable to construction of steps along steep slopes. A series of platforms (1 m x 1 m x 0.3 m high) are lodged in the dune beginning from the highest point. A bobcat or front-end loader can be used to build the platforms.

Firebreaks

Areas covered with brush have a high fuel load, so firebreaks are necessary. Pedestrian accessways and access roads can be designed as part of a firebreak plan for the area. However, where these do not provide sufficient breaks within the brushed area, firebreaks may need to be constructed. Firebreaks should be formed 2 m wide, vegetated with appropriate succulent species (such as pigface) and preferably located in areas protected from strong winds.

Section 7. Sources of advice and further information

Advice and information on aspects of the management and development of the coastal environment may be obtained from a number of sources, including:

The State Government

- The Department of Marine and Harbours: assessment of shoreline fluctuations and coastal stability, investigation of coastal processes, design and assessment of coastal engineering structures, coastal development setback alignments.

- The Department of Planning and Urban Development: coastal rehabilitation and stabilisation plans, statutory planning requirements within the coastal environment, development of coastal and foreshore management plans, coastal development setback alignments, location of recreational facilities, landscape and aesthetic considerations within the coastal environment, site design advice.

- The Environmental Protection Authority: review of formal environmental assessment documents and other documents for proposed developments in the coastal environment.

- The Department of Conservation and Land Management: rare and endangered flora and fauna in the coastal environment, management of coastal vegetation, design of public recreational facilities, management of recreation pressures along the coast, local community participation in land management through CALM's Volunteer Program. In addition, the Western Australian Herbarium provides a plant identification service for the public.

- The Department of Agriculture: encouraging local community involvement and participation in managing the coastal environment through the establishment of Land Conservation Districts and their Committees; coastal rehabilitation and stabilisation techniques.

- The Geological Survey Division, Department of Minerals and Energy: geology and geomorphology of the coastal environment.

- Department of Land Administration: cadastral information and aerial photography of coastal areas.

- The Department of Local Government: gazettal of areas for off-road vehicles.

The commercial sector

- Consultants in natural resources management, civil engineering, landscape architecture: preparation of formal environmental assessment documents and other documents to support coastal development proposals, preparation of coastal management and foreshore management plans, coastal rehabilitation and stabilisation techniques and plans.

- Seed merchants: provision of seed of species appropriate for revegetating the coastal environment.

- APACE – AID Inc: APACE is an organisation promoting the use of appropriate technology for environmental management, predominantly at the local community level. APACE – AID Inc. is its 'commercial' arm. It operates a nursery to provide native plants for revegetation in the Perth metropolitan area, including the coastal environment. It undertakes coastal rehabilitation and management projects, and runs courses on bush regeneration (also applicable to the coastal environment).

The community

- Greening Western Australia: a community organisation that initiates and supports the retention, restoration and increase in vegetation for its conservation, social and economic benefits to the community. Greening Western Australia receives funding from a number of sources including the Federal and State Governments, proceeds from its nursery, and the corporate sector. While focussing primarily on vegetation management in the wheatbelt, Greening Western Australia's activities (providing grants to local communities, providing technical information on vegetation management, and facilitating networking between community groups) encompasses all areas of the State, including the coastal environment.

- Local nature conservation groups: there are a large number of local groups having expertise and knowledge of local plant species, propagation methods and management techniques. Such information is invaluable in developing a locally appropriate coastal rehabilitation plan. These groups include the

Wildflower Society and the Western Australian Naturalists Club, which are long established and have members drawn from across the State, to small local groups such as the Broome Botanical Society.

- Local Authorities: have the responsibility to manage coastal reserves vested in them, to develop and implement coastal management plans, to restore and protect coastal reserves, to provide recreation facilities on coastal reserves and to decide on development proposals in the coastal environment.

- Land Conservation District Committees: local committees established under the Soil and Land Conservation Act 1945 to enable land users in the district to cooperatively develop and implement programs to address their land degradation problems. Several committees have been established over parts of the coastal environment. Other committees have a predominantly rural focus, but several of these have undertaken some activities to protect or restore degraded areas of the coastal environment in their district. These committees should be consulted and involved in any proposals or plans to protect, restore and manage the coast.

Section 8. References and further reading

The references used in the development of this manual are generally available at the following libraries: the Alexander Library (State Reference Library); the Reid Library, University of Western Australia; and the Library of the Department of Planning and Urban Development.

Anon (1974). *Coastal Erosion.* Town planning Department. Perth, Western Australia.

APACE (1992). *Species lists and locality guide for the Swan Coastal Plain.* APACE Revegetation Nursery Catalogue.

Atkinson, W.J. (1974). *Problems arising from the intensive use of coastal dunes in New South Wales, Australia.* International Journal of Biometeorology, Vol. 18, pp. 94-100.

Barr, D.A. and Golinski, K.D. (1969). *Marram grass, mulch and bitumen – a successful trial.* Journal of Soil Conservation, N.S.W., Vol. 25, pp. 251-257.

Barr, D.A. and McKenzie, J.B. (1976). *Dune stabilisation in Queensland, Australia using vegetation and mulches.* International Journal of Biometeorology, Vol. 20, pp. 1-8.

Bauyer, J. K. (1987). *Photogrammetric techniques for the assessment of shoreline variability between North Mole, Fremantle and Trigg Island 1955 to 1985.* B.Sc. Honours Thesis. Department of Geography, University of Western Australia.

Beard, J.S. (ed.) (1970). *Western Australian Plants* (second edition). Society for Growing Australian Plants.

Bird, E.C.F. (1985). *Coastline changes: a global review*. Wiley, Chichester.

Boyce, S.G. (1954). *The salt spray community.* Ecological Monograph, Vol. 24, pp. 29-67.

Chalmers, C.E. (1983). *Coastal management plan, Kalbarri townsite.* Western Australian Department of Conservation and Environment. Bulletin 145.

Chamberlain, L. (1986). *Storm events along the south-west coastline of Western Australia: an historical record.* B.A. Honours Thesis (unpublished). Department of Geography, University of Western Australia.

Chapman, V.J. (1976). *Coastal vegetation.* Pergamon Press.

Collins, L.B. (1983). *Postglacial sediments and history, Rottnest Shelf, Western Australia.* Ph.D. Thesis, University of Western Australia.

Craig, G.F., Hesp, P.A., Rose, T.W. and Glennon, K. (1983). *Pilbara coastal flora*. Department of Agriculture, Western Australia, 103 pp.

Craig, G.F. (1985). *Mulches as aids in the growth of* Acacia *for coastal dune revegetation.* Reclamation Research, Vol. 3, pp. 313-322.

Department of Conservation, Forests and Lands, (1985). *Coastal Erosion Control Guidelines* Land Protection Division, Victorian Government Printer.

Evans, B., Moody, R., Reeves, J. and Luff, P. (1984). *Coastal Report*. City of Stirling.

Geary, M.G. and Lord, D.B. (1981). *Development in the coastal hazard zone: a coastal engineering perspective.* Institute of Engineers, National Conference Publication 81/16, pp. 183-187.

Goldsmith, V. (1985). *Sand dunes.* pp. 303-378 *in* Davis, R.A., (ed.), *Coastal Sedimentary Environments.* Springer-Verlag, New York.

Golinski, K.D. and Lindbeck, K.E. (1979). *Woven plastic for coastal dune-forming fences*. Journal of Soil Conservation, N.S.W., Vol. 35(1), pp. 26-29.

Hesp, P.A. (1984). *The formation of sand 'beach ridges' and foredunes.* Search, Vol. 15(9-10), pp. 289-291.

Hesp, P.A. (1984). *Foredune formation in southeast Australia. In* Thom, B.G. (ed.), *Coastal Geomorphology in Australia.* Academic Press, Sydney.

Hill, D. (1978). *The art of building on sand.* Journal of the Royal Australian Planning Institute. Vol. 16, pp. 5-7.

Hopley, D. and Thom, B.G. (1983). *Australian sea levels in the past 15,000 years: an introductory review*. Geography Department, James Cook University. Occasional Paper No. 3.

Hunter, K.G. (1976). *Sand dune reclamation research trials, Floreat Beach.* Parks and Recreation Department, City of Perth.

Knutson, P. (1977). *Planting guidelines for dune creation and stabilisation,* C.E.R.C. Technical Aid No. 77-4. Coastal Engineering Research Centre, Fort Belvoir, Virginia.

Kuhn, G.G. and Shepard, F.P. (1984). *Sea cliffs, beaches, and coastal valleys of San Diego County: some amazing histories and some horrifying implications*. University of California Press, Berkeley.

McKenzie, J.B. (1983). *Coastal vegetation as an indicator of recent accretion or erosion.* Institute of Engineers, National Conference Publication, 83/6, pp. 95-99.

Mitchell, A. (1974). *Plants and techniques used for sand dune reclamation in Australia.* International Journal of Biometeorology. Vol. 18, pp. 168-173.

Morton, R.W., Bohlen, W.F. and Aubrey, D.G. (1983). *Beach changes at Milford and Fairfield beaches, Connecticut, 1962-1971.* United States Army Corps of Engineers Misc. Paper, 83(5).

National Parks Authority of Western Australia, (1981). *Walpole-Nornalup National Park sand dune stabilisation project.* Nedlands.

Parsons, R.F. and Gill, A.N. (1968). *The effects of salt spray on vegetation at Wilson's Promontory, Victoria*. Proceedings of the Royal Society Victoria, Vol. 81, pp. 1-10.

Pilkey, O.H. and Neal, W.J. (1981). *Barrier island hazard mapping.* Oceanus, Vol. 23, pp. 38-46.

Powell, R. and Emberson, J. (1981). *Woodman Point – a relic of Perth's coastal vegetation.* Artlook, Perth.

Ranwell, D.S. (1972). *Ecology of salt marshes and sand dunes.* Chapman and Hall, London.

Ranwell, D.S. and Boar, R. (1986). *Coastal dune management guide.* National Environment Research Council. Institute of Terrestrial Ecology. School of Biological Studies, East Anglia, Norwich.

Sauer, J. (1965). *Geographic reconnaissance of Western Australian seashore vegetation.* Australian Journal Botany, Vol. 13, pp. 39-69.

Searle, D.J. (1984). *Sediment transport system, Perth sector Rottnest Shelf, Western Australia.* Ph.D. Thesis, Department of Geology, University of Western Australia.

Smith, G.G. (1985). *A Guide to the coastal flora of south-western Australia.* 2nd Edition, Western Australian Naturalists Club Handbook No. 10. Perth.

Story, R. (1982). *Notes on parabolic dunes, winds and vegetation in northern Australia.* CSIRO Division of Water and Land Resources, Technical Paper 43.

Thom, B.G. and Chappell, J. (1975). *Holocene sea levels relative to Australia.* Search, Vol. 6, pp. 90-93.

Tyler, J.P. (1990). *Revegetation with Pilbara seed.* Dampier Salt (Operations) Pty. Ltd. 22 pp.

Watt, B.G. (1976b). *Coastal dune stability and the effect of meteorological conditions and vegetation.* International Journal of Biometeorology. Vol. 21, pp. 51-55.

Western Australian Water Resources Council (1986). *Water conservation through good design.* Publication WRC 4/86. Perth, Western Australia. 133 pp.

White, G.F. (1978). *Natural hazards management in the coastal zone.* Shore and Beach, Vol. 46, pp. 15-17.

Woodhouse, W.W. (1982). *Coastal sand dunes in the U.S. In* Lewis, R.R. (ed.) *Creation and restoration of coastal plant communities.* CRC Press, Florida.

Woods, P.J. (1980). *Coastal management in Western Australia.* Department of Conservation and Environment, Bulletin 49.

Glossary

Aerial photograph	A photograph of the earth's surface taken from the air. It is usually one of a series taken from an aircraft moving in a systematic pattern at a given altitude, in order to obtain a mosaic for mapping soils, geology, vegetation, etc.
Annual plant	A plant which completes its life-cycle in one year or one growing cycle.
Beach berm (or berm)	The flat to seaward sloping, sand terrace formed by wave action, occurring between the coastline and the dunal landforms to landwards.
Beach face	The (generally steeper sloping) section of the beach berm normally exposed to the action of the wave swash.
Biennial	A plant that normally requires two growing seasons to complete its life-cycle.
Blowout	Bare sandy, often elongate hollows formed by wind erosion of pre-existing sand dunes or sandy landforms. These are mobile landforms which advance downwind.
Breakers	A wave breaking at the coastline, or over a reef or longshore bar. Spilling breakers break gradually over a distance; plunging breakers tend to curl over and break with a crash; and surging breakers peak up, but instead of spilling or plunging, they surge up the beach face.
Brushing	The process of covering an area of bare sand with a layer of tree prunings and/or branches. Also called brush matting.

Calcrete	A hard layer forming the deflated surface of, or occurring within, dunes formed by cementing of the sand grains by calcium carbonate under alternating wetting and drying conditions.
Coastal accretion	The deposition of sand onto the beach through wave action, causing the shoreline to build seawards (also known as coastal progradation).
Coastal erosion	The removal of sand from the beach and foredunes by wave action, causing the shoreline to retreat landward.
Coastal recession	Retreat of the shoreline due to short term catastrophic coastal erosion during storms, or progressively over a longer time due to a nett loss of sand in the nearshore zone.
Coastline	The line that forms the boundary between the land and the sea.
Continental shelf	The gentle sloping, shallow submerged platform surrounding the continent, bounded on its seaward margin by an abrupt change in slope down to the depths of the oceans.
Cover crop	An annual grass species that is used to temporarily stabilise bare areas of sand.
Culm	Rooted plantlet formed by sprouting at the base of the parent plant.
Cusped beach	Low mounds separating crescent-shaped troughs formed along the beach face, often spaced at regular intervals.
Cyclone (tropical)	An intensive tropical depression in which winds spiral clockwise inward towards a core of low pressure, with maximum surface wind speeds of 65 knots or more.
Deflation	The removal of loose material from a beach or dune by the wind.

Deflation basin	A sandy or stony depression generally enclosed by parabolic dunes, resulting from removal of sand by wind.
Deflation plain	A more extensive flat area from which sand has been removed by wind, therefore not recognisable as a discrete basin. Often found associated with sand-sheets.
Destabilisation	Damage to, or loss of, the vegetation of stable coastal dunes by natural and human causes.
Dune rehabilitation	The process of restoring degraded dunes to prevent continued erosion and to restore their previously existing environmental qualities.
Dune stabilisation	The process of controlling sand movement (erosion) on coastal dunes.
Ecological succession	The orderly sequence of changes in a plant community during the development of vegetation in an area. Includes all changes which take place from the initial colonisation of a previously unoccupied area, through the maturation of that vegetation, to a stable or climax community which is in balance with the environment. Such a primary succession may take many years to complete. A secondary succession can occur where the original vegetation has been destroyed, e.g. destabilisation of coastal dunes. This secondary succession usually can be completed in a shorter time.
Estuary	The lower saline or brackish parts of rivers which discharge into the ocean and are subject to the rise and fall of the tides. In Western Australia, estuaries may be seasonally or permanently closed off from the ocean by sand bars.
Foredune	The vegetated sand dune occurring immediately inland from the beach. Also called a frontal dune or primary dune. Foredunes are vegetated with primary dune colonisers. The foredune marks the seaward limit of permanent vegetation.

Glacial phase	The period of time experiencing the climatic conditions associated with a glacial period or Ice Age.
Headland	An erosion-resistant promontory or elevated landform projecting seawards of the general alignment of the coast.
Heath vegetation	Vegetation complex dominated by shrubs 0.5 to 2 m tall where the percentage foliage cover is greater than 70%. Heath vegetation gives an impression of being very dense.
Herb	A non-woody plant whose aerial portion naturally dies to the ground at the end of the growing season.
Hinterland	The region occurring inland of the coastal environment, i.e. the region no longer particularly influenced by coastal processes.
Hydromulching	The spraying of material containing seed mixed with paper or wood pulp, and often fertilisers.
Ice Ages	Glacial periods. Prolonged periods over the previous 2 million years when the earth's temperature was lowered, the Polar Ice Caps spread to cover a greater area, and sea level fell to much lower levels than at present.
Incipient foredune	'Starting' or 'seed' foredune. Accumulations of sand occurring around primary dune colonisers, often fronting the (established) foredune, which may in time develop into a foredune if not eroded by winds or waves.
Indigenous plants	Plants native to a region or a country; not introduced or imported.
Interglacial phase	The period between successive Ice Ages, when the earth's temperature increased, melting some of the Polar Ice Caps, hence raising the level of the oceans.
Land breeze	Winds blowing from the land to the sea, because of the different rates of cooling between land and sea at night.

Littoral current	The current created in the littoral zone due to the swell or wind waves reaching the coast at an angle. Littoral currents move along the coast.
Littoral drift	The sediment moved in the littoral zone by littoral currents.
Littoral zone	An indefinite zone extending from the coastline to just beyond the breaker zone. The area influenced by waves.
Longshore bar	A submerged linear ridge of sand built by waves and currents, occurring in the nearshore zone. Longshore bars are generally parallel to the coastline.
Longshore trough	The linear depression associated with a longshore bar or bars.
Mobile dunes	Landforms comprising bare sand which move under the action of wind. Includes blowouts and sand-sheets.
Mulching	The process of covering areas of bare sand with a layer of material (usually organic) to prevent sand movement and to minimise moisture loss from the surface.
Nearshore basin	A deep (greater than about 20 m) basin occurring within the generally much shallower nearshore zone. An area within which sediments tend to accumulate.
Nearshore zone	The submerged area of coast below low water mark to depths of about 20 m, over which wave energy can disturb the sediments on the sea floor.
Parabolic dune	A U-shaped dune, vegetated with coastal species, which has formed under the influence of wind.
Perennial plant	Plants with a life span extending over more than two growing seasons (years). Usually 'woody' plants.
Prevailing winds	The direction of the dominant or most frequent winds.

Primary dune coloniser	Plants growing at the back of the beach which have special adaptations to enable them to thrive in that extremely harsh environment and to trap and bind sands to create dunes.
Relict foredune	A low, linear, vegetated sand ridge which formed as a foredune but has since been left behind by coastal accretion. Numerous relict foredunes can be formed behind the (active) foredune, creating a relict foredune plain.
Relict foredune plain	See relict foredune.
Renourishment (of beaches)	Artificially supplementing the sand supply to a beach by importing sand.
Rhizome	Horizontal underground stems characteristic of plants (such as ginger and spinifex) which have nodes from which roots and vertical plant shoots can develop.
Runup	See swash.
Salt spray	Microscopic particles of salts present in sea water formed by evaporation of sea spray droplets. Salt spray is particularly abundant in the air close to the coastline where breaking waves create abundant sea spray droplets.
Sand-sheet	An extensive area of unconsolidated sand moving across a landscape under the influence of wind.
Sand-trapping fence	A fence designed to trap sand to form a dune. Also called dune-forming fences.
Sea breeze	Winds blowing from the sea to the land, because of the different rate of heating between land and sea during the day.
Secondary dunes	Generic term for those dunes occurring inland of the foredune which are progressively less exposed to coastal processes further inland. The dunes are generally vegetated with heath to shrubland plant species depending on the degree of exposure to winds and salt spray.

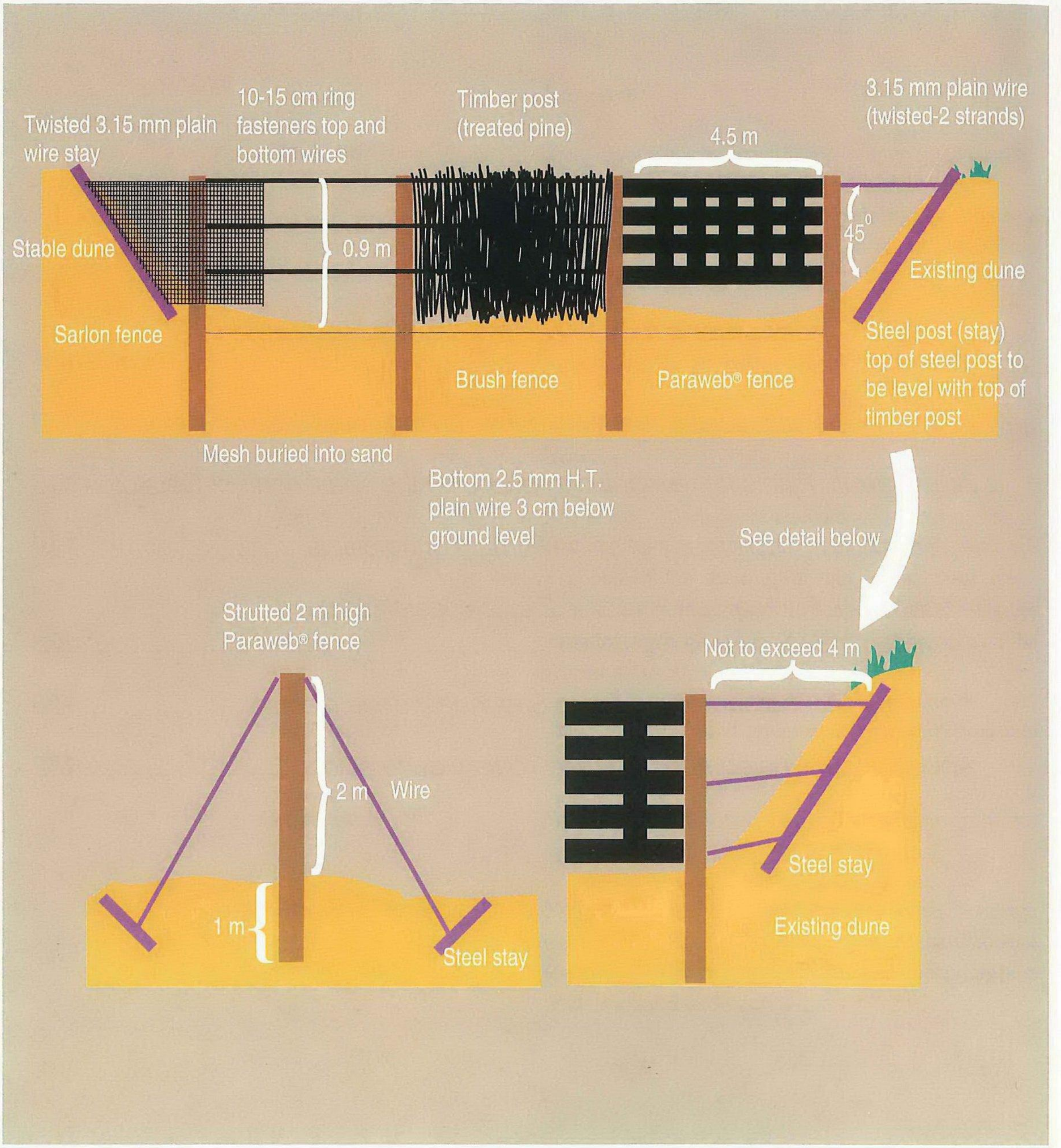
Secondary dune coloniser	Plants which are adapted to grow within the coastal environment, but inland from the foredune where sand movement, salt spray and wind energy is reduced.
Shoreline	See coastline.
Shrub	A perennial woody plant usually with several main stems arising from or near the ground; a bush.
Shrubland vegetation	Vegetation complex dominated by shrubs 0.5 to 2 m tall where the foliage cover ranges from 10 to 70%.
Spray-on stabiliser	A material which can be sprayed onto areas of bare sand to protect the sand from wind erosion by forming a surface crust.
Swale	A valley or depression within a dune or between dunes.
Swash	The rush of water up the beach face following the break of a wave. Also known as uprush or runup.
Swell waves	Waves, generated by distant storms, that have travelled beyond their fetch or generating area.
Scarpface (of dune)	The bare, steep frontal slope of dunes generally initiated by wave erosion, which slump under the influence of gravity.
Storm surge	The increased height (relative to mean sea level) reached by waves during storms or cyclones, due to the lower atmospheric pressure and the greater mass of water which is driven up onto the coast during the event.
Tertiary dune species	Plant species, generally tall shrubs to trees, growing in those inland or particularly sheltered parts of the coastal dune environment which are not greatly exposed to the influence of salt-laden winds.

Tidal flat	A flat, often extensive (in the State's north) marshy or muddy, saline plain which is greatly influenced on a daily or less frequent basis by the rise and fall of the tides.
Uprush	See swash.
Wave diffraction	The phenomenon by which energy is transmitted laterally along a wave crest. When part of a train of waves is interrupted by a barrier, such as an island, the effect of diffraction allows waves into the sheltered area behind the barrier.
Water erosion	The removal or movement of unconsolidated material by the action of rainfall runoff.
Wave erosion	The removal of sand and other unconsolidated materials by waves.
Wave refraction	The process by which the direction of a wave moving in shallow water at an angle to the contours is changed. The part of the wave advancing in shallower water moves slower than the part in deeper water, causing the wave crest to bend towards and become aligned with the seabed contours.
Wind erosion	The removal of sand grains and other unconsolidated materials by winds.
Wind waves	Waves generated locally by wind blowing over the sea surface.
Woodland vegetation	Vegetation complex dominated by trees where the foliage cover ranges from 10 to 70%. Trees are the dominant (tallest) structure of woodlands although there may be a well developed understorey.

Appendices

Contents

Sand-trapping fence



Construction details for a sand-trapping fence (after Golinski and Lindbeck, 1979)

Appendix I. Costs of dune stabilisation techniques and construction methods for fences and steps

(Although the costs are listed from an exercise in 1990, the list of requirements which need to be budgeted for, and the relativity of costs, have remained about the same).

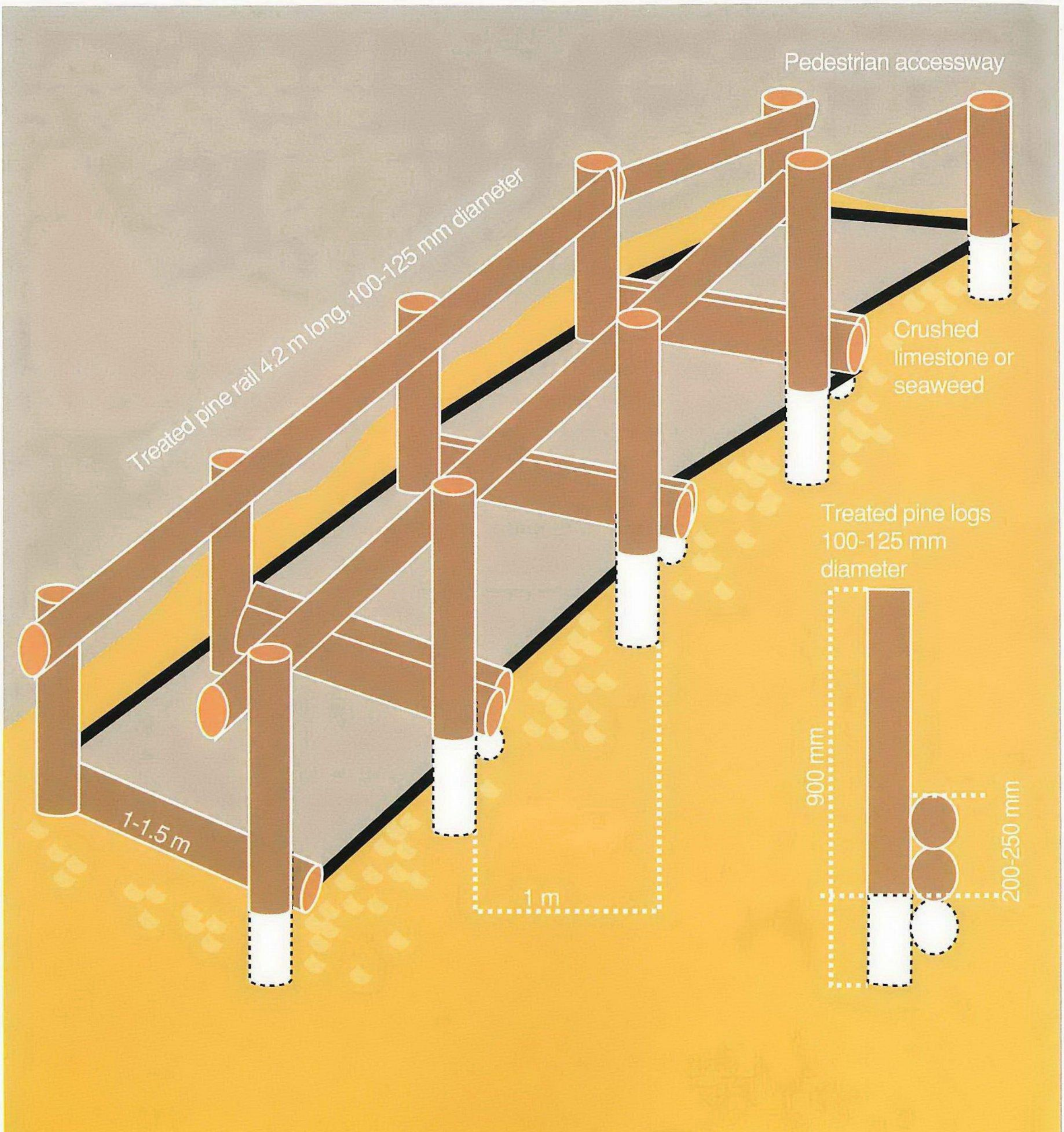
Dune rebuilding

1. Bulldozing $50 to 70/hr	$0.50 to $1.00/cu.m
2. Sand-trapping fence	
(a) Materials	
Paraweb® fence	$10/m (posts and Paraweb®)
Brush fence	$1.50 to $2.50/m (posts, wire and brush)
(b) Erection (Paraweb® or brush fence)	$2 to $3/m
3. Brush on brush	
(a) Brush delivered on site (cost to lay)	$0.50/sq.m
(b) To cut and transport (depending on distance)	$0.50+/sq.m

Mulching

1. Brushing	
(a) Material	
Delivered on site	$nil
Cut and transport	$0.50+/sq.m
(b) Laying	$0.50/sq.m
2. Baled hay	
(a) Cost $2.00/bale (covers 6 sq. m/bale)	$0.33/sq.m
(b) Cartage (depending on distance)	$0.10+/sq.m
(c) Spreading	$0.50/sq.m

Platform steps



Construction details for platform steps

3. Hydromulching

(a) Without seed	$0.20/sq.m
(b) With seed	$0.30/sq.m

Dune planting

1. Seed

Cost
- supplied commercially (see Appendix II and III)
- collected by hand. Cost varies, but probably cheaper than purchasing.

Planting cost	$0.10/sq.m

2. Culms and runners

Marram grass, *Spinifex hirsutus*

To collect and plant	$0.50 to $1.00/sq.m

3. Cover crops (cereal rye, triticale)

(a) Cost of seed (@ $0.20 to $0.50/kg)	$0.00015 to $0.004/sq.m
Cost of fertiliser Agras No.1 bulk (@ $0.34/kg)	$0.0025/sq.m

Note both fertiliser and seed should be applied at the same rate, e.g. 75 kg/ha

(b) Planting (spreading) Seed and fertiliser	$0.01/sq.m

4. Hydromulching

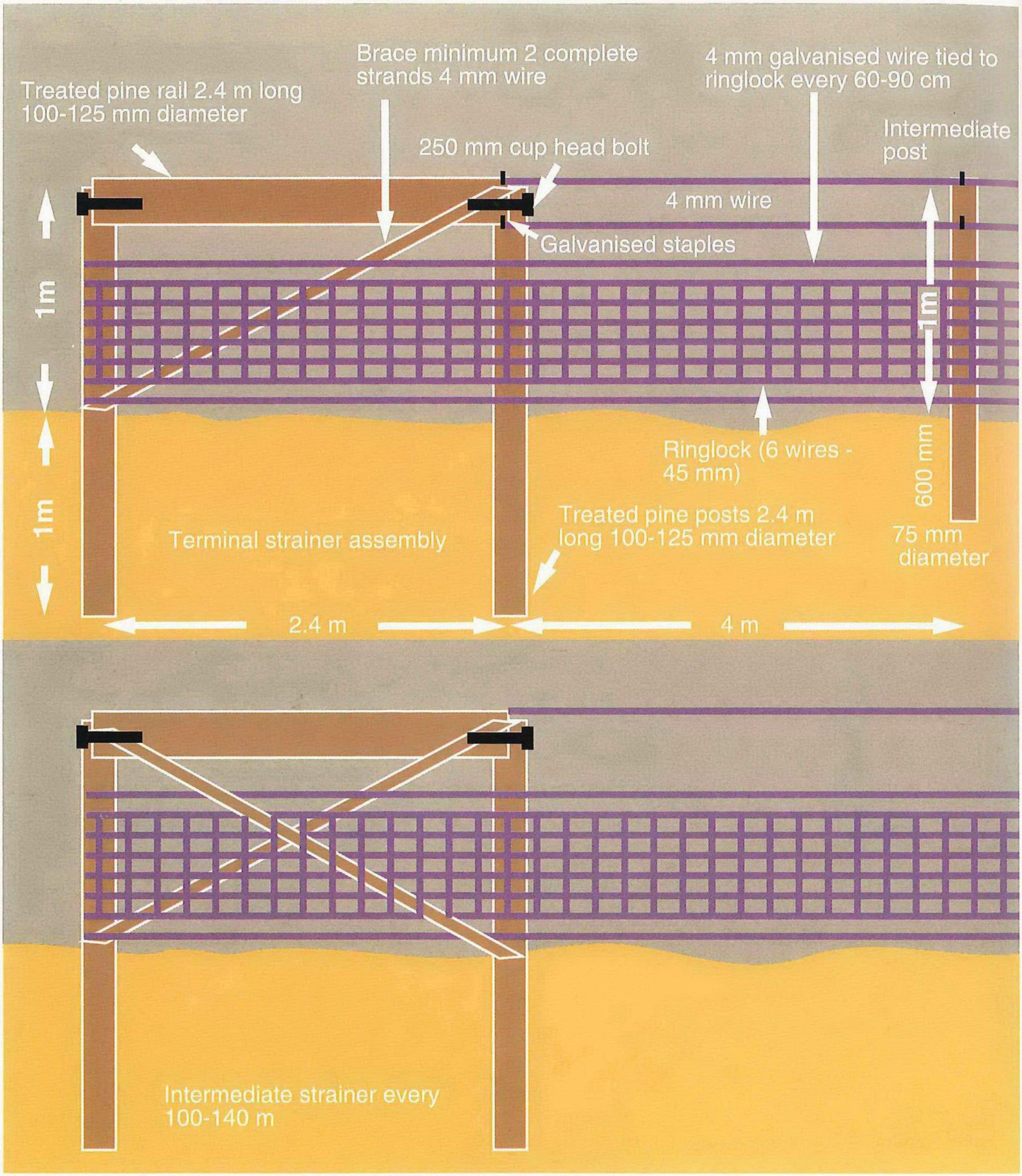
(a) Without seed	$0.20/sq.m
(b) With seed	$0.30/sq.m

5. Seedlings

Seedlings are available through nurseries

Cost (bulk)	$0.04 to $0.10/sq.m
Planting	$0.30/sq.m

Pine post and ringlock fence



Construction details for a post and ringlock fence (after Chalmers, 1983)

Fencing

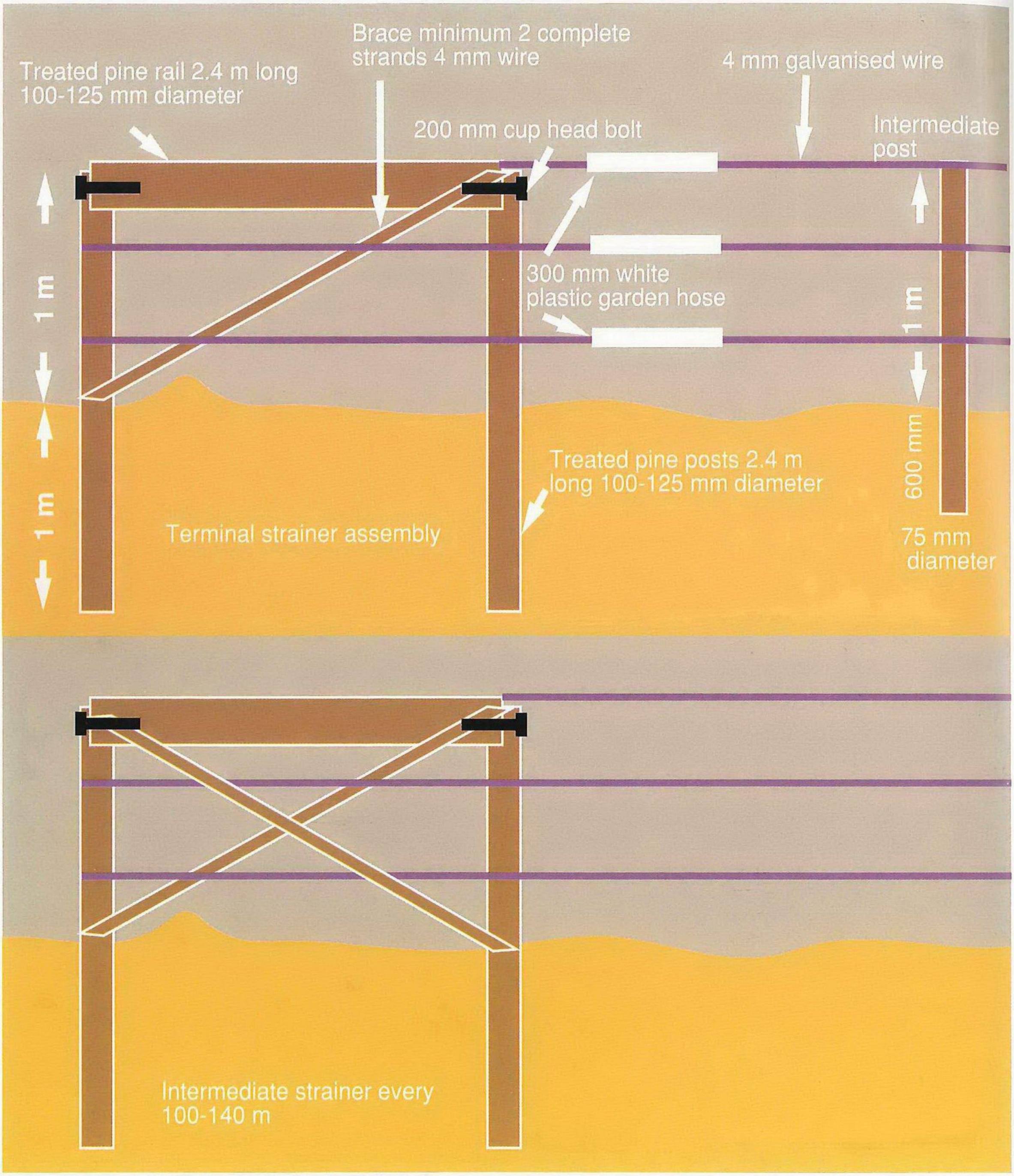
1. Pine post and ringlock

(a) Materials	$2/m
(b) To erect	$2 to $3/m

2. Post and rail

(a) Materials	$7/m
(b) To erect	$2 to $3/m

Pine post and wire fence

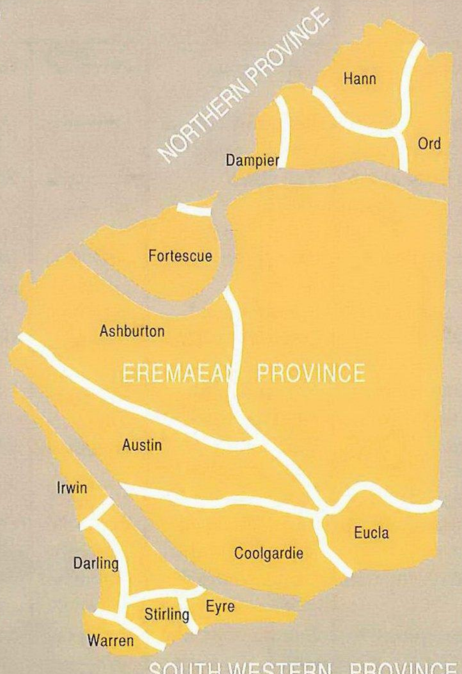


Construction details for a post and wire fence (after Chalmers, 1983)

Map of Western Australia showing division into Botanic Provinces and Districts

This map should be read in conjunction with Appendices II and III.

Northern Province	Eremaean Province	South Western Province
N Widespread in coastal areas of the Northern Province	E Widespread in the coastal areas of the Eremaean Province	S Widespread in the coastal areas of the South Western Province
h Hann Coastal District	au Austin Coastal District	i Irwin Coastal District
o Ord Coastal District	as Ashburton Coastal District	d Darling Coastal District
d Dampier Coastal District		w Warren Coastal District
x Fortescue Coastal District		s Stirling Coastal District
k Kimberley (i.e. Hann and Ord)		e Eyre Coastal District



(after Beard, 1970).

Appendix II. Plants for revegetating dunes on the coast south of Kalbarri

The limited knowledge concerning the distribution of coastal plants in the Coolgardie and Eucla Districts has precluded their consideration in Appendix II of this manual.

Species to plant on foredunes and mobile dunes (see Appendix IV for photographs)

Species	Common name	Growth habit	Annual or perennial	Propagation type	Harvest time	Seed cost $/kg (1990)	Species distribution by botanic province and district (see map and legend)
**Ammophila arenaria*	Marram grass	Tufted grass	Perennial	Culms	June-August		
**Arctotheca populifolia*	Dune arctotheca	Low, soft-leaved herb	Perennial	Seed	December onwards	150	
Atriplex isatidea	Coast saltbush	Tall shrub	Perennial	Seed	September onwards	75	S particularly Si
**Cakile maritima*	Sea rocket	Low shrub	Annual	Seed	December onwards	300	
Isolepis nodosa (formerly *Scirpus nodosus)*	Knotted club-rush	Needle-leaved, brush-like plant	Perennial	Cuttings of rhizomes	June-August		Sidw
Lepidosperma gladiatum	Coast sword sedge	Sword-leaved, sparsely tufted	Perennial	Culms	June-August		Sdw
Salsola kali	Prickly saltwort or roly poly	Low shrub	Annual	Seed	December onwards	50	S
Spinifex hirsutus	Sand spinifex	Large, clumped, spreading grass	Perennial	Cuttings of rhizomes	June-August		Sdw
Spinifex longifolius	Beach spinifex	Large, clumped grass	Perennial	Seed	December onwards	25	S
Tetragonia decumbens	Sea spinach	Succulent ground cover	Perennial	Seed, cuttings	All year	65	S

Species to plant on secondary dunes (see Appendix VI for photographs)

Species	Common name	Growth habit	Annual or perennial	Propagation type	Harvest time	Seed cost $/kg (1990)	Species distribution by botanic province and district (see map and legend)
Acacia cyclops	Red-eyed wattle	Large shrubs in sheltered areas	Perennial	Seed, seedlings	September onwards, nursery	95	Side
Acacia rostellifera	Summer scented wattle	Large shrubs in sheltered areas	Perennial	Seed, seedlings	September onwards, nursery	250	Sid
Acacia saligna	Coojong	Large shrubs in sheltered areas	Perennial	Seed, seedlings	September onwards, nursery	70	Sid
Acanthocarpus preissii	Prickle lily	Few-stemmed, prickly, low shrub	Perennial	Seed	September onwards	280	S
Carpobrotus virescens	Pigface	Succulent ground cover	Perennial	Cuttings	June-August		S
Hardenbergia comptoniana	Wild wisteria	Creeper	Perennial	Seed	November onwards	175	Sdsw
Isolepis nodosa (formerly *Scirpus nodosus)*	Knotted club-rush	Needle-leaved, brush-like plant	Perennial	Cuttings of rhizomes	June-August		Sidw
Melaleuca lanceolata	Rottnest tea-tree	Shrub or tree	Perennial	Seed, seedlings	November onwards, nursery	145	S
Nitraria billardierei	Wild grape	Tangled, medium shrub	Perennial	Seed	September onwards	150	Sidws
Olearia axillaris	Coastal daisy bush	Rounded, medium shrub	Perennial	Seed	February onwards	295	S
**Pelargonium capitatum*	Wild geranium	Low shrub	Perennial	Seed, cuttings	September-November	260	
Rhagodia baccata	Berry saltbush	Tangled, medium shrub	Perennial	Seed	March onwards	200	S
Scaevola crassifolia	Thick-leaved fan flower	Erect, medium shrub	Perennial	Seed	November onwards	300	S
**Secale cereale*	Cereal rye	Single-stemmed grass	Annual	Seed	Seed merchant	0.30	
Senecio lautus	Groundsel	Groundcover	Annual	Seed	September-November		S
Spyridium globulosum	Basket bush	Medium or tall shrub	Perennial	Seed	September onwards	495	Sidws
Templetonia retusa	Cockies tongues	Medium shrub	Perennial	Seed	August onwards	188	Sde
Tetragonia decumbens	Sea spinach	Succulent ground cover	Perennial	Seed, cuttings	All year	65	S
*Triticale		Single-stemmed grass	Annual	Seed	Seed merchant	0.20	

Species for sheltered sites behind dunes (see Appendix VII for photographs)

Species	Common name	Growth habit	Annual or perennial	Propagation type	Harvest time	Seed cost $/kg (1990)	Species distribution by botanic province and district (see map and legend)
Agonis flexuosa	WA peppermint	Shrub or tree	Perennial	Seed, seedlings	October onwards, nursery	280	Sdsw
* *Araucaria heterophylla*	Norfolk Island pine	Tall tree	Perennial	Seed, seedlings	April-June, nursery	65	
**Casuarina equisetifolia*	Horse tail sheoak	Medium tree	Perennial	Seed, seedlings	October onwards, nursery	150	
Eucalyptus platypus	Coastal moort	Small tree	Perennial	Seed, seedlings	January onwards, nursery	175	Sse
Melaleuca lanceolata	Rottnest tea-tree	Shrub or tree	Perennial	Seed, seedlings	November onwards, nursery	145	S
**Paspalum vaginatum*	Salt water couch	Lawn grass	Perennial	Cuttings	During wet season, nursery		
**Tamarix aphylla*	Tamarix or Athol tree	Tree	Perennial	Cuttings	Before the wet season		

NB Tamarix can withstand strong winds (such as around Geraldton) without sand build-up so can be planted behind dunes, for human amenity.

* Denotes introduced and naturalised species.

Appendix III. Plants for revegetating dunes on the coast north of Geraldton

Species to plant on foredunes and mobile dunes (see Appendix IV for photographs)

Species	Common name	Growth habit	Annual or perennial	Propagation type	Harvest time	Seed cost $/kg (1990)	Species distribution by botanic province and district (see map and legend)
Atriplex isatidea	Coast saltbush	Tall shrub	Perennial	Seed	October - December	75	Si,Eau,as
Canavalia rosea (also *C. maritima*)	Wild jack bean	Low spreading shrub	Perennial	Seed	October-March	90	Nkx
Clianthus formosus	Sturt pea	Spreading small shrub	Annual or biennial	Seed	September-December	195	E Nx
Ipomoea brasiliensis (also known as *I. pes-caprae*)	Beach morning glory	Creeper	Perennial	Seed or cuttings	August-† November	220	Eau,as Nkx
Myoporum acuminatum	Boobiala or native myrtle	Medium to tall shrub	Perennial	Seed	September - October	150	Si Eau,as Ndx
Nitraria billardierei	Wild grape	Medium to tall shrub	Perennial	Seed	December - February		Si Eau
Salsola kali	Prickly saltwort or roly poly	Low shrub	Annual	Seed	December onwards	50	S,E,N
Spinifex longifolius	Beach spinifex	Large, clumped grass	Perennial	Seed	March onwards	25	S,E,N
Swainsona pterostylis	Dampier pea	Creeper	Annual	Seed	September-October	150	Eas Nx
Tribulus occidentalis	Perennial caltrop	Creeper	Perennial	Seed or cuttings	September-† November		Eau, as Nkx
Triodia pungens	Soft spinifex	Prickly hummock grass	Perennial	Seed	March onwards	50	Eas Ndxh
Whiteochloa airoides	Sand grass	Tussock grass	Perennial	Seed	March onwards		Eas N

* Denotes introduced and naturalised species.

† Cuttings can be planted during the wet season and following substantial rainfall.

Species to plant on secondary dunes (see Appendix VI for photographs)

Species	Common name	Growth habit	Annual or perennial	Propagation type	Harvest time	Seed cost $/kg (1990)	Species distribution by botanic province and district (see map and legend)
Acacia bivenosa	Two-nerved wattle	Large shrub	Perennial	Seed	September onwards	165	Eas Nx
Acacia coriacea	Leather-leaved wattle	Large shrub (tree in more sheltered locations)	Perennial	Seed	September onwards	90	Eau,as Nkx
Acacia gregorii	Gregory's wattle	Low spreading shrub	Perennial	Seed	September-November	280	Eau
Acacia idiomorpha	Prickly wattle	Low spreading prickly shrub	Perennial	Seed	September-November	150	Si,Eau,as
Acacia ligulata	Dune wattle	Large shrub (small tree in more sheltered locations)	Perennial	Seed	September-November	105	Eau
Acacia morrisonii	Morrison's wattle	Shrub	Perennial	Seed	October-February	80	Eau, as Nx
Acacia murrayana	Sand wattle or sandplain wattle	Tall shrub (or tree in more sheltered areas)	Perennial	Seed	January-February	100	Si Eau,as
Acacia ramulosa	Horse mulga	Spreading shrub	Perennial	Seed	September-November	100	Eau
Acacia sclerosperma	Limestone wattle	Large shrub (tree in more sheltered locations)	Perennial	Seed	October-January	115	Si Eau,as Nx
Acacia trachycarpa	Minni Ritchi	Medium to tall shrub	Perennial	Seed	October-December	175	Eas Nx
Acacia translucens	Glistening wattle	Small spreading shrub	Perennial	Seed	August-November	225	Eas Nkx
Adriana tomentosa		Medium shrub	Perennial	Seed	September-November		Si Eau,as Nx
Brachycome latisquamea	Climbing daisy	Medium to tall shrub	Annual	Seed	September-October		Si Eau
Canavalia rosea	Wild jack bean	Low spreading shrub	Perennial	Seed	October-March	90	Nkx
**Carpobrotus aequilaterus*	Pigface	Succulent ground cover	Perennial	Cuttings, seed	October-† January		Eau
Codonocarpus cotinifolius	Native poplar	Small tree	Perennial	Seed	September-October	200	Eau Nd
Crotalaria cunninghamii	Green bird flower	Medium shrub	Perennial	Seed	October-January	195	Eau,as Nkx

Species to plant on secondary dunes (see Appendix VI for photographs)

Species	Common name	Growth habit	Annual or perennial	Propagation type	Harvest time	Seed cost $/kg (1990)	Species distribution by botanic province and district (see map and legend)
Dodonaea viscosa	Sticky hop bush	Medium shrub	Perennial	Seed	September-November		Eau
Enchylaena tomentosa	Ruby saltbush	Small straggly shrub	Perennial	Seed	April-June		Si E N
Eremophila glabra	Emu bush	Low shrub	Perennial	Seed	October		Si Eau
Eremophila subfloccosa	Yellow emu bush	Small shrub	Perennial	Seed, cuttings	November-† January		Eau
Gomphrena canescens	Pink billy buttons	Medium, soft-stemmed shrub	Perennial	Seed	All year	200	Eau,as Nx
Indigofera monophylla	Single-leafed indigo	Small shrub	Perennial	Seed	September-October	580	Eau Nd
Ipomoea muelleri	Poison morning glory	Shrubby ground cover	Perennial	Seed, cuttings	December-† April		Eau,as Nkx
Ipomoea costata	Native sweet potato or rock morning glory	Shrubby ground cover	Perennial	Seed, cuttings	January-† June		Eau,as Nk
Myoporum acuminatum	Boobiala or native myrtle	Medium to tall shrub	Perennial	Seed	September-October	150	Si Eau,as Ndx
Nitraria billardierei	Wild grape	Medium to tall shrub	Perennial	Seed	December-February		Si Eau
Olearia axillaris	Coastal daisy bush	Rounded, medium shrub	Perennial	Seed	September-November		Si Eau,as Nx
Rhagodia baccata	Berry saltbush	Tangled medium shrub	Perennial	Seed	June onwards		Si Eau
Scaevola crassifolia	Thick leaved fan flower	Erect, medium shrub	Perennial	Seed	September-October		Si Eau,as
Scaevola spinescens	Currant bush or maroon bush	Open, medium prickly shrub	Perennial	Seed	October-November	280	Si E Nxd
Senecio lautus	Groundsel	Groundcover	Annual	Seed	September-November		Si Eau
Stylobasium spathulatum	Pebble bush	Medium to tall spreading shrub	Perennial	Seed	September-November	100	Si Eau,as Nx
Tephrosia rosea	Flinders River poison	Medium shrub	Perennial	Seed	October-November	300	Eas N
Tribulus occidentalis	Perennial caltrop	Creeper	Perennial	Seed, cuttings	September-† November		Eau, as Nkx
Trichodesma zeylanicum	Northern or rough bluebell	Medium, erect, rough herb	Annual	Seed	October-March	300	Si Eas, au N
Triodia pungens	Soft spinifex	Prickly hummock grass	Perennial	Seed	March onwards	50	Eau,as Ndxh

Species for sheltered sites behind dunes (see Appendix VII for photographs)

Species	Common name	Growth habit	Annual or perennial	Propagation type	Harvest time	Seed cost $/kg (1990)	Species distribution by botanic province and district (see map and legend)
Acacia sp. as above							
Acacia ampliceps	Salt wattle	Large shrub to tree	Perennial	Suckers, seed	September-† November	125	Eau,as N
Banksia ashbyi	Ashby's banksia	Tall shrub to tree on red dunes	Perennial	Seed	November-January		Si Eau,as
Brachychiton acuminatus	Northern desert kurrajong	Tree, use only in heavy soils	Perennial	Seed	December-March	140	Eas N
Clerodendrum tomentosum	Woolly clerodendrum	Small to medium tree	Perennial	Seed	October		Eas N
Corchorus elachocarpus	Buttercup	Low shrub	Perennial	Seed	October-November	500	Eau,as Nk
Eucalyptus eudesmioides	Desert mallee	Bushy shrub	Perennial	Seed	July to September		Si Eau
Eucalyptus fruticosa		Small tree	Perennial	Seed	October-December		Eau
Indigofera georgei	Indigo	Ground-covering shrub	Annual	Seed	September-October	200	Eau
Ipomoea muelleri	Poison morning glory	Shrubby ground cover	Perennial	Seed, cuttings	December-† April		Eau,as Nkx
Ipomoea costata	Native sweet potato or rock morning glory	Shrubby ground cover	Perennial	Seed, cuttings	January-† June		Eau,as Nk
Myoporum acuminatum	Boobiala or native myrtle	Medium to tall shrub	Perennial	Seed	September-October	100	Si Eau,as Nd
Pittosporum phylliraeoides	Native willow or weeping pittosporum	Tall shrub to small tree	Perennial	Seed	May-June		Si Eau,as Nx
Rhagodia baccata	Berry saltbush	Tangled medium shrub	Perennial	Seed	June onwards		Si Eau
Solanum orbiculatum	Round leaf solanum or bush tomato	Small prickly shrub	Perennial	Seed	December onwards		Si Eau
Stylobasium spathulatum	Pebble bush	Medium to tall spreading shrub	Perennial	Seed	September-November	100	Si Eau,as Nx
**Tamarix aphylla*	Tamarix or Athol tree	Tree	Perennial	Cuttings, nursery seedlings	Before wet season		

Appendix IV. Photographs of some Primary dune plants

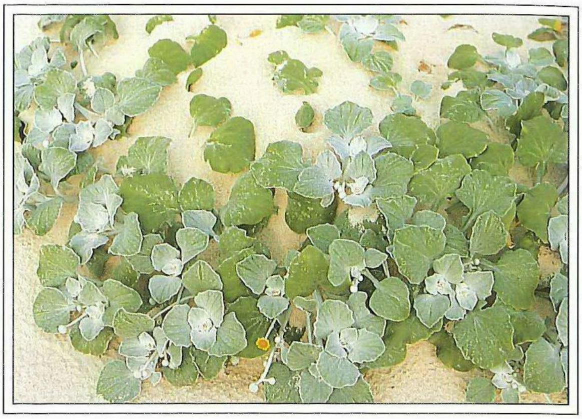
Species south of Kalbarri

Ammophila arenaria	Marram grass
Arctotheca populifolia	Dune arctotheca
Atriplex isatidea	Coast saltbush
Cakile maritima	Sea rocket
Isolepis nodosa (formerly *Scirpus nodosus)*	Knotted club-rush
Lepidosperma gladiatum	Coast sword sedge
Spinifex hirsutus	Sand spinifex
Tetragonia decumbens	Sea spinach

Species north of Geraldton

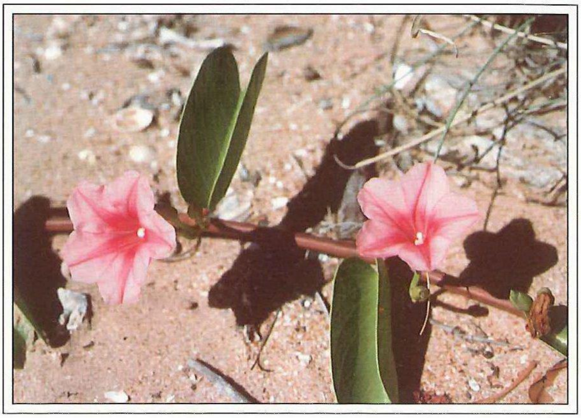
Canavalia rosea	Wild jack bean
Clianthus formosus	Sturt pea
Ipomoea brasiliensis	Beach morning glory
Salsola kali	Prickly saltwort
Spinifex longifolius	Beach spinifex
Swainsona pterostylis	Dampier pea
Tribulus occidentalis	Perennial caltrop
Triodia pungens	Soft spinifex
Whiteochloa airoides	Sand grass

Ammophila arenaria - Marram grass

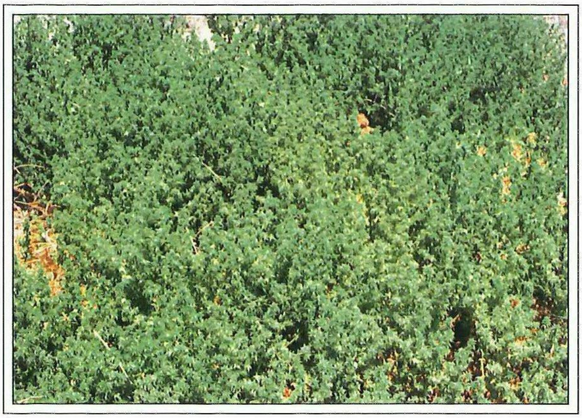


Arctotheca populifolia - Dune arctotheca

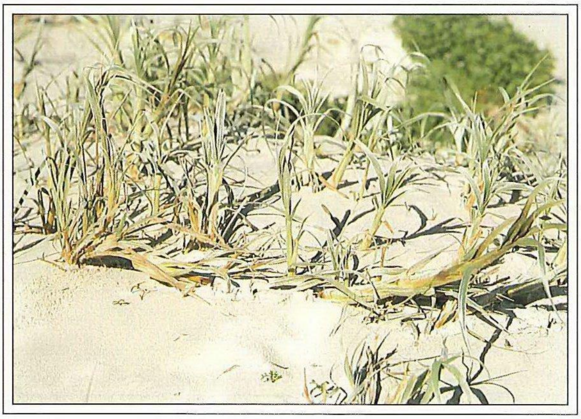
Cakile maritima - Sea rocket



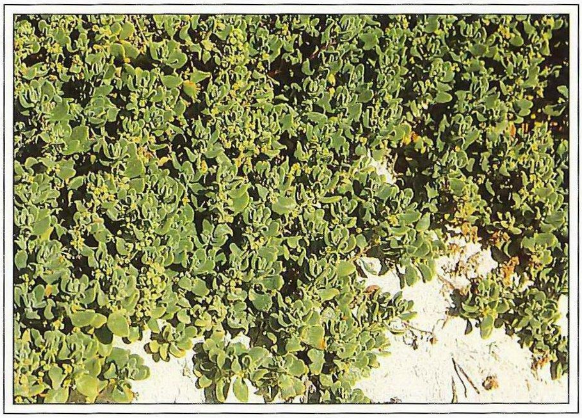
Ipomoea brasiliensis - Beach morning glory



Salsola kali - Prickly saltwort



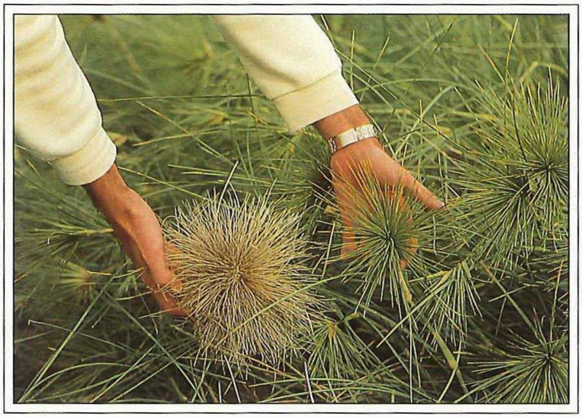
Spinifex hirsutus - Sand spinifex



Tetragonia decumbens - Sea spinach

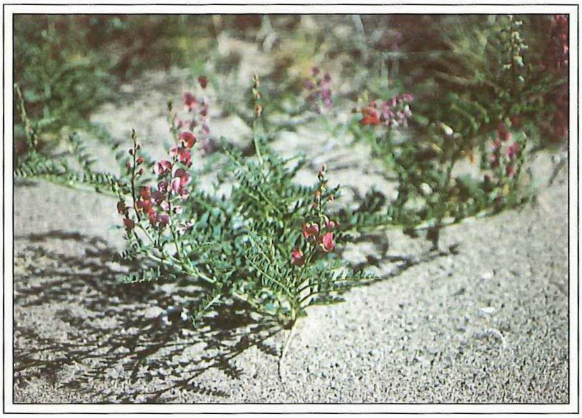
Canavalia rosea - Wild Jack bean

Clianthus formosus - Sturt Pea



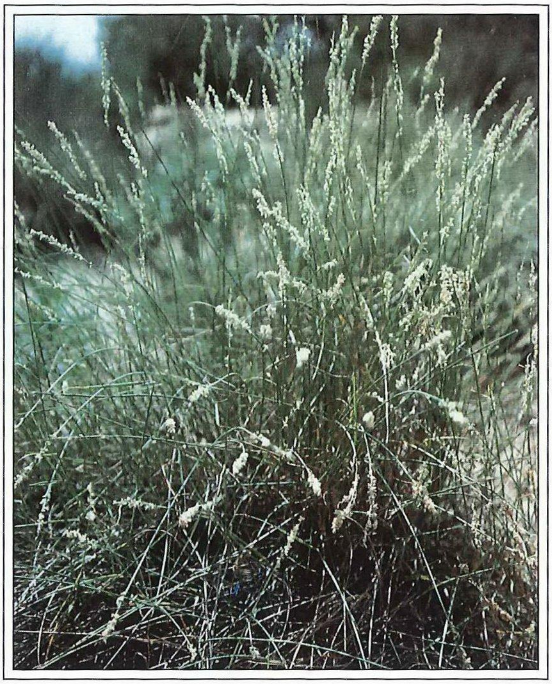
Spinifex longifolius (female flower) - Beach spinifex

Isolepis nodosa - Knotted club-rush



Swainsona pterostylis - Dampier pea

**Tribulus occidentalis* - Perennial caltrop



Whiteochloa airoides

Triodia pungens- Soft spinifex

Lepidosperma gladiatum - Coast sword sedge

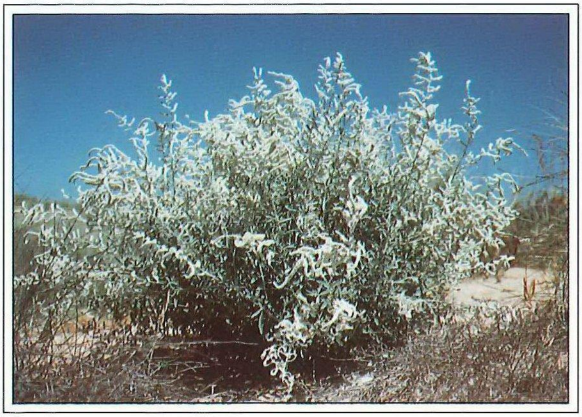
Atriplex isatidea - Coast saltbush

Appendix V. Photographs of some Exotic coastal plants; not recommended for revegetation

Aerva javanica	Kapok bush
Cenchrus ciliaris	Buffel grass
Thinopyrum distichum	Sea wheat
Ehrharta villosa	Pyp grass
Oenothera drummondii	Evening primrose
Arctotis stoechadifolia	Swanbourne daisy
Euphorbia paralias	Sea spurge
Trachyandra divaricata	Onion weed

Cenchrus ciliaris - Buffel grass

Trachyandra divaricata - Onion weed

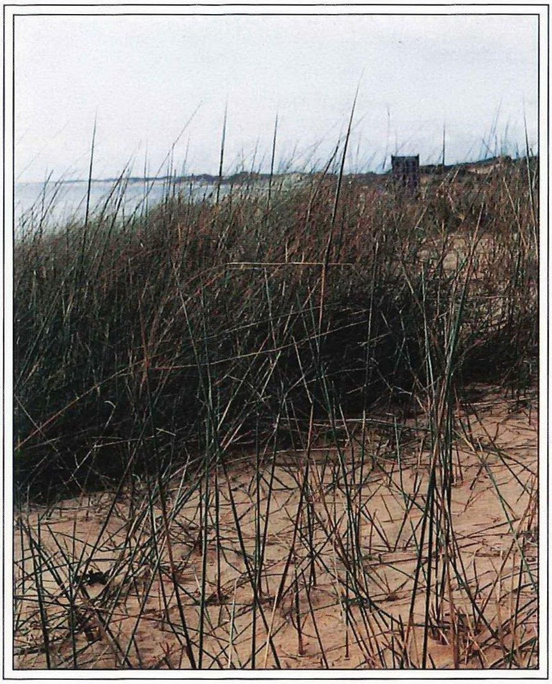


Aerva javanica - Kapok bush

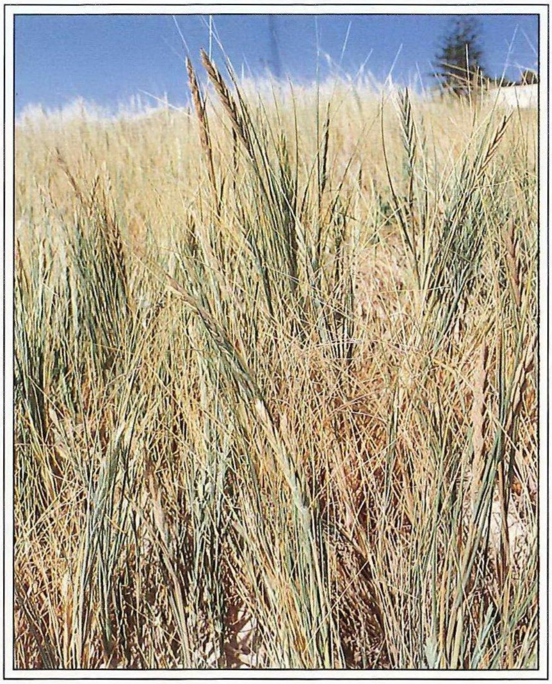
Euphorbia paralias - Sea spurge

Arctotis stoechadifolia - Swanbourne daisy

Oenothera drummondii - Evening primrose



Ehrharta villosa - Pyp grass



**Thinopyrum distichum* - Sea wheat

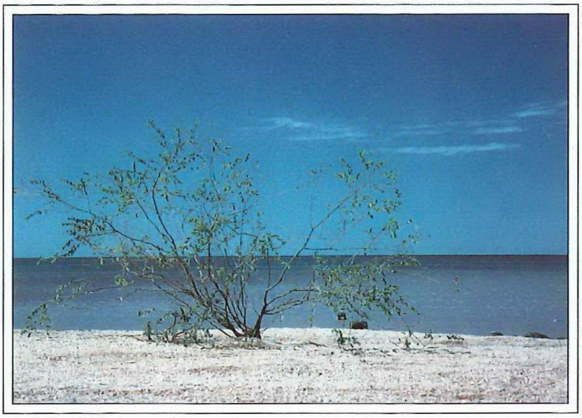
Appendix VI. Photographs of some Secondary dune plants

Species north of Geraldton

Acacia bivenosa	Two-nerved wattle
Acacia coriacea	Leather-leaved wattle
Acacia ligulata	Dune wattle
Acacia sclerosperma	Limestone wattle
Acacia trachycarpa	Minni Ritchi
Acacia translucens	Glistening wattle
Adriana tomentosa	
Crotalaria cunninghamii	Green bird flower
Gomphrena canescens	Pink billy buttons
Indigofera monophylla	Single-leafed indigo
Scaevola spinescens	Currant bush or Maroon bush
Tephrosia rosea	Flinders River poison
Trichodesma zeylanicum	Northern or rough bluebell

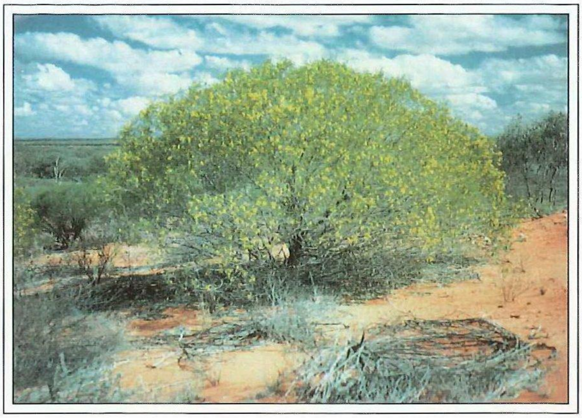
Species south of Kalbarri

Acacia cyclops	Red-eyed wattle
Acacia rostellifera	Summer scented wattle
Acacia saligna	Coojong
Acanthocarpus preissii	Prickle lily
Carpobrotus virescens	Pigface
Hardenbergia comptoniana	Wild wisteria
Nitraria billardierei	Wild grape
Olearia axillaris	Coastal daisy bush
Pelargonium capitatum	Wild geranium
Rhagodia baccata	Berry saltbush
Scaevola crassifolia	Thick-leaved fan flower
Secale cereale	Cereal rye
Spyridium globulosum	Basket bush
Templetonia retusa	Cockies tongues



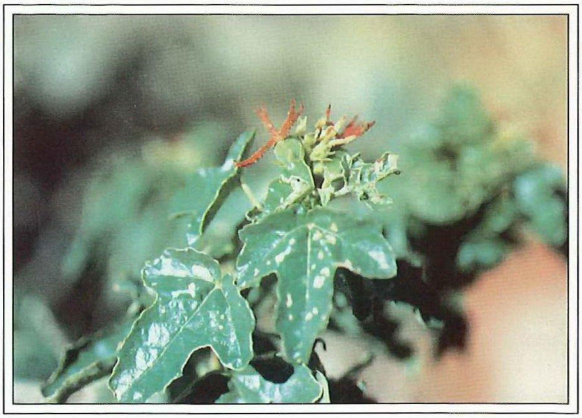
Acacia bivenosa - Two nerved wattle

Acacia coriacea - Leather-leaved wattle

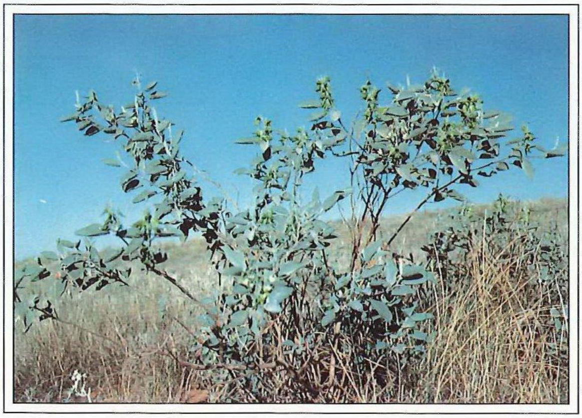


Acacia ligulata - Dune wattle

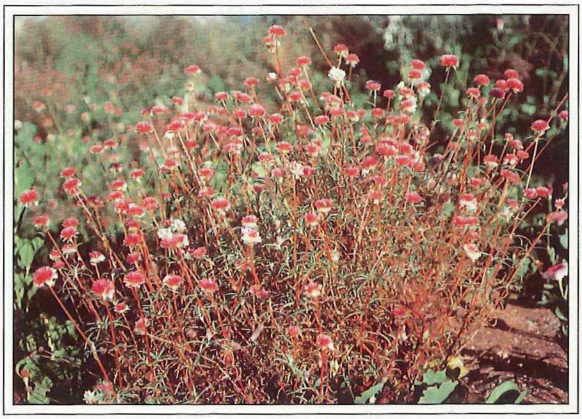
Acacia sclerosperma - Limestone wattle



Adriana tomentosa

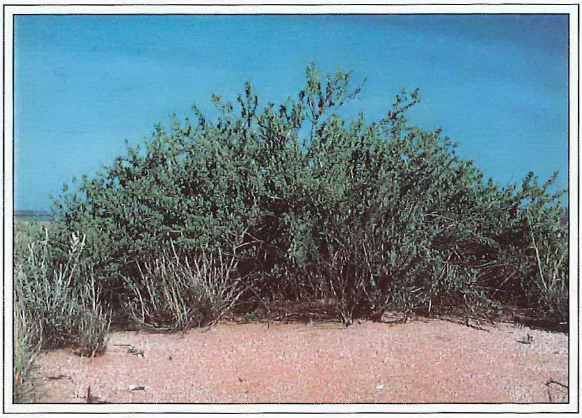


Crotalaria cunninghamii - Green bird flower

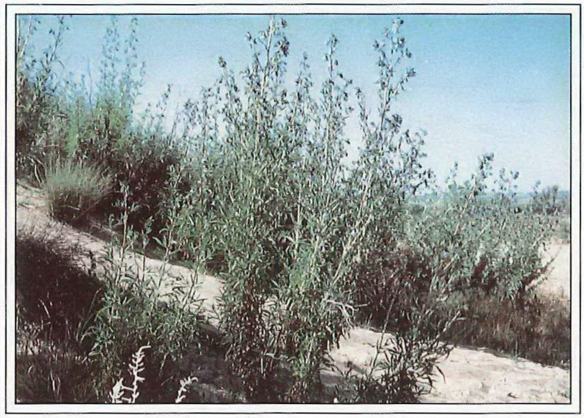


Gomphrena canescens - Pink billy buttons

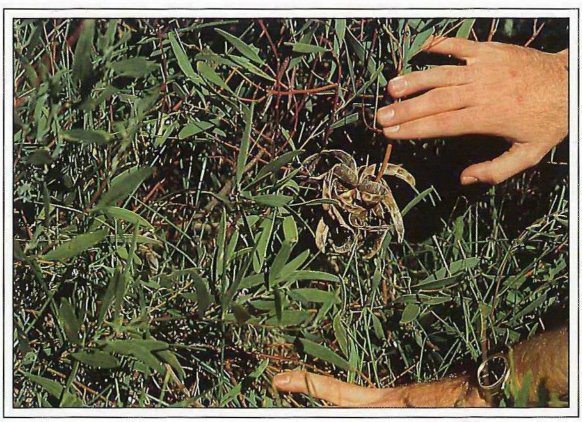
Indigofera monophylla - Single leafed indigo



Scaevola spinescens - Currant bush or Maroon bush



Trichodesma zeylanicum - Northern blue bell

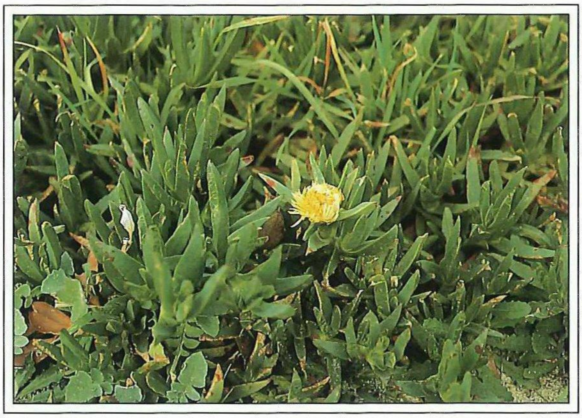


Acacia cyclops - Red-eyed wattle

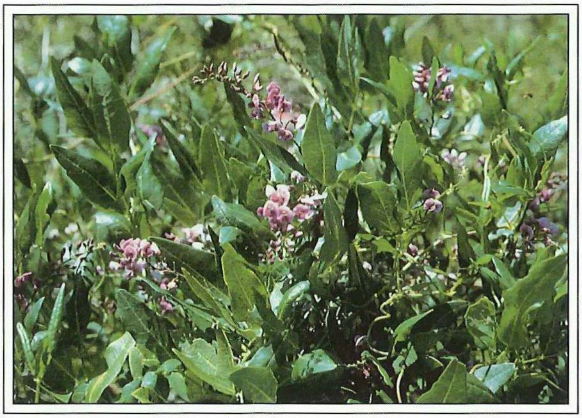
Acacia rostellifera - Summer scented wattle

Acacia saligna - Coojong

Acanthocarpus preissii - Prickle lily

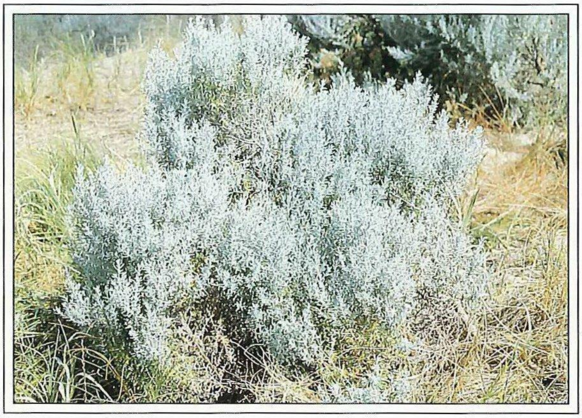


**Carpobrotus virescens* - Pig face

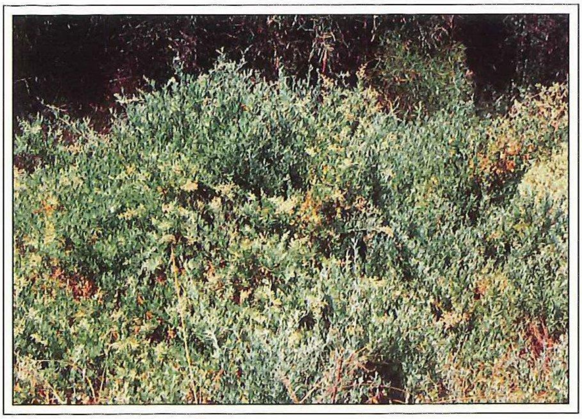


Hardenbergia comptoniana - Wild wisteria

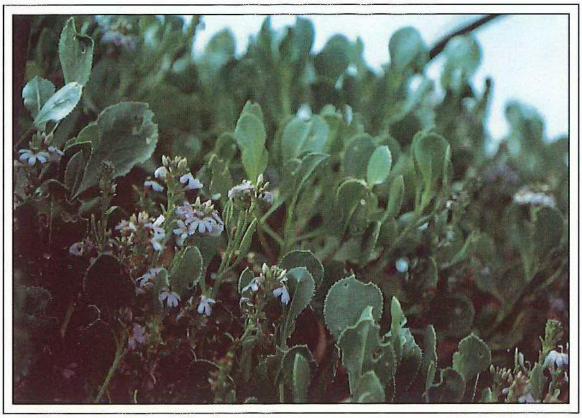
Nitraria billardierei - Wild grape



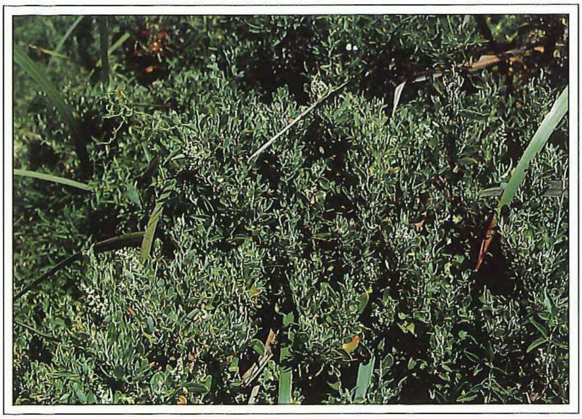
Olearia axillaris - Coastal daisy bush



Rhagodia baccata - Berry saltbush



Scaevola crassifolia - Thick-leaved fan flower

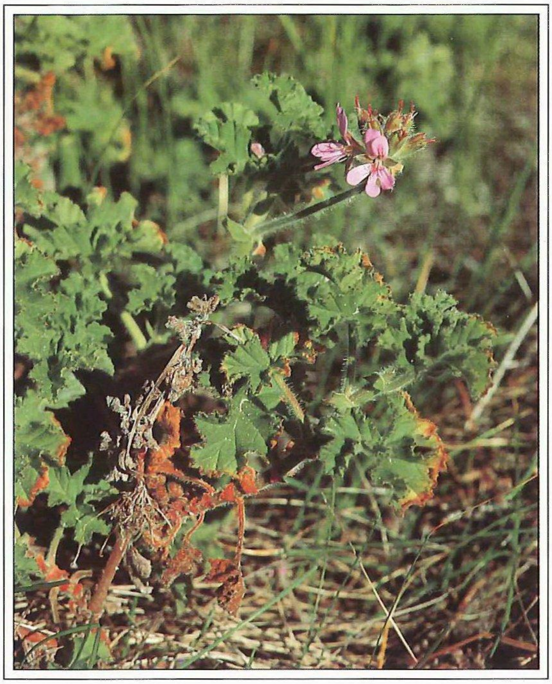


Spyridium globulosum - Basket bush

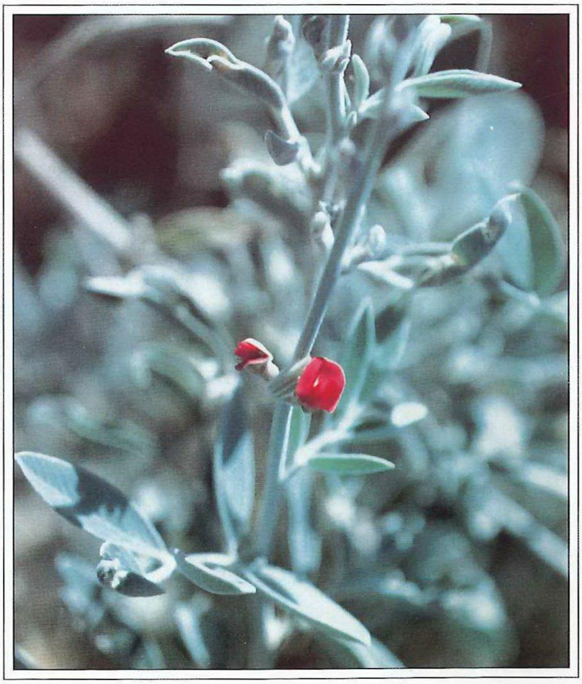
Templetonia retusa - Cockies tongues

Secale cereale - Cereal rye

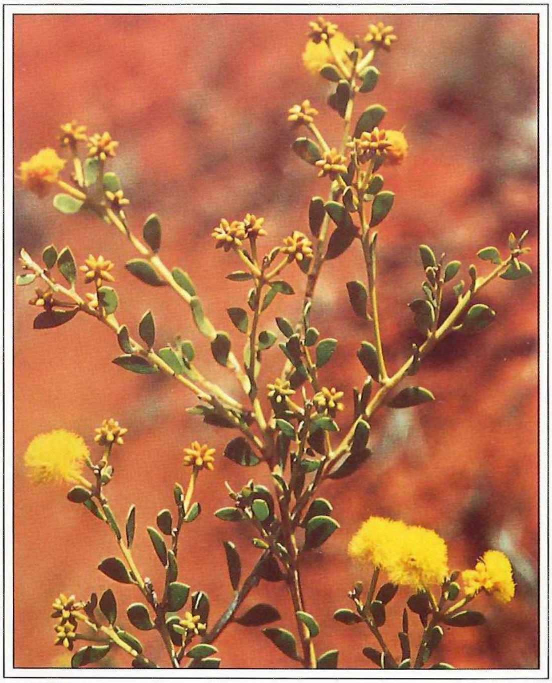
Acacia trachycarpa - Minni ritchi



**Pelargonium capitatum* - Wild geranium



Tephrosia rosea - Flinders River poison



Acacia translucens - Glistening wattle

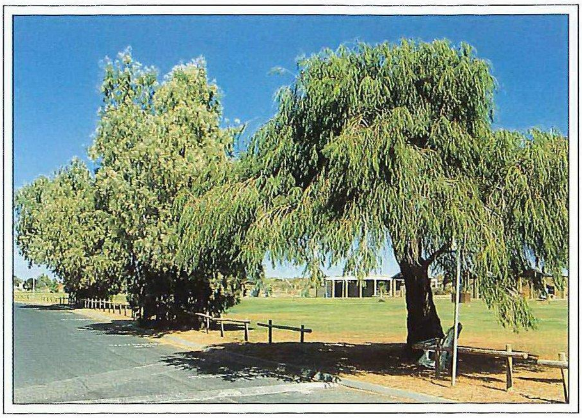
Appendix VII. Photographs of some Tertiary dune plants

Species south of Kalbarri

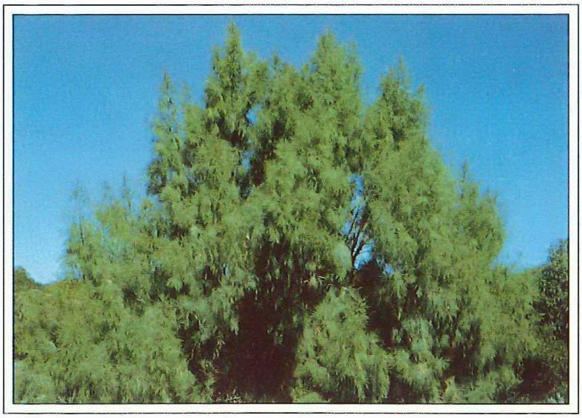
Agonis flexuosa	W.A. peppermint
Araucaria heterophylla	Norfolk Island pine
Casuarina equisetifolia	Horse tail sheoak
Eucalyptus platypus	Coastal moort
Melaleuca lanceolata	Rottnest tea-tree
Tamarix aphylla	Tamarix or Athol tree

Species north of Geraldton

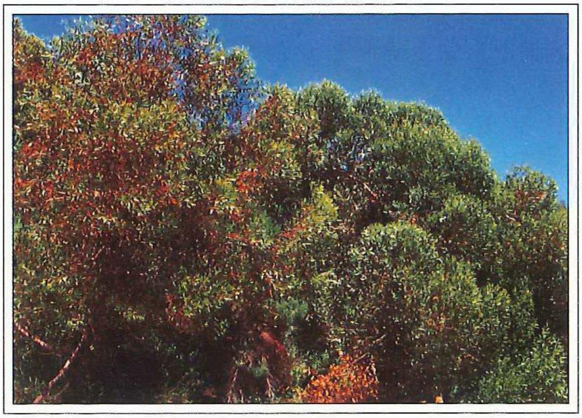
Acacia ampliceps	Salt wattle
Brachychiton acuminatus	Northern desert kurrajong
Clerodendrum tomentosum	Woolly clerodendrum



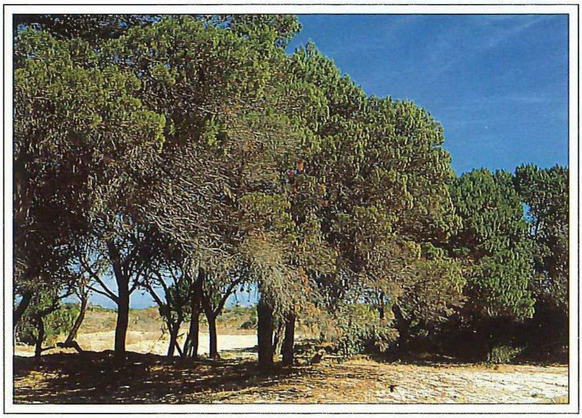
Agonis flexuosa - Western Australian peppermint



**Tamarix aphylla* - Tamarix or Athol tree

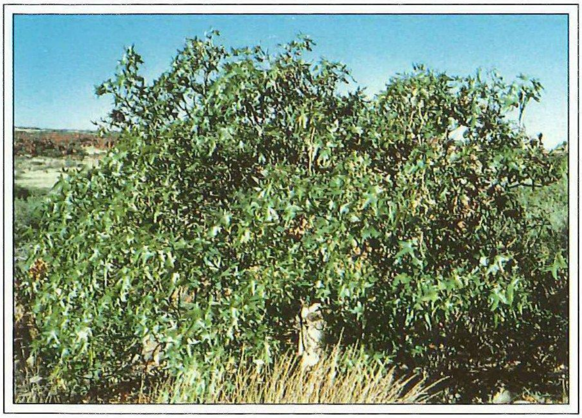


Eucalyptus platypus - Coastal moort

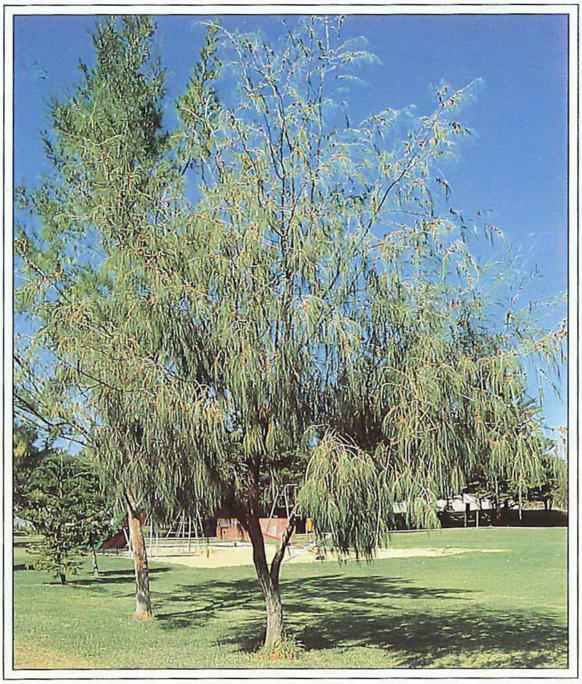


Melaleuca lanceolata - Rottnest tea-tree

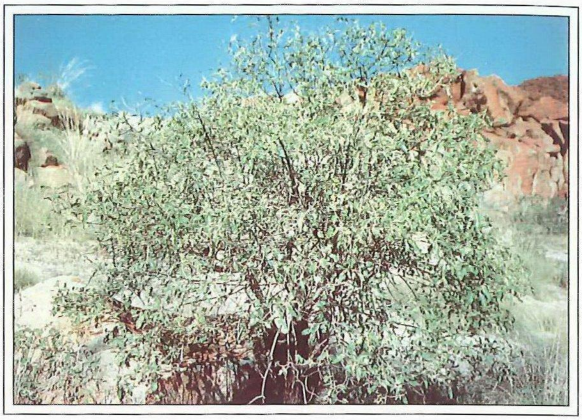
Acacia ampliceps - Salt wattle



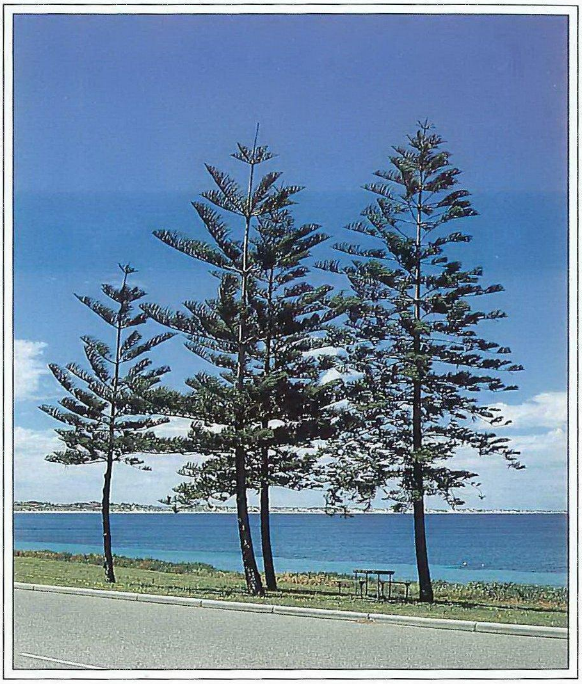
Brachychiton acuminatus - Northern desert kurrajong



Casuarina equisetifolia - Horse tail sheoak



Clerodendrum tomentosum - Woolly clerodendrum



**Araucaria heterophylla* - Norfolk Island pine

1121/3544 1000