doi: 10.1111/emr.12160

Progress with restoration and management of Eastern Suburbs Banksia Scrub on North Head, Sydney

By Geoff Lambert and Judy Lambert

How has management of Eastern Suburbs Banksia Scrub vegetation on North Head progressed over the last 6 years and what insights can be gained from recent treatments?

Key words: *assisted regeneration, ESBS, fire, planting, soil disturbance.*

Figure 1. North Head is the largest remaining example of ESBS and has provided an opportunity for extensive trials of a range of restoration interventions, including those using fire and thinning. Attendees at the Nature Conservation Council NSW 2014 workshop '*Using fire as a restoration tool*' examine a boundary between the two types of ESBS on North Head. (Photo: Kate Nicolson.)

Introduction

Eastern Suburbs Banksia Scrub (ESBS), which is a component of Coastal Sand Mantle Heath (OEH 2013), is a fire-adapted sclerophyllous coastal heath/scrub community which occurs in 24 isolated remnants on Aeolian sand mantles between La Perouse and Manly in Sydney, Australia. The sand – which originated in the Pleistocene – is siliceous, noncalcareous and nutrient poor and occurs on dunes perched on rock headlands. The community is characterised by over 60 species, mainly heathy shrubs and subshrubs (the most widespread of which are shown in Table 1). Wallum Banksia (*Banksia aemula*), after which the ecological community is named (NSW Department of Environment & Conservation 2004), is often a prominent species.

This community is estimated to have occupied some 5300 hectares around the Sydney Harbour and Botany Bay area in 1788. Much has been cleared for development or other land uses and is subject to a range of threats characteristic of relatively

*Dr **Geoff Lambert** is Vice President and Dr **Judy Lambert** is a Committee Member on the North Head Sanctuary Foundation Executive (179 Sydney Rd, Fairlight, New South Wales 2094, Australia; Email: G.Lambert@iinet.net.au; Tel: +61 2 9949 3521).*

Ecological Management & Restoration *Linking science and practice*

Table 1. Some of the more widespread species characteristic of ESBS

Common name	Scientific name	Growth form
Wallum Banksia	*Banksia aemula*	Small tree
Tree Broom Heath	*Monotoca elliptica*	Shrub
Coastal Teatree	*Leptospermum laevigatum*	
Tick Bush	*Kunzea ambigua*	Shrub
Sweet Wattle	*Acacia suaveolens*	Small shrub
Daphne Heath	*Brachyloma daphnoides*	Subshrub
Lepidosperma	*Lepidosperma laterale*	Sedge
Brown's Love Grass	*Eragrostis brownii*	Grass

(For full list see http://www.environment.nsw.gov.au/determinations/EasternSuburbsBanksiaScrubEndComListing.htm).

small urban reserves. By March 2003, only 138 hectares remained (NSW Department of Environment & Conservation 2004). About half of this is at North Head (Figs 1,2).

ESBS is listed as an Endangered Ecological Community both in the NSW *Threatened Species Conservation Act 1995* and in the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.* These listings gave rise to the drafting of an *'Eastern Suburbs Banksia Scrub Recovery Plan'* (NSW Department of Environment & Conservation 2004). The Plan was formally adopted by the Australian Government in 2005 (Australian Government Gazette 1-Jun-2005, p. 1223). The listing specifies 62 species as indicative of ESBS, the so-called 'Characteristic' species. Eight of the characteristic species are found at all 24 ESBS sites; two are found at only one site. The average is 17 ESBS species per site.

North Head ESBS

The site

Although no official boundaries define 'North Head', the area covers approximately 383 hectares, located at -33° 48.7′, E151° 17.9′ (location of median, Fig. 2). The land is owned/leased and managed by several agencies, both State and Federal. The total area of vegetation classified as ESBS is estimated as approximately 69 ha. About 70% of this is managed as 'North Head Sanctuary' by Sydney Harbour Federation Trust (SHFT) and 30% is located within the adjoining Sydney Harbour National Park and managed by NSW National Parks & Wildlife Service (NPWS) (Appendix S1).

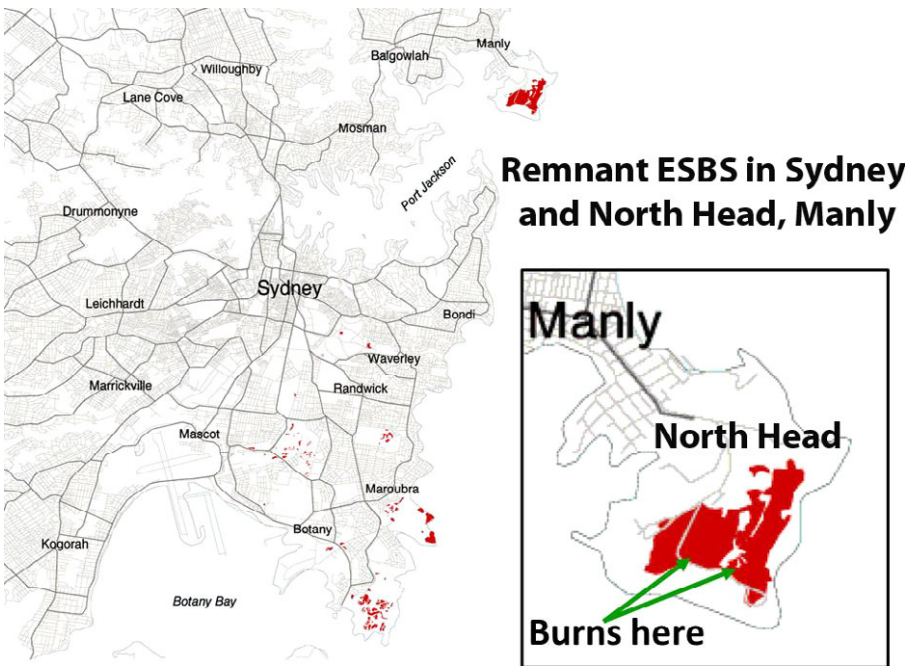


Figure 2. Map of ESBS in Sydney with inset of North Head. (Map adapted from DEC 2004).

Floristics

At least 320 native species are found on the North Head sand mantle upon which the ESBS community grows, a very high number of species per area. Of the 62 Characteristic ESBS species, 57 are present on North Head (North Head Sanctuary Foundation unpublished surveys, Horton & Benson 1986; Skelton *et al.* 2003 and Lambert *et al.* 2015). Walker (2013) found species richness in his survey quadrats on North Head was twice as high ($0.25/m^2$) as that of the other eight ESBS patches in Sydney ($0.13/m^2$).

Fire history

ESBS species are considered to be fire-adapted (Box 1). One of the first documented fires in eastern Australia to be witnessed by Europeans at its point and time of ignition occurred at North Head just after noon on 28 May 1788 [Hunter 1792; (2003 reprint)]. Since that time, some 14 wild and managed fires have been recorded which affected, or could have affected, ESBS, not to mention unrecorded fires. Major wild fires which affected ESBS occurred in 1926 and 1951. Since that time, fire has been infrequent. It seems that a controlled burn, to remove 'ti-tree' and Lantana (*Lantana camara)*, may have occurred on military land in September 1992 (Turner 1996). A subsequent controlled fire occurred on NSW National Parks and Wildlife Service (NSW NPWS) land in 2003. Three controlled fires were carried out in September 2012 (Lambert *et al.* 2015).

Box 1. Fire adaptation by ESBS species

Fire responses. Mechanisms of resprouting from perennating buds and germination from buried seed banks are considered adaptations to the disturbance of fire to which species have been exposed over evolutionary timeframes (Gill 1975). Lesak (2000) reported that ESBS species not present above ground, nevertheless germinated from soil collected from an ESBS site, indicating they are soil seed storers. Some 42 ESBS species are assumed to store their seed in the soil (referred to as '*obligate seeders*' because they do not resprout). The primary storage of the other ESBS species is not known, although 10 ESBS species are known to be resprouting species (Bushfire Research Unit NSW NPWS 2003). Data on seed bank longevity are known for only seven ESBS species and range from 2 to 20 years, with an average of 13 years. Twenty-one of the 62 species are known to need heat and/or smoke for germination (Bushfire Research Unit NSW NPWS 2003), although Lesak (2000) did not find any particular need for smoke water for germination. The needs of the others are not known.

Responses of North Head species. Of 38 ESBS species for which seed storage data appear in the NSW Flora Fire Response Database, 26 could be considered as 're-sprouters' and 12 as 'seeders' (68%:32%). Coastal Teatree appears to be generally killed by fire and does not resprout upon cutting. Yet it does not fall neatly into the category of obligate seeder as it is at least temporarily bradysporous, holding its seed in the canopy for at least a year. Its soil seed density in and around stands of the species can be as high 10,000 per m^2 (Offor 1990), and seeds are generally viable for 1–3 years (Judd 1990; Bennett 1994).

Fire regimes. The recommended fire interval for ESBS species ranges from 5 to 15 years (given for only 6 ESBS species) to enable a sufficiently long fire-free period to allow obligate seeding species to mature and recharge seedbanks. According to the NSW Flora Fire Response Database (Bushfire Research Unit NSW NPWS 2003), 48 species are sensitive to too-frequent fire and 41 to too-infrequent fire. The recommended intervals for successive fires for the community as a whole are not less than 8 (but preferably a little longer) and not more than 15 years (NSW Department of Environment & Conservation 2004). According to the Recovery Plan, fire exclusion for more than 30 years is to be avoided because seed storage declines over time (NSW Department of Environment & Conservation 2004).

Condition

The ESBS on North Head occurs across a spectrum of condition classes, ranging from patches rich in a diversity of extant ESBS species through to degraded patches dominated by Coastal Teatree (*Leptospermum laevigatum*) and lacking in extant species diversity (Box 2, Fig. 3). Weed abundance is relatively low (Box 3) As such, the ESBS on North Head offers opportunities to explore various management strategies – while adopting a spectrum of techniques to cope with a spectrum of conditions.

The ESBS Recovery Plan (NSW Department of Environment & Conservation 2004) identified a need for public land managers of sites with ESBS to undertake management actions to protect, repair and expand remaining patches of this ecosystem. Potential for restoration after domination by Coastal Teatree is evidenced by encouraging results of restoration works at other ESBS sites (Perkins *et al.* 2012). Works at the York Road ESBS site in particular have shown that carefully designed interventions can lead to incremental increases in plant diversity over periods of 5 years or more (including recovery of Characteristic ESBS species) although sites of longer degradation are slower to show increases in species (Parsons Brinkerhoff 2012; Perkins *et al.* 2012).

In this study, we report on a range of interventions and treatments applied during the course of site management between 2009 and 2015, most of them designed to assist in restoring the diversity and vigour of ESBS. Some of these interventions have resulted in valuable qualitative *observations* that we present here, while others have suited quantitative measurement and allowed formal study and *experimentation*, largely reported in Lambert *et al.* (2015) and only summarised and discussed here.

Both the interventions and the studies provided information that enabled stepwise adaptive management and identified a need to consider a range of factors that were likely to affect successful ecosystem recovery – factors including the frequency of fire in the area, the influences of past disturbance and the impacts of current herbivory by European Rabbit (*Oryctolagus cuniculus*).

Programme of (monitored) works

Experiments with fire

In 2010 and 2011, three anticipated hazard reduction burns to be carried out on the SHFT property presented an opportunity to identify whether the Coastal Teatree dominance of much of the area was due to senescence

Box 2. Two types of ESBS?

The declared ESBS vegetation patches (11 patches) on North Head fall across a wide spectrum of richness and diversity, the extremes of which we describe as follows.

1 **ESB: A floristically richer type described as 'Sunshine wattle scrub', 'Open Heath', 'ESBS Open Heath' or 'vigorous ESBS' (Horton & Benson 1986; Benson & Howell 1994; Skelton *et al.* 2003) covering about 20 ha (32% of the ESBS) – Figure 3a. This contains a wide range of ESBS species, a grassy understorey and high light levels at the ground.**

2 **'LEPTO': A floristically poorer type described as '*Leptospermum laevigatum* scrub' or 'Closed Scrub' or 'Senescent ESBS' (Horton & Benson 1986; Benson & Howell 1994; Skelton *et al.* 2003), covering about 43 ha (68% of the ESBS) – Figure 3b. This is dominated by (very particularly) Coastal Teatree, Tree Broom Heath and Heath-leaved Banksia, with low light levels to the ground. It is also characterised by an abundance of twig litter, and an absence of grasses and (especially) of Wallum Banksia.**

Scrub types intermediate between the two extremes of LEPTO and ESB occur on North Head and on other sites in Sydney, but the LEPTO extreme occurs more prominently and over a much greater area on North Head than on other sites. Management guidelines and techniques for patches of Eastern Suburb Banksia Scrub will be contingent upon where in this spectrum the patch being managed is found.

of the ESBS community in the absence of fire or some other impact. Detailed monitoring was undertaken by Australian Wildlife Conservancy (AWC).

How and what was measured

Across two of the three burn sites, 39 7×7 m permanent quadrats were pegged out (methods fully described in Lambert *et al.* 2015). Within each central 5×5 m core area, 4 1×1 m plots were pegged out in a random manner – resulting in a total of 156 plots. The quadrats and plots were marked with fire-proof aluminium corner tags, to enable the plots to be resurveyed after the fire.

A subset of the quadrats (27 of the 39; containing a total of 108 1 m^2 plots) was surveyed prior to the burn and data collected on number of species, number of plants, their stem density, height, developmental stage and presence of seeds or flowers in each plot in each quadrat separately.

The controlled burns (Fig. 4) occurred in Spring on 6 September 2012, a date determined mainly on the basis of vegetation flammability and the forecast weather, by the principal manager, Fire and Rescue NSW. The fire temperature was not measured, but the fire managers estimated it to be very variable over the site, with the above-ground vegetation completely consumed in some places, while only litter and fine fuel consumed in most others. Fire around the edges of the burnt area, involving seven of the 39 quadrats, was extinguished by the fire managers before being fully burned. One of these quadrats was totally unburned and later served as a convenient check against change in the burned quadrats and was surveyed postburn. Within 1 week of the burn, rabbit exclusion fences were placed around 11 quadrats within the burn sites.

The 32 fully burned quadrats, containing 128 plots, were re-surveyed at 6 months and 12 months after the fires, using the same techniques and analysis as used for the prefire surveys.

What we found

The quadrats in which postfire surveys were carried out were classified as being ESB ($N = 18$) or Coastal Teatree dominated (LEPTO, $N = 21$) based on Nearmap aerial photos made 1 month before the fire and by ground observations (Lambert *et al.* 2015).

The prefire surveys showed that plots in the ESB quadrats ($N = 18$ quadrats) exhibited significantly higher densities and richness of plant species than plots in the LEPTO quadrats ($N = 9$ quadrats) ($P < 0.05$). A total of 17 of the species identified were Characteristic ESBS species.

After the burn, there were significant increases in densities and richness of plant species per plot at 12 months after the fire – in both ESB and LEPTO plots (Table 2). The number of Characteristic ESBS species rose from 15 to 23 (+53%) in ESB plots and from 11 to 20 (+81%) in LEPTO plots. There were no significant changes in the plant or species counts nor in vegetation parameters in the unburned 'control' quadrat ($P > 0.2$). Full postburn results can be found in Lambert *et al.* 2015.

Experiments and observations on the consequence of thinning

Experiments with selective thinning

In two areas adjacent to the fires described above, a trial of selective thinning to remove the dominant Coastal Teatree was performed in five quadrats, all of which were classified as LEPTO (Fig. 5). Although there were no prethinning surveys, postthinning surveys were conducted in 20 1 $\times$ 1 metre plots at the same time, using the same techniques, as the postfire surveys at 6 and 12 months. The

Figure 3. (a) An ESB 5 × 5 metre quadrat photographed across a diagonal. There is a wide variety of species and a large number of plants in this open-canopy quadrat. There is no Coastal Teatree in this quadrat. (b). A LEPTO closed-canopy quadrat showing its floristic paucity relative to the ESB quadrat. There are 130 Coastal Teatree in this quadrat.

post-thinning surveys showed that sites that had been thinned had significantly fewer native plants and fewer native species than sites that had been burned ($P < 0.05$; Table 3). Both samples were of LEPTO sites only, to optimise comparability. Full results for this experiment can be found in Lambert *et al.* (2015) and are summarised in Table 3.

Observations made in association with restoration of the 3rd Quarantine Cemetery

The Third Quarantine Cemetery, 0.37 ha in extent, was fenced and remained inaccessible to the public and hence undisturbed from the 1930s. The cemetery was opened to public access in 2011. In association with the opening, the Sydney Harbour Federation Trust cleared the cemetery of its (relatively sparse) cover of Coastal Teatree. A brief spot survey conducted by the authors shortly thereafter, revealed the presence of some 64 species, having a species mix similar to that found in adjoining ESBS areas [see Appendix S2]. In the 3 years since, there has been a clear increase in the numbers of these plant species, most notably of Flannel Flower (*Actinotus helianthi*).

Experimental thinning after long-term disturbance and degradation

A site alongside North Fort Road (-33° 48.8′, E151° 17.9′), which had been

Box 3. Weeds

Most weed species at North Head occur in vegetation communities other than ESBS. The Recovery Plan lists only two weed species – Lantana and African Love Grass (*Eragostris curvula*) – as occurring within ESBS at North Head. The prefire surveys carried out on ESBS on North Head in 2012 and 2014 – as well as the survey by Walker (2013) – revealed no weeds in the core areas of ESBS on North Head. However, weeds appeared in the 2012 postfire survey. Three weed species appeared in the fenced quadrats, but the largest number of weed species (8) appeared in the unfenced burnt quadrats, indicating a possible role for rabbits in the spread of weeds or an effect of ongoing disturbance. A weed species list is presented in Appendix S2. Weeds were removed from survey quadrats after surveys, but not from the wider area. The Harbour Trust contractors weed these areas on an *ad hoc* basis.

Figure 4. The hazard reduction fire of September 2012, burning in the Coastal Teatree-dominated southern edge of the burn site. Twenty-one survey quadrats (seven of them fenced) were laid out in this patch in the week following the fire. At the spot where the fire crew can be seen standing, three 'thinning quadrats' were cleared and fenced in October 2012. (Photo courtesy: Cameron Radford, Australian Wildlife Conservancy).

Table 2. Mean density and richness, plus total number, of native species in 1 m^2 plots inside 27 quadrats surveyed before the controlled burns and in 32 fully burned quadrats surveyed 12 months after the burns

	ESB	LEPTO
Prefire		
Number of plots (total = 108)	60	48
Mean No. of plants per plot (± SE)	22 ± 8	8.0 ± 2.6
Mean No. of species per plot (± SE)	4.3 ± 0.6	2.3 ± 0.4
Total No. of species	55	5
12 months postfire		
Number of plots (total = 128)	88	40
Mean No. of plants per plot (± SE)	48 ± 6	28 ± 3
Mean No. of species per plot (± SE)	8.6 ± 1.2	6.6 ± 1.0
Total No. of species	52	35

extensively and persistently disturbed, was chosen to test the ability of long-degraded scrub to regenerate without fire. The site was first cleared for an unsurfaced 4WD road between 1936 and 1943 and most recently cleared again in 1986. Regrowth occurred from 1995, as judged from aerial photography and tree ring analysis, which indicated nearly a decade when the site remained clear prior to regrowth.

In each July of 2012 and 2013, a single 10 × 10 metre quadrat was cleared and sixty 1 × 1 metre plots were laid out in it. Two-thirds of each quadrat was fenced to control for rabbit herbivory. The species cleared were Coastal Teatree and Tree Broom Heath (Q1 had 12 and Q2 had 53 specimens of these two species removed). Subsequent treatments in the fenced portion of the quadrats were as follows:

1 Do nothing (20 plots);

2 Soil raking to 10 cm (20 plots);

3 Direct seeding in 10 plots (one-half) in each of the plots of treatments (i) and (ii) (in Q2 only).

The decision to use direct seeding in Q2 was made on the basis of the low numbers of regenerating plants in Q1 at 1 year after thinning. A small quantity of seed of 26 species (14 of which were from the Characteristic ESBS list) was sown in Q2 directly after thinning in July 2013. At 2 years after thinning, 91 species of plants were growing inside the fences of Quadrats 1 and 2 (see Appendix S2) – 21 of these were ESBS species, with no significant differences between seeded and unseeded plots in Q2 (Table 4) 12 months after seeding. This suggests that the seeding did not add substantially to the result, although Q2 had only been seeded for 12 months at the time of the recording. Rabbits appeared to be a factor, because there were significantly fewer plants in unraked sections outside the fences of these quadrats. There were fewer plants and species in thinned and raked sections of the quadrats than in thinned and unraked sections (Table 4). A third quadrat was seeded in July 2014, but results are not yet available.

Observations on wide-scale linear clearing

For fire management purposes (Asset Protection Zones, APZ and Strategic Fire Advantage Zones, SFAZ), a programme of clearing has been carried out by NPWS and SHFT, principally alongside a network of historic stone walls which criss-cross North Head. Clearing was carried out by contractors with trittering machinery. The date of the initial clearing is uncertain but was prior to November

Figure 5. Thinning a *Coastal Teatree*-dominated area adjacent to the Third Quarantine Cemetery and to one of the burn sites. (Photo: G. Lambert).

Table 3. The mean number of plants and number of native species per 1 × 1 m plot previously dominated by LEPTO in 10 fenced-burned quadrats and 5 fenced-thinned quadrats 12 months after fire or thinning

	Burned	Thinned
Number of plots (total = 60)	40	20
Mean No. of plants per plot (± SE)	26 ± 2.5	19 ± 2.4
Mean No. of species per plot	5.9 ± 0.4	7.4 ± 0.4
No. of species in all plots of each type	73	25

Table 4. Plant densities and species numbers in Quadrat 2 one year after treatment. (Surveys by GIS consultants for NHSF)

	Fenced, unraked		Fenced, raked		Unfenced
	Sown	Unsown	Sown	Unsown	Unraked
Number of plots	10	10	10	10	20
No. of species	20	26	19	18	20
Plants per m^2	33.0	26.0	13.5	12.0	12.05
SE	2.1	2.0	0.7	0.5	0.4
Student's *t*-test	2.39		1.71		
P	NS		NS		

2009. The second clearing occurred in June 2012 with some further maintenance clearing in April 2014 and January 2015. The vegetation in these cleared areas has not been surveyed quantitatively, but it is clearly observable that the predominant regrowth species has been Coastal Teatree, particularly along the western side of the walls where this species was already a dominant canopy species prior to the 2012 clearings. These observations indicate that this species is capable of readily recolonising disturbed areas where it was previously present.

Observations on cessation of mowing

In late 2006, a 0.14-ha section of a long-mown lawn was cordoned off from mowing and allowed to regenerate. This area, located on the northern fringes of the sand mantle, contained a range of planted tree species and had been mowed for about 50 years. The dominant species that germinated after cessation of mowing was Coastal Teatree, possibly from seed at least somewhat recently dispersed from the nearby stands of this species (it is not considered to be a long soil seed storer – see Box 3). Seventeen other species emerged. A species list for this intervention can be found in Appendix S2 of Perkins *et al.* (2012).

Coastal Teatree has been removed at yearly intervals, and some exotic species (remnants from plantings by the Army) have also been removed.

Observations of supplementary plantings

Since 2000, the Sydney Harbour Federation Trust has been engaged in a planting programme in the surrounds of its buildings, not necessarily confined to species native to North Head. Since 2009, the NHSF has, in consultation with SHFT, been engaged in its own planting programme of ESBS and other species in former garden or lawn areas – all of them thought to occur as ESBS on North Head before 1936. Planting stock was grown in a dedicated native plant nursery, from seed or cuttings sourced from within the North Head ESBS patches. The object of this programme – originally to reinstate locally occurring plant communities and restore habitat – was modified in 2013–14 to ensure the species, at maturity, would meet the lower density and heights appropriate to fire Asset Protection Zones. About 1.6 ha has been planted with 16,000 plants of 136 species, including 7300 grass tube-stock, representing 11 grass species. Thirty species were from the Characteristic ESBS list (see list in Appendix S2).

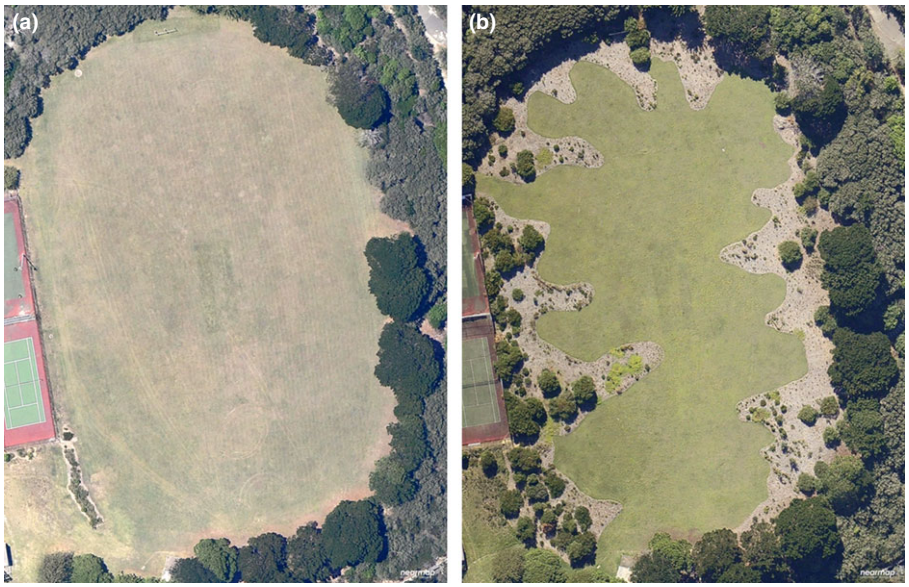


Figure 6. The old sports oval, which has been planted with some 3300 plants from the NHSF plant nursery. Left: 2011, right 2014. The dominant species visible in the plantings in the 2014 photo are Sydney Golden Wattle (*Acacia longifolia*) and Bangalow (*Eucalyptus botryoides*), but there are also a dozen specimens of the rare Camfield's Stringybark (*Eucalyptus camfieldii*). (Photos NHSF).

Figure 7. The visible effects of rabbit exclusion on regrowth thirty months after fire. top – inside a rabbit exclusion fence; and bottom – outside the fence. (Photo: G Lambert).

This has been a remarkably successful programme in re-stablishing swathes of vegetation on cleared areas converted to exotics or lawn, including a sports oval (Fig. 6). It is intended that the oval site will become Long-nosed Bandicoot (*Perameles nasuta*) habitat, with plantings provided for shelter and grass for foraging. The layout of the plantings is driven to differing degrees, by asset protection, bushland restoration, bandicoot habitat and aesthetic imperatives.

Across the planting programme, some of the mature plants, especially the State-listed Endangered ESBS 'Characteristic' species *Acacia terminalis* subsp. *terminalis,* have seeded and second-generation plants have emerged. This programme will continue until the vegetation communities (including both ESBS and non-ESBS as appropriate) have stabilised.

Experiments on the impact of predation by rabbits

In experiments with fire and thinning, the effect of predation by rabbits was formally assessed by enclosing a certain proportion of the quadrats (30–100% depending on the experiment) with rabbit-proof fencing. The impact of rabbits was apparent after all treatments (Fig. 7). In summary, plant density and species density in unfenced plots were, respectively, 54% and 84% of that in fenced plots (Lambert *et al.* 2015).

Overview of the results

Table 5 provides a summary of progress with all the elements of the programme described above. These are viewed as an integrated whole and

Table 5. Summary of results and observations on the management and restoration techniques used on North Head 2009–2014. Plant species results are for Characteristic ESBS species only

Treatment	Area treated (ha)	Pretreatment vegetation types	No. of Characteristic ESBS species	
			Pretreatment	Post-treatment
Controlled burning	1.7	ESB 37%/LEPTO 63%	17	24
Selective thinning	0.03	LEPTO	N/A	9
Thinning after disturbance (2 quadrats)	0.03	LEPTO	3	18
Cessation of mowing	0.14	Garden/lawn	2	19
Cessation of mowing, with seedling planting	0.12	Garden/lawn	N/A	N/A
Broad-scale plantings	1.6	Gardens/lawn/ESB	N/A	31
Clearing for Asset Protection	1.7	ESB/LEPTO	Unknown	TBA
Total	5.3			

Box 4. 130 years of vegetation issues on North Head

There has been concern about the state of vegetation communities on North Head since 1887 when Lady Carrington criticised the '*Rape of the Bush*' after she opened a Manly Flower Show (Sydney Morning Herald, 29 September 1887). In 1925, the Australian Forest League obtained from the Federal Government a commitment to replace exotic vegetation on North Head with native plants, to form '*the first flora sanctuary*' in Sydney (National Archives of Australia Item A1928, 876/3). Six years later, the Sydney Morning Herald (SMH, 1-Jan-1931), led the way in urging that the encroachment of sand dunes be arrested with plantings. In 1986, a *Community Employment Program* project at the Quarantine Station led to the first formal attempts to manage ESBS (Horton & Benson 1986). In 1992, after lobbying from the School of Artillery about the 'depredations of ti-tree' (Turner 1996), a regeneration burn to address the issue was carried out. The work described in the present article thus builds upon some 130 years of effort to protect or restore the scrubland on North Head.

are designed to address the spectrum of degradation factors at North Head.

Implications for management

The projects reported here represent the latest phase in a long process of active concern for the conservation management of vegetation communities at North Head (Box 4). The incorporation of experimentation with management during this phase of work has enabled us to draw a range of insights. For example, increases in Characteristic ESBS species after fire at North Head, and to a lesser extent after the Coastal Teatree thinning, add weight to the findings from other sites that many ESBS species can germinate from seed stored in the soil for some decades, but that regenerative capacity can be lower in some sites; particularly sites with a history of soil disturbance. Burning has proved to be feasible, particularly where combined with hazard reduction activity; and where this is not feasible, thinning has been shown to be a viable alternative to fire.

Burning and thinning to reduce Coastal Teatree domination

North Head is unique among ESBS sites by virtue of its overall size, its patch size, its floristic richness and the existence of a wide spectrum of vegetation condition – from 'ESB' to 'LEPTO'; with Coastal Teatree occurring more prominently and over a much greater area on North Head than on other sites in Sydney.

Skelton *et al.* (2003) speculated that the development of at least some of the patches at the LEPTO extreme of the spectrum arose from too infrequent fire; and it is has been speculated widely that Coastal Teatree-dominated ESBS communities (e.g. LEPTO) are a degraded form of the more floristically rich type, due to absence of fire. On North Head, however, results of our work and close examination of the sites suggest that this may not be the only – or even the main – explanation for Coastal Teatree domination across large areas of the site. There is anecdotal and aerial photographic evidence that parts of the ESBS at North Head now dominated by Coastal Teatree have been affected by historical land clearing and soil disturbance, while the historical evidence for too frequent or too infrequent fire in these areas is less well-documented. It is also well known that Coastal Teatree can be a highly competitive species, which can opportunistically invade sites where disturbances have reduced the cover of other species (Bennett 1994). Continued Coastal Teatree dominance after repeated disturbance at North Head, particularly the mowing, removal and linear firebreak clearing, adds weight to the characterisation of Coastal Teatree as an opportunistic colonising species. It appears then that both excessive disturbance (soil disturbance) and lack of disturbance (lack of fire) can lead to Coastal Teatree dominance and both circumstances seem to have occurred at North Head.

Planting and direct seeding

It is logical to expect that patches with both a long history of disturbance and a prolonged period of dominance by Coastal Teatree might have a depleted soil seed bank and that planting of ESBS species may be required in such areas. Planting at North Head has certainly resulted in high levels of plant establishment, with lower success rates for direct seeding. Dominance by Coastal Teatree in planted and other areas shows, however, that ongoing removal of emergent Coastal Teatree is needed to maintain diversity.

The surprising results of regeneration after cessation of mowing after many decades and after a range of Coastal Teatree thinning works at North Head, however, make it difficult to draw any conclusions about when buried seed banks may be exhausted and reintroductions required. In the light of this, it would be appropriate to delay planting until assisted regeneration approaches have been trialled unless the site is large and long-modified.

Rabbit management

ESBS will not regenerate completely, nor as quickly, in the presence of rabbits. Rabbits are present on North Head at densities which have up to

about six individuals per hectare in the regeneration areas (Lambert & Lambert 2014). This is far in excess of that said to significantly inhibit growth of native seedlings (Muntze *et al.* 2014). In the light of these findings, a substantial proportion of future Controlled Burns on North Head will be fenced after the fires.

Progress and future directions

The listing of ESBS as an Endangered Ecological Community at both State and Federal levels presents a challenge to managers of ESBS to meet specific targets relating to preventing further decline in the extent of ESBS; preventing further degradation of the existing scrub; and where possible, restoring the degraded ESBS to its pre-1936 condition. Have we succeeded in meeting these targets? The answer is a qualified 'Yes', as suggested by (for instance) the near-doubling of the number of Characteristic ESBS species in the LEPTO plots 1 year after fire. Rapid progress cannot be expected in these communities, however (see Parsons Brinkerhoff 2012). Recovery of species diversity and abundance of ESBS areas to a level similar to healthy reference sites is likely to take time, whether after fire, thinning or planting. Pickup *et al.* (2013) reported that species richness in a burned vegetation community did not reach that of a nearby unburned community until 2–5 years after fire. Experiments with small fires at the York Rd ESBS community are yet to demonstrate statistically significant increases (Perkins *et al.* 2012). Evidence from our burn experiments suggests the fire can produce a greater increase in species richness in degraded scrub than in nondegraded scrub even in the short term, but that a full response from all species present in the soil may take years and a range of treatments.

Most of the interventions, management options and experiments will continue at North Head until the management of ESBS on the site fully complies with the recommendations of the Recovery Plan. In particular, further fire experiments are being designed and implemented. For example, Fire and Rescue NSW plan to conduct further controlled burns in mid-2015 for which prefire vegetation surveys have already been carried out. The burn area will be subdivided into two classes, fenced (4 large fenced areas, rather than a multitude of fences around small quadrats) and unfenced. The entire burn area cannot be fenced because of foraging requirements of the Bandicoot population. Postfire surveys will be conducted 6 months after the fire, and results should be available shortly thereafter. Planting and hazard reduction clearing will also continue in their respective areas, and the results will be continually monitored.

The work reported in this study highlights the importance of retaining and sustainably managing Endangered Ecological Communities such as ESBS, given the effort required to restore them once lost or heavily modified. Avoidance of soil disturbance and loss of topsoil – plus maintenance of appropriate fire regimes – appear to be important factors in optimally maintaining the remaining ESBS. Management and restoration techniques for ESBS should be tailored to where along the ESBS vegetation condition spectrum the particular vegetation patch lies.

Acknowledgements

We thank Peter Jensen of the Sydney Harbour Federation Trust for the data he has provided, his management of the North Head ESBS and his helpful comments on the manuscript. We thank the reviewers and the Editor for their advice and guidance on the manuscript. We are indebted to Belinda Pellow of the Australian Museum for conducting flora surveys and for comments on the manuscript. We also thank Nelika Hughes, Jennifer Anson, and Cameron Radford (Australian Wildlife Conservancy), Nick Skelton (GIS Environmental Consultants), the late Sue Halmagyi, Toni Stevenson, Nick Vale and other NHSF Nursery volunteers, Robert Strauch of Fire and Rescue NSW, NSW Rural Fire Service and the NSW National Parks and Wildlife Service for their advice, assistance and/or participation in the projects we have described.

References

Bennett L. (1994) The expansion of *Leptospermum laevigatum* on the yanakie isthmus, wilson's promontory, under changes in the burning and grazing regimes. *Australian Journal of Botany* **42**, 555–564.

Benson D. and Howell J. (1994) Vegetation of the Sydney 1:100,000 map sheet. *Cuuninghamia* **3**, 677–787.

Bushfire Research Unit NSW NPWS (2003) NSW vegetation fire response database, Available on request from NPWS, PO Box 1967, Hurstville, NSW 2220.

Gill A. M. (1975) Fire and the Australian flora: a review. *Australian Forestry* **38**, 4–25.

Horton S. and Benson D. (1986) A vegetation survey of North Head. (unpublished manuscript available from the authors).

Hunter J. (1792) An historical journal of the transactions at Port Jackson and Norfolk Island. Stockdale, London. Bibliolife. Digital text version by University of Sydney 2003 accessed on 1-Dec-2014 at adc.library.usyd.edu.au/data-2/hunhist.pdf

Judd T. S. (1990) The ecology and water relations of the invasive shrubs, Kunzea ambigua (Sm) Drucc, K. ericoides (A. Rich) J. Thompson and Leptospermum laevigatum (J. Gazertn.) F. Muell. Ph. D. thesis, University of Melbourne.

Lambert J. A. and Lambert G. A. (2014) The effect of predation by rabbits on regenerating Eastern Suburbs Banksia Scrub. Proceedings of the Ecological Society of Australia 2014 Annual Conference, Alice Springs, Abstracts p31.

Lambert J. A., Lambert G. A. and Pellow B. (2015) An evaluation of two management options to restore the diversity of Eastern Suburbs Banksia Scrub. *Cunninghamia* **15**, 69–78.

Lesak J. (2000) Effect of smoke water on a soil seedbank: Is glasshouse germination a valid test of field response? Honours Thesis The University of New South Wales.

Muntze G., Cooke B. and Jennings S. (2014) Density-dependent effects of rabbit browsing on Australian native vegetation alter natural ecosystems even at historically low densities. Proceedings of the Ecological Society of Australia 2014 Annual Conference, Alice Springs, Abstracts p119.

NSW Department of Environment and Conservation (2004) *Eastern Suburbs Banksia Scrub Endangered Ecological Community Recovery Plan*. NSW Department of Environment and Conservation, Hurstville.

NSW NPWS (2004) Eastern Suburbs banksia scrub in the Sydney Basin Bioregion - endangered ecological community listing.

[Accessed 5 Jul 2009] Available from URL: http://www.environment.nsw.gov.au/determinations/EasternSuburbsBanksiaScrubEndComListing.htm.

OEH (2013) The native vegetation of the Sydney Metropolitan area. Volume 1: Technical Report. Version 2.0. Office of Environment and Heritage, Department of Premier and Cabinet, Sydney.

Offor T. (1990) What future for the sandy heaths of Wilson's Promontory? *Victorian Naturalist* **107**, 120–123.

Parsons Brinkerhoff (2012) York Road Eastern suburbs banksia scrub ecological monitoring 2012 – Unpublished report to Centennial and Moore Park Trust. Parsons Brinkerhoff Australia P/L39 pp

Perkins I., Diamond J., SanRoque G. *et al.* (2012) Eastern Suburbs Banksia Scrub: rescuing an endangered ecological community. *Ecological Management & Restoration*, **13**, 224–237. (Supporting Information at http://onlinelibrary.wiley.com/doi/10.1111/emr.12002/suppinfo)

Pickup M., Wilson S., Freudenberg D. *et al.* (2013) Post-fire recovery of revegetated woodland communities in south-eastern Australia. *Austral Ecology* **38**, 300–312.

Skelton N., Richmond O., Gilson T. and Wong P. (2003) Flora of North Head. Prepared for Sydney Harbour Federation Trust. GIS Environmental Consultants, Dee Why.

Turner T. (1996) Reflections of former commanding officers_chief instructors. In: *History of the School of Artillery 1885 to 1996*. (ed I. Burch) pp. 232. Development Wing, School of Artillery, Scenic Drive, Manly, NSW.

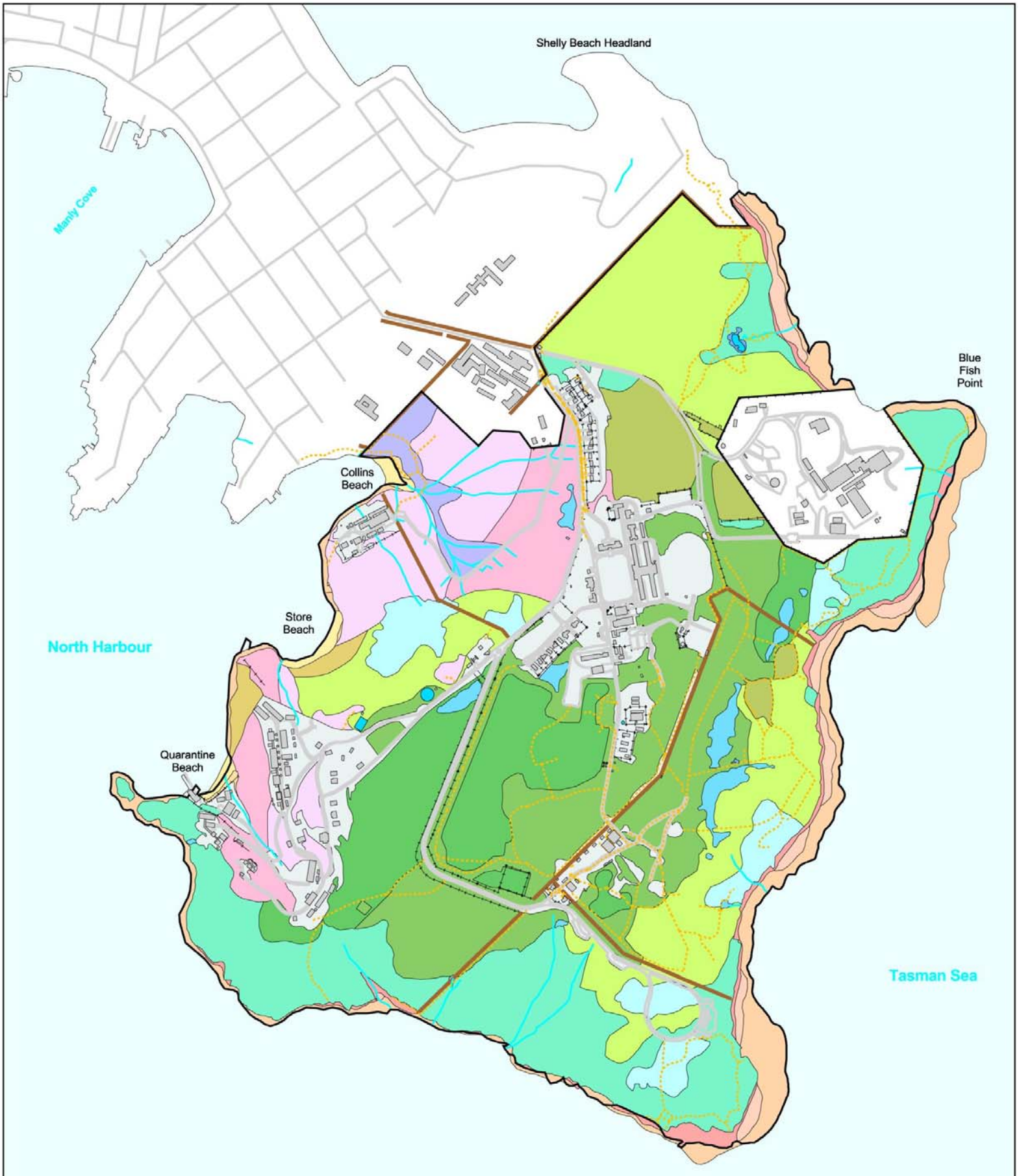
Walker A. (2013) The impact of habitat loss and fragmentation on the diversity of Eastern Suburbs Banksia Scrub. Unpublished Third Year Undergraduate Report, School of Environment, Science and Engineering, Southern Cross University, Lismore.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Vegetation map of North head.

Appendix S2. Flora lists and relative species frequencies for surveys and planting of ESBS communities on the sand mantle at North Head, NSW, Australia.



Vegetation Communities
- Littoral Rainforest
- Forest
- Ridgetop Woodland
- Coastal Banksia Low Woodland
- Shrubland
- Shrubland - Disturbed
- ESBS - Senescent Scrub
- ESBS Banksia Open Heath
- Rocky Heath
- Heath

Key
- Fernland
- Wetland
- Cliff Face
- Boulder Slope
- Rocky Foreshore
- Hind Dune
- Beach
- Exotic Grassland and Urban

- Building
- Study Site
- Coast
- Track
- Road
- Drainage
- Stone Wall
- Fence

Appendix 1

Vegetation Communities **(Map 8)**

Flora Survey of North Head

November 2003

by Nicholas Skelton, GIS Environmental Consultants
for Sydney Harbour Federation Trust

Scale 1:9000 0 50 100 Meters

N

Data collected and mapped during fieldwork by GIS Environmental Consultants Ph: 041 943 8672

APPENDIX 2

Flora lists and relative species frequencies for surveys and planting of ESBS communities on the sand mantle at North Head, NSW, Australia

1 2012 Fire Experiment - by scrub type

2 2012 Fire Experiment - by treatment

3 Third Quarantine Cemetery Species list

4 NHSF plantings list

5 Disturbed soil area thinning experiment

For each list, species names are given−with ESBS *Characteristic Species* names ***in bold***. For quantitative surveys, the first two columns show species names in alphabetical order with counts of this species. Later columns show the same species names ordered by relative species abundance, together with these abundances in each class−treatment or scrub type. The floristically-richer form of ESBS is referred to as “ESB” and the floristically-poorer version as “LEPTO”.

All or a selection of summary statistics appear at the foot of the tables

Number of species

Number of ESBS species

Percentage of species which are Characteristic ESBS

(Inverse) Simpson Diversity Index

Shannon-Weiner Diversity coefficient

Sorenson-Dice similarity coefficient (for comparisons)

Morisita-Horn Overlap index (0 = no overlap of species; 1 = complete overlap)

2012 Fire Experiment - by scrub type

Ordered by species name

Species	BOTH
APIACEAE sp	1
Acacia longifolia	28
Acacia myrtifolia	2
Acacia sp	20
Acacia suaveolens	33
Actinotus helianthi	84
Actinotus minor	17
Allocasuarina distyla	21
Amperea xiphoclada	24
Anagallis arvensis	2
Anisopogon avenaceus	4
Astroloma humifusum	156
Banksia aemula	7
Banksia ericifolia	8
Banksia marginata	14
Banksia sp	1
Billardiera scandens	2
Bossiaea ?scolopendria	2
Bossiaea heterophylla	9
Bossiaea scolopendria	1
Bossiaea sp	13
Brachyloma daphnoides	6
Breynia oblongifolia	4
Caladenia alata	2
Calytrix tetragona	9
Cassytha glabella	28
Caustis pentandra	93
Chordiflex dimorpha	13
Crassula sieberiana	10
Cryptostylis sp?	12
Cyathochaeta diandra	10
Dampiera stricta	4
Dianella caerulea	41
Dianella sp	1
Dillwynia glaberrima	2
Dodonaea triquetra	1
Elaeocarpus reticulatus	1
Empodisma minus	9
Entolasia stricta	12
Eragrostis brownii	4
Euphorbia sp	1
Facelis retusa	1
Gahnia sp	47
Gompholobium glabratum	1
Goodenia sp	2
Grevillea buxifolia	16

Ordered by relative abundance

Species	ESB	LEPTO
Leptospermum laevigatum	17.47%	34.76%
Micrantheum ericoides	11.76%	4.61%
Lepidosperma laterale	8.32%	3.54%
Persoonia levis	5.36%	8.69%
Astroloma humifusum	3.97%	6.97%
Lomandra cylindrica	5.71%	0.21%
Caustis pentandra	3.09%	2.36%
Paspalidium distans	2.31%	4.29%
Phyllanthus hirtellus	3.31%	1.61%
Actinotus helianthi	3.18%	1.18%
Haemodorum planifolium	2.70%	1.72%
Lasiopetalum ferrugineum	2.27%	0.32%
Hibbertia linearis	1.31%	2.47%
Xanthosia tridentata	1.70%	1.39%
Lomandra filiformis	2.09%	0.21%
Gahnia sp	0.83%	3.00%
Dianella caerulea	1.57%	0.54%
Hibbertia fasciculata	0.96%	1.61%
Acacia suaveolens	1.09%	0.86%
Cassytha glabella	0.78%	1.07%
Acacia longifolia	1.00%	0.54%
Kunzea ambigua	0.83%	0.86%
Unknown POACEAE	1.09%	0.11%
Amperea xiphoclada	0.44%	1.50%
Patersonia sp	0.83%	0.32%
POACEAE sp	0.87%	0.21%
Allocasuarina distyla	0.61%	0.75%
Acacia sp	0.44%	1.07%
Schoenus ericetorum	0.39%	1.18%
Hypolaena fastigiata	0.57%	0.64%
Actinotus minor	0.70%	0.11%
Grevillea buxifolia	0.65%	0.11%
Platysace linearifolia	0.65%	
Banksia marginata	0.44%	0.43%
Pultenaea tuberculata	0.44%	0.43%
Lambertia formosa	0.57%	0.11%
Bossiaea sp	0.35%	0.54%
Chordiflex dimorpha	0.57%	
Cryptostylis sp?	0.26%	0.64%
Entolasia stricta	0.52%	
Xanthorrhoea resinosa	0.35%	0.32%
Cyathochaeta diandra		1.07%
Crassula sieberiana	0.44%	
Lomandra glauca	0.26%	0.43%
Selaginella uliginosa	0.39%	
Empodisma minus	0.26%	0.32%

2012 Fire Experiment - by scrub type

Ordered by species name

Species	BOTH
Haemodorum planifolium	78
Hakea gibbosa	1
Hakea sp	1
Hibbertia fasciculata	37
Hibbertia linearis	53
Hibbertia scandens	2
Hovea linearis	1
Hypolaena fastigiata	19
Isopogon anemonifolius	8
Kunzea ambigua	27
Kunzea sp	2
Lagenophora gracilis	4
Lambertia formosa	14
Lasiopetalum ferrugineum	55
Lepidosperma laterale	224
Leptospermum arachnoides	1
Leptospermum laevigatum	725
Leptospermum trinervium	3
Lomandra cylindrica	133
Lomandra filiformis	50
Lomandra glauca	10
Micrantheum ericoides	313
Monotoca elliptica	5
Opercularia sp	1
POACEAE sp	22
Paspalidium distans	93
Patersonia sericea	8
Patersonia sp	22
Persoonia levis	204
Petrophile pulchella	4
Petrophile sp	1
Philotheca buxifolia	1
Phyllanthus hirtellus	91
Pittosporum undulatum	2
Platysace linearifolia	15
Pomax umbellata	4
Poranthera microphylla	4
Pseudanthus orientalis	2
Pultenaea daphnoides	2
Pultenaea tuberculata	14
Ricinocarpos pinifolius	4
Rutaceae sp	1
Schizaea bifida	3
Schoenus ericetorum	20
Selaginella uliginosa	9
Solanum sp	8

Ordered by relative abundance

Species	ESB	LEPTO
Bossiaea heterophylla	0.26%	0.32%
Calytrix tetragona	0.39%	
Patersonia sericea	0.31%	0.11%
Banksia ericifolia	0.35%	
Solanum sp	0.22%	0.32%
Unknown	0.35%	
Unknown herb	0.35%	
Isopogon anemonifolius	0.35%	
Banksia aemula	0.04%	0.64%
Brachyloma daphnoides	0.22%	0.11%
Monotoca elliptica	0.04%	0.43%
Poranthera microphylla		0.43%
Breynia oblongifolia	0.09%	0.21%
Lagenophora gracilis	0.17%	
Anisopogon avenaceus		0.43%
Petrophile pulchella	0.13%	0.11%
Unknown Fabaceae	0.17%	
Pomax umbellata	0.17%	
Dampiera stricta	0.17%	
Styphelia sp		0.43%
Veronica sp	0.17%	
Unknown native	0.13%	0.11%
Ricinocarpos pinifolius	0.13%	0.11%
Eragrostis brownii	0.17%	
Sonchus oleraceus		0.43%
Leptospermum trinervium	0.13%	
Unknown Asteraceae sp		0.32%
Schizaea bifida	0.13%	
Woollsia pungens	0.04%	0.21%
Hibbertia scandens	0.04%	0.11%
Pittosporum undulatum	0.09%	
Goodenia sp	0.09%	
Unknown sp	0.04%	0.11%
Billardiera scandens		0.21%
Dillwynia glaberrima	0.09%	
Pseudanthus orientalis	0.09%	
Caladenia alata	0.09%	
Thysanotus virgatus	0.04%	0.11%
Unknown Liliaceae	0.09%	
Pultenaea daphnoides	0.09%	
Bossiaea ?scolopendria		0.21%
Anagallis arvensis	0.09%	
Kunzea sp	0.09%	
Acacia myrtifolia	0.09%	
Xanthorrhoea sp		0.11%
Facelis retusa		0.11%

2012 Fire Experiment - by scrub type

Ordered by species name

Species	BOTH
Sonchus oleraceus	4
Styphelia sp	4
Thelymitra sp	1
Thysanotus virgatus	2
Unknown	8
Unknown (?Pittosporum revolutum)	1
Unknown (hairy)	1
Unknown (native)	1
Unknown - also at Site 1	1
Unknown Asteraceae sp	3
Unknown Fabaceae	4
Unknown Goodenia?	1
Unknown Liliaceae	2
Unknown POACEAE	26
Unknown herb	8
Unknown native	4
Unknown native- Pseudanthus orientalis	1
Unknown sp	2
Veronica sp	4
Woollsia pungens	3
Xanthorrhoea media	1
Xanthorrhoea resinosa	11
Xanthorrhoea sp	1
Xanthosia pilosa	1
Woollsia pungens	52
No. of plants	3227
No of Species	112
Number of ESBS species	25
%age of ESBS	22%
Simpson Diversity	**0.92**
Shannon-Weiner diversity	**3.34**
Sorenson Similarity (L vs R)	
Morisita-Horn (L vs R)	

Ordered by relative abundance

Species	ESB	LEPTO
APIACEAE sp		0.11%
Philotheca buxifolia		0.11%
Unknown (?Pittosporum revolutum)		0.11%
Gompholobium glabratum	0.04%	
Thelymitra sp		0.11%
Banksia sp		0.11%
Unknown native- Pseudanthus orienta	0.04%	
Bossiaea scolopendria	0.04%	
Xanthorrhoea media		0.11%
Xanthosia pilosa	0.04%	
Opercularia sp	0.04%	
Unknown (native)		0.11%
Hakea sp	0.04%	
Unknown Goodenia?	0.04%	
Petrophile sp	0.04%	
Hakea gibbosa		0.11%
Dodonaea triquetra	0.04%	
Unknown - also at Site 1	0.04%	
Hovea linearis		0.11%
Unknown (hairy)	0.04%	
Dianella sp		0.11%
Leptospermum arachnoides		0.11%
Elaeocarpus reticulatus	0.04%	
Euphorbia sp	0.04%	
Rutaceae sp	0.04%	
	96	75
	23	20
	24%	27%
	0.93	**0.86**
	3.66	**2.96**
		0.52
		0.01

2012 Fire Experiment - by treatment

Ordered by species name		Ordered by abundance in Burned			
Species	**ALL**	**Species**	**Burned Unfenced**	**Burned Fenced**	**Thinned Fenced**
APIACEAE sp	2	***Leptospermum laevigatum***	18.97%	24.20%	5.41%
Acacia longifolia	95	*Micrantheum ericoides*	8.79%	10.31%	
Acacia myrtifolia	2	***Lepidosperma laterale***	8.85%	4.26%	
Acacia sp	21	*Persoonia levis*	5.42%	6.85%	10.13%
Acacia suaveolens	31	*Astroloma humifusum*	5.25%	5.72%	12.16%
Actinotus helianthi	109	*Lomandra cylindrica*	4.70%	3.19%	
Actinotus minor	17	*Paspalidium distans*	1.71%	4.19%	14.19%
Allocasuarina distyla	21	*Phyllanthus hirtellus*	3.32%	2.06%	1.35%
Amperea xiphoclada	24	***Acacia longifolia***	1.33%	4.39%	3.38%
Anagallis arvensis	2	*Actinotus helianthi*	3.76%	1.06%	16.90%
Anisopogon avenaceus	4	***Caustis pentandra***	1.88%	3.06%	
Astroloma humifusum	199	***Haemodorum planifolium***	3.04%	1.53%	
Banksia aemula	12	*Lasiopetalum ferrugineum*	1.49%	1.86%	
Banksia ericifolia	8	*Gahnia sp*	1.44%	1.86%	0.68%
Banksia marginata	14	*Hibbertia linearis*	1.94%	1.20%	
Banksia sp	1	*Lomandra filiformis*	2.43%	0.40%	
Billardiera scandens	3	*POACEAE sp*	1.49%	1.20%	
Bossiaea ?scolopendria	2	*Dianella caerulea*	1.88%	0.53%	
Bossiaea heterophylla	9	***Hibbertia fasciculata***	1.49%	0.66%	2.03%
Bossiaea scolopendria	1	***Acacia suaveolens***	0.66%	1.26%	
Bossiaea sp	13	*Cassytha glabella*	1.05%	0.73%	1.35%
Brachyloma daphnoides	5	***Kunzea ambigua***	0.72%	0.93%	
Breynia oblongifolia	6	*Unknown POACEAE*	1.05%	0.47%	
Caladenia alata	2	*Amperea xiphoclada*	0.72%	0.73%	
Calytrix tetragona	9	*Patersonia sp*	0.88%	0.33%	
Cassytha glabella	32	***Allocasuarina distyla***	0.83%	0.40%	
Caustis pentandra	80	*Schoenus ericetorum*	0.44%	0.80%	0.68%
Chordiflex dimorpha	13	*Acacia sp*	0.55%	0.66%	
Crassula sieberiana	10	***Hypolaena fastigiata***	0.61%	0.53%	
Cryptostylis sp?	12	***Actinotus minor***	0.33%	0.73%	
Cyathochaeta diandra	10	*Pittosporum undulatum*	0.61%	0.40%	2.70%
Cynodon dactylon	3	*Grevillea buxifolia*	0.83%		0.68%
Dampiera stricta	4	*Platysace linearifolia*	0.83%		
Dianella caerulea	42	*Banksia marginata*	0.17%	0.73%	
Dianella sp	1	***Lambertia formosa***	0.33%	0.53%	
Dichelachne crinita	3	*Bossiaea sp*	0.39%	0.40%	
Dillwynia glaberrima	2	*Chordiflex dimorpha*	0.50%	0.27%	
Dodonaea triquetra	1	*Pultenaea tuberculata*		0.80%	
Elaeocarpus reticulatus	1	*Entolasia stricta*	0.22%	0.53%	
Empodisma minus	9	*Cryptostylis sp?*	0.39%	0.33%	
Entolasia stricta	12	*Xanthorrhoea resinosa*	0.61%		
Eragrostis brownii	19	*Crassula sieberiana*	0.06%	0.60%	
Euphorbia sp	1	***Eragrostis brownii***	0.39%	0.20%	
Facelis retusa	1	*Lomandra glauca*	0.17%	0.47%	
Gahnia sp	55	***Cyathochaeta diandra***	0.39%	0.20%	

2012 Fire Experiment - by treatment

Ordered by species name		Ordered by abundance in Burned			
Species	**ALL**	**Species**	**Burned Unfenced**	**Burned Fenced**	**Thinned Fenced**
Geitonoplesium cymosum	4	*Solanum sp*	0.22%	0.40%	6.08%
Glochidion ferdinandi	0	***Bossiaea heterophylla***	0.39%	0.13%	
Gompholobium glabratum	1	*Calytrix tetragona*	0.44%	0.07%	
Goodenia sp	2	*Empodisma minus*	0.06%	0.53%	
Grevillea buxifolia	16	*Lagenophora gracilis*	0.06%	0.53%	
Haemodorum planifolium	78	*Unknown*	0.28%	0.27%	
Hakea gibbosa	1	*Parsonsia straminea*		0.60%	
Hakea sp	1	*Selaginella uliginosa*	0.50%		
Helichrysum elatum	3	***Banksia ericifolia***	0.44%		
Hibbertia fasciculata	40	*Unknown herb*	0.11%	0.40%	
Hibbertia linearis	53	*Patersonia sericea*	0.17%	0.33%	
Hibbertia scandens	2	***Monotoca elliptica***	0.28%	0.13%	3.38%
Hovea linearis	1	***Banksia aemula***	0.17%	0.27%	2.03%
Hypolaena fastigiata	19	*Isopogon anemonifolius*	0.06%	0.40%	
Isopogon anemonifolius	7	*Stephania japonica*	0.22%	0.13%	0.68%
Kunzea ambigua	27	*Schizaea bifida*	0.11%	0.27%	1.35%
Kunzea sp	2	*Poranthera microphylla*	0.11%	0.27%	
Lagenophora gracilis	9	*Breynia oblongifolia*	0.22%	0.07%	
Lambertia formosa	14	***Brachyloma daphnoides***	0.17%	0.13%	0.68%
Lasiopetalum ferrugineum	55	*Anisopogon avenaceus*	0.06%	0.20%	
Lepidosperma laterale	224	*Veronica sp*	0.11%	0.13%	
Leptospermum arachnoides	1	*Dampiera stricta*	0.06%	0.20%	
Leptospermum laevigatum	715	***Pomax umbellata***		0.27%	
Leptospermum trinervium	3	*Petrophile pulchella*	0.17%	0.07%	
Lomandra cylindrica	133	*Unknown Fabaceae*		0.27%	
Lomandra filiformis	50	*Unknown native*	0.17%	0.07%	
Lomandra glauca	10	***Ricinocarpos pinifolius***	0.11%	0.13%	
Lomandra longifolia	5	*Styphelia sp*	0.11%	0.13%	
Micrantheum ericoides	314	*Sonchus oleraceus*	0.11%	0.13%	
Monotoca elliptica	10	***Leptospermum trinervium***	0.11%	0.07%	
Opercularia sp	1	***Woollsia pungens***	0.17%		
Oxalis sp	1	*Unknown Asteraceae sp*	0.11%	0.07%	
POACEAE sp	45	***Dichelachne crinita***	0.06%	0.13%	
Parsonsia straminea	9	*Hibbertia scandens*	0.06%	0.07%	
Paspalidium distans	115	*Acacia myrtifolia*		0.13%	
Patersonia sericea	8	*Anagallis arvensis*	0.11%		
Patersonia sp	21	*Thysanotus virgatus*	0.06%	0.07%	0.68%
Persoonia levis	216	***Billardiera scandens***		0.13%	
Petrophile pulchella	4	*Pseudanthus orientalis*	0.06%	0.07%	
Petrophile sp	1	*Pultenaea daphnoides*	0.11%		
Philotheca buxifolia	2	*Goodenia sp*		0.13%	
Phyllanthus hirtellus	93	*Unknown Liliaceae*	0.06%	0.07%	
Pittosporum undulatum	21	*Unknown sp*		0.13%	
Platysace linearifolia	15	*Kunzea sp*	0.11%		
Pomax umbellata	4	*Dillwynia glaberrima*	0.11%		

2012 Fire Experiment - by treatment

Ordered by species name		Ordered by abundance in Burned			
Species	**ALL**	**Species**	**Burned Unfenced**	**Burned Fenced**	**Thinned Fenced**
Poranthera microphylla	6	*Bossiaea ?scolopendria*	0.11%		
Pseudanthus orientalis	2	*Caladenia alata*		0.13%	
Pultenaea daphnoides	2	*Elaeocarpus reticulatus*	0.06%		
Pultenaea tuberculata	12	*Xanthorrhoea media*		0.07%	
Ricinocarpos pinifolius	4	*Xanthorrhoea sp*	0.06%		
Rutaceae sp	1	*Leptospermum arachnoides*	0.06%		
Schizaea bifida	8	*Unknown (hairy)*	0.06%		
Schoenus ericetorum	20	*APIACEAE sp*		0.07%	
Selaginella uliginosa	9	*Wahlenbergia gracilis*	0.06%		
Solanum sp	10	*Unknown - also at Site 1*	0.06%		
Solanum vescum	2	*Unknown (?Pittosporum revo*		0.07%	
Sonchus oleraceus	4	*Hakea sp*		0.07%	
Stephania japonica	7	*Philotheca buxifolia*	0.06%		0.68%
Styphelia sp	4	*Hovea linearis*	0.06%		
Thelymitra pauciflora	2	*Unknown native- Pseudanthu*		0.07%	0.68%
Thelymitra sp	1	*Hakea gibbosa*	0.06%		
Thysanotus virgatus	2	*Unknown (native)*	0.06%		
Unknown	9	*Oxalis sp*	0.06%		
Unknown (?Pittosporum revolutu	1	*Petrophile sp*	0.06%		
Unknown (hairy)	1	*Dodonaea triquetra*	0.06%		
Unknown (native)	1	*Rutaceae sp*		0.07%	
Unknown - also at Site 1	1	*Facelis retusa*	0.06%		
Unknown Asteraceae sp	3	*Thelymitra sp*		0.07%	
Unknown Fabaceae	4	*Thelymitra pauciflora*	0.06%		
Unknown Goodenia?	1	*Banksia sp*		0.07%	0.68%
Unknown Liliaceae	2	*Euphorbia sp*	0.06%		
Unknown POACEAE	26	*Unknown Goodenia?*		0.07%	
Unknown herb	8	*Dianella sp*	0.06%		
Unknown native	4	*Opercularia sp*		0.07%	
Unknown native- Pseudanthus or	1	***Bossiaea scolopendria***		0.07%	
Unknown sp	2	*Gompholobium glabratum*	0.06%		
Veronica sp	4	*Glochidion ferdinandi*			
Wahlenbergia gracilis	1	*Helichrysum elatum*			1.35%
Woollsia pungens	3	*Solanum vescum*			2.03%
Xanthorrhoea media	1	*Geitonoplesium cymosum*			2.70%
Xanthorrhoea resinosa	11	*Cynodon dactylon*			3.38%
Xanthorrhoea sp	1	***Lomandra longifolia***			2.03%
Xanthosia tridentata	53	*Thelymitra pauciflora*			2.500%
No. of plants	3513		1916	1414	200
No. of Species	127		101	92	29
No. of ESBS species	27		23	24	6
%age of ESBS	21%		23%	26%	21%
Simkpson Diversity					
Shannon-Weiner diversity	3.28		3.38	3.24	2.60

2012 Fire Experiment - by treatment

Ordered by species name		Ordered by abundance in Burned		
Species	**ALL Species**	**Burned Unfenced**	**Burned Fenced**	**Thinned Fenced**
Sorenson Similarity (L vs R)			0.65	0.38
Morisita-Horn (L vs R)			0.90	0.35

Disturbed soil area thinning experiment

Q2

Species (2009-2014 plantings)	Number	Relative Frequency
Acacia sp.	9	1.44%
Acacia terminalis terminalis	0	0.00%
Actinotus helianthi	1	0.16%
Bossiaea sp.	4	0.64%
Dicot	16	2.55%
Dillwynia sp.	52	8.29%
Elaeocarpus reticulatus	1	0.16%
Entolasia marginata	11	1.75%
Gnaphalium sp.	188	29.98%
Grass	5	0.80%
Hibbertia sp.	3	0.48%
Leptospermum laevigatum	224	35.73%
Monotoca elliptica	4	0.64%
Persoonia lanceolata	11	1.75%
Pittosporum undulatum	2	0.32%
Sporobolus sp.	8	1.28%
Commelina cyanea	0	0.00%
Dianella caerulea var caerulea	1	0.16%
Schoenus ericetorum	10	1.59%
Monocot	7	1.12%
Astrotricha floccosa	0	0.00%
Acacia longifolia	7	1.12%
Acacia myrtifolia	0	0.00%
Acacia suaveolens	26	4.15%
Acacia ulicifolia	0	0.00%
Banksia aemula	0	0.00%
Calytrix tetragona	0	0.00%
Comesperma sp.	0	0.00%
Dicot. type 1	0	0.00%
Dicot. type 2	0	0.00%
Dicot. type 3	0	0.00%
Dicot. type 4	0	0.00%
Epacrid sp.	1	0.16%
Eragrostis curvula	0	0.00%
Eriostemon sp.	2	0.32%
Empty	0	0.00%
Glycine sp.	0	0.00%
Gompholobium sp.	0	0.00%
Hardenbergia violaceae	0	0.00%
Helichrysum sp.	0	0.00%
Hibbertia linearis	9	1.44%
Hibbertia fasciculata	0	0.00%
Isopogon anethifolius	0	0.00%
Kunzea ambigua	1	0.16%
Kunzea rupestris	0	0.00%

Disturbed soil area thinning experiment

Q2

Species (2009-2014 plantings)	Number	Relative Frequency
Lasiopetalum sp.	0	0.00%
Leptospermum juniperinum	0	0.00%
Micrantheum ericoides	1	0.16%
Olearia tomentosa	0	0.00%
Omalanthus populifolius	0	0.00%
Patersonia sp	0	0.00%
Persoonia linearis	0	0.00%
Phylotheca buxifolia buxifolia	15	2.39%
Phylotheca salsolifolia salsolifolia	0	0.00%
Pomax umbellata	0	0.00%
Ricinocarpos pinifolius	3	0.48%
Woollsia pungens	0	0.00%
Amperea xiphoclada	0	0.00%
Breynia oblongifolia	0	0.00%
Caustis flexuosa	0	0.00%
Dampiera stricta	0	0.00%
Gahnia sieberiana	2	0.32%
Glochidion ferdinandi	0	0.00%
Haemodorum planifolium	3	0.48%
Hibbertia scandens	0	0.00%
Hypolaena fastigiata	0	0.00%
Lambertia formosa	0	0.00%
Lepidosperma laterale	0	0.00%
Lomandra glauca	0	0.00%
Lomandra longifolia	0	0.00%
Lomandra sp.	0	0.00%
Rutaceae sp.	0	0.00%
Restionaceae sp.	0	0.00%
No. of plants	627	
No. of Species	73	
No. of ESBS species	17	
%age of ESBS	23%	
Simpson Diversity	0.77	
Shannon-Weiner diversity	2.03	

Third Cemetery Species List
Surveys in 2013 and 2015

Species name

Acacia longifolia
Acacia suavolens
Acrinotus helianthii
Actinotus minor
Allocasuarina distylla
Astroloma humifusun
Banksia aemula
Banksia ericifolia
Banksia integrifolia
Banksia marginata
Bossiaea ensata
Brachyloma daphnoides
Breynia oblongifolia
Caladenia alba
Caladenia carnea
Caleana major
Callitris rhomboida
Calochilus johnsonii
Cassytha glabella
Caustis pentandra
Conospermum longifolia
Conospermum taxifolim
Dianella caerulea
Dilwynnia retorta
Diuris sulphurea
Elaeocarpus retivulatus
Entolasia stricta
Euryomyrtis ramosissima
Gahnia sp
Grass 1
Grass 2
Grevillea buxifolia
Grevillea speciosa
Gymnoschoenus sphaerocephalus
Haemodorum planiformum
Hibbertia fascicularis
Hibbertia scandens
Hibbertia serpyllifolia
Lambertia formosa
Lepidosperma laterale
Leptospermum laevigatum
Leptospermum parvifolium
Leptospermum polygafolium
Leptospermum trinervium
Leucopogon ericoides
Leucopogon microphyla

Third Cemetery Species List
Surveys in 2013 and 2015

Species name
Lomandra glauca
Lomandra longifolia
Monotoca elliptica
Patersonia glabrata
Patersonia sericea
Pelargonium australis
Persoonia lanceolata
Persoonia levis
Petrophile pulchella
Philotheca sp
Pittosporum undulatum
Pomax umbellata
Poranthera corymbosa
Schoenus ericatorum
Stephania japonica
Styphelia triflora
Woollsia Pungens
Xanthorrhea resinifera
Xylomelon pyriformes

No. of plants	N/A
No. of Species	65
No. of ESBS species	17

NHSF Plantings List
Species counts for 2012-2014 only

Species (2009-2014 plantings)	Number	Relative Frequency
Themeda australis	994	9.07%
Pomax umbellata	679	6.20%
Hibbertia scandens	602	5.49%
Dillwynia retorta	550	5.02%
Dianella caerulea	441	4.02%
Acacia myrtifolia	437	3.99%
Acacia ulicifolia	377	3.44%
Isolepis nodosa	372	3.39%
Dichelachne crinata	372	3.39%
Lomandra longifolia	364	3.32%
Dichelachne micrantha	352	3.21%
Eragrostis brownii	333	3.04%
Microlaena stipoides	327	2.98%
Actinotus helianthii	292	2.66%
Danthonia sp	244	2.23%
Patersonia sericea	225	2.05%
Acacia suaveolens	194	1.77%
Acacia terminalis var terminalis	187	1.71%
Grevillea speciosa	175	1.60%
Helichrysum elatum	157	1.43%
Xanthorrhoea sp	153	1.40%
Hibbertia diffusa	146	1.33%
Allocasuarina distyla	141	1.29%
Pittosporum revolutum	141	1.29%
Banksia marginata	122	1.11%
Plectranthus parviflorus	120	1.10%
Juncus sp	117	1.07%
Olearia tomentosa	112	1.02%
Glycine clandestina	111	1.01%
Lasiopetalum ferrugineum	108	0.99%
Hakea gibbosa	105	0.96%
Hakea teretifolia	98	0.89%
Hardenbergia violaceae	92	0.84%
Calytrix tetragona	90	0.82%
Callistemon citrinus	80	0.73%
Viminaria juncea	77	0.70%
Grevillea buxifolia	73	0.67%
Melaleuca nodosa	71	0.65%
Banksia ericifolia	68	0.62%
Bossiaea sp	58	0.53%
Eragrostis elongata	58	0.53%
Oplismenus sp	56	0.51%
Eleocarpus reticulatus	51	0.47%
Goodenia sp	50	0.46%
Lambertia formosa	49	0.45%

NHSF Plantings List
Species counts for 2012-2014 only

Species (2009-2014 plantings)	Number	Relative Frequency
Melaleuca hypericifolia	44	0.40%
Pelargonium australe	42	0.38%
Banksia aemula	42	0.38%
Acacia sophorae	41	0.37%
Conospermum elliptica	39	0.36%
Petrophile pulchella	38	0.35%
Acacia longifolia	37	0.34%
Petrophile sessilis	32	0.29%
Epacris longiflora	31	0.28%
Lepidosperma laterale	30	0.27%
Eucalyptus camfieldii	26	0.24%
Sporobolus virginicus	25	0.23%
Gahnia sieberana	23	0.21%
Haemodorum planifolium	23	0.21%
Isopogon anethifolius	20	0.18%
Cyperus polystachyos	20	0.18%
Persicaria decipiens	20	0.18%
Kunzea capitata	20	0.18%
Gonocarpus teucrioides	20	0.18%
Kunzea ambigua	20	0.18%
Hakea dactyloides	19	0.17%
Hibbertia linearis	19	0.17%
Banksia integrifolia	19	0.17%
Cymbopogon refractus	18	0.16%
Darwinia citriodora	17	0.16%
Phyllota phylicoides	16	0.15%
Leptospermum juniperinum	16	0.15%
Callitris rhomboidea	15	0.14%
Banksia robur	15	0.14%
Woollsia pungens	13	0.12%
Bauera rubioides	12	0.11%
Callistemon linearifolius	10	0.09%
Unidentified sedge	10	0.09%
Darwinia fascicularis	10	0.09%
Adiantum aethiopicum	10	0.09%
Bossiaea heterophylla	8	0.07%
Philotheca salsolifolia	7	0.06%
Leptospermum sp	7	0.06%
Eucalyptus botryoides	7	0.06%
Fimbristylis sp	6	0.05%
Hypolaena fastigata	6	0.05%
Hibbertia dentata	6	0.05%
Hakea sericea	5	0.05%
Philotheca buxifolia	5	0.05%
Actinotus minor	5	0.05%

NHSF Plantings List
Species counts for 2012-2014 only

Species (2009-2014 plantings)	Number	Relative Frequency
Lasiopetalum rufum	4	0.04%
Poranthera sp	4	0.04%
Baekea sp	4	0.04%
Amperea xiphoclada	4	0.04%
Persoonia lanceolata	4	0.04%
Hibbertia fasciculata	3	0.03%
Platysace lanceolata	3	0.03%
Epacris obtrusa	3	0.03%
Billardiara scandens	3	0.03%
Restionaceae sp	3	0.03%
Pimelea linifolia	3	0.03%
Micrantheum ericoides	3	0.03%
Bossiaea scolopendria	2	0.02%
Asplenium sp	2	0.02%
Chordifex dimorpha	2	0.02%
Boronia sp	2	0.02%
Grevillea sericea	2	0.02%
Pterostylis nutans	2	0.02%
Caustis sp	1	0.01%
Digitaria parvifolia	1	0.01%
Entolasia marginata	1	0.01%
Parsonsia straminea	1	0.01%
Westringia longifolia	1	0.01%
Pultenaea sp	1	0.01%
Gompholobium sp	1	0.01%
Schizaea sp	1	0.01%
Astroloma humifusum	1	0.01%
Agonis flexuosa	1	0.01%

NHSF Plantings List
Species counts for 2012-2014 only

Species (2009-2014 plantings)	Number	Relative Frequency
Breynia oblongifolia		
Notodanthonia sp		
Dillwynia sp		
Commelina cyanea		
Persoonia laevis		
Centella asiatica		
Sedges		
Phyllota sp		
Allocasuarina littoralis		
Banksia serrata		
Eucalyptus multicaulis		
Wahlenbergia gracilis		
Pultenaea elliptica		
Lomandra glauca		
Carpobrotus glaucescens		
Lobelia elata		
Monotoca elliptica		
Pratia purpurascens		
# of plants	10958	
# of species	136	
# of ESBS species	31	
%age ESBS	23%	
Simpson Diversity	0.97	
Shannon-Weiner diversity	3.56	
Sorenson Similarity (L vs R)	N/A	