Chilean needle grass (*Nassella neesiana*) in the native grasslands of south-eastern Australia: biodiversity effects, invasion drivers and impact mechanisms

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Summary A study of the biodiversity impacts of Chilean needle grass *Nassella neesiana* (Trin. & Rupr.) Barkworth in temperate native grasslands of south-eastern Australia shows that native vascular plant richness (species m^{-2}) is reduced in infested areas and decreases with increasing patch size, with forbs and one or more of the major native grasses most affected. Exotic plant species richness is similar inside and outside patches. There are also reductions in invertebrate species richness and population sizes. Major disturbance (removal/death of the dominant native grasses) enables *N. neesiana* invasion. Gaps of *c.* 1 m enable establishment. Native grasslands in gap-free condition are resistant to invasion. In areas with *N. neesiana* propagule pressure, increased senescence of *Themeda triandra* swards (due to absence of fire or grazing) is accompanied by invasion. *N. neesiana* depletes soil water in spring more than *T. triandra*, a mechanism that may explain the ongoing losses of native species. Historical aerial photos demonstrate that invasion is absent or very slow unless grasslands are in poor ecological condition, when linear expansion rates >5 m per year can be expected. Much of the plant diversity loss in invaded areas probably precedes invasion and is caused by degradation including *T. triandra* dieback, mowing and major soil disturbance.

Keywords *Nassella neesiana*, Chilean needle grass, *Themeda triandra*, grassland, biodiversity, disturbance, impact, invasion mechanisms, invertebrates.

INTRODUCTION

Nassella neesiana is a C_3 perennial tussock grass native to South America that is highly invasive in the native grasslands of south-eastern Australia (Hocking 1998, McLaren *et al.* 2004). Alien plant invasions are a significant cause of biodiversity decline, but there has been little precise information in Australia on the species and communities impacted and the mechanisms of impact (Grice 2004, Coutts-Smith and Downey 2006). Most statements are 'based on more or less casual observations' (Grice 2006), and causal factors have 'generally (been) implied but not demonstrated' (Grice 2004).

Detailed studies of *N. neesiana* as a weed were first undertaken in New Zealand, particularly by G.W. Bourdôt, and its ecology in Australia was first studied in detail by Gardener (1998). Biodiversity impacts of *N. neesiana* have been asserted to be severe, but detailed impact assessment has not been undertaken, apart from a small study by Ens (2002) on invertebrates in Sydney woodlands. Mechanisms of invasion and impact have been little explored.

Negative impacts in the natural temperate grasslands of south-eastern Australia are a particular concern because extant remnants of this endangered ecosystem represent only 1.7% of the pre-1750 area (an estimated 5.8 million ha) and only a small proportion is in good condition (Carter *et al.* 2003). The dominant plant in these grasslands is *Themeda triandra* Forrsk., a C_4 perennial adapted to frequent fire but susceptible to eradication by livestock.

Disturbance usually increases the invasibility of communities (Hobbs and Huenneke 1992, D'Antonio *et al.* 1999), and in perennial grasslands any disturbance that damages or kills the existing vegetation favours grass recruitment (Cheplick 1998, Lauenroth and Aguilera 1998). Nutrient enrichment is another major cause of alien grass invasion (Milton 2004). One of the most critical anthropogenic disturbances in *T. triandra* grasslands is suppression of fire, which results in gradual build-up of dense biomass, leading to senescence dieback of *T. triandra*, and opening of the community to weed invasion (Lunt and Morgan 2000). Propagule pressure is required for any invasion, but all communities may possess biotic resistance to invasion. This paper summarises the results of a PhD study, to be reported in detail elsewhere.

MATERIALS AND METHODS

Investigations were undertaken at four urban and three peri-urban grassland reserves in the Australian Capital Territory and the Melbourne area from 2007 to 2009. Details of sites and methodology have been previously provided (Faithfull *et al.* 2009).

Vascular plant diversity in a total of 36 *N. neesiana* patches at three grasslands was compared with that in uninvaded grassland immediately outside the patches. Presence data and foliar cover estimates were taken in a minimum of two 1 m^2 quadrats inside and outside each patch. Invertebrate diversity was compared at seven sites using 19 sets of paired 15-minute ground + vegetation search samples and 23 sets of paired sweep net samples inside and outside patches. Observations were also made of animal utilisation of *N. neesiana*.

A field experiment was undertaken to test an 'invasion requires disturbance' hypothesis. This examined the effects of 'full kill', 'half kill' and 'no kill' treatments of existing grassland vegetation with glyphosate, along with nutrient addition (urea, superphosphate) and immobilisation or 'reverse fertilisation' (using sugar), with and without addition of *N. neesiana* panicle seeds (500 m^{-2}). Establishment of *N. neesiana* was monitored over 69 weeks and the above-ground biomass of all plants present was quantified at termination.

Pin transect sampling was undertaken at 10 cm intervals along five transects with total length of 20.9 m in stands of senescent *T. triandra* to investigate the correlation between the degree of senescence and the amount of *N. neesiana*. The number and height of pin intercepts of live and dead foliage was recorded for all species. A soil moisture probe was used to compare surface soil water content at 0.1 or 1 m intervals along six transects with a total length of 70 m through the boundaries of *N. neesiana* patches into areas dominated by *T. triandra*, at one site in spring 2008. Historical changes in the dimensions of numerous infestations were determined by interpretation of historical aerial photos, in conjunction with ground measurements. Annual rates of change of patch areas and linear expansion rates at patch boundaries were calculated.

RESULTS

Native plant richness (spp. m^{-2}) in *N. neesiana* patches was less than in areas immediately outside the patches at all three grasslands, and significantly lower in two of them. Reductions of 32–65% were measured. Significant reductions of 31–49% occurred with native grasses at all three grasslands. Native forbs were significantly reduced at the two least degraded grasslands (−70%). Proportionately larger reductions were measured at the two grasslands with relatively high native plant diversity. Native species richness strongly declined with increasing *N. neesiana* patch area, approximately 1 sp. m^{-2} being lost with patch area tripling from 100 to 300 m^2 and a trend to zero at large patch sizes. The relationship indicates that even at the smallest patch sizes, native forbs are reduced by about two thirds, but that loss of native grasses is not as complete.

Sweep net samples demonstrated significant differences in invertebrate species richness in *N. neesiana* patches in autumn (−48%) but not in spring, and the number of invertebrate individuals inside *N. neesiana* patches in spring (−37%). Increased presence of the grass inflorescence spider *Runcinia acuminata* (Thorell) (Thomisidae), and of green midges (Diptera: Chironomidae) outside *N. neesiana* patches explained much of the latter difference. No significant differences were found in the much less speciose search samples. General observations revealed several vertebrates and numerous native insect species with wide host ranges that utilise *N. neesiana* as food.

In the disturbance experiment, establishment of *N. neesiana* was enabled by treatments that killed the pre-existing grass sward. Close to zero recruitment occurred in the absence of such disturbance. Areas dominated by healthy growing native tussocks were resistant to invasion. A gap size of 1 m^2 ('full kill' plots) enabled significant establishment, while gaps of *c.* 10–30 cm ('half kill') largely disallowed it. A maximum of 65 juvenile plants was recorded after 6 months on one of the 'full kill' plots, where the best establishment occurred, but there was high variance with a mean of only 12 plants. Biomass of *N. neesiana* plants that established in areas with larger gaps was much greater than areas with small gaps 69 weeks after seed application, by which time approximately half the plants that established had entered the reproductive phase. Fertilisation with N, P or both had no significant effect on the number of *N. neesiana* plants that established or their biomass, but reverse fertilisation using sugar reduced establishment on 'full kill' plots by 87% and reduced the mean biomass per plant by one-third.

Pin transects in senescent areas demonstrated that the presence of *N. neesiana* increased significantly as the proportion of dead to total *T. triandra* increased. Qualitative observations indicated that dieback occurred in mosaic patterns as well as broader areas and was often accompanied or followed by invasion. Severe senescence dieback at Yarramundi Reach (ACT) was clearly resulting in wide scale occupation by *N. neesiana*.

All soil moisture transects showed markedly lower surface soil water content under *N. neesiana* than under *T. triandra* and the difference was highly significant. This was the case whether the *T. triandra* was senescent or healthy and when both species were shortly mown, and appeared to be independent of micro topographic position, surface soil features and time of day. Soil moisture content was frequently close to zero under *N. neesiana* but frequently exceeded 10% under *T. triandra*.

Historical photos and ground measurements revealed that infestation margins of *N. neesiana* patches were stable over several years where they abutted healthy native grassland and that some infestations occupied areas subject to major soil disturbance in the past. Alarming rates of expansion of patch areas (12–100%+ year^{-1} over *c.* 3 years, 2005–08) occurred at Yarramundi Reach. Expansion rates of 5–7.5 m year^{-1} over 4 years were estimated along roadsides subject to frequent mowing. Regular burning at Laverton North Grassland Reserve, Victoria, appears to have stabilised and sometimes reduced the density and area of infestations.

DISCUSSION

Nassella neesiana infestations were found to have greatly reduced native plant and invertebrate species richness and reduced invertebrate numbers compared to uninvaded areas, but similar exotic plant richness. Investigations of the mechanisms of invasion indicate that much of the diversity impact is attributable to prior disturbances that result in death of the native vegetation and enable *N. neesiana* to invade, including senescence dieback of *T. triandra* – critical invasion drivers most probably include major soil disturbance, overgrazing by livestock and short mowing of the vegetation.

If larger patches are older than smaller patches, and this is probably the case with most patches, the relationship between native plant richness within a patch and patch area suggests that *N. neesiana* has a continuing negative impact on native plant diversity after establishment as the dominant grass. Major losses at the smallest patch sizes indicate a prior effect (i.e. severe disturbance) is both the cause of major biodiversity loss and of occupancy by *N. neesiana*. Absence of detectable impacts of *N. neesiana* on exotic plant richness is explained by the much greater abilities of exotics to recolonise disturbed areas. The natives generally lack or have transient seed banks and are highly recruitment-limited (Morgan 2001).

The invertebrate findings support and extend the conclusions of Ens (2002), who found major changes in the insect fauna in invaded areas, attributed mainly to structural change in the vegetation. The effects on the two insect taxa most severely reduced in the presence of *N. neesiana* appear to be indirect, since the spider is an ambush predator and larval chironomids inhabit freshwater.

Death of a native grass sward due to senescing and decaying vegetation results in a strong nutrient pulse that enables the establishment of weeds (Wijesuriya and Hocking 1999). It appears that sufficient nutrients were released from breakdown of the killed grasses in the disturbance experiment to enable *N. neesiana* establishment, but where sugar was applied the nutrients were immobilised and establishment and subsequent production was greatly reduced. Observations associated with this experiment suggest that competition for water may be more important than for nutrients in determining the extent of *N. neesiana* establishment.

Nassella neesiana and *T. triandra* have complementary growth periods, the former in phase and competing directly with a high proportion of the native vascular flora, the latter mostly out of phase. Depletion of soil water in spring under *N. neesiana* stands must have pronounced negative impact on co-occurring plants and at the edges of infestations, and may be one mechanism that explains higher impacts in larger patches and patch expansion. At a landscape scale, the widespread replacement of C_4 native grasses by C_3 exotics has caused runoff and stream flow declines and increased deep drainage, all of which have contributed to dryland salinity, soil acidification and eutrophication of catchments (Johnston *et al.* 2003, Reseigh *et al.* 2008). *N. neesiana* displacement of *T. triandra* may therefore affect biodiversity well beyond the areas invaded.

Patch expansion over periods of several years is minimal where infestations are bounded by native grassland in good condition. Where infestations abut areas of senescent *T. triandra*, linear expansion rates >1 m per year can be expected and much faster rates in frequently close-mown areas. *N. neesiana* invasion and biodiversity loss are minimised when native grasslands are kept healthy by biomass reduction. Maintenance of healthy native grassland, in particular the management of *T. triandra* biomass accumulation by burning and the avoidance of severe anthropogenic disturbance, is the best defence against *N. neesiana* invasion and biodiversity loss.

ACKNOWLEDGMENTS

Research was enabled by permits from the Victorian Departments of Primary Industries (PP-004-07) and Sustainability and Environment (10004227) and licences issued by the ACT Government Territory and Municipal Services (LT2007263 and 2008312).

Investigations were funded by the Australian Government Department of Agriculture Fisheries and Forestry under the Defeating the Weed Menace Programme. We thank C. Grech, J. Bonilla, S. Ramasamy, H. Bennett and other officers of cooperating authorities for assistance. Special thanks to K. Butler (DPI) for biometrical assistance and S. Sharp for enabling activities in the ACT.

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