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Article

Construction of an Environmentally Sustainable Development on a Modified Coastal Sand Mined and Landfill Site—Part 2. Re-Establishing the Natural Ecosystems on the Reconstructed Beach Dunes

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Abstract: Mimicking natural processes lead to progressive colonization and stabilization of the reconstructed beach dune ecosystem, as part of the ecologically sustainable development of Magenta Shores, on the central coast of New South Wales, Australia. The retained and enhanced incipient dune formed the first line of storm defence. Placement of fibrous *Leptospermum* windrows allowed wind blown sand to form crests and swales parallel to the beach. Burial of Spinifex seed head in the moist sand layer achieved primary colonization of the reconstructed dune and development of a soil fungal hyphae network prior to introduction of secondary colonizing species. Monitoring stakes were used as roosts by birds, promoting re-introduction of native plant species requiring germination by digestive tract stimulation. Bush regeneration reduced competition from weeds, allowing

native vegetation cover to succeed. On-going weeding and monitoring are essential at Magenta Shores until bitou bush is controlled for the entire length of beach. The reconstructed dunes provide enhanced protection from sand movement and storm bite, for built assets, remnant significant vegetation and sensitive estuarine ecosystems.

Keywords: coastal erosion; revegetation; Spinifex; fungal hyphae; sustainable development; bitou bush

1. Introduction

This paper describes how the natural dune ecosystems of the Coastal Protection Zone (CPZ) were restored to increase protection from storm and sand erosion, for the Magenta Shores development on the central coast of New South Wales, Australia. The Coastal Protection Zone at Magenta Shores fronts 2.3 km of the exposed approximately 7.5 km long Tuggerah Beach (Figure 1). Natural erosion risk at Tuggerah Beach has been increased as a result of previous sand mining [1].

Figure 1. Site location and location of CPZ overlaid on 2007 Google Earth Image.

Beaches and dunes are part of natural coastal defences [2]. Restoration of the natural beach dune ecosystems at Magenta Shores was directed to reducing erosion risk from storm bite and sand movement. This increased protection of the built assets, environmentally significant vegetation and sensitive estuarine systems [1].

At commencement of the development, approximately 2 km of the Coastal Protection Zone (CPZ) and the coastal strip to the south had more than 66 percent cover by exotic species. Only the northern third of the CPZ had more than 50 percent native component, with sufficient potential for assisted natural regeneration.

2. Vegetation and Sand Stability in 2004

Prior to commencement of the Magenta Shores project in 2004, mineral sand mining had resulted in a modified landform, establishment of exotic species, loss of native vegetation and reduction of soil binding fungi. The extraction of the heavy mineral component re-sorted the sands and destroyed the natural dune profile [1]. To stabilise the sand surface, the South African dune plant *Chrysanthemoides monilifera* subsp. *rotundata* (bitou bush) was widely planted [3]. More intense establishment of bitou bush occurred close to the township of the North Entrance, immediately south of Magenta Shores.

Bitou bush deleteriously affects the emergence and growth of seedlings of the dominant native dune species *Acacia longifolia* subsp. *sophorae* and other native dune species [4,5]. It alters soil properties through increased litter that promotes juvenile bitou bush growth rates and simultaneously impairs the establishment of native species [6].

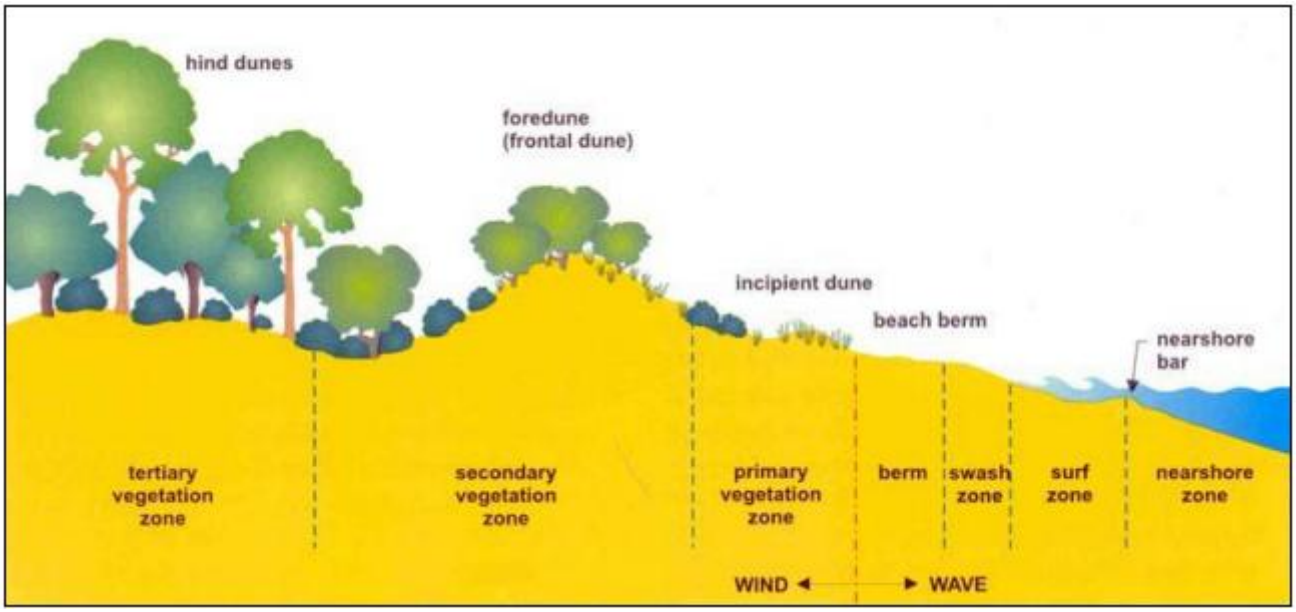
In 2004, thirty years post mining, the consequential landform for much of the Magenta Shores CPZ consisted of highly erodible steep faced dune slopes, covered by monostands of bitou bush (Figure 2).

Figure 2. Eroded landform dominated by bitou bush post sand mining.

3. Relationship between Vegetation, Mycorrhiza and Landform

In a stable dune ecosystem the landform consists of an incipient dune, followed by the foredune and landward by a hind dune (Figure 3).

Figure 3. Landform of a stable dune ecosystem [7].



On the central coast of New South Wales, *Spinifex sericeus* (Spinifex) is the primary native coloniser of the incipient dune. The incipient dune is an active sand zone, with accretion in storm-free periods and loss in storms. Spinifex is adapted to survive, move with, and loosely hold these shifting sands. Spinifex rapidly naturally colonizes the incipient dune from seed washed on shore by springtides [8]. For Spinifex germination, seed burial by sand is necessary and the seedling will emerge from depths as great as 12.5 cm [9]. During the early colonisation stage, areas with highest densities of Spinifex seedlings become the locus of maximum sand deposition [8]. Vigorous growth of Spinifex on dynamic sections of dunes is possibly stimulated by sand deposition [9]. Seaward growth of Spinifex rhizomes produces a gradual seaward translocation of aeolian sand deposition and eventual formation of a second incipient foredune [8].

On the seaward foredune on the central coast of New South Wales, the early colonisers Spinifex and *Carpobrotus glaucescens* (Pigface) are gradually replaced by secondary colonising species including *Scaevola calendulacea*, *Lomandra longifolia, Imperata cylindrica, Ficinia nodosa, Kennedia rubicunda, Correa alba, Acacia longifolia* subsp. *sophoreae* and *Leucopogon parviflorus.* The landward foredune is dominated by *Leptospermum laevigatum* and *Monotoca elliptica.*

In 2004 at Magenta Shores, there was a marked difference between the north and south ends of the CPZ; in the slope of the dunes and the width of the incipient foredune [1] (Figure 4). This difference in landform was related to the vegetation composition. In the south, bitou bush dominated areas had a highly erodible steep landform; with slopes of up to 30 degrees and teepee shaped sand mounds around bitou bush roots; separated by bare, wind eroded sand (Figures 2 and 4). Here, native vegetation was restricted to a narrow band of Spinifex on the poorly developed incipient dune. Further inland the

occassional native species was interspersed between monostands of bitou bush. Towards the north, areas with greater native component had a greater volume of sand in the beach dune, a more even gradient of about 10 degrees, and a wider and more developed incipient foredune (Figures 4 and 5).

Figure 4. Difference in south and north dune profiles and vegetation prior to works; mAHD = metres Australian Height Datum. Zero metres is equivalent to mean sea level around the coast of the Australian continent [10].

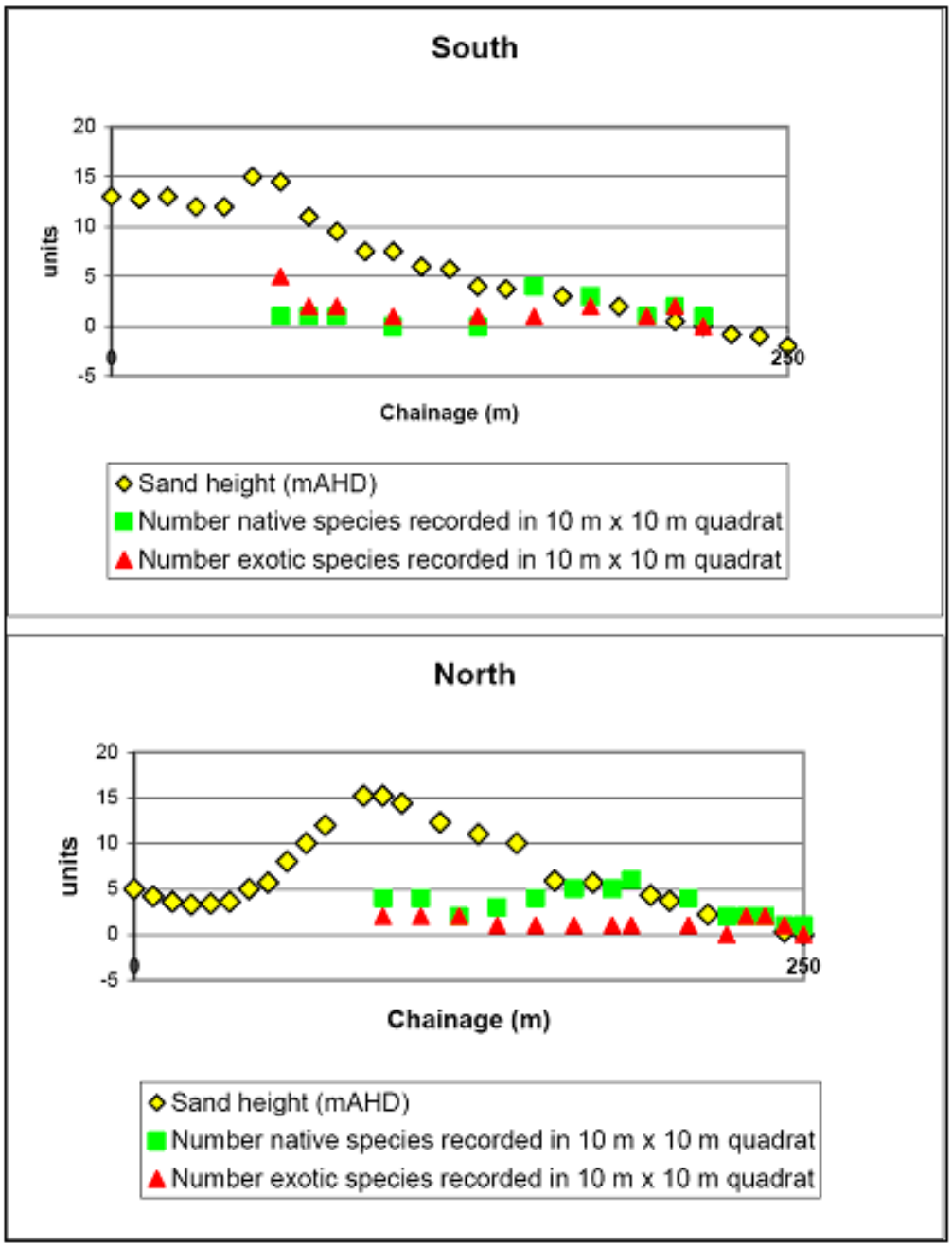


Figure 5. (a) Spinifex seaward on the incipient dune; (b) *Acacia longifolia* subsp. *sophorae* seaward on the foredune.

(a) (b)

The relationship between type of vegetation and shape of the dune is related to plant structure and density and the root growth form of different dune species and their mycorrhizal associations. Plant root systems assist in binding soil, with fungal mycelium the dominant factor in aggregation of soil particles [11,12]. Sand particles are loosely trapped by a network of hyphae [12] or cemented when sand particles adhere to the hyphae, both when the fungus is in active symbiosis with the host plant and also after death and collapse of the hyphae [13].

There are two main types of mycorrhizal associations; arbuscular or endomycorrhizae (AM) which penetrate the intracellular space within root cells and form specialised structures within these cells; and ectomycorrhizae (EM) that only penetrate the extracellular space of plant roots and form specialised structures. There are two distinct types of arbuscular mycorrhizae; ericoid mycorrhizae that occur only on members of the Ericaceae family, such as *Leucopogon parviflorus*, and vesicular-arbuscular mycorrhizae (VA or VAM) associations which occur between the majority of plants and fungi [14].

The primary dune colonisers *Spinifex sericeus* and *Carpobrotus glaucescens* both possess AM and VAM mycorrhizal associations, although Spinifex may utilise these fungal associations to a greater extent than *C. glaucescens* [15]. Growth form of Spinifex in different sections of the dune is influenced by both sand burial and nutrient availability, with large below ground biomass occurring on the crest of the incipient foredune [9]. Evidence indicates that sand burial can and does promote growth of most native foredune species by increasing CO_2 exchange rate, leaf area and biomass; and this growth is increased by and or due to mycorrhizal fungi [16].

Limited evidence has shown that bitou bush forms both AM and VAM associations [15], however bitou bush roots appear to support lesser extent of fungi colonisation than Spinifex and other local native species (see Section 4.3). *Chrysanthemoides monilifera* subsp. *rotundata* has a well developed root system that penetrates deeply into the soil [17]. In contrast, Spinifex develops long horizontal stolons, supports more extensive fungi colonisation and has the ability to shift in response to the

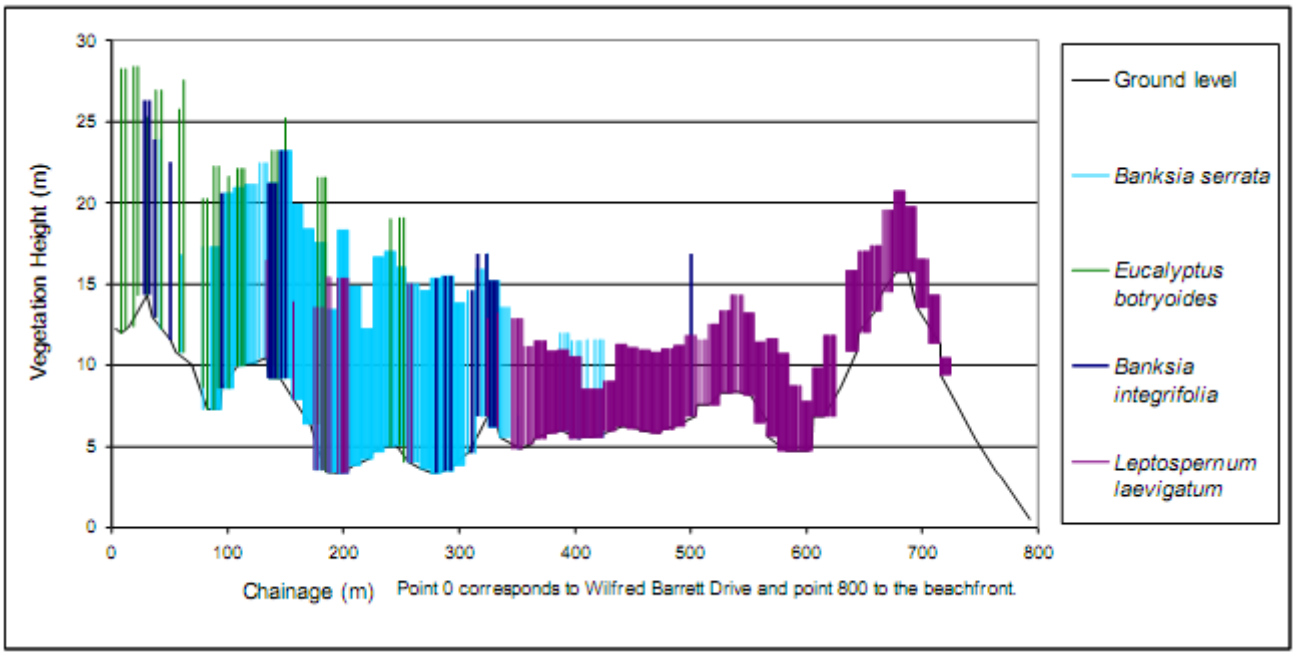
movement of the sand. The different growth forms and fungal sand binding capacity result in very different landforms and rate of sand loss.

Reference Sites

In planning the restoration of the dune ecosystem, the two reference sites used were an area of more intact vegetation along the northern boundary of Magenta Shores; and reconstructed beach dunes at Budgewoi Beach [7], located 10 km north of Magenta Shores.

The vegetation and landform along the northern boundary of the Magenta Shores site was surveyed using an 800 metre long transect (Figure 6). A higher native component occurred on the more natural landforms. The extensive mined central area (chainage 350 to 500 metres) had a modified, flattened landform. It supported dense stands of the native foredune species *Leptospermum leavigatum* (coastal tea-tree). The native vegetation component on the incipient beach dune immediately landward of Tuggerah Beach included *Carpobrotus glaucescens* (Pigface) and Spinifex. The landward foredune vegetation consisted mainly of coastal tea-tree, with *Acacia longifolia*, *Leucopogon parviflorus*, *Monotoca elliptica* and Pigface.

Figure 6. Topography and maximum height of vegetation > 2 metres high along northern transect.



The Budgewoi Beach site had been reconstructed and revegetated by a local community group [7]. The reconstructed landform had a long gentle slope with no well-defined incipient dune, negligible presence of weeds and a diversity of local native vegetation (Figure 7). The dunes were constructed using bulldozers; with the burial of Bitou Bush in the constructed dunes and extensive use of conventional sediment control fencing at right angles to prevailing strongest winds. Native species recorded here included *Acacia longifolia* subsp. *sophorae*, Pigface, *Westringia fruticosa*, Spinifex, *Pelargonium australe*, coastal tea-tree, *Scaevola calendulacea* and *Correa alba*. Exotic species recorded included bitou bush and *Cakile maritima* (Cakile).

Figure 7. Restored Budgewoi dune.

4. Rehabilitation Methods Employed at Magenta Shores

4.1. Landform Reconstruction

The dense stands of bitou bush upslope of the incipient dune were removed and re-used as a soil additive in the development area [1]. Initial attempts to lift the live bitou bush were difficult, even with use of large machinery. To reduce the bitou bush hold on the sand, and reduce sand loss, the bitou bush was hand-sprayed with 1:100 Glyphosate. Four to five days later, bitou bush and its intact root mats lifted easily from the sand (Figure 8). The sand was then reshaped to mimic natural dune slopes, using a bull dozer.

Figure 8. Excavator removing bitou bush.

The incipient dune with its Spinifex cover, though of often narrow width and weed infested, was retained and carefully weeded to maintain existing beach protection. To create calmer microclimatic conditions on the exposed re-constructed dune, cut coastal tea-tree was placed as windrows on two

constructed crests, parallel to the beach [1]. Deep swales formed as sand was rapidly blown into the windrow crests, with sand height changes of up to 600 mm occurring over the first night after construction.

4.2. Spinifex Trials and Primary Planting

After two to three months of crest/swale formation on the newly constructed dunes, planting of early dune colonizing species was trialled (Figure 9). For the more than 1 km of reconstructed dune, a rapid and efficient method to re-establish the native colonizing species Spinifex was required.

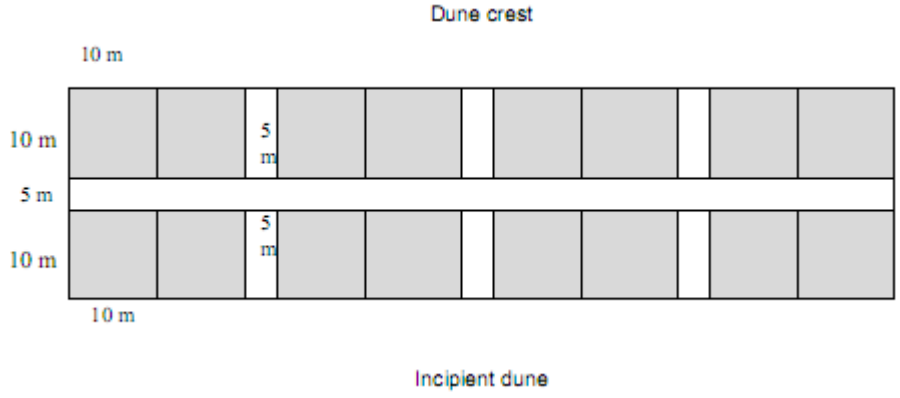
The methods trialled at Magenta Shores had previously been used successfully on the New South Wales coast. These included harvesting and planting stolons (used at Casuarina and Salt developments in northern New South Wales); burial of Spinifex seed heads [9] (used at Budgewoi) [7]; and planting nursery grown plants (used by the first author at Kurnell in southern Sydney).

Figure 9. Bush regenerators carrying out preliminary planting below coastal tea-tree windrows.

Five methods of Spinifex introduction, at three different planting densities, were trialled in the southern dune section from 11 November 2004. By 10 January 2005, a clear trend was evident. Final data was collected in November 2005.

A split plot design was applied to a 550 × 25 metre stretch of the CPZ with the sampling area consisting of twenty-two 20 × 20 metre quadrats each divided into four 10 × 10 metre subquadrats. The 20 × 20 metre quadrats were separated by 5 metre intervals (Figure 10).

Figure 10. Spinifex planting trial layout with four subquadrats per treatment cell.



The methods trialled were firstly, Spinifex stolons planted upright at 2 metre and 5 metre intervals; secondly, Pigface and Spinifex stolons co-planted horizontally at 0.8 metre intervals; thirdly, well-rooted nursery grown plants of Spinifex planted at 2 metre intervals; fourthly, Spinifex seed head buried at up to 30 cm depth in naturally occurring moist sand at 0.8 metre and 2 metre intervals; and fifthly, no planting or seeding (control). Depth of seed burial was increased due to the sand being highly mobile.

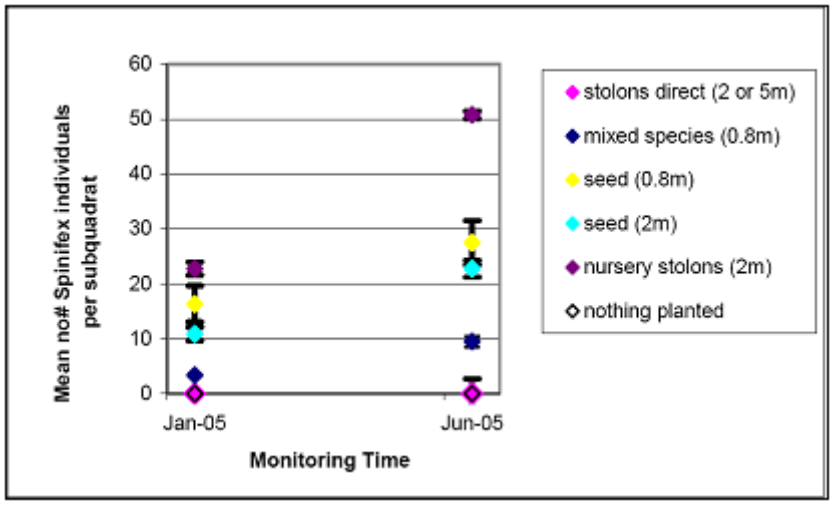
All of the plant material used was local provenance, with the majority from the re-constructed Budgewoi Beach dune and a small amount from the development area at Magenta Shores. The original source of Budgewoi plant material was from 3 km north of Magenta Shores on Tuggerah Beach. Stolons collected consisted of cut sections with two to three rooting nodes. No whole plants were dug up. The donor site was assessed prior to and post the collection to ensure that adequate cover was maintained. To avoid moisture loss, all stolons were collected in early morning, and transplanted on site during the day; and all stolons collected for propagation were transported to the nursery within four hours of collection.

Fresh seed was planted as split seed heads at up to 30 cm depth. Spinifex seed ripens quickly with ripeness indicated by the presence of Galah (*Cacatua roseicapilla*). The Galah arrives in flocks to eat the carbohydrate rich grass seed. About one third of the ripe fertile seed heads were harvested, packed into large open weaved bags and stored for planting.

The trial plantings occurred between 11 November and 9 December 2004. Apart from about 15 mm of rain falling between 16 and 19 November 2004 when Pigface and Spinifex stolons from Budgewoi beach were planted, most planting days had little to no rain. There were five days with > 1 mm rain during planting in November and December 2004 which was lower than the long term average of 9 rain days in November and 7 rain days in December. The daily temperatures ranged from 16.5 to 25 degrees Celsius [18].

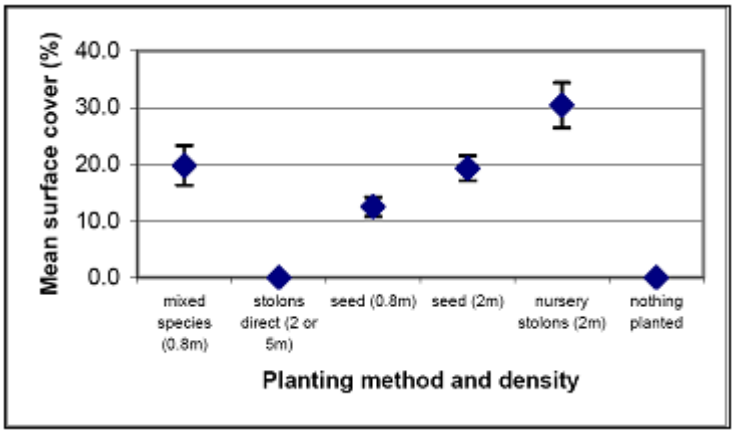
By 10 January 2005, all of the vertically planted Spinifex stolons had died regardless of planting density and the unplanted cells remained bare, except for weed growth (Figure 11). These cells were criss-crossed with long Spinifex runners planted in the naturally occurring moist subsurface sand, with only a small part of the foliage emerging.

Figure 11. January 2005 and June 2005 survival.



By June 2005, planting seed-head at 0.8 metre density appeared to have better establishment than planting it at 2 metre density (Figure 11). By November 2005, there was higher Spinifex cover for the 2 metre interval planting density (average of 19.3 percent cover) than for the 0.8 metre interval planting density (average of 12.5 percent cover) (Figure 12).

Figure 12. Surface cover by Spinifex achieved by 8 November 2005.



Germination and establishment of Spinifex from buried seed resulted in two to eleven runners per subquadrat within three of the nine seed trial cells at 19 May 2005; and germination in all seed trial cells by 8 November 2005, with between 14 to 60 percent surface cover in seven out of nine cells, and a mean cover of 14 to 17 percent (Figures 12 and 13).

Figure 13. Buried Spinifex seed resulting in long runners by November 2005.

Cover for Pigface stolons and planted seed head of Spinifex was similar to the 2 metre interval Spinifex seed head planting density and was a very cost effective and satisfactory method for achieving initial cover. The results of planting a mix of Pigface and Spinifex showed no significant difference in contribution to establishment and survival of the Spinifex planted with the Pigface. However, it was observed that Pigface would establish cover rapidly and then die back, providing soil nutrient that in turn would promote growth of more complex species (Figure 14).

Figure 14. Pigface dying back and native diversity and cover increasing in 2007.

The nursery grown stolons had well developed runners at the time of planting. At 19 May 2005, one to 13 long runners were present within 38 percent of the nursery plant trial subquadrats; and by November 2005 between 20 to 90 percent surface cover had been achieved in half of the nursery plant subquadrats, with an overall mean cover of >30 percent at 8 November 2005 (Figure 12). The nursery grown stolons were the most effective in achieving rapid cover (Figure 11), but expensive (Table 1).

Table 1. Cost of each revegetation method.

Method	Cost per plant	Cost at 5 m density per 20 m × 20 m quadrat	Cost at 2 m density per 20 m × 20 m quadrat	Cost at 0.8 m density per 20 m × 20 m quadrat
Nursery grown stolons	$2.33	NA—not trialled	$233	NA—not trialled
Seed head	$1.60	NA—not trialled	$160	$1,000
Direct planted stolons (including mixed planting)	$3.39	$ 54.24	$339	$2,118.75

The planted Spinifex seed head was a successful technique for achieving cover within a 12 month period. Spinifex germination in the spikelet is inhibited by slow rate of gas exchange between embryo and atmosphere when whole spikes are planted rather than seed that has been removed from the spikelet [19]. Planting single seed into the moist sand horizon may achieve cover more quickly than burying whole spikelets, however removal of the seed from the spike would be more time consuming.

Relative cost of each method

Nursery stolons cost one dollar each plus initial stolon collection and planting labour costs, which worked out to a total of $2.33 per nursery stolon planted. Seed heads and transplanted stolons had no buying cost, but had both collection and planting labour costs; with seed heads costing $1.60 per seed head planted and planted stolons costing $3.39 per stolon planted. This cost increased with increasing density of planting (Table 1). Nursery stolons worked out to be cheaper than collecting and directly planting stolons because more plants could be grown and planted for each stolon length collected.

The most cost effective method proved to be burial of Spinifex seed head in moist sand at 0.2 metre density. This method mimicked the natural process of seed blown on shore and buried by mobile sand. Following the Spinifex trials, the remainder of the shaped seaward facing dune was extensively planted and seeded with the primary colonizing species Pigface and Spinifex to provide early rapid cover and promote establishment of sand holding fungal hyphae and organic content prior to re-introduction of secondary native species.

4.3. Soil Fungi Testing

Fungi are important for colonisation and survival of plants [20]. Mycorrhizal fungi increases nutrient uptake by plants growing in nutrient poor environments [16]. Plants with no pre-existing root colonisation by mycorrhizal fungi will become colonised by mycorrhizal fungi if planted into sand containing mycorrhizal fungi, however area of root colonised will be lower than in that of plants with existing mycorrhiza prior to planting in sand containing mycorrhiza [16].

Seed of secondary native colonising species, including *Acacia longifolia* subsp. *sophorae, Kennedia rubicunda, Ficinia nodosa, Leucopogon parviflorus, Lomandra longifolia, Imperata cylindrica* and *Scaevola calendulacea* (all known to have mycorrhizal associations) [15,21,22], was distributed heavily mainly on the crests of the reconstructed dunes, annually from 2005 to 2008, during late Spring to early Autumn when rains are expected. The seed was buried under a shallow layer of sand to prevent birds eating it and to promote sand burial and natural abrasion of the seed coat by sand movement. Seed was not pretreated to break dormancy, as natural germination under favourable conditions such as rain was more likely to favour plant survival than instant germination. Although germinations occurred during the first year, they did not begin to survive and flourish until 2006. The earlier germinations died, usually as a result of being swamped by the highly mobile sands. There was insufficient cover by Spinifex, and presumed corresponding inadequate levels of fungal hyphae present throughout the sand to hold the sands and also to colonise the roots of and assist in sustaining the growth of secondary colonising species.

It was surmised that there were low levels of fungi owing to the disturbed nature of the habitat, with very low levels of organic and carbon content following previous mining and ensuing domination by bitou bush. Development of fungi may be dependent on the presence of sufficient and appropriate nutrients [16,23]. Sudden addition of nutrient in the form of fertilizer, although of possible benefit to the growth of some native species [23], was not desirable, as addition of Phosphorus could have a detrimental impact on fungi growth [24]. Inoculation of roots of nursery propagated plants prior to planting in the field has been used successfully in revegetation, especially of woodland ecosystems [23, 25 , 26], but less is known about using this practice in restoration of dune ecosystems [15]. It is possible that to be effective, mycorrhizal strains used need to be compatible with the provenance of the host species [23,27,28].

Introduction of fungi via inoculation of local native species prior to planting was not used because Magenta Shores was a conservation site with existing local native vegetation within 10 m of the dune reconstruction. Time was allowed for sufficient organic and carbon content to develop naturally in the soil, following recolonisation by Spinifex and Pigface, for natural colonisation of fungi from the present low levels in the reconstructed area; and from existing adjacent native vegetated areas in the

hind dune. The more resilient northern area and the incipient dune were preserved and carefully weeded throughout the reconstruction.

From May 2005 to September 2006, studies were undertaken to assess the presence/absence of sand binding fungal hyphae along the reconstructed dunes, as an indicator of the progress of the dune stabilisation. On 19 May 2005, 12 fine root samples were collected from four plant species Spinifex, *Leucopogon parviflorus* (Coast Beard Heath), bitou bush and *Scaevola calendulacea* (Fan Flower) along the Coastal Protection Zone (Figure 15 and Table 2). All specimens were found to have hyphae present on or near the roots, however, only *Leucopogon parviflorus* (Ericaceae) had frequent intracellular hyphae. There was evidence of hyphae penetrating cell walls and growing within the root cells of bitou bush and *Scaevola calendulacea,* although they did not form well defined structures and could not be considered as mycorrhizal.

Table 2. Observations of root samples at May 2005.

Specimen No.	Plant Species	Hyphae present	Observations
1	*Chrysanthemoides monilifera* subsp. *rotunda*	Yes	Some hyphal penetration. Intracellular hyphae.
2	*Scaevola calendulacea*	Yes	Some penetration, no mycorrhizal structures.
3	*Chrysanthemoides monilifera* subsp. *rotunda*	Yes	Possible some penetration
4	*Leucopogon parviflorus*	Yes	Cell penetration, some hyphae coiling.
5	*Leucopogon parviflorus*	Yes	Cell penetration, some hyphae coiling, early ericoid mycorrhizal structures.
6	*Chrysanthemoides monilifera* subsp. *rotunda*	Yes	Possible some penetration. No mycorrhizal structures.
7	*Spinifex sericeus*	Yes	Possible some penetration. No mycorrhizal structures.
8	*Spinifex sericeus*	Yes	No penetration.
9	Unknown, near *Leucopogon parviflorus*	Yes	Root heavily colonised by hyphae.
10	*Spinifex sericeus*	Yes	Possible some penetration. No mycorrhizal structures.
11	*Spinifex sericeus*	Yes	Possible some penetration. No mycorrhizal structures.
12	*Spinifex sericeus*	Yes	Possible some penetration. No mycorrhizal structures.

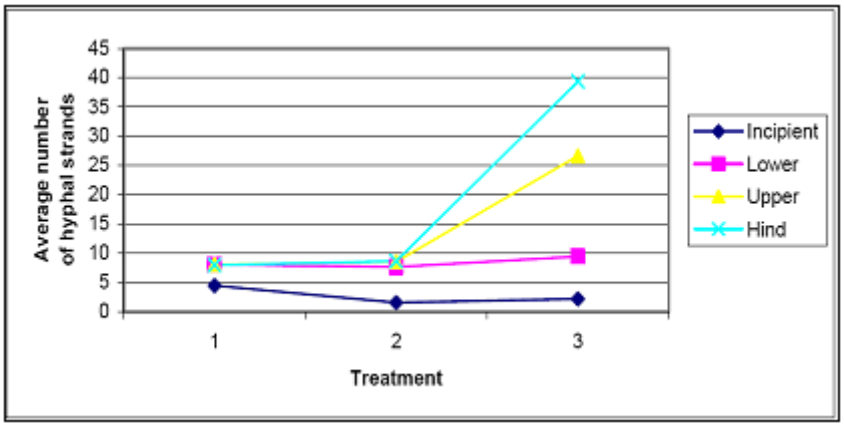
Figure 15. Fungi sampling locations.

Further sampling was undertaken from 12 to 18 July 2005, with 88 soil samples collected at a depth of between 2 and 5 cm, from three treatment types located in incipient, lower, upper and hind dune areas of 22 transects (Figure 15). Samples were taken from the bitou bush dominated area immediately south of the Magenta Shores site (Treatment 1); areas previously invaded by bitou bush that were reshaped and then revegetated (Treatment 2); and dunes that were not reshaped and had minor infestations of bitou bush that were being controlled via spraying of herbicide and cut and paint methods (Treatment 3).

All three treatments suggested a trend of increasing hyphal abundance along the dune gradient from incipient foredune to hind dune, and a substantially higher abundance of hyphae in Treatment 3 that had more native vegetation and less bitou bush (Figure 16).

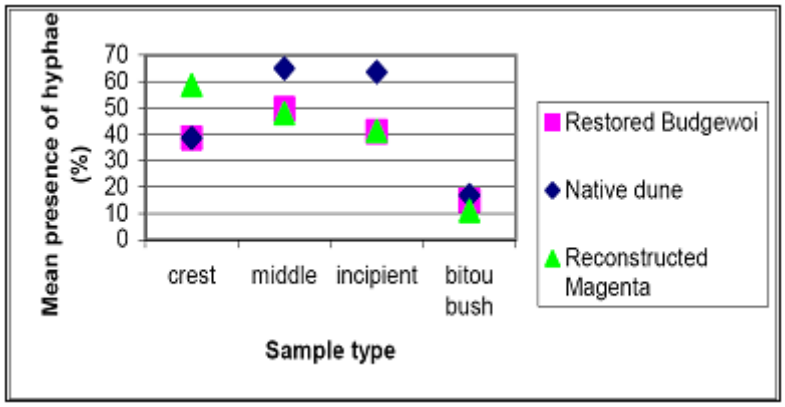
In September 2006, approximately 22 months after commencement of dune restoration, the fungal status was reviewed. Root samples were collected from the Magenta Shores reconstructed foredunes in the south, more intact foredune in the north and Budgewoi revegetation site. At each site a total of twelve samples were collected from three 50m transects. Samples were taken from the hind dune (small trees and shrubs, coastal tea-tree and *Acacia* species); dune crest (Spinifex); middle (Spinifex); and incipient dune (Spinifex and bitou bush). Additional root samples from bitou bush were also collected from the bitou bush infested dune south of Magenta Shores. The root samples were inspected and the extent of fungi present in each sample was recorded as a percentage of the total root length.

Figure 16. Average fungal hyphae counts for three dune treatment areas at July 2005.



The results showed that the reconstructed dunes at Magenta Shores had levels of fungal hyphae comparable to the native dune and restored Budgewoi dune areas (Figure 17), (however one relatively high fungal count in the incipient area of the reconstructed Magenta Shores dune was mainly due to the presence of pathogenic species, possibly *Pithium* or *Phytophthora*, rather than AM fungi). The native dune with the lowest disturbance had high occurrence of fungal hyphae within the incipient and middle dune areas. Both ectomycorrhizal fungi (EM) and some endomycorrhizal (AM) fungi were recorded. The bitou bush root samples showed consistently lower occurrence of fungal hyphae (Figure 17).

Figure 17. Mean rates of fungal hyphae recorded at three sites in September 2006.



Most of the mycorrhizal infection observed in the roots of *Leptospermum* in the hind dune was made up of ectomycorrhizal fungi (EM) (80%). However, some endomycorrhizal (AM) fungi were also present. Spinifex roots collected at Budgewoi harboured at least three fungal species, including EM. *Gigaspora* was the main AM genus found in these roots. In addition, Ascomycetes and other fungi were found on the root surface. Roots collected on the incipient dune at Magenta showed signs of pathogenic infection, however were also colonized by AM fungi, including *Archeospora*. The confirmed presence of hyphae growing on the constructed dune at rates comparable to more stable sites indicated that the constructed dune sands were stabilising.

4.4. Weeding and Secondary Seeding and Planting

Throughout the project, bush regeneration teams actively removed bitou bush, Cakile, *Lupin* spp. and other weeds to reduce competition with the germination and establishment of the primary colonizing native species. Following confirmation of the presence of fungal hyphae, seed dispersal and tubestock planting of secondary species including *Acacia longifolia* subsp. *sophorae, Correa alba, Glycine clandestina, Hardenbergia violacea, Isolepis nodosa, Kennedia rubicunda, Lomandra longifolia* and *Leucopogon parviflorus* intensified. Additional minor placement of coastal tea-tree seed bearing branches aided in sand and seed trapping and provided shelter to juveniles (Figure 18).

Figure 18. Placed coastal tea-tree branches trapping sand and Spinifex seed.

4.5. Fauna Habitat Values

Bush regenerators recorded fauna observed on the dunes. In the first year fauna species were infrequent with eight species recorded. These were the insects Lady Bird Beetle (Coccinelidae), Praying Mantis (Order Mantodea) and Green Ant (*Rhytidoponera metallica*); reptiles Jackie Lizard (*Amphibolurus* sp., Agamidae), Brown Snake (*Psuedonaja textilis*) and Skink (Scincidae); and the birds Australian Raven (*Corvus coronoides*) and White-breasted Sea-Eagle (*Haliaeetus laucogaster*).

Over the next four years two native mammals (*Antechinus* sp. and *Psudomys* sp.); 16 reptile species; 44 arthropod species including four ant species; and 57 native bird species were recorded. The most common avifauna recorded were Australian Ravens (*Corvus coronoides*), White-breasted Sea-Eagles (*Haliaeetus laucogaster*), Superb Blue Wrens (*Malurus cyaneus*), Eastern Whipbirds (*Psophodes olivaceus*), Australian Magpies (*Gymnorhina tibicen*), Magpie Larks (*Grallina cyanoleuca*) and Crested Pidgeons (*Ocyphaps lophotes*). Australian Ravens were often observed roosting on monitoring stakes. The monitoring stakes consisted of 2 metre high wooden stakes driven into the sand at approximately 40 metre intervals. Bird droppings full of native seed which require digestive tract stimulation for germination [29], such as *Leucopogon parviflorus* (Coastal Bearded-heath), were also seen frequently.

5. Establishment of a Diverse Local Native Sand Barrier Ecosystem

The progress of vegetation cover was monitored from February 2006 to December 2008. Vegetation was monitored using five long transects running from the beach in the east, to the main road in the west, and a series of shorter transects on the reconstructed dune system (Figure 19).

Figure 19. Vegetation monitoring transects.

The transects consisted of contiguous 10 × 10 metre quadrats in which the presence of all species and the number and maximum height of all species taller than 2 metres were recorded within a 5 × 5 metre sub-quadrat (Figure 20).

From the regular monitoring, colonisation has occurred in stages (Figures 21 and 22). By April 2007, the diversity of both exotic and native species increased as new germinations of bitou bush decreased. As native diversity continued to increase and wind blown weed invasion was removed, weed cover decreased and native species dominated the stabilized dune by the Summer of 2008. The

middle reconstructed dune area had the greatest overall increase in native species diversity (Figure 21), with overall native cover increasing in both the south and middle sections of the reconstructed dune. However, along the northern boundary of the site, in the assisted natural regeneration area, native cover actually decreased in some areas, particularly in the hind dune area (Figure 22).

Figure 20. Layout of sampling areas.

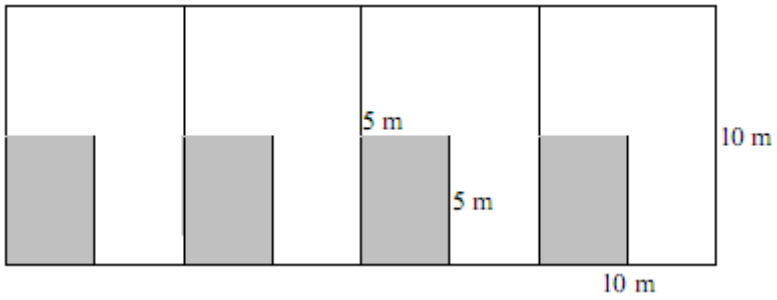


Figure 21. Increasing native diversity.

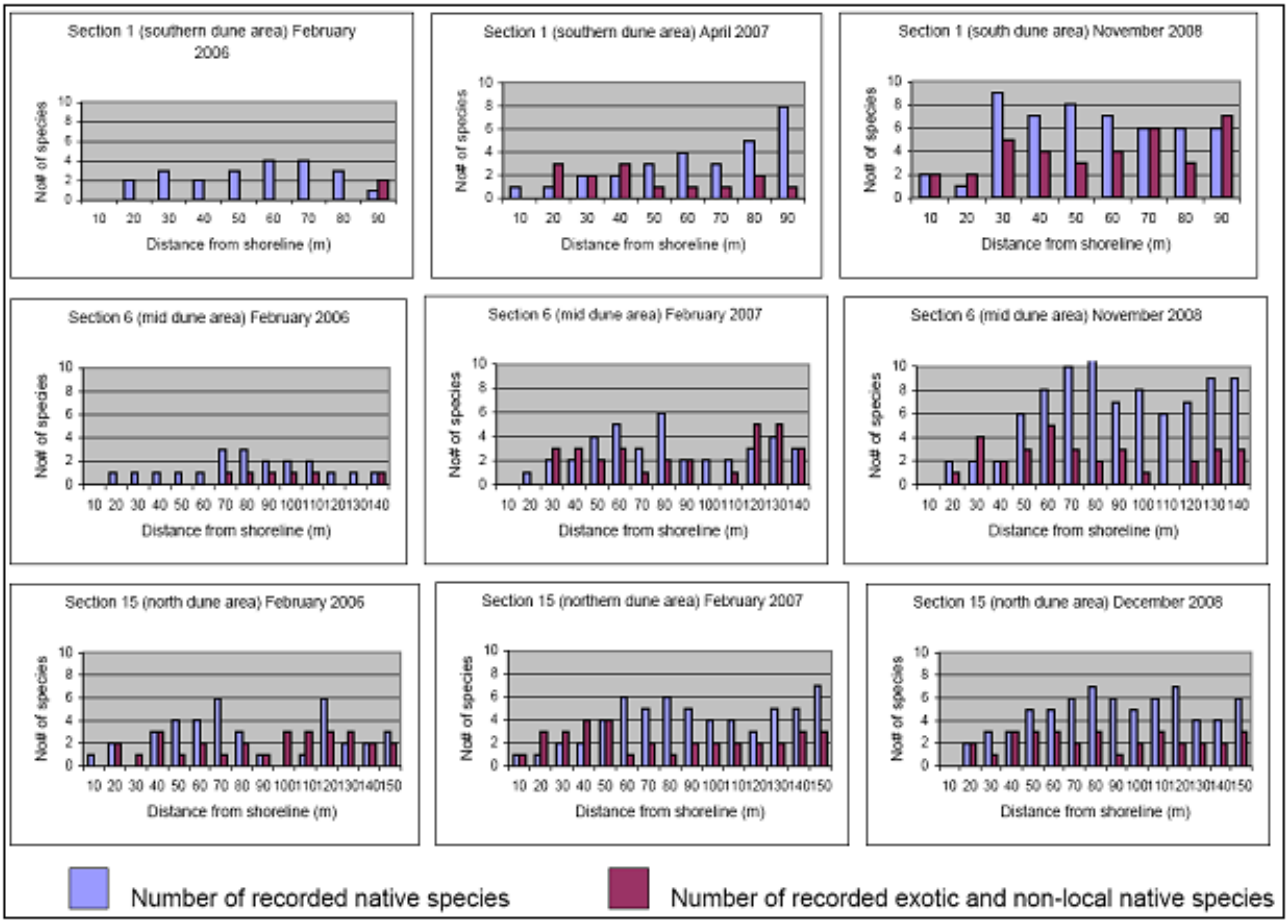
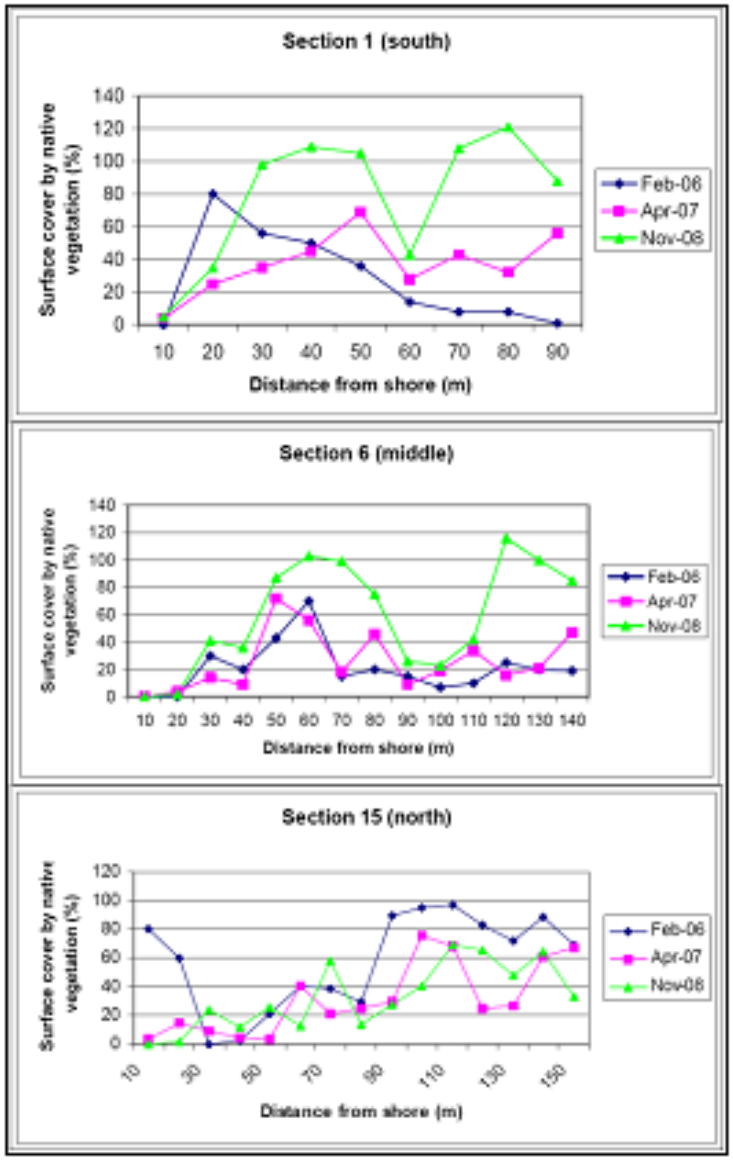


Figure 22. Increasing native surface cover.



In Summer of 2008, the secondary colonizing native species on the dunes were fruiting and self seeding (Figure 23).

Figure 23. Seed and fruit development of secondary colonizing native species on the reconstructed dunes.

Kennedia rubicunda *Banksia integrifolia* *Scaevola calendulacea*

Survey of sand heights showed sand being retained and the volume increasing along the length of the beach [1]. Loss of sand is minimised by entrapment in native vegetation, allowing for faster recovery of the dune system following strong winds, storm attack and future sea level changes (Figure 24). The problems of major sand losses threatening homes less than 1 km to the south, at the Entrance North [30] are not being experienced on the reconstructed dune at Magenta Shores.

Figure 24. Dense primary native species cover in Section 6.

6. Conclusions and Recommendations

The native dune vegetation is currently holding the sand and maintaining a wide incipient dune (Figures 25 to 27). Weed species require ongoing maintenance, even as native vegetation reaches competitive superiority, as the Magenta Shores dune adjoins un-maintained bitou bush dominated dunes, especially to the south (Figure 28).

Figure 25. Looking south across restored incipient dune from north end at November 2008.

Figure 26. Looking south from mid dune area at November 2008.

Figure 27. Looking north across restored dune from south end at November 2008.

Erosion present in the south is due to the remaining bitou bush dominated landform further south (Figure 28). The entire Tuggerah Beach needs to be restored, and the local Council is now working to restore part of this southern area [31].

Figure 28. Unmanaged Bitou Bush area immediately south of rehabilitated area is contributing to erosion.

Overall, the project demonstrated the importance of mimicking natural processes by allowing wind blown sand to form crests and swales parallel to the beach; creating protected fibrous coastal tea-tree windrow microenvironments; burying Spinifex seed head in the moist sand layer for primary colonization of the reconstructed dune; and establishing primary colonizing native vegetation cover prior to introduction of secondary colonizing species, to trap both sand and seed and provide shelter for emerging seedlings. Monitoring soil fungal hyphae was an indicator of the progress of dune stability. The project also found that placement of bird roosts could also be a useful tool for promoting re-introduction of native plant species requiring germination by digestive tract stimulation. On-going weeding is essential at Magenta Shores until bitou bush is controlled for the entire length of Tuggerah Beach.

The Magenta Shores project has demonstrated practical methods to show how rehabilitation can be successfully achieved on previously sand-mined beaches prone to strong wind and wave attack, to protect built assets as part of sustainable coastal development.

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