Restoration and resilience in weed-invaded ecosystems

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Summary Strategic post-border management of the Australian Weeds of National Significance (WoNS) encompasses eradication, containment and asset protection, depending on the stage and location of invasion. While eradication and containment concentrate on the target weed, asset protection integrates weed control into larger holistic programs. If the management goal is recovery or protection of biological assets, the weed program needs to encompass more than just weed control. This paper uses two WoNS, bitou bush (*Chrysanthemoides monilifera* subsp. *monilifera*) and bridal creeper (*Asparagus asparagoides*), to illustrate this need for increased restoration of invaded native communities. These two weeds are used as examples because there is a large amount of information about their impacts, the attributes of the ecosystems they have invaded and the biodiversity response to their control. Weed control is a vital part of protecting and restoring native biodiversity and normal ecosystem processes. However, unless weed invasion is at an early stage, weed control alone may not be sufficient to restore an invaded ecosystem. Further restoration may be needed to ameliorate the long term residual impacts of weed invasion.

Keywords Asset protection, dispersal, residual impacts, seed bank, weed substitution.

INTRODUCTION

The Australian WoNS program focuses on 20 widespread weeds that impact on Australia's environmental, social and economic assets (Thorp and Lynch 2000). These weeds are targets of strategic management efforts encompassing eradication, containment and asset protection, depending on the stage and location of invasion. Containment and eradication programs are weed-led, focusing primarily on the target weed (e.g. containment lines preventing further spread). Conversely, asset protection is a site-based approach that integrates control of a widespread weed into holistic programs to achieve conservation outcomes, such as biodiversity protection (Williams *et al.* 2009).

Weed control is a vital aspect of protecting native biodiversity and normal ecosystem processes (Byers *et al.* 2002). The ultimate goal for many land managers is to restore native ecosystems to an earlier and better condition. In this regard, the WoNS programs have supported research into control methodologies and produced best practice guidelines that provide up-to-date control advice to weed managers. Most WoNS, and indeed many weeds, have effective and available control methods. But if ecosystem processes or structure have been significantly altered by weed invasion, weed management alone will not necessarily restore the native ecosystem (Hobbs and Humphries 1995).

Unfortunately, little work has been conducted on the impacts of invasive plants (Byers *et al.* 2002). This lack of knowledge hampers restoration efforts because, if we do not know the impacts of the weeds, we cannot know what is required to adequately restore invaded ecosystems. A review of the WoNS program (Reid *et al.* 2009) found that biodiversity often did not improve following weed control, so other interventions are clearly needed. Greater understanding of how to manage ecosystem recovery is needed given that many ecosystems, especially those long-invaded, cannot recover after weed control without additional restoration (Richardson and van Wilgen 2004). If the goal of a weed management program is protection of biological assets, then additional restoration may be needed to eliminate the long-term impacts caused by weed invasion.

This paper uses examples from two WoNS, bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) and bridal creeper (*Asparagus asparagoides*, (L.) Druce), to illustrate the need for increased awareness of restoration and call for an increase in restoration effort following weed management. These two weeds are used as examples because there is a large amount of information about their impacts on native ecosystems, as well as on the response of ecosystems to their control. This information is critical to adequately design restoration activities.

RESTORING RESILIENCE

Resilience is the capacity of an ecosystem to tolerate disturbance or to recover from damage (Buchanan 2009), such as a storm event or disease. This capacity to regenerate can be harnessed to help natural areas recover after disturbances, including that of weed control. However, evidence from impact studies of bitou bush and bridal creeper-invaded ecosystems indicates that resilience levels in weed-invaded ecosystems are currently low (French *et al.* 2008, Turner 2008).

If the goal of weed management is protecting natural ecosystems, then an outcome of the program must be to ensure that the ecosystems are as resilient as possible after weed control. This will provide greater regeneration potential for the invaded ecosystem and increased protection from further disturbances. Management must reduce the weed threat on native species and ecological communities and must also restore the resilience of these species and communities to combat future threats, such as climate change. Resilience in native ecosystems can be increased by having many different species in each different ecosystem layer (e.g. multiple shrub species, multiple grass species, etc.) and by ensuring there are high numbers of each of those different species (Tilman and Downing 1994, Ives *et al.* 2000). Therefore high species diversity and abundance should be restored after weed control to ensure development of resilient ecosystems.

BITOU BUSH

Bitou bush invasion reduces native plant species abundance (Mason and French 2007, French *et al.* 2008) and alters the diversity of native seeds and seedlings (Mason *et al.* 2007). In bitou bush invaded ecosystems, native species from all layers (grasses, herbs, shrubs, trees and vines) were less abundant and occurred more infrequently (Mason and French 2007). In addition, management actions (i.e. controlling bitou bush) can also reduce abundance and alter native species diversity (Mason and French 2007). Off-target herbicide damage during bitou bush control can cause lower native plant species abundance (Mason and French 2007). Intensive bitou bush management (e.g. bush regeneration), while reducing the bitou bush threat, has been associated with an increase in other weeds that may secondarily invade after bitou bush removal (Mason and French 2007, French *et al.* 2008).

Thus, bitou bush invasion and its subsequent management can lead to a reduction of resilience in native ecosystems. To restore that resilience, there must be increases in native species abundance and diversity following bitou bush control. Bitou bush control can and does lead to a moderate increase in native species abundance (Mason and French 2007), however, this may not be an adequate increase in diversity because some native species may not be present in the seed bank (Mason *et al.* 2007). Furthermore, control measures must strive to prevent off-target damage and introduction of other weeds. Hygiene procedures should be put in place for bush regenerators and contractors, along with follow-up removal of secondary weeds, which are likely to be present in the seed bank.

Studies in bitou bush-invaded habitats show that many native species are absent from below or aboveground seed banks (Mason *et al.* 2007). In addition, recent work indicates that the majority of native species that are expected to recolonise through natural dispersal are not doing so. Multiple factors may contribute to lack of dispersal into sites (K. French, T. Mason and N. Sullivan unpublished data). Seed dispersal mechanisms may only allow short-distance dispersal, e.g. many are ant-dispersed and move usually less than 9 m, while many other species have no dispersal mechanism at all and simply fall beneath the parent plant. A lack of connectivity between biodiversity-rich sites may also limit the species that are able to recolonise a restoration area, e.g. seed sources for wind or vertebrate dispersed species may be too far away for effective dispersal. In addition, insufficient propagule pressure, due to desired species being present only in low numbers and producing very limited seed, can reduce likelihood of dispersal. Thus, natural dispersal and existing seed banks alone may not be sufficient to provide the full suite of species necessary to restore ecosystem resilience.

BRIDAL CREEPER

Bridal creeper reduces native plant diversity and abundance (Turner and Virtue 2006, Turner *et al.* 2008a). Bridal creeper invasion alters native plant community structure and adversely effects understorey shrubs and trees that the weed uses as supports (Turner and Virtue 2006, Turner *et al.* 2008a). In addition, bridal creeper produces a large tuberous mat that occupies extensive space in the top-soil and excludes other plants (Turner 2008). Thus, bridal creeper invasion can lead to a reduction in resilience in native ecosystems.

A suite of native and exotic plants benefit following bridal creeper control, and species that readily germinate from the seed bank will replace bridal creeper. The species most likely to dominate are other weeds, as invaded sites have large exotic seed banks that readily germinate (Turner *et al.* 2008a). Efforts will be necessary to prevent those weeds from establishing and to ensure native plant recovery. However, in some instances, native species abundance and diversity do not increase following bridal creeper control (Turner and Virtue 2006, Turner *et al.* 2008b) and sites may require further restoration. In addition, the tuberous mats of older bridal creeper plants can leave a detrimental legacy. Large, dead tuber mats may remain many years after control (Turner 2008). These mats can prevent native plant root growth and establishment and can continue to impact native vegetation long after bridal creeper plants are killed (Turner and Virtue 2006, Turner 2008).

Integrating other restoration techniques with bridal creeper management will be necessary to build ecosystem resilience. Fire may be an important restoration tool, as it may stimulate the regeneration of some native plants and speed up the recovery of bridal creeper-invaded ecosystems, provided that bridal creeper and other secondary weeds are kept at a low post-fire density (Turner and Virtue 2009).

DISCUSSION

Many restoration programs depend on natural dispersal and unassisted natural regeneration from the seed bank – 'letting nature take its course'. However, if native seed is not present in the seed bank (or will not readily germinate) and there is a low chance of natural re-colonisation at a site, then restoration work must increase the species diversity following weed control. Due to budget constraints, most restoration work currently involves re-planting three or four different species in low densities in post-control sites. These species, at most, represent two or three ecosystem layers (e.g. vines, shrubs or trees) but seldom represent all ecosystem layers (grasses, herbs, vines, shrubs and trees). Furthermore, the species planted are often already present, so they do not increase diversity or assist in re-establishing 'missing' species. Woody invaders, such as bitou bush, can have very strong negative impacts on the smaller, more cryptic species in the herb and grass layers, and these should be a focus during restoration efforts (Mason *et al.* 2009).

To build resilient ecosystems, the full complement of species should be re-established. All species present before the weed invasion should be present after restoration, in both number and composition. Diverse systems will be more successful at maintaining themselves over time. This will provide an ecological 'backup,' so that if something should eliminate one species in a layer (disease, drought, etc.), there will be another species to provide similar function in the ecosystem. Species should also be planted as densely as resources and space permit to allow for attrition and to establish densities similar to those in natural sites. In other words, each layer should have a full suite of species and each of these should be as abundant as possible. Re-planting densely will result in very few spaces available to undesirable species, such as weeds, thus providing some protection from re-invasion. While re-planting at high density means some native species will die due to over-crowding, it is better to sacrifice these than spend future conservation dollars on long-term weed management. Sites for weed management and restoration should therefore be prioritised based on ability to achieve control and likelihood of protecting biodiversity (Hamilton *et al.* 2010). When prioritising sites, land managers should be aware of the high costs of restoring heavily invaded areas and ensure management is only undertaken where resources allow the desired biodiversity outcome.

Re-building resilient ecosystems after weed control, especially if the area is long-invaded, will require significant investment in resources and participation at all levels of Natural Resource Management (NRM). The high costs should not prevent appropriate action, rather scientists and land managers must justify to policy makers that this expense is required to achieve desired biodiversity outcomes. To that end, research is now needed to investigate methods to reduce the impacts of environmental weeds by integrating weed management and restoration. Such research should also develop a rapid assessment of site health that will assist land managers to proactively implement ecologically-appropriate weed management and restoration. Guidelines are currently being developed to aid restoration efforts in two southeast Australian coastal ecosystems following bitou bush control (J. Wallace and K. French unpublished data). These guidelines focus on rebuilding ecosystem resilience and provide a template to: (1) assess what native species should be present at the site, (2) assess what species are present at the site post-weed control, (3) determine what species are 'missing', and (4) provide information on how to restore those species. It is hoped that these types of monitoring and adaptive management tools for restoration can be expanded to include other invaded ecosystems and ultimately be incorporated as standard practice in NRM.

Although costly, investment in ecosystem restoration is justified by the urgent need to protect native biodiversity from current threats. As NRM policies evolve to account for climate change adaptation, building ecosystem resilience should be a key consideration of environmental weed management, as those ecosystems that are healthy and resilient will most likely be the best equipped to respond to the demands of a changing climate and to other disturbances.

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