package for teachers to educate students about the impacts of weeds, while fulfilling curriculum requirements.

The program is initially being developed around the 20 Weeds of National Significance (using bitou bush in the first iteration) and resources will include agricultural and environmental weed information. The resources will conform to national curriculum standards to allow national adoption. Students will investigate the impacts of weeds on a global scale and learn about weed science principles and weed impacts to biodiversity and the environment. They will also work with local weed managers and community groups, as part of the Weed Warriors program, to implement a biological control program for a locally significant weed, thus empowering students to apply effective weed control measures in their local community.

Weeds: Educate to Eradicate is an innovative approach to raising weed awareness among young Australians by educating students using integrated learning tools. The partnership developed in the program will provide expertise for state-wide implementation and the capacity to foster national expansion of the project.

Bitou bush aerial spraying in New South Wales – what have we learned?

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Summary
Developing the aerial boom spraying methodology
Bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) is a significant environmental weed in coastal New South Wales (NSW). Control of extensive infestations of bitou bush within native vegetation can be undertaken using aerial herbicide application. Aerial spraying to control bitou bush proved to be a suitable control option following herbicide studies on native plant species which showed they were tolerant to the aerial application at very low rates during winter months (Toth *et al.* 1993). This technique was developed following ground based herbicide trials carried out in the late 1980s near Jervis Bay, NSW, in which six herbicides were initially trialled for the control of bitou bush. At the same time, a permit was granted to deliberately apply the same herbicides to seven native plant species, being *Acacia longifolia* subsp. *sophorae* (Labill.) Court, *Banksia integrifolia* L.f., *Casuarina glauca* Sieber ex Spreng., *Leptospermum laevigatum* (Gaertn.) F.Muell., *Leucopogon parviflorus* (Andrews) Lindl., *Monotoca elliptica* (Sm.) R.Br. and *Lomandra longifolia* Labill., to determine their response to off-target damage associated with bitou bush control. The results showed that only herbicides containing glyphosate or metsulfuron methyl as the only active ingredient were effective for controlling bitou bush (Toth *et al.* 1996). In addition, the effect of low rates of glyphosate on the native species produced no measurable damage, and low rates of metsulfuron methyl resulted in only ephemeral damage to *L. laevigatum* and *L. parviflorus*. Hence these two herbicides proved sufficiently selective for bitou bush (Toth *et al.* 1993).

A subsequent trial was undertaken to examine the seasonal sensitivity of bitou bush to glyphosate and metsulfuron methyl. These herbicides were also trialled to determine an effective application rate for bitou bush control amongst native species. The two-year trial indicated that bitou bush is at least twice as sensitive to glyphosate in winter than during summer, especially following peak winter flowering (Toth 1997). There was no apparent trend with metsulfuron methyl. Effective bitou bush control during the winter was also achieved with very low rates of both herbicides. Similar seasonal and rate trials were subsequently carried out on five of the native plant species, being *A. longifolia* subsp. *sophorae*, *B. integrifolia*, *L. laevigatum*, *L. parviflorus* and *L. longifolia* to examine if there was also a seasonal and application rate tolerance. The results showed a seasonal tolerance of these native plants to low rates of herbicides applied during winter. However, seedlings of *A. longifolia* subsp. *sophorae* showed some sensitivity to glyphosate (Toth *et al.* 1996). The combined results indicated that low rates of glyphosate and metsulfuron methyl applied during winter not only controlled bitou bush, but were unlikely to result in significant off-target damage to native plant species.

Independently, Anderson (1989) trialled aerial boom spraying of bitou bush at 8 L ha^{-1} of glyphosate [four times the current rate] at South Stradbroke Island which showed control was selective for bitou bush with little damage to native species. However subsequent examination showed that three species may be adversely impacted (see Toth *et al.* 1996); further analysis of these three species following control at 2 L ha^{-1} shows that such impacts are likely to be reduced at the lower application rates currently used.

A series of herbicide trials were then carried out using aerial boom spraying in NSW in which very low rates of glyphosate (2 L ha^{-1} of Roundup® (36 g L^{-1} glyphosate)) and metsulfuron methyl (30g L^{-1} of Brushoff® (600 g kg^{-1} metsulfuron methyl)) were applied to bitou bush infestations. These results supported the original ground based trials described above.

Penetrants were also trialled during the ground based herbicide applications for glyphosate and metsulfuron methyl. The addition of Pulse® (1020 g L^{-1} polyether modified polysiloxane) had a negative effect on *L. lavigatum* in that it lead to a greater degree of leaf burn. Based on this result Pulse® has not been recommended for use in the aerial spraying of bitou bush (Toth *et al.* 1996).

A further trial in 1997 examined the potential use of Roundup Bioactive® (36 g L^{-1} glyphosate) for aerial spraying of bitou bush, however, the results indicated that Roundup Bioactive is more phytotoxic to the following five native plant species *Scaevola calendulacea* (Andrews) Druce, *Carpobrotus glaucescens* (Haw.) Schwantes, *Myoporum boninense* Koidz. and *Correa alba*

Andrews, than either Roundup® or Brushoff® (Toth unpublished data). As no other herbicide was used in this trial the results do not necessarily translate to other generic brands of glyphosate or metsulfuron methyl.

Using aerial boom spraying to control bitou bush in New South Wales

Aerial boom spraying (hereafter aerial spraying) to control bitou bush has been undertaken along the NSW coastline between Narooma and Tweed Heads since 1992. However, it was not until 2006 that best practice guidelines were developed (Broese van Groenou and Downey 2006). The guidelines, which are a checklist of events in chronological order, highlight the complexity of aerial spraying for weeds, especially in natural ecosystems, and the degree of coordination and knowledge needed to undertake aerial spraying. These guidelines are now used widely when planning and undertaking aerial spraying of bitou bush in NSW.

The outcome of 15 years of aerial spraying to control bitou bush in New South Wales has revealed that while large areas can be treated effectively, follow-up control is essential to managing bitou bush recruitment, as well as secondary weed invasion, after each aerial spraying operation. And, more importantly, that aerial spraying should only be undertaken when resources are available to undertake such follow-up control work.

Where areas are being aerially sprayed on a regular basis (i.e. annually), the use of one application of metsulfuron methyl may help to prevent any possibility of herbicide resistance to glyphosate developing in bitou bush. Repetitive use of metsulfuron methyl in annual applications is not recommended at this stage because of the residual effects of metsulfuron methyl and comparatively less information available on its impact to native species.

To assist with revegetation, aerial direct seeding during aerial spraying operations has also been employed in some areas. The results of these aerial seeding trials are inconclusive due to the influence from a number of external factors. For example, success when using scarified seeds is dependent on rain within several days of the application. However if rain does not occur, seed viability can decrease dramatically.

Aerial spraying has proved to be efficient and cost effective for broad-acre control of bitou bush in NSW compared to ground based herbicide application, especially over large areas and in areas that are otherwise inaccessible (e.g. coastal cliffs).

Developing an aerial spot spraying methodology

In the past few years, another method of aerial control has been developed for bitou bush. The technique, known as aerial spot spraying, uses ground based spraying equipment mounted onto a helicopter. This spray rig has a modified nozzle within a metal conical casing which is lowered from the helicopter directly over the targeted plants. The herbicide can therefore be applied to individual or isolated bitou bush plants within native vegetation or in inaccessible areas (e.g. cliff faces). This technique has been used widely over the past few years and is now contributing to the aerial management of bitou bush in NSW. It must be noted that this techniques uses ground based application rates of herbicide and not the low herbicide rates used in aerial boom spraying.

Assessing the impact of aerial spraying on native species

In addition to the seven native species originally tested for herbicide sensitivity (see above), further information has been gathered over the past 15 years on the herbicide sensitivity of other plant species (native and weeds). This observational data has been collected on the response of 220 plant species (weeds and natives) to glyphosate and 83 to metsulfuron methyl to date (see Broese van Groenou and Downey 2006). However information is still needed for many native plant species, particularly in relation to their response to metsulfuron methyl. It should be noted that these data are based on results from basic formulations of glyphosate (i.e. Roundup® – 36 g L^{-1} glyphosate) and metsulfuron methyl (Brushoff® – 600 g kg^{-1} metsulfuron methyl) only. Thus, further research is needed into other formulations, as extrapolations to such formulations are not warranted based on the trials with penetrants (see above).

The effect of aerial spraying on rare and endangered species is of particular significance, for example research by Matarczyk *et al.* (2002) found that spray drift from ground-based applications of glyphosate can adversely impact populations of *Pimelea spicata* R.Br., an endangered species in NSW. It is therefore important to take a precautionary approach and locate rare and threatened species on each site prior to aerial spraying, so that these areas can be appropriately protected from any potential adverse impacts (see Broese van Groenou and Downey 2006). These species can either be excluded from the aerial spraying area with suitable buffers demarcated, or in some instances covered, for example with hessian (see Broese van Groenou and Downey 2006).

Mason and French (2007) discovered that while aerial spraying reduced the diversity of weeds in the areas treated for bitou bush control, the native species assemblage did not necessarily return to non-invaded site conditions. This result suggests that native plant community restoration will not necessarily occur naturally following aerial spraying, and direct seeding or planting of native species may be required. Also, they found that aerially sprayed sites had lower native species diversity than sites where on-ground bitou bush management occurred. However, there were several compounding factors not accounted for in this study and, thus, further investigation into the possible impacts of aerial spraying on native species is still needed. In particular some plant groups, like orchids, should be targeted for such studies (P. Flower personal communication).

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References

Anderson, T. (1989). Experiences with bitou bush in Queensland. Proceedings of the 5th Biennial Noxious Plants Conference, pp. 69-72. (New South Wales Department of Agriculture and Fisheries, Sydney).

Broese van Groenou, E.A. and Downey, P.O. (2006). Best practice guidelines for aerial spraying of bitou bush in New South Wales. New South Wales Department of Environment and Conservation, Hurstville.

Matarczyk, J.A., Willis, A.J., Vranjic, J.A. and Ash, J.E. (2002). Herbicides, weeds and endangered species: management of bitou bush (*Chrysanthemoides monilifera* ssp. *rotundata*) with glyphosate and impacts on the endangered shrub, *Pimelea spicata*. *Biological Conservation* 108, 133-41.

Mason, T.J. and French, K. (2007). Management regimes for a plant invader differentially impact resident communities. *Biological Conservation* 136, 246-59.

Toth, J. (1997). Research into bitou bush control. Proceedings of the bitou bush workshop, pp. 28-9. NSW National Parks and Wildlife Service and the CRC for Weed Management Systems, Adelaide.

Toth, J., Milham, P.J. and Meszaros, I. (1993). Aerially applied herbicides selectively control bitou bush growing in communities of indigenous plants on sand dunes. Proceedings of the 10th Australian Weeds Conference and the 14th Asian-Pacific Weed Science Society Conference. (2), pp. 67-71. (The Weed Society of Queensland, Brisbane).

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 of the 11th Australian Weeds Conference Proceedings, ed. R.C.H. Shepherd, pp. 468-75. (Weed Science Society of Victoria, Frankston).