Chapter 3. Historically quantified infestations revisited

"*Stipa neesiana* is a serious threat to remnant stands of native grassland, including the Laverton North Grassland Reserve ... invasion has now occurred over a wide area ... several large patches are extremely dense and spreading ... It is a particular concern ... that the spread ... will destroy research plots containing threatened plants. Expansion of the presently invaded areas will significantly degrade the conservation value of the Reserve ..."

M.J. Bartley, R.F. Parsons and N.H. Scarlett of the Botany Department, La Trobe University, in a letter to the Victorian Department of Conservation and Environment, 7 May 1990.

Summary

This chapter compares contemporary data on the cover of *N. neesiana* and the vegetation of small invaded areas at Yarramundi Reach and Laverton North grasslands with data recorded in historical botanical surveys. Contrary to published predictions, the infested areas assessed were found to have not greatly expanded over periods approaching two decades. *Nassella neesiana* cover values were found to have fluctuated markedly over time. Disturbances that destroy native grassland vegetation demonstrably enable *N. neesiana* invasion, but may also destroy *N. neesiana* populations without subsequent reinvasion. *Nassella neesiana* can disappear from areas where it has not achieved high cover, but once it has achieved high cover it can maintain its presence. Major soil disturbance can permanently decimate the native grassland flora and disturbances that kill the native flora appear to be a more important cause of vascular plant diversity loss than active invasion by *N. neesiana* itself.

Introduction

Under the theory of competitive exclusion a more competitive invader can occupy the niche previously occupied by a native species (Woods 1997, Seabloom *et al.* 2003, Cox 2004). *Nassella neesiana* has been characterised as an "aggressive" (McDougall and Morgan 2005 p. 35), very competitive (Cook 1999), highly invasive (Morfe *et al.* 2003) weed and a strong resource competitor (Iaconis 2003) that is rapidly expanding its range (Lunt and Morgan 2000), has the ability to actively invade native grasslands (Hocking 1998, 2007) and potentially outcompete *Themeda triandra* (Ens 2002a). Some weeds can invade in the absence of major prior disturbance, by virtue of their superior competitive abilities (Carr 1993) and *N. neesiana* appears to have sometimes been classed amongst them. However Bourdôt and Hurrell (1989a p. 415) considered its invasiveness in sheep pastures to be due to "adaptations that enable the plant to survive the hazards of semi-arid, low-fertility environments, rather than to high competitive ability". Fears about its high invasiveness in native grassland may be exaggerated and its success in these systems may have more to do with their mismanagement and the level of anthropogenic disturbance to which they are subject, rather than to superior competitive abilities. Intact grasslands on the Victorian basalt plains are highly resistant to weed invasion (Patton 1935) and when not overgrazed, species-rich, high quality grassland is in general less weed-invasible (Beames *et al.* 2005). Morgan (1998d) for example found that exotic plant richness was negatively correlated with native plant richness. Minimisation of disturbance to maintain an intact stratum of native ground vegetation is one of the prime measures needed to prevent exotic weed invasion (Davies 1997). Exotic stipoid grasses in Australia have generally invaded areas with a history of disturbance, in which the native plant communities are already highly degraded (Gardener and Sindel 1998). If superior competitive abilities are driving invasion it could be expected that infestations that are not deliberately controlled should generally expand over time. If invasions are largely disturbance-driven, it could be expected that *N. neesiana* infestations would expand more in areas subject to more intense or frequent anthropogenic disturbance and to have had less success in better managed grasslands.

The aims of this component of the study were to determine whether infestations that were historically quantified by botanical workers have expanded, remained stable or contracted, and the circumstances under which these changes have occurred. Changes that have occurred in the extent of infested areas, their species composition and other characteristics should provide further insight into, and better quantification of, the biodiversity impact of *N. neesiana,* and help to illuminate factors that have influenced its invasion.

Two sets of historical data were found that appeared suitable for reassessment: (1) square metre floristic quadrats assessed for the purposes of long term monitoring of grassland condition and floristic change along permanently marked transects in a number of Australian Capital Territory grasslands (Environment ACT database), and (2) detailed studies of the vegetation at Laverton North Grassland before and after the installation of a below-ground oxygen pipeline, which were intended to guide restoration activities (McMahon *et al*. 1990, Todd 1991, Muir and Carr 1994).

Data on *N. neesiana* and other vegetation from the earlier baseline studies was compared with current data by reassessment of the same areas, using, where possible, the same methods, and the findings are interpreted in terms of effects on vascular plant diversity and the influence of particular management regimes at the grasslands in question.

ACT sites

Permanently marked transects in the ACT were set up by Sarah Sharp of Environment ACT in the early 1990s and were monitored annually by Environment ACT staff from 1993 to

2002. The cover class of all species was recorded in square metre quadrats at set distances along the transects (S. Sharp pers. comm. 8 May 2007). The transects had initially been located in high quality areas, which often had no *N. neesiana* present, so the historical records of *N. neesiana* cover were few. Transects were inspected in grasslands at Crace, Dudley Street and Yarramundi Reach grasslands, but only those in the latter grassland warranted study, there being 25 database records of *N. neesiana* in transect quadrats at the site over the nine years of observations. Reference to original data sheets revealed one further record at this grassland. Cover values for each species present in a quadrat had been recorded in this database to the nearest 5%.

Nassella neesiana appears to have been first recorded in published literature at Yarramundi Reach by Berry and Mulvaney (1995) who noted that it was not one of the major weeds, but was "common along the bicycle path" (Berry and Mulvaney 1995 Vol. 2 Appendices p. 261). However the Environment ACT database records it with high cover along one transect in 1993, when the monitoring first commenced.

Laverton North oxygen pipeline

The Laverton North records were made by Ecological Horticulture Pty Ltd (later renamed Ecology Australia Ltd), a consulting company engaged by the pipeline proponent, Air Liquide Australia Ltd. Permission to construct the below ground pipeline across Crown land at the western end of the Reserve was granted by the Department of Conservation and Environment in October 1990 (Muir and Carr 1994). The pipeline was built to deliver gaseous oxygen from the Air Liquide gas treatment plant on Kororoit Creek Road, immediately to the south of the Reserve, to the Smorgon steel mill to the north of the Reserve and the north of the Princes Highway, and the company was licensed to operate it for 20 years (Craigie 1993). The pipeline was allowed to be laid along the southern edge of the grassland for 125 m then north through the grassland for 280 m, then for 290 m along the Highway within the Reserve (Craigie 1993). The permit required that land affected by construction works be rehabilitated and that areas rehabilitated be maintained for a period of five years. Rehabilitation works were required to include vegetation re-establishment and weed control (Muir and Carr 1994). The location of the pipeline is currently indicated by signage and steel posts set in the ground (Fig. 3.1).

The vegetation of the pipeline zone was surveyed prior to construction (McMahon *et al.* 1990) and twice after construction (Todd 1991, Muir and Carr 1994). McMahon *et al.* (1990) prescribed methods to re-establish *Themeda triandra* in areas denuded by construction, by application of *T. triandra* hay, but the restoration undertaken was largely unsuccessful (Todd 1991, Muir and Carr 1994, personal observations). All three studies estimated cover of vascular plant species, using the Braun-Blanquet scale, in 5 m x 20 m quadrats with their long axes over the pipeline (G. Carr pers. comm. April 2007). The latter two studies reportedly resurveyed the same quadrats as those in the initial study, which were marked with wooden pegs.

Figure 3.1. Location of the north-south section of the oxygen pipeline across the Laverton North Grassland, looking north, 13 April 2007. Recently burnt grassland can be seen in the Reserve to the right.

McDougall (1987 p. 36) recommended that the spread of *N. neesiana* in the reserve "should be monitored", and the plant had a major presence before pipeline construction (McMahon *et al.* 1990). Construction activities reputedly resulted in further invasion (Frances Overmars pers. comm.). Humphries and Webster (1992 p. 2) wrote that "aggressive invasion" at the reserve needed "immediate attention" if the grassland values were to be preserved. Kirkpatrick *et al.* (1995 p. 35) stated that the "rate of spread in the two grassland reserves [Derrimut and Laverton North] ... [had] shocked botanists".

Pipeline construction activity resulted in major disturbance including burial of the surface soil, replacement of surface soil with subsoil, widespread elimination of vegetation leaving only exposed soil, and severe soil compaction where vehicle traffic was heavy (Todd 1991). Lack of soil settling and water logging were also notable along the pipeline trench immediately post-construction (Todd 1991). Cover of weed species doubled, 18 spp. disappeared, 25 previously unrecorded species appeared, and native *Austrodanthonia* and *Austrostipa* grasses were largely eliminated (Todd 1991).

For the purposes of the current study it was hypothesised that destruction of the native plant cover, particularly the dominant native grasses, by pipeline works, the failure of the attempt to revegetate the disturbed zone with *T. triandra*, and the proximity of actively seeding *N.*

neesiana in the immediate vicinity of the disturbed zone should have enabled *N. neesiana* to become dominant in the disturbed areas.

Methods

Australian Capital Territory

Cover data for all quadrats on permanent transects in which *N. neesiana* occurred in any year from 1993 to 2002 at Yarramundi Reach grassland was extracted from the Environment ACT database or paper records. The permanent transects (Table 3.1), marked with steel star pickets with white plastic caps, were located using the hand drawn maps on Environment ACT files and during field inspections with Sarah Sharp. Transects were closely inspected, and if no *N. neesiana* was detected along the whole transect, cover values of zero for *N. neesiana* were recorded for the full length. Inspection on 9 May 2007 found no *N. neesiana* along transects A and C.

If *N. neesiana* was detected in a transect, the vegetation of the whole transect was quantified in detail. The presence and cover along the whole of these transects was assessed on 23 May 2007. A GPS device was used to record the location of each end of the transects (Table 3.1). Projective foliar cover values (the proportion of ground covered by foliage) were estimated using a 1m x 1m steel frame quadrat with 2 crossbars dividing the square metre into quarters, and attached strings at 10 cm intervals further subdividing the area and forming 100 subquadrats each of 0.01 m^2. Cover was estimated to the nearest percent for each vascular species and for bare ground and litter. All species detected were recorded; those with less than 1% cover were recorded as present. Square metre quadrats were assessed progressively along each transect, and numbered successively from 1 to 30 from the start to the end of the transect. Time series data was graphed.

Table 3.1. Locations of permanent transects at Yarramundi Reach re-assessed for *N. neesiana* cover on 23 May 2007.

Transect	**Location**	
	start	**finish**
A	35°17.269’ 149°05.110’	35°17.284’ 149°05.096’
B	35°17.535’ 149°04.956’	35°17.540’ 149°04.974’
C	35°17.416’ 149°04.947’	35°17.421’ 149°04.958’
D	35°17.441’ 149°04.933’	35°17.454’ 149°04.918’

Reassessment of Laverton North 1990s 10 m x 5 m quadrats, April 2007

An attempt was made to re-examine the quadrats surveyed in the previous studies. However identification of their locations using the latitude/longitude data provided by McMahon *et al.* (1990) proved to be impossible. The most likely explanation appears to be the poor quality of GPS position data available at that time (Geoff Carr pers. comm. 2007). Fortunately

McMahon *et al.* (1990) also mapped the locations of their quadrats in relation to the pipeline, enabling them to be approximately relocated using scaling techniques, although with some uncertainty due to the loss of ground marker pegs over the years (Figure 3.2).

The positions of the re-located quadrats was recorded with a GPS device and by ground measurements and the quadrats, each of 100 m^2, were botanically assessed from 22 to 30 April 2007 using a 1 m x 1m steel frame subdivided at 0.5 m into four equal areas (Table 3.2).

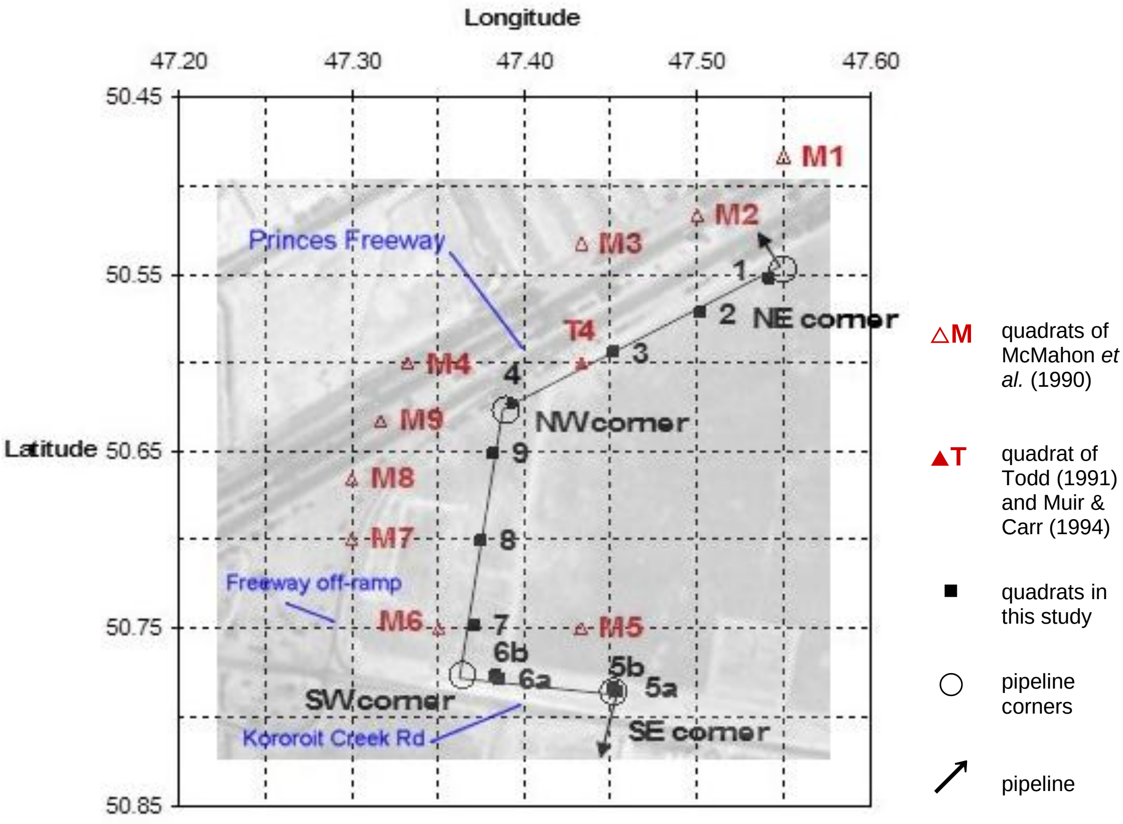

Figure 3.2. Location of the oxygen pipeline at Laverton North in relation to the quadrats applied in this study, the nine quadrats of McMahon *et al.* (1990) and the supposedly co-located quadrat 4 of Todd (1991) and Muir and Carr (1994) (M4 supposedly collocated with T4), based on their cited latitudes and longitudes.

Table 3.2. Location and date of assessment of quadrats at Laverton North Grassland in the April 2007 study.

Quadrat	Pipeline	Lat Long (of point or quadrat centre)	Quadrat location (centre of quadrat)	Assessment date
-	NE corner	37° 50.548’S 144° 47.550’E	-	-
1	N	37° 50.553’S 144° 47.542’E	12.1 m SW of NE corner	27April 2007
2	N	37° 50.572’S 144° 47.502’E	82.4 m SW of NE corner 192.8 m NE of NW corner	27 April 2007
3	N	37° 50.595’S 144° 47.452’E	107.2 m NE of NW corner	27 April 2007
-	NW corner	37° 50.627’S 144° 47.390’E	-	-
4	NW corner	37° 50.624’S 144° 47.394’E	8.9 m NE of NW corner	26 April 2007
-	SE corner	37° 50.786’S 144° 47.452’E	-	-
5a	S	37° 50.786’S 144° 47.454’E	4.9 m W of SE corner, 0- 5 m N of fenceline	22 April 2007
5b	S	37° 50.784’S 144° 47.452’E	4.9 m W of SE corner, 5-10 m N of fenceline	30 April 2007
6a	S	37° 50.779’S 144° 47.386’E	28.1 m E of SW corner, 0-5 m N of fenceline	22 April 2007
6b	S	37° 50.777’S 144° 47.384’E	28.1 m E of SW corner, 5-10 m N of fenceline	30 April 2007
-	SW corner	37° 50.777’S 144° 47.365’E	-	-
7	W	37° 50.748’S 144° 47.372’E	55.1 m N of SW corner	24 April 2007
8	W	37° 50.701’S 144° 47.376’E	146.6 m N of SW corner	26 April 2007
9	W	37° 50.652’S 144° 47.383’E	225.5 m N of SW corner 58.6 m S of NW corner	26 April 2007

Laverton North zone study, January 2008.

Doubts about whether the quadrats assessed corresponded closely enough with the quadrats that had earlier been studied by McMahon et al. (1990), Todd (1991) and Muir and Carr (1994) led to a new examination in January 2008. Five quadrats of 5 m x 2 m were surveyed in each of three parallel zones, running north-south across the site (Table 3.3):

1. grassland within the Reserve, managed by fire and burnt on 6 April 2007 (Fig. 3.3);

2. the pipeline zone (Fig. 3.4); and

3. rank, unmanaged grassland to the west of the pipeline (Figure 3.5).

The ‘reserve’ zone was c. 19 m east of the pipeline, and the ‘unmanaged’ zone was c. 10 m west of the pipeline. A strip of mown grassland to the west of a low fence occupied some of the area between the pipeline and reserve zones. A wide buffer was allowed at the end of each zone to minimise edge effects and ensure that the reserve zone did not include areas of disturbance associated with the pipeline and that the other zones did not include areas that appeared to be subject to regular mowing. Quadrats were randomly located along north-south transects through each zone, with their long axes aligned along the transect.

The position of the north-west corner of each quadrat was recorded with a GPS device, along with its measured distance from the southern boundary fence (Table 3.3). The projective foliar cover of *N. neesiana* and other species was estimated in each quadrat using a 1 m x 1 m steel frame subdivided at 0.5 m into four equal areas. The number of tussocks of *N. neesiana* in each quadrat was counted and the size of each tussock was determined within categories of small (<5 cm diameter tussock), medium (5-10 cm diameter) and large (>10 cm diameter), but this data is not reported here. Quadrats in the 'Reserve' zone were assessed on 26 January, in the 'Unmanaged' zone on 27 January and in the 'Pipeline' zone on 30 January.

Cover values for the species detected were grouped into categories for analysis based on Walsh and Stajsic (2007): native perennial grasses, exotic perennial grasses, annual grasses, native forbs and exotic forbs.

Table 3.3. Location and date of assessment of quadrats in the January 2008 zone survey at Laverton North. A GPS reading was taken for the north-west corner of each quadrat, which was a measured distance north of the south fenceline (along Kororoit Creek Road).

Zone	**Quadrat**	**Latitude**	**Longitude**	**m N of S fence**
Reserve	1	37° 50.746'	144° 47.383'	65
Reserve	2	37° 50.706'	144° 47.393'	140
Reserve	3	37° 50.664'	144° 47.403'	220
Reserve	4	37° 50.644'	144° 47.406'	255
Reserve	5	37° 50.631'	144° 47.409'	280
Unmanaged	1	37° 50.721'	144° 47.362'	106
Unmanaged	2	37° 50.677'	144° 47.372'	191
Unmanaged	3	37° 50.662'	144° 47.375'	216
Unmanaged	4	37° 50.652'	144° 47.378'	236
Unmanaged	5	37° 50.642'	144° 47.379'	256
Pipeline	1	37° 50.725'	144° 47.371'	89
Pipeline	2	37°50.720'	144° 47.372'	104
Pipeline	3	37° 50.695'	144°47.377'	154
Pipeline	4	37° 50.689'	144° 47.378'	164
Pipeline	5	37° 50.681'	144° 47.379'	179

Figure 3.3. The ‘reserve’ zone at the western end of Laverton North Grassland Reserve, 28 January 2008, looking north.

Figure 3.4. The ‘unmanaged’ zone on private land immediately west of the Laverton North Grassland Reserve, 28 January 2008, looking north.

Figure 3.5. The ‘pipeline’ zone, immediately west of Laverton North Grassland Reserve, 28 January 2008, looking north.

Statistical analysis

Statistical analysis was not applied to the small Yarramundi Reach data set or to the replicate quadrat study at Laverton North. The mean cover of different species or groups of species from the January 2008 Laverton North zone survey was analysed as a five replicate one way analysis of variance, after angular transformation, with a single quadrat as the unit of analysis. Preliminary analysis indicated that the largest differences were between the pipeline zone and the other two zones; thus the treatment effects were divided into two orthogonal contrasts, namely: (i) the pipeline area *vs* the other two areas and (ii) the reserve *vs* the unmanaged area. The mean numbers of native, exotic and all species were analysed similarly, except using a square root transformation. Due to the low cover of native forbs and consequent discreteness of the data, a permutation variance ratio test was used to test the difference between zones for native forbs. In this test the P value for the F value is compared to the permutation distribution of the data values, rather than to F tables based on the normal distribution.

Results

ACT transect quadrats

Cover of *N. neesiana* consistently maintained high values in only a single quadrat, on transect D (Table 3.4, Fig. 3.6). In every other quadrat cover was not observed to exceed 30% over the period. The grass appeared, achieved minor cover, and then more or less disappeared in five of eight quadrats in which it was recorded. *Nassella neesiana* cover fluctuated markedly over the period but there was no evidence that it achieved and maintained overwhelming dominance apart from this one quadrat.

The assessment of the whole of transect B in 2007 showed that cover of *N. neesiana* did not exceed 20% in any quadrat along the entire length of the transect (Fig. 3.7), although the grass had first been recorded in the transect in December 2000 (Table 3.4). It occurred in two quadrats in 2003 from which it was absent in 2007, although this section of the transect was found to be occupied in 2007 by *Austrostipa bigeniculata*, for which it might have previously been mistaken.

In 2007 transect D was dominated by *N. neesiana* at one end but by *T. triandra* and some *Poa labillardierei* at the other (Fig. 3.8). The historical ACT data (Table 3.4) indicate that there had been reasonably high cover of *N. neesiana* in 1993 in quadrat 8 (Environment ACT quadrat D2), but that the grass then disappeared for 9 years. It was detected again at high cover at this point in 2007. The profile of cover along this transect (Fig. 3.8) indicates that quadrat 8 was at that time about 3-4 m from the high-cover fringe of an expanding *N. neesiana* infestation and approximately 6-7 m from its outer edge, so the earlier data suggest that from zero cover in 2002 the infestation had expanded at the rate of approximately 1.3 m y^{-1}.

Table 3.4. Percent foliar cover of *N. neesiana* in quadrats along permanent transects at Yarramundi Reach. Columns 1 and 2 give the quadrat code numbers used by Environment ACT and columns 3 and 4 the corresponding numbers used in this study. Environment ACT cover values are to the nearest 5%.

Envt ACT		**This study**		**Environment ACT data**										**This study**
				1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2007**
Transect	**Quadrat**	**Transect**	**Quadrat**	**6/12/93**	**15/12/94**	**28/12/95**	**9/12/96**	**3/12/97**	**1/12/98**	**30/12/19**	**13/12/00**	**13/12/01**	**18/12/02**	**23/05/07**
A	**3**	**A**	**13**	0	0	0	0	0	5	0	5	5	0	0
B	**2**	**B**	**8**	0	0	0	0	0	0	0	0	0	5	0
B	**3**	**B**	**13**	0	0	0	0	0	0	0	5	0	5	0
C	**1**	**C**	**3**	0	0	0	0	15	0	0	0	0	0	0
C	**3**	**C**	**13**	0	5	5	5	5	0	0	0	0	0	0
C	**5**	**C**	**23**	0	25	15	5	0	0	0	0	5	0	0
D	**1**	**D**	**3**	85	55	75	85	95	65	65	45	35	55	55
D	**2**	**D**	**8**	30	0	0	0	0	0	0	0	0	0	63

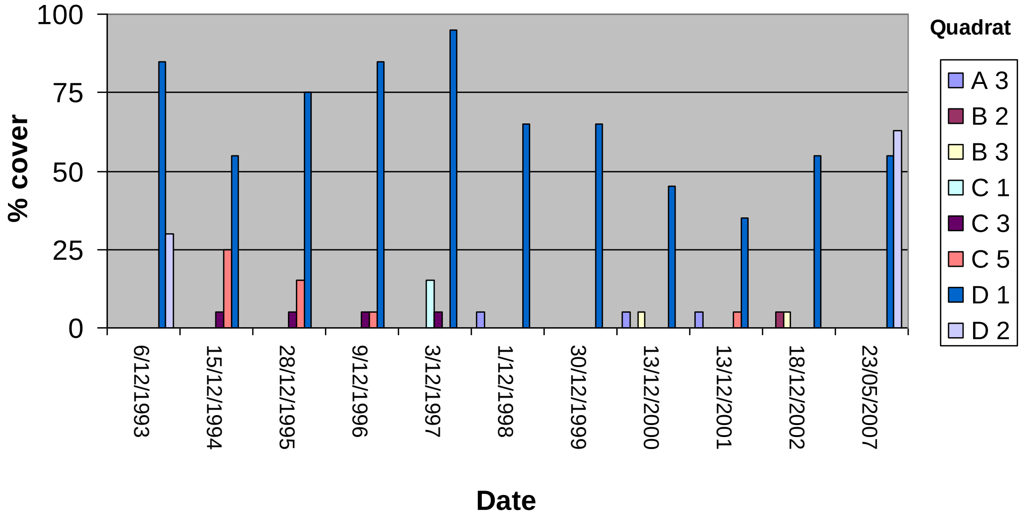

Figure 3.6. Variation in the cover of *N. neesiana* in quadrats along permanent transects at Yarramundi Reach grassland, 1993-2007. Note that cover values were not recorded during the years 2003-2006.

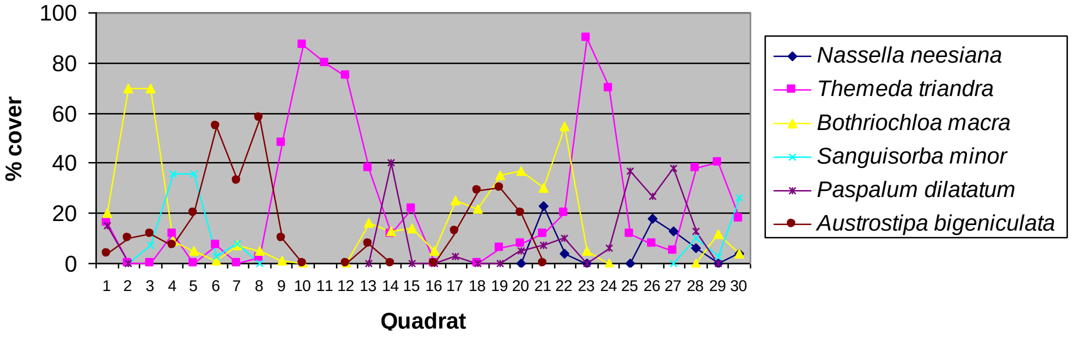

Figure 3.7. Percent foliar cover of major species contributing to ground cover along transect B, Yarramundi Reach grassland, 23 May 2007.

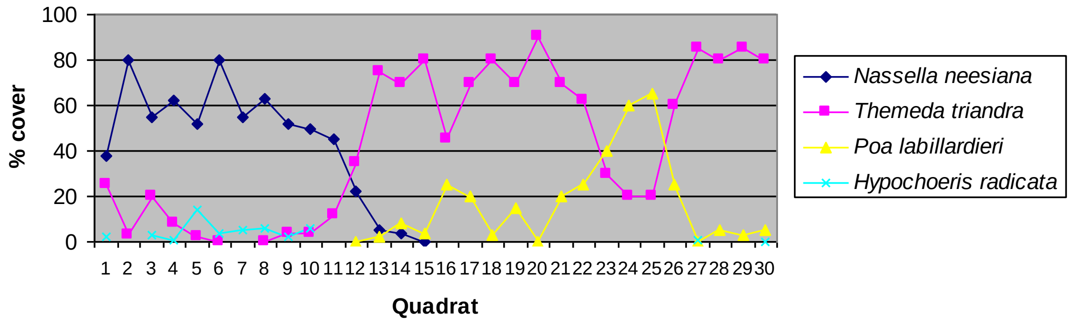

Figure 3.8. Percent foliar cover of major species contributing to ground cover along transect D, Yarramundi Reach grassland, 23 May 2007.

Figure 3.9 (Next page). Sequential cover/abundance ratings of major species and bare ground in quadrats along the oxygen pipeline at Laverton North grassland, 1990 (McMahon *et al.* 1990), 1991 (Todd 1991), 1994 (Muir and Carr 1994) and 2007 (this study).

Cover classes: 0.1 = <5% cover, few individuals; 1 = cover <5%, any number of individuals; 2 = cover 5-20%, any number of individuals; 3 = cover 20-50%, any number of individuals; 4 = cover 50-75%, any number of individuals; 5 = cover 75-100%, any number of individuals.

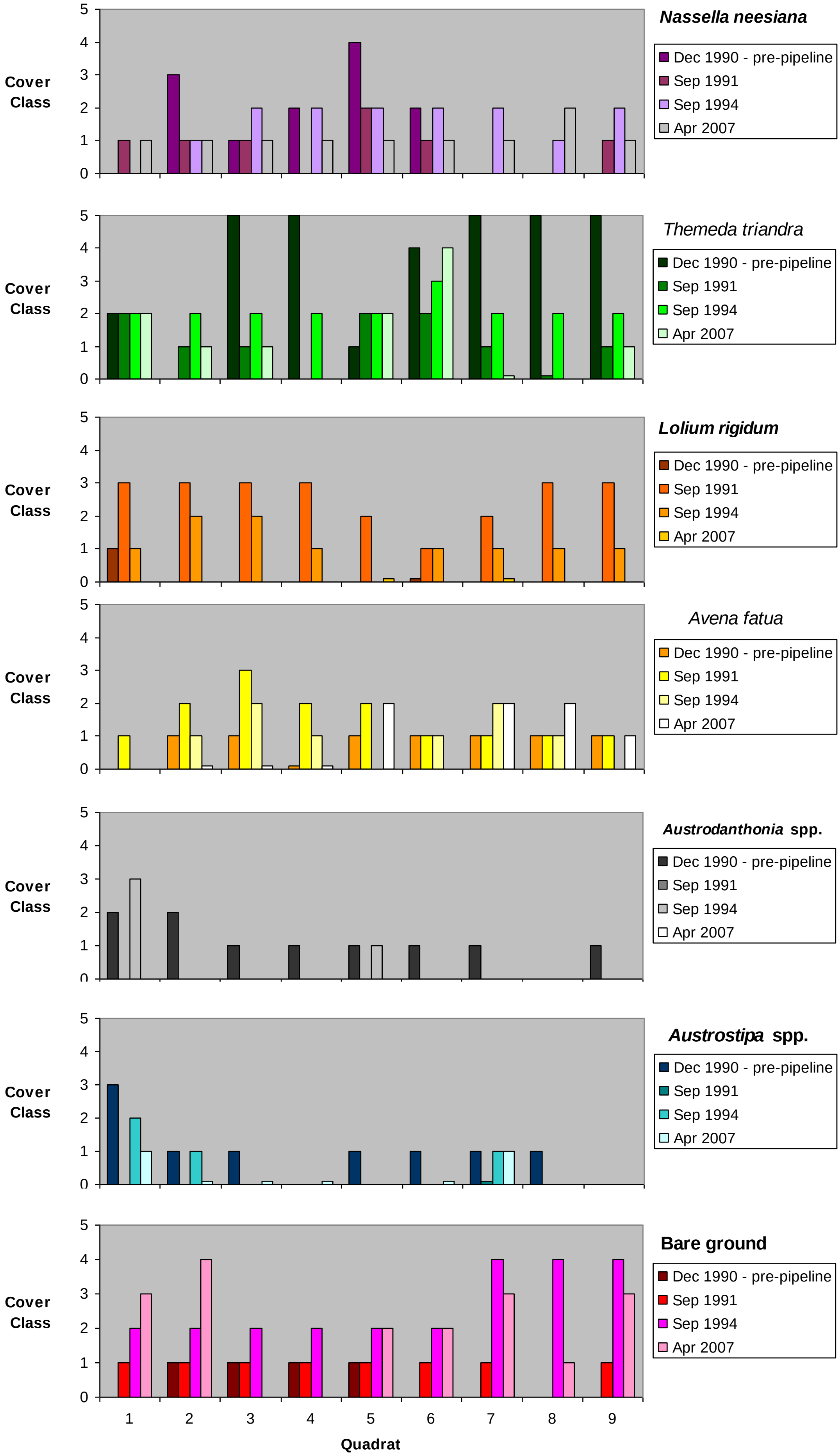

Figure 3.9 (caption on previous page).

Laverton North pipeline quadrats

In 1990, prior to construction of the pipeline, the cover of *T. triandra* exceeded 75% in five of nine 5 x 20 m quadrats assessed by McMahon *et al.* (1990), and one additional quadrat had cover of 50-75% (Fig. 3.9). Three of the quadrats with >75% *T. triandra* cover in 1990 contained no *N. neesiana* at that time (quadrats 7, 8 and 9, Fig. 3.9). Cover of *T. triandra* in these three quadrats plummeted after pipeline construction but substantial bare ground did not result in the following year. In quadrat 9, *N. neesiana* achieved measurable cover (<5%) in 1991, although the main response was from *Lolium rigidum*. In 1994 *N. neesiana* increased its cover in this quadrat to 5-20%, *L. rigidum* cover fell and 50-75% of the area was bare ground. Plant cover in quadrats 7 and 8 showed a similar response, with an initial increase of *L. rigidum*, followed by substantial bare ground and increased cover of *N. neesiana* in 1994 from undetectable levels in 1991.

Before pipeline construction the other two quadrats with >75% *T. triandra* cover (quadrats 3 and 4) had *N. neesiana* cover of <20% (Fig. 3.9). After pipeline construction there was a marked response from the disturbance-driven annual grasses *Lolium rigidum* and *Avena fatua*, which both increased their cover, while *N. neesiana* cover remained more or less stable in quadrat 3 and dropped to an undetectable level in quadrat 4. By 1994 *N. neesiana* had increased in both these quadrats while some *T. triandra* cover (5-20%) had been maintained. By 2007 *N. neesiana* had maintained its presence in these quadrats, but had not achieved high cover, and *T. triandra* had disappeared from one quadrat and retained cover only in a small area in the other.

Quadrat 6 had *T. triandra* cover of 50-75% before the pipeline work and maintained it a relatively stable level (5-75%) over the whole period (Fig. 3.9), despite the initial presence of *N. neesiana* in 1990. *N. neesiana* had maintained its presence in this quadrat by 2007.

N. neesiana cover actually fell after pipeline construction in the two quadrats (quadrats 2 and 5) in which its cover was greatest (>20%) prior to construction, and remained lower than initial values for the whole period.

Quadrat 1 had mixed native cover of *T. triandra* and *Austrodanthonia* and *Austrostipa* spp. before the pipeline works, and no *N. neesiana*. Minor *N. neesiana* invasion occurred in the following year, but the grass never achieved high cover.

Deliberate *T. triandra* revegetation efforts were largely a failure. *T. triandra* did not regain high cover in any quadrat. There was also little or no recovery of the subdominant *Austrodanthonia* and *Austrostipa* species.

Laverton North zone study

In January 2008, native perennial grasses covered approximately one third of the ground in quadrats located in the reserve and unmanaged zones, but constituted a very minor proportion of total vascular plant cover in the pipeline zone, with the difference being highly significant (Table 3.5). The almost complete absence of *Themeda triandra* in the pipeline zone was the main contributing factor. That zone had significantly greater mean coverage of exotic annual grasses (23%), mainly consisting of *Avena* spp., significantly greater mean cover of litter (mainly derived from the exotic grasses), and significantly less mean cover of native forbs (Table 3.5). It also had close to a significantly higher proportion of bare ground ($p = 0.053$).

Mean *N. neesiana* cover in the pipeline zone was double that in the unmanaged zone, which in turn was more than three times that in the reserve zone, however due to very high variance between quadrats there was no significant difference in its cover between any of the zones. And although the reserve zone appeared to have reduced cover of exotic perennial grasses as a category, this too was not significant.

The mean number of native species per quadrat and the mean total number of species per quadrat in the pipeline zone was significantly less than in the other two zones (Table 3.6).

Discussion

Yarramundi Reach

The limited data from Yarramundi Reach suggest that *N. neesiana* does not necessarily come to dominate small areas where it occurs (that is, it may not be an aggressive invader), that its cover at the square metre scale can shift markedly from year to year and that it can disappear from areas in which it may initially establish and form low cover, possibly due to competition from and the development of very high cover by *T. triandra*. Evidence from one quadrat indicates that an *N. neesiana* invasion front can expand at a rate of 1.3 m y^{-1}.

However variation in the overall density of grass growth from year to year may greatly affect cover values at this scale (square metre quadrats), and significant cover of grasses of the size of *N. neesiana* may be recorded without any *N. neesiana* plants having a rooted presence in a quadrat, but instead may be over-hanging from an adjacent quadrat in some years. Climatic variations in the productivity of *N. neesiana* and other species present in the area may explain much of the variation. It is likely that the apparent coming and going of the grass is not real and is due in part to the difficulty of accurately relocating unmarked square metre areas from year to year along extended transects on uneven ground. Mistakes in the data collection may have led to different areas being assessed from year to year.

Table 3.5. Mean projective foliar cover of plant species and categories, litter cover and proportion of bare ground (%) in five 10 m^2 quadrats in each of three management zones (Reserve, Unmanaged, Pipeline) at Laverton North, January 2008. Significant P values in bold.

Cover (%)	**sed**	**Back transformed**			**P-Values**	
		Reserve	**Unmanaged**	**Pipeline**	**Pipeline vs Other**	**Reserve vs Unmanaged**
Native perennial grasses	4.8	31	33	4	**0.00011**	0.77
Themeda triandra	3.9	29	25	0	**8.1 x 10^{-7}**	0.47
Exotic perennial grasses	4.1	15	25	25	0.38	0.10
Nassella neesiana	8.2	2	7	14	0.17	0.32
Phalaris aquatica	6.7	7	19	8	0.51	0.15
Exotic annual grasses	4.5	4	6	23	**0.0025**	0.58
Avena spp.	4.5	0	6	23	**0.00030**	**0.034**
Native forbs	3.6	1	4	0	**0.042***	0.15*
Exotic forbs	5.0	10	10	15	0.36	0.93
Litter	1.8	9	13	30	**1.3 x 10^{-6}**	**0.049**
Bare ground	2.8	45	37	32	0.053	0.12

* using permutation variance ratio test

Table 3.6. Mean numbers of native, exotic and total vascular plant species per 10 m^2 in three management zones at Laverton North, January 2008.

Number of species	**sed**	**Back transformed**			**P-Values**	
		Reserve	**Unmanaged**	**Pipeline**	**Pipeline vs Other**	**Reserve vs Unmanaged**
Native	0.22	4.9	6.1	2.5	**0.0019**	0.24
Exotic	0.23	9.6	8.5	6.9	0.087	0.43
Total	0.26	14.6	14.7	9.5	**0.0073**	0.96

Identification failures or misidentifications may have contributed. One conclusion that can be reached is that the sampling of a few small quadrats along a 30 metre transect does not provide much insight into the interannual variation in *N. neesiana* dominance or changes in the area of an infestation.

Laverton North

Nassella neesiana invasion along the oxygen pipeline at Laverton North has been anecdotally attributed to the destruction of native plants resulting from pipeline construction. The data demonstrates that invasion did occur in some disturbed areas along the pipeline, even over a long time frame. Areas along the north-south section of the pipeline (quadrats 7-9) that had previously lacked *N. neesiana* were subject to major destruction of *T. triandra* and developed increased cover of annual grasses the following year, with *N. neesiana* invasion in one quadrat. By 1994 all three of these quadrats had high levels of bare ground and all had been occupied to some extent by *N. neesiana*. By 2007 *N. neesiana* had maintained its presence in these quadrats but had not achieved high cover and there were still substantial areas of bare ground.

Some areas lost *N. neesiana* cover as a result of pipeline works and did not recover it. Exotic annual grasses increased their cover in these areas, or the ground remained bare (at least at the time of assessment). In other areas (quadrats 3 and 4 along the Princes Highway) *N. neesiana* was already present in areas of very high *T. triandra* cover prior to pipeline construction. Invasion accompanying high *T. triandra* cover is indicative of probable senescence dieback of *T. triandra* as the cause of invasion. Failure to find any significant difference in the cover of *N. neesiana* between the pipeline zone and the other zones adds some weight to this impression.

The zone study demonstrates that pipeline construction resulted in devastation of native species, including *T. triandra*, subdominant native grasses and native forbs, and that no recovery had occurred by 2008, 18 years later, despite active attempts to re-establish *T. triandra* and other natives. Areas of bared ground created by disturbances such as pipeline construction would be expected to be colonised by other species. Chan (1980 p. 10) noted that *T. triandra* “can and does invade and dominate almost any ground that is cleared and protected from grazing”. However the studies of Morgan (2001 p. 908) in basalt plain grasslands found that recruitment of most native species was always very rare or completely absent, “despite their abundance in the standing flora”. A near-complete failure of native species to re-establish is clearly apparent in the pipeline zone, which by 2008 was still dominated by exotic annual grasses, mainly *Avena* spp., had zero recolonisation by the dominant native grass *T. triandra* and an almost complete absence of native forbs. Despite attempted amelioration, pipeline construction transformed the affected land into a new metastable vegetation state, which natural processes seem powerless to shift.

Role of *Themeda triandra* senescence in the invasion

Senescence dieback of *T. triandra* is preceded by high foliar cover of *T. triandra* (Morgan and Lunt 1999) and values of 75-100% of *T. triandra* cover were recorded by McMahon *et al.* (1990) prior to pipeline construction in some areas where *N. neesiana* had already invaded. Similar high cover of *T. triandra* persisted at the grassland for some years – for example, Craigie (1993 p. 7) noted that most of the reserve was dominated by very dense *T. triandra*, with cover generally exceeding 90%. High cover of *T. triandra* can be achieved rapidly at this site: Lunt and Morgan (1999a) recorded mean cover in a frequently burnt zone of 63%, 20 months after the most recent fire. They also noted that substantial mortality of *T. triandra*, preceded by senescence, occurred in the Reserve after 1986. Occurrence of senescence dieback in the reserve and unmanaged zones, allowing *N. neesiana* invasion, may account for the lack of any significant difference in *N. neesiana* cover in the three zones, and for the lack of a significant difference in the mean number of native species between the reserve and the unmanaged zones.

Effects of revegetation and herbicidal control works

The impacts of deliberate revegetation and weed control works are confounding factors in the interpretation of the cover and species richness values. Efforts to revegetate with *T. triandra* were clearly a failure as observed by Todd (1991) and Muir and Carr (1994), and confirmed by both the repeated quadrat study and the zone study.

Deliberate herbicidal weed control was undertaken through some of this period. Todd (1991) recommended spot spraying or hand weeding of a set of exotic species including *N. neesiana*. Muir and Carr (1994) recommended spraying of the whole easement with a selective broadleaf herbicide and control of *N. neesiana* and other exotic perennial grasses with spot spraying. These activities were required for a period of five years (i.e. to 1995) and may have led to changes in the dominant vegetation. In particular the reduced total vascular plant species richness in the pipeline zone (Table 3.6), partly due to reduced exotic richness, may be attributable in part to herbicidal control works. However records of the actual spraying undertaken and the species controlled are not available.

Conclusions

Concerns that the initial quadrat areas at both Yarramundi Reach and Laverton North were not relocated with great precision require that the findings for the repeat studies be treated with considerable caution.

However repeated monitoring of *N. neesiana* presence in a few small quadrats at Yarramundi Reach indicate that its cover can fluctuate markedly from year to year, that it may disappear from areas in which its establishes with low cover, that it can maintain its presence with relatively high cover for periods exceeding 13 years and that infestations can expand at rates of >1 m y^{-1}.

The Laverton North studies demonstrate that severe soil disturbance involving major destruction of the native flora does not necessarily lead to *N. neesiana* invasion in areas where it is widely present. The ground can be captured and held for a long period by exotic annual grasses as well as exotic perennials. Fears about massive occupation by the grass as a near-monoculture at Laverton North have proved to be poorly founded. The zone study data indicate that the native floristic diversity was significantly greater in the unmanaged zone and in the regularly burnt Reserve than along the pipeline, suggesting that construction permanently destroyed most of the native flora. There is some indication that the management regime in the Reserve has resulted in lower cover of *N. neesiana* and other exotic perennial grasses, but the differences are not statistically significant.

At Laverton North the *N. neesiana* invasion that had already occurred before construction of the oxygen pipeline, possibly due to senescence dieback of *T. triandra*, was not exacerbated by pipeline works in some areas. In other areas the disturbances associated with construction resulted in a high proportion of bare ground that was not occupied by *N. neesiana*. Substantial invasion did occur in some parts of the disturbed area, but high cover only occurred on a relatively small part of the overall area disturbed. Revegetation works and herbicidal control activities were confounding factors that contribute considerable uncertainty to the interpretation of the findings, and determination of the mechanisms involved in each area are difficult.

Overall the results concur with the findings of Morgan (2001) that conservation of the native vascular flora requires maintenance of the existing bud and tuber bank, i.e. ongoing survival of living individuals in the standing vegetation. The findings indicate that *N. neesiana* invades as a consequence of soil disturbance that kills the native vegetation, that this capacity for invasion is highly variable depending on site specific characteristics, including what other species are available for invasion, and that, under some circumstances, similar disturbance that kills *N. neesiana* can result in its displacement by annual grasses.