Managing native grasslands to minimise invasion by Chilean needle grass (*Nassella neesiana*)

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Summary A set of practical management measures to minimise *Nassella neesiana* invasion of *Themeda triandra* dominated south-eastern Australian native grasslands is proposed, based on understanding of the factors that result in its ingress. Disturbance that creates bare ground and a nutrient flush drives invasion. Loss of or damage to the dominant native grass enables *N. neesiana* to establish; intact native grassland is resistant to invasion. Management should focus on minimising the invasibility of grassland areas and maintaining intact native grass swards. Prevention of senescence of *T. triandra* tussocks *via* ongoing biomass reduction is a key requirement. Where the native soil seed bank is depleted and native grass establishment is to be attempted, the application of carbohydrates (e.g. sugar) to temporarily reduce available soil nutrients can preferentially promote the natives, but further experimentation is needed to determine the practicalities of this approach. Continuous reduction of propagule pressure by repeated herbicidal control or manual removal of isolated plants is an ongoing requirement, but herbicidal control of larger patches without follow-up rehabilitation may promote re-establishment. These measures are more or less consistent with existing idealised management guidelines for native grasslands.

Keywords Native grassland, *Nassella neesiana*, *Themeda triandra*, disturbance, senescence, management, rehabilitation.

INTRODUCTION

Nassella neesiana (Trin. & Rupr.) Barkworth is one of the most serious weed threats in the temperate native grasslands of south-eastern Australia (McLaren *et al.* 2004), where the dominant native grass is *Themeda triandra* Forrsk.; the presence of the weed is correlated with much reduced native plant and invertebrate biodiversity (Faithfull *et al.* 2009, 2010, Faithfull 2012). Its distribution can be characterised as synanthropic: infestations are strongly associated with urban areas, roads, pastures and the cultural steppe; and its dispersal and establishment are promoted by ongoing land management practices (Hocking 2007, Snell *et al.* 2007). Major infestations are largely a consequence of poor management decisions in the past; they can continuously occupy the ground for many years if no control activity is undertaken (Faithfull *et al.* 2009). Typically a large soil seed bank is formed, along with a reservoir of protected cleistogenes above ground. In contrast, the native grassland species usually lack or have small soil seed banks, so have to produce and disperse a new generation of seeds to a site if they are to occupy it. The dilemma for grassland managers is that the conditions that facilitate the establishment of *N. neesiana* appear to be similar to those required for establishment of native forbs and probably, in many instances, the recruitment of native grasses, i.e. soil disturbance, and large canopy gaps associated with reduced shade and below-ground competition, particularly from established perennial grasses (Robinson 2006, Reynolds 2006). Lunt and Morgan (1998) suggested that maintaining a healthy sward of *T. triandra* was likely to be the most cost-effective method of reducing *N. neesiana* invasions, a suggestion supported by more recent studies and strongly endorsed here.

Snell *et al.* (2007) provided a widely used guide to best practice management of *N. neesiana*. The main challenge is to integrate the more recent ecological understanding of the weed and the grassland system with the current institutional management capabilities (Hocking 2007).

MATERIALS AND METHODS

Methods advocated for managing *N. neesiana* in native grasslands were critically evaluated in relation to recently developed understandings of the factors that drive *N. neesiana* invasions and the connection between ongoing grassland management regimes and the severity of infestations. Effective practices and ineffective or potentially counter-productive approaches were identified.

RESULTS AND DISCUSSION

Much of the older work on *N. neesiana* seems to be predicated on the assumption that superior competitive abilities explain its success as a weed in Australia. Disturbance-related factors were more or less ignored, although they are now known to enable the grass to occupy large areas. Conditions that result in *N. neesiana* invasion in native grassland are primarily those that remove the competition provided by the native vegetation. Presence of *N. neesiana* results from prior loss of plant diversity, as intact native grassland is resistant to invasion under high propagule pressure (Faithfull *et al.* 2009, Faithfull 2012). *Themeda triandra* is probably the main provider of this biotic resistance to weed invasion, and appears to function as a keystone species (Prober and Lunt 2009). Dominance by an invader like *N. neesiana*, suggestive of competitive superiority, may actually be just a priority effect: the weed is the first to invade after strong disturbance, and establishes dominance and an alternative stable state (Seabloom *et al.* 2003). The perception that *N. neesiana* is able to actively invade grasslands appears to be based in part on this misunderstanding.

The core management principles for *T. triandra* grasslands require frequent biomass reduction, preferably by burning, or by short-term livestock grazing, minimisation of disturbances to the soil that cause mortality of the native flora, including intensive grazing and close mowing, and reduction of weed propagule pressure by control of infestations at grassland edges and along thoroughfares (Williams 2005, Wong and Morgan 2007). Strategic, sensitively-managed rotational grazing can be minimally degradative and mimic some of the beneficial ecological effects of the mostly-extirpated native vertebrate fauna.

The main *N. neesiana* management guide (Snell *et al.* 2007) focused largely on *N. neesiana* in an agricultural context but included brief integrated management guidelines for native pastures and "ungrazed native grass" (p. 33). Apart from hygiene, the methods advocated for natural grasslands were manual removal, spot-spraying for infestations of all sizes, and the use of fire to prevent panicle seed production and destroy seed. Restoration of native species was briefly addressed, the 'spray and hay' method for establishing *T. triandra* (Mason and Hocking 2002) being recommended. The relatively brief guidelines for natural grasslands carried the risk that measures advocated for non-pasture situations might, by default, be applied to native grasslands where they could cause serious damage, or be counterproductive.

Herbicidal management of *N. neesiana* in agricultural situations has often resulted in expansion of *N. neesiana* populations and exacerbation of spread due to the elimination of competition (Slay 2002). Whatever the herbicide used, *N. neesiana* cleistogenes (concealed basal and stem seeds) that have already matured but remain attached to the plant beneath leaf sheaths are not killed (Hurrell *et al.* 1994). Many herbicides used to control *Nassella* spp. have severe impacts on native vegetation and can result in major weed invasion or re-invasion (Hocking 1998). Faithfull (2012) demonstrated that where there was propagule pressure, herbicidal kills of 1 m^2 patches of native grass enabled substantial establishment of *N. neesiana*, that when spraying created smaller gaps (10–30 cm) establishment was very low, and that unsprayed swards were resistant to invasion. Herbicides need to be applied with great care to avoid off-target damage and accidental native grass death. When a seed bank of *N. neesiana* is present, baring the ground with herbicides encourages seedling recruitment and may lead to rapid re-establishment and an ultimate increase in density and cover of the weed (Gardener *et al.* 2003). However, there is strong evidence that finely targeted (both spatially and temporally), selective, biannual herbicidal spray treatment, over at least four years in native grasslands can reduce the soil seed banks of the weed to very low levels (Beames *et al.* 2005). Herbicidal control programs of the required frequency and precision may be more the exception than the rule. Infrequent 'spray outs' of *N. neesiana* resulting in bare ground are most likely to result in rapid reoccupation from the weed seed bank, and hence competitive replacement with desirable native species is a required adjunct (Hocking 2007).

However, cost-effective, consistently reliable rehabilitation treatments after herbicidal kill are not available: *T. triandra* hay is expensive and may have few seeds, and the 'spray and hay' method is often ineffective in dry years (Cole and Lunt 2005). Established infestations with stable margins under prevailing management regimes may be better left untreated until rehabilitation techniques are improved, or conditions for effective 'spray and hay' treatment occur. Herbicidal control should probably be prioritised for very small infestations and isolated tussocks, to reduce propagule pressure amongst un-invaded vegetation, and perhaps directed at larger infestations that have large boundary: area ratios, so that natural recolonisation by native grasses can occur more readily.

Maintenance of regular burning has long been recognised as important to minimise weed invasion, maintain healthy swards of native grass and conserve plant diversity (Williams 2005, Wong and Morgan 2007). In the absence of fire or other biomass reduction, a process of *T. triandra* sward densification and senescence proceeds, after a period of a few years, to a self-shading effect that prevents the growth of new tillers, and eventually results in tussock death (Morgan and Lunt 1999). This senescence has been found to remove biotic resistance and open the community to invasion by weeds (Lunt and Morgan 2000) including *N. neesiana* (Faithfull 2012). The process was evidently a major cause of the massive increase of *N. neesiana* at the ungrazed and unburned Yarramundi Reach grassland in the ACT, *c*. 2003–07, where infestations expanded at rates of >5 m per year in areas around senescent stands (Faithfull *et al.* 2009). Frequent fire strengthens invasion resistance by maintenance of a healthy cover of non-senescent *T. triandra*. Annual burning aimed at preventing *N. neesiana* seeding is not generally an option because standing biomass sufficient to maintain a fire usually requires longer than one year to develop. Mowing to remove biomass is a risky approach because it appears to differentially affect *T. triandra*, which has growing points that are more elevated and prone to damage than *N. neesiana* which is able to produce new tillers that grow near-horizontally. Average linear infestation expansion rates of up to 7.5 m per year have been measured in areas regularly mown short (Faithfull 2012).

Prevention of soil disturbance is considered vital to minimise weed invasion (Williams 2005) but Faithfull (2012) found that *N. neesiana* established readily in its absence if native grasses were killed. Soil disturbances such as earthworks, that remove competing grasses, are an invitation to trouble, but the outcome in terms of plant cover depends on existing soil seed banks and the timing of seed production of surrounding grasses: whatever grass establishes first will likely come to dominate.

Soil disturbances that result in death of the native vegetation produce a nutrient flush, probably largely from the rapid breakdown of fine roots, and such nutrient flushes preferentially benefit *N. neesiana* compared to *T. triandra* (Faithfull 2012). Reduction of nutrient inputs and the use of nutrient 'drawdown' techniques by application of a carbon source (e.g. sugar, sawdust) were advocated by Williams (2005) and have been demonstrated to be an effective technique for the restoration of *T. triandra* and some native forbs in grassy woodlands dominated by exotic annuals in Australia (Smallbone *et al.* 2007, Prober and Lunt 2009). Sugar has been found to greatly reduce *N. neesiana* establishment after disturbance-related nutrient enrichment (Faithfull *et al.* 2009).

Whatever the weed species, buffer zones around healthy grassland and management of the weed in surrounding areas are highly desirable (Williams 2005). One buffering approach that appears effective was applied by Jenny Conolly at Constitution Avenue grassland in Canberra. A band of *N. neesiana* several metres wide adjoining native grassland was spray-killed and covered with a layer of woodchips deep enough to prevent *N. neesiana* seedling emergence. Propagule pressure on the native grassland was reduced, the soil seed bank could decay beneath the wood chips and the added C minimised available soil nutrients. Mechanical weed wipers have recently been demonstrated to provide effective control along roadsides where there is a clear height differential between *N. neesiana* and the other grasses (Hocking 2009).

Recent advances in ecological understanding need to be better incorporated into management planning. The main practical measures to minimise invasion are: 1. Extensive and intensive monitoring and mapping during the main flowering season (September to December) when the plant is most readily detectable and identifiable, late October being the optimal time; 2. Ensuring that the matrix of *T. triandra* is maintained by frequent burning at least every 3–5 years or by strategic grazing, to prevent senescence of *T. triandra*; 3. Finely targeted, selective herbicidal control of isolated plants and small infestations twice yearly for four or more years; 4. Herbicidal control of larger infestations only under circumstances in which rehabilitation measures to establish competitive native grasses are likely to be successful; 5. Judicious use of a carbon source (sugar, sawdust) to temporarily reduce plant-available nutrients in rehabilitation activities - long term nutrient drawdown measures may also be required and broad scale testing is needed to develop effective practical C application measures for large infestations; 6. Reduction of *N. neesiana* in the landscape and buffer zones around grasslands, e.g. by mechanical wick-wiping in areas that need to be mown. Mitigation of the factors that cause degradation and consequent invasions should be the primary aim; infrequent herbicidal treatment alone may perpetuate the weed problem.

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