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An evaluation of two management options to restore species diversity of Eastern Suburbs Banksia Scrub at North Head, Sydney

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Abstract: Eastern Suburbs Banksia Scrub (ESBS) is a listed Endangered Ecological Community that becomes senescent and loses species diversity in its plant cover in the long-term absence of fire. However, the reintroduction of fire into remnant vegetation within urban areas presents management challenges and selective thinning is sometimes presented as an alternative management option. This project sought to evaluate fire and selective thinning of dominant species as tools for reinvigorating senescent ESBS.

Two peri-urban ESBS sites at North Head, Sydney, New South Wales, scheduled for hazard reduction burns to protect assets, were surveyed for their floristic attributes. Surveys were carried out in 7 x 7 metre quadrats, one third of which were fenced after fire to assess predation by herbivores. Similar quadrats were established on adjoining unburnt sites from which dominant species were removed through selective thinning.

Twelve months after treatment (and to a lesser extent at 6 months) burned ESBS displayed greater vigour and diversity than did thinned sites. Burned ESBS had more native plants, greater plant cover, more native species, greater species diversity and fewer weeds than did thinned ESBS. Burned and thinned ESBS sites had significantly low overlap in native species mix. Areas that had been fenced after fire had "superior" attributes to those that had not been fenced. There was nearly complete overlap of species between fenced and unfenced ESBS subjected to fire.

The results suggest that fire can be used advantageously to rejuvenate this type of heath and that this method produces superior results to thinning, but with a different species mix. These advantages accrue with time. The results of either method would be greatly inferior were attempts not made to control predation by exotic herbivores such as rabbits.

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Introduction

In 2012–13 the North Head Sanctuary Foundation (NHSF) in partnership with the Australian Wildlife Conservancy (AWC), conducted a comparative study of the use of fire and selective thinning as tools for the restoration of senescent Eastern Suburbs Banksia Scrub (ESBS) at North Head, Sydney. The name Eastern Suburbs Banksia Scrub, first used by Benson & Howell (1990) for vegetation on deep sands perched on sandstone in the south-eastern suburbs between Sydney Harbour and Botany Bay, is now used more broadly to include similar vegetation elsewhere on Sydney's eastern coast (Department of the Environment 2014).

ESBS is an open to closed heath found on the sand mantles which perch on Sydney's sandstone headlands (NSW National Parks and Wildlife Service 2004). It is a form of Coastal Sand Mantle Heath, (NSW Office of Environment and Heritage and Sydney Metropolitan Catchment Management Authority 2013) characterised by its highly podsolised soils derived from aeolian sand and by its heath community. A total of some 173 species of native plants have been recorded for Sand Mantle Heath. Two-thirds of these species are also found in ESBS; 54 of which are used to define ESBS (Department of the Environment 2014).

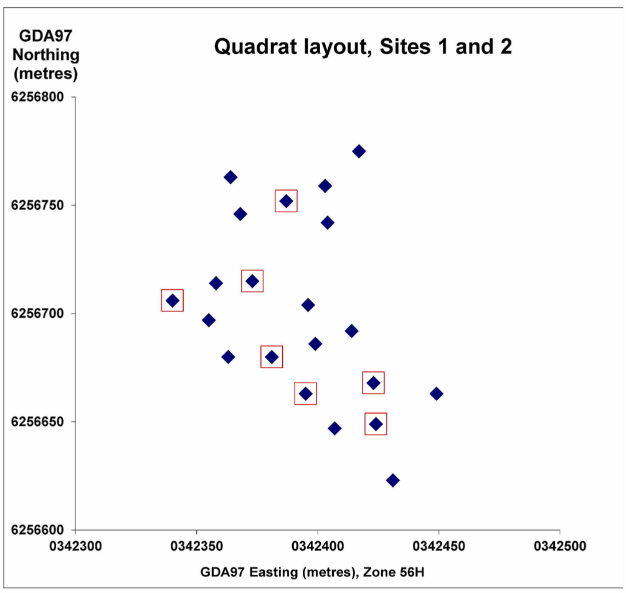
The vegetation was first noted by Joseph Banks in 1770 when he and Solander collected the first plant specimens at Botany Bay on Cook's *Endeavour* voyage (Banks 1963). At that time ESBS probably covered about 5,300ha (NSW National Parks and Wildlife Service 2004), but has now been largely destroyed by the suburban growth of Sydney. Substantial remnants of ESBS still occur at North Head, which contains an estimated 69ha of the remaining 146ha in Sydney. ESBS is an endangered ecological community, listed both nationally within the *Environment Protection and Biodiversity Conservation Act* 1999 and at state level within the *NSW Threatened Species Conservation Act* 1995 (Department of the Environment 2014; NSW National Parks and Wildlife Service 2004) .

Fire was an important tool used by Aboriginal people in coastal scrub communities (Wilson 1999) and was first recorded in the ESBS at North Head in 1788, when Bradley, Hunter and Worgan documented such a fire (Bradley 1969; Hunter 2009; Worgan 1978). A survey of pre-European fire-management practices for Sydney bushland can be found in McLoughlin (1998).

ESBS is an open, rich and diverse ecological community in the first few years after fire, when it is has been referred to as being *vigorous* by Skelton et al. (2003). With time the canopy closes, species richness and diversity in the standing vegetation decreases, and the community becomes dominated by a few large shrub species including *Leptospermum laevigatum*, *Banksia ericifolia* and *Monotoca elliptica*. Skelton et al. (2003) refer to this closed heath as *senescent*, its standing vegetation being less diverse than younger, more vigorous ESBS. The senescent state has been regarded as inferior both aesthetically and botanically by some (Department of Environment and Climate Change NSW 2009), but this inference neglects the fact that ESBS may have many post-fire states, and that although some species may not be in the plant cover at all times, they may still exist as seedbank propagules in the soil (Keith 1996; Keith et al. 2002; Keith and Tozer 2012).

Fire has been shown to both open the canopy and promote seeding and regeneration (Keith 1995; Keith et al. 2002; Keith and Tozer 2012), whereas thinning opens the canopy without the other beneficial effects of raised temperature and smoke on seed release and germination (Bradstock 1991; Dixon et al. 1995). For this reason fire is preferred as a regenerative tool. The preferred fire interval for ESBS is probably 8–30 years (Clemens and Franklin 1980; Clark and McLoughlin 1986; Morrison and Cary 1995; Kenny et al. 2004). However, best practice management guidelines recommend patchwork fires every 10–15 years (Department of Environment and Climate Change NSW 2009). The challenges in using fire close to densely settled urban areas are numerous and many bushland areas remain unburned beyond ecologically-preferred intervals (Cary et al. 2003; Jurskis et al. 2003; Driscoll et al. 2010;).

This project was designed to inform ecological management of ESBS across different land tenures by exploring the relative regenerative benefits of planned fire *versus* selective thinning. Protection from post-regenerative grazing by rabbits and other herbivores was an important management consideration.



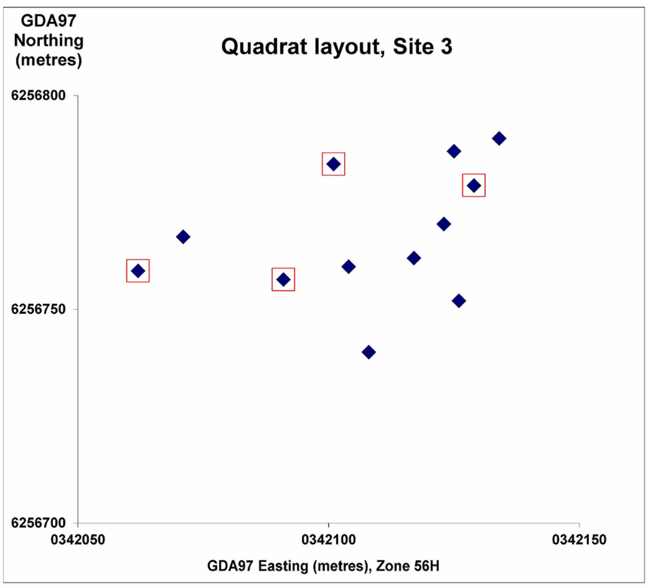


Fig 1 Layout of quadrats within burn sites. Each marker represents the south-west corner of a survey quadrat. Markers with surrounding squares indicate quadrats with fences.

Methods

We took advantage of two long-scheduled hazard reduction burns planned for three sites on North Head by the regional Bush Fire Management Committee. The burn sites were on Sydney Harbour Federation Trust land at North Fort and near the Third Quarantine Cemetery, but NPWS (as a designated fire agency) assisted with the burns (lat/long of the burn sites: S33º 49.058' E151º 17.827' and S33º 49.054' E151º 17.632'). As for all such burns, timing critically depended on the fire management personnel and resources available when the burns could be safely and effectively completed.

Burns were conducted on 6 September 2012; the areas burned totalled 1.3 ha and 0.7 ha. Slope within each site varied from flat to about 10%, and they were generally south facing sites with a mantle of aeolian sand.

Before the fires, a total of 37, 7x7 metre quadrats were allocated by a randomisation process across fire sites (31 quadrats) and thinning sites (5 quadrats) (one quadrat within the scheduled burn area did not burn and was not included in data analysis). Within the central 5x5 m core of each quadrat, four 1 x 1 m plots were selected randomly. Quadrat and plot corners were marked with aluminium tags (see Figure 1 for treatment layout).

Immediately after burning or thinning, fences were established around 10 burned quadrats and all five thinned quadrats to prevent access by herbivores. The wire mesh and star-picket fence design included a pegged skirt to deter burrowing. Fences were designed by Nicholas Skelton (pers. comm.) and trialled successfully by NHSF prior to the project.

To minimise the extent of ESBS removal and disturbance it was decided to have fewer thinned quadrats and locate them on track-side areas immediately opposite the burn sites. The dominant overstorey of *Leptospermum laevigatum* and *Monotoca elliptica* was cut and removed with chainsaws, with as little other disturbance to the site as possible. The process sought to approximate vegetation removal consistent with alternative fire risk management practices. Removal of the dominant species resulted in a nearly 100% opening up of the previous canopy, with only a few low-growing species and *Leptospermum* seedlings remaining.

Plots were surveyed at six and 12 months post-treatment. After the fire and subsequent fencing, wide-angle photographs were taken from the top of the north-west corner post of each quadrat, looking east, south-east and south. Photo surveys were repeated quarterly. We also examined NearMap© aerial photographs of the area taken at approximately 2–monthly intervals in the 2009–2014 period, to aid interpretation of the progress of regeneration.

Plots were measured botanically six and 12 months after burning or thinning. For every plant in each 1–metre plot in each quadrat, the following attributes and measurements were recorded:

Species identification

Classification as "Native" or "Weed"

Whether the plant was a species listed as characteristic of ESBS in the Final Determination under the NSW *Threatened Species Act*

The fire response of the plant (if known)

Developmental stage (seedling, juvenile, mature)

Reproductive status when observed (flowering, seeding, etc.)

Height in cm

From the data means of plant counts, species counts, cover, and median plant height were calculated across plots for the Burned-unfenced, Burned-fenced, and Thinned-fenced

Fig 2. North Fort burn site one month before and two days after the fire. The "vigorous" core of ESBS is outlined in the pre-fire photograph. The patchiness of the fire is apparent. (Photos by NearMap©)

treatment comparisons. A Simpson diversity index (Gregorius and Gillet 2008) and a Morisita-Horn overlap index (Horn 1966) were used to measure the effects of treatments on the diversity and similarity of species present 12 months after treatment. Differences between mean values of parametric data were tested by Student's t-test. Differences among count data were tested by a χ^2 test. These tests had a power of 0.95. A permutation-driven Generalised Linear Model was used to test the significance of the Morisita-Horn overlap indices (Garratt and Steinhorst 1976; Nelder and Wedderburn 1972) from 0 (no overlap) to 1 (complete overlap). A probability level of $P \leq 0.05$ was accepted as "significant".

Results

Pre-treatment conditions and surveys

The greater part of the sites were densely vegetated, impeding comprehensive inspection. Under the vegetation layers, the ground surfaces comprised the following averages for "bare"– 8%; leaf litter– 16%; other plant litter– 75%; and rock– 2.4%. Some 104 different native species could be distinguished but only 57 could be assigned a definite species identification. There were 4% of plants at the seedling stage, 17% juvenile and 79% adult. Other than *Leptospermum laevigatum,* there were very few plants at all in the thinned sites, the ground cover of which was almost entirely leaf and twig litter.

Post-treatment conditions and surveys

Reports from fire crews (R. Strauch, pers. comm. 2013), on-ground visual inspection and oblique or vertical NearMap© aerial photography immediately post-fire, indicated the fire intensity varied widely across sites (Figure 2). Observation by fire professionals during the burn and the state of the remaining vegetation post-fire supported this assessment. One quadrat was completely unburned and was surveyed to act as a check against pre-burn status, but was not included in the post-fire analyses.

Except in the unburnt area, the post-fire surfaces were bare, consisting of on average 97% sand and 3% rock under the ash. It became apparent post-fire that the sites selected for thinning were not ideally matched with the burn areas, being somewhat flatter, with shallower sand and influenced by edge effects from the adjoining fire trails.

Table 1 Richness and abundance of plants within fenced plots six and 12 months after fire or thinning

		Burned (n=44)		**Thinned (n=20)**		
Time		**Mean ± S.E**			**Mean ± SE**	**Significance (P)**
A – 6 months	No. of ESBS plants per plot	3.7 ± 0.5			4.6 ± 0.7	NS
	No. of ESBS species per plot	1.5 ± 0.2			1.8 ± 0.2	NS
	No. of native plants per plot	11.6 ± 1.2			13.1 ± 1.5	NS
	No. of native species per plot	3.8 ± 0.3			4.9 ± 0.3	**<0.01**
	Plant cover (%)	23.1 ± 3.2			21.2 ± 4.3	NS
	Plant height (cm, Median)	3.0 ± 0.7			5.0 ± 1.3	NS
	Simpson Diversity	0.59 ± 0.03			0.73 ± 0.02	**<0.002**
	Morisita-Horn Overlap	Not calculated				
B – 12 months	No. of ESBS plants per plot		17.0 ± 1.9	6.2 ± 2.3		**< 0.01**
	No. of ESBS species per plot	3.3 ±0.2	2.2 ± 0.2		**<0.001**	
	No. of native plants per plot	36.5 ± 2.8	19.1 ± 2.4		**< 0.005**	
	No. of native species per plot	9.3 ± 0.4	7.4 ± 0.4		**<0.01**	
	Plant cover (%)	41.2 ± 4.4	25.3 ± 4.7		**<0.001**	
	Plant height(cm, Median)	12.0 ± 1.2	4.0 ± 0.8		**<0.05**	
	Simpson Diversity	0.75 ± 0.02	0.79 ± 0.03		NS	
	Morisita-Horn Overlap	0.36 ± 0.15			N/A	

Table 2 Species mix at six *versus* 12 months

	All native species			**ESBS Indicator Species**		
	Present in burned only	**Present in thinned only**	**Present in both**	**Present in burned only**	**Present in thinned only**	**Present in both**
6 months	61	17	16	24	10	7
12 months	76	10	34	24	9	7

As time since fire increased, the density of vegetation in many of the fenced plots increased, with the wattle species, *Acacia longifolia,* often dominant. Canopy cover changed from 0% to 100% in quadrats which had a high population of resprouting species such as *Banksia aemula, Lambertia formosa* and *Xanthorrhoea resinosa*. The latter species flowered within four months after the fire.

Six months after treatment (Table 1–A)

Although the fire sites were relatively small and the quadrats quite close together, data collected six months after fire showed considerable variation between quadrats. Mean canopy cover and median plant height were the same in thinned and burned plots. There was little difference in the number of plants (all or native) in fenced-burned versus fenced-thinned plots. The fenced-thinned plots were slightly more diverse. Almost twice as many weeds were found in the thinned plots compared with those in the burned plots. There were also differences in the mix of native species present in burned *vs* thinned plots.

Twelve months after treatment (Table 1–B)

By 12 months after treatment much more plant growth had occurred and cover, richness and abundance of plants were greater in burned areas than in thinned areas. The burned plots had more plants compared with thinned plots; more plant species and more native species. The diversity of species present in burned *versus* thinned plots (as measured by the Simpson's Index) were almost identical, but the Morisita-Horn coefficient for this comparison (0.36 ± 0.15)

Fig. 3. Difference in the distribution of native plant heights in fenced and unfenced plots

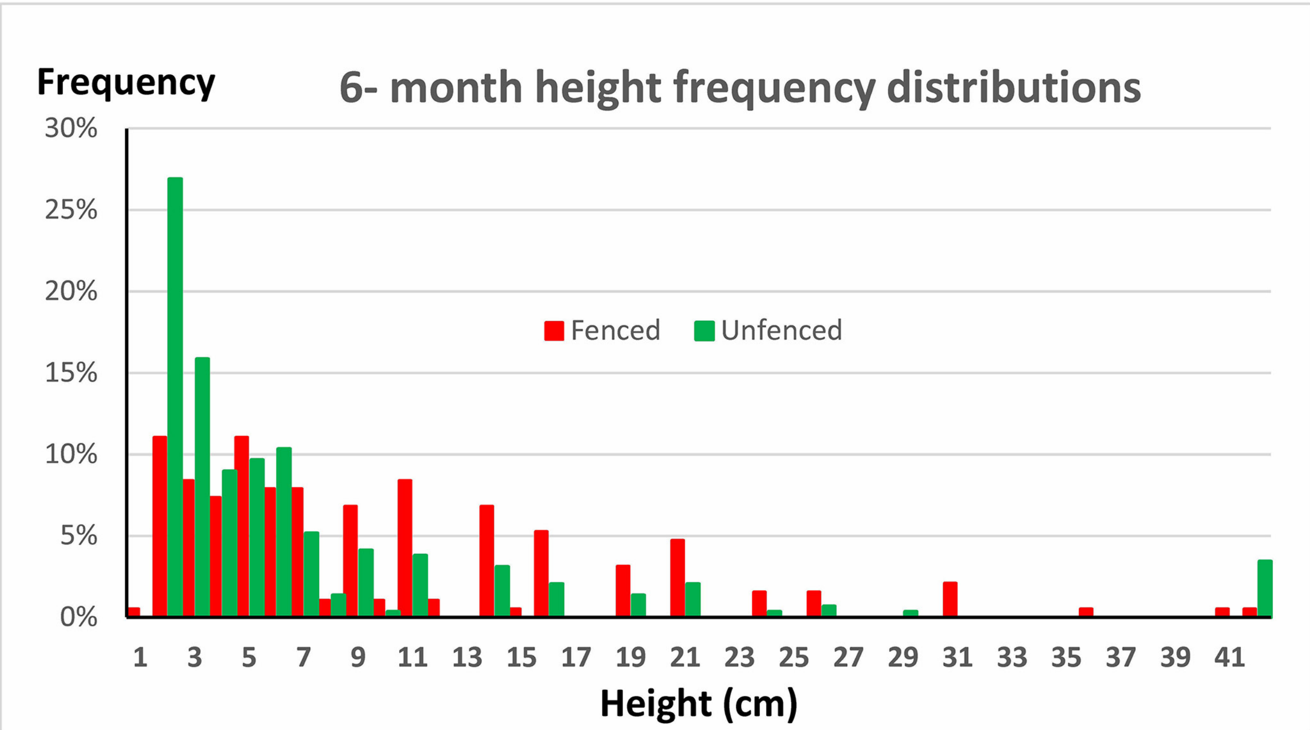


Table 3 Weed richness and abundance within fenced and unfenced plots at six and at 12 months after fire or thinning

		Burned/Unfenced (n=76) Mean ± S.E.	Burned/Fenced (n=44) Mean ± S.E.	Thinned/Fenced (n=20) Mean ± S.E.
A – months	No. of weeds/plot	0.8 ± 0.1	0.4 ± 0.2	1.7 ± 0.5*
	No. of weed species /plot	0.5 ± 0.1	0.3 ±0.1	1.1 ± 0.2*
B – 12 months	No. of weeds/plot	0.6 ± 0.1	1.4 ± 0.6	2.3 ± 0.8
	No. of weed species /plot	1.5 ± 0.1	0.5 ±0.2	0.9 ± 0.2*

*Significantly more weeds and weed species present in thinned plots (p<0.005) indicated a pronounced lack of overlap of species between burned-fenced and thinned-fenced plots. This lack of overlap is illustrated in Table 2, which shows the counts in the thinned and burned plots. The median height of plants in the burn plots at 12 months was greater than the height at 6 months. This difference was not seen with thinned plots.

Effects on ESBS species at 12 months

The indicator species identified for ESBS in national and state listings as an Endangered Ecological Community were used to assess success in reinvigorating the community. Twelve months after burning or thinning, the burned plots that were fenced had a greater diversity of ESBS indicator species per plot (mean 3.3 ± 0.2) than did thinned fenced plots (mean 2.2 ± 0.2). There was also a greater abundance of ESBS plants in the burned-fenced plots (17.0 ± 1.9) than in thinned-fenced plots (6.2 ± 2.3).

Impacts of disturbance on weeds

Compared with the native species present, there were relatively few weeds found in both burnt and thinned plots. At both six and 12 months after treatment the burn plots which had been fenced had fewer weeds and fewer weed species than did thinned plots (see Table 3). . Despite removal of identified weeds after assessment at six months, diversity and numbers of weed species were generally greater at 12 months than at six months.

Herbivore predation

The differences between fenced and unfenced quadrats which had been burned were striking (Table 4). At six months after burning, quadrats with rabbit exclusion fences appeared to be rabbit-free and had significantly more plants than the unfenced quadrats and a slightly greater number of native species. Plant cover was twice as high in fenced quadrats. The median height of native plants in the unfenced plots was slightly smaller (but not significantly so) than those in the fenced plots. However, the frequency distribution of heights at 6 months (Fig. 3) were highly skewed and indicated a far greater proportion of seedling, juvenile or eaten-down plants in the unfenced plots at 6 months. After twelve months this effect was less pronounced.

By 12 months after fire, the fenced plots still remained rabbit-free. Burned-fenced plots contained almost twice as many individual plants as did the burned-unfenced plots. The number of native plant species present in burned-fenced plots was 19% higher than in the burned-unfenced plots and plant cover was 160% higher. The species present in both types of quadrats were essentially identical.

Fig. 4 Typical illustration of fencing impacts on vegetation inside and outside the quadrat

Examination of plots indicated a few species showed exceptions to these observations. In particular, as might be anticipated from the work of Eldridge and Myers (2001) and Cooke and McPhee (2007) coarse, wiry species with fewer succulent leaves, such as *Lepidosperma laterale*, remained largely intact, whereas other more palatable species, especially *Acacia longifolia*, were visibly eaten down to just 1–2 cm in height, and were only very occasionally found in unfenced plots. Where these species were still present, their average heights were reduced by more than 50% in unfenced quadrats.

Discussion

Summary of findings

The present study was designed to compare the consequences of two fire management strategies on the regeneration of an Endangered Ecological Community, Eastern Suburbs Banksia Scrub. The results show that there was a greater increase in floristic richness in the plant cover of burned quadrats than in that of unburned but thinned quadrats, in which cover of the dominant species had been removed by selective thinning instead of burning. There was no significant difference in the Simpson Diversity Index between these two treatments at 12 months, although there was at six months. However the Morisita Overlap Index indicated a highly significant lack of overlap, a result of the two treatments affecting emergence of different species in different ways. These results also support the proposition that although plant cover of long unburnt ESBS may be species poor above-ground, species diversity is maintained in the soil seed bank.

Fire Intensity is recognised to influence species abundance in Sydney area heaths (Morrison 2002) but in this present study there were no consistent differences between areas where fire was judged to have been intense and those where fire was less intense. This observation is consistent with Morrison's finding (Morrison 2002; Morrison and Renwick 2000) that variations in fire intensity account for only approximately 10% of the floristic variation in a post-fire community.

As the results at six and 12 months after treatment demonstrate, time is needed for the impacts of a burn in ESBS to become apparent. A long period of relatively low rainfall immediately following the early September 2012 burn may have been an important factor in this delay but results with other ecological communities suggest that 3–5 years or more are needed for many vegetation communities to recover fully from fire (Pickup et al. 2013).

One of the strongest messages to emerge from this project is the importance of protecting recently burned or cleared areas from predation by rabbits and other herbivores. Plots in the fenced quadrats had more native plants and fewer weeds than plots in unfenced quadrats. This is supported by other research that has shown that predators not only eat native plants, they also spread weeds (Leigh et al. 1987). Cooke (1981) showed that in South Australia a rabbit density of one or two animals per hectare was sufficient to eliminate seedling emergence of some species and severely inhibit many others. From surveys currently underway on North Head, we estimate the rabbit population to be about five per hectare. Attempts at ecological restoration in ESBS without a mechanism to prevent rabbit predation may well be wasted effort and a major rabbit reduction program should be conducted in the period leading up to a burn. However, rabbit eradication is a labour- and cost-intensive task and, in the absence of full eradication, beneficial results may not endure. In the face of uncertainty as to when a controlled burn will actually take place and unpredictability of achieving appropriate burn conditions, other measures such as erection of an effective exclusion fence around the fire area immediately after a burn should be considered for all ecologically sensitive sites.

Context of the findings

Our findings need to be placed in the context of the ESBS community, the reported history of fire management by Indigenous people and two centuries of European impact

Table 4 Richness and abundance of plants within fenced and unfenced burned plots six months and 12 months after burning

	Fenced (n==44)	**Unfenced(n==76)**		
		Mean ± S.E.	**Mean ± S.E.**	**Significance P**
A – **6 months**	No. of plants per plot	14.4 ± 1.2	9.4 ± 0.8	<0.005
	No. of native plants per plot	11.6 ± 1.2	9.3 ± 0.8	NS
	No. of species per plot	4.8 ± 0.3	4.1 ± 0.2	NS
	No. of native species per plot	3.8 ± 0.3	.0 ± 0.2	NS
	Cover (per cent)	23.1 ± 3.2	12.2 ± 3.2	<0.02
	Height (median)	3.0 ± 0.7	2.0 ± 0.4	NS
B – 12 months	No. of plants per plot	37.9 ± 3.0	20.6 ± 1.3	< 0.001
	No. of native plants per plot	36.5 ± 2.8	20.0 ± 1.3	< 0.005
	No. of species per plot	10.6 ± 0.4	8.0 ± 0.3	<0.005
	No. of native species per plot	9.3 ± 0.4	7.8 ± 0.3	<0.001
	Cover (per cent)	41.2 ± 4.4	15.7 ± 3.0	<0.001
	Height (median)	12.0 ± 1.2	6.0 ± 1.4	<0.005

including wild and managed fires (Jurkis et al. 2003; Jurkis and Underwood 2013).

The evolutionary history of ESBS communities of Sydney is unclear. The aeolian sand dunes on which ESBS grows are a defining feature for the community. In 1969 Langford-Smith and Thom observed that "although they have been fixed for a long time"… "the sand dunes which mantle the cliff tops" in many parts of the New South Wales coast have "not been satisfactorily accounted for". The sand is probably of Pleistocene origin and of similar age to the soils of the Shoalhaven region (Nott and Price 1991), and that which supports ecological communities closely related to ESBS further north, on Bombi and Mourawaring Moors on the Bouddi Peninsula (McRae 1990), on Wybung Headland (Benson 1986) and the coastal wallum vegetation of southeast Queensland. Its origin may be congruent with that of the Quaternary aeolian dune field sands of the Newnes Plateau (Hesse et al. 2003) in the Blue Mountains. Leaching by 9,000 years of rain has reduced the fertility to a very low level (Wheen and Johnson 1986).

Attempts to evaluate ESBS at North Head have a long history. The descriptions of ESBS at Botany Bay in 1770 by Joseph Banks (1768–1771) are limited but congruent with current definitions of ESBS (NSW National Parks and Wildlife Service 2004; Department of Environment 2014). Early descriptions of the North Head landscape are sketchy and somewhat contradictory. Describing a visit on 28 May 1788 Bradley (see 1969) describes "an easy walk" over "sandy ground between the top of the rocks, cover'd with a variety of brush wood & shrubs some of which have very pretty blossoms", while Worgan (see 1978) refers to ascent of "a steep Rocky Hill, thickly covered with Brush- Wood". Conrad Martens' paintings of North Head, done over 43 years from the same position in Balmoral show gradual change in vegetation patterns. Evidence contained in old documents, previous surveys and anecdotal reports point to a diversity of use and change across the site since the late 1800s associated with its major uses as quarantine area, military occupation and nature park (Dawbin Architects Pty Ltd 2008; Robertson and Hindmarsh P/L 2010; Turner et al. 1996).

In 1986 Horton and Benson (1986) conducted a comprehensive survey of the Sydney Harbour National Park land area on North Head and delineated the Specht vegetation types- see also Benson (2011). A later survey by Skelton et al. (2003) extended this classification to delineate "vigorous ESBS" from "senescent ESBS", with the latter having a plant cover of low species diversity and being dominated by *Leptospermum laevigatum*.

Floristic lists for North Head (in Keith 1988) indicate the total native species count is of the order of 490, making the headland very species-rich. Some 140 native species were identified within the 1–metre plots of the study area. Fifty of these are species indicative of ESBS. Fire responses are not known for all of the North Head species, but of the total species within the plots, 45 could be classified as predominantly "resprouters" and 30 as "seeders" (Driscoll et al. 2010).

The fire history of North Head, fragmentary through the 19th and early- to mid-20th century, has been pieced together from 1929 to 2014 by the authors, from multiple historical and aerial photographs. There have been at least 50 wildfires and five controlled fires, ranging in area from a few square metres to almost the whole of North Head. The most recent large scale hot fires affecting the study area appear to have been in 1930, 1936, 1937 and 1951.

ESBS is an ecological community shaped by fire, but the picture is not simple. It is generally considered that over periods of 30–50 years, in the absence of fire, ESBS becomes senescent (Skelton et al. 2003); the community becomes dominated by an overstorey mainly of *Leptospermum laevigatum, Monotoca elliptica* and *Banksia ericifolia* with little groundcover variety. In Victoria *Leptospermum laevigatum* has been recognised as a species that invades and ultimately dominates heath communities on dry sandy substrates (Burrell 1981, Bennett 1994) and may be capable of shading out other species and reducing the diversity of extant ESBS. Moxham et al. (2010) describe in some detail the invasions of woody native species into a coastal dune system in Victoria in a 30–year absence of fire, slashing and human habitation. Bennett (1994) reported that neither fire nor its absence is the primary cause of the spread of *Leptospermum laevigatum* but the absence of fire over periods of more than 30 years is a significant factor at North Head (NSW NPWS 2004). In the current study, by 12 months after treatment, *Leptospermum laevigatum* plant density in the thinned plots (most of which were seedlings) exceeded that of the burnt plots by more than 50:1.

On North Head, ESBS communities generally have a core of "vigorous" scrub surrounded by an annulus of *Leptospermum* dominated scrub (Fig. 2 left). This occurs even where the core and the annulus have identical fire histories. It is independent of the size of the parcel, which is generally delineated by roads, fire-trails or walking tracks. The reason for this pattern is not clear but it may be related to an edge effect of light and/or access-related disturbance. Analysis of aerial photographs over the period 1929 to 2014 supports the idea that prior removal of ESBS resulted in invasion or dominance by *Leptospermum laevigatum.* From the 1940s there was extensive mechanical reshaping of sand surfaces for military purposes and this probably increased the extent of the quick growing seedling colonisers, particularly *Leptospermum laevigatum* colonising inn the absence of fire, while destroying the lignotubers and rootstocks of the resprouter species such as *Banksia aemula*. The military use of the area probably meant that because of stored ammunitions etc. there was also a policy of avoiding fire.

Conclusions

The challenges in introducing managed fire into urban and peri-urban bushland areas in a safe manner and with scarce resources have constrained the use of fire for ecological management. These challenges may be acute for species and ecological communities already at risk of extinction. Alternatives to fire as a management option such as vegetation thinning are often proposed, with little evidence of their relative effectiveness. This report begins to fill that gap. While small in scale and budget, the project provides managers with guidance on **the relatively greater benefits of fire over thinning** as a tool for enhancing regeneration of senescent coastal scrub, while seeking to minimise the risks of wildfire. It also dramatically illustrates **the deleterious impact of herbivory by rabbits on young post-fire vegetation**. Importantly, the project also illustrated how community effort, supported by appropriate technical expertise, can enhance agency management of significant areas of urban bushland.

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