Urban grasslands, their management and restoration

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Best practise management of Chilean needle grass (*Nassella neesiana*) in conservation reserves – the seedbank story

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Summary
The viable seedbank and capacity for recruitment of *Nassella neesiana* was greatly reduced at two management sites west of Melbourne, Victoria. These sites have been subjected to four or more years of ongoing, consistent and selective herbicide management, operating under typical unpredictable budgetary constraints and delays. *N. neesiana* infestations had high numbers of seed in the seedbank, however this was significantly reduced within management areas. The seedbank did not appear to be as prolific as originally estimated and was comprised of large amounts of unviable seed and unsuccessful germinating seed across all areas. Significantly more potentially viable seed and more successful germinants were found outside management areas. No significant difference was found between the seedbanks under different types of management within the Laverton site, though some were found at Melbourne Airport. Further investigation of the recruitment of *N. neesiana* may show that different management strategies have varying impacts upon the emergence of germinants from the seed bank or seed production.

Introduction
Nassella neesiana has been selected by the Australian federal government as one of the twenty weeds of national significance (WONS). This exotic stipoid has been identified as a serious environmental weed in south-eastern Australia's native grasslands and grassy woodlands (McLaren *et al.* 1998). Morgan (1998b) regarded *N. neesiana* as one the most potentially threatening species to south-eastern Australian grassland remnants due to its potential to out compete most native species. Native grassy ecosystems are among Australia's most threatened, with less than 1% of Australia's temperate native grassland remaining (O'Dwyer and Attwill 2000). In Victoria, less than 0.1% remains of the Western Basalt Plains Grassland that once covered one tenth of the state (Govanstone *et al.* 1992). Between 1985 and 2000, 21% of the remaining native grassland (7230 ha) around Melbourne had been degraded by weed invasion and other process into non native grassland (Williams *et al.* 2004). This sustained degradation of urban remnants by weed invasion and inappropriate management continue to reduce the area, extent and biodiversity of native grasslands in the Melbourne area therefore increasing their vulnerability to these factors. *N. neesiana* is particularly well adapted to the intensively cultivated areas surrounding urban areas and poses a significant threat to mismanaged urban grassland remnants.

Previous studies of the biology of *N. neesiana* have described its large seed production, large and persistent seed bank (Gardener 1998, Slay 2002, Gardener *et al.* 2003a,b) and high seedling recruitment (Gardener 1998, Gardener *et al.* 2003b, WONS 2003) and attributed these as mechanisms for its successful invasion and dominance of native grassland and pasture areas.

Plant population ecology is heavily influenced by the seed bank strategies of desirable and undesirable plant species and often has major implications for the management of conservation landscapes (Smith *et al.* 1999, Araki and Washitani 2000, Funes *et al.* 2001). A number of studies have investigated the functionality of managing weeds by managing the weed seed bank (Grundy 1998, Rahman *et al.* 2001). Measurement of the seed bank can also allow managers to predict weed emergence (Grundy 2003).

As well as being an indicator for the type of management required for an area, the seed bank and above ground weed flora are greatly influenced by the type of management applied to the area (Mayor and Dessaint 1998). In a study of *N. pulchra*, Dyer (2002) surmized that seeds from plants that had been subjected to burning or burning and grazing were more likely to contribute to a persistent seed bank than seeds from plants managed differently. Gardener *et al.* (2003b) found that *N. neesiana* areas that had been bared were likely to have a faster seedbank decline than those that were vegetated.

Competition for resources, within and between species (intra and interspeciefic competition) is likely to influence the diversity and abundance of plants germinating from the soil seedbank. Dense ground cover has been shown to reduce seedling emergence of *N. neesiana* (Gardener *et al.* 1996). These findings suggest that factors associated with dense ground cover may inhibit germination or maintain dormancy of seeds.

Currently, there are no best practise management procedures established for control and containment of *N. neesiana* and no effective method has been described that can remove and replace it with competitive species and prevent re-establishment (Hocking 1998). Most managers of non-farming areas, conservation reserves, roadsides and other infested land rely on various herbicide regimes as control measures for the weed. There has been no evaluation of the effectiveness of these types of programs on *N. neesiana*.

High quality and biodiverse native grasslands resist weed invasion (Hector *et al*. 2001). Previous studies (Phillips 1998) and observations from on-ground management (Native Vegetation Management Services®), have shown that well managed *Themeda triandra* swards can be effective in controlling *N. trichotoma* (serrated tussock). In a few instances there have been attempts to replace *N. neesiana* with native grasses, notably *T. triandra*. The effectiveness of this strategy has not been evaluated.

Best management practice evaluation

Native Vegetation Management Services (NVMS) has been trialling methods in applied management of *N. neesiana* in the environmental landscapes for the past decade. Victoria University (VU) and NVMS, with the assistance of WONS, have united the NVMS experience and expertise of applied techniques with the VU theoretical and analytical proficiency, through the project outlined in this article. The aim of the project is to scientifically assess and evaluate NVMS management of *N. neesiana* so that best practice management procedures might begin to be formulated for the control of *N. neesiana* in native grasslands.

The hypotheses for the project are that management at each site has resulted in a declining seed bank, declining recruitment rates and declining numbers and densities of *N. neesiana* plants when compared to areas adjacent, with similar *N. neesiana* infestation history, but not under NVMS management. This paper presents the first stage findings for the project in regards to the composition of the soil seedbank.

Project sites

Two sites on the outskirts of Melbourne were chosen for evaluation. Various types of management had been applied for the control of *N. neesiana* over several years. The sites are distributed across the scale as shown in Figure 1. At each site the management aim has been to move the site status from low quality native grassland to high quality native grassland.

Management tools available in suburban fringe native grasslands are generally restricted to herbicide application and slashing with burning with grazing used to a lesser extent. The finer elements of these management tools are timing, technique, intensity and frequency of their use. NVMS has designed the management to attend to the biology of the plant within the ecology of the vegetation type in which it is occurring, whilst operating under a declining budget. This has been done using a combination of native vegetation establishment, management and the CMASC (Consistent Micro Application of Selective Chemicals) approach. A broad description of the management techniques applied by NVMS and other entities at the study sites is listed in Table 1.

Laverton former RAAF base Grassland Reserve

This site is a high quality basalt plains grassland remnant dominated by *Austrostipa* spp. and *Austrodanthonia* spp. with rich patches of forbs. It is primarily managed for conservation and is frequently burnt – in most cases at least every two years. NVMS has been employed at this site from 1998 to 2003 to control *N. neesiana* and other weeds such as serrated tussock.

Patchy infestations of *N. neesiana* and individual outlying tussocks have been selectively sprayed at least twice per year for five years using glyphosate and a one-off application of flupropionate and previous to this, atrazine was used. The frequency of treatment was dependent on the timing and allocation of funding from the landowner. For some more extensive patches where *N. neesiana* had been sprayed out, the site was oversown with *T. triandra* seed harvested from nearby remnants, using a Bandicoot® Native Grass Harvester. The quality of the *T. triandra* seed and the rate of sowing were not recorded. It is likely, from estimates of similar harvested seed applied elsewhere that the rate of application of *T. triandra* seed was in excess of 50 viable seeds m^{-2}.

Systematic coverage of the areas during spot spraying would reveal most mature *N. neesiana* plants and seedlings over several herbicide campaigns throughout the year. Due to the expertise of the operator and the consistency and persistence of the campaign, the rate of error was estimated to be less than one in one fifty plants missed. Over time this error rate may have increased, as plants became smaller and more sparsely distributed. The CMASC approach resulted in most plants being sprayed well before flowering and seeding

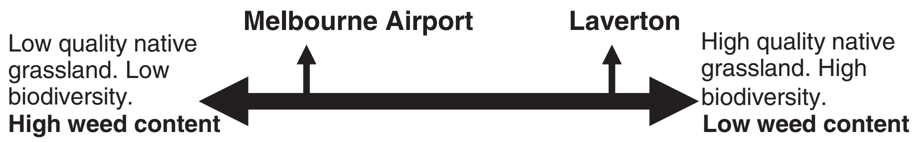

Figure 1. Sites chosen for evaluation of *N. neesiana* management programs.

Table 1. Management techniques applied by NVMS and other entities at the study sites.

Site	Tool	Timing/duration	Technique	Frequency	Intensity
Laverton	Herbicide application	Five years	CMASC and broad application	Consistent	High – Low
	Burning	Autumn	Entire area	Two years	Moderate
Outside NVMS management	Slashing	Early summer (seeding time)	Around fence lines	Consistent	Moderate
	Burning	Ad hoc	Ad hoc	Inconsistent	Mod – High
Melbourne airport	Herbicide application	Seven years	CMASC and broad application	Consistent	High – Low
	Burning	Spring/early summer	Ad hoc	1–2 years	High – Mod
	Slashing	Two years	Stage 3 only	Yearly	Mod
	Macropod/ rabbit grazing	Seven years	Sporadic	High to Low	Mod – Low
Outside NVMS management	Slashing	Early summer and throughout year	–	High	High

and nearly all plants were treated before seed set.

Melbourne Airport greybox woodland revegetation area

The Melbourne Airport site is a greybox woodland revegetation area. The site under evaluation consists of three staged areas of revegetation over a seven year period. Much of the area was exotic pasture, heavily infested with *N. neesiana*, and interspersed with small swathes of native grass, including *Austrodanthonia* spp., *Austrostipa* spp. and *Elymus scaber.* As described for Laverton, a management overlay of CMASC has been applied at the Melbourne Airport. The rate of error in the beginning was larger during the first years of management due to the density and area covered by the plants. This rate of error declined sharply after the first few years to be less than one in fifty plants missed. Over time this error rate may have increased, as plants become smaller and more sparsely distributed. CMASC results in a large percentage of the target plants being treated long before seed set.

Stage 1. (S1) *N. neesiana* was initially boom sprayed with atrazine in 1997, and then regrowth was regularly spot sprayed several times each year with atrazine until 2000. Stage 1 was planted out in 1997 with indigenous trees and shrubs synonymous with a greybox woodland. These were established at a density of approximately one in each 10 m^2 (i.e. spacings of 3–5 m). Tree and shrub heights at the time of sampling ranged between 2 m and 8 m. Sampled sites were set at least 2 m from the nearest tree. After 2000, emerging *N. neesiana* on the site was spot sprayed with glyphosate.

Stage 2. (S2) Similar to Stage 1, except that *N. neesiana* was first sprayed out with atrazine in 2000, and planted out with native trees and shrubs at similar densities to Stage 1. *N. neesiana* emerging in the area continued to be sprayed with atrazine until 2002, which was then replaced with glyphosate. Tree and shrub heights at the time of sampling ranged between 1 m and 4 m.

Stage 3. (S3) Similar to Stage 1 and 2, except that *N. neesiana* was first boom sprayed with flupropanate in 2002. Large areas were missed in this herbicide application and some areas have been burnt by outside entities. A majority of the area was planted out with native trees and shrubs at similar densities to Stage 1. Tree and shrub heights at the time of sampling ranged between 0.3 m and 1 m. One area has been subjected to native grass establishment (*T. triandra*).

This has created four sub-areas within stage 3:

- (B) Burnt and unsprayed and planted
- (U) Unburnt and unsprayed
- (S3) Unburnt, sprayed and planted
- (K) Burnt, unsprayed, *T. triandra* establishment area.

CMASC operations using glyphosate began over the site in 2003.

In addition to comparisons of management of different duration and technique, areas outside NVMS management and outside the fence were compared to all stages within the management area.

Methods

Quadrat layout

Natural vegetation is rarely uniform and almost always patchy in nature. To account for this, quadrats (n = 7) were set up into vegetatively equivalent zones in a method of systematic random sampling (Ambrosio *et al*. 2004). Setting quadrats up in visually homogenous vegetation is an approved method in grassland vegetation sampling and has been used in a number of studies (Morgan 1998a,b, Morgan and Lunt 1999, Morgan 2001)

At Laverton, an area 50 m × 100 m, lacking confounding factors such as wet depressions or rocky rises was chosen to contain seven 1 m × 1 m replicates that were set up for each vegetative equivalent sampling type. These were as follows:

- (B) Dense infestations sprayed and allowed to re-recruit naturally
- (K) Dense infestation sprayed and oversown with *T. triandra*
- (C) Original vegetative areas dominated by *Austrostipa* and *Austrodanthonia* spp.

In addition, an infestation divided by the fence line and therefore management was sampled by placing quadrats 2 m either side of the fence line, and spaced 4 m apart, dictating inside (IF) and outside (OF) NVMS management.

At Melbourne Airport quadrats were set up in an equivalent manner but were at least 2 m from any tree. The vegetative sampling sites were as follows:

- (S1) Stage 1
- (S2) Stage 2
- (S3) Stage 3
- (B) Burned
- (K) Burned, oversown with *T. triandra*
- (U) Unburned, unsprayed
- (O) Outside management area

The systematic random sampling method used can overcome the confounding spatial variability of the vegetation and allows less quadrats to be statistically useful in describing the vegetation zones. This sampling method corresponds with Ambrosio *et al*. (2004) who found that in areas where there is spatial variability, systematic sampling allows smaller sample sizes without loss of precision or confidence level.

Soil cores

Four aspects of soil core sampling were taken into account; timing, relationship of the sample site to the vegetation, surface area covered and depth.

Timing Samples were taken after seed set and before the spring flush of germination. Morgan (1998a) took soil samples for *T. triandra* within this time frame but prior to the *Themeda* germination period in Autumn. Hence, this study will give the best indication of *N. neesiana* seedbank rather than *T. triandra*, as *T. triandra* germination for that year will have already occurred in autumn. Other studies have taken seed samples prior to the fresh seed rain. (Maccherini and De Dominicis 2003) The soil samples will contain old and new seed as in Morgan (1998a), but will give an indication of the changes in the soil seed bank for each of the management treatments at each site.

Relationship to vegetation Soil cores were taken within and outside the management areas so that the seed bank may be analysed with regards to the different management and resulting vegetation structure of the areas. The soil cores have been taken at least 20 cm from a designated corner of each of the vegetation sampling quadrats.

Area The diameter of the soil cores taken was 15 cm. Forcella (1984) showed that for an adequate estimation of the seed bank of pastures, a cumulative area of at least 255 cm^2 must be sampled. Within each sampling set, seven soil cores have been taken. In accordance with Forcella (1984), a more than adequate cumulative sampling area of 1237 cm squared has been taken for each set of quadrats.

Depth The depth of the soil cores was 5 cm. As 99% of *N. neesiana* seeds are likely to be found in the top 25 mm of the soil (Bourdot and Hurrell 1992) this depth is more than sufficient in obtaining an accurate measure of the amount of seeds within the soil core area. Only 3 cm depth has been taken in previous studies of *T. triandra* grasslands (Morgan 1998a). Other studies have taken depths of 5 cm (Rahman *et al*. 2001, Maccherini and De Dominicis 2003).

Analysis of seed

All soil samples were kept in cold storage until they could be analysed. The soil samples were sifted through by adding water to disperse the soil particles and collecting seed found. All *N. neesiana*, *T. triandra*, *Stipa* and *Danthonia* spp. seed was identified. Once *N. neesiana* was collected it was analysed and sorted into four categories:

1. Filled *N. neesiana* where the caryopsis was still contained within the seed and therefore the seed was potentially viable.

2. Non filled *N. neesiana* where seed decay had resulted in the loss of the caryopsis and the seed was no longer viable.
3. Successful germinants, seed that had been germinating at the time of sampling.
4. Unsuccessful germinants, seed that showed evidence of germinating but had since succumbed to mortality.

Results

Laverton

The mean number of seeds found outside the management area was in excess of 2000 seeds per square meter. A one-way ANOVA was performed and plots outside the management area were found to contain significantly greater amounts of seed within the seedbank than all subsets of management within the management area (Table 2).

When the seed was broken down into the four categories it was seen that the seed bank of all areas was comprised of large amounts of unfilled seed and unsuccessful germinants (Figure 2).

A greater amount of unfilled seed was found outside the management area. A non parametric Mann-Whitney test showed that the management subsets, B (P = 0.023), C (P = 0.006) and K (P = 0.008)) contained significantly less unfilled seeds per square metre than the area outside management (OF).

Non parametric Mann-Whitney tests showed that areas outside the fence (OF) had greater amounts of unsuccessful germinants than all areas inside the fence (Figure 3). As the total amount of seeds outside the fence was greater, K independent non parametric tests were performed for each treatment's percentage allocation to each seed category. A non parametric Mann-Whitney test revealed that OF (μ = 8.4%) seedbanks had a significantly greater percentage of the seedbank comprised of filled seed than the managed areas B (μ = 3.2%, P = 0.048) and IF (μ = 0.8%, P = 0.011). The percentage composition of seed samples to each seed category was not significantly different across all other areas.

Non parametric tests showed that areas outside the fence had a greater density of potentially viable (filled) seed in comparison to managed areas (Table 3). There was no difference between the different subsets of management.

Non parametric Mann-Whitney Tests showed that OF had significantly more successful germinants within the soil seedbank at the time of sampling in comparison to kangaroo grass sown areas (K), inside the fence infestation (IF) and *Stipa/Danthonia* dominated areas (C) (Table 4).

Melbourne Airport

Melbourne airport sites contained more seeds per square metre than Laverton sites, the highest being in excess of 7000 seeds. A one-way ANOVA was performed and unburnt, unsprayed swards (U) were found to have significantly less total seeds per square metre than S1 (P = 0.023), S3 (P = 0.03), B (0.009) and K (0.011) (Table 5).

Table 2. One way ANOVA, data is positively skewed though subsets were homogenous and a Kolmogorov-Smirnov test indicated normal data.

	ANOVA				
	Total *N. neesiana* seeds per m²				
	Sum of Squares	df	Mean Square	F	Significance
Between groups	19931013	5	3986202.553	7.533	.000
Within groups	17990860	34	529142.936		
Total	37921873	39			

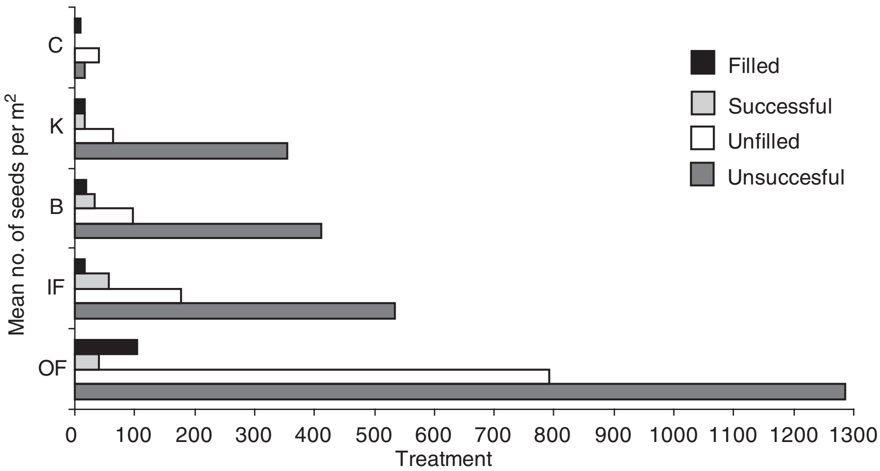

Figure 2. Composition of *N. neesiana* soil stored seedbanks at Laverton.

No filled seed was found in S2, U, B or K. Non parametric tests showed that significantly more filled seed was found in unburnt, dry sward (O) (μ = 235.8) outside the management area in comparison to the remaining management areas S1 (μ = 24.3, P = 0.049) and S3 (μ = 24.3, P = 0.049).

A one way ANOVA found that there was a significant difference (P = 0.024) between the unsuccessful germinants contained within the soil seedbank of S3 (μ = 2473.8) in comparison to S2 (μ = 986.3).

Data for successful germinants was transformed using the square root transformation X′ = √(X + 0.5). Mann-Whitney analysis of the data found that the later stages of management (S3) and (K) had significantly more successful germinants than other areas (Table 6).

Burned areas (B, K) and managed areas (S1, S2, S3) and dry *N. neesiana* swards had significantly more unfilled seed than unburned areas. B, K and S3 also had significantly more unfilled seed than S2 (Table 7).

As the total amount of seeds within each area varied, each treatment's percentage allocation to each seed category was statistically analysed. A one way ANOVA (P = 0.000) and a Tukey breakdown found that burned area, B and unburnt unsprayed swards, U had a greater percentage of the seed bank comprised of unfilled seed than S1, S2 and S3. A Shapiro-Wilk test indicated normal data though it was slightly skewed.

A one-way ANOVA (P = 0.000) and a Tukey breakdown found that B and U had a significantly reduced percentage of unsuccessful germinants comprising the seedbank in comparison to S1, S2, S3

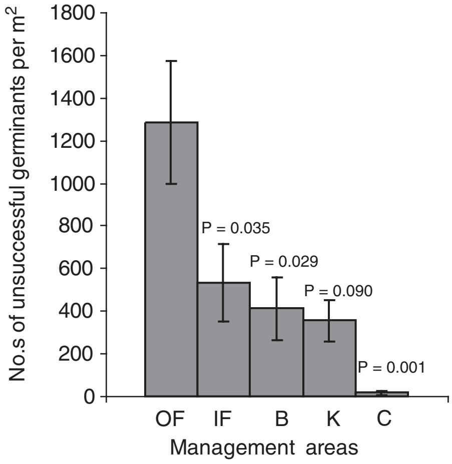

Figure 3. Mean number of unsuccessful germinants in the soil stored seed bank at Laverton. Standard error and P-values for non parametric tests displayed.

Table 3. Non Parametric Mann-Whitney Test results for filled seed.

Management area	Mean rank	OF Mean rank	ASymp. Sig (2-tailed)
IF	4.93	10.07	0.014
B	4.93	10.07	0.014
K	4.93	10.07	0.015
C	4.71	10.29	0.007

Table 4. Non Parametric Mann-Whitney Test results for successful germinants.

Management area	Mean rank	OF Mean rank	ASymp. Sig (2-tailed)
IF	4.86	10.14	0.013
B	7.86	7.14	0.705
K	4.86	10.14	0.011
C	4.21	10.79	0.002

Table 5. One way ANOVA comparing management subsets within Melbourne Airport. Data is skewed, though subsets were homogenous and a Shapiro-Wilk test indicated normality.

	ANOVA Total *N. neesiana* seeds per m^2				
	Sum of Squares	df	Mean Square	F	Significance
Between groups	1.89E+08	6	31512321.07	4.819	.001
Within groups	2.55E+08	39	6539817.344		
Total	4.44E+08	45			

Table 6. Mann-Whitney Tests on transformed successful *N. neesiana* germinants at Melbourne Airport.

Management area	Mean rank	S3 Mean rank	ASymp. Sig (2-tailed)
U	2.63	7.93	0.001
K	4.57	10.43	0.008
B	4.00	11.00	0.001
S2	4.00	11.00	0.001
O	3.50	10.00	0.002
		K Mean rank	
B	5.50	9.50	0.025
S2	5.50	9.50	0.025
O	5.00	8.71	0.036

Table 7. Mann-Whitney Tests on transformed non-filled *N. neesiana* seed at Melbourne Airport.

Management area	Mean Rank	U Mean Rank	ASymp. Sig (2-tailed)
S1	8.00	2.50	0.008
S2	7.71	3.00	0.023
S3	8.00	2.50	0.008
K	8.00	2.50	0.008
B	8.00	2.50	0.008
		S2 Mean rank	
B	10.29	4.71	0.013
K	11.00	4.00	0.002
S3	11.00	4.00	0.002

and O. A Kolmogorov-Smirnov test indicated normal data though it was slightly skewed.

Non parametric tests indicated that outside the management area O ($\mu = 3.1\%$), a greater percentage of the seedbank was comprised of filled seed than K, B and S2, which contained no filled seed ($P = 0.48$)

Discussion

The sampling design of the project has been limited by its retrospective nature, and therefore the data extracted can only be used as an indication of trends rather than as powerful statistical evidence. Not surprisingly the weakness of the project has also been its strength as there are very few conservation sites under long term management that have been assessed as to their value in controlling *N. neesiana*. Unfortunately, as there was no initial assessment, an accurate representation of the initial infestations is not available. It is possible that the infestations were always larger outside the fence than inside the fence and may have dictated its position; however, it is also a key point that the management has enabled the area to resist of dense swards intruding beyond the fence line.

The soil stored seed sampled has not included an assessment of cleistogenic seeds which have been found to contribute 21.5% to 26.1% of the annual total seed production in NSW tablelands (Gardener *et al*. 2003a) and initiating germination in 46.9% and 29.1% of emergent seedlings in the field and glasshouse respectively (Gardener 1998). The aerial seeds investigated may show a general trend of seed persistence and production of both seed types, or cleistogenes may follow a pattern independent of this.

Laverton

The quantity of seed per square metre was highest in areas outside the management zone indicating that this area contained the greatest and most productive infestations of *N. neesiana*. When broken down into four categories, it was found that a large percentage of seed from all seedbanks was comprised of significant amounts unfilled seed and unsuccessful germinants compared to potentially viable seed or successful germinants. This suggests that the seedbank may be more transitory than persistent. Grassy ecosystems across the world tend to follow this transient seed bank strategy where the dominant grass vegetation is not well represented in the seed bank and relies heavily on vegetative persistence. This strategy has been found in semi arid, *Stipa tenacissima* dominated grasslands in the Mediterranean Basin, SE Spain (Gasque and Garcia-Fayos 2003), in the dominant grass species of Argentinean mountain grasslands (Funes *et al*. 2001), in European grasslands (Maccherini and

De Dominicis 2003) as well as in *T. triandra* dominated south-eastern Australian grasslands (Morgan 1998a, 2001).

The percentage allocation to the four seed categories was unchanged over all areas with exception of plots outside the management area which contained a greater percentage of filled seed than herbicide-only treated areas. This indicates that all other significant differences found between quantities of seed from the four categories were a result of reduced seed input rather than changed seed input properties. The significant result indicates that herbicide treated areas may have impacted upon the input of potentially viable seed or increased recruitment from these seed banks which have then subsequently succumbed to herbicide induced mortality leaving behind the seed husks.

Effectiveness of *T. triandra* Areas that were oversown with *T .triandra* were not more effective in reducing the seedbank quantity or composition than herbicide treated areas. The results suggest that *T. triandra* may not be an effective competitive replacement species for *N. neesiana*, as it is for *N. trichotoma.* This may be because the growing times for both *Nassella* species differ and a different native grass species may be useful in providing the niche overlap required for successful competitive replacement. As the biodiverse *Austrostipa* and *Austrodanthonia* dominated areas appeared the most resistant to infiltration of the seed, it may be that the use of these plants as a competitive replacement under various management regimes should be investigated.

As the results from the above ground vegetative sampling are analysed a clearer picture of these species as competitive replacement may be obtained, however, as *T. triandra* areas were treated more intensely with herbicide, it must be considered that these plants would have suffered a greater induced mortality than *N. neesiana* free areas.

Melbourne Airport

The maximum amount of soil stored *N. neesiana* seed found at Melbourne Airport was considerably more than any samples from Laverton, suggesting that the infestation was considerably greater over space and time at this site. Such a finding allows this site to sit comfortably on the scale shown in Figure 1.

In contrast to Laverton, it was found that the unmanaged moist sward contained significantly less seeds per metre squared than some managed areas. The above ground vegetation of this area was not representative of this seedbank, as the vegetation was entirely *N. neesiana.* A number of studies have found that the species composition of the seed bank does not necessarily dictate the composition of above-ground weed flora (Forcella 1992, Kremer 1993, Chikoye and Ekeleme 1999, Funes *et al.* 2001, Maccherini and De Dominicis 2003) and findings such as the unmanaged dry sward containing more filled seed than any other area, suggests that it is possible that the vegetation structure may also influence seed production.

S3 contained more unsuccessful germinants than S2 and had been under management longer, however, this is likely to be a symptom of the use of flupropoante less than 12 months prior to sampling. Flupropoante persists in the soil and continues to act upon germinants for approximately 18 months. This finding conflicts with the results that S3 contained more successful germinants in the seed bank than other areas, and it is possible that these germinants were successful at germinating at time of sampling, and had not yet been impacted upon by the residual herbicide. The kangaroo grass sown area also had more successful germinants than a number of other areas including B, which was also burnt but not subjected to oversow or herbicide. It is possible that the baring of the ground encouraged more seeds from dormancy to recruitment in a similar pattern to that found by Gardener *et al.*(2003b) where bared areas showed faster seedbank decline than those that were vegetated.

Seed category results based on quantity of seed may be slightly biased in that it does not reflect percentage allocation of these categories within the soil seed bank. The unburned unsprayed area and the burned area had a greater percentage of the seedbank comprised of unfilled and unsuccessful germinating seed than other areas of management. Two factors may be at play; greater recruitment from the seedbank occurring following the burn and/or changed seed production strategies in these vegetation structures. Outside the management area, the seedbank had the highest percentage allocation of potentially viable seed also indicating a potentially different seed production or seed persistence of plants not being managed.

Conclusion

The seed bank of *N. neesiana*, though it can reach large quantities of seed per metre squared, may not be as persistent as previously thought. Ongoing, consistent and selective herbicide treatment has great potential to reduce the soil stored seed bank to low levels. This type of management may also impact upon seed production or persistence and alter the percentage of the seedbank that is comprised of potentially viable seeds.

There is an urgent need to determine the types of management and vegetation contexts that translate into low recruitment rates and high levels of non-viable and deteriorated seed. If this type of management recipe using native grass establishment, selective spraying and project assessment via the seedbank can be developed further, and include varying grades of ingredients such as burning and grazing, intimidating weeds such as *N. neesiana* can become conquerable.

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