doi: 10.1111/j1442-8903.2006.00262.x

Bitou Bush control (after fire) in Bundjalung National Park on the New South Wales North Coast

By Jeff Thomas, Damien Hofmeyer and Andrew S. Benwell

Bitou Bush has already invaded extensive coastal dunes in subtropical and temperate eastern Australia. Can it be treated at a large enough scale to make a difference? Results to date of a targeted aerial spraying program (applied after wildfire at Bundjalung National Park) are showing strong recovery of high conservation value dunal vegetation along 35 km of the northern New South Wales coastline.

Jeff Thomas *(North Coast Region, PO Box 361, Grafton, NSW 2460, Australia. Tel. 02 66 411506. E-mail: jeff.thomas@environment.nsw.gov.au) is Pest Management Officer and* ***Damien Hofmeyer*** *(Richmond River Area, PO Box 856, Alstonville, NSW 2477, Australia. Tel. 02 6627 0221. Email: damien.hofmeyer@environment.nsw.gov.au) is a Ranger at the Parks and Wildlife Division of the Department of Environment and Conservation (NSW).* ***Andrew Benwell*** *(PO Box 641, Mullumbimby, NSW 2482, Australia. Tel. 6684 5496. Email: ecos@nrg.com.au) is an ecological consultant engaged within the program. This article provides an overview of 4 years' treatment of Bitou Bush and the effects of this treatment on the recovery of native vegetation.*

Figure 1. Prior to 2002 about 75% of the foredunes in Bundjalung National Park contained heavy infestations of Bitou Bush (the lighter-coloured vegetation visible along the coast). This is just a portion of the approximately 900 km of the New South Wales coastline (80% of the coast) already infested by Bitou Bush. Without successful control, this nationally declared environmental weed is considered to have potential to expand its range across a much larger area of the Australian coastline. (Photo: Department of Environment and Conservation)

Introduction

Over the Christmas and New Year period of 2001/2002, an intense wildfire burnt through approximately two-thirds of Bundjalung National Park, including its extensive dune system (Fig. 1). Mapping of the nationally significant weed Bitou Bush (*Chrysanthemoides monilifera* ssp. *rotundata*) (Box 1 and Fig. 2) had shown that in 2002, about 75% of the foredunes in the park contained heavy infestations (i.e. greater than 40% of total vegetation cover) (NPWS 2001; Fig. 3). Based on the high level of Bitou Bush infestation of the dunes and understanding of the role of fire as an important component in Bitou Bush control (Weiss 1983; Flower & Clarke 2002), a proposal was developed

Box 1. Bitou Bush (*Chrysanthemoides monilifera* ssp. *rotundata*)

Figure 2. Bitou Bush is listed as one of the initial 20 Weeds of National Significance (WONS) and is a declared noxious weed. Invasion of native plant communities by Bitou Bush is listed as a Key Threatening Process under the NSW TSC Act 1995. Bitou Bush, originated in South Africa and was introduced into Australia in 1908. (Photo: T. McDonald)

Bitou Bush is listed as one of the initial 20 Weeds of National Significance (WONS – see ARMCANZ, ANZELL and ANZFM 2000) and is a declared noxious weed. Invasion of native plant communities by Bitou Bush is listed as a Key Threatening Process under the TSC Act 1995. Mapping of Bitou Bush in 2000 found approximately 900 km (80%) of the New South Wales coastline infested, with a conservative estimate of 36 000 ha infested (NPWS 2001). Bitou Bush originates from South Africa and was introduced into Australia in 1908.

In the 1950s, Bitou Bush was among a number of plants trialled for sand-dune stabilization and was still being recommended for planting in 1970. A mature Bitou Bush plant can produce up to 48 000 seeds per plant per year (Weiss *et al*. 1998). Prostrate stems enable vegetative reproduction to occur by sending roots from adventitious buds. Seeds can be spread over large distances by animals such as birds and foxes. Dispersal of seeds also occurs by wind, water, vehicle movements, and movement of contaminated soil. In established infestations, soil seed banks can contain up to 5000 seeds/m^2, with a small percentage of seeds remaining viable in the soil for up to 10 years, thereby providing a source for reinfestation. Disturbance, especially by fire, promotes seed germination, but germination still occurs in undisturbed situations. A variety of controls including biological, chemical and physical methods are available to control Bitou Bush with site-specific assessment required to determine the most appropriate technique or combination of techniques for a particular location.

In recent years, national, state, regional and local strategies have been prepared and are being implemented to reduce the impacts of this plant. Many coastal community 'care groups' focus their attention on this plant. Successful control programs share a number of common features:

- A variety of stakeholders working cooperatively, often with a formal plan that outlines priorities, roles and responsibilities
- A commitment from decision-makers at all levels
- Persistence and continuity for long-term commitment
- The presence of key individuals who coordinate and motivate participants
- The matching of the scale of work (including follow up) to the available resources

by the Department of Environment and Conservation (New South Wales) to take advantage of the fire and control Bitou Bush to prevent it from completely dominating and degrading the entire dune system (80% or more cover).

Prior to the fire (the extent of which is mapped in Fig. 3), successful but limited Bitou Bush control had been undertaken at a small number of sites with community support. The Defence Department, which uses a large area of the park as a bombing range, agreed to participate in this program and provide substantial resources.

Site description

Declared in 1980, Bundjalung National Park, is a large (20 326 ha) conservation reserve on the subtropical northern New South Wales coast (Fig. 3). It extends over approximately 35 km of coastline from south of Evans Head Village to the Clarence River. Together with the adjoining World Heritage-listed Iluka Nature Reserve (136 ha) to the south and the 3800-ha Broadwater National Park to the north, the three reserves form the second largest protected area on the New South Wales northern coastline. A 10 655-ha area of the park is gazetted as wilderness under the Wilderness Act 1987.

Bundjalung National Park contains a variety of coastal vegetation communities including wet and dry heathland, littoral rainforest, mangrove, eucalypt forests and *Melaleuca* woodlands, as well as freshwater and estuarine wetlands, headland grasslands and dune communities (Griffith 1983). A total of 712 plant species have been recorded in the park, including 47 exotic species (NPWS Wildlife Atlas database, 2006). In Bundjalung NP, as in most of the North Coast, Bitou Bush occurs mainly in the frontal dune landform but also extends to hind dunes and dune swales. This dunal landform is naturally susceptible to Bitou Bush invasion. The predominant vegetation type on the frontal dune today is Coast Banksia (*Banksia integrifolia*) woodland; and remnants of littoral rainforest, a Threatened Ecological Community in New South Wales, occur in several places in the 35-km-long dune system. (Plant nomenclature used in this note is consistent with Harden (1990–1993)).

Aboriginal people have lived in the area for thousands of years and have continued to maintain strong links with the park. Impacts from this period on the dune are likely to have been minimal. However, European uses of the area since settlement have caused significant impacts primarily through mineral exploitation and defence activities. For example, gold was mined in the late 19th century and mineral sandmining occurred over extensive areas of dunes and heathlands between the 1930s to the early 1980s. Quarrying for gravel and rock occurred in several locations and there was sporadic and seasonal cattle grazing throughout much of the area. Commercial and recreational fishing have a long tradition and the park has always been popular with day visitors and campers. Two target areas occur in the north of the park and are included within the 2572-ha Evans Head Air Weapons Range (known as the Bombing Range). These have been used by the defence forces since the 1940s with the southern part of the range still operational and used for various military purposes.

Although all these disturbances have had some effect on the dunes, the highest impact on the dunal system in the southern section has arisen from sandmining. This extensively disturbed the dune landforms, reshaping the dunes to a much lower profile and leaving a patchwork of cleared and uncleared/mined remnant vegetation (including patches of littoral rainforest, which was probably much more extensive in the southern section than is the case today). Post-mining rehabilitation in the southern section involved revegetation with a limited suite of species including Coast Banksia, Coastal Wattle (*Acacia sophorae*) and Sand Spinifex (*Spinifex hirsuta*). In the northern section, in contrast, dunes were not significantly disturbed by sandmining but certain areas were subject to disturbance for recreational access by vehicular and foot traffic.

For geographical and administrative reasons the park is managed by both the Northern Rivers and North Coast Regions of the Parks and Wildlife Division of the Department of Environment and Conservation, (NSW) formerly known as the NSW National Parks and Wildlife Service. This arrangement works well in practice, as there are distinct park management issues in the different regions, as well as issues requiring a consistent approach throughout the park (e.g. fire and weed management).

Bitou Bush invasion in Bundjalung National Park

At the commencement of the project, Bitou Bush was the most abundant weed in Bundjalung National Park. It reached greatest densities in previous foredune sandmined areas and can also be found in areas up to 5 km inland, remote from camping or residential locations, where it can be the only weed species present.

With growing concern about the effect of this weed upon native vegetation (Box 2 and Fig. 4), the density and extent of infestation of Bitou Bush was mapped along the New South Wales coast in 2000 as part of the preparation of the New South Wales and NSW North Coast Bitou Bush management strategies (NPWS 2001; Scanlon 2001). The survey, based upon aerial photography interpretation and ground truthing, found that Bitou Bush infested approximately 680 ha of Bundjalung National Park, occurring in a nearly continuous strip from north to south (Fig. 3). Within this infestation 320 ha were mapped as heavy (>40% cover), 107 ha as medium (10–40%) and 235 ha as light (<10%).

Control of Bitou Bush in the park

The first attempt at larger scale control was the release of biological control agents, the Bitou Bush Tip Moth (*Comostolopsis germana*) in 1990 and the Bitou Bush Seed Fly (*Mesoclanis polana*) in 1996. Until this project

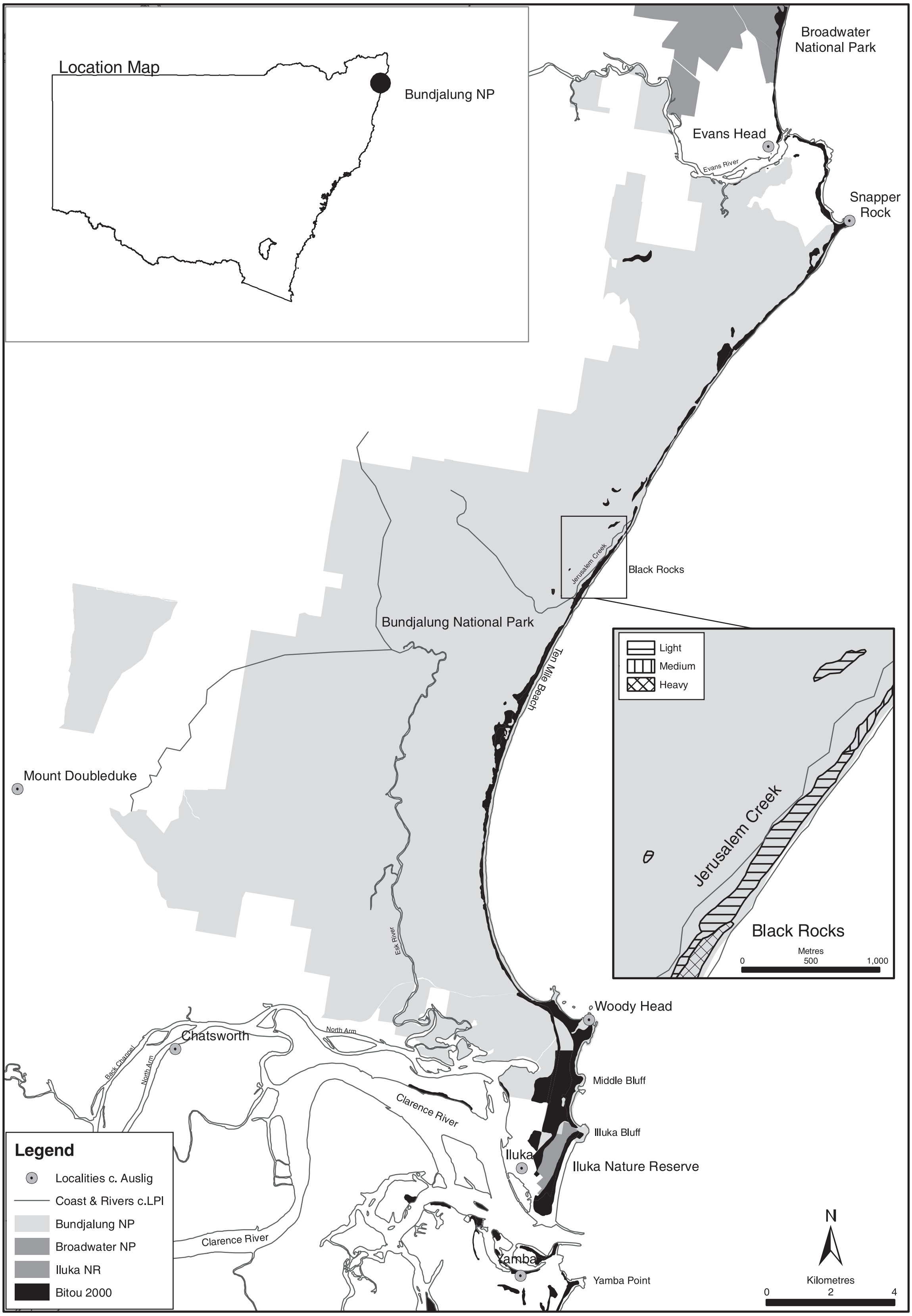

Figure 3. Location map of Bundjalung National Park, showing Bitou Bush distribution prior to treatment. As in most of the North Coast, Bitou Bush in the park occurs mainly in the frontal dune landform, extending inland where conditions are suitable. Of the approximately 680 ha affected, nearly half was mapped as heavily infested. (Map: Department of Environment and Conservation)

commenced, Bitou Bush control work was generally confined to visitor area precincts or as part of more comprehensive restoration projects on small sites, often involving community groups. For example, in 1995, a joint community group (Iluka Landcare Group) and NPWS project began to restore the natural vegetation of the 5-ha Iluka Bluff area at the southern end of the park. A variety of controls (including overspraying, fire, mechanical crushing and manual follow-up methods) were used in this iconic and heavily infested headland and dune area with extensive replantings in certain sections. (CRC for Australian Weed Management 2003; Natural Heritage Trust 2003).

Cost-effective control of large Bitou Bush infestations has been available since the early 1990s through the development of aerial herbicide application techniques by the former NSW Agriculture (Toth *et al*. 1991, 1993, 1996). Low volume application of principally glyphosate-based herbicides are applied in winter by helicopter at rates sufficient to kill Bitou Bush and cause negligible impacts on most native plants that are found in Bitou Bush-infested areas.

Project initiation and planning

The aim of the long-term Bitou Bush control program currently underway in Bundjalung National Park is to protect biodiversity by the targeted post-wildfire control of an extensive Bitou Bush infestation in the coastal dunes, to create conditions suitable for the regeneration and restoration of the native coastal vegetation (McDonald 2002).

An opportunity to gain efficiencies from combining herbicide treatments

Box 2. Native vegetation affected by Bitou Bush

Figure 4. Bitou Bush seed is regularly dropped under Coast Banksia by birds perching in its branches. As Bitou Bush can adopt a scandent habit, it can extend into the canopy of mature Coast Banksia, effectively suppressing this shade-sensitive native species. (Photo: T. McDonald)

A variety of coastal vegetation communities are affected by Bitou Bush including sand-dune heathlands and grasslands, headland heathlands and grasslands, various coastal woodlands, dry sclerophyll forests, wet sclerophyll forests, and littoral rainforests. At least 158 species are considered at risk from Bitou Bush, including 68 species listed under the Threatened Species Act 1995 (DEC 2006). In Bundjalung National Park foredune Coast Banksia (*Banksia integrifolia*) woodlands and Coastal Wattle (*Acacia sophorae*) shrublands are most affected by Bitou Bush almost completely replacing these and other species.

Coast Banksia is the dominant native species in most frontal dune vegetation on the North Coast and an important food source for a wide range of fauna. Flowering of Coast Banksia occurs between late autumn and early spring in this area and seeds are released over summer and autumn each year. Seed dormancy may be temporarily induced by dry conditions, but seed longevity is probably no more than 1 year. After fire, Coast Banksia regenerates from seed or by resprouting, which varies between habitats. The dense growth of Bitou Bush can completely suppress regeneration of Coast Banksia leading to long-term declines in populations of this species.

Threatened plant species most at risk of competition from Bitou Bush in Bundjalung National Park include *Chamaesyce psammogeton*, *Pultenea maritima* and *Sophora tomentosa*.

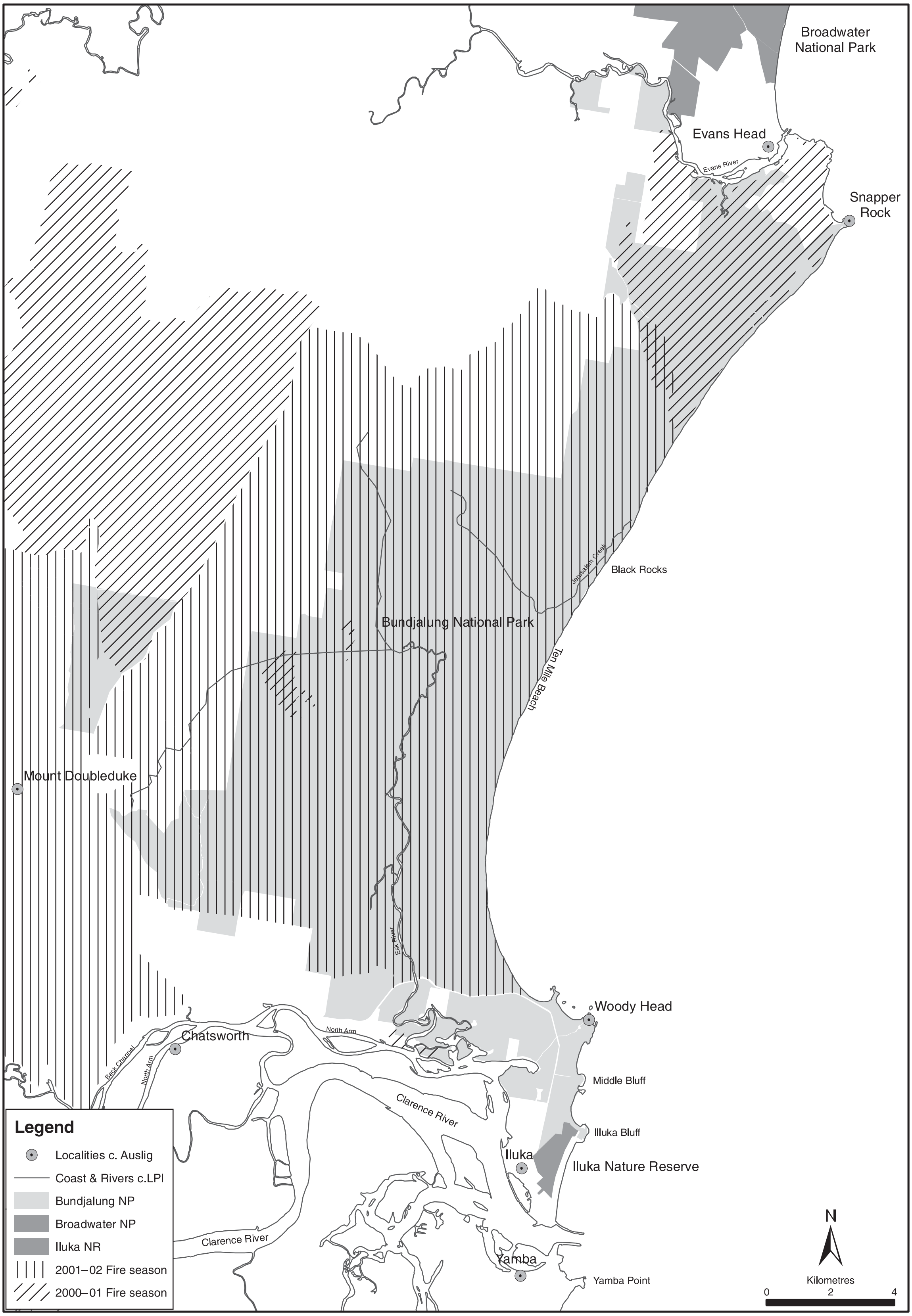

Figure 5. Extent of wildfire in Bundjalung National Park. The December 2001/January 2002 wildfire was unusually intense and burned most of the vegetation in the park, including the dune system. Although such an extensive wildfire was not ideal for a range of reasons, it provided an unprecedented opportunity to access Bitou Bush for subsequent treatment. (Map: Department of Environment and Conservation)

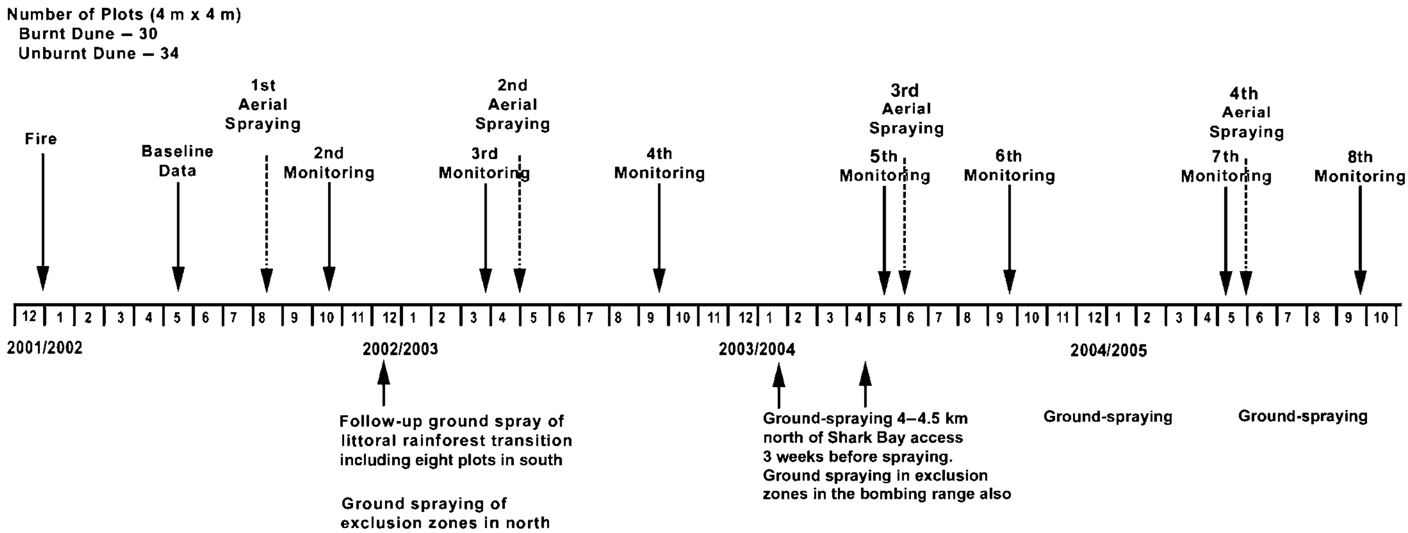

Figure 6. A schedule of progressive treatments, interspersed with monitoring events, was established early in the program and was used to guide the sequence of works over the first 4 years, with a review to occur after 5 years. (Diagram: Andrew Benwell)

with the effects of fire (see Box 3) was presented by an extensive wildfire that swept through the park between 21 December 2001 and 12 January 2002 (Fig. 5). This wildfire occurred under extreme fire weather conditions (i.e. temperatures >40°C, relative humidity <10%) and was driven by strong west to north-westerly winds, severely burning the southern two-thirds of Bundjalung National Park including 258 ha of Bitou Bush-infested vegetation (Fig. 3). The fire consumed Bitou Bush even on the seaward side of the foredune, down to the vegetation limit. There was no significantly large area of unburnt Bitou Bush (Flower & Clarke 2002). Remnant natural vegetation was also severely burnt with the understorey and margins of littoral rainforest patches affected.

The principal control method chosen for post-fire treatment was aerial herbicide application, supplemented by ground-based herbicide application and some manual control, with appropriate follow up for 5 years or more. Information on the impact of aerial Roundup® herbicide (2 L/ha) on native plants was provided by Toth (2003) who recorded 197 of 230 species of coastal native plants unaffected by Roundup with 25 species showing temporary effects and eight species showing some mortality. A number of species in the treatment area, however, had never been assessed for impact.

Review of environmental factors and exclusion zones

The scale and complexity of the project, together with high biodiversity values and potential impact of the project, required the preparation of a detailed Review of Environmental Factors (REF). As part of the REF, a targeted flora survey was undertaken with emphasis on 101 species considered of ecological significance. This and other environmental considerations required the exclusion from aerial spraying of 104 ha of the 510-ha project area. Areas were excluded because of glyphosate sensitivity or unknown sensitivity (littoral rainforest, *Themeda* grassland), aquatic habitats and margins, headland communities, threatened or significant plant localities, and vegetation with dense overstorey foliage cover. The control program was planned for a 5-year period followed by a review to determine the success or otherwise of the treatments and directions for further work.

Monitoring strategy

A monitoring program was established to examine the vegetation response to the control program (Fig. 6). In particular, the program aimed to assess the impact of aerial spraying on both recently burnt and unburnt dune vegetation by addressing the following questions:

1 How effectively was Bitou Bush abundance reduced by aerial spraying? Was the level of control achieved in burnt and unburnt stands significantly different?
2 Was there a significant impact of aerial spraying of herbicide on the richness or abundance of native dunal species in burnt and unburnt vegetation?

The monitoring strategy involved collecting of data from 49 quadrats established in dune vegetation in April 2002 – approximately 3 months before the first aerial spraying but 4 months after the fire. This has been followed by formal observations taken twice yearly since the project's inception (i.e. an autumn 'pre-spray' observation and a spring 'post-spray' observation). Additional quadrats were established at the third monitoring so that approximately equal numbers of quadrats were monitored in burnt (n = 30) and unburnt vegetation (n = 34).

Site attributes recorded in each quadrat included topographic position, aspect, vegetation height, vegetation layers and the initial size distribution of

Box 3. Bitou Bush – Where is its Achilles heel?

Effect of herbicide

Research carried out in the 1980s (Toth *et al*. 1991, 1993; Toth 2003) found that Bitou Bush was susceptible to Roundup herbicide sprayed during winter at low doses. This application method has been found to have negligible effect on most native species in the project area, although some are shown to the sensitive and require exclusion from spraying. As the higher concentrations needed for summer spraying cause more damage to natives, taking advantage of this susceptibility of Bitou Bush during winter means that aerial spraying is best to be confined to the colder weeks of the year, which on the NSW North Coast occur mid-May to mid-July.

As flowering of Bitou Bush after post-fire germination has been observed at 8 months on the NSW North Coast, treatment is required on an annual basis to avoid regrowth recharging soil seed banks.

Effect of fire

Fire is recognized as being an important factor in the ecology of Bitou Bush (Weiss 1983; CRC for Australian Weed Management 2003). A hot fire will kill mature Bitou Bush whereas cooler fires will lead to resprouting (if the plant burns at all). A hot fire also kills seeds in the litter and topsoil and stimulates germination of much of the remaining soil seedbank – with the implication that if control of this initial post-fire flush occurs prior to plants maturing and seeding, then the subsequent requirements for follow-up controls over the expected 10 years can be significantly reduced (Weiss 1983).

Conversely, if Bitou is not treated after fire, its rapid germination and resprouting has been shown to overwhelm and outcompete natural regeneration, resulting in significant loss of biodiversity. This was seen after the 1994 fires of a similar nature in central Yuraygir National Park, where Bitou Bush abundance increased dramatically and resources were not available to manage the regrowth until several years later (Flower & Clarke 2002).

dominant trees/shrubs. Each vascular plant species present in each quadrat was counted individually to provide species richness and density data. Percentage crown-cover for each species – defined as the percentage of a quadrat covered by the horizontal projection of the outer extent of live plant crowns (Mueller-Dombois & Ellenberg 1974; Walker & Hopkins 1990) – was also estimated visually in each 4 m × 4 m quadrat (values of less than 1% were recorded as 0.5%). Seedling density (numbers of seedlings of all species) in each quadrat was counted and seedling height (or lateral spread if greater) of selected shrub species was estimated.

In addition to sampling burnt and unburnt vegetation, the sampling was stratified on the basis of topographic position (e.g. seaward and lee dune slopes), stands of Coast Banksia (*Banksia integrifolia*) of different height, vegetation with greater/lesser littoral rainforest influence and incipient dune vegetation. Stratification was also applied to ensure quadrats were sited to ensure a wide geographical spread and to ensure inclusion of some Coast Banksia to maximize the amount of data collected on the response of this key dune species.

Although the monitoring program was initially designed to monitor the effects of aerial spraying, about 20% of the plots have been subjected to other control treatments as well as aerial spraying, as they have not been excluded from ground-spraying or manual follow up applied to the general area. The data in this context therefore represent the effects of the total control effort. The initial pre-fire Bitou Bush cover was estimated for the overall site using the percentage cover recorded from plots in the unburnt section, prior to the first spraying.

Post-fire vegetation condition

The 2001/2002 wildfire in the dune vegetation triggered seed germination from soil and canopy seedbanks. Bitou Bush seedling regeneration in the southern burnt section outnumbered the total native seedling population in the first year after fire by a ratio of 12:1. The mean density of native seedlings in post-fire regeneration was very low, peaking at about 1.0 seedling/m^2 in June 2002, 6 months after the fire but prior to any spray treatments. The peak mean seedling density in a healthy ecosystem of this type after fire should be in the range of 50–200 seedlings/m^2 (Benwell 1998).

Treatments

The first aerial spraying treatment of approximately 400 ha took place over the week of 12 August 2002. Ground-based treatment occurred at the southern end of Shark Bay, Jerusalem Creek and Snapper Rock between July 2002 and January 2003. During 2003 and 2004, aerial spraying of the frontal dune crest was coupled with aerial seeding of Coast Wattle (untreated seed) and manual seeding of Coast Wattle and Spinifex in selected areas around Black Rocks.

Control programs involving both aerial- and ground-based control have occurred each subsequent year, with the amount of area controlled by both methods varying each year. This is determined by the success of previous years' control, extent, location and size of Bitou Bush regrowth, recovery of natural vegetation, access and available resources. Other complementary weed control has focused on scattered occurrences of Glory Lily (*Gloriosa superba*) and Groundsel Bush (*Baccharis halimifolia*), a declared noxious weed. South of Shark Bay, on the Iluka Peninsula, Bitou Bush is being progressively controlled in association with extensive natural vegetation restoration activities (Fig. 7a–c).

Results of the aerial spray treatments

Within weeks of the treatments, yellowing of Bitou Bush seedlings and resprouts could be readily observed and contrasted sharply with the green of the prolific post-fire native regeneration, which appeared unaffected by the spray (Fig. 8). Closer examination of the quadrat data, however, provided a more accurate picture of the degree of mortality of Bitou Bush over time and the effect of the herbicide on individual native species.

Bitou Bush control

Figure 9 shows the changes in Bitou Bush percentage cover in both the burnt and unburnt areas over time. The initial mean percentage cover of Bitou Bush at the end of 2001 was 55%, which was reduced to 5% after the third aerial spraying in 2004. Between 2004 and 2005, Bitou Bush increased only slightly from 5% to 6% cover prior to the 2005 spraying. In the current (September 2005) post-spray monitoring, Bitou Bush was reduced to a mean of about 1% cover in burnt and unburnt vegetation.

The mean seedling density of Bitou Bush in the sampled vegetation since the start of monitoring is shown in Table 1. In general, Bitou Bush seedlings have continued to germinate from the soil seedbank, with higher numbers of seedlings germinating in the unburnt sites; but this is reducing over time. (Note: the higher number of seedlings recorded in September 2005 – a mean of 2 seedlings/quadrat in burnt quadrats and 11 seedlings/quadrat in unburnt quadrats (Table 1) – may be explained by the end of the drought and the above-average rain that occurred after the June 2005 aerial spraying.)

Changes in native species cover

Figure 10 shows the changes in the cover of six frequently occurring native species since the start of Bitou Bush control in 2002, contrasted against the decline in Bitou Bush cover. Four of the species – Tuckeroo (*Cupaniopsis anacardioides*), Prickly Couch (*Zoysia macrantha*), Snake Vine (*Hibbertia scandens*) and Coastal Wattle – showed gradual increases in cover over time, consistent with what would be expected during a post-fire recovery phase. Oscillating abundance (due to spray-induced toxicity followed by recovery) occurred for Blady Grass (*Imperata cylindrica*) and other species including Lawyer Vine (*Smilax australis*) and Hairy Clerodendron (*Clerodendron floribundum*).

Declines over time (apparently due to spray toxicity) occurred for the grass *Paspalidium distans*, Bracken Fern (*Pteridium esculentum*), Dusky Coral Pea (*Kennedia rubicunda*), Scrambling Lily (*Geitonoplesium cymosum*) and Native Fireweed (*Senecio lautus* ssp. *maritimus*). Other declines could be better explained by the life history of individual species. For example, the short-lived, fire ephemerals *Diplocyclos palmatus* and Slender Lignum (*Muehlenbeckia gracillima*) declined over time, as would be expected over time after fire; whereas an increase followed by a predictable decline occurred for the colonizing groundcovers Blue Periwinkle (*Commelina cyanea*) and Native Violet (*Viola hederacea*).

It should be emphasized that these patterns are often based on low-frequency data, meaning that although the total number of samples was reasonably high, the majority of species occurred at low frequency, less than five quadrats out of 66. These patterns of response are therefore tentative and based on data trends rather than formal significance testing. Information on all other species is found in Benwell (2002–2005).

Changes in number of native species

Although high native species cover overall was evident on the site, data from the quadrats were needed to provide more concrete information on the species diversity (i.e. species richness) of the recovering native plant community. Comparisons of data from burnt and unburnt areas enabled some insight into which changes may be due to the removal of Bitou Bush alone, controlling for the effect of fire.

For example, mean species richness in burnt quadrats has remained more or less constant between 2002 and 2005 (Table 2) as the fire's sudden removal of all competition is likely to have triggered recovery of all resilient species present on site, with no increases to be expected (note: the dataset analysed includes exotic and native species). In contrast, however, mean species richness in unburnt vegetation continued to increase gradually (Table 2) showing gradual recovery of species previously suppressed by Bitou Bush. The increase in species richness per quadrat in the unburnt sites between April 2002 and September 2005 (5.5 ± 0.5 to 8.5 ± 0.7) was statistically significant ($P = 0.05$).

Figure 7. On the Iluka Peninsula, Bitou Bush is being progressively controlled in association with extensive vegetation restoration activities. Iluka Bluff, for example, was heavily dominated by Bitou Bush prior to Quikspray (high volume) spraying in winter 1997 (coupled with hand work in sensitive areas such as the remnant grassland patch). Natural regeneration was initially limited, due to the impacts of Bitou Bush and drought (7a) but commenced soon after soaking rains (7b), supplemented by reintroductions of species typical of the pre-existing Kangaroo Grass (*Themeda triandra*)-dominated plant community. Cover of Kangaroo Grass and other natives (7c) is now secured across the site. (Photos: T. McDonald)

Figure 8. After herbicide was aerially applied across most of the coastal strip in winter (except in sensitive areas), the target species, Bitou Bush, readily died, leaving the vast majority of native plant species unaffected. (Photo: Jeff Thomas)

Costs of the program

Aerial spraying of Bitou Bush costs approximately $100/ha compared with the ground-based high volume spraying cost of up to $1200/ha. Manual control (either by physically removing plants or cutting and painting with herbicide) can cost between $100 and $500 per hectare for low infestations and up to $30 000/ha for dense, multi-species infestations in areas of high environmental significance (Department of Environment and Conservation 2006). Voluntary input can assist (e.g. in a 5-ha area around Black Rocks camping area the Black Rocks Dunecare group is helping to reduce Bitou Bush to a low infestation level and restore natural vegetation, largely by backpack spraying); but voluntary work is not practical over larger areas.

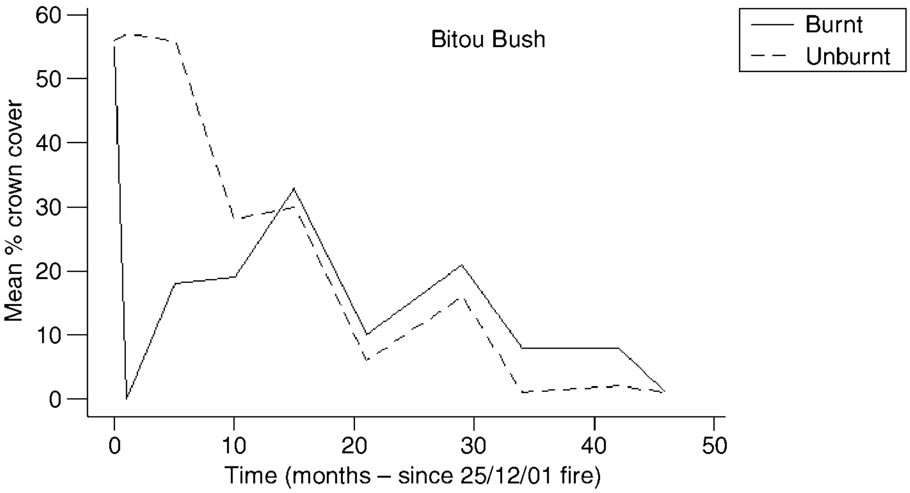

Figure 9. Change in the mean percentage cover of Bitou Bush in burnt and unburnt quadrats. Falls in cover were recorded post-spray (in spring) and increases were recorded pre-spray (late autumn), except for the first fall in burnt quadrats, which was of course due to fire.

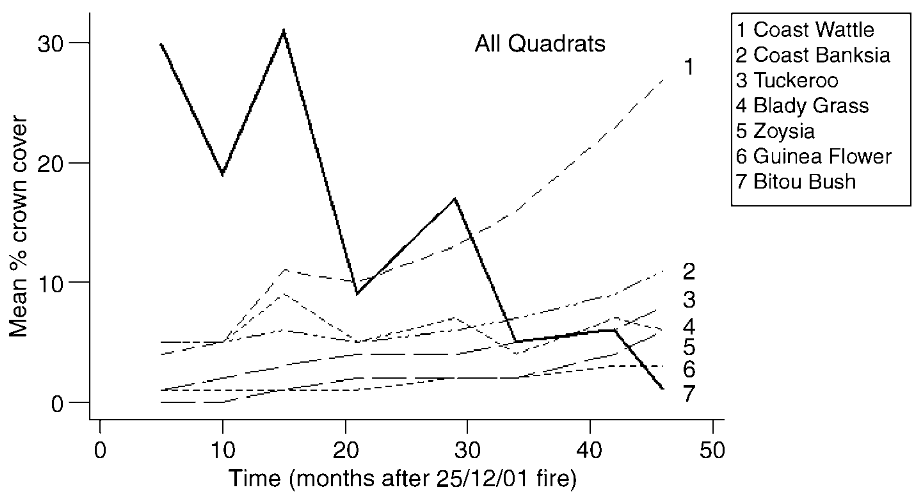

Figure 10. Changes in the mean percentage cover of Bitou Bush and six of the most frequently occurring native species in 4 years averaged over all quadrats. The four decreases in Bitou Bush occurred after aerial spraying each year. Blady Grass has a similar oscillating pattern due to die-off of foliage after spraying then regrowth from rhizomes. Other native species show increasing cover-abundance, particularly Coast Wattle.

The current integrated Bitou Bush control program has an annual average expenditure of approximately $75 000. This can be broken down into $40 000 for contract aerial and ground-based spraying, $15 000 for contract monitoring and $20 000 for in-kind ground-based control and project management.

Implications for management

Has Bitou Bush control been effective to date?

It appears the program has been successful to date in reducing Bitou Bush cover, with 4 years sustained control reducing its cover from 55% pre-fire to 1%, 3 months after the winter 2005 control. Results from the last 2 years show that cover of Bitou Bush is returning to an average of 5–6% just prior to control. This number reflects a pattern in the landscape where the majority of the project sites have very low densities of Bitou Bush but there are still significant areas with higher densities of Bitou Bush. Sites with higher densities result from previously higher cover of Bitou Bush (and lower levels of native species resilience – see Fig. 11) combined with less effective control in some cases, for a variety of reasons. Aerial spraying in 2002 and 2003 was unsuccessful in achieving the required kill rate in a large part of the project site, resulting in plants maturing and flowering and seeding, thereby replenishing the soil seed bank.

Achieving uniform control annually over a large area has proven to be impractical, with plants missed due to sheltering effects from canopy trees and the difficulty in treating Bitou Bush in some exclusion zones. In the first year, no exclusion zones around water-bodies were treated because of lack of access and some dune crests were excluded because of uncertainty about potential dune erosion (Fig. 12). The development of aerial spot spraying technology and adaption of newer boom spraying technology in the last few years has improved the ability to control more remote and inaccessible

Table 1. Bitou Bush mean seedling density (seedlings per 4 m^2) ± standard error in burnt and unburnt dune vegetation during Bitou Bush spraying at Bundjalung National Park

Treatment monitoring	1 August 2002		2 May 2003		3 June 2004		4 May 2005	
	April 2002	October 2002	April 2003	September 2003	May 2004	September 2004	May 2005	September 2005
Burnt	134.1 ± 29.6	68.5 ± 13.0	28.1 ± 7.1	24.0 ± 4.9	2.2 ± 2.5	0.3 ± 0.2	1.8 ± 0.7	2.1 ± 0.9
Unburnt	27.4 ± 11.1	6.2 ± 5.2	216.6 ± 70.1	32.12 ± 5.9	24.5 ± 4.6	1.4 ± 0.9	9.1 ± 2.1	10.9 ± 5.1

Table 2. Mean species richness ± standard error in burnt and unburnt dune vegetation during Bitou Bush spraying at Bundjalung National Park

Treatment monitoring	1 August 2002		2 May 2003		3 June 2004		4 May 2005	
	April 2002	October 2002	April 2003	September 2003	May 2004	September 2004	May 2005	September 2005
Burnt	9.3 ± 1.1	10.5 ± 1.2	9.2 ± 1.0	10.5 ± 0.9	9.0 ± 0.9	8.6 ± 0.9	8.7 ± 0.6	9.0 ± 0.8
Unburnt	5.5 ± 0.5	5.6 ± 0.5	6.3 ± 0.6	7.0 ± 0.6	7.3 ± 0.7	6.6 ± 0.6	8.0 ± 0.7	8.5 ± 0.7

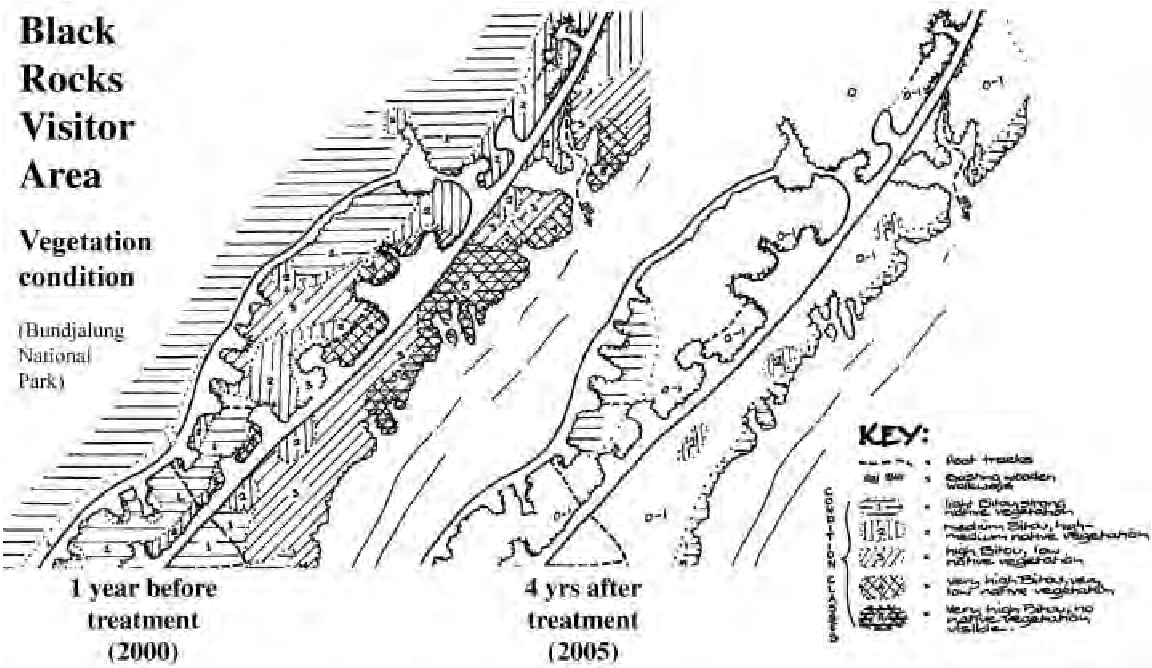

Figure 11. Condition mapping carried out at Black Rocks visitor area shows that, prior to the wildfire and subsequent herbicide treatment in 2000, Bitou Bush was dominant (Classes 3–5) along the frontal dunes and particularly high where associated with unstable dunes. Reassessment in 2005, 5 years after aerial and ground-based herbicide treatments (carried out annually in winter), found Bitou Bush rarely occurring in most of the site, although clusters persisted in some areas where treatment was either inconsistent or the original infestation was most intense. (Adapted from: McDonald 2002)

infestations and infestations in environmentally sensitive areas.

The reduction in Bitou bush germination rate over time as shown in Table 1 is another indication that the treatment program is achieving timely control, although the relatively higher numbers in the unburnt area point to the need to maintain a similar level of control for at least few more years.

How long will it take?

The time required for completion of the project as a whole is yet to be determined and will depend to a large extent on the level of control required to achieve the initial aim of biodiversity protection with significant Bitou Bush reductions and recovery of native vegetation. Little published data exist on the timeframe required to achieve a specified level of control. We do know, however, that discontinuation of a project too early, or reduction of resources below the rate required to maintain control, can result in reinfestations. In addition, it is known that infestations on the North Coast will return to pre-existing densities within 2 years after a single control unless follow up is implemented (Thomas, pers. obs., 2002) and experience has shown that ongoing maintenance for minimum of 5 and more likely 10 years is required to achieve sustained reductions in infestations

The change in Bitou Bush infestations varies with location and is influenced by the existing soil seedbank and seed dispersed into the treated areas from nearby untreated infestations. Competition from existing native vegetation and native species germinating from soil-stored seed and suppressed rootstocks (i.e. ecosystem resilience) also affects Bitou Bush densities. In areas with low resilience (such as some previously sandmined but unrevegetated areas), supplementary revegetation with native species is required to provide competition for Bitou Bush.

The control program has now reached a stage where after this year's treatment the annual broadacre aerial spraying is likely to be no longer required in terms of achieving cost-effective control of large infestations,

Figure 12. Dune crests at Black Rocks were among areas excluded from aerial spraying in the first year of treatment due to concern about potential for erosion. This delay (coupled with the ready resprouting of layering Bitou on dune crests) has meant that control in these sites has been more gradual than other areas. This gradual treatment – coupled with direct seeding of sites at Black Rocks with Coastal Acacia and Spinifex – has resulted in secure revegetation and stability of dune crests at Black Rocks. (Photo: T. McDonald)

which has to be balanced against the impacts of spraying native species. Current and further stages of the program are therefore likely to combine the newer targeted aerial application methods with increased on-ground effort, focusing on exclusion zones, areas of persistently high Bitou Bush cover and existing or potential environmental impact. Work will also continue on the timely control of other weed species such as Glory Lily (*Gloriosa superba*), Lantana (*Lantana camara*) and Winter Senna (*Senna pendula* var. *glabrata*) which can proliferate after Bitou Bush control.

Impact of aerial spraying on native vegetation

Aerial spraying elsewhere and on this site has been found to have negative impacts on a range of native species. The decision to use the treatment at this site, however, was influenced by weighing up these costs against the anticipated economic and ecological benefits of Bitou removal using this method in the preliminary phase, prior to more use of better-targeted methods.

The benefits of this decision appear to have been borne out by the results to date. Seedlings of Coast Wattle (*Acacia sophorae*) and Coast Banksia (*Banksia integrifolia*), the two dominant native species in the coastal dune ecosystem, appeared to be unaffected by aerial spraying. Most other native species showed no observable affects with effects of spray observed only for the species listed in Table 3.

Further observations on the recovery of the plant communities

Seedling densities throughout the site were initially lower after fire than would be expected at a healthy site – possibly due to the effect of Bitou Bush over recent decades.

During 3 years of monitoring, littoral rainforest species exhibited little to no seedling recruitment. Sclerophyll trees, shrubs and herbaceous species produced more seedlings than littoral rainforest species, but mean densities were still very low.

Monitoring did not detect the expected seedling numbers or resprouting of Coast Banksia immediately after the 2001/2002 fire; both in the taller woodland ecotype and in much of the stunted shrubland ecotype. The poor initial regeneration is likely to have been due to very low seedling recruitment in the Coast Banksia woodland ecotype and failure of resprouting in the Coast Banksia shrubland ecotype. In the taller ecotype, competition with Bitou Bush over a decade or more may have depressed flowering and seed production and the post-fire recovery of Bitou may also have smothered seedlings. Another factor, however, may have been that the fire occurred at the point of seed shed, reducing regeneration potential. In the stunted ecotype, Bitou Bush competition before fire (or

Table 3. Species that exhibited post-spray foliage dieback and decrease in mean crown-cover and/or seedling death in the study area (Benwell 2002–2005)* indicates exotic species

Acacia melanoxylon	*Eragrostis interrupta*	*Isolepis nodosa*	*Persoonia stradbrokensis*
Austromyrtus dulcis	*Geitonoplesium cymosum*	*Kennedia rubicunda*	*Phytolacca octandra**
Chrysanthemoides monilifera ssp. *rotundata**	*Hydrocotyle bonariensis**	*Muehlenbeckia gracillima*	*Pteridium esculentum*
Clerodendron tomentosum	*Imperata cylindrica*	*Oplismenus aemulus*	*Senecio lautus* ssp. *maritimus*
Cyperus stradbrokensis	*Ipomoea cairica**	*Ottochloa gracillima*	*Smilax australis*
Desmodium varians	*Ipomoea pres-caprae* ssp. *brasiliensis*	*Paspalidium distans*	*Spinifex hirsutus*
Diplocyclos palmatus			

sudden exposure to salt-laden winds) may have reduced the vigour of Coast Banksia, as several individuals produced initial suckers then died in the first year after fire.

Despite this, Coast Banksia still exists over much of the southern burnt section in 2005 (3 years after fire) and, has recruited well over much of the northern burnt section, possibly since effective control of the highly competitive Bitou Bush. The surviving Coast Banksia population should continue to increase in number and vigour with the ongoing control of Bitou Bush.

Concluding comments

In summary, this project has shown that Bitou Bush control using a range of treatments including extensive aerial application of low concentrations of herbicide has been successful both in burnt and unburnt areas. After fire, burnt sites have demonstrated a more rapid reduction of Bitou Bush germination than have unburnt sites. Although there are clear benefits of aerial spraying, caution is required to ensure sensitive plants and plant communities are not adversely affected and that adequate follow up – by increasingly more targeted methods – is available to prevent the recovery of Bitou Bush and the spread of other weeds that may benefit from the reduction of this highly competitive weed species.

Acknowledgements

We thank Aleks Maric, Technical officer at the Department of Environment and Conservation (DEC), for the provision of maps. We also thank other DEC staff, contractors and volunteers who have contributed to this control program.

References

ARMCANZ, ANZECC and ANZFM (2000) *Weeds of National Significance Bitou Bush and Boneseed* (Chrysanthemoides monilifera *ssp.* rotundata *and* monilifera*) Strategic Plan*. Agriculture & Resource Management Council of Australia & New Zealand, Australian & New Zealand Environment & Conservation Council and Forestry Ministers. National Weeds Strategy Executive Committee, Launceston.

Benwell A. S. (1998) Post-fire seedling recruitment in coastal heathland in relation to regeneration strategy and habitat. *Australian Journal of Botany* **46**, 75–101.

Benwell A. S. (2002a, 2002b, 2003a, 2003b, 2004, 2005) *Monitoring of Plant Species Composition in Recently Burnt and Unburnt Frontal Dune Vegetation Subject to Aerial Spraying of Bitou Bush* (Chrysanthemoides monilifera *subsp.* rotundata*) in Bundjalung National Park*. Reports to the Department of Environment and Conservation (NSW), Hurstville, NSW.

CRC for Australian Weed Management (2003) *Weed Management Guide: Bitou Bush*. CRC for Australian Weed Management, Adelaide, SA.

Department of Environment and Conservation (NSW) (2006) *Threat Abatement Plan for Invasion of Native Plant Communities by* Chrysanthemoides monilifera *(Bitou bush and boneseed)*. Department of Environment and Conservation (NSW), Hurstville, NSW.

Flower P. and Clarke M. (2002) *The Control of Bitou Bush by Aerial Application of Glyphosate, Bundjalung National Park 2002–06*, Vol. 1 Environmental Review. Internal report to the NSW National Parks and Wildlife Service, Grafton, NSW.

Griffith S. J. (1983) *Vegetation Survey of Bundjalung National Park*. Internal report to the NSW National Parks and Wildlife Service. Hurstville, NSW.

Harden G. J. (ed.) (1990–93) *Flora of New South Wales*, Vols 1–4. New South Wales University Press, Kensington, NSW.

McDonald T. (2002) *Bundjalung National Park Vegetation Restoration and Rehabilitation Plan (Incorporating Pest plant survey and control guidelines)*. National Parks & Wildlife Service, Alstonville, NSW.

Mueller-Dombois D. and Ellenberg H. (1974) *Aims and Methods of Vegetation Ecology*. John Wiley and Sons, New York.

Natural Heritage Trust (2003) *The Work Doesn't Stop on Award-Winning Iluka Bluff Beach*. Natural Heritage Trust, No. 16, p. 11. Department of Environment and Heritage, Canberra, ACT.

NSW National Parks and Wildlife Service (2001) *NSW Bitou Bush Strategy*. NSW National Parks and Wildlife Service, Hurstville, NSW.

Scanlon T. (2001) *NSW North Coast Bitou Bush Management Strategies*. North Coast Weeds Advisory Committee.

Toth J. (2003) *Toxicity of Roundup® to Native and Some Introduced Plants*. Management of Environmental Weeds Pty Ltd, Mona Vale, NSW.

Toth J., Milham P. J. and Maguire M. J. (1991) Seasonal differences in tolerance of glyphosate and metsulfuron methyl by Bitou bush and four plants species indigenous to coastal NSW. *Proceedings of the 6th Noxious Plants Conference* **4**, 18–20.

Toth J., Milham P. and Nazer C. (1993) Aerially applied herbicides selectively control Bitou bush growing in communities of indigenous plants on sand dunes. *Proceedings of the 14th Asian Pacific Weeds Conference*, Vol. 2, pp. 67–71. Asian-Pacific Weed Science Society.

Toth J., Milham P. J., Meszaros I., Kaldor C. J., Fullerton R. N. and Burrows F. (1996) Research on chemical control of Bitou bush in New South Wales. *Proceedings 11th Australian Weeds Conference, Melbourne*, pp. 468–475. Weed Science Society of Victoria, Frankston, Victoria.

Walker J. and Hopkins M. S. (1990) Vegetation. In: *Australian Soil and Land Survey Field Handbook*, 2nd edn. (eds R. F. McDonald, R. F. Isbell, J. G. Speight, J. Walker and M. S. Hopkins), pp. 58–86. Inkata Press, Melbourne.

Weiss P. W. (1983) *Invasion of Coastal Acacia Communities by Chrysanthemoides*. PhD Thesis, Australian National University, Canberra, ACT.

Weiss P. W., Adair R. J. and Edwards P. B. (1998) *Chrysanthemoides monilifera* (L.) T. Norl. In: *The Biology of Australian Weeds* (eds F. D. Panetta, R. H. Groves and R. C. H. Shepherd), Vol. 2, pp. 49–61. R.G. and F.J Richardson, Melbourne, Vic.